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Commercial Mobile Telephone Services and the Canadian Emergency Management Community:

Prospects and Challenges for the Coming Decade

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Executive Summary[1]

Over the next five to ten years, new commercial wireless technologies will dramatically reshape emergency management in Canada. New mobile telecommunications products and services have become important communications tools within the emergency management and public safety communities, offering cost-effective and flexible alternatives to traditional land mobile radio systems. The potential benefits of commercial mobile telephone systems are far from assured, however, as numerous technical, regulatory, and economic uncertainties remain to be resolved. This report describes the growing role of commercial mobile telephone services in emergency management, examines the potential vulnerability of mobile telephone networks to natural hazards, and identifies a number of important concerns relevant to emergency preparedness planning in Canada.

The recent and dramatic growth of commercial mobile telephone technology in Canada is being driven by a deregulated telecommunications sector, in conjunction with rapid technological innovation and widespread consumer acceptance. From a technical standpoint, these developments are creating interoperable networks comprised of a complicated array of interconnected infrastructures. From an industry and regulatory standpoint, telecommunications is shifting from a monopoly-based tradition into a dynamic marketplace following the adoption of a competitive policy framework by Industry Canada and the Canadian Radio-television and Telecommunications Commission.

Commercial mobile telephone services represent a leading edge of this new communications environment and are now available in every major population centre of Canada, with market penetration continuing at an astounding rate. Many organizations in the emergency management community have already adopted mobile telephones for routine business communications. Further innovation in wireless technology is expected to lower costs of mobile telephone service and to dramatically expand the current range of consumer products and services.

Following from these and other developments, mobile telecommunications products and services will soon include a wide range of sophisticated voice and data applications suited to emergency management activities, creating opportunities for improved emergency communications. Already, mobile telephone systems are capable of providing services that do not currently exist in conventional land mobile radio, such as advanced text messaging, and it is conceivable that increasing amounts of mission critical emergency traffic are likely to flow over these public networks. Numerous public safety

[1] While the information in this report was current at the time of writing, the authors wish to remind the reader that the telecommunications sector is characterized by rapid developments in technology and business practice. Since submission of this report in March 2000, a number of important changes in the telecommunications sector have taken place. Many of these changes are relevant to the contents of this report. The reader is strongly advised to consult latest sources for up to date information on technical, corporate, and regulatory matters.

organizations at all levels of government already consider mobile telephones a significant component of their overall communications strategy.

In many cases, unfortunately, adoption of the mobile telephone is done for convenience and cost benefits, rather than as part of a strategic decision making process flowing from a well-defined technology assessment. As a result, very little is known about the actual utility of mobile telephones during widespread public emergencies. Natural hazards, for instance, pose a significant threat to the mobile telecommunications infrastructure. Evidence drawn from the Red River Flood (1997), the Quebec Ice Storm (1998), and the Chi-Chi earthquake in Taiwan (1999) indicate that mobile telephone systems are extremely vulnerable to natural hazards in a number of significant ways. This suggests that emergency response activities may be hindered by loss of performance in mobile telephone systems due to infrastructure damage, loss of power, congestion and/or other forms of service degradation. As such, there is an immediate need to educate emergency planners about the potential vulnerability of mobile telecommunications networks. A long-term strategy should emphasize mitigation initiatives aimed at resolving vulnerability concerns through the cooperative efforts of industry, government, and emergency planners.

This report offers a “first brush” examination of the increasing importance of wireless telecommunications in Canadian emergency management activities and, in particular, the growing dependency on public mobile telephone systems. Major findings and recommendations fall into three general categories: (1) education and awareness in the mobile telephone user-community; (2) vulnerability analysis of mobile telephone systems, and (3) policy issues and concerns.

Specifically, there is a need to:

- educate emergency management officials about mobile telephone technology, to ensure appropriate use and selection of available technology and service providers;

- provide support for the development of a standardized methodology to improve emergency communications planning with respect to the use of mobile telephone networks during emergencies;

- clarify and resolve Priority Access Dialing (PAD) and other call completion issues as they pertain to mobile telecommunications networks; and

- consider an overarching policy framework for emergency telecommunications that will include mobile telecommunications within an integrated program of long-term risk reduction.

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Acronyms

2G	second generation mobile telecommunications
3G	third generation mobile telecommunications
AC	alternating current
ALI	automatic location information
AMPS	Advanced Mobile Phone System
ANI	automatic number identification
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
BCE	Bell Canada Enterprises
BTS	base transceiver station
CCP	call completion probability
CCPC	NATO Civil Communications Planning Committee
CDMA	code division multiple access
CEAA	Canadian Environmental Assessment Act
CEPTAG	US Civil Emergency Preparedness Telecommunications Advisory Group
CGP	community gathering point
CLEC	competitive local exchange carrier
CO	central office
CoW	cellular on wheels
CPAS	Cellular Priority Access System
CRTC	Canadian Radio-television and Telecommunications Committee
CSA	Canadian Standards Association
CWTA	Canadian Wireless Telecommunications Association
DC	direct current
DOC	Department of Communication
DRR	distance-to-reuse ratio
EMO	emergency management organization
EOC	emergency operations centre
EPC	Emergency Preparedness Canada
ERP	effective radiated power
ESMR	enhanced specialized mobile radio
FCC	US Federal Communications Commission
FCFS	first-come-first-served
GHz	Gigahertz
GIS	geographic information system
GSM	Global System for Mobile Communications
GVRD	Greater Vancouver Regional District
HPC	High Probability of Completion
HVAC	heating, ventilation, air-conditioning
ILEC	incumbent local exchange carrier
ITU	International Telecommunications Union

LAN	local area network
LLC	Line Load Control
LMCS	local multipoint communication system
MCS	multipoint communications system
MHz	MegaHertz
MMI	Modified Mercalli Intensity
MTSO	mobile telephone switching office
mW	milliwatts
NCS	US National Communication System
NETC	National Emergency Telecommunications Committee
NHEMATIS	Natural Hazards Electronic Map and Assessment Tools Information System
NMC	network management controls
NOAA	US National Oceanographic and Atmospheric Administration
NOC	network operations centre
PAD	Priority Access to Dialing
PBX	private branch exchange
PCS	Personal Communications Services
PEP	British Columbia Provincial Emergency Program
PGA	peak ground acceleration
POP	population count
PSAP	public safety answering point
PSTN	public switched telephone network
RCMP	Royal Canadian Mounted Police
RETC	Regional Emergency Telecommunications Committee
RF	radio frequency
SAR	specific absorption rate
SHF	super high frequency
SMR	specialized mobile radio
SONET	synchronous optical network
TAMI	Traffic Assessment by Method of Iteration
TDMA	time division multiple access
TSACC	Telecommunications Standards Advisory Council of Canada
UHF	ultra high frequency
VHF	very high frequency
WAP	Wireless Access Protocol
WGET	UN Working Group on Emergency Telecommunications

1. Introduction

Reliable communication is a fundamental requirement in all phases of emergency management from mitigation and preparedness through response to recovery. Operationally, primary response and support agencies rely heavily upon communication to support a comprehensive and complex emergency management system necessary to ensure a coordinated and well-orchestrated response to any and all emergency incidents. Further, these activities must take place within the scope of a system that integrates incident site command, local, regional, provincial and federal coordination within a multi-disciplinary environment.

Effective communication between agencies, officials and the general public can make the difference between averting or facing a disaster situation. For instance, advance or early warning communication between scientists and planners provides a basis for mitigating some disasters altogether; in other cases, effective communication during the early stages of a community-wide emergency may prevent the event from escalating into a disaster scenario. In the event of imminent emergencies, effective communication is necessary to provide information to local responders and to initiate vital back-up support arrangements.

However, communication, if poorly executed, can also be a significant factor in reducing coping capacity by creating problems when preparing for and responding to emergency situations. Communication problems, be they technical or organizational, can lead to a breakdown in control and coordination, and hence, lead to tactical and logistic confusion between response agencies and support teams, as well as result in the propagation of misinformation to the other agencies and the public. In some cases, poor communication between support and responding agencies may result in unwanted escalations of small-scale events into community-wide emergencies. Communication, therefore, is the underpinning for identifying and coordinating all other resources (human and technical) that are brought to bear by the emergency management community.

The “emergency management community” itself is a very broad concept and includes virtually any organization or individual that might be affected by a large-scale emergency or disaster. It not only includes primary public safety agencies, such as police, fire and emergency medical, but conceivably anyone else required to respond to or support an organized response to hazard events. It thus cuts across *all* sectors of society and jurisdictions.

1.1 Wireless Communication and Emergency Management

Telecommunications has become the critical infrastructure to link these diverse interests across geographical and jurisdictional boundaries, and a wide range of technologies support emergency management activities including two-way radio, wireline and mobile telephone, facsimile, satellite and distributed computer networks.

Since its rapid evolution during World War II, wireless communication technology has become one of the most critical components of the emergency communications infrastructure, in part because of its portability, low cost and capability to operate independently from fixed and potentially vulnerable wireline-based trunking for transmission and reception of information.

Today, public safety agencies rely heavily on their land mobile radio networks for communication and coordination within their own and among other organizations, as do numerous other public and private organizations. However, despite these capabilities, achieving organizational integration and coordination during emergencies remain among the most difficult tasks to achieve because of the lack of common, reliable, scaleable and interoperable communications systems.

Public safety agencies commonly operate their own wireless systems, using frequencies, modes and equipment incompatible with those of other agencies, with the result that agencies are unable to communicate with each other by radio. Often, agencies from different jurisdictions or disciplines are forced to borrow radios from each other in order to coordinate combined efforts. Even with this capability, communications links are often underscaled and quickly become overcrowded. Further, many other agencies simply do not possess their own radio facilities. The underpinning infrastructure itself may be vulnerable to degradation from overuse or damage from the hazard event itself. When these situations arise, telecommunications, rather than being a strategically important response resource, becomes a hazard in its own right.

It is not surprising then, that local, provincial and federal emergency management agencies have begun to look beyond their own networks for solutions to these problems, especially in the commercial telecommunications sector. In particular, the expansion of the commercial cellular and new personal communications services (PCS) provides an attractive incentive for emergency management organizations (EMOs). For many organizations these services appear to be cost-effective adjuncts to public wireline networks or alternatives to private wireless networks. There is evidence to suggest that EMOs now consider mobile telephones a viable technology option for inter-organizational communication, as well as for integrating community-wide response and recovery activities during emergencies. Moreover, this perception may be further supported by the fact that new digital forms of commercial service are playing a significant role in the development of a seamless mobile telecommunications architecture that is significantly more advanced than most public safety networks.

Despite the promise of this emerging technology, the specific benefits, limitations and ultimate implications of emergency mobile telephone usage are not yet well understood. The emergency management community, policy makers or, for that matter, service providers themselves may not clearly understand the limitations of mobile telephones during emergencies. To the best of our knowledge, neither Canadian nor international researchers have yet systematically examined the performance of such facilities under emergency or disaster conditions, especially when such facilities themselves are impacted by the same hazard event. Despite this, recent experience in

Canada and other countries—including the United States, Europe, Japan and Taiwan—indicates that a number of problems persist that may limit availability of public telecommunications services to EMOs during the most crucial stages of their operations. Some of these problems include the physical survivability and sustainability of networks, network congestion and priority access provisioning, coverage and connectivity, interoperability among systems and timeliness in facilitating restoration.

1.2 The Changing Context of Emergency Communications

Many important developments are taking place that offer new solutions and strategies to mitigate the pressing issues in emergency communications. These developments include new technologies and standards, increased knowledge about hazards, development of improved risk reduction strategies and a growing recognition of community emergency management itself as a critical social, economic and public safety component. At the same time, however, solutions to communications issues are also made more complicated by increased competition within the telecommunications industry. This has resulted in the disappearance of single or select points of contact within industry to satisfy emergency telecommunications requirements. Rapidly changing regulatory, industry and technological standards and requirements also affect the provisioning of emergency telecommunications services (including rising competitive demand for radio spectrum). Evidence of this changing context is clearly visible in the growing interdependence of commercial and private telecommunications and intelligent systems to support critical emergency communication infrastructures and functions. The public policy framework and associated institutional arrangements that shape and guide these activities are also going through radical transformation, away from direct government intervention and towards market-driven solutions and greater self-regulation.

1.3 Scope and Objectives of this Study

In effect, a distributed decision-making environment has emerged within the telecommunications sector. In this new environment, critical decisions about best communications practice become increasingly a shared responsibility among stakeholders, with the greatest responsibility migrating to the end-users . In order to ensure a better understanding of the emergency communications requirements within this new context, research is needed to critically evaluate and expand current understanding of the growing benefits and implications of Canadian wireless usage. More specifically, Canadian emergency mobile telephone usage needs to be closely studied if effective risk reduction strategies are going to be developed in the future.

In order to place this research in a proper emergency communications context, it must include an analysis of current emergency communications needs and practices, along with supporting technical and policy arrangements. Further impetus for enhancing mitigation strategies will come from identification and specification of vulnerability to communications infrastructure. Policy makers, regulators, service providers and emergency personnel can all benefit from detailed research that:

- identifies potential problem areas.
- calls attention to the need for contingency planning incorporating new consensus-driven strategies.
- stimulates policies and standards and obligations for ensuring effective emergency communication.
- recommends means for strengthening infrastructure to withstand anticipated effects of known hazards.

This study is intended to contribute to these objectives. In particular, this report offers a "first brush" examination of the increasing importance of wireless telecommunications in Canadian emergency management activities and, in particular, the growing dependency on public mobile telephone systems. It also includes a review of mitigation strategies employed by the telecommunications industry, regulators and EMOs to protect and enhance critical communications systems and infrastructure, and establishes a preliminary methodology for studying the performance of mobile telephone networks during widespread public emergencies.

1.4 Methodology

The most formidable challenge faced at the outset of this study was two-fold. First, the novelty of mobile telephones is such that there is little formal research available in the area. Much of the current literature consists of technical descriptions of mobile telephone technology for engineers or managers, or articles reporting on the potential health effects of radio transmissions. Research on the vulnerability of mobile telephone networks to natural hazards is sparse and research into the professional use of mobile telephones in emergency management is virtually non-existent.

A second challenge to this study was its interdisciplinary nature. In order to study mobile telephone networks, a wide range of expertise must be gathered and integrated into a coherent analysis. As such, we decided early in the study to organize our research into three related but distinct streams of inquiry:

- Mobile telecommunications profile
- Mobile telephone performance during emergencies
- Policy Review

The mobile telecommunications profile was intended to examine and report on the basic technical principles of mobile telephone networks, the commercial wireless industry in Canada, and the professional use of mobile telephones in the emergency management community. This stream of inquiry was initiated with a review of the technical elements of mobile telephone systems, with the intent of establishing a basic framework for the other areas of inquiry. Findings from this review are reported in Sections 3 and 4 of the report.

In order to establish a profile of mobile telephone use in the emergency management community, we designed and administered an exploratory survey of public safety officials in the Greater Vancouver Regional District (GVRD). As far as we can determine, this is the first of its kind anywhere in North America. Approximately 70 interviews were conducted with officials from all levels of government and from a wide range of emergency management functions. Findings from this survey are reported in Section 7 of the report, and reveal some important issues worthy of closer scrutiny.

Determining the performance of mobile telephone networks during emergencies turned out to be much more complex than we had initially anticipated. At present, research in this field is carried out under the specialty of lifeline engineering. Much of the available research is oriented toward structural concerns, although network traffic methodologies have been developed for both wireline and wireless telecommunications lifelines. At present, however, there is no comprehensive methodology for studying mobile telephone networks under emergency conditions. Through a review of research on communication lifelines, particularly the work done by the American Society of Civil Engineers (ASCE), we were able to establish the building blocks for a methodology to study mobile telephone networks under emergency conditions. The building blocks have been integrated into a methodological framework reported in Sections 8 and 9.

The subsequent step after establishing a methodological framework is to identify an analytic tool that is suited to an empirical assessment of mobile telephone networks. Section 10 reports on the practical use of geographic information systems (GIS) for planning and assessment with mobile telephone systems. A brief literature review provides examples of related GIS applications for emergency management. This section also describes a number of suggestions for operationalizing the methodological framework reported in the previous section.

Mobile telecommunications are comprised of both social and technical systems. In other words, the shape and direction of development is intimately bound to social constraints, most notably those set forth in government policy and regulation. As such, a significant component of this study involved the analysis of current public policy related to mobile telecommunications in Canada. This analysis centred on a comprehensive review of telecommunications legislation and the current policy frameworks of Industry Canada and the CRTC. Numerous pieces of legislation intersect with mobile telecommunications, most notably the Telecommunications Act and the Radiocommunication Act, as do also resultant regulations and practices stemming from the numerous standards bodies in Canada such as the Canadian Standards Association (CSA).

An important corollary to this review was a review of emergency telecommunications and emergency preparedness legislation. This was undertaken to better understand how mobile telephone systems might interface with current emergency communications planning and policy, and where opportunities and challenges for future policy development might reveal themselves. These reviews are reported in Sections 5 and 6 respectively.

Findings gathered from the three streams of inquiry are summarized in Section 11, as are recommendations for further study.

2. Wireless Communication in the Information Age

New developments in wireless and wireline voice and data networking open significant opportunities to Canadian emergency management organizations for integrating and sharing vital emergency management information across jurisdictions and geopolitical boundaries. Technical capabilities of modern systems have become so diffused that fixed equipment, such as telephone sets, fax machines, computers and other communication devices, connected wired telecommunications networks and electrical sources have become ubiquitous throughout industrialized countries like Canada. The next major challenge is to develop affordable, reliable, widespread uses for "untethered" communications—the union of wireless and mobile technologies (Committee on Evolution of Untethered Communications, 1997; National Research Council, 1997)**.**

In the last twenty years almost every facet of telecommunications (including its meaning) has changed radically. These changes are being shaped by a number of major interrelated contributing factors including:

- trade agreements and globalization
- liberalization
- technological innovation and convergence

2.0.1 Trade Agreements and Globalization

Facing the challenges of increasing international competition, many large national firms are attempting to reposition themselves by seeking to achieve a critical size abroad through acquisitions, mergers or strategic alliances. In the telecommunications field, large telephone companies are pursuing transnational strategies by forming regional and global alliances. In some cases, companies, like Teleglobe (formerly Teleglobe Canada) and Telesat (formerly Telesat Canada), have abandoned their government-protected monopoly positions altogether in order to gain reciprocal access to foreign carriers' markets.

2.0.2 Liberalization

The internationalization of the telecommunications market has caused governments to reconsider their approaches to protecting domestic firms and to embark upon major policy reform programs.

For Canada, these programs have resulted in liberalized trade agreements with the U.S. and Mexico through NAFTA, and other countries through a World Trade Organization accord signed in 1997. This accord includes elimination of tariffs on information technology by the year 2000.

Domestically they have resulted in: the privatization of provincially-owned telephone operations in Alberta and Manitoba; federal privatization of its investments in

Northwestel, Telesat Canada and Teleglobe Canada; permitting of competition to enter into the previously monopolized telephone equipment, long distance and local service markets; deregulation of former telephone monopolies; adoption of international technical standards and protocols, and revision of foreign ownership rules. Further, the federal government has established an active policy agenda to make Canada the most connected country in the world in order to capitalize on economic and learning opportunities in the knowledge-based economy and to enhance Canada's ability to attract domestic and foreign investment.

2.0.3 Technological Innovation and Convergence

The most significant driving force behind the communications and information revolution, however, is technological innovation. In particular, the application of digital communication techniques and the adoption of common communication protocols are bringing about a revolution in communication networking and electronic information sharing.

These techniques, in turn, are being constantly enhanced by microprocessors whose processing power is doubling approximately every 18 months, while their unit costs are cut in half during the same period. Concurrent improvements are being made in areas of signal processing, digital compression of data and transmission media that allow significantly increased amounts of data, video and audio signals to be carried through existing and new transmission facilities, drastically reducing distribution costs.

These developments are also spawning the convergence of previously independent communication media, such as radio and television broadcasting, computers and wired and wireless telecommunications systems to forge new forms of addressable and personalized services linking private and public organizations all over the world and laying the foundations of new information highways.

Traffic over these networks is translated into "packets" or "cells" of data that are controlled electronically rather than physically, and flow over "virtual" networks created and flexibly managed by computer software. The result is that the same information can now be addressed and sent over a variety of substitutable communication media, and, if properly designed and implemented, sent with a high degree of accuracy, speed and reliability. In this environment, even voice over a telecommunications network becomes just another data application.

Throughout many regions of Canada, these changes are being reflected in the delivery of almost every aspect of telecommunication service. Prior to liberalization, monopoly carriers effectively provided and controlled the majority of telecommunications within their serving territories—right down to the devices that were to be connected to their networks. As such, they were single points of contact for local, provincial and federal governments to arrange for communications services which greatly simplified emergency communications planning. However, in this environment there were no market-driven stimuli for the development of new features to promote telephone services, including radio telephone service.

Times have changed dramatically. Canadian residents, businesses and government departments and agencies, depending upon location, can choose from a growing array of service providers. In addition to the incumbent telephone companies, there are now numerous alternative facilities-based domestic long distance carriers, local exchange carriers, telephone service resellers, alternative pay telephone providers, satellite-based carriers and wireless service providers, paging and other radio common carriers. Some of these also include cable television and satellite direct broadcast service providers.

Despite these impressive developments, more changes are yet to come, and some of the most impressive ones will impact wired networks, and the wireless market, especially mobile telephony. Within the next few years, a third generation of mobile phones will be capable of delivering voice, electronic mail, worldwide web access and video conferencing, as well as broadcast or multicast modes of networking. These services will be addressable and permit one-to-one and many-to-many forms of communication. They will also be capable of integrating first generation (analog) and second generation (digital and personal communications services-PCS) services, as well as paging services.

Interconnected to these networks will be a variety of new satellite systems that will incorporate the advantages of both conventional satellite (coverage) and new cellular (addressability and mobility) features into single global-scale networks. During the 1980's, the first international mobile satellite service was inaugurated by INMARSAT, whose coverage today extends over regions of Canada. The mid-1990's saw the introduction of MSAT, a Canadian geostationary mobile satellite service offered by TMI Communications Inc. On November 1, 1998, Iridium, the first cellular system using a configuration of 66 low earth-orbiting satellites, entered commercial service, followed by Globalstar in 1999, with a configuration of 48 satellites. Waiting in the wings are a variety of voice and data-oriented satellite systems employing different constellations of low, medium and equatorial earth-orbiting satellites. Over the next five years, these systems will be interconnected, and will merge with optical fibre and terrestrial networks to provide a seamless, high data-rate mobile telecommunications environment.

This ability to interoperate and substitute components, as well as employ telecommunications facilities wherever they are needed, can potentially fulfill a critical requirement for emergency management.

2.1 Wireless Applications for Emergency Management

Emergency management agencies must be able to exchange information pertaining to their daily operations, as well as during on-scene mutual aid or joint operations. Today, many of their information exchange needs have expanded beyond basic voice transmission to include transmission of video and high-speed data. This requirement exists both for intra-organizational and inter-agency purposes. However, to do so within a traditionally closed networking environment requires agencies to operate on contiguous frequencies and use similar or, at least, compatible technologies.

> Wireless communication links are generally classified as one of two types (Federal Communications Commission, 1997):
>
> Infrastructure-independent: The communications link occurs between users over a direct RF (radio frequency) path (e.g. portable-to-portable or mobile-to-portable).
>
> Infrastructure-dependent: The communications link requires use of equipment, other than a basic radio transceiver, for the establishment of the link and for complete operation. Examples include a communications link for which a repeater station is required; a communications link that provides full system coverage for a visiting subscriber unit with a host trunked radio system, and a communications link that provides interconnectivity between two or more incompatible radio systems by cross-connecting the audio signals and/or appropriate signaling functions at some control point (e.g., bridge or autopatch for access to the public telephone network).
>
> Regardless of the type of communications, it must also satisfy one or all of the following requirements (Federal Communications Commission, 1997):
>
> Intra-organizational: Wireless communications within a specific agency. This may be for local requirements or extend across a large territory (e.g., RCMP, regional or provincial police).
>
> Multi-jurisdictional: Wireless communications involving two or more similar agencies having different areas of responsibility (e.g., fire departments from different communities communicating to facilitate mutual aid or provincial and federal environmental agencies coordinating clean-up operations from a chemical fire).
>
> Multi-disciplinary: Wireless communications involving two or more different agencies (e.g., police, fire and emergency medical services and Transport Canada responding to a passenger plane crash).

From a community emergency response perspective, all requirements are likely to be present concurrently. Moreover, they may require integration to facilitate mission critical communications that must be immediate, ubiquitous, reliable, and secure (Federal Communications Commission, 1997) (e.g., during evacuation of a community threatened by a forest fire or flash flood). However, these communications links are often complex and can require any possible combination of subscriber units and fixed equipment, such as repeaters, dispatch positions, data and fax resources, etc. Their configuration is also shaped by physical circumstances and the community of interest responding to the situation. For example, a marine oil spill could require quite a different communications matrix than a response to a tornado.

Unfortunately, these links must often be established amidst disasters and under conditions that may preclude prior planning. In these situations, on-site communications must be established among numerous groups, each with its own radio frequencies, but often without commonly shared mutual aid or interoperability channels. In many cases, entirely new links must be established as the situation escalates or changes, not only adding further complexity, but also raising the issue of capacity to coordinate communications among groups. Where mutual aid and/or interoperability capabilities exist, they may be underscaled to meet the on-air demands of users or needs for different “talk groups” to facilitate effective tactical and back-up support coordination. Other technical problems that regularly surface are intermodulation and interference problems, lack of sufficient back-up power (including batteries), inadequate coverage and lack of commonality of operating procedures and on-air verbal terminology.

As a situation escalates, it is commonplace to establish on-scene command posts, as well as back-up emergency operations centres, often outside the immediately impacted area, and mutual aid links to other communities and jurisdictions. To be most effective, these arrangements need to be pre-planned and, where possible, standardized.

These requirements, cannot be met through existing arrangements that are based solely upon agency-specific or multi-agency public safety wireless communications networks. First, from an emergency community perspective, many public agencies fall outside the traditional “public safety” definition (e.g., public works, parks and recreation, school boards, etc.), and rarely are included in planning or use of public safety networks. Second, many of the organizations performing important public safety functions increasingly are non-government organizations that are contracted to provide services (e.g., security, trucking and transportation, emergency lodging and feeding, etc.) and depend upon other communication means (e.g., PSTN and mobile telephone or their own two-way radio networks) that are not interconnected to public safety networks.

Third, radio spectrum for public safety communications in Canada, as in many other countries, has traditionally been licensed on a first-come, first-served basis, initially in absence of specially reserved blocks of public safety frequencies. Consequently, in most regions, it is common for public safety agencies stationed in close physical proximity to be operating in entirely different bands of the radio spectrum (e.g., VHF, 400MHz and 800MHz bands), such that they cannot achieve interoperability on an infrastructure-independent basis and often with difficulty on an infrastructure-dependent basis.

2.1.1 Emergence of Trunked Radio

To resolve these problems, many agencies have migrated towards trunk-radio systems where frequencies are grouped together in the same frequency band, but are shared internally and/or with other agencies. A trunked mobile radio is one in which the communication traffic may pass through one of the “trunked group of channels” selected automatically by the system (Industry Canada, 1983). Normally, a repeater transmitter-receiver combination is used to increase the coverage area of a two-way radio or to insure more reliable performance in areas where signals are reflected or attenuated by buildings or terrain. Repeater systems are commonly deployed in metropolitan and suburban areas to obtain coverage to all mobile units in the area. In hilly and mountainous regions, repeaters are used for more reliable coverage in low lying areas and valleys. They are also used in remote areas where a large coverage is required. A conventional repeater system may consist of a group of repeaters, each operating on its own pair of frequencies. With these systems, one repeater can become overloaded, while other adjacent repeaters in the same system are inactive. To better utilize these frequencies, a trunked radio system employing a central switching and logic system is used to automatically assign an inactive repeater whenever the others are active (Noll, 1985).

Ten years ago the need for interagency communications was recognized in Canada, and the federal government allocated the 821-824/866-869 MHz sub-bands to facilitate interoperability among public safety services during certain emergency activities. One additional allocation of channels was set aside for public safety organizations in both Canada and the U.S. on a shared basis to facilitate mutual aid (Industry Canada, 1999i).

Under this spectrum utilization policy (Industry Canada, 1995e), public safety services are considered to be those which are *exclusively* related to the preservation and the protection of property. Within this context, the policy establishes the following hierarchy with respect to eligibility of service providers for licensing:

1. Police, fire and emergency medical services;
2. Forestry, public works, public transit, dangerous clean-up, customs and other agencies contributing to public safety;
3. Other government agencies and certain non-government agencies.

Category 1 system users are eligible for either trunked or conventional systems within these bands.

Category 2 system users are eligible to share trunked systems with Category 1 users provided the latter remain the major users of the system. Major users are agencies which have priority over other types of users on the system. Further, Category 2 system users are not eligible to operate their own systems within this band unless it can be demonstrated that their operation would not preclude the future introduction of a Category 1 system.

Category 3 users may be permitted access to public safety systems *during* periods of emergency where their services are required but access *must be* controlled by the major users operating those systems.

There are additional restrictions on eligibility and operation in the use of public safety bands. For example, because of limited spectrum availability in congested areas access to these frequencies may be restricted to Category 1 users (Industry Canada, 1991). For mutual aid purposes, inter-agency frequencies are allocated in blocks of five pairs, one for a public safety common channel and four for tactical communications. The public safety common channel is intended for use by public safety agencies for inter-agency calling and day-to-day coordination of mutual aid activities. However, tactical channels can be used by public safety agencies *only* for coordination and response communications in times of emergency. Further, if channels become loaded, Category 2 and 3 users can find themselves locked out if Category 1 users don't have a need to communicate with them, despite Category 2 or 3 users having a need to communicate with each other. Current spectrum allocation is therefore not an adequate community-wide solution to the challenge of wireless emergency communications.

2.2 Types of Communications

On a day-to-day non-emergency basis, emergency management agencies are growing accustomed to utilizing a diverse range of electronic communications including voice, data, image and video. Many of these services are provided and integrated over fixed, often wireline-based networks, including the Internet, other specialized data, PSTN and cable television networks. However, agencies are also recognizing the importance of having access to these facilities in field operations, especially through mobile, wireless means that enable them to exchange data with their home and other necessary agencies. New digital narrow and wideband wireless technologies raise the possibility of developing Internet-based mutual aid systems to enable intra-organizational, multi-jurisdictional and multi-disciplinary systems to interoperate through common infrastructure anywhere and anytime.

Canada, however, has yet to establish a public safety or emergency management communications policy framework to determine whether or not additional spectrum should be reserved for these purposes, while existing public safety allocations are restricted to narrowband applications. At the same time, commercial wireless technologies and services are now becoming extremely attractive in terms of their general performance, quality and cost. It is the market place that is driving the telecommunications industry to resolve interoperability issues in order to allow commercial providers to achieve access to customers in an increasing global market.

A principal attraction of wireless communication growth is its capability to service mobile users. Because mobile communication has been such an important feature of emergency and military operations, these sectors have traditionally played key roles in the development and deployment of wireless communication technology. However, it now appears that because of vigorous public demand for wireless products and services, the commercial sector has sufficient economic incentive and momentum to push the wireless development envelope on its own. At the same time, declining or flat emergency management budgets are motivating public safety and emergency management community-at-large to adopt commercial products and services at an astonishing rate (National Research Council, 1997). In the absence of equivalent public safety capabilities, public commercial networks may very well become surrogates for enabling the emergency management community to achieve interoperability across all modes of electronic communication.

Yet, there can be significant differences between emergency management and commercial requirements, especially in the areas of reliability and access. These variations can also be reflected in differences in policy and regulatory requirements and herein lies the challenge:

> **Can the emergency management community exploit the advances in affordable, interoperable, commercial technology, fueled by consumer demand, while also maintaining technical and operational capabilities that meet its fundamental goals of preserving life and protecting property and the environment?**

In this report, we will attempt to address this question, specifically as it relates to emergency use of commercial mobile telephone services. Before doing so, however, it will be necessary to first examine the industrial, technological, regulatory and other institutional arrangements that have shaped the development of these services, since these arrangements form the basis for how and to what extent emergency mobile services might be enabled and supported.

3. Industry Structure

The Canadian telecommunications service industry is one of the fastest growing segments of the Canadian service economy, outpaced only by the software and computer industry. In 1998, (latest available figures) the telecommunications service industry had revenues of approximately $25.1 billion (Industry Canada, 1999d). The Canadian wireless telecommunications market segment is amongst the most competitive of the overall telecommunications industry. The Canadian Wireless Telecommunications Association reports that revenues totaled $3.9 billion in 1998, an increase of 11 percent over 1997 (Canadian Wireless Telecommunications Association, 1999a). This wireless market includes cellular, PCS, paging, specialized mobile radiotelephone services and other radio common carrier services such as mobile radio dispatch.

3.1 Evolution of the Canadian Cellular and PCS Industry

The mobile telephone industry can be divided into two phases of development over the course of the last 16 years:

<u>Phase one</u>: introduction of analog cellular systems (first-generation).
<u>Phase two</u>: introduction of digital PCS systems and new value-added data services (second-generation).

From 1984 to 1996, the industry was essentially a duopoly held by Mobility Canada (a consortium of cellular service providers that are affiliated with incumbent telecommunications carriers) and Rogers Cantel Mobile Communications (now Rogers AT&T). Both groups held national licences to operate at 800MHz and provided analog cellular services in conjunction with their traditional wireline operations.

In 1995, through a comparative licence review process, two other licensees, Microcell Telecommunications Inc. (Microcell) and Clearnet Communications Inc. (Clearnet), along with the incumbent cellular carriers, were selected by Industry Canada to offer a range of new digital cellular services entitled, “Personal Communications Services” or PCS in the 1.9 GHz band. Clearnet and Microcell each received 30 MHz of spectrum, while the Mobility Canada consortium and Cantel each received 10MHz of new spectrum.

In December 1996, Microcell began rolling out service followed by Clearnet in October 1997. Clearnet also began offering Enhanced Specialized Mobile Radio (ESMR) in 1996, an enhanced service that provides half-duplex dispatch and connection to the public switched telephone network (MobileInfo, 1999). Since that time, Rogers and many of the Mobility Canada companies have upgraded their 800MHz analog cellular networks to offer digital PCS, as well as services over their new 1.9 GHz PCS networks.

3.2 Relative Position of the Cellular and PCS Industry

Mobile telephony is the largest segment of the Canadian telecommunications market. According to a Statistics Canada report, in just 11 years and in terms of revenue, the mobile phone industry (including PCS) has grown to one-fifth the size of the traditional wireline telecommunications segment of the industry (Chodorowicz & Sciadas, 1998).

Some recent statistics illustrate the penetration and expected growth of mobile telephones in Canada (Canadian Wireless Telecommunications Association, 1999a):

- mobile telephones are one of the fastest growing consumer products in history.
- approximately 10 million wireless devices are currently used by Canadians on a daily basis, including 7 million wireless phones, more than 1.8 million pagers, 1 million mobile radios and 10, 000 mobile satellite phones. .
- more than half of all Canadians have a choice of four mobile telephone service providers:
    i. Rogers AT&T (formerly Cantel)
    ii. Mobility companies (formerly Mobility Canada)
    iii. Microcell (Fido)
    iv. Clearnet PCS (Clearnet/Mike)
- the number of wireless telephones in Canada is expected to increase between 20 to 30 percent in the next year alone.
- on a household basis, 41 percent of Canadian households owned or had access to a wireless telephone in 1999, compared to 37 percent in 1998.
- per capita penetration of mobile telephones by mid 1999 was reported at around 20 percent and is expected to climb to more than 50 percent by 2005.
- on average, Canadians use their mobile telephones approximately 185 minutes per month, with usage increasing.
- 4 percent of Canadians use wireless Internet service, and 24 percent are forecasted to purchase this service in the coming year.

Carrier	Current Operating Territory	1999 Subscribers (millions)
Bell Mobility	Regional – Ontario and Quebec British Columbia and Alberta through reselling agreement with Telus Mobility	1.8
Telus Mobility	Regional – British Columbia and Alberta Ontario and Quebec through reselling agreement with Bell Mobility	1.1
Other Mobility	Regional	N/A
Rogers AT&T	National	2.15
Clearnet	British Columbia, Alberta, Ontario and Quebec National through roaming	0.57
Microcell	British Columbia, Alberta, Ontario and Quebec National through roaming	0.58
Source: Company Reports, Yankee Group and Industry Canada		

3.3 Contributing Growth Factors

Major drivers to this growth include:

- nationwide coverage without roaming charges.
- mobile and fixed voice and digital (Internet, email, telemetry, etc.) applications.
- migration from wireline to wireless services.
    - businesses find mobility an attractive alternative/adjunct to fixed telephone services.
- pricing
    - prepaid monthly plans have dramatically driven rates downward to as low as 10 cents per minute and many plans include enhanced services (call waiting, etc.) normally charged extra for by wireline carriers. Simultaneously, wholesale prices on handsets have also dropped significantly, and carriers are willing to allow customers to spread handset costs over long periods of time. These changes have made Canada one of the least expensive wireless markets in the world.
- competition
    - new local exchange competitors are viewing wireless telephony as one of the most cost-effective means to provide local loop (last mile) access to customers, especially in the consumer/residential market.

    - the recent dissolution of the monopoly carrier alliances through Stentor and Mobility Canada has enabled regional carriers to expand their presence nationally.
- global investment
    - U.S. and other foreign carriers are increasing their investments in the burgeoning Canadian wireless and wireline markets, in part, through direct investment in established Canadian telecommunications companies. Recent examples include a 33 percent investment in Rogers Cantel Mobile Communications by AT&T Corp. and British Telecom (and renaming the company Rogers AT&T Wireless) and a 20 percent investment in Bell Canada Enterprises (BCE) by Ameritech.
- convergence
    - through vertical and horizontal integration, corporate mergers and acquisitions and alliances, many companies are levering their investments to broaden the scope and range of carrier offerings to include local wireless, wireline, long distance, Internet, cable television and satellite-based services.
- regulatory and technological change
    - Industry Canada is preparing to release additional spectrum to encourage wireless operators to enhance existing applications by way of new digital voice and data services as well as the introduction of third-generation (3G) wireless services.

4. Technical Overview

Cellular and PCS services are distinct from other wireless services inasmuch as they refer to *mobile* systems based on a *terrestrial infrastructure*. This distinction provides a point of contrast between mobile telephones and other commercial wireless telecommunications systems (such as mobile satellite). For our purposes, we have adopted industry and government distinctions between mobile telephones and other mobile wireless telecommunications services. The table below illustrates the various types of wireless systems as they are categorized by the Canadian Wireless Telecommunications Association (CWTA).

System	Description
Paging	One-way messaging service
Mobile radio	Powerful radio (max. 30 watts) permanently installed in a vehicle
Local multipoint communication services (LMCS)	High bandwidth wireless services operating at the 28GHz band
Mobile satellite carriers	An emerging class of radiocommunication networks typically using LEO or MEO satellites
Cellular	***The mobile radio-telephone service licensed by Industry Canada to utilize 50MHz of spectrum in the 800MHz band which is interconnected to the PSTN.***
Personal Communications Services	***Mobile communications system interconnected with the PSTN. Spectrum has been allocated for use by public systems at the 2.0GHz frequency range.***

Source: Canadian Wireless Telecommunications Association.

Among the essential characteristics that distinguish mobile telephones from other wireless services, two can be most readily identified from the table above:

- Unique spectrum allocation
- Interconnection with the public switched telephone network (PSTN)

Mobile telephone systems are differentiated from other wireless telecommunications by Industry Canada licensing requirements. Analog cellular systems were originally licensed to operate in the 800MHz range, while more recent PCS services have been assigned frequencies within the 2.0GHz range. This is a primary point of distinction for mobile telephones from other wireless services.[2]

[2] Industry Canada (1997f; 1997g); Canadian Wireless Telecommunications Association (CWTA) website (1999a).

Another important point of distinction between mobile telephone systems and other wireless services is an interconnection with the public-switched telephone network (PSTN). *The primary function of a mobile telephone system is to allow users to place calls through the PSTN, much like any conventional telephone service*. Other wireless services are not necessarily interconnected with the PSTN (although they may have provisions for interconnection).

For the purposes of this study we have further narrowed our focus by adopting a third determining characteristic:

- two-way terminal devices (voice/data)

Not found in the table above is a key component of a mobile telephone system—the two-way terminal device. In contrast to one-way pager systems, two-way terminal devices allow users to place and receive calls on the PSTN. In contrast to many HF, VHF and UHF radio systems, two-way devices also allow for the simultaneous transmission of incoming and outgoing signals (full-duplex).

4.1 Basic Principles of Cellular Mobile Telephone Services

Aside from frequency spectrum differences, mobile telephones are distinct from other wireless communication systems because of three important features, which together, represent the fundamental operational concepts of a "cellular" system:

- addressability
- signal re-use
- hand-off

Unlike traditional radio systems, mobile telephone systems are designed around addressable terminal devices, each with a unique telephone number. When a call is made on a cellular system, a circuit is established between two unique addresses and subsequent communication is confined to that circuit. By contrast, communications over traditional radio systems are generally not addressable.

Another important innovation that makes cellular systems different from previous forms of mobile radio is signal re-use. Cellular systems use a large number of relatively low power transmitters in order to re-use (or recycle) frequencies, thereby expanding the carrying capacity of the network. In older forms of mobile radio systems, transmitters of relatively high power were used to cover large areas. The major problem with all wireless systems is spectrum scarcity—a finite number of frequencies are available to a carrier, and when a frequency is occupied it is effectively unavailable to other users. As such, early forms of mobile telephony were significantly constrained by the available number of frequencies and subscriber demand on the system. The use of relatively high power transmitters meant that when a call was being placed on the network, the frequency assigned to that call became unavailable for other users, often throughout an entire city or region. Bedell (1999: 3) notes that in some cases, less than 50% call completion rates were considered normal for early mobile telephone systems.

Cellular systems lessen the problem of spectrum scarcity by using low power transmitters and then re-using frequencies within a coverage area. This is achieved through the creation of "cells" that are confined to specified blocks of frequencies. At the centre of each cell is a base station that contains an antenna, transmitter, receiver, and some computer equipment. Adjacent cells use different frequency blocks to avoid interference. Careful design of the cell network allows for re-use of blocks of frequencies across a wide geographic area without interference. The *frequency re-use plan* is typically based on groups of seven (7) cells, each assigned several channels per cell. Frequency re-use must be carefully calculated based on a *distance-to-reuse ratio* (DRR) dictated by the size and shape of cells throughout a system. The DRR represents the required distance between cells that are using identical frequencies.

To enable users to move between cells without call disruption (when driving a car, for example) the network must be able to transfer the call-in-progress from one base station to another. This is done by "handing-off" the call through a complicated series of actions taken by computer-controlled switching equipment at the base stations, the mobile telephone switching office (MTSO), and inside the terminal device (i.e., the handset). All instructions to the base stations and terminal devices are carried out over-air on subfrequencies not audible to the callers. Calls-in-progress are transferred from one cell to another by changing the operating channel on which the call is being carried. The computers at the MTSO are continually coordinating this complex process between cells and terminal devices. Hand-off is technically possible because *frequency agility* is built into the cellular system. Frequency agility refers to "the capability of the mobile phone [and base stations] to operate on any given frequency in the cellular radio spectrum," as commanded by the computers at the MTSO (Bedell, 1999: 17).

Call management on a cellular network is extremely complex and requires a tremendous amount of continuous data exchange between base stations and terminal devices—even when a call is not in progress. For instance, when a call is made to a cellular telephone number from the PSTN, the network must first locate the terminal device from among all of its possible base stations, it must then find and assign an open frequency between the nearest base station to the terminal device, and it must then proceed through a complicated sequence of maneuvers to establish a voice connection between the terminal device and the incoming call. If the terminal device is in motion, then a number of hand-offs may need to take place during the call, which initiates another series of data exchanges in order to find the nearest base station for the hand-off, and then to coordinate the actual hand-off procedure.

The Cellular Concept

Instead of having just a few radio channels that everyone must share [like citizens' band (CB) radio], cellular radio channels are reused simultaneously in nearby geographic areas yet customers do not interfere with each other's calls.

The cellular system is similar in functional design to the public switched telephone network, or landline network: fundamentally it contains the subscribers, transmission systems, and switches. The existence and control of the radio function of the cellular system is what differentiates cellular from landline telephone service (the PSTN). The cellular radio telephone system is the culmination of all prior mobile communication systems.

Paul Bedell. *Cellular/PCS Management: A Real World Perspective.* McGraw-Hill, 1999 (p. 6)

4.2 Analog and Digital Systems

Fifteen years ago, cellular networks were virtually all FM analog systems. With the introduction of digital technologies, incumbent wireless service providers have been converting their analog networks to digital technology to realize greater efficiencies and offer a greater array of services. However, analog cellular remains the most widely available commercial wireless service across Canada and utilizes a technology standard known as Advanced Mobile Phone System (AMPS). This enables users to "roam" among networks in different regions of Canada and the United States and allows users to switch between Mobility and Rogers AT&T services utilizing the same handset. Analog services typically include voice, call forwarding and three way conferencing as part of basic service, with optional voice mail service.

Digital services are typically offered in metropolitan areas and along major corridors. Digital networks provide additional features including enhanced voice quality, one and/or two-way text messaging, paging, call waiting, caller ID and packet-based data services.

Subscribers today have a choice between analog and dual-mode handsets. Analog handsets only support analog communication, while dual mode handsets can support both analog and digital. Users with dual-mode handsets can roam into other regions and use digital service if their handsets are compatible with the visited carrier's digital standards. If they use different standards, users can default to analog through the dual-mode capability of the handset. This feature has enabled Clearnet and Microcell to offer digital service initially in selected markets of Canada, while enabling subscribers nationwide roaming on competitors' analog cellular networks.

Today, both cellular and PCS networks may support similar services, depending upon carrier offerings. The main difference between digital "cellular" and PCS is that they operate in different portions of the radio spectrum. Some manufacturers are now preparing to offer tri-mode handsets to cover all modes available in both frequency bands. For purposes of our study, unless it is important to distinguish between digital and analog or cellular (800 MHz) and PCS (1.9 GHz), we will generically use the term "mobile telephone" to refer to cellular and/or PCS systems and services.

4.3 Network Elements

There are five basic components to a mobile telephone system (Fig. 1):

Terminal device (handset)
Cellular base stations
Fixed cellular network
Mobile telephone switching office (MTSO)
Public switched telephone network (PSTN)

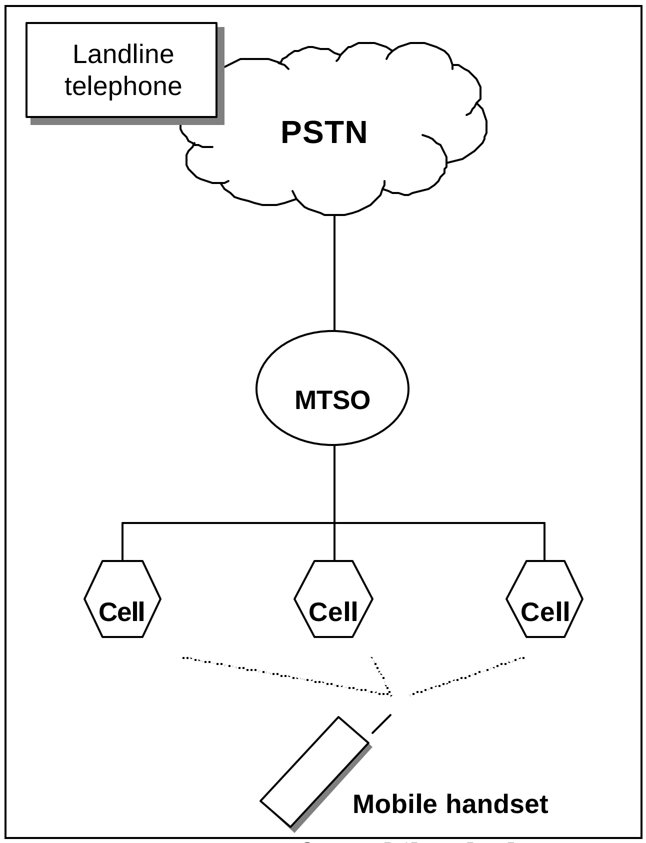

Figure 1. Components of a mobile telephone system.

4.3.1 Terminal Device

The terminal device represents the subscriber-end of the cellular system and the component most familiar to mobile phone users. Terminal devices come in varying degrees of 'mobility', from fixed mobile units in vehicles to small, pocket-sized units. Power and range capabilities will be influenced by the size and weight of terminal devices, but significant advances have been made in recent years. Today's cellular telephones are generally much smaller and more "mobile" than the shoulder-bag or vehicle-mounted variety of the 1980s. A cursory review of current PCS technology reveals that today's handsets have a typical size of 14cm x 5cm x 3cm, and weigh-in at about 140g (5.0 oz.). Standard features include voice and text messaging, call logging, a calculator, a clock/calendar and alarm, phone book, and even videogames and FM radio receivers. Mini-browsers for special Internet applications are also becoming increasingly popular. Battery life on mobile handsets has improved dramatically in recent years, and "talk time" can range between 2 and 10 hours, with "standby time" being as long as 10 days for some phones.

It is expected that the functionality of terminal devices will expand dramatically in the next few years, as wireless access protocol (WAP) applications are introduced into the marketplace enabling a variety of new Internet-type applications (WAP Forum, 2000; WAP.NET, 1999).

4.3.2 Cellular Base Stations

Terminal devices communicate with cellular base stations, which serve as the air-interface point for a cellular network. Each base station is, from a functional standpoint, a base transceiver station (BTS) capable of receiving and transmitting multiple simultaneous calls (usually 14 channels are available at each base station). Potential traffic at a BTS is measured by a POP count (population count), which indicates the number of potential customers within a defined geographical area. An industry practice for measuring the value of a particular cell market is to examine its POP count, with the most profitable areas being densely populated areas, such as urban centres (Bedell 1999,: 24).

A typical BTS consists of five major components:

- a set of radio transceivers and associated computer equipment
- a link to the mobile telephone switching office (MTSO)
- a set of antennas for transmitting and receiving calls
- antenna mounting hardware
- equipment housing and power supply

Radio transceivers and associated computer equipment perform two key simultaneous functions: (a) radio transmissions received from customers undergo preliminary processing for delivery to the MTSO; and (b) calls delivered from the MTSO undergo final processing and for over-air transmission to customers within the local cell. This equipment is housed at the site of the BTS, often located near the antenna base, and requires a continuous supply of electrical power to operate.

In effect, each BTS serves as a distribution point for a number of wireless local loops. It is linked to the MTSO either by means of wireline or by microwave distribution trunk, and if this link is severed then the cell is effectively out of service. A further discussion of the BTS-MTSO link is discussed below in the subsection on the fixed cellular network.

Air-interface from the BTS to the subscriber handset is achieved by means of a set of antennas located at the base station. Two main types of antennas are used in mobile telephone systems: omnidirectional and directional. Omnidirectional antennas radiate radio frequency (RF) energy equally in 360 degrees horizontal, and are sometimes referred to as *omni cells* (Bedell 1999, p. 66). Typical of analog cell systems, omni directional antenna look similar to fluorescent light tubes. An omni cell consists of three antennas: two for reception and one for transmission (Fig. 2).[3]

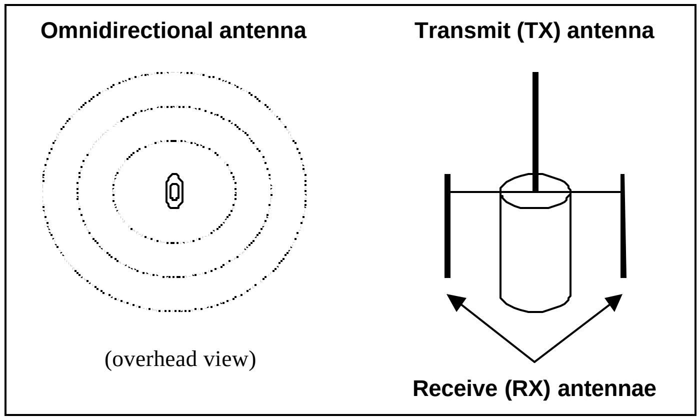

Figure 2: Omni Cell

With the advent of digital PCS systems, directional antennas are becoming more common place. These antennas transmit and receive RF within a relatively narrow beam of focus, usually in the order of 120 degrees horizontal. In more sophisticated systems this beam can also be dynamically adjusted by the carrier in order to compensate for changing traffic patterns. Directional cells are often divided into three or six separate subcells, with three antennas (2 receive and 1 transmit) per subcell (Fig 3).

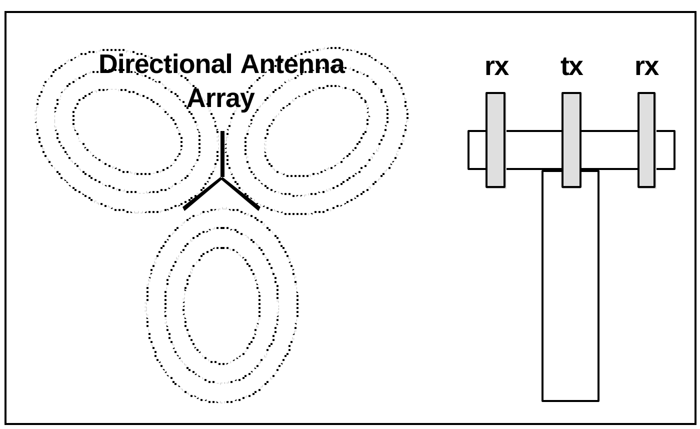

Figure 3: Directional Cell (3-way)

Other types of antennas used with mobile telephone systems include enhancers, microcells, and picocells. Enhancers are used to amplify RF signals without otherwise processing those signals, and are used to extend coverage in areas where an additional BTS is not necessary or appropriate. Microcells use small antennas to fill in small

[3] The reason for this is a technical matter and will not be discussed in detail.

coverage holes, often in urban centres where coverage is impeded by large buildings. Picocells use even smaller antennas to provide minute coverage detail in locations such as shopping centres or other public buildings.

Antennas can be found mounted on a wide variety of structures and numerous towers. The need for many cells, especially in densely populated urban centres makes it impractical to build a new tower each time a new BTS is needed. As a result, base stations are often located at existing structures such as office towers, apartment buildings, or local community facilities (e.g., churches, schools, etc.). In these cases, antennas are typically placed on short towers or mounted directly to the sides of the building.

When towers are needed to support the antennas for a BTS (as is often the case in rural areas), several designs are typically used. Monopole towers consist of a single mast of vertical-mounted sections of tubular steel alloy (usually in 40 ft. sections) stacked to a height that ranges between 150-250 ft. The tower is freestanding, with the base mounted to a concrete pad or footings.

Free-standing towers, also known as self-supporting or lattice towers, consist of three or four-sided steel cross-arm sections anchored to a concrete pad. Anchoring methods for both lattice and monopole towers can take the form of a spread-foot or pier-footing method. Whereas the spread-foot method uses a wide concrete pad to anchor the tower, the pier-foot method means of a set of narrow but deeply sunk concrete footings as the support base for the tower.

Guyed towers present another option for mounting antenna arrays. These consist of triangular steel cross-arms (usually in 20 ft. sections) that are built to a height of 300 ft. The tower is not free-standing and is “guyed” by a set of tensioned support cables anchored to the ground. Because of the large amount of space that these towers require, they tend to be reserved for rural settings. This type of tower also requires routine maintenance to check tension levels on the supporting guy-wires.

It is not uncommon to see clusters of antennas—also known as antenna farms—in both urban and rural areas. Antenna farms are often revenue-generating ventures offered by landowners who provide space for several carriers to erect antenna towers.

All cellular base stations require some form of equipment housing and a steady supply of electrical power. Equipment housing is typically located near the antenna or mounting structure, and must be accessible to technicians for servicing. Electrical power is necessary for all operation of transceivers and computer equipment at the BTS, and is generally supplied by the local power authority. Depending on the location of the BTS, backup AC electrical power may or may not be readily available, although battery backup systems are available. Typical battery life for a BTS has been cited at three hours, with a recharge time of anywhere from two to ten hours.[4]

[4] Interview with Alex Tang from Nortel (March 15, 2000)

4.3.3 Fixed Cellular Network

All cellular base stations within a cellular system must be connected to the mobile telephone switching office (MTSO), which coordinates the handoff process and links the cellular system to the PSTN. "The process of transporting traffic across a cellular network back to the MTSO for switching is known as *backhauling*" (Bedell, 1999: 130). The *fixed network overlay* refers to the infrastructure that connects cells to the MTSO and consists of:

- leased copper cable or fibre optic trunks, or
- microwave radio or satellite links, or
- a combination thereof.

A *fixed network methodology* determines the design by which the cells are connected back to the MTSO. Three basic designs are possible: star formation, ring formation, and a daisy-chain formation (Fig 4). Bedell (1999: 130) indicates that ring and daisy-chain formations are the most common, while star formations are less common due to the high cost of independently connecting each cell to the MTSO. Ring and daisy-chain formations can be designed around pre-existing infrastructure (usually as leased lines). A fibre ring formation (SONET) provides redundancy in the event of line failure due to disasters or accidents, and is common in more densely populated urban centres. Daisy-chain formations are more vulnerable to single-point failures because they link cells in an additive, serial pattern back to the MTSO. This design is particularly vulnerable to single-point failures, especially those that occur near the MTSO, as cell-sites are gradually aggregated into a single trunk.

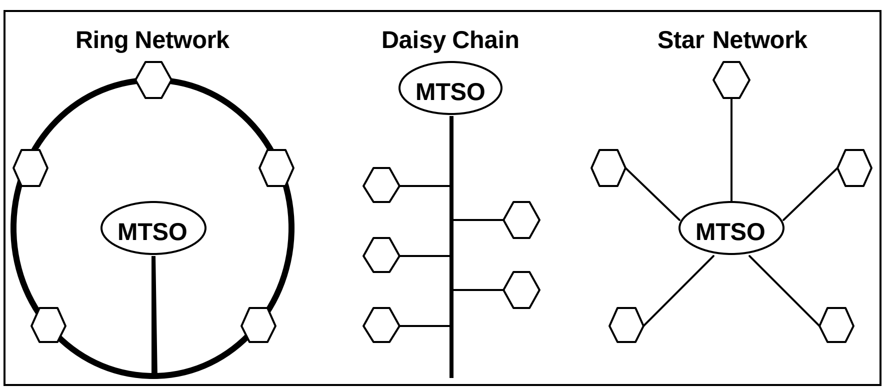

Figure 4: Fixed Cellular Network Methodologies

The entire fixed network is monitored and controlled from a network operations centre (NOC), where the core network management functions are performed. Typical functions at an NOC include fault management, configuration management, security management, accounting management, and performance management (Bedell, 1999: 142). Wireless carriers may have one or more NOCs which are geographically dispersed. If a carrier has more than one NOC they will be regionalized, yet remain connected in order to provide mutual emergency backup support if necessary (Bedell, 1999: 141).

4.3.4 Mobile Telephone Switching Office (MTSO)

The MTSO provides the switching functions for a cellular system, similar to what is known as a "Class 5" end-office switch for wireline telephone systems. Calls are backhauled from the cellular base stations to the MTSO by means of wireline or microwave trunks, processed at the MTSO, and then delivered to the PSTN. The process is identical in reverse: calls are routed from the PSTN, through the MTSO, to cellular base stations and, finally, to mobile handsets.

In essence, the MTSO provides a *voice path connection* between a mobile telephone and a landline telephone or other mobile telephone (Bedell, 1999: 118). However, in addition to providing this voice path connection (also known as "call routing"), the MTSO provides a number of other critical functions, including call handoff, roaming data, traffic and call processing statistics, and billing operations.

4.3.5 Public Switched Telephone Network (PSTN)

Mobile telephone systems interconnect with the PSTN to provide subscribers with access to landline telephones as well as other mobile telephones. It is estimated that 75 percent of all cellular telephone calls made today are directed to landline telephones (Bedell 1999: 146). These are known as *mobile-to-land* calls, and require that mobile carriers provide cost-effective interconnections with the PSTN:

> The public switched telephone network is that which we use every day to place our telephone calls, whether they are across town, cross-country, or across the world. In its most basic form, the PSTN is accessed every time a person picks up a telephone and hears a dial tone. (Bedell 1999: 142)

Interconnection at the PSTN can take place at two main junction points: a local exchange carrier's access tandem, which serves as a hubbing centre for two or more central offices (COs); or, directly at a local carrier's CO. The basic elements of interconnection include a circuit (known as a DS1 or DS3 circuit), a trunk, and a set of telephone numbers (purchased from the local exchange carrier).

Interconnection at the mobile carrier's end can take place at either the MTSO or directly with a cellular base station (BTS). There are several types of interconnection configurations, each associated with details such as the specific junction point and local calling areas provided by the local carrier.[5]

[5] According to Bedell (1999: 152), "the underlying principle in ordering any type of interconnection used for carrying cellular traffic is to obtain the largest available geographic 'footprint' at each point of interconnection." A review of each type of interconnection, while potentially relevant to vulnerability issues, is beyond the scope of this report.

5. Regulatory Overview

Governments often regulate industries because of their special importance to society. Industries such as telecommunications, electricity, gas and water are often referred to as public utilities because they hold themselves out to the public at large as suppliers of a service or a commodity that is essential or in widespread demand and that is typically provided on a monopoly or quasi-monopoly basis (Ryan, 1999). Historically, common law has imposed special obligations on businesses "affected with a public interest" (Melody, 1997b).

Interference with a telecommunications carrier's private rights has been justified on the grounds that, by devoting its property to a use in which the public has an interest, it is, in effect, granting the public a right in that use and, therefore, may be required to submit to control by the public for the common good. One such obligation is a duty on telecommunications carriers (often referred to as a common carrier) to supply service at a reasonable price and without undue discrimination to all who seek it. However, despite additional public responsibility, telecommunications carriers do not automatically enjoy a special position in common law and any particular powers or privileges they may require to provide services must come from legislation (Ryan, 1999).

Implementing statutory objectives and imposing obligations on telecommunications carriers has been a complex process in Canada, not only because of historical debates about monopoly versus market driven approaches to regulation, or because of their mixed public and private investment, but also because of constitutional issues.

5.1 Constitutional Framework

The Canadian Constitution does not specifically assign jurisdiction over telecommunications to either provinces or Parliament. However, through constitutional interpretation rendered in a series of Supreme Court decisions[6] and subsequent legislative actions, jurisdiction over telecommunications has been ceded exclusively to the federal government. Part of the legal rationale for this is that even though carriers may reside solely within provincial boundaries, because of their interconnectedness with external carriers, they are interprovincial undertakings and consequently subject to exclusive federal legislative jurisdiction.

Authority for this position is based on Section 92 of the Constitution Act, 1867 (U.K.), which defines provincial jurisdiction as follows:

> "In each Province the Legislature may exclusively make laws in relation to matters coming within the Classes of Subjects next here-in-after enumerated; that is to say, -

[6] Alberta Government Telephones v Canada, [1989] 2 S.C.R, at p.262 (in Ryan, 1-4); Telephone Guevremont Inc. c. Quebec (Regie des telecommunications) (1992), 99 D.L.R. (4th) 241 (C.A.) at p.256 (in Ryan, 1-4).

> 10. Local Works and Undertakings other than such as are of the following Classes;
> a. Lines of Steam or other Ships, Railways, Canals, Telegraphs, and other works and Undertakings connecting the Province with any other or others of the Province, or extending beyond the Limits of the Province.

In Supreme Court decisions, "Telegraphs and other Works" has been interpreted to include telephones as well as all forms of wireless radio communication (Ryan, 1999).

In Canada, historically, telephone companies generally offered both local and interprovincial services as an integrated package. Successive Supreme Court decisions have rejected the notion that a single undertaking, for constitutional purposes, can have a dual character under which, local services are subject to provincial legislative jurisdiction and interprovincial to federal legislative jurisdiction. In cases where both services are provided by the same undertaking, the undertaking as a whole is classified as a federal undertaking (Ryan, 1999).

In the case of jurisdiction over radio communication, the Privy Council in its 1932 decision *"Re Regulation & Control of Radio Communication in Canada (the "Radio Reference")*[7] confirmed the constitutionality of exclusive federal jurisdiction through its treaty-making powers and domestic obligations assumed under the International Radio Telegraph Convention, as well as its authority over interprovincial radio communication. Similar Supreme Court decisions have extended Parliament's jurisdiction over cable television[8].

However, federal undertakings are required to observe provincial laws of general application in the province or provinces in which they operate, unless such laws affect the undertakings in matters that place them specifically under federal jurisdiction, such as the management of telecommunications undertakings and tariffs they establish for their services (Ryan, 1999) or placement of towers, antennae, wires and other equipment required for telecommunications.

5.2 Legislative Framework

The principal federal legislation concerning Canadian telecommunications is contained in two statutes, the Telecommunications Act[9] and the Radiocommunication Act[10]. The original framework for telecommunications dates back to 1906 when the Board of Railway Commissioners for Canada was granted the power to regulate telephone and telegraph companies under federal jurisdiction. The Board was given responsibility for approving telephone service rates, ordering the interconnection of telephone systems and installation of lines along highways and in other public places.[11]

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[7] Re: Regulation & Control of Radio Communication in Canada (the "Radio Reference"), [1932] A.C. 304, 1t p314 (in Ryan, 1-2)
[8] Capital Cities Communications Inc. v Canada (CRTC) [1978] 2 S.C.R. 141, at p.159 (in Ryan, 1-6)
[9] Telecommunications Act, R.S.C. 1993, c.38
[10] Radiocommunication Act, R.S.C. 1985, c.R-2
[11] Railway Act, R.S.C. 1985, c. R-3

In 1976, these powers and responsibilities were transferred to the Canadian Radio-television and Telecommunications Commission (CRTC) which already regulated Canadian broadcasting and cable television undertakings. In October 1993, a new Telecommunications Act came into force replacing the Railway Act and officially extending federal regulatory authority over all telecommunications in Canada. The Act represents the first comprehensive reform of Canadian telecommunications law since the original 1906 legislation. The CRTC itself is established under separate statute, the Canadian Radio-television and Telecommunications Commission Act (CRTC Act).[12]

In addition to these Acts, a number of special Acts that pertain to specific carriers have been enacted by Parliament; they include: Bell Canada[13], British Columbia Telephone Company[14], Teleglobe Canada[15], and Telesat Canada[16].

5.3 Regulation Under the Telecommunications Act

The Telecommunications Act contains a number of important provisions governing the CRTC's authority to regulate Canadian carriers and conditions that must be met by undertakings to qualify as a Canadian carrier. For example, Section 16(1) stipulates that a "Canadian carrier is eligible to operate as a telecommunications common carrier if it is a Canadian-owned and controlled corporation incorporated or continued under the laws of Canada or a province." A "Canadian carrier" is defined as a "telecommunications common carrier that is subject to the legislative authority of Parliament." A "telecommunications common carrier" itself is defined as "a person who owns and operates a transmission facility used by that person or another person to provide telecommunications services to the public for compensation." A "transmission facility" is defined as "any wire, cable, radio, optical or other electromagnetic system, or any similar technical system, for the transmission of intelligence between network termination points, but does not include any exempt transmission apparatus". "Intelligence" is defined as "signs, signals, writing, images, sounds or intelligence of any nature."

The distinction between owning and operating a transmission facility and merely using facilities is an important one. Those who *own* and *operate* transmission facilities qualify as "telecommunications common carriers" and may be subject to CRTC regulation, while those who merely *use* them to provide services to the public (value added services providers and resellers) *are not*.

In exercising its authority to regulate Canadian carriers, the Commission is guided by a number of provisions. An overarching Canadian Telecommunications Policy, stated in Section 7, sets out the objectives for regulation. That section provides as follows:

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[12] Canadian Radio-television and Telecommunications Act, R.S.C. 1985, c. C-22
[13] Bell Canada Act, S.C. 1987, c.12
[14] British Columbia Telephone Company Special Act, S.C. 1916, c.66
[15] Teleglobe Canada Reorganization and Divestiture Act, S.C. 1987, c.12
[16] Telesat Canada Reorganization and Divestiture Act, S.C. 1991, c.52

7. It is hereby affirmed that telecommunications performs an essential role in the maintenance of Canada's identity and sovereignty and that the Canadian telecommunications policy has as its objectives:

a) to facilitate the orderly development throughout Canada of a telecommunications system that serves to safeguard, enrich and strengthen the social and economic fabric of Canada;

b) to render reliable and affordable telecommunications services of high quality accessible to Canadians in both urban and rural areas in all regions of Canada;

c) to enhance the efficiency and competitiveness of the national and international levels of Canadian telecommunications;

d) to promote the ownership and control of Canadian carriers by Canadians;

e) to promote the use of Canadian transmission facilities for telecommunications within Canada and between Canada and points outside Canada;

f) to foster increased reliance on market forces for the provision of telecommunications services and to ensure that regulation, where required, is efficient and effective;

g) to stimulate research and development in Canada in the field of telecommunications and to encourage innovation in the provision of telecommunications services;

h) to respond to the economic and social requirements of users of telecommunications services; and

i) to contribute to protection of the privacy of persons.

The Act further stipulates that the CRTC must exercise its powers and perform its duties with a view to implementing these objectives, as well as ensure that Canadian carriers provide telecommunications services and charge rates that are just and reasonable and are applied in such a way as they do not unjustly discriminate or give undue or unreasonable preference, or subject a person to undue or unreasonable disadvantage (Section 27). CRTC's activities must also be conducted in accordance with any orders made by the Governor in Council on broad policy matters (Section 8) or any standards prescribed by the Minister of Industry in respect of technical standards for telecommunications (Section 69).

The Act provides a wide range of powers that the Commission can exercise in discharging its duties. These include, among others: approving working agreements among carriers; authorizing or prescribing a Canadian carrier's liability in respect of a telecommunications service; approving classes of telecommunications services and permitting different rates to be charged for different classes of service; determining technical standards applicable to telecommunications facilities operated by or connected to those of a Canadian carrier; amending, suspending or disallowing tariffs, agreements or arrangements submitted for approval; ordering a Canadian carrier to provide or discontinue a telecommunications service or class of service; and making rules, orders and regulations respecting any matter within its jurisdiction under the Act.

5.3.1 Tariffs

Traditionally, the CRTC has regulated telecommunications through approval of tariffs submitted by Canadian carriers. Tariffs are defined under the CRTC's Rules of Procedure as "any publication containing rates, charges, rules, regulations, conditions, specifications or requirements relating in anyway to the furnishing by a regulated company of telecommunications services or facilities to any person."[17]

5.3.2 Obligation to Serve and Terms of Service

The Telecommunications Act does not specifically impose a statutory duty to serve on Canadian carrier, although Bell Canada has some limited obligations under Section 6 of the Bell Canada Act.

Terms of service for tariffed services provided by Canadian carriers are prescribed by the CRTC and set out the basic rights and obligations of carriers and their subscribers (Canadian Radio-television and Telecommunications Commission, 1986). Article 1.1 of the Terms of Service provides that except as otherwise specified, the Terms of Service apply with regard to services for which the CRTC has approved a tariff. This stipulation has implications for provision of mobile telephone services and will be addressed later in this report.

With regard to obligations of carriers, the Terms of Service cover areas such as limitations of the carrier's obligation to provide service; installation, possession and maintenance of carrier facilities; right of a carrier to enter premises on which service is or is to be provided; and conditions for requesting deposits and/or establishing alternatives. For customers, the Terms contain provision for: customers' financial liability for calls and other charges; confidentiality of customer records; provision of directories; company initiated changes in telephone numbers and service arrangements; refunds in case of service problems; limitation of carrier liability, and customer-initiated termination and company-initiated suspension or termination of service (Canadian Radio-television and Telecommunications Commission, 1986).

5.3.3 Quality of Service

Section 7(b) of the Telecommunications Act sets a policy objective to "render reliable and affordable telecommunications services of high quality accessible to Canadians in both urban and rural areas in all regions of Canada." Canadian carriers report on service quality using a set of uniform national standards. These standards, originally developed in 1982, are intended to ensure that telephone consumers receive an acceptable level of service from their telephone company. The telephone companies identify service quality issues through self-reporting and subscriber complaints. Each telephone company submits a quarterly report on 19 indicators to the Commission. The service level of each indicator is measured against a prescribed standard that has been set

[17] CRTC Telecommunications Rules of Procedure, SOR/79-554

by the Commission. If a standard is not met, the telephone company is required to report to the CRTC as to why it has not been met and propose a remedy (Canadian Radio-television and Telecommunications Commission, 2000).

The quality of service indicators are:

- the number of days required to provide service from the date of the customer's request;
- the total number of installation appointments booked and the number met;
- the number of outstanding requests for Network Access Services not met because of facility shortages;
- the number of rural outstanding requests for higher grades of service (e.g., from 4-party to 2-party service) unfilled for more than 30 days;
- the percentage of calls to a business office answered in 20 seconds or less;
- competitor installation appointments met;
- on-time activation of service switched to a competitor;
- the total number of out-of-service trouble reports and those cleared within 24 hours;
- repair appointments met;
- initial customer trouble reports indicating improper functioning of service;
- community isolation resulting from trunk failure that last one hour or more;
- the percentage of calls to a repair bureau answered in 20 seconds or less;
- the total number of installation appointments booked and the number met, who are competitors;
- the percentage of attempted calls during the busy hour experiencing dial tone delay of three seconds or less;
- the percentage of customer listings in the white pages of company directories published without errors or omissions;
- number of days required to resolve customer complaints addressed (in writing or orally) to officers and Department Heads of the telephone companies and the Commission;
- the time it takes to field customer requests and inquiries;*
- the number of customer complaints that have not been satisfied within 10 working days;* and
- the speed and accuracy of directory assistance.*

(*standards remain to be established for these indicators)

The telephone companies required to provide quarterly quality of service reports are only those with more than 25,000 access lines. Further, Northwestel, because of its unique far northern territory, is required to report certain service indicators at community levels rather than on territory-wide basis required of other telephone companies (Canadian Radio-television and Telecommunications Commission, 2000).

5.3.4 Technical Standards

In an increasingly competitive environment, efficient interconnection is fundamentally important to ensuring that the Canadian telecommunications system can function as an integrated system. Users want end-to-end services within a "seamless" network, regardless of who owns the various facilities in the overall system or how the telecommunications links are actually established. For this to occur, a high degree of cooperation and coordination is required of all parties concerned. Since a system is only as strong as its weakest links, cooperation must extend across technical standards and protocols, service quality and definitions, investment obligations, tariff structures and revenue settlements (Melody, 1997a).

In Canada, the circumstances for interconnection negotiations have changed from cooperation among geographically-based monopolies to cooperation between direct competitors for similar services in the same area, as has the process for setting interconnection standards. Under a local services monopoly regime the incumbent local exchange carrier is the one who normally permits the exchange calls between *all* local subscribers, access to long distance service providers and access to other telecommunications networks. However, in today's increasingly competitive market, to ensure the integration of *new* competitive networks into what is evolving into a "network-of-networks" and to ensure maintenance of subscriber-to-subscriber access, all local exchange carriers in a local calling area must be interconnected.

In this regard, the CRTC has established under the authority of Section 32(b) of the Telecommunications Act that carriers must rely upon the use of industry standard network interfaces to the greatest extent possible rather than non-standard interfaces and proprietary standards. The Canadian Standards Association (CSA) is designated as the prime source of standards used. If CSA has not developed standards, ANSI, ITU standards and Bellcore General Requirements can be used. The CRTC Industry Steering Committee is designated as the body to provide the Commission with recommendations regarding the standards that should be adhered to for network interconnection and interoperation (Canadian Radio-television and Telecommunications Commission, 1997). Carriers, however, are free to implement standards and specifications of their choice within their own networks (Canadian Radio-television and Telecommunications Commission, 1998b).

Further to this, the Governor in Council under Section 69.4 of the Act may also make regulations respecting requirements for technical specifications and certification that may be issued and administered by the Minister of Industry.

5.3.5 Forbearance and Exemptions from Regulation

A significant difference of the Telecommunications Act from previous legislation concerns granting the Commission authority to forgo (forbear or exempt) regulation. Section 34 of the Act empowers the Commission to refrain, in whole or in part and conditionally or unconditionally, from exercising any power in the performance of certain duties in relation to a telecommunications service or class of services provided by a Canadian carrier, where the CRTC finds that to refrain would be consistent with the Canadian telecommunications policy objectives outlined in Section 7.

This change reflects a shift away from direct government intervention toward a market driven approach. The Commission's powers and duties, referred to in Section 34, relate to: the conditions under which telecommunications services may be offered and provided by Canadian carriers (imposed or contained in tariffs approved by the CRTC); the approval of rates contained in tariffs (Section 24); the determination that such rates are just and reasonable, and that the provision of a service by a Canadian carrier and rates charged by it are not unjustly discriminatory (Section 27); the approval of interconnection and other agreements involving a Canadian carrier (Section 29); and the authorization or prescription of a Canadian carrier's limitations on liability (Section 31).

Further to this, if the Commission finds that a telecommunications service or class of service provided by a Canadian carrier *is* or *will* be subject to competition sufficient to protect the interests of users, Section 34 makes it *mandatory* that the CRTC make a determination to forbear from exercising any of these powers or performing any of these duties, to the extent that it considers appropriate.

Finally, Section 9 of the Act empowers the CRTC to exempt any Canadian carrier from application of the Act, subject to any conditions, where the Commission is satisfied that the exemption would be consistent with the Canadian telecommunications policy objectives.

As will be discussed later in this report, forbearance and exemptions have important implications for wireless emergency telecommunications.

5.4 Regulation Under the Radiocommunication Act.

The radio spectrum has been a fundamental element in the development of the Canadian telecommunications infrastructure. Canada depends on the radio spectrum to support a wide range of industrial, scientific, medical, research, defence, public safety, business, social and cultural activities. The spectrum as a resource supports a multi-billion dollar industry and, with the rapid evolution and application of new radio technologies, wireless technologies are expected to play key roles in the development of the Canadian information highway. However, as a finite resource, the radio spectrum is also becoming increasingly congested, particularly in light of increasing and competing demands for new services.

The Minister of Industry, through the Department of Industry Act and the Radiocommunication Act, is responsible for developing national policies and goals for spectrum resource use. Other than those specifically exempted, radio authorizations are required for the use of the radio spectrum to provide wireless communication services. The Radiocommunication Act designates two authorities for the development and implementation of regulatory procedures: the Governor in Council and the Minister.

Section 6 empowers the Governor in Council, among other things, to make regulations: respecting technical requirements and standards; prescribing eligibility and qualifications of persons who can possess authorizations; prescribing terms and conditions of radio authorizations; prescribing conditions and restrictions for any prescribed radio service; prohibiting or regulating interference or adverse effects of electromagnetic energy; prescribing fees; prescribing exemptions, either absolutely or subject to qualifications for radio apparatus or classes thereof; prohibiting or regulating the further telecommunication of radiocommunications and prescribing maximum fines or terms of imprisonment for contravening or failing to comply with a regulation.

Subject to any of these regulations, the Minister, or any person authorized by the Minister, among other powers set out in Section 5 of the Act, may: issue radio licences, spectrum licences, broadcasting, radio operator and technical certificates and fix and/or add terms and conditions of any licence, certificate or authorization; establish technical requirements and standards; plan the allocation and use of spectrum; approve radio sites, including antenna systems and support structures; test radio apparatus for compliance with established technical standards; and determine existence of harmful interference and take mitigating action, including the issuance of orders for ceasing or modifying operation of interfering equipment.

In exercising these powers, the Minister or Minister-authorized persons (Industry Canada) may be guided by the objectives of the Canadian telecommunications policy set out in section 7 of the Telecommunications Act (Section 5.1.1).

5.4.1 Spectrum and Radio Systems Policy

Through public consultation processes, specific policies are established regarding the particular use to be made of a given frequency band (frequency utilization policies) or concerning what generic types and developments of radio equipment will be furthered in Canada (radio systems policies). These policies are intended to reflect, in part, the major responsibilities of the Minister of Industry to:

a) optimize the utilization of the radio spectrum;
b) provide for the planning of the efficient and orderly growth of the Canadian radio telecommunications network as an entire system;
c) ensure the public is served through consideration of all relevant factors in the granting of licences for new radio transmission facilities;
d) anticipate, analyze and resolve interference problems in the early stages of system development;
e) consider future system plans and provide these to the extent possible;
f) ensure that Canadian radiocommunication systems conform to the extent practicable to the International Radio Regulations established by the International Telecommunications Union (ITU) (Industry Canada, 1987).

5.4.2 Public Interest

The frequency spectrum is a special type of natural resource that, by its nature, does not respect geopolitical boundaries. Its use, therefore, is contingent on an efficient and effective body of policies, rules, procedures and practices designed to equitably accommodate as many users as possible in an interference-free environment (Industry Canada, 1987).

In this regard, Industry Canada must consider how the spectrum should be used and regulated for the public good. For instance, since the spectrum is a limited resource, generally those undertakings that provide and extend similar services to the greatest number of users or subscribers, or that use more sophisticated technology to increase the efficiency of spectrum use and, hence, number of subscribers which can be served, are generally given preference particularly in areas of moderate or intense spectrum use.

Spectrum is also allocated to services whose special needs are best tailored to the use of that particular spectrum. Each frequency range possesses propagation and other characteristics that determine its optimal use. Because of this, Industry Canada gives preference to local mobile radio (including cellular and PCS) over fixed point-to-point in the VHF and UHF bands and preference to fixed operations in the higher UHF and SHF bands.

However, in rendering decisions in areas where there is intense spectrum use and/or competing applicants for the same spectrum, various public interest factors must be carefully assessed. For example, services involving safety of life and property (safety services) are to take precedence over others to be established for industrial or business communications purposes. Included in this “preferred services” category are federal and provincial civil defence systems, provincial and municipal hydro electric power, highways and transportation systems and other essential public utility systems. Furthermore, generally, non-shared, exclusive use assignments are made to operations in the safety services category. Other applicants whose systems are not encompassed by the safety services category are often assigned frequencies that are time-shared as necessary with other like non-competing systems in the same local areas (Industry Canada, 1987).

5.4.3 Spectrum Allocations

The traditional licensing approach practiced by Industry Canada has been to deal with most applications for mobile and fixed radio systems on a first-come, first-served basis (FCFS). This approach is generally used in instances where there is sufficient spectrum to meet the demand in a given frequency band and where there is no apparent additional measure required to advance particular telecommunications policy objectives. This process is facilitated through an integrated management system that includes spectrum allocation and utilization policies, licensing policies, radiocommunication regulations, technical and radio system standards (Industry Canada, 1999g).

In the mobile bands, channels were traditionally assigned one at a time until no assignable channels assignments remain. This process is referred to as horizontal loading. Additional users were then added on a shared basis to lightly loaded channels (vertical loading). However, because of rapidly increasing demand for new mobile spectrum and the introduction of automated trunk radio systems, these practices were revised in 1983 to make vertical loading the norm, especially in urban areas. Each new channel would be loaded to a prescribed minimum level until this level was reached before a new channel would be allocated. This required most channels to be shared from the outset, but could be compensated for by use of trunked radio systems that allowed a greater number of mobiles to obtain service in comparison with conventional systems, reduced waiting times, greater privacy and removal of manual monitoring of channels.

Although Section 40 of the Radiocommunication Regulations specifies that the assignment of a frequency or frequencies does not confer a monopoly on the use of the frequency or frequencies, public safety services, generally, are not expected to share channels with users of other services and are assigned lower loading requirements than other services. Two methodologies are used to determine channel loading specifications – mobiles per channel and traffic modeling. In terms of the number of mobiles per channel for trunked radio systems, the basic loading guideline is 50 mobiles per channel for public safety versus 90 mobiles per communication channel for other users and 30 mobiles per channel versus 75 per channel for conventional radio systems. Traffic modeling, another approach based on traffic theory and the Erlang C model, is being used more frequently by Industry Canada. This model assumes that the radio system will queue a certain number of blocked calls. A grade of service specification is set that is defined by a specified delay, in message lengths, that should not be exceeded. That is, 97 per cent of the calls placed will not be delayed by greater than the specified length. For public safety, the specified delay is 1 average message length versus 3 average message lengths for other services[18] (Industry Canada, 1999i).

Over the last two decades, growth of mobile radio has continued to climb steeply, and in situations where there is, or is likely to be, more demand for spectrum than available supply in a given frequency band, or where there is a requirement to meet certain telecommunications policy objectives, Industry Canada has chosen to initiate a competitive licensing process. In these cases, a comparative selection or auction licensing approach may be initiated according to conditions. Factors that could trigger a competitive approach include new technologies with compelling service opportunities (e.g., PCS), increased desires to establish national systems, bands nearing exhaustion (75% full) and requests for significant spectrum (25% of a band). Both cellular and PCS have been subjected to a comparative licensing approach, and Industry Canada anticipates using the competitive process (auction) in several upcoming licensing situations including: most frequency bands for multipoint communications systems (MCS) in urban areas; spectrum for broadband wireless access applications and additional public mobile telephone service. Furthermore, if conditions change affecting the orderly development of any area of radiocommunication, Industry Canada reserves

[18] The average length is defined by the average "push-to-talk" duration.

the right with advance notice to interested parties, to change from one licensing process to another (Industry Canada, 1999g).

5.4.4 Non-Reservation of Spectrum

As a general matter of principle, Industry Canada does not reserve spectrum for any particular user(s), with the exception of a limited number of specific bands for the exclusive use of federal government programs.

5.5 Regulatory Framework for Cellular and PCS Telecommunications

Unlike new wireline telephone services, cellular telephone services were not introduced through CRTC regulatory action, but rather through licensing under the Radiocommunication Act. In October 1982, the federal Department of Communications (DOC), the predecessor to Industry Canada, issued a call for cellular mobile radio licences, inviting applications to operate cellular mobile radio systems in twenty-three designated metropolitan areas (MAs) throughout Canada.

5.5.1 Industry Canada Regulation

DOC had allocated frequencies for cellular radio (824-849 MHz and 869-894 MHz), a new high capacity-type of mobile radio telephone system, expressly to alleviate a shortage of frequencies for mobile telephone service, and to provide for long term growth, including the introduction of the portable telephone. DOC's intention was to license only two cellular systems in each MA, one of which would be operated by the monopoly telephone company within whose territory the MA was located. DOC also indicated that it was only prepared to consider applications to provide a public mobile telephone service with some form of interconnection with the public switched telephone network (Canadian Radio-television and Telecommunications Commission, 1984a), despite the fact that only the CRTC could approve or order interconnection. In response to this, the CRTC concurred that interconnection of cellular mobile radio to the PSTN was in the public interest, and would likely result in significant advantages, including increased consumer choice among mobile telephone services and technological developments, innovation, lower prices as competition developed and more enhanced forms of mobile communications services (Canadian Radio-television and Telecommunications Commission, 1984a).

As mentioned earlier, the essential characteristic of a cellular mobile radio system is its potential for frequency reuse within a service area, which provides an opportunity for higher capacity, more efficient spectrum utilization, and improved grade of service. In return, however, it must be recognized that cellular systems are complex and expensive, and require large amounts of spectrum to make them economically viable (Department of Communications, 1981). From the viewpoint of radio licensing, then, it became necessary to distinguish between cellular and other mobile systems, and for this purpose, DOC adopted the following definition for this new class of service:

> A cellular system is a high capacity mobile radio system in which radio channels are assigned to one or more geographic cells within a defined service area. For systems of more than one cell, the service is uninterrupted as the mobile unit moves from cell to cell. The high capacity of the system is obtained by means of a multi-cell configuration in which special radio channels are reused in different cells within the service area.

In 1983, Cantel was chosen by the Department of Communications to provide alternative cellular mobile radio telephone service in the 23 MAs across Canada, and dominant carriers were licensed in 1984 to compete with Cantel within their respective territories. Each was awarded 25 MHz of radio spectrum. In establishing conditions of licence for these systems, DOC mandated the implementation of a nationwide high-capacity mobile radio service capable of serving both local and "roaming" mobile telephone users. The two systems were to be technically and operationally compatible with each other and with systems operating in the United States to enable wide-area roaming (Department of Communications, 1988). As services rolled out, networks expanded to include adjacent communities and corridors between cities, and under an expanded policy introduced in 1986, DOC accepted applications from service providers to offer service in areas not originally designated as MAs.

5.5.1.1 Personal Communications Services

In 1995, Industry Canada issued a call for applications for a new cellular service classified as Personal Communications Services or PCS. PCS represents the second generation (2G) of North American mobile cellular telephone service and the allocation of spectrum that goes with it. Its main distinguishing feature is that it employs digital rather than analog technology used in the first generation cellular telephony. Although still employing a similar cellular system concept, digital PCS allows for significantly more efficient use of spectrum than conventional analog systems. Other potential benefits include higher level of security, better quality voice communication, faster and more reliable data transfer, and lower levels of transmitter power. Another distinguishing feature that separates PCS from traditional wireline service is its unfettered nature. Telephone communications traditionally have been designed around the use of unique numbers that are tied to particular locations, where a piece of terminal equipment, mostly the telephone handset, is physically tied to the wired network. With PCS, telephone numbers are intended to be issued to individuals rather than locations, with the expectation that, as networks roll-out and are interconnected via terrestrial and mobile satellite telephone networks, users can be in touch with each other anytime and anywhere (Industry Canada, 1999h).

The timing of PCS introduction was also important, coinciding with the development of a federal strategy for a new Canadian Information Highway[19]. Three key objectives identified in the information highway strategy were factored into the implementation of PCS: the creation of jobs through innovation and investment; the reinforcement of Canadian sovereignty and cultural identity; and the provision of access

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[19] The Information Highway is the metaphorical name given to Canada's rapidly emerging, seamless web of high-speed networks, capable of carrying voice, txt, data, graphics and video services to and from all Canadians.

at reasonable cost. Five principles guiding the development and implementation of the information highway were also considered:

- an interconnected and interoperable network of networks;
- collaborative private and public sector development;
- competition in facilities, products and services;
- privacy protection and network security; and
- life long learning.

In addition to these general policy objectives, Industry Canada also adopted the following detailed objectives specifically for the development and deployment of PCS (Industry Canada, 1995c):

- the stimulation of additional choice in the provision of cellular-like mobile radiotelephone services and the support of new technologies and facilities of high security and low cost which could compete with existing local wireline services;
- the provision of additional and innovative personal communications services at 2GHz, rather than only the replication by similar services of the mobile services currently operating below 1 GHz;
- the facilitation of national, North American and world-wide service offerings, to enable both Canadian equipment suppliers and consumers to benefit from the availability of larger markets, and to allow Canadian users the opportunity to make use of wide-scale roaming capabilities;
- the stimulation of competitive and comprehensive service offerings, provided through the utilization of both existing and new facilities, through, among other measures, the non-discriminatory access by third parties to networks, thereby also promoting value-added services and content;
- the support of the provision of services to the greatest possible number of Canadians; and
- the promotion of jobs and investment in Canada, through the support of research and development activities in Canada and the concomitant development of expertise for international trade and investment opportunities.

One of the key issues to be dealt with in awarding new PCS licences was the issue of the potential for incumbent cellular licensees to use their established position in the mobile radio market to their advantage in the new PCS market if they were awarded licences with the same provisions as new entrants. Among the solutions promulgated was to establish a limitation on the aggregation of spectrum, to be known as a "Spectrum Cap". This cap was set at 40 MHZ and consisted of frequency assignments for cellular radio telephony, PCS at 2 GHZ and similar public mobile radio telephony services in the 800 MHz band. Two new entrants, Clearnet PCS Inc. and Microcell Networks Inc. were each granted 30 MHz of spectrum while the major incumbent cellular operators were each granted 10 MHz. One 30 MHz licence (block 'C') and one 10 MHz licence (block 'E') were kept in reserve (Industry Canada, 1995c).

5.5.1.2 Provision of Cellular Services by New Parties

In 1998, Industry Canada announced that it would amend its policy respecting the authorization of cellular providers in order to permit third parties to provide cellular mobile telephony service in unserved or underserved[20] areas. The new policy is aimed at situations where the local wireline company and Cantel (or the local wireline telephone company or Cantel, as the case may be) had received appropriate notification of the intention of a third party to initiate cellular service and subsequently had not undertaken to provide cellular service itself in substantially the entire identified geographic area within a time frame of not longer than one year. Third parties are generally new cellular mobile voice telephony providers that are not affiliated with either the local incumbent wireline company or Cantel. Third party providers are encouraged to offer both voice and other than cellular mobile voice telephony services (e.g., fixed wireless access services) in the available cellular sub-band. There is also provision for Industry Canada to accept applications from *any* party (including affiliates of incumbent licensees) to provide other than cellular mobile voice telephony services provided sufficient spectrum for voice telephony services are reserved in the sub-band (Industry Canada, 1995d). A review to permit similar licensing of PCS in unserved or underserved regions is also underway.

5.5.1.3 Additional Spectrum for Mobile PCS Service

In large Canadian centres such as Toronto, Industry Canada has forecasted that some PCS service providers will experience a shortage of 2 GHz spectrum within the next year or so. To address potential emerging congestion problems, Industry Canada is considering releasing the unused PCS spectrum, and possibly 2110-2150 MHz, for the expansion of second generation PCS service and to begin implementation of third generation PCS. While second-generation systems (2G) provide higher efficiency voice over analog systems combined with limited data capability[21], third-generation systems, known as 3G (IMT-2000) are based on International Telecommunications Union standards and provide for much higher data rate capability. Because of this, they permit a wide range of multimedia services, including Internet applications and video-oriented services. Target data rates are up to 2 Mbps for in-building/low mobility applications, up to 384 Kbps for pedestrian applications and up to 144 Kbps for vehicular environments. It is expected that there will be transitional stages between 2G and 3G systems, and current and future PCS licensees are encouraged to incorporate plans for evolution to 3G services (Industry Canada, 1999e).

In preparation for release of this new spectrum, Industry Canada has also revised the Spectrum Cap to enable any PCS licensee to hold an aggregate assignment up to 55 MHz of spectrum.

[20] Areas served by only one cellular provider.
[21] Limited data capability is due to the data rate limitation of the access technology.

5.5.2 Specific Industry Canada Licence Requirements for Mobile telephones

A wide range of Industry Canada policies, regulations, procedures, radio standards and other technical requirements exist for guiding the development and implementation of cellular and PCS services. These are intended to establish the minimum requirements for efficient utilization of these bands and to ensure conformity with existing government policy. A brief introduction and review of some of the key requirements will be presented in this section in order to establish a regulatory context for later discussion of emergency telecommunications issues.

5.5.2.1 Technical Requirements

Cellular and PCS equipment generally must be certified in accordance with Industry Canada radio standards and procedures and related industry standards[22] established within a broader framework set out in the Radiocommunication Regulations made under the Radiocommunication Act. These requirements are specified in a series of published documents, and cover such areas as: certification of radio and terminal equipment; carrier modulation schemes[23]; transmitter power and antenna height limitations; minimum performance standards; signal bandwidths; compatibility standards; channel spacing; unique electronic serial numbers for each mobile transmitter; allocations and use of sub-band frequencies by specific licensed carriers; and coordination of systems in the Canada/US Border area (Industry Canada, 1990, 1996c, 1997e, 1999a, 1999b, 1999c, 1999j). Cellular radio telephone service is also not intended to be provided to airborne mobile terminals (Industry Canada, 1997e).

In addition to these requirements, cellular and PCS licensees are required to take into account the potential impact of antennas and their supporting structures on their surroundings. These requirements fall under three key areas: the environment, exposure to radio frequency fields, and land-use considerations.

5.5.2.2 Environmental Impact

In terms of the environment, the Canadian Environmental Assessment Act (CEAA) (*Canadian Environmental Assessment Act*, 1992) requires that all federal departments take into account environmental effects in the exercise of their authority. However, before one can examine how these measures affect cellular and PCS cell site installations, it is important to note some fundamental differences in the way cellular and PCS services are licensed. Cellular base stations are licensed as Type 1 stations that *require site-specific authorization*, normally in the form of a radio licence, *prior* to the installation and operation of any cellular mobile radiotelephone base station. Among the filing requirements for authorization are disclosure of the address or description of location, including latitude and longitude coordinates, and a Preliminary Environmental

[22] The primary industry standards are those issued by U.S.-based American National Standards Institute (ANSI) and Telecommunications Industry Association (TIA).
[23] Frequency Division Multiplex Access (analogue FM), Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA).

Information Attestation statement indicating potential environmental impact (Industry Canada, 1995a).

In contrast, PCS radio stations are licensed as Type 2 stations under a relatively new licensing category called "Spectrum Licensing". Common to all spectrum licences is that authorization is given by geographical area(s) and frequencies or frequency block(s). Since Type 2 stations *do not require* site-specific authorization, they *are not* considered to be "captured" by the requirements of the CEAA (Industry Canada, 1995a).

5.5.2.3 Exposure of Humans to Radio Frequency Fields

Although Industry Canada approves equipment and facilities that emit radiofrequency fields, areas involving health are not within its mandate. Instead, it relies upon Health Canada for advice on safe levels of exposure to radiofrequency fields. In 1991, the Department of Health and Welfare published a set of recommended safety procedures for the installation and use of radio frequency-emitting devices under the title of "Limits of Exposure to Radiofrequency Fields at Frequencies from 10 kHz 0 30 GHz" or "Safety Code 6". Maximum exposure levels and duration of exposure are used to determine whether or not a signal emitted can be considered safe. Industry Canada requires that all radio stations be installed and operate in compliance with Safety Code 6. Cellular stations, as Type 1 stations, are analyzed prior to authorization for their effects within the existing radio environment. If the analysis indicates that the maximum radio frequency field level prescribed by Safety Code 6 will be exceeded, mitigation measures may need to be undertaken, including reducing the power of the transmitter, changing the type, direction or height of an antenna, or restricting access to areas near the antenna. PCS (Type 2) stations must also comply with Safety Code 6, and must use similar mitigation techniques in instances where the operation of the proposed station may be in non-compliance with Safety Code 6. However, prior approval is not required to construct and operate a PCS base station (Industry Canada, 1995a).

Safety Code 6 guidelines (Industry Canada, 1999f) also apply to portable and mobile radio transmitters for establishing specific absorption rate (SAR) limits for human tissue. All transmitters (including portable, handheld, mobile or push-to-talk types, including cellular and PCS phones) are exempted from the SAR and radio frequency (RF) evaluation if their power output complies with the following power levels:

- Operation at frequencies below 1.GHz with an output power equal to or less than 200 milliwatts (mW);
- Operation at frequencies between 1.0 and 2.2 GHz with an output power equal to or less than 100 mW;
- Mobile radios[24](not portables) are exempt from RF evaluation if the operating frequency is below 1.5 GHz with effective radiated power (ERP) of 1.5 watts or less or above 1.5 GHz with ERP of 3 watts or less.

[24] Mobiles radios that are not body-worn (e.g., mounted on vehicles or placed on desks, etc.) and operated such that humans are normally separated from their radiating element.

- Multi-mode radios (e.g., analog and digital modes in cellular radios) are only required to be evaluated in the modes that do not qualify for exemption. Multi-mode radios must also be evaluated against all frequency bands used (Industry Canada, 1999f).

5.5.2.4 Land-Use Consultation

Prior to installation of an antenna structure for which community concerns could be raised, owners of cellular and PCS stations must consult with their land-use authority. Cellular Type 1 station applicants must complete and submit a signed Municipal/Land-Use Consultation Attestation for any new or modified antenna structures. In the event of a land-use authority and an applicant being unable to come to an agreement, Industry Canada, after reviewing all of the pertinent information, under authority of the Radiocommunication Act, reserves the right to make the final determination. Although PCS Type 2 owners are also required to consult with land-use authorities prior to installation of antennas, there is no specific procedure for this consultation, nor is there any requirement to receive prior approval from Industry Canada to construct the antenna or its supporting structure. However, if a PCS station owner chooses to proceed with construction without consulting a land use authority, it must be done with the acceptance of any consequences of this decision. Further, where Industry Canada believes that the installation may not be appropriate within its surroundings, it may request submissions explaining why the structure should not be modified or removed (Industry Canada, 1999f).

5.5.2.5 System Enhancers

System enhancers are used to improve the quality of signals in shadowed (poor coverage) areas. They are not intelligent devices and, used in cellular and PCS applications, they do not perform signal hand-offs. Enhancers for cellular use are not required to be licensed if the coverage area of the enhancer is totally within the area of the main stations; it does not increase the channel capacity of the main station, and abides by certain prescribed equipment certification procedures and power and antenna height limits (Industry Canada, 1995f). For similar reasons, applications for PCS enhancers are not required to be filed with Industry Canada (Industry Canada, 1997a).

5.5.2.6 Interception of Radiocommunications

Radio signals such as analog cellular signals can easily be received using simple, widely available UHF receivers. However, because the primary purpose of cellular and PCS systems is to provide interconnection to the PSTN, it is assumed that conversations transmitted over their networks are intended as private conversations. In 1993, amendments were introduced to the Criminal Code and the Radiocommunication Act that defined radio-based telephone communication as:

> any radiocommunication within the meaning of the Radiocommunication Act that is made over apparatus that is used primarily for connection to a public switched telephone network.

In so doing, users of radio-based telephone services were given the same privacy considerations enjoyed by conventional telephone users. Although listening is not prohibited, subsection 9(1.1) of the Radiocommunication Act makes it an offence to divulge or use information obtained from radio-based telephone communication without permission of the originator or intended receiver of the communication. Additionally, the Criminal Code makes it an offence to intercept some forms of radiocommunication (including radio-based telephone communication) maliciously or for gain. These provisions will normally be enforced by police agencies in the same way as they would be for any illegal wiretapping or eavesdropping (Industry Canada, 1995b). Further, certain types of receivers, such as scanners capable of receiving digitally modulated signals must now be licensed (Industry Canada, 1996a).

5.5.2.7 Other Conditions

A number of additional conditions apply to cellular and PCs operators, some of which are Industry Canada specified and others self-imposed by applicants and are contained within the specific licences issued or in the detailed application submissions. Examples include rollout plans, investing a percentage (usually 2 per cent) of adjusted gross revenue in research and development, compliance with Canadian ownership criteria, annual reporting and cellular and PCS reselling and cellular roaming arrangements.

5.5.3 CRTC Regulation of Cellular and PCS

Since cellular mobile radiotelephone services were to be competitive undertakings from the outset, one of the key issues immediately faced by the CRTC was to determine to what extent, if any, should they be regulated. In its first rulings, the Commission indicated that cellular telephone companies met the definition of telephone companies under existing legislation and, therefore, were subject to the jurisdiction of the CRTC. However, the Commission considered that, being a competitive industry, the benefits which users might derive from the cellular industry were likely to be greater if the terms of its provision were governed, as much as possible, by market forces rather than by regulation. In the case of monopoly telephone company affiliates, this position was conditional on there being adequate safeguards to ensure that their cellular activities were at arms' length from, and not subsidized by revenues, from regulated telephone company activities. Accordingly, the Commission ruled that both Cantel and any arms' length telephone company affiliate could charge tolls to the public for cellular radio service without filing or having to file tariffs (Canadian Radio-television and Telecommunications Commission, 1984b).

It did pose one restriction, however, on the use of cellular telephones as substitutes for local fixed telephones; mobile systems were not permitted to carry fixed landline station to fixed landline station traffic. Only mobile-to-mobile calls or calls initiated or terminated on a mobile terminal would be permitted to be carried on interexchange facilities between mobile systems. In other words, cellular telephone exchanges could not be used to switch locally wired telephones in competition with incumbent monopoly carriers (Canadian Radio-television and Telecommunications Commission, 1984a).

However, in 1989, the Commission's approach to forbearance was rejected by the Federal Court of Appeal in *Telecommunications Workers' Union v. CRTC and CNCP* (1989) 2F.C.280, on the grounds that the CRTC was compelled within the meaning of the Railway Act to require all "companies" to file their services for approval (Canadian Radio-television and Telecommunications Commission, 1993).

With the passage of the new Telecommunications Act in 1993, the CRTC had an opportunity to revisit cellular regulation, and through a series of decisions, the Commission chose not to forbear completely in order to ensure that all carriers complied with the policy objectives of the Telecommunications and Radiocommunication Acts, especially concerning Canadian ownership. Further, all cellular and PCS carriers were and continue to be required to protect the confidentiality of customer information and all such provisions are to be included in customer service contracts; the Mobility group of companies and Cantel (Rogers AT&T) must file (but not seek approval for) agreements with their affiliated PCS carriers on the public record, and the Commission will continue to exercise its powers in relation to Mobility and Rogers AT&T services to ensure they don't unjustly discriminate or give undue or unreasonable preference to, or disadvantage to any person.

Other areas still requiring authorization by the CRTC concern various interconnection agreements between incumbent wireline telephone companies and wireless service providers. In order to compensate telephone companies from traffic originating on the wireless network but terminating on the wireline network, wireless service providers pay the telephone companies a per trunk charge, as approved by the CRTC. For traffic originating on a telephone company network and terminating on a wireless network, the wireless service providers pay the telephone companies a monthly rate for telephone numbers. Wireless carriers also pay carriers, who provide such services, charges for access to 9-1-1 service (Canadian Radio-television and Telecommunications Commission, 1999). Tariffs for these services are filed by the wireline, not wireless, carriers.

In all other key areas, however, such as regulating rates and other general terms and conditions for the provision of cellular, PCS and ESMR services are *not* regulated because the Commission has determined that these markets are now sufficiently competitive to protect consumers (Canadian Radio-television and Telecommunications Commission, 1998a).

Finally, should cellular or PCS carriers wish to become competitive local exchange carriers (CLECs) in competition with wireline local telephone companies, they will be subject to the same regulatory requirements as any other CLEC. Among the obligations are those that require them to file tariffs for any services provided to other local exchange carriers and intercarrier agreements. However, with respect to end-users, consistent with their general regulation, they are not required to file tariffs. Other CLEC obligations include: providing access to 9-1-1 services; satisfying all existing and future regulatory requirements designed to protect customer privacy; providing serving area maps; providing customers with information about the company and its services and basic terms of service information. With respect to operator services, the Commission does not consider it necessary to mandate the provision of, or terms to and conditions for, operator services provided by CLECs. It considers that market forces will be sufficient to discipline the provision of these services (Canadian Radio-television and Telecommunications Commission, 1997).

6. Legal and Constitutional Basis for Canadian Emergency Telecommunications

Like other areas of telecommunications, jurisdiction over Canadian emergency telecommunications matters rests with the federal government. Overall emergency preparedness arrangements within the federal government are based on responsibilities set out in the *Emergencies Act*, *Emergency Preparedness Act* and in accordance with an established national framework for emergencies.

6.1 The Canadian Emergency Management System

Canada's emergency management system, in keeping with the country's legal and constitutional framework, places the responsibility for initial emergency response with the individual who is expected to be prepared to do what is reasonably possible to protect life and property. Different orders of government are also expected to intervene but only as their resources and response capabilities are required to help control and respond to the situation, and generally do so in the following normal sequence of actions:

- if the individual cannot cope, the municipal services respond. Mayors and other elected heads of local governments are expected to have emergency plans within their municipalities and that they are exercised regularly. Most emergencies occur within, and are dealt with effectively by, a municipality;
- if the municipality cannot manage to respond effectively, the province or territory is expected to assist. Provincial and territorial governments are responsible for coordinating the interface with the municipalities; and
- if a province or territory needs help, the federal government's aid is formally requested, usually - but not necessarily - the Office of Critical Infrastructure Protection and Emergency Preparedness[25]). The federal government intervenes only when asked or when the emergency clearly impacts on areas of federal jurisdiction (e.g., floods or fires on federal lands) or in a national emergency (Emergency Preparedness Canada, 1995).

The Emergencies Act enables the federal government to fulfill its constitutional responsibility to provide for the safety and security of Canadians during national emergencies. A national emergency is defined as:

> "an urgent and critical situation of a temporary nature that seriously endangers the lives, health or safety of Canadians and is of such proportions or nature as to exceed the capacity or authority of a province to deal with it, or seriously threatens the ability of the Government of Canada, and cannot be effectively dealt with under any other law of Canada." (Canada, 1988)

[25] The responsibilities of Emergency Preparedness Canada were incorporated into the new Office of Critical Infrastructure Protection and Emergency Preparedness in February, 2001.

This definition means that the Act is only applied in those extraordinary situations where the emergency doctrine falls within the responsibility of the federal government. In all other cases, federal emergency response is generally facilitated through existing programs.

Statutory requirements for federal emergency planning and preparedness programs are set out in a companion statute, the *Emergency Preparedness Act*. The Act requires federal ministers to plan and prepare for emergencies related to their normal areas of responsibility. The Office of Critical Infrastructure Protection and Emergency Preparedness (formerly Emergency Preparedness Canada) assists departments and agencies in their planning, and helps to coordinate plans and arrangements within the overall federal emergency management system and between the federal and provincial governments.

Emergency plans and preparations undertaken by the federal government focus on the following aims:

- to secure and preserve the well-being of Canadians, their property and the environment from the harmful effects of emergencies;
- to develop a credible national capability to meet emergencies of all types;
- to provide leadership in working toward improved emergency planning and preparedness in Canada; and
- to work closely and cooperatively with the provinces and territories to develop adequate and reasonably uniform standards of emergency services across Canada (Emergency Preparedness Canada, 1995).

When the federal government does respond, the lead authority is usually the department whose normal responsibilities are most closely related to the circumstances of the disaster or request for assistance. This response, however, is normally conducted under the overall direction and control of the responsible provincial government or, in the event of a national emergency or primarily federal emergency, in collaboration with provincial responders (Emergency Preparedness Canada, 1995).

6.2 Industry Canada Civil Emergency Telecommunications Responsibilities

Industry Canada is designated as the lead federal department responsible for developing and maintaining emergency plans for civil emergency telecommunications. It does so by supporting the following functions:

- providing advice and assistance to federal departments and agencies with respect to the telecommunications requirements of their emergency response functions and related civil emergency plans;
- providing advice and planning assistance to provinces and municipalities with respect to emergency telecommunications and related warning systems;

- coordinating the provision of an emergency broadcast service, based on the facilities and services of the Canadian Broadcasting Corporation, Environment Canada and, as required, privately owned networks and stations;
- facilitating the provision of appropriate telecommunications equipment or services required in emergency response operations, as requested by lead federal departments or responsible provincial authorities;
- providing advice and assistance, as appropriate, to private or public telecommunications undertakings in mitigating the disruptive effects of emergencies on domestic and external telecommunications;
- providing guidance, advice and coordination assistance to Canada's national and international telecommunications networks and broadcasting systems, with respect to the communications requirements of emergency responders, the rapid reception and transmission of inter-regional and transborder warnings to affected populations, and the dissemination of essential public information; and
- coordinating and managing of programs to ensure the availability of telecommunications to meet federal requirements during periods of system overload or degradation (Emergency Preparedness Canada, 1995).

To discharge these responsibilities, Industry Canada does not specifically regulate emergency telecommunications. Rather, it promotes a collaborative approach that encourages voluntary participation between the telecommunications industry, the emergency management community and Industry Canada to develop emergency telecommunications standards and initiatives.

Planning activities are generally facilitated through committees and agreements, and are coordinated across the country through Regional Emergency Telecommunications Committees (RETCs), whose primary functions are to:

- provide a forum to exchange information and discuss telecommunications support in times of emergency;
- identify telecommunications resources, including their technical parameters, and explore technical possibilities and developments that may support emergency telecommunications preparedness;
- make technical and operational recommendations to the:
    - emergency preparedness community
    - management at Industry Canada (Telecommunications)
    - management at telecommunications carriers and manufacturing companies, and
- identify the need for national standards or practices for the development and provision of telecommunications resources which may support emergency telecommunications plans (Industry Canada, 1997d).

Membership is primarily made up of federal departments and agencies and telecommunications carriers, but also, includes provincial governments, public and private agencies and individuals with interests in regional emergency telecommunications. RETC meetings are normally held twice a year and are chaired by regional or district representatives of Industry Canada (Industry Canada, 1997d). Sub-committees and working groups may also be struck around specific issues or topics such as priority access and emergency broadcasting.

At the national level, the National Emergency Telecommunications Committee (NETC) serves a similar role with some additional goals:

- in times of emergency and during emergency exercises, to coordinate between key telecommunications undertakings in Canada and provide a body of telecommunications management expertise and networking contacts to advise the federal government, and
- to promulgate national standards for the development and provision of telecommunications resources which may support emergency telecommunications plans (Industry Canada, 1997c).

Another national level activity involves participation in emergency telecommunications courses at the Canadian Emergency Preparedness College.

At the international level, Industry Canada represents Canada in various planning committees including the Canada – United States Civil Emergency Preparedness Telecommunications Advisory Group (CEPTAG), the NATO Civil Communications Planning Committee (CCPC) and the United Nations Working Group on Emergency Telecommunications (WGET).

During emergencies, Industry Canada provides support to telecommunications carriers and the emergency management community through a number of support functions including:

- maintaining, in close cooperation with the telecommunications industry, a national and regional inventory of telecommunications equipment;
- facilitating transport of personnel and equipment in Canada and across borders; and
- issuing special radio licences to support emergency operations.

6.3 CRTC Emergency Telecommunications Responsibilities

Aside from adjudicating emergency-related tariffs and interconnection matters, the Canadian Radio-television and Telecommunications Commission has traditionally not taken any specific steps with regard to the provisioning of telecommunications services in times of emergencies or disasters. The Telecommunications Act does not specifically mandate the CRTC to ensure the provision of emergency telecommunications service, although the Act does establish a policy objective of rendering “reliable and affordable telecommunications services of high quality accessible to Canadians in both urban and rural areas in all regions of Canada.” In recent years, however, the CRTC has become more directly involved in emergency matters through regulating carrier quality of service requirements and new interconnection arrangements. [23]

[23] See for example, CRTC Letter Decision – March 17, 2000, in which the CRTC ordered NewTel (Newfoundland and Labrador) to improve telephone access to emergency services. See also Telecom Decision CRTC 97-8, wherein the Commission obliges all competitive local exchange carriers to provide access to emergency 9-1-1 service.

7. Emergency Management Implications

In section 2, we posed the question: **Can the emergency management community exploit the advances in affordable, interoperable, commercial technology, fueled by consumer demand, while also maintaining technical and operational capabilities that meet its fundamental goals of preserving life and protecting property and the environment?**

In the following sections we will respond to this question by first analyzing growing dependency on mobile telephones and expectations concerning their availability during emergencies and disasters. We also wish to remind the reader that consistent with the Canadian emergency management practices, we have deliberately chosen a broad definition of "community" to include any organization or individual that may be required to respond to a hazardous incident, as opposed to including only public safety agencies. Our analysis begins with a look at general usage of mobile telephone systems to access primary community emergency services, followed by an exploration of usage during major emergencies and disasters.

7.1 Importance of Wireless Enhanced 9-1-1 Service

Introduced in the 1970s, the 9-1-1 emergency number has become the most widely recognized and used number in Canada. One of the most compelling reasons why Canadians lease or purchase cellular telephones is for safety, especially in emergencies, and having a wireless phone on hand enables calls to 911 when and where they are most needed.

Nearly three million 9-1-1 calls are made annually in Canada using a wireless telephone, and now account for almost 25 percent of all 9-1-1 calls (Canadian Wireless Telecommunications Association, 1999b). With a 20 to 30 per cent annual growth of wireless telephony, the proportion of wireless calls is expected to continue to rise dramatically in the next three-to-five years.

The concept of 9-1-1 originated in the U.S. in the late 1950's when the National Association of Fire Chiefs recommended use of a single number for reporting fires. In 1968, AT&T, the then dominant U.S. carrier, announced that it would establish 9-1-1 as the emergency number throughout the United States. The code 9-1-1 was chosen because it was easy to remember, could be dialed quickly and had never been authorized as an office, area or service code, thereby meeting long range numbering plans and switching configuration of the telephone industry (National Emergency Numbering Association, 1999a). Because Canada's telephone industry conformed to the same standards as in the U.S., 9-1-1 was also adopted in a number of regions rather than use of a different emergency reporting system, thereby promoting a North American concept. Several countries around the world have adopted similar practices.

In a modern wireline telephone network, enhanced 9-1-1 calls are sent to the nearest emergency response centre, also known as a Public Safety Answering Point (PSAP), along with the telephone number and address from which the call is originating. The telephone number provides a means for the call-taker to call back in the event that the call is dropped, or there is a follow-up requirement. The accompanying address information enables emergency assistance to be sent to the precise location—this is especially important when a caller accidentally gives out an incorrect address or is unable to adequately communicate with their call-taker.

Unlike the wired PSTN, however, mobile wireless networks do not generally pass along the telephone number or other customer information (including location) when connecting its subscribers to a PSAP, even in areas where it is available over wireless systems. This deficiency has created significant problems for PSAPs when it comes to effective 9-1-1 response.

Firstly, in the event that cellular calls are dropped or the conversations are disrupted because of weak signals, it is critical that the call-taker can call back a subscriber. Secondly, location of call is also critical, since, using a mobile service, calls often do not originate from the customer's residence or business premises. In the southernmost regions of Canada, 9-1-1 calls can even cross international borders. This means that when a subscriber calls, it is important that he or she give the *complete* telephone number to the call-taker, including the area code and, if possible, the location of the call. However, because the call can be placed from anywhere service is available, mobile subscribers may not be familiar enough with the area to give proper location details.

Further, not all local governments in Canada operate 9-1-1 systems. Wireless carriers may endeavor to route mobile 9-1-1 callers to the nearest PSAP, but the decision about whether or not to take a call ultimately rests with local authorities. Depending upon location of the call, it may be beyond the normal jurisdiction of the authority (especially a local fire service). In many cases, where 9-1-1 is not available, mobile subscribers may not even know the alternative number necessary to reach the appropriate local authority. Consequently, wireless calls often take more time to process.

U.S. concerns about these same issues have resulted in the issuance of several 9-1-1 rulemakings by its regulator, the Federal Communications Commission. The first was to outline criteria for the establishment of 911 as a national emergency number for wireline phones. The second, the E911 rulemaking Docket No.94-102, required wireless carriers to deliver 9-1-1 calls and to meet a schedule for introducing the features of enhanced 9-1-1 (Federal Communications Commission, 1999a). For example, by April 1, 1998, wireless carriers were required to provide automatic number identification (ANI) and cell site information for 9-1-1 calls to the PSAP. Phase II required deployment, by October 1, 2001, of the capability to determine the location of callers within an accuracy of 125 meters. These requirements, however, were only to apply if the wireless carrier receives a request for such services from a PSAP that is capable of receiving and using the enhanced services (Federal Communications Commission, 1999a). State and local governments were also required to pass funding legislation to support the related costs of public safety entities (National Emergency Numbering Association, 1999b).

These requirements were subsequently amended in September 1999 to broaden the scope of mandated technology that could be employed in 9-1-1 wireless services. At the time of its Phase II rulemaking in 1996, the FCC believed that automatic location information (ALI) could only be affected by technologies based in or overlaid on carrier networks, and it, therefore, mandated network-based solutions. Since that time, however, improvements in hand-set technology have also demonstrated this capability, and current network and hand-set solutions appear capable, by 2001, of providing location information that meets or exceeds the Commission's accuracy requirements.

Consequently, the new Order adopts rules that:

- allow a phase-in for handset-based solutions (by December 31, 2004 for 100 percent penetration).
- establish a higher than network-based accuracy standard for handset-based solutions (50 meters for 67 percent of all calls and 150 meters for 95 percent of all calls).
- establish a higher than previous accuracy standard for network-based solutions (100 meters for 67 percent of all calls and 300 meters for 95 percent of all calls), but phased in (by October 1, 2002 for 100 percent penetration).
- for the remaining 5 percent of calls, location attempts must be made and a location estimate for each call must be provided to the appropriate PSAP.
- require that hand-set deployment begin earlier than the current October 1, 2001 deployment date, and that this deployment date occur for wireless carriers employing a hand-set solution, regardless of whether the Public Safety Answering Point has requested Phase II ALI. (There are also numerous commercial applications of this technology).
- require that wireless carriers employing handset-based solutions take additional steps to provide location information for roamers and callers with non-ALI capable handsets.
- require that carriers take action to ensure that any phase-in for hand-set-based solutions is brief and complete.
- allow wireless carriers employing network-based location technology to reach 50 percent coverage within six months of PSAP request for Phase II service and 100 percent coverage eighteen months after a PSAP request (Federal Communications Commission, 1999c).

On the issue of subscribers trying to complete 9-1-1 calls from locations where the preferred wireless carriers' signal is very weak or non-existent (blank spots), the FCC issued an Order in May 1999 requiring that analog mobile phones, as well as dual mode (analog and digital) phones when operating in the analog mode, include a separate capability for processing 9-1-1 calls that permit those calls to be handled, where necessary, by another wireless carrier. The purpose of this measure is to improve 9-1-1 reliability, increase the probability that 9-1-1 calls will be efficiently and successfully transmitted to PSAPs, and help to maintain 9-1-1 service during the duration of the call.

This requirement became effective in February 2000, but applies only to new handsets operating in the analog mode, not to existing handsets, dual mode phones operating in digital mode or to purely digital handsets (Federal Communications Commission, 1999b).

These rules have prompted manufacturers to seek new innovation methods to satisfy Phase II location requirements, and trials are being conducted in many U.S. locations. Increasingly, automatic location capability has been recognized as a major new investment opportunity, both in North America and abroad. However, despite these opportunities, many issues and obstacles remain for successful U.S. implementation, including the need for PSAP equipment upgrades, lack of funding and lack of uniform agreement between carriers and PSAPs as to the most appropriate technology to deploy. These issues and others have pointed to the need for an overarching national policy for improving public safety by helping 9-1-1 work effectively for all wireless callers and to make 9-1-1 the universal emergency number across the U.S. (Federal Communications Commission, 1999a).

To address this requirement, the U.S. government approved new legislation, known as the Wireless Communications and Public Safety Act of 1999, recognizing 9-1-1 as the universal telephone number in the U.S. for both wireless and wireline telephone services, and giving the FCC responsibility for designating it as the universal emergency number.

In Canada, technical work on these issues has proceeded along similar lines, in part, due to commonly adopted wireless standards to the U.S. and the consequent effects of FCC Phase I and Phase II rules on wireless technology. Unlike the U.S., however, Canadian regulators—namely, the CRTC and Industry Canada—have largely forborne from regulating specific 9-1-1 technical requirements. Instead, they have encouraged a consultative process among PSAPs, wireline and wireless carriers through two specific working groups, the Emergency Services 9-1-1 Working Group and the Wireless E9-1-1 Working Group.

The Emergency Services 9-1-1 Working Group is a sub-group of the CRTC Industry Steering Committee formed to undertake tasks related to emergency services issues on matters assigned by the CRTC that fall within the scope of the CRTC's jurisdiction. Most of its current activity focuses on developing E91-1-1 service assurance routines among new competitive local exchange carriers (CLECs), the incumbent local exchange carrier (ILEC) and PSAPs. At present, there are no wireless CLECs although Clearnet, a PCS licensee, has applied to the CRTC for CLEC status.

The Wireless E9-1-1 Working Group was established in 1997 following a Canadian Wireless Telecommunications Association (CWTA) initiated roundtable forum on E9-1-1. The CWTA represents various sectors of the Canadian wireless telecommunications industry including cellular and PCS mobile radio, paging, mobile satellite and newly emerging broadband fixed wireless carriers. Other working group members include representatives from PSAPs, the CRTC and Industry Canada. It is co-chaired by the CWTA and a representative from the PSAPs. Its primary mandate is to examine the migration of E9-1-1 services in a wireless environment in order to give it the equivalent of wireline E91-1 in locations where the public safety answering point is capable of receiving the information (Canadian Wireless Telecommunications Association 1999b). To-date the working group has concentrated on developing methodologies to deliver 10-digit call-back numbers and cell-site location, delivery of mobile caller's location, data standards and public education. In 1998 and 1999, field trials took place in Nova Scotia and Alberta to demonstrate 10-digit call-back and cell-site location (including cell sector location) functionality. Plans are underway to conduct field trials in other Canadian regions, and some carriers are intending to actually roll-out services commercially in 2000.

From a policy perspective, implementation of wireless E9-1-1 in Canada is not mandated by government (neither Industry Canada nor the CRTC)—unlike it is in the U.S. However, should wireless service providers choose to become CLECs, the CRTC requires that they provide access to 9-1-1 service and, to the extent technically feasible, that the appropriate end-user information is provided to the Automatic Location Identification database to the same extent as that provided by the ILEC (Canadian Radio-television and Telecommunications Commission, 1997).

7.2 Mobile telephone Usage Within the Canadian Emergency Management Community

As described earlier, some of the main attractions for choosing commercial mobile telephone over traditional private wireless networks are their widespread availability in populated areas and ability to offer increasingly seamless interoperability on a multi-disciplinary and multi-jurisdictional basis. In reviewing the literature, however, we found very little published information indicating the extent and type of usage within the emergency management community. Much of the literature describes usage during individual incidents, often only within the overall context of the emergency response.

For purposes of our study, we felt that it was important to establish some basic indicators of how mobile telephone-based emergency communications were being applied within a Canadian context. Consequently, we undertook a sample survey using the Greater Vancouver region as a case study. While we recognize that many local, regional and other factors may influence how organizations and individuals choose to use mobile telephone services, we feel that many of the findings derived from the survey are sufficiently generic that they can be applied to other regions of Canada.

The survey consisted of conducting interviews among 70 individuals representing important emergency response or support organizations in local, provincial or federal emergency plans. Key groups included police, fire, ambulance, hospitals and health districts, search and rescue, emergency planning and coordination, environment, utilities, public works, human resources, universities, emergency social services, air transportation, ports, public transit, agriculture, forests, highways, native affairs, multiculturalism and media.

The results are broken down into two main categories, general usage and emergency usage. Respondents were interviewed about their personal use of mobile telephones as well as general use within their organizations. In order to examine usage during emergencies, two natural hazards—earthquakes and floods—were selected as focal points. Both pose major threats to the southwestern British Columbia region, as well as other regions of Canada.

The results reveal some interesting trends in usage, dependency, expectations and implications for policy makers, service providers and emergency management users.

7.2.1 General Usage

The survey confirmed the great extent to which cellular and PCS technology has become the wireless technology of choice by the emergency management community, given the following findings:

- The vast majority (92 percent) of those surveyed indicated that they had a cellular telephone and, of those who possessed them, 98 percent use them to support their functions within the emergency management system, and 84 percent reported carrying them at all times.
- Only 4 of the respondents shared their mobile telephones with other users, indicating that cellular telephones are becoming synonymous with individuals rather than organizational functions.
- 85 percent of respondents had mobile telephones provided by their emergency management organizations.
- Average usage varies considerably from a minimum of 10 minutes per month to over 3000, with a mean average of 296 minutes per month. However, during an emergency, 88 percent of respondents indicated there would be an expected increase in usage.
- In the Greater Vancouver region, our findings indicate that the two incumbent cellular carriers are currently the dominant service providers within the emergency management community, with Telus the leading provider (63 percent) and Rogers AT&T second (15 percent). Contributing factors may be their early entry into the market, exclusive analog coverage (PCS competitors roam on their networks) and being the only two currently supporting emergency priority access to dialing arrangements. Microcell's Fido services were selected by 2 percent of respondents, as were the same for Clearnet. However, a growing number of emergency management organizations, including public safety, are being attracted to Clearnet's 'Mike' enhanced mobile radio telephone service because of its ability to combine basic cellular functionality with more traditional two-way radio features, such as "talk groups".

7.2.2 Factors Influencing Choice of Service Provider

A number of factors influenced why individuals or organizations chose a particular service provider. Responses included the following factors:

- cost effectiveness
- reliability
- area coverage
- arbitrary choice
- personal referral
- personal preference
- service bundling
- good service plan
- provider contract
- free phone
- pooling of minutes
- flexibility
- consistency
- quality of communication
- features
- servicing
- consumer confidence
- competitive bidding
- organizational purchasing policy
- matches operational requirements
- priority access provisioning

Some respondents indicated they deliberately chose a mix of providers to increase redundancy of communications.

7.2.3 Types of Users

The survey results revealed that cellular/PCS technology now extends broadly across disciplines and jurisdictions. The following sample illustrates the diversity of functions using cellular telephones as reported within respondents' organizations.

- everyone within organization
- operations personnel
- control centre managers
- fire chiefs and assistant chiefs
- first responders
- site assessment personnel
- mobile emergency command centres
- all responding vehicles
- police superintendents
- patrol officers
- detectives
- after hours contact personnel
- hazardous materials and spill response officers
- security services
- duty clerks
- medical health officers
- environmental services
- executives and program directors
- deputy ministers and senior
- government officials
- mayors and councilors
- city managers
- city finance officers
- emergency planners
- emergency coordinators
- media relations officers
- engineers
- water services managers
- airport operations personnel
- roads and construction managers and crews
- public works managers and crews
- radio technicians

- physicians
- home care nurses
- occupational health and safety personnel
- search and rescue volunteers and coordinators
- Amateur radio volunteers
- building managers
- emergency social services managers
- information technology managers and staff

7.2.4 Emergency Use of Cellular /PCS

Given this extensive reliance upon mobile telephone technology for routine use within the Greater Vancouver emergency management community, it should not be surprising that many respondents also have expectations that it will be deployable during major emergencies. Our survey data revealed some interesting observations about such expectations, including the following:

- 91 percent have included use of cellular telephones in their organizational emergency plans.
- 38 percent use cellular telephones to call in volunteers.
- 12 percent of the organizations surveyed rely on cellular telephones as their *primary* communications system during an emergency and 43 percent as their *backup* system.
- 91 percent expect to use their cellular telephones at their emergency operations centres during an earthquake or flood emergency. There were conflicting views, however, about the amount of network usage. Some indicated that networks were more likely to be useable during floods than earthquakes because floods had more gradual onset. Others expected cellular telephones to be used more during earthquakes because of potential loss of wireline services.
- 88 percent of respondents expect there will be increased usage during an emergency. For example, 84 percent of respondents indicated they would consider renting additional handsets during an emergency. Others have kept additional sets in reserve to be brought out and activated specifically during emergencies. Some are relying on them to keep in constant communication with front-line personnel, while others expect increased usage because cellular systems enable more simultaneous person-to-person contact than their traditional two-way radio systems.

Some view group calling important, and are attracted to using an Enhanced Mobile Radio Service (EMRS) such as Telus's (formerly Clearnet's) Mike service because it can network cross-sections of disciplines and jurisdictions when and where required, and offers greater privacy than their existing radio networks. Others have linked cellular usage to pagers, where personnel are contacted by pager and then expected to respond by mobile telephone, indicating yet further increases in cellular calling.

Expectations of actual use during emergencies were mixed. Overall, despite their high levels of dependency on cellular technology, only 26 percent were very confident that they would be able to use their cell telephones during an emergency such as an earthquake or flood. Some assumed that service would be down only for a short time. In the event of loss of service, however, respondents reported a range of potentially serious organizational and operational impacts, including:

- no communication at all if wireline service is also down;
- impeding of notification;

- difficulty contacting personnel;
- increased response time and, thus, delayed response;
- emergency coordination difficulties;
- difficulties acquiring critical information, especially from field personnel;
- reduced capacity;
- loss of backup communication;
- delays in obtaining needed resources;
- increased anxiety for out-of-office personnel;
- depending upon time of day, potential after hours difficulties in calling in personnel.

Some respondents indicated that loss of cellular service would have less impact because of other backup measures in place, including agency and amateur two-way radio, satellite telephones, and procedures for personnel to automatically report to designated locations during emergencies when normal communications links become unavailable. Other communications emergency backup plans appear underdeveloped because of the assumption that cellular telephones will be available. Moreover, only 21 percent of respondents indicated that their organizations have developed policies that set out guidelines for use of cellular telephones during an emergency.

7.2.5 Coverage and Roaming

A majority (72 percent) of respondents indicated that the area of intended usage of cellular telephones was within their local calling area. Some noted difficulties accessing services inside buildings, outside urban areas, along the Canada/United States border and receiving calls while traveling through the U.S. Analog service was preferred by some because its coverage remains better than digital in many outlying areas, although only 45 percent reported knowing whether or not they actually had roaming problems.

7.2.6 Familiarity with Cellular/PCS Technology and Emergency Usage Procedures.

Response to a number of the survey questions revealed that familiarity with the general and emergency usage of cellular telephones ranged considerably. In terms of general awareness, 36 percent of respondents indicated they had not received any instruction in the use and care of mobile telephones; 9 percent didn’t know who their service providers were;55 percent were not aware of any programs governing or assisting mobile usage by emergency managers during emergencies. Despite this, 64 percent of respondents indicated their mobile telephones were registered for priority access.

7.3 Other Factors Stimulating Usage

While conducting a review of literature and post event briefings, and as a result of discussions with emergency managers, we unearthed a number of other factors that influence migration towards greater use of mobile telephone technology, including:

- cost of licensing private agency network two-way radios not required for everyday use. Mobile telephones are viewed as an inexpensive alternative. Some pay-as-you-go plans allow emergency management organizations to hold cell phones in reserve and only activate them when needed. Many used decommissioned phones that were donated and held in reserve for this purpose.
- high cost of maintaining wireline PSTN lines in emergency operations centres. Many communities have chosen only to activate lines during emergencies and use mobile telephones until they are available. Further, many don't have sufficient wireline capacity to accommodate all personnel showing up at their EOCs and rely upon mobile telephones to augment facilities.
- others have chosen not to rely upon fixed wireline at all, especially in cases where no fixed emergency operations centre has been designated. The same situation holds true for many community emergency social services centres.
- delays in getting wireline services installed or activated. Carriers generally focus on restoring service during major emergencies and disasters, and often don't have the personnel to install new lines.
- for some, mobile telephones are their only means of portable voice and/or data communication.

Extrapolating from these findings, it appears that:

- the majority of emergency management personnel rely on mobile telephone networks for at least some day-to-day and routine emergency communication, and expect to use them during major emergencies and disasters.
- the volume of calling is expected to rise rapidly during an emergency due to organizations moving over to mobile telephone systems as part of their emergency plan activation and opening or setting up emergency facilities that do not have alternative communication infrastructure in place.

7.4 Availability during Emergencies

These survey results along with our review of post-event briefing and other reports also indicate that many organizations are not fully aware and/or have not adequately assessed the implications of such dependency. In this regard, there are numerous systemic factors that can affect availability and reliability of mobile telephone service, irrespective of the potential impact on infrastructure that might result from the effects of a natural hazard.

7.4.1 Coverage

Despite relatively widespread coverage in populated regions, users can still experience coverage gaps in service because:

- terrain interferes with wireless signals, or users on higher slopes “see” too many cell sites and cannot properly lock onto a specific site long enough to hold a call.
- signals are blocked by building structures or are simply unavailable (e.g., within some buildings, under structures and in underground facilities such as subways).
- urban and rural land use planning restrictions prevent cell sites from being located in optimal locations.
- water ways and other natural features affect cell-site location and signal propagation.
- carriers may not provide adequate coverage in rural areas or away from majors routes because of comparatively low demand for service.

Also, because mobile telephones operate over the air, they may be subject to signal impairments that arise in any radio communication environment, including noise, interference, fading and rapidly changing channel quality particularly while mobile (Public Safety Wireless Network, 1998). For rural users, distance from cell-sites is also a critical factor.

7.4.2 Compatibility

As the table below suggests, the existence of multiple air interfacestandards (e.g., AMPS, CDMA, TDMA and GSM) may complicate the ability of users to communicate seamlessly across a region with a single device. Traditionally, analog (AMPS) has been the common bridge between services. For example, analog mobile phones can be programmed to allow users to switch between one or other of the available analog services, and dual mode handsets were specifically designed to enable access to digital services of a provider and at least one of the incumbent carriers’ analog services. However, in the digital environment, while competing carriers may use the same digital technology standards, they operate in different frequency bands and most hand sets are not programmed to interoperate. Furthermore, analog services are gradually being phased out, so analog channel availability is being reduced. In one particular case, a competing carrier is locking out analog access as its own digital services become available in the same service area and uses a different airface standard than competitors. It is anticipated that third generation (3G) wireless handsets will enable greater interoperability. In the meantime, the public switched telephone network to which each carrier is interconnected may become the dominant interface to pass voice traffic between systems.

Air Interface Standards for Canadian Wireless Service Providers

Carrier	Current Spectrum	Frequency Band	Airface Standard
Mobility companies	25 MHz	800 MHz sub-band A	AMPS (analog)
	10 MHz	1.9 GHz block D/D	CDMA (digital)
Rogers AT&T	25 MHz	800 MHz sub-band B	AMPS (analog)
	10 MHz	1.9 GHz block F/F	TDMA (digital)
Clearnet (now Telus)	30 MHz	1.9 GHz block B/B	CDMA (digital)
	15 MHz	800 MHz	SMR/ESMR
		900 MHz	SMR
Microcell	30 MHz	1.9 GHz	GSM (digital)

Note: Rogers AT&T Mobility is expected to deploy the GSM standard by 2002.

7.4.3 Privacy

Mobile analog carriers do not encrypt the transmission link and, therefore, analog calls inherently are not secure. Digital systems incorporate encryption and offer a higher standard of privacy. However, users must still be aware of who they are communicating with and what security features are enabled, inasmuch as a digital connection to an analog phone is still unsecure.

7.4.4 Accessibility and Congestion

From our review of the development of the Canadian mobile telephone industry, it is apparent that wireless networks were never designed or scaled to facilitate community wide responses to emergencies or disasters. A key restraining factor is that subscribers must share a limited amount of radio spectrum and, therefore, compete for access to the network. At times, demand for channels at a given cell-site may exceed supply. In many urban areas, analog systems have reached full capacity or have reduced capacity as systems are converted to digital technology. When congestion occurs, users may experience delays in call setup or receive “fast busy” signals. Even when the local cell-site is not congested, the call may still be routed to users at other congested cell-sites, or, especially in the case of emergencies, be blocked at a congested PSTN switching centre. When this occurs, users must dial a number several times before a call can be placed successfully, if this is at all possible. Even without emergencies, congestion can often occur during rush hours along major routes or in urban centres during peak lunch periods or public events.

7.5 Priority Access to Dialing

Currently, neither the CRTC nor Industry Canada require wireless service providers to provide a means for authorized users to gain priority access to their networks during emergency situations. However, largely through Industry Canada-led initiatives, wireless carriers have been encouraged to voluntarily support provision for priority access. These arrangements are based on a similar initiative that has been implemented nationally for wireline voice telecommunications carriers known as “Priority Access to

Dialing" (PAD). Previously known as Line Load Control (LLC), PAD is a control method used to limit the telephone line load on a telephone switch so that priority lines can continue to place calls when the switch becomes congested. Depending upon the telephone company's technology, some systems can also provide graduated support for priority uses up until LLC measures must be applied and may sometimes be referred to as Essential Line Treatment or Essential Services Protection (Industry Canada, 1999k). Further, given the dynamic nature and interconnectedness of switching systems in North America, it is often possible for calls to be re-routed in order to establish alternate paths. When severe overloading occurs, selective call blocking can also be applied, especially to long distance networks to ensure maximum service availability for local callers.

PAD establishes a framework and a set of guidelines for assisting emergency management organizations to identify and register the telephone numbers of personnel who need to *originate* calls during an emergency. PAD listings are largely drawn from emergency or disasters plans. Traditionally, Industry Canada has worked with federal departments and principal provincial and territorial emergency measures organizations to collect PAD data. Provinces and territories, in turn, have worked with their departments and local governments to collect this data.

Industry Canada is responsible for managing a central database of all listings and for supplying qualifying telephone numbers to the Canadian carriers. . Recently, Industry Canada implemented a new technique for managing PAD data using Internet technology to collect data from all three jurisdictional levels. Carriers also have access to the system, but data is filtered so they only extract those elements that are required for implementation in their systems (e.g., telephone numbers and not names). Carriers may also designate public pay telephones for priority treatment. PAD is designed to accept all types of telephone service including basic voice and fax, mobile telephone, mobile satellite (MSAT) and other numbers that might require priority access support. Although not all services may have priority access capability, these numbers are important for identifying future implementation and priority service restoration requirements (Industry Canada, 1996b). Further to this, PAD users are encouraged to register both essential and non-essential numbers and to use the system as a central database for managing their critical communication resources information. In this regard, PAD currently stores data on over 220,000 essential and non-essential numbers including pagers.

PAD is currently available on the incumbent wireline telephone networks throughout Canada. At present, the system attempts to ensure that those identified numbers will be able to obtain dial-tone from their *local* switch. It does not guarantee that a call can be completed, especially where it involves connection through other switches that may be congested or out-of-service (Industry Canada, 1996b). Industry Canada is working with carriers to implement a new end-to-end priority scheme known as High Probability of Completion (HPC). Other factors that can affect the overall effectiveness of PAD are timeliness and accuracy of record updating in the central database and carrier switches and the impact of local competition. In the latter case, with the advent of new competitive local exchange and pay telephone services, new providers may be unfamiliar with emergency management community needs and may not have yet considered enabling priority provisioning or have chosen to forgo it.

7.5.1 Cellular Priority Access

Within Canada, presently, only two wireless service providers have implemented methods for providing priority access; Telus Mobility (British Columbia) and Rogers AT&T. Each employs a different method. Telus relies upon number registration in the switch to set priority access at affected cell sites, while Rogers AT&T requires handsets to be programmed for priority treatment. When priority access is invoked at a given site, existing users who may be on-line but who do not have priority status may be permitted to complete calls but may not able to connect again at the site. In some cases, priority users may be assigned specific channels, allowing limited public access to continue. In British Columbia, when an emergency or disaster requires priority provisioning, the Provincial Emergency Program (PEP) is the organization designated as having the authority to invoke priority access for cell sites. This is done by contract between PEP and the wireless service provider (Industry Canada, 1996b).

In cases where there is a sustained requirement for extra channels, additional channels may be installed and/or activated at existing sites, or a Cell on Wheels (CoW) may be temporarily installed to augment the capacity within the affected area, in order to quickly enable service in a previously unserved area or to restore service to one where the local site infrastructure is damaged.

7.6 Other Factors Affecting Availability

A number of other factors can also affect the availability of service for a given area such as:

- the particular configuration of the site, including number of channels made available and mixture of analog and digital services.
- end-user calling habits. Some users occupy channels for long periods of time. Common examples include media who often establish connections and keep them open for the duration of an incident to ensure access at scheduled times; users of circuit-based connections for computer network access; fax centres at EOCs and EOC staff who may elect to use mobile telephones rather than wireline telephones.
- sheer numbers of essential users competing for scarce channels at critical periods when communication is required to support crucial functions.
- whether or not mobile telephone numbers have been registered or programmed for priority access before measures are invoked. Many bring phones from outside the impacted region that may not be included in PAD provisioning (where available).

Despite all of the above factors affecting availability, one other remains the most complex and challenging to mitigate – vulnerability of infrastructure.

8. Natural Hazards and the Performance of Wireless Communication Lifelines

Much of the research on the vulnerability of communication networks to natural hazards has been led by the field of earthquake engineering, which produces a wide range of research reports based on yearly conferences and ongoing studies (ASCE, 2000; EERI, 2000; EQE Inc., 1999; MCEER, 2000). Within this field of research, telecommunications networks are referred to as *communication lifelines* and are studied in conjunction with other community lifelines including power, water, gas, and transportation. Findings from earthquake engineering provide a baseline for identifying the vulnerable components of wireless communication lifelines in addition to highlighting critical areas that may be vulnerable to other types of hazards. This is fortunate because systematic studies of communications lifeline vulnerability related to other hazards, including floods and severe weather, do not appear to be widely available. We have, therefore, generalized the framework provided by earthquake engineering literature to include flooding and severe weather hazards, with the intention of providing a foothold for further research in this area.

Tang and Schiff (1996) have published an excellent monograph on the seismic performance of communication lifelines that we have used to identify key components of infrastructure and their related vulnerability factors. While this report is restricted to a discussion of telecommunications systems limited to terrestrial wireless (mobile telephone) systems, for the sake of convenience the more general term 'communication lifelines' appears throughout this section. We do not attempt to address other communication lifelines such as wireline telecommunications, broadcast radio and television, two-way forms of private or amateur radio, satellite-based telecommunications, cable television systems, or high-speed data networks. Each of these communication systems shares similarities—and it may be possible to develop a comprehensive approach to studying lifelines that can include a wide range of systems—but each system is also significantly different from one another.

8.1 Architecture and Vulnerability of Communication Lifelines

At the most general level, communication lifelines can be represented as a network of nodes and links, often with a network traffic control system. Telecommunications networks are designed around three key stages: trunking, distribution, and termination (Fig. 5). Each stage serves a different function and usually is designed around a specific network methodology best suited to that purpose. Typical network methodologies include ring, daisychain, and hub and spoke configurations.[26]

For our purposes, communication lifelines can also be divided into two basic kinds of networks: PSTN (wireline public-switched telephone network) and the wireless (mobile telephone) networks which interconnect with the PSTN. Both types of networks

[26] It is recommended that the reader review the technical overview (Section 4) of this report in order to understand the basic operational principles and concepts of cellular/PCS networks.

may have subnetworks linked to them as well. These subnetworks typically consist of private branch exchanges (PBXs) or wireless local area networks (LANs).[27]

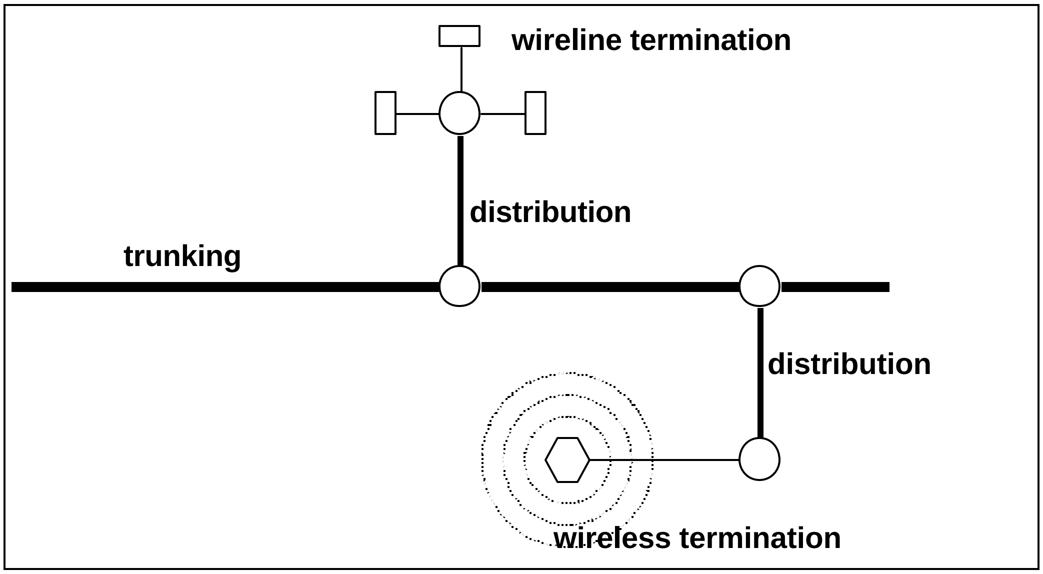

Figure 5: Basic Components of a Telecommunications Network

Telecommunications engineers make a distinction between two primary categories of equipment in a communications lifeline—inside and outside plant facilities (Figure 2). *Inside plant facilities* include switching and transmission equipment as well as support facilities to house and enable the operation of communication equipment. *Outside plant facilities* include transmission lines and support facilities, such as telephone poles and underground conduit. Numerous elements of both inside and outside facilities are similar for both wired and wireless networks, most notably in the trunking and switching functions. This report will note where they tend to differ and the resulting considerations for vulnerability to natural hazards.

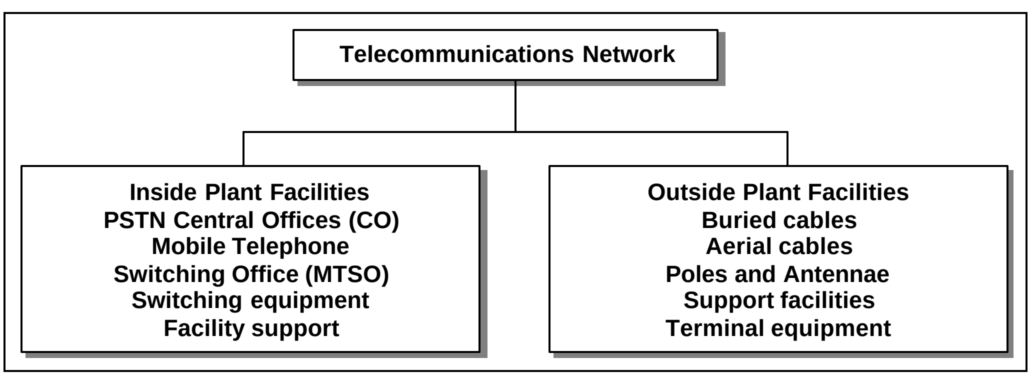

Figure 6: Primary Categories of Telecommunications Equipment

[27] From a functional standpoint, cellular/PCS networks could be considered a form of PBX insofar as they represent a discrete, 'private' exchange that is linked to the PSTN.

8.1.1 Inside Plant Facilities

Inside plant facilities consist of various classes of central offices (COs) or mobile telephone switching offices (MTSOs) that house communication equipment, and provide equipment and facilities support.[28] Communication equipment includes switching and transmission devices, while equipment support includes cable vaults (where trunks enter the CO/MTSO), internal distribution frames, cable-handling systems (racks and conduits). Facilities support includes the facility itself, its electric power supply and its climate control system.

Seismic threats to inside plant facilities typically come from groundshaking and physical displacement. Researchers have found, however, that much of the communication equipment in a CO generally sustains little damage from direct seismic effects. Nonetheless, ground shaking is often responsible for moving unrestrained equipment and bringing down improperly secured cable racks and conduit. Shaking may also damage microelectronics in switching equipment, as well as cause failure of disk drives and other electro-mechanical components. Physical displacement is responsible for snapped cable, and displacement may also lead to water damage from broken seals or cracked cable vaults. Much of the damage to communication equipment can be controlled through proper restraint, adequate slack in cables and by setting load limits and restraint measures for equipment racks and conduit.

The most significant seismic performance factor in the CO tends to be the electric power supply system (Tang and Schiff, 1996: 67). Communication equipment in the CO operates on DC power, thus requiring commercial AC power to be rectified as it enters the facility. The electric power supply system consists of three parts: (1) a DC power plant made of batteries and fed by a commercial AC source; (2) an emergency generating system that is supplied by a diesel or other fuel source generator; (3) a power distribution grid that directs power to equipment at the CO. Commercial power failure—a common occurrence in earthquakes floods, and severe weather—may cause a CO to resort to its back-up generator or its batteries. Often, however, generators fail to provide emergency service for a variety of reasons including cracked starting batteries, overheating due to heavy demand on the generator, failure in fuel/oil/water lines to the generator (Tang and Schiff, 1996: 74). Without a serviceable generator, battery life at a CO is generally limited to several hours. In some instances, batteries that are unrestrained may fall or suffer damage due to ground shaking during earthquakes. Short term power failures may have a limited impact on performance at the CO but long term power failures may cause a variety of secondary problems including memory loss in digital switching equipment, which may take up to eight hours for technicians to reload (Tang and Schiff, 1996: 69). PBX systems connected to a public network may have no backup power source to support operations during the loss of commercial power (p. 73).

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[28] The term ‘central office’ (CO) as it appears throughout this section can be considered roughly equivalent to ‘mobile telephone switching office’ (MTSO), although there are important differences between these two elements. In all cases, MTSOs must interconnect with a CO in order to link with the public switched telephone network (PSTN).

Support facilities at the CO may prove to be factors in lifeline vulnerability, most notably when they damage communication equipment or prevent effective restoration of service. Specific elements that are categorized as inside plant support facilities include: the building which houses the CO equipment; HVAC (heating, ventilation, air conditioning) equipment used to cool electronic equipment; spare equipment and repair supplies; and other building systems such as fire suppression, AC power distribution, and access devices (lifts and elevators) (Figure 7).

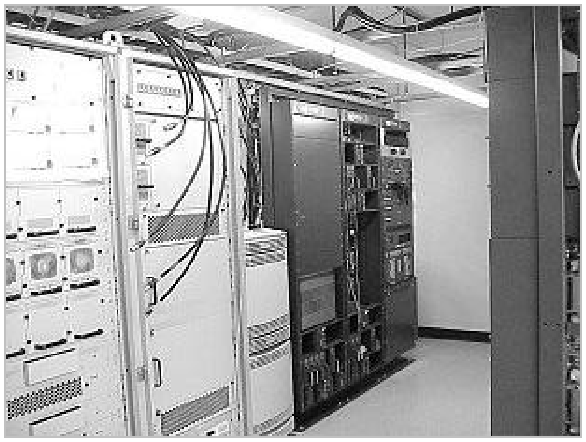

Figure 7. Inside plant facility (wireless service provider)
Source: http://www.geckobeach.com/cellular/

One major risk factor to inside plant support facilities includes the structural collapse of the CO building itself. Tang and Schiff note that older structures may not meet current seismic requirements, even though they have been retrofitted with new communication equipment:

> Digital equipment requires much less space than the equipment for which the CO buildings were originally designed. Thus, as new equipment is introduced, there is no need to expand the building stock. Also, a new building would require that existing trunks be relocated, a costly and disruptive task. Thus, there are major incentives to continue to use existing buildings, even though they may be very vulnerable by today's seismic standards. (p. 79)

Seismic performance of HVAC systems has been reported as mixed and remains a major concern (p. 81). HVAC systems are especially vulnerable to groundshaking and physical displacement, yet can be protected through proper anchoring and isolation. HVAC failure may cause ambient temperatures in a CO to rise above critical levels for electronic equipment, eventually causing further equipment problems (p. 80).

Spare parts and back-up supplies can also be damaged and disordered during seismic events because of inadequate storage procedures (p. 84). Damage to spare parts may impair a technician's attempts to restore services at a CO. Other building systems may become factors in lifeline vulnerability when they restrict access to facilities or cause secondary hazards. Activation of fire suppression systems, for instance, may prevent the use of a back-up power supply system. This was the case in the July 1999 switch fire at a Bell Canada CO in Toronto. Backup generators could not be started because of an electrocution hazard created by sprinkler activation in the building (Surtees, 1999). Access to a CO may also be restricted due to failures in lifts, elevators, AC power to control rooms (Tang and Schiff, 1996: 86), or because of travel or premise access restrictions imposed by public safety agencies.

8.1.2 Outside Plant Facilities

Telecommunications nodes are linked together through a collection of equipment referred to as the outside plant (Tang and Schiff, 1996: 89). The outside plant consists of two categories of equipment: transmission media and support facilities. Transmission media include outside plant cables and their supports or, in the case of wireless systems, radiowaves. Support facilities consist of repeaters, towers, manholes, connection hardware, special conveyances,[29] and terminal equipment (p. 91).

Outside plant cables consist of aerial and buried lines that are either copper cable or optical fibre. Three levels of transmission function are fulfilled by outside plant cables: trunk, distribution, and drop (p. 92). Trunks are used to interconnect COs to one another or to connect a CO to a distribution area, where they may terminate at junctions such as manholes. Distribution lines are then used to connect from these junctions to local cross connect pedestals, and drops are used to connect from distribution lines to subscriber premises—known as the local loop. Trunk and distribution cables are usually buried, with junctions at manholes or local cross connect pedestals. Drops can be either aerial or buried.

In the case of wireless networks, the interconnection of mobile telephone switching offices (MTSO) is generally done with copper cable/fibre optic trunks. Distribution from the MTSO to the cellular base stations may be either cable/fibre or, in many cases, by microwave (see photograph below). Drops from cellular base-stations to subscriber terminals (mobile handsets) are done by air-interface, either in the 800MHz or 2GHz bands of radio spectrum. Interconnection of a wireless network with the PSTN is typically done with cable/fibre trunk at one of several classes of a wireline carrier's Central Office.[30]

Support facilities for outside plant cables can be divided into construction hardware and connections hardware (Tang and Schiff, 1996: 93). Construction hardware consists of poles, towers, and underground conduits that are often shared with other utilities.[31] Earthquake performance with cables is contingent on the performance of construction hardware which is, in turn, affected by ground deformation, soil liquefaction, and lateral spreading (p. 95). Ground deformation and lateral spreading can damage conduits and cables, particularly when inadequate slack is provided. Support

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[29] Special conveyances refer to existing, specialized facilities for routing cable. These typically include bridges and tunnels associated with railroad or highway rights of way (Tang and Schiff, 1996: 111).

[30] Interconnection between a cellular/PCS network and the PSTN typically takes place at either an End Office or an Access Tandem (See Bedell, 1999: 146)

[31] See Marvin (1997) for a discussion of issues around utility space-sharing.

structures such as telephone poles may sustain damage from four general failure modes (p. 96): tipping in poor or liquefied soil, sinking, failure at pole base due to dry rot, and failure of pole itself, usually at its cross-arm (p. 98). Cables and support facilities may also be vulnerable to secondary hazards such as fire or explosion. Incidents in Kobe, Japan, and Northridge, California confirm this type of secondary hazard. Building collapse or landslides may also induce failure in cables and their supports.

Mitigation practices for cables and their supports include providing generous slack to accommodate ground shaking or lateral spreading, as well as designing redundant routing for trunk traffic. Redundant routing is especially important when cables are high capacity (such as fibre optic), or when they are routed through special conveyances such as bridges or tunnels. Tang and Schiff (p. 100) note that GIS technology may prove a useful tool for evaluating and planning cable routing during the early stages of infrastructure development.

With respect to severe weather, the 1998 ice storm in Eastern Canada revealed the vulnerability of cables and support facilities due to severe icing conditions (Industry Canada, 1998; Kerry, Kelk, Etkin, Burton, & Kalhok, 1999; Nicolet, 1999). Reports from the incident indicate that "freezing rain severely damaged the telephone network [when] the collapse of thousands of poles and the damage to certain antenna sites caused a breakdown in telephone service." With respect to the wireless network, it was reported that "the breaking of antennas and other components and the collapse of antenna sites directly affected transmissions using mobile phones" (Nicolet, 1999: 261).

Mitigation-oriented recommendations following from a review of the incident suggest that a number of current CSA standards need to be reconsidered. These standards deal primarily with spacing of telephone poles and telephone pole construction, ice-loading on cables, and standards for antenna site structures and related components.

Excerpts from the Nicolet Report on the Ice Storm of 1998

Recommendations for hardening outside plant facilities against severe weather:

- the CAN/CSA standard 22.3 no 1, designed for a heavy load corresponding to a 12.7mm radial thickness of ice on the cables combined with a 385 Pa horizontal wind pressure must be re-examined.
- The S37-94 standard of the CSA, applicable to antenna site structures, must be updated, in light of what has been learned from ice storms;
- In collaboration with antenna manufacturers, the possibility should be studied of increasing the sturdiness of components installed on antenna sites. A request along these lines could be transmitted to the CSA.

Nicolet, 1999: 267

Linkage between distribution points in both wireline and wireless networks is also achieved through radiowaves, typically in the microwave band (Tang and Schiff, 1996: 100, see Figure 4). CO/MTSO structures and cellular base-stations may house transmitters and receivers. In some cases, repeaters may be necessary to boost signals over long distances. Microwave towers are typically placed on strategically high points, usually on a building at or near the CO/MTSO, or directly on a cellular tower (Fig. 8). Repeaters are generally located on hilltops or other buildings. Distance between towers and repeaters is reported at about 25km (p. 101).

Figure 8. Cell site with microwave link

Equipment at microwave or repeater stations has performed well in earthquakes but is vulnerable to ground deformation (misalignment of wave-guides and dishes), tower failure, as well as loss of commercial power (p. 104). Towers consist of lattice structures or tubular steel masts, and should be manufactured to meet local seismic and wind load criteria (wind loads usually determine design), yet these may be exceeded under extreme conditions. Earthquake performance of microwave towers in the United States has been good, with occurrences of minor buckling and dish misalignment (usually attributed to mounting hardware). There have been, however, cases of collapse of tall, guyed radio towers (p. 105).[32]

Other important components of the outside plant include manholes and conduits, as well as cross connects and protectors.[33] Manholes serve as junction points as well as repair access points, whereas conduit serves to protect cables (p. 106). Earthquake performance of manholes has included numerous points of vulnerability, with cable failures occurring usually in conjunction with conduit failure. Damage often results from

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32 Ghodrati (1998) has developed a prioritization methodology for identifying towers that may need further seismic testing. This study was developed using criteria for Victoria, BC.

33 While it may seem that manholes, cross connects, and the like would have less relevance to cellular/PCS systems, it is important to keep in mind that trunking and interconnection of cellular/PCS systems may include these components.

water entry or soil liquefaction and lateral spreading (p. 108). Cross-connect pedestals have performed well, yet remain vulnerable to secondary hazards such as fire or building collapse.

Figure 9. Cell-site electronics cabinets
Source: http://www.geckobeach.com/cellular/

In the case of flooding, manholes and other buried junction points are subject to water entry. Wireless service providers may route their networks through these junction points when linking MTSOs or interconnecting with the PSTN. Figure 9 shows typical installation of electronic cabinets at a cell-site.

The termination point for the outside plant is subscriber equipment. A wide range of equipment types has appeared in recent years and now includes telephones, fax machines, answering machines, and computer modems. A private branch exchange (PBX)—or an entire mobile telephone network, for that matter—could also be considered a special type of terminal point for the PSTN. Major vulnerability factors with subscriber equipment are attributable to device design (e.g., poor cradle design for telephone handsets) and commercial power failure. For wireline systems, groundshaking may cause significant 'off-hooks' that can result in line failures by tying up switches. A report from the Northridge earthquake notes that ten percent of line failure alarms came from off-hooks (p. 113). Modern digital switching systems may be capable of detecting and responding to off-hooks. More significantly, loss of commercial power may prevent some subscriber equipment from working, especially computer equipment, cordless telephones and even entire PBX systems (which often require commercial power to operate).

8.1.3 Summary of Factors Related to Mobile telecommunications Lifelines

Compared to wireline telecommunications networks, mobile telephone systems share similar components but with important differences. Mobile systems also consist of both inside and outside plant facilities. For the most part, inside plant facilities and their vulnerability factors are similar to those of wireline networks. Outside plant facilities, however, consist of towers and antennas as transmission media, with wireless handsets operating within and between 'cells' at the subscriber end. The counterpoint to the CO in the wireless network is the mobile telephone switching office (MTSO) which may be connected by wired trunks or microwave to one another. Distribution is done through cellular base stations which in turn may have cable/fibre or microwave connections to adjacent cell cites. Each base station will have a tower to support an antenna. Cellular base stations are vulnerable to commercial power loss, and this may be compounded if local noise restrictions prevent the installation of engine generators. As such, battery backup power may be limited to several hours in the event of an earthquake (Tang and Schiff, 1996: 119). Recent experience in Taiwan indicates that battery backup is not sufficient to provide reliable cellular service after a major earthquake.[34] Vulnerability factors for cables and towers at the cell sites are similar to those for wireline systems.

8.2 Empirical studies into lifeline performance

Actual seismic performance of communication lifelines in major earthquakes and other hazards indicates that major points of network vulnerability are power failure and congestion. Empirical data from flood and severe weather is harder to find with respect to communication lifelines. This is unlike earthquake engineering, where a systematic program of research and knowledge exchange has been long established.

Empirical data drawn from major earthquakes also indicates that physical vulnerability of communication lifelines is determined largely by factors related to outside plant facilities and building services, such as power outages leading to battery failure and HVAC disruption. This form of vulnerability is also relevant to flooding and severe weather conditions. In countries where seismic standards have been developed and are in force, much of the inside plant facilities show good seismic performance, particularly with the hardening of support facilities and transmission equipment at the manufacturing stage (Schiff, 1995: 26; Tang, 1996: 2).

8.2.1 Chi-Chi Earthquake 1999, Taiwan

A report from the Chi-Chi, Taiwan earthquake of September 21, 1999, indicates that the 7.3 magnitude tremblor affected four thousand cellular base stations across the country, cutting service to nearly all of Taiwan's 3.7 million cellular customers (Peng et al., 2000). Power failure was the major problem:

> According to the DGT, [Taiwan's] national telecom authority, wireline local calls in the northern region remained fairly normal. However, lack of power affected the mobile operators in a more serious manner. Once the backup power was exhausted—just a few hours after the tremblor—wireless operators needed 24 hours of constant recharging to restore service. Due to power rationing, however—meaning power would be cut off several times a day—the base station batteries could not charge sufficiently. Some operators were forced to use diesel generators to restore power to the base stations.

The report also claims that at least one operator could not fully recharge its backup battery system for "weeks" because of ongoing power rationing. In some cases, power generators were flown in to help supply power to the network.

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[34] See Peng, *et al.* (2000)

A first-hand report from Taiwan indicated that of the 332 cellular base-stations in the impacted area, 225 were reported out of service (68 per cent) after the earthquake. It took 48 hours to restore the essential 37 locations needed to provide core service to the cellular system. The three major problems resulting from the earthquake were reported as power failure, followed by destruction of antenna and base station equipment from building collapse, and damage in remote areas from landslides and tower collapse. Repairs in the remote areas were compounded by accessibility problems created by damaged transportation infrastructure (bridges and roadways) (Tang, 2000, March 15).

8.2.2 Ice Storm 1998, Eastern Canada

A Quebec government report on the Ice Storm of 1998 clearly indicates the vulnerability of mobile telephone services to severe weather (Nicolet, 1999). An unusual accumulation of freezing rain "severely damaged the telephone network" when it caused the collapse of antenna structures and damaged cell-sites. A widespread and long duration power failure also proved to be a major concern during the event:

> The disaster confirmed the considerable degree to which the telecommunication networks are dependent on the power supply. Since electricity was unavailable, generators were set up in the central offices of telephone companies and on the cellular phone and radio communication companies' antenna sites. (p. 263)

While generators were made available to the telecommunications companies, it appears that repair personnel had problems reaching sites because of weather and road conditions. Moreover, the fuel supply to operate backup generators was also limited during the disaster, "causing a certain number of problems and concerns" (p. 262).

The report recommends revising standards for antenna structures and by adopting redundant design principles for strategic components of the communications lifeline infrastructure (p. 264). A specific item referred to in the report is CSA standard S37-94––applicable to antenna site structures (p. 267). With regard to emergency power, the report recommends that in the future telecommunications companies be given priority access to power as it is made available and, during periods of restricted travel, be assigned priority access to transportation routes in order to service their field sites (p. 267).

8.2.3 Red River Flood 1997, Manitoba

Industry Canada situation reports from the 1997 Red River flood indicate that early during the flooding cellular networks were overloaded. Capacity on the MTS Mobility network, for instance, had to be increased to meet demands of the emergency agencies that were relying on wireless service during flood response operations. One situation report indicates that "Cantel [now Rogers AT&T] had to relocate some cells and some [had to be made] ready to operate from generators." Even within evacuated zones cellular carriers had to increase channel capacity to handle increased demand from emergency responders. In some cases, additional cell-sites had to be installed in evacuated areas, which also required Industry Canada authorization in order to activate microwave links to interconnect the new sites with the existing network (Industry Canada, 1997b).

8.2.4 The Great Hanshin Earthquake 1995, Kobe, Japan

Following the 1995 earthquake in Kobe, Japan, network congestion became a major problem when call volume increased fifty times its usual level. Researchers who investigated communications following the earthquake noted that with Kobe, as in other earthquakes, "telephone networks are not so much destroyed as congested into uselessness" (Noam & Sato, 1995: 595). In Kobe the majority of service disruption was caused by power failure (285,000 lines) and cut transmission lines (approximately 100,000)—mostly above ground. Wireless systems were also heavily congested, and in heavily damaged areas NTTs transmission facilities failed due to physical displacement, damage, or power failure (Noam & Sato, 1995: 596). Emergency communications in Kobe were also hampered when a satellite communication system designed to connect Kobe's Prefecture with local and national government offices, as well as public safety officials, failed in part due to power outage when backup generators became overloaded. Moreover, "only two calls were logged on the entire system on the morning of the calamity", as officials did not even know how to re-align dishes that had been displaced by the earthquake (Noam & Sato, 1995: 597).

8.2.5 Northridge (1994) and Loma Prieta (1989) Earthquakes, California

Reports from recent California earthquakes do not provide specific information about mobile telephone systems. Nevertheless, communication lifelines were seriously impacted by these events. The Northridge, California, earthquake in 1994 impacted five large COs within 15km of its epicenter, affecting 200,000 lines and trunks. Call volume at one CO shot up to 100 times beyond normal demand for service. Post-earthquake examination revealed that switching equipment properly designed and anchored to meet seismic specifications actually performed 'very well' in spite of the fact that the COs themselves suffered extensive structural damage (Lau, Tang, & Pierre, 1995). Nonetheless, all five COs affected by the Northridge earthquake experienced power failures and problems with backup generators. The main cause of generator failure was overload, but groundshaking also caused cracked and damaged batteries. One CO remained on mobile backup power for five days after the initial earthquake. HVAC failed at the COs, and electric fans had to be used to cool off electronic equipment (Lau et al., 1995: 450). Some minor problems with unseating of circuit boards or the malfunction of cards was reported with electronic equipment (Lund, 1996: 356). Structural damage to the COs also limited access to facilities, slowing repair and restoration efforts (Lund: 356). Outside plant damage in Northridge was limited, although two optical cables were reported destroyed by a gas fire that occurred as a result of the earthquake (Schiff & Tang, 1995: 5).

Previous to Northridge, the Loma Prieta (California) earthquake in 1989 caused similar problems with major impacts stemming from power failure and generator failures, as well as increased call volume (Eguchi & Seligson, 1994). Loss of commercial power also knocked out PBX systems, negatively affecting business recovery from the earthquake (Phipps & Eguchi, 1990).

8.3 Summary of Major Vulnerability Factors for Communication Lifelines

The most significant vulnerability factor for communication lifelines appears to be **network congestion** due to increased traffic volume following a natural disaster. Even if no damage occurs to the lifeline infrastructure itself, dramatic increases in call volume can drastically reduce the performance of the communications lifeline through gridlock. Related to congestion is the issue of providing connections for essential services. In this case, a measure of lifeline performance is priority access or restoration of essential service lines during periods of high congestion (Schiff & Tang, 1995: 20).

Following congestion, **emergency power** is another major factor related to the performance of communication lifelines. Power outages are commonplace during many natural hazard events and the loss of commercial power is usually responsible for major failures at CO/MTSO structures and cell-sites. Backup generators may be overloaded or damaged, and battery backup is often limited to several hours. As a result, there remains a need to establish standards for emergency power supplies (Schiff & Tang, 1995: 23). As such, a measure of lifeline performance should include provisions for backup power and battery life.

The **structural integrity** of CO/MTSO structures has also been identified as another major factor related to the performance of communication lifelines, especially in earthquakes. In this case, concern is mainly with older facilities that pre-date current seismic codes. These facilities may not meet minimum structural standards for earthquakes or other hazards. This is compounded by the fact that, in many cases, new kinds of equipment may lead to a greater concentration of lines in fewer buildings as transmission and switching capacity is enhanced. Similarly, competitive local exchange carriers are encouraged to co-locate switching and other associated equipment in incumbent carriers' or other competitors' central offices. Such a concentration of facilities creates the potential for serious single point failures at the CO/MTSO: "As nodes consolidate, central offices, a toll office, and a single transfer point all may be located in a single building, so that structural damage or a loss of power could be very disruptive [to the entire system]" (Schiff & Tang, 1995: 22). The risk of single point failures may also increase (depending upon network configurations) as redundant and alternative pathways disappear with the growing installation of high capacity optical fibre trunks and the practice of leasing capacity on established networks.

Another major, and perhaps overlooked, factor is the **adequacy of disaster response plans** developed by telephone service providers. The adequacy of these plans is based on the provision of mobile backup power and switching systems, as well as the availability of spare parts and repair equipment, effective dispatch protocols for service restoration, and familiarity with local community emergency plans to ensure priority access to sites.

Key variables when measuring communication lifeline vulnerability:

- Priority access and restoration of essential services
- Backup power and battery life
- Single points of failure
- Adequacy of disaster response plans

The growing use of commercial mobile telephone systems within the emergency management community underscores concerns about power failure and congestion with wireless communication lifelines. Less obvious factors affecting vulnerability include the impact of deregulation of the telecommunications industry (mentioned previously in this report) and the potential appearance of alternative and non-traditional telecommunications service providers (such as cable television companies) who may not possess the same level of expertise in and understanding of mitigation best practices and emergency telecommunications matters. From our review of experience in other countries and our analysis of the Canadian experience, it appears that questions remain about interconnection of systems and possible oversights in performance standards across industries that are operating outside of traditional telecommunications licensing and regulation[35] regimes. These factors may become increasing important as competition spreads across all facets of telecommunications and where minimal standards for quality of service assurance no longer exist.

This section has adopted a framework from the field of earthquake engineering to examine the major vulnerability factors of wireless communication lifelines to natural hazards. Of all the major components of a mobile telecommunications lifeline, outside plant facilities are the most vulnerable to secondary impacts such as power and third party structural failure. Dramatic increases in call volume and congestion pose the most serious problems for call completion during major emergencies and disasters. Empirical case studies were introduced to provide further evidence for this assessment.

[35] see Schiff and Tang, 1995: 25

9. Assessing System Performance

This section offers a preliminary framework for assessing system performance of communication lifelines susceptible to seismic and other natural hazards. Assessing the vulnerability of communication lifelines is partly contingent on documenting system response to natural hazard events. Standards and practices can only evolve through observation and measurement of simulated or actual physical damage to facilities and network performance. Documentation is difficult for a number of reasons, including the complexity of communication lifelines themselves and the increasing proprietary nature of the data held by competitive interests (Schiff & Tang, 1995: 23). Schiff and Tang stress the ongoing need to develop a standardized means of evaluating seismic performance as well as disseminating the results to stakeholders in order to contribute to a growing knowledge base.

A challenge that remains is to incorporate vulnerability factors into a systematic method for assessing lifeline performance and, ultimately, for identifying costs and techniques associated with improved performance of mobile telecommunications lifelines under various hazard conditions. Schiff and Tang (1995: 26) offer an important statement for consideration:

> Performance standards should be developed that can be translated into facility and equipment design specifications that can be implemented and measured and are technically and economically achievable. Ideally, these should be based on system models that realistically represent the system and its operation and should include the redundancy incorporated into the networks and nodes and emergency operating practices used to restore service. These models will require equipment fragility data, structure serviceability data, and network performance data during earthquakes. ... [F]or communication systems computer simulations will probably be necessary. These models should be able to estimate direct losses, the extent and duration of outages, and the secondary losses associated with disruption.

This statement provides an important set of guidelines for a methodological framework with which to assess the vulnerability of wireless communication lifelines. It suggests that a model needs to be capable of representing the diversity of the communication lifeline infrastructure, or a selected portion of it. It also identifies three potential inputs and three output variables for the model. The three *input* variables are (1) fragility, (2) serviceability, and (3) network performance. The three *output* variables are direct losses, extent and duration of outage, and secondary losses/associated disruptions.

9.1 Describing Communication Lifeline Vulnerability: Fragility, Robustness, Serviceability

Three input variables are particularly useful as categories for studying communication lifelines. We can expand upon the discussion of fragility, serviceability and network performance to further describe communication lifeline performance:

- Performance of equipment (inside plant and outside plant). This includes switching, transmission, and terminal equipment. The description of performance in this category can be referred to as *fragility.*
- Performance of the network as an integrated system of nodes, pathways, and network management methodologies. The description of performance in this category can be referred to as *robustness.*
- Performance of technicians assigned to service equipment and manage the network. This category includes site accessibility, training, manpower, intra/inter-organizational communications (e.g., dispatch), and access to repair equipment and tools, including diagnostic software. The description of performance in this category can be referred to as *serviceability.*

Vulnerability analysis of wireless communication lifelines can be organized around these three variables. For instance, reviewing some of the major factors affecting the seismic vulnerability of communication lifelines, we discover that they can be usefully grouped into each of the three classes of performance above, and assigned a corresponding measure of performance:

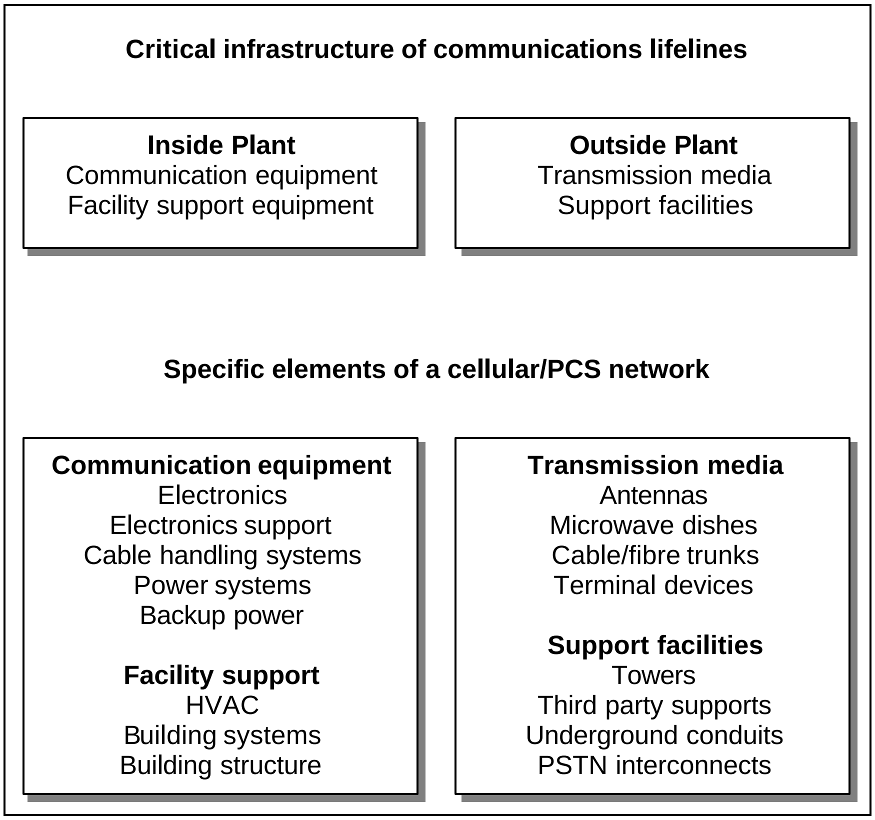
Factors Affecting Vulnerability of Communication Lifelines

Issue	Class of performance	Measure of Performance
Network congestion	Network	Robustness
Priority access/line load control	Network	Robustness
Emergency power	Equipment	Fragility
CO/MTSO structures/cell site locations	Equipment	Fragility
Seismic performance of trunk cables	Equipment	Fragility
Concentration of facilities and loss of route diversity	Network	Robustness
Documentation and system response	Management	Serviceability
Support systems	Equipment	Fragility
Disaster response plans	Management	Serviceability
Service centres and spare parts	Management	Serviceability

9.1.1 Fragility

Fragility is the description of equipment performance. It could be measured through two primary means: (1) manufacturer specifications and associated standards, and (2) performance audit. Fragility could refer to single pieces of equipment but it could also be aggregated into an index that registers an overall measure of fragility at a specific location (e.g., cell base station).

Based on the major factors affecting communication lifelines identified in lifeline engineering literature, we have established the following list of items that can be placed within the category of fragility for a mobile telephone network:



The next step in developing a fragility measure is then to identify the corresponding baseline standards or best practices for each specific element within a mobile telephone network. From here it may be possible to develop an assessment measure for inside and outside plant equipment. In Canada, the first source for information in this area is the Telecommunications Standards Advisory Council of Canada (TSACC), which

> … provides a bridge between the telecommunications and information technology industries and related standards communities. It is a focal point for standards information, and builds awareness of the role of standards in the rapidly evolving global IT&T industries. It is a major contributor to the development of requirements and recommendations concerning new IT&T standards infrastructure in Canada (TSACC, 1999).

TSACC should be able to help researchers further identify specific standards for inside and outside plant telecommunications equipment, such as CSA standards for antenna structures and cables. Once these standards are identified, it is then possible to cross-reference them with established baseline standards established for physical threats to telecommunications infrastructure and establish criteria for vulnerability assessments.

The American National Standards Institute (ANSI) in the US has published a range of standards for baseline and above baseline physical threats to telecommunications facilities. For instance, ANSI T1.329-1995 *Telecommunications - Network Equipment - Earthquake* "sets forth the test methods and acceptance criteria for determining earthquake resistance of network telecommunications equipment." ANSI defines earthquake resistance as "the equipment's ability to maintain a defined level of functionality, without physical damage, disruption of service, or personnel hazard, during and after an earthquake" (American National Standards Institute, 1995). It is this standard which therefore determines the seismic rating of all telecommunications network equipment in the United States. Canadian standards will likely correspond closely to those established in the U.S.

ANSI has also established baseline standards for the protection of outside plant facilities against a wide range of physical stresses. These were developed in the US under the auspices of the National Communications System (National Communications System, 1993b).[36] These baseline standards, formally adopted as ANSI T1.328-1995 *American National Standards for Telecommunications—Protection of Telecommunications Links from Physical Stresses and Radiation Effects and Associated Requirements for DC Power Systems*, are intended to "establish foundation-level protection" and to "help define generally accepted practices" intended to meet the needs of public telecommunications networks. Physical stresses included in the NCS contribution include:

- vibration, including seismic
- water penetration
- temperature and fire
- lightning and AC power-line exposure threats
- wind and ice threats
- threats from rodents, birds, and insects
- construction activity
- corrosion (above and below ground)
- threats to telecommunications power systems

A follow-up report issued by the NCS in 1997, goes beyond baseline standards established in ANSI T1.328-1995 and characterizes *above baseline* physical threats to outside plant telecommunications links. This report, while not currently adopted by ANSI, can nevertheless contribute to vulnerability studies because it provides valuable "information about the physical stresses that can affect telecommunications links but which are not ordinarily protected against by telecommunications service providers" (National Communications System, 1997b).

Telcordia Technologies Inc. (previously known as Bellcore) has also developed the Network Equipment-Building System (NEBS) to establish environmental and generic spatial evaluation criteria for new telecommunications equipment systems used in a telecommunications network. The environmental criteria covers: (1) temperature & humidity; (2) fire Resistance; (3) equipment handling; (4) earthquake, office vibration &

[36] The US National Communications System undertakes research to assess the vulnerability of telecommunications in its mission to "lead the planning, coordination and integration of government telecommunications capabilities to ensure access to, and use of critical information services required for effective response in an all hazards environment" (National Communications System, 1997a).

transportation vibration; (5) airborne contaminants; (6) acoustic noise, and (7) illumination. The spatial section includes criteria for systems and the associated cable distribution systems, distributing and interconnecting frames, power equipment, operations support systems, and cable entrance facilities (Telcordia Technologies Inc., 2000). NEBS criteria has contributed to the establishment of many baseline standards, including ANSI standards.

Another Canadian body of standards that has a bearing on mobile telecommunications infrastructure is the National Building Code of Canada, which sets forth requirements for building systems and building structures (Canadian Commission on Building and Fire Codes, 1996).[37] An important consideration with respect to mobile telephone systems is that many cell-sites are located on third-party structures (e.g., office towers, utility towers) which may have varying levels of conformity to stated standards for telecommunications facilities, depending on date of construction and primary (third-party) function (Figure 10).[38]

Several state and federal organizations in the United States have also funded research to develop a set of procedures for post earthquake safety evaluation of buildings (Applied Technology Council, 1989), which may have some application for evaluating various cell-site structures.

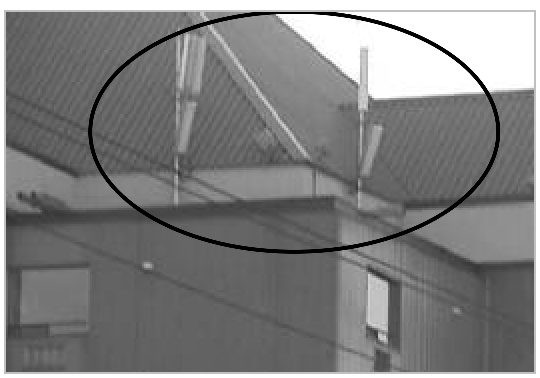


Figure 10. Cellular antennas mounted on a building

9.1.2 Robustness

Robustness is a description of network performance that can be measured by a probability of call completion. It can be specified through a relationship between total number of nodes and pathways, capacity, and single points of failure, as well as network management software and traffic control programs (e.g., priority access to dialtone).

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[37] For a reference to seismic hazard information in the NBC see Natural Resources Canada (1999); for a reference to floodproofing for buildings see Williams (1978).

[38] By "primary (third party) function" we are referring to situations in which a cell-site has been established on a structure that has been designed for an otherwise different role (e.g., electrical tower, apartment building, etc.)

Measurements could be in the form of access/coverage indexes defined by geographic boundaries, or by estimated levels of message traffic. For instance, an MTSO linked to a high volume trunk subject to a single-point failure (e.g., in a daisy-chain configuration) with no provisions for emergency call management would be identified as having a low measure of robustness. A similar high volume MTSO in a ring configuration with provisions for emergency priority access would have a relatively high measure of robustness by comparison. In the latter case, telephone calls would have a higher probability of completion because of the more robust network design and the emergency traffic management system.

In order to examine robustness of telecommunications networks, the U.S. National Communication System (NCS) has developed the "Traffic Assessment by Method of Iteration" (TAMI) model to study congestion in both wireline and wireless networks (Sparrow, 1997):

> Congestion is often caused by increased calling due to a nationwide or regional event. Congestion can also be caused by network management controls (NMC) activated by commercial carriers to protect their network assets from focused overloads in the event of a local or regional disaster. TAMI considers these increased call volumes in terms of multiples of busy-hour, busy-day call loads. These overloads can be evaluated on a local access and transport area (LATA)-by-LATA basis, allowing TAMI to evaluate both national and regional congestion events.

The TAMI model is also capable of considering priority treatment services for public safety responders, including the U.S. Cellular Priority Access Service (CPAS). This modeling capability is used by public safety officials in the U.S. to assess the robustness "of current and proposed network enhancement" of wireline and wireless telecommunications networks for emergency response operations. Network congestion is measured by a "traffic-weighted average inter-LATA call completion probability (CCP) between head offices" in the public network. TAMI is capable of measuring CCP for cellular-to-cellular, cellular-to-wireline, and wireline-to-cellular types of calls. A cellular network is defined by TAMI "as a mobile switching center [MTSO] and the cell sites that depend on that [MTSO]."

9.1.3 Serviceability

Serviceability is, ultimately, a description of human performance as constrained or enabled by standard operating procedures and emergency preparedness. It could be measured by developing a standard checklist for maintenance and service procedures, the evaluation of emergency plans, facility locations and accessibility criteria. Like fragility, serviceability could be developed on a discrete, single-point basis (e.g., cellular base station), or be aggregated into an index of wider service areas (e.g., MTSO hub). Measures of serviceability could be used to approximate service restoration during or after a major incident.

During our review we did not locate any research or models that have been developed in North America for *measuring* serviceability of telecommunications networks, although we are aware that most carriers have developed elaborate service restoration plans and procedures. Our research did reveal, however, that the events following the 1999 Chi-Chi earthquake in Taiwan indicate that serviceability is a serious issue (Tang, 2000, March 15). Restoration of wireless service in Taiwan was not only hampered by damage to transportation infrastructure (roads and bridges) but also by the need to bring in technicians from outside the affected region, as local technicians committed themselves to family and domestic affairs immediately after the earthquake. As a result, restoration of services was delayed while outside technicians worked to become familiar with the particulars of an unfamiliar service area. It is not known whether the coordination of the carriers' restoration efforts (e.g., dispatch operations) were affected by the loss of wireless service after the earthquake, although this apparently was the case for the local gas utility in the region, which relied upon mobile telephones for communicating with its field personnel.

9.2 Output Measures: Direct Losses, Extent and Duration of Outage, Secondary Losses

Output measures are the other side of the vulnerability assessment equation, and are important because they indicate the probable impact of a degraded wireless network resulting from a natural hazard. Outputs of a vulnerability assessment can be classified into three general types:

(1) direct losses of telecommunications infrastructure;
(2) extent and duration of outage; and
(3) secondary losses/associated disruptions due to loss of telecommunications service.

Direct losses refer to the actual cost of replacing and repairing infrastructure that is part of the inside or outside plant facility. It is not clear at this point in time whether the Canadian wireless carriers have undertaken any replacement cost studies based on the potential impact of natural hazards. There is some evidence, however, to suggest that a number of the incumbent carriers have done some analysis pertaining to key parts of building infrastructure. A model for a replacement cost study of the commercial wireless sector could be derived from research done to examine the replacement value of land mobile radio equipment and infrastructure for the US public safety community (Booz Allen & Hamilton Inc., 1998).

Direct losses will have a bearing on **extent and duration of outages**. This output measure can be specified in subscriber lines and units of time. One British Telecom engineer has proposed, only slightly tongue-in-cheek, that system outages could be measured like earthquakes ('netquakes') by a logarithmic formula that combines the number of subscribers affected and the total down time of the network. The resulting number would be identified as the 'magnitude' of the disruption (Cochrane, 1997).[39] This approach to measuring extent and duration of outages is also similar to that used in the TAMI model (mentioned above), which generates call completion probability (CCP) measures based on network conditions and subscriber demand.

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[39] For instance, a magnitude 6.0 netquake would equal 100 subscriber lines being down for 10,000 seconds (2.8hrs).

Although direct losses do bear a relationship to extent and duration of network outages, this relationship may not necessarily be a simple linear linkage. Depending on where a direct loss occurs, extent and duration of an outage may vary greatly. On the one hand, a failure of a single component at a CO or MTSO could conceivably shut down a large portion of a network whereas, on the other hand, a massive failure at a small distribution hub might be confined to only a few subscriber lines. It could be expected that a model such as TAMI is able to account for such infrastructure weighting.

Of the three output measures discussed in this section, **secondary losses** are probably the most difficult to identify and quantify. This is increasingly the case, as telecommunications networks become enmeshed in all facets of daily life. Voice and data networks are now part of an indispensable infrastructure that supports an astonishing range of business and social activities, as well as an equally astonishing range of telematic control systems for other utilities and social infrastructures (e.g., hydro, road traffic control). The process of gathering such data is complex and will require a comprehensive measure of system performance under a variety of circumstances. Secondary losses are likely to be measured in monetary terms, threats to public safety, or loss of life. These measurements are important with respect to identifying social risk in relation to communication lifelines, and may provide an important incentive to encourage the development of a comprehensive mitigation-oriented loss reduction strategy for Canadian communication lifeline infrastructures.

While the challenge remains formidable, a number of resources may be available to help develop secondary loss assessment models. For instance, a recent UN publication provides a methodological framework for assessing the socio-economic impact of natural disasters that might be adapted to suit wireless communications lifelines (ECLAC, 1999). The Christchurch Engineering Lifelines Group has completed an extensive multidisciplinary study on the vulnerability of lifelines to natural hazards in New Zealand (Christchurch Engineering Lifelines Group, 1997). This research may also provide a model for studying secondary losses resulting from failures in wireless communication lifelines (p. 107).

The international risk consulting firm, EQE, is also actively involved in looking at wide aspects of social risk related to natural disasters, and may prove to be a valuable resource in contributing to a secondary loss assessment model for wireless communication lifelines. Further consideration of the company's activities in consultation, software development, and information services is recommended (EQE International, 2000).

FEMA's ongoing *Project Impact* may provide a model for secondary loss assessment (ESRI/FEMA, 1999). *Project Impact* could be considered a 'grassroots' approach to promote emergency preparedness by providing information to the public to help local planners more carefully examine their communities for risk. The model includes access to online hazard maps and information to help communities better identify and assess local risk.

A similar model to *Project Impact* might be developed to provide community planners in Canada with information about local hazards and the vulnerability of communication lifelines, including mobile telephone networks. Such information might then be incorporated into local risk assessment initiatives that could in turn provide critical feedback for researchers trying to identify and estimate secondary losses related to vulnerability.

9.3 Summary

This section has suggested major input and output measures useful to an assessment of communication lifeline performance. Where possible, related research and standards bodies have been identified for these measures and are intended to serve as starting points for encouraging further development of a comprehensive model for assessing lifeline vulnerability to natural hazards.

10. GIS and the Analysis of Communication Lifeline Performance

Geographic information systems (GIS) are an important tool for studying wireless communication lifelines because they can provide the kind of system models that are necessary for measuring communication lifeline performance (Schiff and Tang, 1995: 26). This section first describes some GIS applications related to emergency management planning, A methodological framework for using GIS tools to assess the vulnerability of wireless communication lifelines to natural hazards is then introduced, building on the framework that was initiated in the previous section on vulnerability.

10.1 Geographic Information Systems (GIS)

Lifelines are important civil infrastructures, typically divided into five categories: (1) electric power, (2) water and sewage, (3) gas and liquid fuels, (4) transportation systems, and (5) communication (Lau et al., 1995: 438). GIS technology has been used to study most of these systems. It is not clear to what extent GIS has been used to study the vulnerability of wireless communication lifelines to natural or technological hazards, although we have located a small number of related studies.

Geographic Information Systems (GIS) are computer-based applications for doing spatial analyses and problem solving, and can be defined as a

> system of computer hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially referenced data for solving complex planning and management problems. (Korte, 1997: 401)

In general, GIS systems have two major components: (1) spatial data and (2) attribute data. From a functional standpoint, GIS applications provide a means of storing and manipulating spatial and attribute information in the form of numerical data, as well as providing a systematic means of displaying this data in visual maps consisting of data layers--known as *coverages* or *themes*.

> GIS software is designed to permit the routine examination of both spatial and attribute data at the same time. The user is able to search the attribute data and relate it to the spatial data, and vice versa. For instance, [in municipal tax mapping] the city planner may ask where are all lots in the west end that are larger than one acre and zoned for industrial use. The GIS can respond by either listing their lot numbers or by plotting their location on the city street map. (Korte, 1997: 34)

Spatial and attribute data may also be combined and re-generated through the development of special scripts and algorithms that can simulate interactions between user-specified variables. This is a form of *dynamic modeling*, and this technique can be applied to generate simulated scenarios for studying the impact of natural hazards on selected infrastructure.

10.2 GIS for Risk Assessment and Emergency Management

GIS can be usefully applied to practically any kind of problem that involves spatial information. As such, researchers have begun to recognize its value to risk analysis and emergency planning activities. For instance, one popular use of GIS for risk analysis is found in the area of transportation studies, where case studies include evaluation of highway and bridge networks for seismic upgrading (Basoz & Kiremidjian, 1996; Jernigan, 1998; Kim, 1993); hazardous materials transportation planning (Gheorghe & Vamanu, 1998; Lepofsky, 1994); modelling risk from hazardous material spills (Unger, Gerharz, Mieth, & Wottrich, 1998); and post earthquake traffic flows (Deakin, 1996).

Other areas of risk analysis and emergency management that utilize GIS include community vulnerability (Cova & Church, 1997; Morrow, 1999); natural hazards risk assessment and decision support (Montz, 1998; Poli, Ippoliti, & Marino, 1997; Scholten, LoCashio, & Overduin, 1998; Wybo, 1998); seismic risk assessment of water and sewer utilities (Mark, Wennberg, vanKalken, Rabbi, & Albinsson, 1998; Toprak, 1998); and evaluation and decision support for municipal emergency response activities (Heino & Kakko, 1998; Ilmavirta, 1995; Peters, 1998).

A good example of a GIS-based community emergency planning tool is the Coastal Services Center project, which assists communities on the east coast of the US in their efforts to reduce hazard vulnerability. The project was developed by the US National Oceanographic and Atmospheric Administration (NOAA) in partnership with New Hanover County, North Carolina. The project takes the form of an ArcView (GIS) application available on CD-ROM (NOAA Coastal Services Center, 1999):

> The general methodology is [presented as] a tutorial that steps the user through a process of analyzing physical, social, economic and environmental vulnerability at the community level. The foundation for the methodology was established by the Heinz Panel on Risk, Vulnerability, and the True Cost of Hazards (1999). This panel of multi-disciplinary experts conducted a study to identify the full range of disaster costs. They found that many disaster costs go far beyond government assistance and insured losses. Many of the things that cause individuals and communities to suffer great losses can be traced to social, economic, and environmental vulnerabilities. Therefore, this new methodology was developed to help communities look at their vulnerabilities from a more comprehensive perspective. (Eslinger, 1999)

In this instance, a GIS provides means of analyzing vulnerability with community assets and risk considerations presented in the form of spatial data layers. GIS enhances the process of community planning because it can suggest interdependencies and risk factors that might not otherwise be discovered. Moreover, as the NOAA Coastal Services Center project demonstrates, GIS provides a powerful platform for a community-wide comprehensive, all-hazards planning strategy.

10.3 GIS, Emergency Management, and Wireless Communication Lifelines

Based on an extensive search of literature published over the past ten years, in both the scientific and social scientific databases, we have discovered no research that has been reported using GIS to study the impact of natural hazards on wireless communication lifelines in North America. In only a few cases did we find evidence of GIS being used in conjunction with emergency management and wireline communication lifelines (National Communications System, 1992, 1993a; Sedgwick & Gilley, 1996; Wong & Isenberg, 1996).

Of this small body of literature, reports published by the U.S. National Communications System (NCS) are most relevant to this project inasmuch as they describe a GIS-based methodology for modeling earthquake damage to communication lifelines in general. None of this research, however, is focused specifically on wireless communication lifelines even though NCS has reported on wireless congestion modeling capabilities (Sparrow, 1997).

Despite its exclusive focus on wireline telecommunications, the NCS does offer a methodological framework that can be usefully adapted to wireless communication lifelines. In fact, NCS research efforts compliment the lifeline engineering work of Tang and Schiff (1996) insofar as both provide a foundation for identifying data requirements and recognized approaches to network modeling.

10.4 GIS and Spatial Analysis of Communication Lifelines

NCS reports concur with our assertion that GIS is a valuable tool for studying communication lifelines. In many respects this is largely because GIS is capable of integrating a wide range of data for detailed modeling and analysis. This data can include telecommunications network infrastructure, support facilities (e.g., power supply network), community infrastructure, transportation routes, and hazard maps. Once integrated into a set of related databases, planners can begin to look at interaction effects between these kinds of data, such as the effect of power failure on the telecommunications network and its subsequent impact on community emergency centres. Several applications of GIS to telecommunications are possible (National Communications System, 1992:45-47) including:

- spatial database of infrastructure assets.
- spatial depiction of traffic flows over telecommunications networks.
- spatial depiction of telecommunications infrastructure in relation to other community assets (e.g., public buildings, transportation routes, etc.).
- modeling of interactions between environmental variables and telecommunications (e.g., natural hazards).

These types of applications are not necessarily mutually exclusive and some may, provide the necessary foundation for more advanced applications. For instance, it is necessary to have a spatial database of infrastructure assets in order to depict network traffic flows or to study the interactions between natural hazards and telephone service.

Using GIS to study the vulnerability of communication lifelines is a three phase process that involves data collection, damage vector generation, and an assessment of network performance (National Communications System, 1993a). The extent to which each of these phases can be successfully implemented depends ultimately on the availability and accuracy of data to researchers and planners.

10.5 Conducting a Spatial Analysis of Wireless Communication Lifelines

The following describes a methodological framework for a spatial analysis of wireless communication lifelines. It is similar to a methodology developed by the National Communications System to study the impact of earthquakes on U.S. wireline communication lifelines. While the NCS methodology is designed primarily for seismic hazards, it may also be adaptable to other natural hazards including floods and severe weather.

10.5.1 Data Collection

When undertaking a spatial analysis of wireless communication lifelines, a wide range of data can be included. As such, a key operational step at the outset of any study is to establish a set of core data requirements based on overall objectives and, ultimately, on a realistic appraisal of the availability and cost of obtaining data.

We have identified a range of data types relevant to a spatial analysis of wireless communication lifelines. This data has been categorized into three types of inputs we previously described in the section on lifeline vulnerability:[40]

Fragility data

- locations and attributes of cellular base stations and MTSOs (by carrier)
- locations and attributes of trunks and other wireline distribution paths
- cell site coverages (per base station or by MTSO grouping)
- cell site capacity (call volume)
- equipment fragility ratings (based on equipment, mounting, and other relevant factors)
- environmental conditions (e.g., geophysical data, flood data, weather data)

Robustness data

- fragility curves (i.e., anticipated infrastructure damage generated from fragility data)
- cellular user profiles
- community gathering points (e.g., emergency centres, schools, malls, etc.)
- network management operations (e.g., priority access to dialtone provisions)

Serviceability data

- fragility curves (i.e., anticipated infrastructure damage generated from fragility data)

[40] We remind the reader that this list is intended as an exploratory methodological framework to encourage and support further research in this area.

- call completion probability measures (i.e., results from robustness data)
- commercial power distribution (e.g., substation zoning)
- support facilities data (e.g., service/repair zones and field centres)
- transportation routes (incl. designated disaster response routes)
- time of day and vehicle traffic data (accessibility issue)

The collection and compilation of data for input into a GIS system is a time consuming process requiring considerable resources. Much of the data may not be readily available and may need to be generated from firsthand empirical research. Data that has been collected may also be difficult to include in a published study because of proprietary interests or other factors that limit its availability (e.g., cost, format). On the other hand, some types of data may be widely available or can be generated with relatively little cost on the part of researchers. These factors must be identified and decided upon before further plans are made with respect to the scope and objectives of a spatial analysis.

At present, data on the mobile telecommunications infrastructure in Canada is not widely available. This is due, in part, to changes in licensing policies. For example, as mentioned in earlier sections, Industry Canada has established different filing requirements for wireless service providers, especially as they relate to cell site locations. Presently, only cellular licensees have to file site specific location data for each cell site prior to installation. This data is made freely available over the Internet. PCS data, however, is not. Since it is licensed on a frequency block basis, PCS cell site location data is not recorded in the database. Similarly, extenders are not licensed and, as such, not included. Developing an accurate coverage profile for each proposed study area, therefore, requires close cooperation with wireless carriers.

Fragility ratings for mobile telecommunications equipment are also not readily available and, moreover, will require expert consultation with carriers when being applied to the varied settings where mobile network equipment is located.

Mobile telephone user profiles, particularly those developed with the emergency management community in mind, are also not readily available. A mobile telephone user profile provides important *social data* on the presence of mobile telephones in the emergency management community, as well as on the anticipated location and movement of priority users of those telephones. *In effect, this data acts as a critical bridge between the mobile telecommunications infrastructure and the communication needs of the emergency management community during an emergency*. As such, it can be used to anticipate potential communication problems resulting from the interaction between a natural hazard, the mobile telephone network, and the projected needs of local public safety officials.

Community gathering points (CGPs) can include a wide range of public and private facilities. For our purposes we identified emergency operation centres, public safety facilities (fire, police, ambulance, hospital), schools, community centres, and malls as primary CGPs. Much more research needs to be done in this area to examine the location and communication needs of people during widespread public emergencies and disaster events. Less evident CGPs might include senior citizen residents, transportation hubs (e.g., train or bus stations), office buildings, public parks, industrial complexes, or virtually any place where large numbers of people might be located during or shortly after a major emergency or disaster. In some cases, this data may be currently available from local emergency management organizations or community planners. In other cases, some of this data may need to be generated through field research before it can be incorporated into a spatial analysis. CGPs offer important input to a spatial analysis because they are locations where high call volume will likely be concentrated during an emergency event. Findings from a spatial analysis that examines the mobile telephone network in conjunction with primary CGPs can be used in emergency planning to identify important cell sites for emergency telecommunications, including priority access provisions.

Serviceability data includes mobile telephone service zones, field centres, commercial power distribution, transportation routes, and vehicle traffic data. This data provides important input for studying the impact of a natural hazard event on the recovery time of mobile telephone service. Service zones and field centres provide a spatial inventory of technical support resources that might be needed for service restoration. Anticipated damage to transportation routes and vehicular traffic data provide a means of measuring the mobility of service technicians and the accessibility of cell-sites during or after a major emergency. Vehicular traffic data can also help to predict mobile concentrations of mobile telephone users at different times of day. Commercial power distribution provides a basis for studying the effects of power failure scenarios on a mobile telephone network, suggesting vital points for backup power systems. Much of this data, particularly service zones and field centres, may be difficult to obtain because of the reluctance of wireless service providers to issue such details to the public. Emergency planners and researchers, again, will need to solicit cooperation from carriers.

We should emphasize that it may not be necessary to obtain the complete range of data described above in order to develop effective spatial analyses of the mobile telephone network. This list provides a framework of potential data only—specific data requirements will vary depending on the objectives and scope of any particular analysis.

10.5.2 Damage Vector Generation

Subsequent to the data collection phase, the next step in developing a spatial analysis is to create a formula for generating damage scenarios. This is a more complex step that involves linking environmental variables to fragility data in order to generate a set of facility fragility curves for specified components of a wireless communication lifeline. In this case, ‘environmental variables’ refers to ground motion data for earthquakes, water level and flow data for floods, and ice loading and wind conditions for severe weather (e.g., ice storms).[41] NCS has developed a methodology for generating damage vectors for telecommunications lifelines in earthquake settings:

> The most complex part of [an] earthquake damage assessment methodology is contained in the second phase of the implementation plan. Damage vectors are generated using seismic facility fragility functions and estimates of ground motion intensity. A seismic facility fragility function represents the susceptibility of different types of facilities to damage in an earthquake. In engineering terms, a seismic fragility model defines the probability that the damage a facility will experience will exceed a certain level. These probabilities are defined as a function of ground motion intensity, measured in terms of Modified Mercalli Intensity (MMI) or peak ground acceleration (PGA) (National Communications System, 1993a: 6).

This same model could be drawn upon as a model for wireless lifelines and a wide range of natural hazard conditions by substituting ground motion intensity with different inputs (e.g.., water level/flow rate, or ice loading).

Developing valid and reliable links between environmental variables and fragility curves, however, is a complicated process that was beyond the scope of our project, although the OMNCS methodology describes this process in some detail. Further research to identify—and develop where feasible—a set of generic facility fragility functions applicable to wireless lifelines under seismic, flood, and severe weather conditions is recommended. These could then be made available for incorporation into a wide range of GIS modeling systems, and used for future vulnerability analyses of wireless lifelines within a broad range of emergency communications planning activities.

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[41] Some environmental variables may need to be generated out of other factors. For instance, ground motion data for earthquakes will need to be generated from at least a basic knowledge of soil conditions in a local area. As such, researchers and planners should not underestimate the potentially complex undertaking involved in generating any set of environmental variables.

10.5.3 Assessment of Network Performance

The final step in a spatial analysis is to develop a model that can translate damage vectors into a measure of network performance (e.g., probability of call completion). The NCS Traffic Analysis by Method of Iteration (TAMI) model used to assess network performance from damaged communication lifelines described in the previous section, provides a method to calculate probability of call completion (PCC) based on the assessment of damage vectors that represent *extent of outage*. We would suggest that network performance in a GIS-based spatial analysis could be usefully widened to include *duration of outages*, as well to suggest *probable secondary losses* related to the reduction of mobile telephone performance during an emergency.

> 8.4.2 Output Measures: Direct Losses, Extent and Duration of Outage, Secondary Losses
>
> Output measures are the other side of the vulnerability assessment equation, and are important because they indicate the probable impact of a degraded wireless network resulting from a natural hazard. Outputs of a vulnerability assessment can be classified into three general types: direct losses of telecommunications infrastructure, extent and duration of outage, secondary losses/associated disruptions due to loss of telecommunications service.

Duration of outages is proportional to restoration of service (serviceability), while probable secondary losses describes a potentially wide range of "cascading" impacts related to emergency communications and emergency operations support. Moreover, with careful identification and collection of other forms of data, it might be possible to analyze even more complex secondary losses such as widespread socio-economic impacts resulting from the loss of mobile telephone service, as well as related prospects for short and long term community recovery.

Specific outputs for network performance are also drawn from the three types of input variables—fragility, robustness and serviceability:

Fragility

- loss of coverage
- reduction of coverage
- call migration between cells

Robustness

- traffic-weighted end office-to-end office blockage
- probabilities of call completion (PCC)
- expectations for emergency planners

Serviceability (restoration of service)

- identification of high priority cell sites
- potential problems accessing base stations for service restoration
- anticipated delays in restoration of service

The creation of facility fragility curves will provide a basis for fragility-based outputs, including loss of coverage, reduction of coverage, and call migration. These are direct impact and extent/duration of outage measures. Loss of coverage differs from reduction of coverage to the extent that loss refers to *total failure* of mobile telephone communications and reduction to varying levels of congestion related to network failures. Call migration refers to the movement of subscribers to adjacent cells during periods of congestion or network failure. Migration may be a function initiated by carriers by increasing the range of a cell-site, or may be a function of the physical movement of subscribers to adjacent cells.

Models such as TAMI are necessary to produce assessments of robustness based on blockage and call completion measures. These measures, when incorporated into a spatial analysis, could provide important information for emergency planners—particularly with respect to expectations for mobile telephone performance in various geographical locations during an emergency. For instance, depending on mobile telephone network architecture and call management planning, locations will likely vary in their levels of robustness. This information could be used to aid in evaluating locations for emergency operations centres (EOCs) and other designated community gathering points because it highlights problem areas for wireless emergency communications. Conversely, it could assist wireless service providers when considering improvements for capacity, robustness and location of cell sites that can be predicted to be used during emergency conditions.

Serviceability assessments could provide important information to emergency planners by highlighting high priority cell-sites, and assist them in working with carriers to resolve accessibility issues related to service restoration (e.g., road/bridge and premise access to cell-sites). Being able to anticipate delays in restoration of service is also valuable for emergency communications planning purposes to ensure alternative telecommunications arrangements are in place when they are needed the most and for business resumption purposes during the recovery phase of a disaster.

Finally, because of the complex nature of data gathering required to undertake telecommunications vulnerability analysis, it is important to acknowledge the symbiotic relationship that exists between the mobile telephone industry, emergency planners, researchers and regulators based on information interdependency. No single group can undertake this type of analysis on its own because it does not possess all of the necessary information. Assuming a spirit of cooperation exists, however, each group can make its own unique contribution to such a knowledge base. What is required is an appropriate emergency telecommunications policy framework and process to facilitate this.

10.6 GIS and the Analysis of Communication Lifeline Performance - Summary

This section has examined the application of GIS for modeling the performance of mobile telecommunications lifelines. We have provided evidence to indicate that spatial analysis, using GIS, provides a means of effectively studying the vulnerability of mobile telephone systems during widespread public emergencies such as those precipitated by earthquake, floods, and severe weather.

A methodological framework was introduced that provides suggestions for incorporating findings and measures from the previous section on vulnerability into a GIS system. Findings from a GIS-based spatial analysis can provide planning information on direct losses, extent and duration of outages, and on secondary losses. Not all data, however, may be necessary or readily available to researchers. As such, decisions must be made early in any analysis to determine the appropriate scope and extent of a GIS-based assessment and the requisite data needs.

This section also described a three-phase process for operationalizing the assessment methodology. This process involved data collection, damage vector generation, and assessment of network performance. Specific forms of data were identified and described, and damage vector models as well as specific assessment criteria were described.

11. Summary and Recommendations

Wireless communications provide key capabilities for the Canadian emergency management community because they enable operational mobility and provide critical communication pathways when wireline telephone service is unsuitable or unavailable. Even wireless technology has its limitations, however, and emergency management organizations (EMOs) are often faced with the problem of integrating and coordinating their activities through incompatible systems and shared spectrum. Common, reliable, scaleable and interoperable agency-based communications remain difficult to achieve with traditional land mobile radio systems. Although the federal government has allocated spectrum to enable interoperability among public safety organizations, it is not sufficient to satisfy all of the requirements of an extended emergency management community that could include possibly any organization or individual required to respond to and/or support an organized community response to hazard events.

As a result, commercial mobile telephone technology is now being perceived by most emergency management organizations as a strategically important solution to these deficiencies and as a potential communication bridge between wireless systems and the public switched telephone network (PSTN). Interoperability has become especially important for the emergency management community because it provides the foundation for an easily deployable and increasingly flexible emergency communications system. Moreover, mobile telephones offer this interoperability without the added costs of establishing and maintaining agency-specific networking arrangements.

Mobile interoperability is further enhanced by the migration from analog to digital technology and by the implementation of common data standards. This rapid migration is creating new markets for enhanced wireless telecommunications services based on advanced data applications such as Internet text and multimedia. The resulting convergence of voice and data applications will likely lead to the evolution of hybrid networks that combine infrastructures of different jurisdictions and disciplines with those of public wireline and wireless carriers. As a result, increasing amounts of mission critical emergency traffic are likely to flow over public networks.

Despite the promise of this emerging technology, the specific benefits, limitations and ultimate implications of emergency mobile telephone usage are not yet well understood by the emergency management community, policy makers or, for that matter, by all service providers. Our analysis identifies a number of critical issues concerning the viability of commercial mobile telephone systems for emergency communications. For example, when we reviewed the evolution of the Canadian mobile telephone industry and its regulation, it became apparent that:

- commercial mobile telephone systems are not designed, scaled and/or fortified to serve as community emergency networks. Their primary purpose is to support business and consumer needs.

- new wireless service providers may not be fully aware of the importance of their role in emergencies or of the emergency telecommunications requirements of their customers.

- current second-generation handsets from competing service providers are not interchangeable because of different air-interface standards. This poses a potential interoperability issue for emergency telecommunications. In the absence of direct interoperability between carriers, customers are still dependent upon the public switched wireline telephone networks for call routing between different wireless service providers.

- telecommunications networks are rapidly becoming globally integrated and automated systems, and their management is widely distributed among various stakeholders. The growing interconnectivity among wireless and wireline networks makes overall quality control complex, difficult to achieve, sustain and even to monitor.

- aside from tariff and interconnection matters, the Canadian Radio-television and Telecommunications Commission (CRTC) has largely forborne from regulating wireless service providers and, therefore, generally does not concern itself with matters relating to emergency telecommunications.

- CRTC forbearance also means that wireless service providers are not required to meet any prescribed level of quality of service.

- commercial wireless carriers generally have no CRTC-imposed obligations to support emergency communications requirements (except for the provision of access to 9-1-1 service in the event they become competitive local exchange carriers).

- mobile telephone calls placed to 9-1-1 generally require more time to process than wireline calls because caller locations and call-back numbers must be obtained manually.

- Industry Canada, designated as the lead federal authority for emergency telecommunications and the radio licensing authority over Canadian mobile telephone systems, traditionally has not established any emergency–specific telecommunications regulations, conditions of licence or mandatory standards, including priority access, for wireless service providers or other emerging digital wireless services.

- although the primary responsibilities for civil emergency response rest at provincial and local levels, the federal government carries the primary jurisdictional responsibility for ensuring emergency telecommunications provisioning.

- Canada has not yet established any overarching emergency telecommunications policy framework.

11.1 Education and Awareness

These observations suggest that numerous stakeholders now share the responsibility of making important decisions affecting emergency telecommunications best practices. Under current circumstances, however, the greatest responsibility appears to rest with members of the emergency management community, who must make the final decisions about adopting mobile telephone technology and who will likely bear the most immediate consequences for such decisions. As such, there is a real need to educate emergency management officials about mobile telephone technology so that they are able to make informed decisions when choosing public commercial over agency-based solutions. In the longer term, the emergency management community will need to consider means of staying abreast of emerging wireless technologies in order maintain effective emergency communications preparedness.

Findings from our survey research further suggest that the concerns of end-user education and emergency technology planning have not yet been formally addressed, and could be greatly enhanced with:

- improved end-user understanding of vulnerabilities and risks associated with mobile telephone systems during times of emergency.
- clearly identified and specified communications needs for emergency management organizations.
- the establishment of widely recognized mobile telephone emergency operating standards and guidelines.
- improved understanding of the full range of options and techniques available to reduce communications congestion and delays[42].
- a comprehensive understanding of alternative communication strategies to address connectivity and interoperability needs when public network services are unavailable.

Emergency management organizations clearly need to be able to evaluate their specific or unique functional communications needs and resulting requirements against commercial mobile telephone service attributes. To use commercial technology effectively, the emergency management community will have to carefully select and promote the implementation of products and services that meet its special requirements. This is especially important because the emergency management community is, in effect, a loosely knit group of mobile telephone customers who at present have little control over network design and performance.

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[42] Among these options are a variety of value added cellular/PCS services such as text messaging and other data services that utilize networking techniques not linked to traditional circuit-based services. These services may not be subject to the same congestion/access problems. Other alternatives include amateur radio and non-site specific facilities such as mobile satellite telephones.

11.2 Priority Access

One of the most critical performance-related requirements is priority access. Because of the spectacular growth of the mobile telephone industry, and with the current absence of nation-wide quality of service and priority access procedures, reliability and accessibility will remain major concerns for mobile telephone users. In the case of congestion, the problem is not simply access to a given cell-site, but rather needs to be viewed more holistically. To achieve true wireless priority access in this new integrated environment, priority access treatment ultimately will have to be established throughout all network segments—wireline *and* wireless—to ensure call completion on an end-to-end basis. Moreover, if data networking becomes an important component of emergency telecommunications, then text-based messaging and other forms of electronic data exchange will also require prioritization. This points toward a need for priority access standards to be adopted in both the telecommunications and information technology sectors to ensure emergency lanes are available on the emerging information highways.

The Canadian public also needs to be educated about restricting non-essential use of mobile telephone services during emergencies. This could present a challenge for the industry, since its revenues are derived directly from timed network usage. Nevertheless, a careful balancing of stakeholder interests is in order, even if this ultimately requires government policy direction.

11.3 Vulnerability Assessments

Above all, stakeholders must be able to access more complete information about the performance of mobile telephone networks under emergency conditions if they are to make informed decisions about emergency communications preparedness and planning. Our research has demonstrated that much information is available but will need to be more systematically collected and organized if it is to provide a decision support function for the emergency management community.

In effect, emergency communications planning requires a methodology for studying the vulnerability of mobile telephone networks under extreme conditions of natural hazards and other types of public emergencies. The adoption of a consistent methodology among various stakeholders could provide the basis for more informed decision making on the part of public officials and telecommunications carriers alike by providing a standard reference point for consultation.

Empirical data drawn from a variety of natural hazard events in recent years indicates that network congestion, electrical power failure, and structural failure to outside plant facilities are the three primary sources of vulnerability in communication lifelines, including mobile telephone systems. Another vulnerability factor, often overlooked, is the adequacy of disaster planning itself, particularly on the part of telecommunications carriers.

The identified set of input variables useful to a systematic study of mobile communication lifelines—fragility, robustness, and serviceability—present unique challenges for data gathering and standardization. We have attempted to identify current baseline standards and relevant standards organizations that might be considered for use in further formalizing these input variables. We have also identified a preliminary set of output measures that include both direct and indirect impacts on emergency communications. Where possible, these output measures are compared with pre-existing methods and planning tools as examples of potential resources.

11.4 Emergency Communications Spatial Database

Effective community assessments for emergency communications could be promoted through the creation of relatively standardized input data sets and procedures for generating assessment outputs. One approach to this is the adoption of national planning guidelines and the creation of a research database designed to support emergency communications planning activities at the community level. While considerable work would need to be done to achieve this objective, the methodological framework presented in this report serves to identify some basic starting points.

Implementation of a methodology for wireless emergency communications planning could be achieved through the use of spatial analysis tools. Geographic information systems (GIS) present the most obvious solution, and are widely used for a variety of emergency management and risk assessment applications. GIS is a flexible tool that could provide a common platform for stakeholder assessment of emergency communications needs and vulnerabilities. Several decision support functions could be served by the adoption of GIS in emergency planning. For instance, a well-designed GIS application could provide the following:

- a spatial database of infrastructure assets.
- spatial depiction of traffic flows over telecommunication networks.
- spatial depiction of telecommunications infrastructure in relation to critical community assets.
- interactive modeling of interactions between environmental variables and telecommunications performance (e.g., impact of a natural hazard).

Using GIS for decision support is a three-phase process that involves data collection, damage vector generation, and an assessment of network performance. Each of these phases has been described in brief in this report. Data collection remains the first challenge that needs to be addressed, and this will require the ongoing cooperation of a wide range of stakeholders including the telecommunications carriers, utility companies (e.g., hydro), and all levels of government. Various obstacles to data collection will need to be overcome if GIS is to be effective as a decision support tool. Most generally, these obstacles are access, costs, data formats and standards. Damage vector generation and network performance assessments will require further refinements of the methodology proposed in this report, with additional support from experts in various fields such as lifeline engineering, earth sciences, community and emergency planning.

GIS can provide a useful decision support tool for emergency communications preparedness and is widely available at the community level because of its growing application in municipal planning.

The development and implementation of a standard methodology and decision support tool for emergency communications planning is an important pre-requisite for effective stakeholder consultation on mobile telephone systems. Better information is the first step to enhanced emergency communications preparedness for mobile telecommunications. Decision support can benefit from the adoption of baseline standards for data collection and a consistent methodology for generating assessment scenarios and output measures. This can only be achieved, however, through ongoing collaboration among all concerned stakeholders.

Telecommunications and information systems not only support timely emergency communication, but are now at the core of an even larger collection of infrastructures that support Canada's vital social, economic and cultural interests. Such interdependency creates a new technological hazard: a widespread network outage. Although the probability appears low these days, the social and economic impacts of such an outage could be enormous especially if turns into a prolonged interruption. In Canada, various natural hazards are catalysts for these situations, and include earthquakes, widespread flooding, and ice storms that result in physical damage to infrastructure, prolonged power outages and travel restrictions that hamper restoration efforts. Other causes can be the result of cyber attacks, power grid failures or even fires in telecommunications central offices.

In order to secure the emergency telecommunications infrastructure, carriers and service providers need to know what to secure and how to secure it. New vulnerability analysis and impact modeling tools can contribute to these requirements.

11.5 National Emergency Telecommunications Strategy

Perhaps it is time to examine the need for a new comprehensive and integrated national emergency telecommunications strategy that includes commercial mobile telephone services among other existing and emerging telecommunications services. A national strategy, if appropriately implemented, would help to establish and implement common elements, standards and procedural guidelines for an increasingly interconnected range of telecommunications technologies and services. This strategy should provide both a policy and practical framework at the federal national and regional, territorial and provincial and municipal levels, and should ensure flexibility to meet the wide variety of specific communications needs in different areas of the country.

Some of the possible goals of such a strategy could include:

- educating the emergency management community about wireless telecommunications and help them identify and articulate emergency telecommunications needs.
- promoting ongoing information exchange among user groups, standards organizations, policy makers, regulators, manufacturers, carriers and value added service providers to ensure emergency telecommunications needs are met.
- creating incentives for industry to invest in emergency telecommunications as a niche market, including creating and/or adapting new technologies and services.
- promoting infrastructure assurance education and training among stakeholders and advocate best practice within the telecommunications and information technology sectors.
- incorporating vulnerability assessment and risk reduction into licensing and policy considerations, especially where facilities are deemed critical infrastructure.
- establishing and integrating a set of emergency communications principles into policy setting processes, similar to those evolving for privacy and information security.
- supporting ongoing research into emergency networking vulnerability and mitigation strategies, identifying research and development needs and incorporating them into a national emergency telecommunications program.
- facilitating partnerships and joint efforts to develop and deploy network-based systems.

12. Topics for Further Study

In closing, we suggest various topics for further study, based on the three streams of inquiry around which our research has been structured: mobile telephone technology, industry and users; spatial analysis; and policy review.

12.1 Mobile telephones: Technology, Industry and User Profile

A key ongoing objective in emergency telecommunications is to better understand developments in the wireless telecommunications sector from technology, industry and user perspectives. Such understanding is important for building a more complete profile of current and future needs and concerns with respect to mobile telephone systems and emergency communications. Some questions for further study include:

- what organizations and what wireless and wireline services currently require interoperability?
- how is the application of new wireless technology changing interoperability needs among agency-specific and/or public networks?
- what is the current experience of wireless usage within the Canadian emergency management community?
- what are the present capabilities for the Canadian emergency management community to assess emergency telecommunications requirements and how well does it the understand the capabilities of wireless telecommunications?
- what innovations can we expect from wireless technology in 5 or 10 years? How can priority access and other critical emergency telecommunications requirements be designed and effectively implemented?
- what impact will global developments in wireless telecommunications have on Canadian emergency telecommunications needs and services?

12.2 Spatial Analysis

A primary objective in this area is to develop a standard methodology to support emergency communications planning for mobile telephone services. Spatial analysis and vulnerability assessments of mobile telephone networks need to be further explored with the goal of providing community planners with easily accessible, high quality information and planning tools. Such assessments could be enhanced by:

- establishing national guidelines for emergency communications planning. These would include provisions for methodology, data collection and formatting, as well as the creation of a planning database and spatial analysis tool for emergency managers.
- developing an online communications planning guide for the emergency management community.

- undertaking a national data audit to examine the availability of, and need for, spatial data for mobile telephone emergency planning assessments.
- developing specialized GIS-based applications to support wireless emergency telecommunications planning.

12.3 Policy Review

Our study's initial policy review indicates that while Canada does not possess an overarching emergency telecommunications policy framework, there are many programs and institutional arrangements already in place that can serve as a foundation upon which to build such a policy framework. Examples include: the emergency support functions of Industry Canada enabled under the Emergency Preparedness Act; consultative processes established by government and industry, including the National and Regional Emergency Telecommunications Committees, Wireless E9-1-1 Working Group, the CRTC's Interconnection Steering Committee, and standards-based organizations such as the Telecommunications Standards Advisory Council of Canada and Canadian Standards Association, among others; and the emergence of a number of emergency management organizations such as the Association of Public Safety Communications Officials and the Canadian Emergency Preparedness Association that could help to articulate and represent emergency management community needs and interests. Similarly, new programs are emerging at Canadian universities that can assist in emergency telecommunications policy and applied research. Moreover, concern for improving and coordinating emergency telecommunications policy is being reinforced internationally through numerous initiatives including the International Convention on Emergency Telecommunications, the UN Working Group on Emergency Telecommunications, NATO committees and working groups and activities emerging from the Global Disaster Information Network. Some of the key Canadian policy and regulatory questions to be addressed include:

- can additional spectrum be reserved or made available specifically for facilitating emergency telecommunications interoperability? If so, should this be done? Should it be restricted to public safety organizations, made available on a broader emergency management community basis, and/or incorporated into commercial service provisioning requirements?
- what regulatory regime(s) best suit(s) emergency telecommunications requirements?
- what is the experience of other jurisdictions outside Canada?
- how can policies, regulations and standards be implemented to meet specific Canadian requirements and remain compatible with evolving international practices?
- what is the best forum for stakeholder consultation and consensus building?
- how can emergency telecommunications requirements be better integrated into existing policy frameworks?

Finally, these suggested activities outline above and elsewhere in this report complement and can meaningfully contribute to other associated national assessments underway including a new Canadian assessment of natural hazards, and progress towards a national disaster mitigation strategy.

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