COMMERCE SPECTRUM MANAGEMENT ADVISORY COMMITTEE (CSMAC)

Opportunities for Government Adoption of Commercial Technologies

As adopted from the

TECHNICAL EFFICIENCY SUBCOMMITTEE (TES)

WORKING GROUP 4

FINAL REPORT:

Opportunities for Government Adoption of Commercial Technologies

February 25, 2008

SUMMARY

The task set for WG4 was to identify (in a broad sense) opportunities for introducing more spectrally efficient technologies into Federal government systems that utilize the radio spectrum. The focus was on providing the Federal government with visibility into private sector experience in developing and deploying more spectrally efficient devices/systems.

It was an objective of this task to analyze major categories of Federal radio spectrum usage (e.g., point-to-point microwave and mobile communications systems) in especially important regions of the spectrum and to forward to the full committee for its consideration possible opportunities for adoption of commercial techniques for improving such usage.

It was further understood that this task would require ongoing input from NTIA in terms of major usage categories and, where national security and other considerations permit, an indication of the state-the-art of the equipment/systems that are deployed in each category. The committee recognized that the Federal government, including the DoD, is already taking important steps to develop and deploy more technically efficient systems.

Given the desire of the committee and NTIA for an early report on the deliberations of the full committee, it was understood that only a limited number of opportunities could be addressed in this initial effort.

This interim report is provided as a summary on the preliminary activities of WG4. This report has been prepared based on submissions to the WG, discussions and other appropriate material. The topics covered include aspects of mobile communications and the experiences of the commercial systems in this arena.

Throughout this discussion and review, it was recognised that there are two aspects of government adoption of commercial technologies. In some cases it may be appropriate for government traffic to be carried by suitable commercial service networks. In other cases it may be more appropriate for aspects of the technology of commercial systems to be incorporated into the radio systems operated by the government. Generally, the recommendation would be to utilise commercial services when appropriate. However, as many government services operate in areas beyond the reach or capability of commercial services, much of the discussion in this report considers the application of commercial technology to systems operated by the government.

A number of underlying technical factors have shaped the recent development of commercial mobile radio systems and are the basis for their current success and efficiency. An understanding of these fundamentals of the commercial systems may be useful for development and evolution of some government radio communications systems. The most fundamental basic development in the commercial systems has been the widespread adoption of standards that can accommodate and evolve to support a wide variety of services and features. It is the commonality of the standardised systems that has achieved the low cost and ubiquitous availability of the commercial networks. Such standards also include procedures for compliance testing of conformance and network interoperability. Some of the fundamental technologies in these standards include:

(a) standardised source and service coding and interconnection of networks;

(b) pooling of radio system resources across multiple users and services;

(c) computing resources in the end user terminals;

(d) digital radio modulation including

i. error control coding & standardisation;
ii. network inter-working and aggregation of spectrum and traffic;
iii. interference limited frequency reuse; and
iv. advanced antenna systems.

It is suggested that the government radio systems would benefit, to the extent that they have not done so already, from adopting common commercial standards for radio systems across compatible applications and sharing the radio system network resources across compatible services/users/groups. Adopting a common radio system would facilitate common digital platforms with such features as co-channel frequency reuse, common coding of services, common authentication (authorisation/accounting/billing, etc.), shared use of channels where applicable, compliance/interoperability testing, and adaptation to multiple radio modes. Interworking of traffic among various existing networks would also facilitate flexibility and communications among diverse agencies. The objective in introducing these techniques would be to move towards a commercially derived common system design to accommodate as many users and applications as possible to gain economies of scale in equipment availability and development.

By incorporating widely-used commercial mobile communication technologies, government radio systems will benefit from greater economies of scale. Leveraging technologies developed on open standards will lead to communication systems with flexible services and improved spectral efficiency. The competitive open standard environment will permit ongoing evolution of capabilities adapted to the complex communications environment required by government operations. The adopted system design and associated devices, however, must be capable of meeting the rigorous operational requirements of governmental users, regardless of the underlying technology.

Improvements in the efficiency of use of the spectrum allocated for government services and operation may also be achieved through an ongoing program of review of actual allocations and usage and the reallocation of services or the adoption of new technology when appropriate. This is best done across multiple departments as there is synergy in the potential combination of traffic across multiple groups.

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OPPORTUNITIES FOR GOVERNMENT ADOPTION of COMMERCIAL TECHNOLOGIES

1. INTRODUCTION

In May 2003, the "Spectrum Policy Initiative" ("SPI") was established which called for "a comprehensive review of spectrum management policies . . . with the objective of identifying recommendations for revising policies and procedures to *promote more efficient and beneficial use of spectrum without harmful interference to critical incumbent users.*"[1] Shortly thereafter, an additional goal was added — the universal availability of affordable broadband technology.[2]

The SPI directed the Secretary of Commerce, after consultation with other agencies and public meetings, to prepare reports with recommendations for:

- Facilitating a modernized and improved spectrum management system;
- Identifying policy changes that would create incentives for more efficient and beneficial use of spectrum, particularly given the inefficient manner in which government spectrum has traditionally been used;
- Encouraging scientific research and developing methods for streamlining the deployment of new and innovative technologies, while preserving national security, homeland security, and public safety;
- Addressing the spectrum needs associated with critical government functions, such as national security, homeland security, and public safety.[3]

These reports were released in June 2004 and, among other things, recommended:

- Establishing a Spectrum Management Advisory Committee ("SMAC") "to advise the Assistant Secretary of Communications and Information, Department of Commerce on needed reforms to spectrum policies and management to enable the introduction of new spectrum dependant technologies and services including expediting America's access to broadband services;[4]

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[1] Presidential Memo on Spectrum Policy: Spectrum Policy for the 21st Century, 39 Weekly Comp. Pres. Doc. 726, 727 (May 29, 2003) ("SPI Memo"), *available at* http://www.whitehouse.gov/news/releases/2003/06/20030605-4.html.

[2] Remarks by the President on Home ownership, Before the Expo New Mexico, Albuquerque, New Mexico (Mar. 26, 2004), *available at* http://www.whitehouse.gov/news/releases/2004/ 03/20040326-9.html.

[3] SPI Memo at § 2.

[4] *See* Spectrum Policy for the 21st Century — The President's Spectrum Policy Initiative: Report 2 — Recommendations from State and Local Governments and Private Sector Responders at B-2 (June 2004) ("Report 2").

- Creating a Test-Bed for the purpose of evaluating technologies and methods for improving spectrum sharing between federal government and non-federal government users;[5] and
- Facilitating interoperability of first responder communications and other government communications.[6]

In November 2004, the heads of executive departments and agencies were directed to implement the recommendations from the June reports. In response, the Secretary of Commerce established the SMAC and instructed the committee to focus on, among other things:

> Expediting the introduction of wireless broadband services; addressing governmental and commercial concerns regarding public safety spectrum management issues; . . . assisting in efforts to encourage the establishment of long-range spectrum planning processes; . . . gathering input on the latest technology and market trends; examining the latest radio-frequency research and development outputs; and evaluating the value of spectrum to the public and private sectors.[7]

The first SMAC meeting was held on December 12, 2006 and two subcommittees were established: the Technical Efficiency Subcommittee ("TES") and the Operational Efficiency Subcommittee ("OES"). Working groups were formed within each subcommittee, and Working Group 4 within the TES was given the following charge:

Working Group 4 ("WG4") – Opportunities for Government Adoption of Commercial Technologies

> The task for WG4 was to identify, in a broad sense, opportunities for introducing more spectrally efficient technologies into Federal government systems by providing the Federal government with visibility into private sector experience in developing and deploying such spectrally efficient devices/systems.
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> It was recognized that many government users are already taking important steps to adopt technically efficient systems. The task was to examine major categories of Federal radio spectrum usage (e.g., point-to-point microwave and mobile communications systems) in especially important regions of the spectrum and to present to the full committee for its consideration possible opportunities for adoption of commercial techniques for improving such usage.
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> Given the desire of the committee and NTIA for an early report on the deliberations of the full committee, coupled with the very wide diversity of Federal Government uses of spectrum, it was understood that only a limited range of opportunities could be addressed in an initial report.

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[5] *Id;* Spectrum Policy for the 21st Century — The President's Spectrum Policy Initiative: Report 1 — Recommendations of the Federal Government Spectrum Task Force at B-2 (June 2004) ("Report 1").

[6] Report 1 at B-2.

[7] SMAC Charter at 1.

> It was further understood that this task would require input from NTIA in terms of major usage categories and, where national security and other considerations permit, an indication of the state-the-art of the equipment/systems that are deployed in each category.[8]

What follows is the initial report generated by WG4 based on a review of the comments submitted to the working group by members and interested parties.

[8] Although "spectral efficiency" is a critical factor in considering technologies that topic, however, is being addressed by a separate working group, Working Group 2 ("WG2") – Understanding Technical Efficiency.

2. WG4 ACTIVITIES

The WG4 met two times since its inception in [May 2007], [twice via conference call]. The committee received three written contributions towards its subject of opportunities for government adoption of commercial system technologies.

All of these contributions focused on the area of commercial mobile radio services. These contributions were complimentary in topics and discussion and their material has been used to form the basis for this early report.

One contribution from Nortel Networks ("*Fundamental technologies in commercial radio systems*" prepared by Dr. David Steer of the Nortel Wireless Technology Laboratories) outlined and discussed the background of basic areas of technology that have been the root of the success for the commercial mobile systems. These include standardisation of services and systems as well as internetworking, interoperability-testing and the introduction of flexible digital radio and network techniques.

A second contribution from Motorola ("*Government Adoption of Commercial Technologies*" prepared by Bruce Oberlies of the Motorola Government and Public Safety business Enterprise Mobility Solutions group) discussed a number of mobile radio systems including those used by public safety agencies and the benefits of standardisation among these systems. These systems are some examples of commercial systems that may be adapted and adopted for some government applications.

A third contribution from Mobile Satellite Ventures ("*Integrated Mobile Satellite-Terrestrial-Wireless System*" prepared by Dr. Peter D. Karabinis. and Jennifer A. Manner of Mobile Satellite Ventures, L.P.) outlined the integration between new mobile satellite systems and terrestrial mobile networks. This illustrates how multi-beam satellite technology could permit the operation of practical mobile handsets with a national coverage footprint and the integration of these into standardised terrestrial mobile communications systems. Such a facility provides a means for complete nationwide coverage with interoperable mobile services and a high degree of robustness.

In addition, a letter from John E. DeFeo and A. Riley Eller of CoCo Communications Corporation was received. This refers to the possibility of improving the interoperability, sustainability and security of military and public safety communication systems through the use of a proprietary network protocol, referred to as a Cryptographic Overlay Mesh Protocol.

Material from these contributions has been extracted and summarised to form the basis for this initial report from WG4 and the suggested conclusions in the area of mobile radio systems.

3. SUMMARY OF WG4 RECOMMENDATIONS

3.1. Traffic Services and Networks

Throughout this discussion and review, it was noted that there are two avenues for government adoption of commercial technologies. In some cases it may be appropriate for government traffic to be carried by suitable commercial service networks. In other cases it may be appropriate for aspects of the technology of commercial systems to be incorporated into the radio systems operated by the government.

In the first case, government agencies may make use of commercial services for their operations where the service is available and where it meets the needed user requirements. This may be appropriate, for example, for some point-to-point communications and some mobile services where commercial coverage and quality-of-service are suitable. It may also be appropriate for a government radio system to connect to a commercial terrestrial or wireless network. As commercial services continually extend their operations and develop new services, new opportunities for such transfers will develop for government services on an ongoing basis[9].

Many government communications services, however, are in areas that are not covered by commercial service or they have requirements that are not met by commercial operations. In these cases, adoption of commercial technologies within the government radio operations may be appropriate. For example, the government operations may include areas beyond the range of commercial services and they may have service requirements (i.e. low delay, PTT[10] and security) that are not part of commercial service offerings. However, such systems may still benefit from the standardisation, channel sharing and network inter-working technologies used by commercial systems.

Much of the discussion in this report centres on the opportunities and advantages for incorporation of commercial technologies into the radio systems that are operated by the government.

3.2. Commercial services and technology

By incorporating widely-used commercial mobile communication technologies, government radio systems will benefit from improved capacity and performance, new capabilities and greater economies-of-scale. Leveraging technologies based on open standards will lead to communication systems with flexible services and improved spectral efficiency. The competitive open-standard environment has lead to technologies that can offer rich solutions to the complex communications environment required by government operations. These services will also grow in capability as the commercial standards evolve and develop.

A number of underlying technologies have shaped the recent development of commercial mobile radio systems and are the basis for their current success and efficiency. An

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[9] In this context of adoption of commercial services, it is noted that the GSA already provides some omnibus contracts with satellite (e.g. SATCOM II) and terrestrial network operators. These enable convenient and rapid contracting by government departments to commercial networks when the needs of the government agencies and the commercial service capabilities are aligned.

[10] PTT – Push-to-Talk

understanding of these fundamentals of the commercial systems is useful for considering the possible evolution of government radio communications systems. The most fundamental basic development in the commercial systems has been the ubiquitous adoption of standards that can accommodate a wide variety of services and features. It is the commonality of the standardised systems that has achieved the low cost and ubiquitous availability of the commercial networks. Such standards also include network inter-working and procedures for compliance testing of equipment for conformance and interoperability. Some of the underlying technologies included in these standards are:

(a) standardised source and service coding;

(b) pooling of radio and network resources across multiple users and services;

(c) computing resources in the end user terminals;

(d) digital radio modulation including:

i. error control coding & standardisation;

ii. network inter-working and aggregation of traffic from multiple services;

iii. interference limited frequency reuse; and

iv. advanced antenna systems.

It is suggested that the government radio systems would benefit, to the extent that they have not done so already, from adopting common standards for radio systems across compatible applications and the sharing of networks and radio resources[11] across compatible services/users/groups. The adoption of a common radio access system would facilitate common digital platforms with such features as co-channel frequency reuse, common coding of services, common authentication (authorisation/accounting/billing, etc.), shared use of channels where applicable, compliance/interoperability testing, and adaptation to multiple radio waveform. Inter-working among the radio access networks using a common protocol will also provide benefits in both intercommunication among user groups and sharing of (terrestrial) network resources. The objective in introducing these techniques would be to move towards a commercially derived common system design to accommodate as many users and applications as possible to gain economies of scale in equipment availability and development. Considerable savings can be achieved through the adoption of a commercial standard as the basis for new government system's operations. The equipment for these systems may thus be based on commercial platforms, for both network and user terminal equipment, and hence benefit from the mass manufacture and global development of such equipment.

The adopted system design and associated devices, however, must be capable of meeting the rigorous operational requirements of governmental users, regardless of the underlying technology. Furthermore any adoption of changes in technology or practices must take into account the need for ongoing continuity of the provision of the vital services provided by the government radio systems. To facilitate the adoption of system designs for government services it may be helpful for a government/industry committee to be formed to assist the development of appropriate requirements and standards.

[11] Including frequency assignments

3.3. Introduction of new technology

The introduction of new commercially derived networks and technologies for government radio communications must be considered in the context of continued assurance of service using the many existing systems.

Synergy on the network side may be achieved through the development of inter-working protocols among the existing networks to facilitate improved coupling among systems and services[12]. This inter-working should include a suitable common protocol that supports multiple services including real-time voice[13], multimedia[14] and data transmissions. Some public safety agencies, for example, have already started to interconnect their disparate radio access systems using the IP[15]. Such interconnection would both improve interdepartmental communications as well as provide some redundancy against the failure of an individual system. Such evolution need not disrupt the individual system operations and should be planned and further extended to additional appropriate groups.

Synergy on the radio access side would be fostered through the evolution to a common, multi-capability radio standard. Such a standard would include multiple services (real-time voice, video, packet data, broadband and streaming data) in a common format to better enable common network and terminal platforms. If such a standard was derived from a common commercial standard, there would be benefits from the economies of scale from the procurement of devices for the large composite market. The extensions to the standard would take due account to maintain service quality and required government features such as security, low-delay and guaranteed access. Such an evolution to a new standard would be carefully planned in order not to cause disruption to existing programs and services.

The evolution to the new common radio access system could be facilitated through the use of adaptive radios in the access network that can operate in multiple bands and provide services in a number of possible radio system configurations (including both the legacy and the new waveforms). Such flexible platforms on the access side would permit the continued use of the user's legacy radios while at the same time enabling the operation of new radios and devices as they become available.

As the new common system is introduced and proven, the use of dual mode terminals and network stations would permit the gradual migration of traffic to the new system. This would enable conversion to happen as part of the equipment life-cycle and hence not require wholesale replacement of all equipment at once. Furthermore, those services that cannot be accommodated with the standardised common system could remain as they are until either they can be accommodated, or other new alternatives are developed. Such speciality services may, none-the-less, still benefit from the network inter-working and the availability of dual mode radio systems.

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[12] This inter-working may, for example, include connection with commercial networks.

[13] This includes, for example, speech with low delay suitable for dynamic control applications.

[14] Multimedia may include real-time speech and video, data communications, packetised data and various simultaneous combinations of these.

[15] IP – Internet Protocol

3.4. Ongoing management of spectrum allocations and usage

As with any other resource, the efficient use of spectrum allocated to government usage requires ongoing monitoring and proactive management. In outline, such management involves monitoring allocations and usage, considering future needs and new technologies, and planning and adapting equipment and services to best suit the changing situations. The following provides some brief points of these management functions.

3.4.1. Monitor Allocations and Usage

i. maintain up-to-date "inventory" of radios systems in use, including where, why and technical details

ii. measure traffic usage of each application/service

iii. look for growth/shrinkage in uses

Note that some assignments will remain relatively constant

3.4.2. Consider Future Needs and New Technologies

review operations including the following aspects:

i. can it be combined with another (government) service?

ii. could it be accommodated on a commercial service?

iii. what are the future needs for growth/decline?

iv. is there new technology in this application?

v. can the service or system make use of a suitable standard?

vi. plan for future changes evolution

3.4.3. Plan and Adapt Equipment and Services

i. budget for ongoing evolution change

ii. shift to commercial services (or vice versa) where appropriate

iii. make proactive adjustments in system operations and services when practical

iv. develop continuous renewal & ongoing updates for those systems that have changing requirements or traffic growth

This general process of continual renewal will help to assure the optimum and efficient use of the spectrum resources allocated for government services. Although these management/planning processes may already be in effect for some government radio systems, there is additional synergy to be had by applying the process across many systems together as often services can be combined in ways to achieve gains in efficiency. Of course, some systems and services are unique and require their own resources and these cannot be practically combined with other services[16].

[16] For example, the science and radio astronomy applications are fixed in spectrum location by the basic physics and cannot be combined with other active services.

4. BASIS OF COMMERCIAL MOBILE TECHNOLOGIES

4.1. Introduction

This sub-section discusses some of the fundamental technology factors that have shaped the recent development of commercial radio systems and are the basis for their current success and efficiency. The development of these fundamentals, and their supporting technologies over the past few decades, have enabled the advances in modern commercial radio communications systems. The purpose of this review is to set in place an understanding of the technological basics in the commercial systems so that appropriate aspects may be considered for adoption in development and evolution of some government radio communications systems.

This review deliberately concentrates on the fundamental, generic aspects of the commercial radio systems in order to avoid debates among the alphabet-acronym systems ("FLA"[17]) or detailed technology. Debates about the features of individual FLA systems or individual technologies are better postponed until the fundamentals are understood. As will be seen, the basis of modern commercial radio communication systems are not so much in the details of the FLA system implementation, but rather are in such generic areas as standardisation, compliance testing, network inter-working and ubiquitous deployment.

In considering possible application of commercial technology to government radio systems, it needs to be recognised that there is no single magic pill that can be applied to improve efficiency or capacity performance overnight. It also is especially important to keep in mind that government radio systems are already being fully used to deliver services, and any upgrades or changes must be made without disrupting the continuing operation of these services[18].

By understanding the fundamental principles, it becomes possible to map some new techniques into a strategy for improving performance of government radio systems. Many government systems will already be using some or all of these techniques. And so, benefits may come as much from the more wide-spread adoption of techniques and the inter-working among existing systems as from the implementation of yet another system apparatus. The most fundamental basic development within the commercial radio networks has been the widespread adoption of standardised systems that can accommodate a wide variety of services and features. It is the commonality of the standardised systems, together with compliance test programs, that has achieved the low cost and ubiquitous availability of the commercial networks.

There are four generic technology principles that have had a significant recent[19] influence on the standardised commercial radio systems. These include:

(a) standardised source and service coding;

(b) pooling of radio resources across multiple users and services;

[17] **FLA** Four-Letter Acronym – Generally the commercial systems have four letter identifiers (e.g. UMTS, HSDPA, CDMA), however some systems are labelled with three letters (e.g. GSM, P25, LTE) or five letter sequences (e.g. W-CDMA).

[18] Indeed, many government systems are already well suited to their intended purposes and may not warrant significant changes.

[19] i.e. in the past 25-30 years

(c) providing computing resources in the end user terminals (i.e. "intelligent terminals");

(d) digital radio modulation including:

i. error control coding & standardisation;

ii. network inter-working and aggregation of spectrum and traffic;

iii. interference limited frequency reuse; and

iv. advanced antenna systems.

These fundamentals, in various combinations, are responsible for much of the capacity/efficiency of the commercial systems. Of course, these are not quite the whole story. In most cases these fundamentals have been supported by (or have spawned) many related technologies and implementations. Together, these have ensured the success of the commercial radio communications systems. Some of these topics may seem obvious in hindsight, but it is hoped that by discussing their role, their importance may be better recognised in further developments. These generic technology areas are the basic principles for modern system design and their appropriate adoption in government systems has the potential to lead to improved performance and efficiency.

4.1.1. Source coding and services standardisation

It goes almost without saying that standardised source and service coding is very important to the efficiency of operation of a communications system. It is so fundamental that its importance and implications are often overlooked.

4.1.1.1. Source coding standardisation

Source coding has a fundamental effect on the performance of a communications system. If the commercial mobile networks were still sending speech at the (telephony) standard 64 kilobits/sec (or images at TV rates of 12 megabit/s or more), wireless communications would not be so inexpensive, practical or popular. The compact coding of speech and images has taken many years to develop and has required much research and advance in the fundamental understanding of speech (or images). But, the shift from 64 kilobits/s speech coding to rates of 10 kilobit/s (or less) has been one of the most significant enablers of digital radio systems for speech services. Similarly for images and video, the reduction in image data sizes from hundreds of Mega-bytes, to a few Mega-bytes, is what makes wireless systems and their image services practical today[20].

But it is not just the development of efficient source coding techniques that is significant. Of equal importance is the standardisation of the coding techniques and algorithms so that they can be used across devices and networks of differing application, manufacture and location. Convergence of the commercial systems on common robust standardised algorithms has been as important as the details of the algorithms[21]. The standardisation of the coders and decoding permits mass manufacture of devices, inter-working across networks and terminals and compact implementations on chips. Together, these are important system enablers.

It is worth noting in this regard that source coding involves much more than just an efficient algorithm. A voice coding algorithm for example, must also support tandem coding across network elements (i.e. encoding/decoding and then re-encoding and decoding) without

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[20] As many of the FLA systems have built-in embedded coding assumptions, it is sometimes difficult to distinguish the performance/efficiency benefit of the basic radio technology from the source coding.

[21] The ITU has had a large role in this development and standardisation process for speech coding.

degradation of quality, accommodate multiple languages, be tolerant of transmission errors or background noise and, support other services such as tones and music. As the coding introduces delay in the communications path, management of the delay to suit the service is another important factor. Not all services are able to accept a large coding (or transmission) delay.

The various coding algorithms have been further supported by advances in "chip" technology that permit the standardised algorithms to be performed economically and with low power consumption in devices and user terminals. These chips (e.g. microprocessor or ASIC[22]) used in terminal devices also enable intelligent/flexible services standardisation (including numbering, authentication, billing etc.) as will be discussed later.

This is not to say that more research into coding is needed. It's about as good as it will get or needs to be. But, it is important to understand that the basis of success for digital radio communications systems rests on the efficient standardised coding of services. Other radio communications services may benefit from adopting the standardised source and services coding that have been adopted by the commercial industry. The lesson for new services is that efficient and standardised coding at the source is an important aspect of system efficiency[23].

4.1.1.2. Services standardisation

There is also a real benefit of services standardisation across a radio system and its associated and inter-worked networks. This may include, for example, service features such as dialling plan (numbering), message services, program menus, billing authorisation, user identification and network signalling (etc). It is to be noted that many thousands of pages of documents are in the commercial standards to define and support these aspects and these have taken many years to develop across industry. Such standardisation across service levels enables mass manufacturing of the equipment, particularly the end-user terminals. It is this top-to-bottom service standardisation that achieves the low cost and ubiquity of the commercial systems. Many diverse user services can be supported using common radio system platforms and networks.

The benefits of adopting a commercial standardised radio system include reuse of the considerable effort expended across the industry in developing the standards. These standards are the product of thousands of engineers from hundreds of vendors and operators working together over many years to develop the system design, implementations and testing verification. The end result is much more fully developed than any single entity could create on its own. The open nature of the process also ensures widespread manufacture and availability of systems and their components. These standards are also complimented by performance verification and compliance testing procedures that ensure the specified end user performance is delivered.

The adoption of systems based on standards derived from established commercial standards is an effective approach to extending the capabilities and improving the economics of government radio communications systems. Progress may be made by building upon the foundations that have gone before.

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[22] ASIC – Application Specific Integrated Circuit

[23] For example, halving the user's coded data rate (approximately) doubles the capacity of the radio system.

4.1.2. Pooling of radio system resources and inter-networking

The translation of the user's communications traffic and services to a common digital ("transport") format also enables multiple users and services to be aggregated together on the radio system and so enhance its capacity by accommodating the statistical characteristics of the aggregated traffic[24]. Employing a common digital format for the users' signalling and service data also permits sharing traffic types and services across channels and networks. In this way the channels may be kept busy and the traffic prioritised among different users. In digital data services, this may involve a "store and forward" for the user's data and this has the disadvantage of introducing delay in the service. Sometimes speech or data may be delayed (due to sharing in the channel) beyond what is tolerable for the service and dedicated, or specialised, channels are needed. The multiplexing of different traffic together must carefully consider the possibility of traffic peaks occurring simultaneously and so causing some traffic to be blocked or delayed.

The benefits of digitisation of the user's data extend beyond the radio physical layer. The standardisation of common digital formats for many types of user data (e.g. speech, images, data, sensors and control information) enables many different types of communications services to be aggregated and transmitted over common radio resources and between networks. Thus, the resources can be used very efficiently as they can be kept constantly filled with traffic from multiple sources. The communications channels need no longer be idle ("wasted") when an individual user has no traffic. Currently, for example, the Internet Protocol ("IP") provides a common format for equitable packaging and transport of a wide variety of services and user traffic. Through the use of a common protocol between networks, the traffic from multiple radio systems can be inter-worked together enabling both intercommunications among different user groups as well as synergy in sharing of terrestrial network resources and services. Initially such inter-working among commercial networks has focused on real-time voice services, but current standards and networks now support also inter-working of broadband, multimedia and data communications.

The commercial systems benefit from this sharing of multiple radio resources across many users and traffic types and thereby achieving high utilisation rates (and hence efficiency) in the system. With higher efficiency comes higher capacity and through-put of the aggregate system.

However, although the basic lesson is that sharing of traffic across multiple shared communications channels is a good idea, it must be understood that the gains, real as they are in practice, are achieved at the cost of some delay and variability in delivery of service. There is always a probability that, at times of high traffic, some user's traffic may be blocked or delayed excessively. Hence, while the sharing of traffic and resources is applicable for general traffic, there may be some traffic that must be transported in dedicated channels to guarantee its delivery, even under high traffic or overload conditions. For example, process control channels (e.g. air traffic control voice commands or public safety incident team voice communications) generally are allocated dedicated channels for their communications as the time delays associated with the allocation and usage of shared channels are unacceptable for their applications.

[24] For example traffic often comes in "bursts" among intervals of quiet and the multiplexing of these together enables the quiet intervals in one stream to accommodate the traffic burst of others.

4.1.3. Intelligent terminals

The introduction of computing resources and software controlled processes in the end user terminals has had a major effect on the communications systems. No longer are the terminals confined to a fixed service pattern or fixed assumptions about the radio channel conditions (i.e. worst case).

For example, adaptive algorithms in the end user terminals are one important aspect of modern commercial radio systems. The radio communications is no longer limited by a design assumption of "worst case" link conditions. By measuring the radio performance and adapting the system parameters dynamically, the adaptive radios are able to take advantage of good channel conditions when available, and to also accommodate the channel when it is severely degraded. Such adaptation enables communication over a wide variety of radio and traffic conditions with the benefit of both improved reliability and improved aggregate throughput.

A further advantage of introducing intelligent terminals to the networks is that it has moved many aspects of service control and applications to the end user terminal. Services are no longer as dependent on the network, and so new services and applications can be developed (largely) independently of network facilities. The end devices are free to negotiate among the services they support within the context of a generalised digital transport network. This has led to significant advances in the rate at which new services and applications are developed and delivered for the end users. Specialised applications, that operate using the standardised network, are now practical and can be implemented independently of the main network facilities. Hence many application projects can be developed and implemented in parallel which speeds their delivery and ensures customer satisfaction.

Many of the commercial mobile systems also include global reach, even with differing spectrum assignments in different regions. This capability is due not only to a common radio standard and agile radios, but also standardisation of authentication/authorisation/billing and services among all the operators (networks) using the standard. Standardised subscriber identification enables reliable authentication and billing to be recognised throughout the world.

As the commercial systems develop further there will be more use of "cognitive radio", "agile radio" and "software defined radio" techniques. These techniques provide the ability of the radio system to adapt to multiple services and radio/spectrum assignments and hence spread the benefit of inter-working and standardisation across a wide base of users' channels and services. The wireless local area network systems[25] and the multi-band global mobile systems[26] are some current examples of these flexible and cognitive systems. Such techniques may be expected to be of a major benefit in the development of future government radios systems as they may provide adaptation and flexibility to permit new radio systems to co-exist and inter-work in a compatible way with existing systems. They will thus help to preserve continuity of services during the transition from established to new systems. The capability of "intelligent processing" in the end user terminals thus provides a way for not only improved performance with a new generation system design, but also enables backward compatibility with previous generation systems.

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[25] E.g. WLAN such as the IEEE 802.11

[26] E.g. the global system for mobile communications GSM

4.1.4. Digital radio techniques

4.1.4.1. Digital Modulation

The use of digital modulation in commercial systems is probably the most often cited advance in modern radio systems. The conversion of the users' data/payload/service to digital format and its transmission via digital modulation and coding has great benefits in several areas.

With the digital transformation of the user's data, for example, error control coding can be added in the transmissions to enable the receiver to detect and overcome transmission errors. This enables a quality of service to be delivered even with an error-prone transmission link.

In the previous generation of designs the coding and modulation were chosen and fixed based on the expected worst case performance of the radio channels. As the channel quite often is much better than the worst case, choosing radio parameters for the poorest conditions is often inefficient as the channel is typically much better than the worst case. In more recent radio system designs, the channel performance is measured and monitored, and the modulation and coding are assigned dynamically to suit the current conditions. The effect is that the data rate and services are adjusted dynamically to match the changing radio link conditions, and a real gain in efficiency is achieved, even when accounting for the extra signalling overhead needed to control the dynamic system. As has been mentioned, with the recent introduction of more computing power in the end user terminals, these dynamically adaptive systems are practical and provide improved performance.

4.1.4.2. Interference limited channel/frequency reuse

One of the significant techniques in the commercial radio systems is the technique interference-limited reuse of the radio channels. Being able to reuse channels, especially in areas of high traffic, is key to being able to add capacity to a radio system. The modern radio communications systems are deployed with multiple cells for coverage and capacity across the service region. While cells may be initially deployed at large sizes to maximise coverage[27], in areas where there are service and traffic concentrations, extra cells may be deployed for those spots. These extra cells may reuse the same channel frequencies. The advantage of digital modulation[28] is that these cells can be accommodated without spoiling the performance of other traffic in nearby cells.

In a mobile service, the user and their traffic are transferred, or "handed-over", among the radio cells and channels as they move about. Thus a single user is not locked into a single channel for the duration of their traffic and journey. This "interference limited" channel usage with hand-over enables the spectrum resource to be reused multiple times and so provide improved radio system utilisation[29].

Hence, for those services that can be accommodated with hand-over, deployments with smaller cells and channel reuse may be a way to improve capacity and efficiency of government radio

[27] large cell sizes are usually desired to minimise initial deployment costs

[28] also usually together with dynamic power control and other interference control techniques

[29] The practical spectral efficiency of a radio system is often considered in terms of bits/second/Hertz/per unit area. Thus a system that can "reuse" the same channel more frequently to provide ubiquitous coverage has a higher efficiency. The efficiency gain, however, is achieved at the cost of increased infrastructure.

systems that have been planned using the traditional single high-tower, maximum-range, clear-channel model of deployment.

4.1.5. Advanced antenna systems

Another of the significant techniques used in the commercial radio systems are advanced antenna systems. The use of antenna systems, typically including multiple elements, together with good modelling of the radio propagation conditions in indoor, urban and suburban environments has lead to significantly improved ubiquity and reliability of coverage for mobile systems. The mobile radio channel is a highly variable system with statistical properties of propagation, fading and interference. Advanced antenna systems have been developed to account for the radio propagation environment. These techniques often include antennas with multiple radiating (or receiving) elements as well as configurations with multiple (separate) antennas (each of which may have multiple elements). These various antenna techniques may operate to:

(a) provide gain to improve the transmitted or received signal strength;

(b) provide directionality to suppress the interference given to or received by other systems (this may be through either (or both) the focusing of signals in the desired direction, or the steering of nulls at undesired signals);

(c) provide diversity in signal transmission or reception to avoid nulls in the fading signal propagation; and

(d) provide multiple paths for the signal transmissions and reception and so provide multiple parallel communications links to improve capacity and throughput (this is the so-called Multiple Input Multiple Output (MIMO) mode of operation).

Various combinations of these techniques are used in different mobile systems. For the dynamic fading environment, the use of multiple antennas (separated sufficiently to have statistically independent fading), has a very significant improvement in reliability of communications. Most WLAN terminal devices, for example, utilise transceivers with dual antenna to combat fading and this is particularly effective in the harsh indoor environment.

To attain long range coverage for commercial mobile communications, some cell sites have been equipped with high gain antennas on high towers (or suitable high-points of land). These so-called "boomer" cells are effective in providing long range coverage for areas such as offshore oil installations and remote, low density "outback" regions. Such regions are thus able to take advantage of the services and interconnectivity of the mainstream communications networks. With these installations, the coverage of the cellular mobile systems may be extended to ranges of 200 km[30]. These cells give coverage equivalent to the traditional high-tower single-cell public safety installations (when using equivalent spectrum band assignments).

The adoption of such advanced antenna systems to dynamically adapt to the mobile propagation environment may be an effective means to improve performance and efficiency of government radio systems.

4.2. Observations – Recommendations - Conclusions

This review has highlighted a number of underlying areas of technology that are at the root of the success of the commercial mobile radio systems. Some of these may be applicable for

[30] Such ranges have been achieved in the 800 MHz band with an antenna effective height of 1400 meters.

government radio communications systems. The most fundamental basic technology development in the commercial systems has been the widespread adoption of standardised systems that can accommodate a wide variety of services and features. It is the commonality of the standardised systems that has achieved the low cost and ubiquitous availability of the commercial networks.

The underlying technologies in the commercial standards include:

- standardised, efficient source and service coding,
- pooling of radio system resources across users and services
- application of intelligence in the terminals, and
- the use of various standardised digital radio technologies including:
    - aspects of sharing of channels among services,
    - network integration (including traffic inter-working between networks)
    - flexibility through cognitive radios,
    - interference limited channel reuse, and
    - advanced antenna configurations.

5. COMMERCIAL MOBILE SYSTEM TECHNOLOGIES

5.1. Introduction

While considering government wireless communication systems the applications that will be used on these systems must be taken into account. Applications are being developed and implemented today that may provide government users with productivity enhancements that will allow them to move from a traditional response mode to a prevention mode. These include relatively low bandwidth applications like voice, dispatch and text messaging, and database inquiries. Higher bandwidth applications include vehicle and personnel location and tracking, internet/intranet access, and photo, image, remote sensors, and video and multi-media transmission. The data rate required to support these applications can range from below 10 Kbit/s to beyond 1 Mbit/s. Today's mission critical communications are addressed primarily by voice communication systems designed to meet users' requirements. Spurred by the availability of additional spectrum, new technologies and systems are being deployed to provide mission critical wireless data at greater data rates and throughput.

To cover the broad range of applications required, a government communication system must provide rich, reliable, yet economical solutions for voice, data and/or multi-media services over small (incident area) and large (wide area) geographical areas. A system designer must make tradeoffs to fit the available spectrum and provide the required coverage footprint, coverage reliability, and system throughput. There is no single communication system that economically meets all these needs for rural, suburban and urban geographies. There are open standards with the support of multiple suppliers that define economical solutions, each optimized for operation requirements, to support a broad spectrum of applications. The experience resulting from 9/11 and hurricane Katrina reinforce the importance of requirements for robust availability and interoperability among Federal, state and local first and second responders.

This sub-section will review current wireless network and device technologies. These are based on open standards that address the applications discussed above. This sub-section will also briefly consider how commercial solutions fit the challenge of interoperability among government communications users.

5.2. Narrowband Voice and Data Technologies

In examining the potential for commercial technologies to serve the government, it is important to first understand the requirements and communications solutions on which the government has relied for many years. Land mobile radio (LMR) systems have been optimized to meet the voice communication needs of Federal, state and local public safety users as well as light and industrial business users. These systems have a positive track record of operation for over 75 years and have evolved as additional bands of spectrum became available and additional functions and features became technically possible. Dedicated mission critical systems are typically designed as noise limited systems that have 95% coverage reliability with high power subscriber devices to cover wide areas. These networks operate in the licensed VHF, UHF, 700 MHz, 800 MHz and 900 MHz frequency bands. Depending on terrain and system design, systems normally support 10 to 15 mile radius coverage footprints per site. These systems have, in many cases, been deployed before the advent of commercial mobile systems and so provide coverage well beyond the range of commercial systems. Such high-site designs are relatively economical for low and medium density population areas, as compared to systems requiring more sites to obtain equivalent coverage. Commercial cellular systems, which are most often thought of as low site systems, may also use higher sites for extended coverage in lesser populated areas, as evidenced by the antenna towers along most interstate highways[31].

Depending on user requirements, mission critical systems are designed to provide either mobile, portable on-street or portable in-building coverage at defined levels of reliability. Coverage issues can and have occurred when systems intentionally specified by an agency for mobile or on-street portable use are later expected to provide equivalent in-building coverage. As a result of major incidents like hurricane Katrina, user awareness of how system design must match requirements has increased. As the requirement for robustness and in-building portable coverage expands, so does the need to design and fund the infrastructure to match that need.

Group communications, "one-to-many" versus peer-to-peer, have become an expectation with a number of radio applications optimized to improve productivity of groups. User-to-user direct mode communications that do not rely on routing communications through network infrastructure is another fundamental mission critical system capability as it allows communication in the event of infrastructure failure from a terrorist or natural disaster, or whenever the users have roamed out of infrastructure coverage. Trends indicate that narrowband mobile systems, such as those meeting the "Project 25" (P25) interoperable open standard, will be used for mission critical voice communications for the foreseeable future. In addition, commercialization of the cellular broadband data technologies will allow the use of VoIP (Voice over Internet Protocol) as an alternative for less mission critical voice operations and data-intensive services.

5.2.1. P25

Over ten years ago, the first responder community recognized that one standard for future digital wireless systems was imperative. Representatives from the Association of Public Safety Communications Officials International (APCO), the National Association of State Telecommunications Directors (NASTD), selected federal agencies and the National Communications System (NCS) established Project 25 (P25). Through the P25 steering committee, an open national suite of standards for digital public safety radio system communications were developed. These standards, incorporating a set of 30+ documents, were developed by the Telecommunications Industry Association (TIA) TR-8 committee through its role as an ANSI-accredited Standards Development Organization (SDO). The suite of documents defines standards ranging from the Common Air Interface (CAI) to Security and Key Management. Both performance levels and interoperability conditions are mandated by the standards. As with most technology standards in both the commercial and public safety arena, P25 has continued to be updated and has evolved, while maintaining backward compatibility. For example, a new Inter-RF-Subsystem Interface (ISSI) element of the standard has been developed.

More than a dozen vendors are currently making equipment compatible with the P25 Phase 1 system, and systems have been deployed in 49 countries. Phase 2 of the P25 standard, which is being actively developed with multiple vendors participating, defines a more spectrally efficient Time Division Multiple Access (TDMA) protocol, enabling a 6.25 kHz equivalent voice channel. Phase 2 is being developed considering a migration path and backward compatibility with fielded Phase 1 systems.

[31] The "boomer" cells mentioned in section 4.1.5 are an example of this extended overage.

The P25 Phase 1 standard also defined a 9.6 Kbit/s fixed data rate mode of operation. While many P25 systems support only voice solutions, integrated voice and data network solutions are also available. This capability enables dispatch and text messaging, database inquiries and limited Automatic Vehicle Location data applications over wide coverage areas. Because public safety requires coverage in rural areas, these users now have data coverage in areas with little or no commercial coverage. Multiple P25 infrastructure equipment providers utilize IP backbones to distribute mission critical voice and data. Having IP backbones allows leveraging the ubiquity of wired IP networks as a common transport medium to tie the various agency networks together. This is an important attribute when considering interoperability across disparate communication systems.

The traditional allocation of the individual narrow band voice or P25 channels to individual users or agencies and local areas has been useful for past regional operations. However, to facilitate interoperability among agencies as well as multi-area combined operations, the future deployments of such radio systems and user devices would benefit from additional capabilities for channel sharing, trunking of traffic and the ability to dynamically adapt channel assignments based on local incident needs and capabilities.

5.2.2 Interoperability Across Networks

The proven nature of P25 communication Push-to-Talk and related services and the worldwide convergence of communications on IP networks together provide a strong base upon which to build future interoperability for voice systems. Several P25 infrastructure equipment providers utilize IP backbones to distribute mission critical voice and data. These are predominantly group-oriented communications. Many of today's interoperability gateways support bridging of disparate communication technologies by converting P25 digital and legacy analog radio, as well as cellular voice audio, into Voice over IP (VoIP) protocols (also including the Session Initiation Protocol (SIP)). With these industry standard network formats, agencies can leverage the ubiquity of wired IP networks as a common transport medium to tie their various networks together.

Several new technologies are emerging that promise to improve both the day-to-day capabilities of Homeland Security communications and interoperability for all elements of an emergency response. With specific mission critical enhancements to commercial Internet and mobile wireless technologies, and advances in innovative gateway technologies for bridging mission critical radio networks to Internet Protocol (IP) networks, a new class of interoperable voice, data and multimedia services can be deployed. These new services provide seamless mobility across any and all available access networks. Further, gateways will be capable of extending the trusted P25 communication services that are relied upon by public safety users across these new networks in a manner that preserves end-to-end quality and security.

Today's various Land Mobile Radio to IP gateways cannot interoperate with one another because they do not conform to a common VoIP protocol definition. Further they support only a basic audio patch to the different access networks. This often requires tandem voice coding that diminishes audio quality and which also breaks user-to-user security. In order to improve end-to-end services and achieve interoperability between these IP gateways, it will be necessary to standardize the protocols used to carry public safety communication services across IP networks. One aspect of this is the P25 ISSI standard being developed in TIA. Another alternative would be a mission critical enhanced version of the Open Mobile Alliance (OMA)

PTT (Push-to-Talk) over Cellular (PoC) standard. This latter project started after the ISSI work began. A third possibility would be to take the P25 specific elements of the ISSI implementation and blend them into an OMA POC architecture and standard to gain the best aspects of both.

If done correctly, this new protocol standard would provide the ability to extend P25 services seamlessly across all wired or wireless IP networks, whether a government owned network, or a public or enterprise-owned network. This would allow user devices that support either one or all of multiple client radios including P25, 3G Cellular/4G broadband, and WLAN to interoperate with common end-to-end audio and security with the P25 radios carried by first responders. Public Safety users with either multiple single mode access devices or with new multi-network access devices would then be able to use any of multiple available access networks for their emergency communications. Second responders or public service users who are not allowed to use public safety licensed bands, but who instead are on public or enterprise networks, possibly using commercial PoC services, would also be able to interoperate with first responders at the network level, rather than merely through an audio patch.

The Project 25 open standard is an economic solution for voice and low data rate applications. Currently there are greater than a dozen manufacturers providing equipment for the P25 standard. The P25 project also has a migration path for improved services, performance and spectral efficiency.

5.3. Wide Area Broadband Technologies

Broadband data communication systems can bring government users enhanced applications such as internet/intranet access, photo, image, video and multimedia. These applications have been largely confined to small areas such as a government office, police station or fire station. However, the availability of additional spectrum offers the opportunity to expand access to broadband services into the field where it is most needed for prevention and response operations. For example, in the state and local government arena, spectrum at 4.9 GHz has been made available and spectrum at 700 MHz will be cleared throughout the U.S. by February 2009. Further synergy and efficiency in use of government spectrum could be achieved if channels in the 5.1 GHz area, already allocated to the Federal Government, were opened to all Federal agencies for deployment of broadband systems. These systems could make use of technologies developed for the nearby 4.9 GHz public safety band and 5 GHz unlicensed commercial bands.

As discussed earlier, some voice services will also be handled by broadband communication systems. By relying on widely-used commercial broadband technologies, government agencies will undoubtedly benefit from greater economies of scale. Because of the vastness of the commercial broadband market, any appreciable synergy in economies of scale for public safety systems will leverage commercial technologies to the extent those technologies can be deployed in configurations and system designs and packaged into subscriber units to meet mission critical requirements.

Motorola estimates that the public safety market, even with federal and critical infrastructure added, is well under 10 million units in the United States. In contrast, the commercial market consists of over 230 million cellular subscriber units in the United States and globally over 2 billion subscribers with deployments in 200 countries. Significant economies of scale are thus available through public safety system synergy with commercial system designs.

Wide area broadband technologies being deployed today and being developed for tomorrow are highly efficient and can be deployed in a 1:1 frequency reuse configuration. This means same channel availability at every site, allowing government users to interoperate and roam into adjacent jurisdictions nationwide. This configuration also provides flexibility to expand systems by adding available channels as capacity requirements increase, to the extent additional spectrum is available. These are the same technical efficiencies that have been successfully applied to commercial systems and their subscribers.

One challenge with broadband wireless technologies may be devising deployments to obtain coverage and reliability equivalent to traditional narrowband voice systems. For example, a typical narrowband voice system can cover 10 to 15 miles radius, whereas a commercial broadband data system with the sought-after equipment economies of scale typically covers approximately 5 mile radius per site. This is a consequence of two technical factors. First, as bandwidth increases, coverage decreases, assuming all other parameters are equal. Second, the commercial off-the-shelf broadband technologies utilize portable units of much lower power levels than the traditional public safety mobile terminals. This creates particular challenges for less populated areas, where coverage realities with broadband may take priority over the capacity and data rate it offers.

The next generation of broadband radio technologies will offer improved performance and lower costs over current technologies, as well as the potential for improved performance in the future. Examples of this next generation technology include Orthogonal Frequency Division Multiplex (OFDM) based technologies, such as WiMAX and LTE (Long Term Evolution). OFDM technologies enable flexibility on channels scaling with channel bandwidths ranging from 1.25 to 20 MHz. Benefits of these OFDM-based technologies include wider bandwidths, greater spectral efficiency and true orthogonality, resulting in greater throughput and capacity, improved performance in multi-path environments, lower self-interference, and lower latency, as compared to other commercial technologies. OFDM technologies allow the easier implementation of advanced antenna systems, including beam forming, transmit diversity and MIMO allowing greater link margin performance that can enhance the system coverage or improve data throughput. Coverage, however, is still likely to be less than that of traditional narrowband voice systems for the reasons addressed above.

5.3.1. WiMAX

WiMAX is the quickly emerging broadband standard based on IEEE 802.16 specification. There are multiple flavors of WiMAX, but the one of greatest interest for mobile coverage is "Mobile WiMAX", which is based on the 802.16e specification. The WiMAX Forum, the industry-led organization formed to certify the compatibility of WiMAX products, has certified 28 products produced by a total of 12 manufacturers[32]. WiMAX is currently being deployed as a single frequency TDD (Time Domain Duplex) technology, although, an FDD implementation of 802.16e is also included in the IEEE standard. In principle, the availability of TDD or FDD formats simplifies spectrum acquisition and frequency planning. In practice some bands may not support TDD technologies as well as others because of the band configuration or presence of directly adjacent FDD (Frequency Domain Duplex) operations. An advantage of TDD WiMAX over that of FDD WiMAX is the ability to more easily implement beam forming since channel reciprocity exists when transmit and receive occurs on the same channel. The radius of coverage for WiMAX in a mobile application is very dependent on frequency band and

[32] As of July 2007.

terrain but can be on the order of one to five miles. Work on the WiMAX standard and associated technology continues with a focus on greater data rates and coverage areas.

5.3.2. LTE

Long Term Evolution ("LTE") technology is an evolution to next generation capabilities. LTE combines flexible bandwidth with advanced antenna solutions, such as beam-forming and MIMO technology, to provide advanced capabilities more efficiently. LTE will provide very high data rates, reduced latency, high spectral efficiency, and spectrum flexibility. LTE's data rates increase as follows:

Through the use of Adaptive Multi-Layer OFDM ("AML-OFDM"), LTE can produce high data rates. AML-OFDM supports operations in different bandwidth sizes and provides very-high data rates in large bandwidths. Further, LTE benefits from multi-antenna techniques and multi-layer transmissions to provide parallel data stream transmissions to end-user terminals, which increases its efficiency. On the uplink side, LTE uses single-carrier FDMA. Due to its flexible nature, LTE offers an efficient network solution for many different operators. For example, LTE will be capable of operating in a wide range of different spectrum bands, including current and future spectrum, such as 700 MHz. Additionally, the technology operates efficiently in different spectrum allocations; it provides very-high data rates in 20 MHz spectrum blocks, and can be deployed in allocations below 5 MHz. Therefore, LTE is an attractive and suitable next generation solution for operators using both different channel sizes and different spectrum allocations.

LTE is the evolution path in 3GPP for GSM/UMTS/HSPA technologies. Indeed, GSM mobile network operators and the multiple manufacturers who supply GSM technology have focused on developing LTE as the migration path for broadband. LTE is designed as a FDD implementation specifically for mobile applications. Like WiMAX, LTE coverage radius is on the order of one to five miles. Data rates for both WiMAX and LTE exceed 15 Mbps for 10MHz TDD or 5+5 MHz FDD bandwidths. These data rates scale depending on channel width. The diverse and global interest in LTE and the ability to leverage the economies of scale of a technology that currently has over 2 billion subscribers for today's GSM and 3G systems will ensure widespread availability of products in a strong competitive market.

The Federal Government should consider adopting next generation commercial technologies, LTE and WiMAX, as the basis for the deployment and operation of broadband networks. These OFDM technology platforms will offer improved performance and lower costs over current technologies. OFDM technology platforms would also have a long lifespan as they are currently in the relatively early stages of deployment, compared to other broadband technologies which may approach their end of life sooner.

5.4. Wireless Local Area Networks (WLANs)

Wireless Local Area Network (WLAN) technologies provide broadband data capabilities over local areas versus the wide area network (WAN) capabilities of WiMAX and LTE. WLAN is widely adopted in the general market, primarily for residential, enterprise and hot spot applications, at 2.4 GHz and 5.1 GHz. A common use case for Local Broadband in Public Safety is for an Incident Area Network, where multiple units need to exchange large amounts of data (files), along with voice and video services. Wireless Local Area Networks are ideal for this. The government users can benefit from the maturity of commercial technologies within the

Wireless Local Area Network space, notably those specified in the IEEE 802.11 suite of standards[33]. WLAN has also been adapted for Public Safety, in the 4.9 GHz band where mesh and ad-hoc technologies provide the capabilities for multiple vehicles arriving at a scene to dynamically form their own network.

Similar to the WiMAX and LTE WAN technologies, the WLAN 802.11a & g technologies utilizes OFDM. While the majority of the commercial implementations of the OFDM-based 802.11 use 20 MHz channels, the standard supports, and associated chips are available for 5 MHz, 10 MHz and 20 MHz channels. The 20 MHz channel width supports from 6 Mbit/s to 54 Mbit/s raw throughput rates, with direct scaling for the narrower channels. These protocols operating in the 2.5 and 5.1 GHz frequency bands, give end-user (application) broadband throughput rates over 1 Mbit/s at short range. The challenges with WLAN technology is a typical range of only a few hundred feet[34] and the poor building penetration at the 2.5 and 5.1 GHz bands.

Several technology enhancers are layered on top of the basic 802.11 standards, those being robust link layer security, quality of service mechanisms, and meshing capabilities. These are specified in 802.11i, 802.11e and 802.11s, respectively. There has been much written about wireless security for Federal Government use. The 802.11i security mechanisms have been FIPS validated as sufficiently secure for the Federal Government. Quality of Service (QoS) is improved by utilizing the mechanisms specified in 802.11e. These mechanisms address the prioritization and delivery of specified packets ahead of other, lower priority, packets. Support of voice already exists via the APSD (Automatic Power Save Delivery) mechanism, and the industry has a roadmap for robust support of video.

5.4.1. Broadband IP

The field of wireless broadband IP networks, a technology area that is advancing rapidly, involves using Wi-Fi, WiMAX, and optimized mesh radio technologies in conjunction with special mesh networking software. This allows user client devices and/or infrastructure based access point devices to self-form networks, as well as provide immediate re-routing around any unexpected device or link failures. These types of networks have been used by the military for some time. They are now also becoming one of the multiple wireless IP network options for public safety agencies who demand the highest broadband capacities as well as a robust solution for transporting P25 voice services, video and other enhanced services at incident scenes. The 802.11 based technologies overcome a weakness with many other commercial broadband technologies by satisfying a key requirement of emergency communications. They support a peer-to-peer (direct user device to user device) mode of operation, such that communications are possible even if the network infrastructure is damaged or not available in the vicinity of the incident.

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[33] The IEEE 802.11 standard has a number of options which are derivatives of the base standard (802.11) that are denoted by a letter suffix. As an example, the base standard covers operation in the 2.4 GHz ISM band. The "a" option extends this to the 5 GHz ISM bands, the "g" option includes extended data rates, the "h" option includes dynamic frequency sharing with RADAR systems, and the "j" option covers operation in the 4.9 GHz public safety bands. There are many more options than listed here.

[34] This is in a "cluttered" office or urban environment. Somewhat longer ranges, of several kilometers, can be achieved outdoors with line-of-sight, point-to-point links and high-gain antennas.

Standardization efforts, including 802.11s for meshing Wi-Fi devices, will help guarantee the necessary interoperability that is required by emergency responders. However, further standards efforts are needed to address the unique issues of security and command and control faced by multiple agencies responding and forming ad-hoc networks at an incident scene.

The meshing standard 802.11s enables broader area coverage by hopping packets from one device through multiple devices toward its destination. The meshing capabilities also improve the reliability of the network due to the self-forming/ self-healing properties inherent in the protocol. In other application scenarios, Municipal Networks (MuniWiFi solutions), based on meshing, continue to be rolled out in many municipalities.

5.4.2. Operations with 4.9 GHz band

Operating WLAN systems in an unlicensed frequency band like 2.4 GHz might appear to be feasible for government users, given the availability of strong security within the IEEE WLAN system designs (as discussed above). However, operating in an unlicensed frequency band would not be optimal, as the spectrum is shared. The 2.4 GHz band already supports consumer wireless LANS, cordless phones, and a host of ISM devices and interference to government users could negatively impact communications reliability. If the Federal Government requires a licensed or unshared WLAN network, then a specific frequency band would need to be allocated.

In February 2002, public safety agencies were allocated 50 MHz of spectrum in the 4.9 GHz band (4.940 – 4.990 GHz) for implementation of local area broadband data applications. This spectrum is ideally located near the unlicensed bands in the 5 GHz range and so may leverage advances in commercial broadband technology and chipsets. This provides public safety systems with economies of scale in commercial equipment purchases that may be modified to their specific requirements. At the same time, many local, state or Federal Government uses for localized broadband are expected to require the security of dedicated licensed spectrum that the unlicensed bands do not provide.

At present, it appears that there are few 4.9 GHz products available on the market and the the 4.9 GHz band is not being used extensively. If however, the band starts to become well utilized, the reassignment of already allocated Federal Government spectrum that is adjacent to the broadband public safety band at 4.9 GHz would offer advantages of seamless communication and broadband interoperability among agencies at all levels of government, both federal and local. This proximity would also make it technically feasible to support both bands in common broadband products. Such seamless interoperability facilitates many advantages in sharing high speed data and video across Federal, state and local agencies. Critical Infrastructure entities may operate in both the 4.9 GHz and the Federal assignments under certain conditions. Such interoperability accelerates set-up of command and control, improved safety through greater situational awareness, rapid sharing of databases at all levels, and provides high levels of security for transmission of highly sensitive data. In some cases the Federal agencies may also make use of the 4.9 GHz channels when so designated by the local agencies. Federal agencies will also get the benefit of the economies of scale, not only from nearby commercial equipment in the unlicensed bands, but also from the mission critical applications and features that are being developed for the 4.9 GHz state and local public safety band.

5.5. VoIP

VoIP has been primarily implemented on wired broadband networks to this point. As federal, state, and local agencies begin to deploy private wireless IP broadband networks to improve their data and multimedia communication capabilities, VoIP will be implemented over new broadband wireless networks. Mission critical voice traffic is likely to be maintained on the P25 system for several years.

VoIP can provide significant benefits in terms of cost and interoperability. Ideally, VoIP applications should be enhanced in the future to support direct mode, user-to-user communication. A second VoIP enhancement needed should address the lack of efficient multicast services required for group VoIP calls over commercial broadband technologies.

Overall, VoIP is a commercial technology that the federal government should consider adopting as next-generation broadband wireless systems are implemented.

5.6. Devices

Government entities have been interested in a mission critical portable radio that offers substantially more services than narrowband voice for some time. In the age of mobile computing, PDAs, and next generation "smart" cell phones, government users are very savvy to the productivity improvements realized from use of these products and how well suited they could be in performing their day to day tasks. More and more, these agencies are also at the forefront of considering commercial broadband technologies, which bring higher tier data features that broadband throughputs enable.

The open standards environment coupled with a large demand for devices has created a strong ecosystem for multiple chip vendors to produce 802.11 WLAN and 3G mobile radio system chips. This same ecosystem is developing with the new broadband WAN standards of WiMAX and LTE. These chips enable integration of WLAN and WAN commercial modems into PCs as well as voice and data capable Smartphones, PDAs and application specific data devices. Several manufacturers have leveraged the economies of scale of these commercially available platforms to create economical, rugged, application specific devices to meet the needs of enterprise, industrial and public safety users.

Trends indicate that narrowband open standard radios, such as P25, will continue to be used for mission critical voice communications, but some of the commercial technologies, such as WLAN, and broadband WANs, will be leveraged in these devices to fulfill interoperability and data connectivity visions in the future. In the near term, rugged enterprise handheld PDA and "lap-top" computer devices are available that have integrated commercial modems and can be utilized in conjunction with a P25 radio, to perform broadband data and telephony functions.

Integrated devices in the future will have the capabilities of primarily operating as a narrowband voice radio, but also will have the capability of jumping to alternate private or public broadband networks utilizing the commercial modem technologies available today to perform broadband data services including VoIP, imaging, and video.

5.8. Observations – Recommendations - Conclusions

Commercial technologies have been proven throughout the world to meet many of public safety's requirements while also providing advanced capabilities and emerging technologies at a low cost. These technologies can be and have been used to complement dedicated public safety equipment and networks and even replace some dedicated equipment entirely[35].

Government communication systems can leverage commercial open standards to improve spectrum efficiencies. The Project 25 open standard is an economic solution for voice and low data rate applications. Currently there are greater than a dozen manufacturers providing equipment for the P25 standard. The P25 project also has a migration path for improved services, performance and spectral efficiency. The advent of OFDM technologies for WLAN and WAN systems such as LTE and WiMAX, brings the promise of new flexible and scalable radio systems well suited for government use with disparate spectrum availability. Leveraging these commercial technologies, together with IP based networks, will allow interoperability across these various systems.

The open standards environment and large demand for devices has created a strong ecosystem for multiple chip vendors to produce 802.11 WLAN and WiMAX/LTE chips. Manufacturers will be able to leverage the economies of scale created to develop rugged voice and data centric devices as well as application specific devices. The adoption of these commercial technologies will enable solutions to provide Federal users with mission critical high speed data, photo, image, video and multi-media transmission, real time dynamic mapping, vehicle and personnel location and tracking, biometric monitoring, remote sensors and internet/intranet access. To be most effective, commercial technologies must be implemented with system designs that offer mission critical types of coverage, functions and features and in ruggedized end-user devices that provide the features and ergonomics matched to various types of prevention and response activities.

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35 *See* "Public Safety & Disaster Relief: A Wireless Network Operators Perspective," Bell Mobility, *available at* <http://www.rcmp-grc.ca/news/2003/n_0319_e.htm> (Mar. 26, 2002) at 3 and *See* "Northern Exposure," Government Technology, *available at* <http://www.govtech.net/ magazine/story.print.php?id=20945> (Aug. 8, 2002).

6. MOBILE SATELLITE NETWORKS AND TERRESTRIAL SERVICES

6.1. The Hybrid System Concept

New architectures have been developed for a hybrid network between satellite and terrestrial networks with unparalleled coverage and spectral efficiency. Currently, in the United States, there are two licensees for these new systems, Mobile Satellite Ventures, LP and Globalstar, LP. TerreStar Networks has also applied for a license, and other operators, including ICO, have indicated that they plan to apply for FCC authority in the near future. Internationally, other operators have also expressed interest.[36] Users of these new systems will be able to transmit and receive information from virtually everywhere using "lightweight, handheld mobile terminals" that communicate via both a Mobile Satellite System (MSS) and an Ancillary Terrestrial Component (ATC).[37]

These new systems offer the government users access coverage that is substantially increased over basic terrestrial systems and is also very robust to outage of local communications infrastructure. This is especially advantageous for emergency communications where the extensive coverage, reliability and ubiquity of satellite systems ensures communications under conditions of disruption. This sub-section outlines the basic technology for these new systems.

6.1.1. Basic Principles of Hybrid Networks

ATC technology creates a hybrid wireless network by integrating terrestrial cell sites with a multi-spot-beam satellite system. A powerful space segment integrated with ATC achieves the critical network property of transparency. Transparency means that a given communications service, such as voice or packet data, can be supported by the same user device in both terrestrial and satellite modes in a manner that is transparent to the end user. Transparent communications equipment provides terrestrial and satellite connectivity via devices that are similar in cost, aesthetics, and talk time to terrestrial-only devices. Transparency is crucial to the success of any hybrid network offering, because of synergy with the mass consumer market, which, in turn, drives economies of scale in chipset and device manufacturing. Historically, MSS systems have not previously been able to achieve transparency for two key reasons:

- Space segments lacked sufficient power (AEIRP) and receiver sensitivity (G/T) to close the link with small cellular-like devices; and
- Satellite air interfaces typically were proprietary and independent of mainstream cellular air interfaces, particularly at the physical layer. This required user equipment with two radios in one package (the so-called sandwich phone) in order to support both satellite and cellular modes.

As illustrated in Figure 1, next-generation hybrid networks address both of these shortcomings in the following ways. First, they will use a very powerful, spectrally efficient satellite system, with large antenna apertures. This ensures that the space segment appears to subscriber devices as another standard (Cellular/PCS-like) "base-station in-the-sky". Second,

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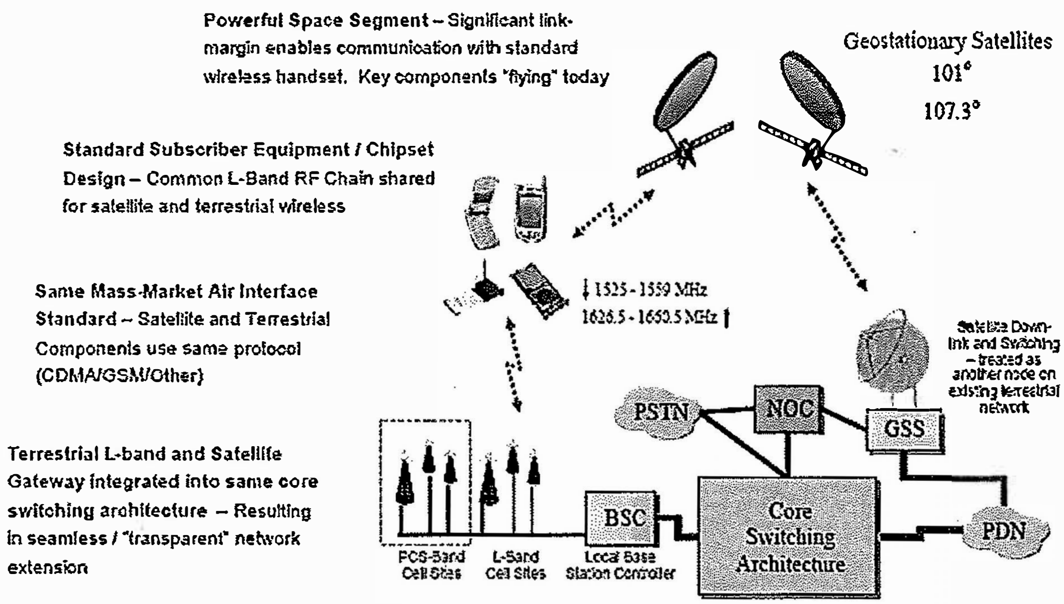
[36] It should be noted that while several of these systems are currently being constructed, to date there has been no commercial deployment of hybrid MSS/ATC systems.

[37] The three frequency bands typically associated with MSS/ATC are the Big LEO Band, the L-band and the S-band.

next-generation networks will support the same mainstream terrestrial air interface standards (cdma2000, GSM, 802.16, 802.20, W-CDMA, WiMAX, UMB and others) over both the terrestrial and satellite networks. Together, these two features enable the use of terminal equipment like those commonly available in the terrestrial wireless markets. The network operators can thereby take advantage of the economies of scale and aesthetics of standard cellular devices[38].

Figure 1 – Hybrid Terrestrial/Satellite Wireless Network



6.1.2. Key Benefits of Hybrid MSS/ATC Networks

The hybrid MSS/ATC networks can:

(1) increase the efficiency of spectrum use through MSS network integration and terrestrial reuse and permit better coverage in areas that MSS providers could not otherwise serve;

(2) provide additional communications that may enhance public protection; and

(3) provide new services in the markets served by MSS.

The integrated wireless system of transparent next-generation ATC networks offers each of these features with added benefits, including the following:

- A truly ubiquitous communications service via transparent devices
- Network scalability driving dramatically reduced equipment pricing
- Spectrum efficiency
- Platform for innovative and differentiated service offerings.

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[38] For the satellite system to operate as another node of a terrestrial network, the special needs of satellite transport relative to terrestrial transport can be accommodated via minor modifications to the selected terrestrial air interface in a manner that has a minimal cost impact and zero aesthetic impact to the terrestrial handset.

6.1.2.1.Ubiquity

As noted, satellites can now be built that are powerful enough to enable end-users to use wireless devices that are virtually identical to current PCS/Cellular terminals in terms of aesthetics, cost, form factor, and functionality. The terrestrial and satellite components of the hybrid network provide complementary coverage. The terrestrial component ensures service availability in major urban areas, where satellite only systems suffer blockage from buildings. Likewise, the satellite component provides coverage to those areas that are impractical or uneconomical to serve terrestrially. The ubiquitous coverage enabled by hybrid networks promotes safety and security applications in a variety of wireless segments, most importantly among public safety and mass-market wireless users.

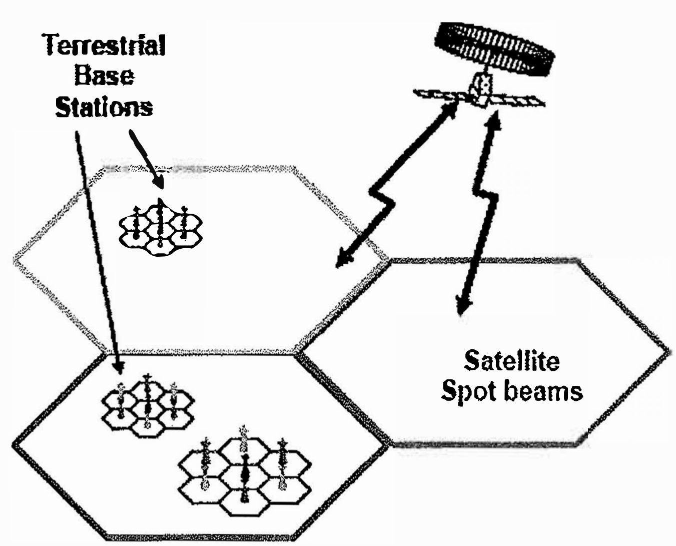
6.1.2.2. Network Scalability

Next-generation hybrid MSS/ATC networks are fundamentally different from prior satellite-only networks and will overcome challenges of earlier MSS systems. This is because, in addition to providing urban coverage, the terrestrial component ensures scalability. The overall system can thereby accommodate the traffic volume of national U.S. wireless operations (tens of millions of subscribers) versus the volume levels handled by satellite-only systems (hundreds of thousands of subscribers). The large number of subscribers drives the economies of scale in device production and network utilization that, in turn, support service and equipment pricing that is in line with terrestrial wireless pricing.

6.1.2.3. Spectrum Efficiency

Next-generation MSS/ATC networks will dramatically improve spectral efficiency. Figure 2 depicts MSV's approach to spectrum reuse between the satellite and terrestrial portions of such a system. In effect, terrestrial cells are nested inside satellite spot beam cells, as the spot beams of the satellites are relatively large (over one hundred kilometers in diameter). At the same time, at L-band frequencies, ATC cells can range from one-half kilometer across in dense urban environments to nearly five kilometers across in suburban areas, depending on subscriber density and network utilization.

Figure 2 – Satellite Spot Beams Allow Frequencies to be Reused by Terrestrial Base Stations



Network management techniques can be used to allow mobile devices to seamlessly transition from satellite to terrestrial mode, through adaptations of existing techniques used in cellular/PCS systems for mobile-assisted handoff. Such techniques ensure seamless and transparent system interoperability over the entirety of the hybrid infrastructure.

6.2. Hybrid System Architecture

Figure 3 illustrates the architecture of the hybrid MSS/ATC system to be launched by MSV comprising a space segment and a terrestrial network. The space segment includes two geostationary satellites. In order to minimize requirements on the transmitter of the end-user device and maximize link availability, signals from both satellites are combined optimally and utilized at a satellite gateway.

Figure 3 also shows a terrestrial network having a number of ATC components, each conforming to a mass-market air interface standard. Since the service footprint of the MSS can be relatively large (covering, for example, all of Central and North America) there may be a number of Terrestrial Wireless Networks ("TWNs") already deployed within the MSS footprint using various air interface standards.

An operator of a TWN may incorporate a satellite band (e.g., L-band[39]) into the TWN's base stations and end-user devices thus augmenting the TWN.[40] Having done so, the TWN gains transparent range extension and significant additional capacity. That is, the TWN's end-user devices are now capable of operating over the entire service footprint of the space segment via satellite connectivity and the TWN has gained significant new terrestrial capacity via the ATC network.

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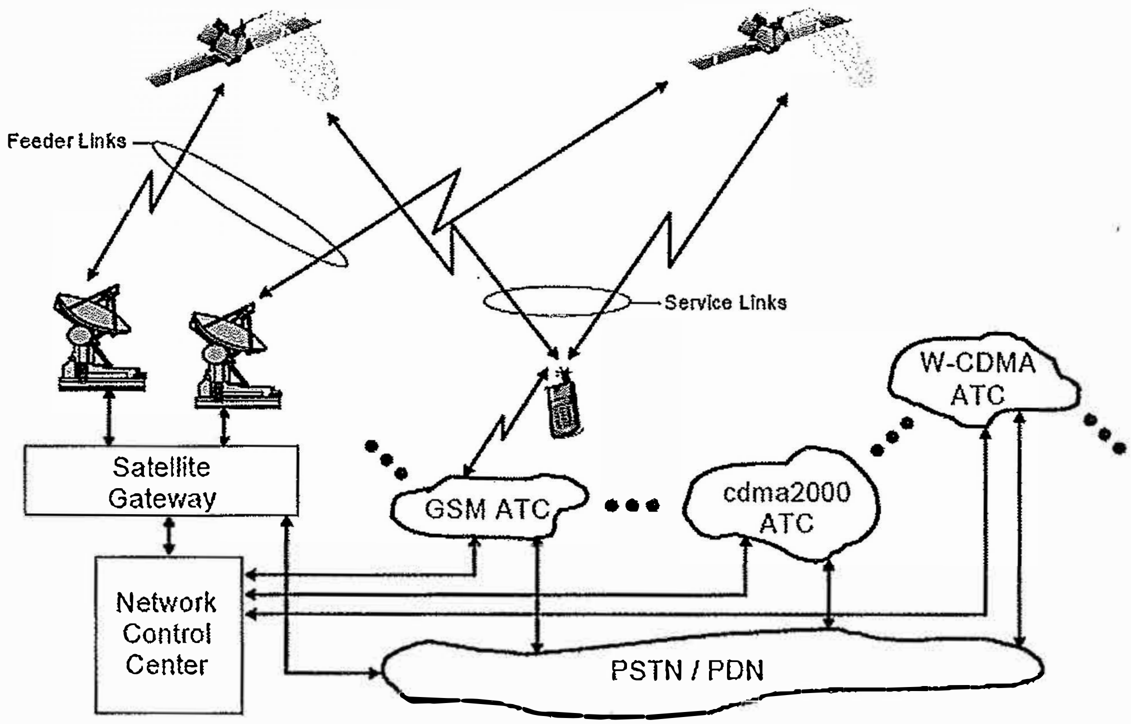
[39] The L-band forward service links (satellite-to-handset) use frequencies from 1525 to 1559 MHz; the L-band return service links (handset-to-satellite) use frequencies from 1626.5 to 1660.5 MHz.

[40] If, for example, the TWN is a GSM network, equipping the TWN with satellite- and ATC-mode GSM capability would allow the network to provide services via its preferred (GSM) air interface protocol over the additional (satellite) band.

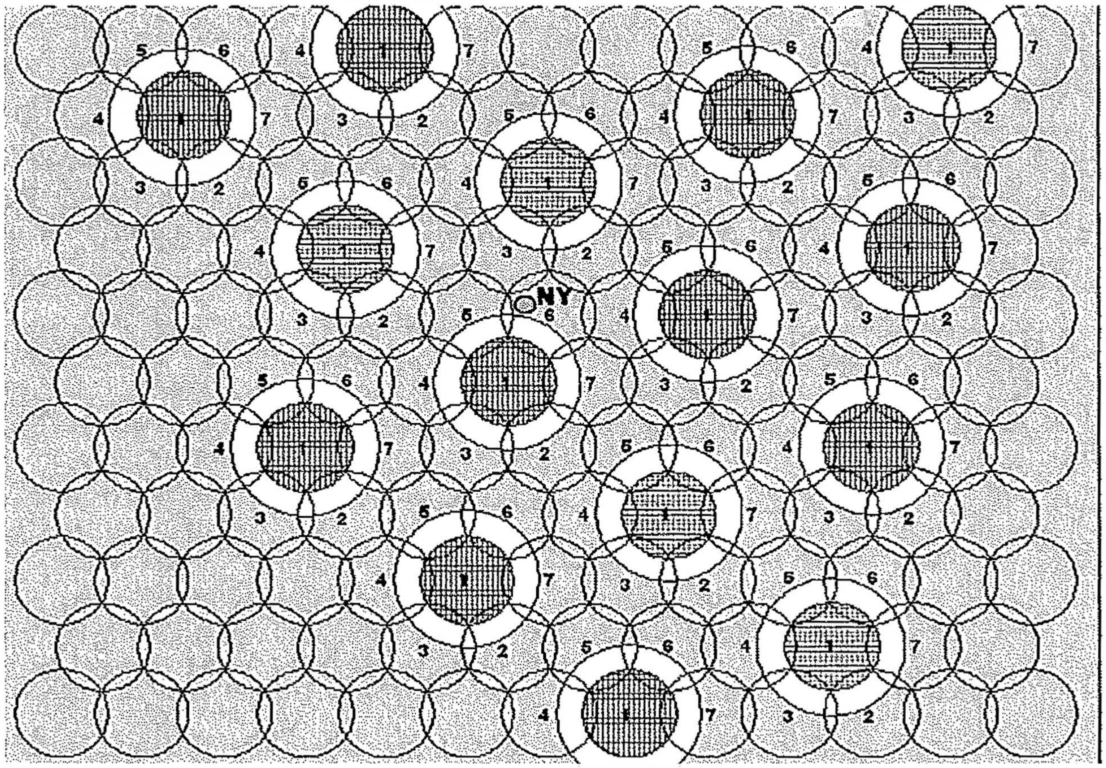
Figure 3 – Hybrid MSS/ATC Network System Architecture



As is further illustrated in Figure 3, the MSS including the satellite gateway(s) is configured to support simultaneously a plurality of air interface protocols/standards thus allowing more than one TWN to potentially derive the benefits of transparent range extension and additional capacity as described above.

The Network Control Center (NCC) assures that the available satellite-band spectrum is optimally "space-time" multiplexed and reused by the space segment and the ATC network while keeping intra-system interference levels to a minimum. This is accomplished by using inter-satellite cell frequency reuse between the space segment and the ATC network while avoiding intra-satellite cell frequency reuse. That is, an ATC that may be deployed, for example, in New York will not be allowed to reuse the same frequencies used by the satellite cell serving New York. Figure 4 further illustrates this principle.

Figure 4 – Illustrative MSS/ATC Frequency Reuse



In Figure 4, the circles labeled with the number 1, represent satellite cells that are using and reusing a particular set of satellite band frequencies in accordance with a seven-cell frequency reuse pattern. This same set of satellite band frequencies may also be used and reused by the ATC network over geographic areas that lie outside of the satellite cells labeled with the number 1 and also outside of the designated "white ring" exclusion regions. Each exclusion region represents a spatial guard band that allows the encircled satellite cell antenna pattern to develop additional discrimination relative to an ATC area that may reuse the frequency set used by the encircled satellite cell 1. This, in conjunction with ATC-aided satellite antenna beam shaping (illustrated in Figure 5 and discussed further below) and adaptive ground-based beam forming signal processing would allow the New York ATC to reuse all satellite band frequencies that are being used by satellite cells 1, 2, 4, and 7 (and perhaps to a lesser extent the frequencies used by cells 3 and 5).

6.2.1. Transparency -- Hybrid Transparent Network

In accordance with the concept of transparency, a user device of an MSS/ATC network is indistinguishable in every respect from a cellular/PCS-only user device. The user device of the MSS/ATC network need be capable of providing communications with the MSS and the ATC at power levels that are no greater than those of cellular/PCS specifications. This ensures compatibility of the user handsets with the form factors, features and battery life expected of terrestrial only handsets.

6.2.1.1.1. The Enablers of Transparency

There are two enablers of transparency. The first relates to the space segment.

The space segment must include a sufficiently large space-based antenna aperture and optimum signal processing to maximize the system's available link margin. Calculations show that a space segment antenna Gain-to-noise-Temperature ratio (G/T) of about 25 dB/°K is necessary to provide significant link margin (. 10 dB) with a user device whose EIRP is limited to about -6 dBW (average). A 25 dB/°K space segment G/T can be achieved by deploying two satellites configured to operate in return-link diversity mode with optimum combining of signals at a satellite gateway. Assuming that each satellite can deliver a 21 dB/°K G/T (as can be attained at L-band by a 22 meter antenna aperture), space diversity with optimum combining processing yields the desired performance (25 dB/°K space segment G/T).

For example, MSV's satellite system currently under construction will consist of two geostationary satellites each having a 22-meter antenna. This will create sufficient link margin to ensure user terminals that need be no larger or more power-hungry than terrestrial-only units with link margins of about 10 dB (in satellite mode). Figures 5 and Table 1 summarize MSV's system characteristics.

Figure 5 – MSV Satellite Coverage

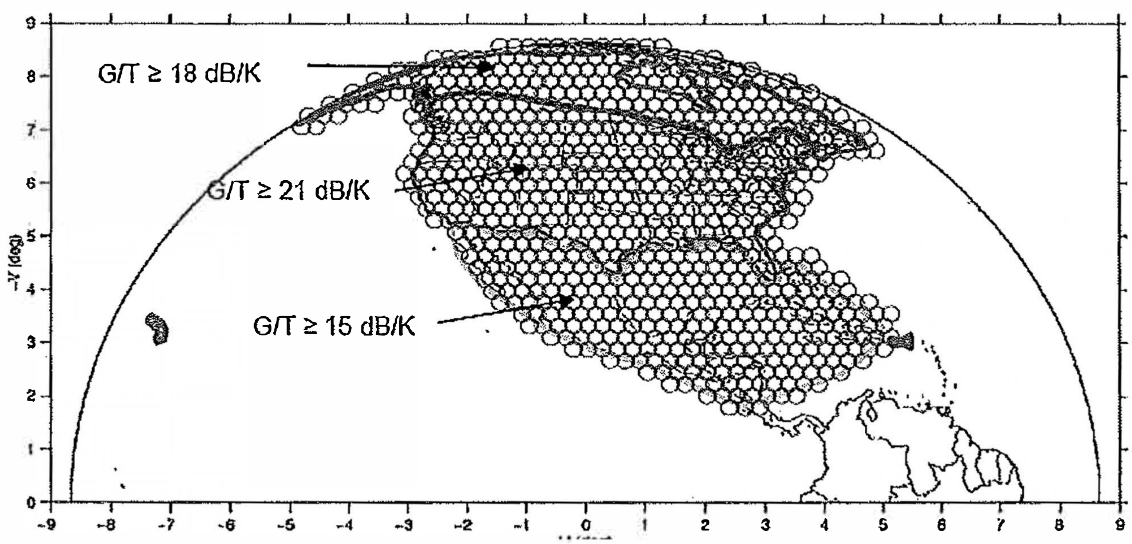


Table 1: MSV Satellite Principal Characteristics

Satellite Orbit Locations	101° W.L. and 107.3° W.L
Service Links	1525-1559 MHz (forward) 1626.5-1660.5 MHz (return)
Feeder Links	12.75 – 13.25 GHz (uplink) 10.75 – 10.95 GHz and 11.20 – 11.45 GHz (downlink)
AEIRP (dBW)	80 per satellite
G/T (dB/K)	See Figure 5
Coverage	See Figure 5
Number of spot beams	Over 500 (0.25°)
Supported protocols	Wideband (3G or 4G)
Processing	Digital channelizer & digital adaptive ground-based beam forming with interference suppression capability
Design life	15 yrs inclined

The second enabler of transparency is the use of a compatible air interface protocol for the satellite link. This simply means that if X is the air interface protocol that an end-user device is using terrestrially, X' must be the satellite-mode air interface protocol, where X' is as similar as possible (if not identical) to X. The adaptation of X to X' may entail, for example, a different vocoder, modifications to signaling channels, and timing changes to the protocol to accommodate the longer propagation delay of the satellite link. The physical layer of the satellite protocol can remain compatible with the terrestrial parent in order to avoid duplication of components. Thus, with a substantially common physical layer between terrestrial- and satellite-modes, the "deltas" of X that define X' can be inserted within a common baseband and RF chip-set with negligible impact to the manufacturing cost of the end-user product.

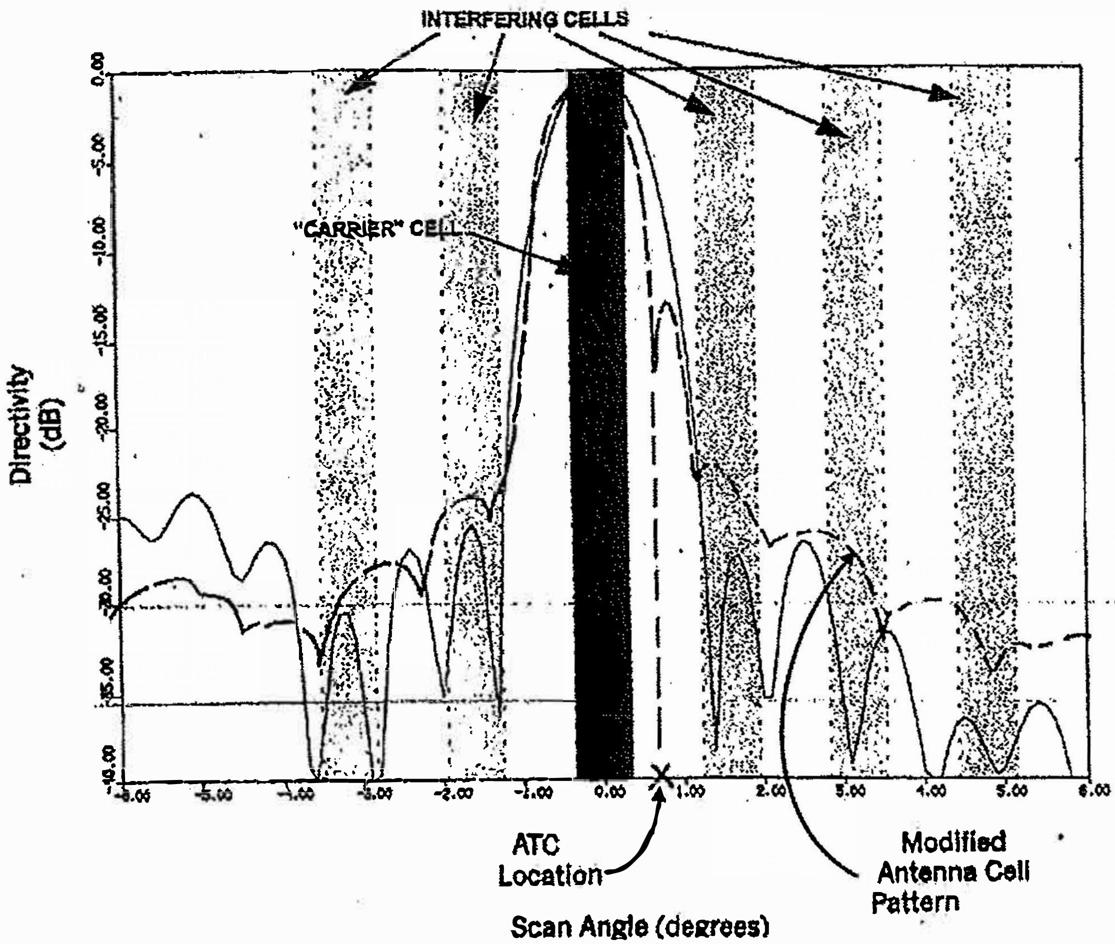
6.2.1.2. Satellite Antenna Beam Shaping

The space segment will form satellite spot beams digitally, thus affording maximum flexibility to reconfigure the satellite beams, system-wide, in response to ground signal processing. A space-based or ground-based "digital beam former" responsive to digital coefficient inputs is configured to produce optimum satellite cells in substantially real time. Referring again to Figure 4, we see that the New York ATC is within a satellite beam 6 and close to the "edge" of both satellite cells 3 and 5. Thus, the satellite receivers associated with satellite cells 3 and 5 may be the most vulnerable to interference if the NY ATC initiates terrestrial reuse of their corresponding frequencies.

In order to reduce the potential of interference into the satellite receivers associated with satellite cells 3 and 5, the satellite antenna pattern associated with satellite cells 3 and 5 may be altered by the digital beam former to increase discrimination in the direction of the NY ATC. Figure 6 further illustrates the concept. The solid curve of Figure 6 represents an original beam pattern while the dashed curve represents a modified beam pattern which increases discrimination in the direction of the NY ATC.

Since an ATC network over any given city will be rather small compared to the size of a satellite cell, the satellite cell gain variation over the geographic area spanned by the ATC network can be assumed negligible. As such, one location within the ATC can be configured to receive the control channels radiated by the space segment. The system may be operative such that reception of such control channels by the ATC will reveal to the ATC the satellite antenna discrimination of neighboring satellite cells as well as the frequencies that the ATC may reuse. As such, closed loop adaptive control may be enabled between an ATC and the space segment whereby the space segment may control the frequencies that the ATC may use and the ATC may suggest modifications of certain satellite antenna beam contours of the space segment.

Figure 6 – Modification of Satellite Beam Pattern Responsive to Location of ATC



6.3. Observations – Recommendations - Conclusions

This sub-section has set forth an overview of the technology required to provide an integrated MSS-terrestrial system. This type of system may be of particular use to government users who require ubiquitous, reliable, redundant communications services. To this end, the government can look to partnerships with existing and future integrated MSS terrestrial providers to integrate these services into their communications networks.

A first step the government can take is to test an integrated MSS-terrestrial system within the framework of existing applications. Once these tests prove out, the government will have the ability to determine how to best integrate these systems into their current and future networks.

Second, the government can also explore the potential to add an MSS-terrestrial system enabled chipset to systems with wireless technology such as LMR radio, and so enable their service providers to offer an "always-available" emergency response device.

The FCC has already recognized the importance of a satellite component to emergency response communications. In the 700 MHz Proceeding, the FCC expressly required that the licensee in the C block integrate a MSS component into at least one device that will be made available for emergency response. In doing so, the FCC recognized the importance of scale in ensuring that MSS is an affordable service for users.