The Resurgence of Push-to-Talk Technologies

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ABSTRACT

Push-to-talk (PTT) technologies date back to the advent of the telegraph and more recently have been the domain of traditional land mobile radio (LMR) networks. The past few years have brought about a resurgence in PTT as a service offered by commercial providers, driven first by private subscribers and, increasingly, by organizations such as law enforcement agencies that traditionally rely on LMRs. This technology, today one of the growth areas in the communications industry, has received little attention in the scientific literature. In this article, we discuss some of the emerging technologies (voice over IP, CDMA used in 2.5G/3G systems) that relate to today's PTT service. We also discuss the market and financial implications of commercial PTT on current LMR deployments.

INTRODUCTION

Land mobile radio (LMR) networks have long provided push-to-talk (PTT) voice capabilities, often in support of law enforcement personnel. In a traditional LMR environment, calls can be established directly between portable or mobile devices or relayed through base stations. In turn, these base stations are connected in a network, forming a wireless (microwave or satellite) and wireline (fiber) backbone. Circuit-switching technologies are typically employed throughout this backbone. Figure 1 illustrates this scenario.

Lately, there has been increased interest on the part of commercial service providers regarding "always on" types of applications, including instant messaging, wireless chat, and PTT. This type of service is claimed to achieve higher average revenue per user for the operator as well as lower subscriber churn [1], although it can be argued that this is more a result of strong customer-service performance by current operators of commercial PTT than a characteristic of the technology itself. In terms of patterns of usage, PTT can be thought of as a voice version of the extremely popular short-message service available from most cellular providers. While the primary market so far has been private subscribers, the potential exists to use commercial PTT services to meet demand from the public sector (law enforcement and public safety in particular), replacing or complementing existing LMR networks.

The technical literature on PTT is sparse since most implementations are currently proprietary. In this article, we address the main forces driving the development of PTT, and market impacts of commercial PTT on the traditional LMR market. In particular, we highlight:

Evolution of mobile wireless networks: PTT capabilities are being integrated into 2.5G and 3G mobile wireless systems such as Global System for Mobile Communication/General Packet Radio Services (GSM/GPRS) and Universal Mobile Telecommunication Systems (UMTS), respectively. Support for PTT in Code Division Multiple Access (CDMA) systems has become increasingly important in the evolution to 3G systems and beyond. There have also been commercial demonstrations of PTT calls between GSM/GPRS and CDMA 2000-1x networks.

Packet radio: Modern implementations of PTT rely on packet transmissions over the wireless links, often supported by the Internet Protocol (IP) suite. The Real-Time Protocol (RTP) provides support for continuous media transmission, including timing reconstruction, security, and content identification. The Session Initiation Protocol (SIP) provides call control and user authentication.

Integration with IEEE 802.11: PTT is starting to be supported over wireless local area networks (WLANs) following the IEEE 802.11 suite of standards.

IP-based backbone: A variety of packet-switched technologies can be used in the backbone network, including asynchronous transfer mode (ATM), frame relay, and IP. Using IP in both the radio link and over the backbone provides advantages such as authentication and end-to-end encryption by establishing a Virtual Private Network (VPN), and challenges, such as

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support for acceptable quality of service (QoS). The QoS requirements on the wireline backbone — upper bounds on latency in particular — may be achieved through technologies such as Multiprotocol Label Switching (MPLS).

Nextel filed for a trademark on the term "push-to-talk" in 2002. In the context of this article, we apply the term, whose usage dates back to the advent of the telegraph, in its broader sense, meaning services that, at the push of a button, allow transmission of data or voice to a pre-established user or group of users. Manufacturers and service providers are mentioned whenever we make reference to specific services and/or equipment supplied by them.

Although in recent years PTT technology has become primarily associated with Nextel's Direct Connect® service, a number of other providers have recently entered this market. For instance, Cingular and T-Mobile now offer walkie-talkie style service in selected areas in the United States. While this technology is largely ignored in recent scientific literature on wireless communications, this is one of the growth areas in the industry today.

PTT is now being supported by fairly new technologies such as CDMA and IP. However, PTT systems date back to the original LMRs and to citizens' band (CB) radios; we start this article by providing a historical perspective on the evolution of these systems. The following sections address the support for PTT applications by the IP protocol suite and their integration in wireless and mobile systems. The article ends with a discussion of the main market drivers for PTT, with emphasis on the role of commercial PTT in competing with or complementing traditional LMRs.

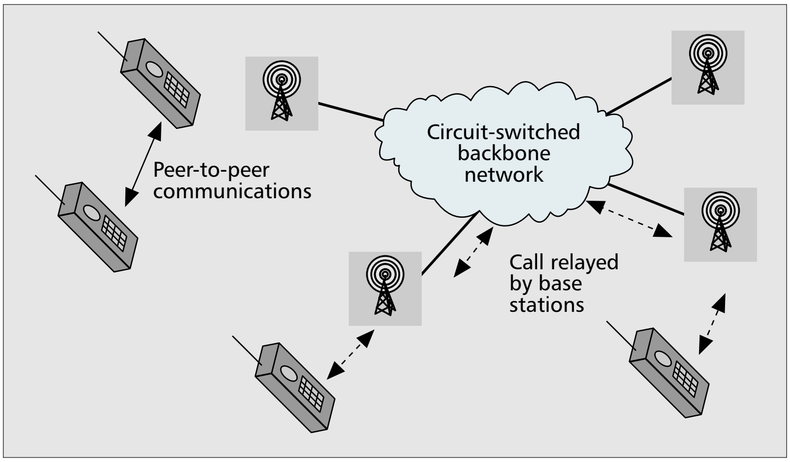

Figure 1. *Push to talk capabilities in a traditional LMR network.*

HISTORICAL PERSPECTIVE

The *IEEE Standard Dictionary of Electrical and Electronics Terms* (3rd ed.) defines a PTT circuit as "A method of communication over a speech channel in which transmission occurs in only one direction at a time, the talker being required to keep a switch operated while he is talking." PTT operation was a standard part of all nonbroadcast voice radio services for so long that its exact origin is impossible to pin down. Virtually all two-way radio stations used a single antenna and transmitted and received on the same frequency. When switching from transmit to receive, it was obviously necessary to turn the transmitter off and connect the receiver to the antenna. The sequence was reversed when the operator switched from receive to transmit. The PTT switch performed these functions. The term probably came into radio usage from telephony, where "push" in the sense of "push button" dates to at least 1878 (*Oxford English Dictionary*). It is commonly asserted that the bypass switch on early telegraph keys was the first PTT switch.

The earliest transmitter circuit the authors can find that provided a switch used by the operator to turn the transmitter on when he wanted (in that day) to talk appears in a 1920 article "Wireless Telephony on Aeroplanes" by Major C. E. Prince. Whether there was a "release to listen" function is unclear. Prince states that "There was for a long time no demand for both-way working and a machine was equipped either for transmission (for the leader to give orders), or reception (for his formation to receive them)" (reproduced in George Shiers, Ed., *The Development of Wireless to 1920*, New York: Arno Press, 1977). Terman's 1932 first edition of his classic *Radio Engineering* text (New York: McGraw Hill) refers to the practice of designing transmitters with single control and shows circuitry that performs the PTT function, but never employs the term.

The earliest (1940s) mobile telephone systems (which were called "radio telephones") used PTT. Because PTT confused the untrained, it was soon replaced by full duplex operation in mobile telephony. By the mid 1950s PTT was considered obsolete in radio amateur circles and more up-to-date equipment used voice-operated break-in or VOX to switch between transmission and reception. Simplex operation with VOX was impractical in most mobile and high-noise environments, and PTT was retained in land mobile and aeronautical mobile radio. While useful there, it carried a connotation of obsolescence.

Commercial PTT services have resurfaced in the past few years. The main drive in everyday use is the ability to be in contact with one's closest friends and relatives at the touch of a button. A combination of features makes a PTT service attractive: an always-on direct connection including peer-to-peer operation and push button to send/talk, and an attractive form factor. As the prevalence of this service increases (and well as its coverage area), commercial PTT will also become a contender in law enforcement, security, and maintenance scenarios thus far supported by privately owned LMR networks. In the next sections, we discuss some of the technical requirements that today's generation of PTT must meet.

PUSH-TO-TALK REQUIREMENTS

PTT allows half-duplex communications at the push of a button. Although the most common applications are one-to-one and one-to-many voice communications, it is also possible to pro-

VoIP is a technology that packetizes audio for transmission over wired and wireless networks. Widespread commercial deployment is well under way. VoIP is viewed as a means of implementing PTT service for commercial wireless phone customers.

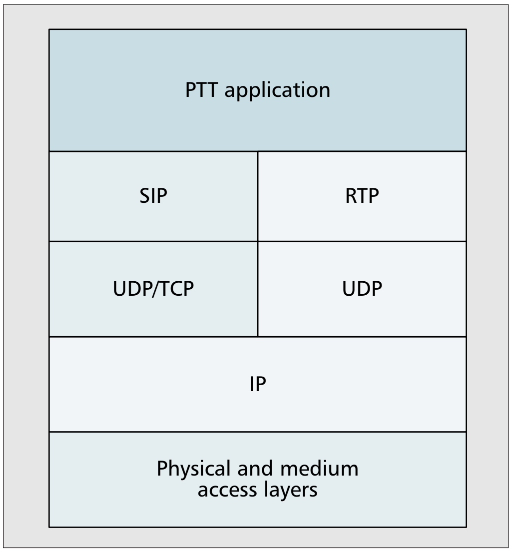

Figure 2. *Protocol stack for support of PTT over VoIP.*

vide PTT capabilities for data communications (sometimes referred to as push-to-send).

Typical PTT users of traditional LMR networks include law enforcement and public safety personnel, first responders to emergency situations, medical personnel, event coordination staff, and dispatcher services. Commercial PTT services today primarily serve recreational uses for communications among friends and family members. In all these examples, due to the real-time nature of PTT, latency is a primary consideration; in law enforcement and public safety, priority and encryption are additional requirements to ensure service availability at times of heavy traffic and secure communications, respectively.

A fundamental requirement is low connection-setup delay, on the order of hundreds of milliseconds to one or two seconds. Recent developments in LMR technology have been driven by major standardization efforts in the United States and Europe (see the description of Project 25 and TETRA). For commercial PTT services to be able to compete for applications traditionally supported by LMR, they will need to meet, at a minimum, the specifications defined by these standards. Some of the specifications, such as voice quality, are not very stringent and will be easily met by commercial service providers. Call-setup latency may present a greater challenge, especially in the deployment of PTT service across long distances. Prediction and soft reservation of resources along paths where calls are expected play a role in achieving acceptable call-setup delay.

Since peer-to-peer communications is one of the major modes of operation for PTT systems in law enforcement environments, portable and mobile nodes require synchronization capabilities that are independent of a fixed system (such as a base-station infrastructure). Some work in the literature has proposed the use of synchronization frames that account for the nodes' sleep cycles, thus ensuring that all receiving units will awaken in time to receive the synchronization signal [2]. The trade-off here is between call-setup time and battery life: longer synchronization frames allow the portables to adopt longer sleep cycles, extending battery life but resulting in potentially longer delays to initiate the call.

Other requirements include encryption and prioritization. Encryption is needed to prevent eavesdropping of sensitive information sent over PTT. Prioritization would allow a set of users, such as first responders to an emergency situation, to preempt the use of available channels and ensure adequate communications, to the detriment of regular users. Both capabilities are seen as fundamental requirements by law enforcement agencies, and will need to be deployed if commercial PTT is to become a viable alternative to traditional LMRs in this type of application.

Traffic engineering for PTT services to date has typically employed traditional telephony assumptions (Erlang models) with different parameterization. For instance, PTT calls tend to last a shorter time (on the order of 30 s, rather than 3 to 5 min for traditional telephony) but are more frequent than phone calls. However, recent studies of public safety traffic on trunked LMR indicate that call interarrival time exhibits some degree of long-range dependence [3]. The prevalence of talk groups further affects traditional traffic-engineering assumptions, and signaling load may also be significant. With increasing popularity of text, images, and, eventually, video over push-to-send, most of the assumptions as to the underlying traffic characteristics must be revised for appropriate network dimensioning by the service provider.

The implementation of these services using protocols in the IP suite presents its own set of challenges, which is discussed next.

IP Support

Packet-switched communications often rely on the IP protocol suite, due to its ubiquity, scalability, and potential for interoperability. Voice-over-Internet Protocol (VoIP) is a technology that packetizes audio for transmission over wired and wireless networks. Widespread commercial deployment is well under way. VoIP is viewed as a means of implementing PTT service for commercial wireless phone customers.

When PTT applications are implemented over VoIP, the protocol stack might look as shown in Fig. 2. The Session Initiation Protocol (SIP), described in IETF RFC 3261, is an application-control protocol that can be used to establish and manage a multimedia session; IP telephony is one of its primary applications. Among the services supported by SIP are personal mobility and terminal capability negotiation, both necessary for mobile wireless communications. The RTP, described in IETF RFC 1889, provides end-to-end real-time delivery of audio and video payloads.

None of the protocols shown in the stack in Fig. 2 has native support for QoS, an issue for real-time services to be supported by push-to-talk and push-to-send. We expect the short-term solution by service providers to be a combination of overprovisioning and deterministic resource

Project 25 and TETRA

Project 25 is a standardization effort that addresses LMR technologies and their use by law enforcement agencies. The development of a set of specifications is expected to enhance communication capabilities among agencies and increase interoperability of equipment from different vendors, ultimately creating a more competitive environment and driving down costs. Other objectives include increased spectral efficiency and support for both trunked and conventional systems. Several local and federal law enforcement agencies in the United States are participating in this effort. The International Telecommunication Union (ITU) is currently considering the Project 25 specifications for approval as a standard.

Terrestrial Trunked Radio (TETRA) is a digital cellular communication system providing voice and data services for public safety and professional fleet users. Since the inception of its standardization process by ETSI in 1989 it has experienced some popularity as a digital private mobile radio (PMR) solution, particularly in Europe. There are estimates that approximately 80 percent of the digital PMR market in Europe will eventually operate using TETRA technology. The North American TETRA Forum (NATF) has been formed to promote, discuss, and enhance TETRA technology in North America.

Box 1.

management in the wireless links (as provided by slot allocation in TDMA) and provisioning of the backbone by using technologies such as MPLS, ATM, and frame relay. Native end-to-end IP will require that some of the current IP QoS support architectures and technologies (such as DiffServ) be widely available.

HP and Tobagi have designed an architecture for PTT over any IP-based network, as illustrated in Fig. 3 [4]. In this architecture, the PacketChat client runs on mobile devices such as personal digital assistants (PDAs) and mobile phone handsets. The PacketChat server encompasses an application server, a media processor, and service management modules. Client functions include packetization of speech into RTP packets (and vice versa) and setup and clear-down of calls, as well as functionality for obtaining buddy lists from the PTT server and establishing presence information. The application server interfaces with SIP for call establishment and maintenance of billing information and maintains a cache of group- and buddy-list definitions for the clients. The media processor replicates voice packets for other call members, encodes/decodes from various speech formats, and provides medium arbitration.

QChat is a development of Qualcomm designed to implement PTT using VoIP, promoted as a way to support public safety organizations with communications capabilities [1]. QChat operates on wireless handsets that use binary runtime environment for wireless (BREW), which enables handsets to execute software applications. QChat supports one-to-one and one-to-many PTT connections. While Qualcomm is most noted for its development of CDMA technology, QChat is designed to operate on wireless IP networks in general. In fact, the development of QChat was in response to a Nextel request for a PTT technology for packet CDMA networks.

Technical risks of VoIP over wireless include potentially increasing the latency of PTT transmissions. When a data connection is made over a wireless network (VoIP is a data connection, not a traditional voice-call connection), several delays come into play. A call-setup delay is experienced between the request of a handset for a wireless channel and the time when the wireless network will allow transmission of the handset's data. Delays also exist for other protocols used during the data communications, such as delays of setting up data sessions between PTT users. Total latency can reach 5 to 10 s while the network sets up a data connection between originating and terminating handsets.

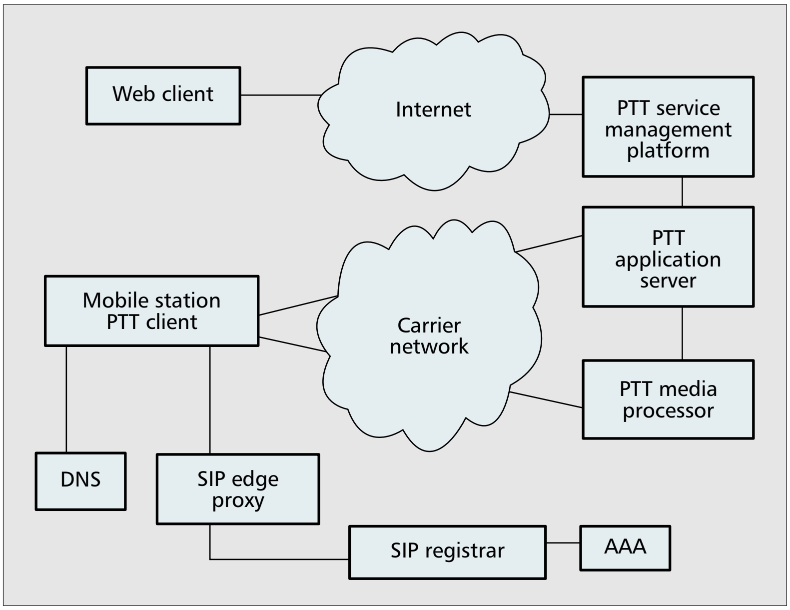

Figure 3. *HP/Tobagi PacketChat architecture (adapted from [4]). DNS is the Domain Name Service module, and AAA is the authentication, authorization, and accounting module.*

Once a data session is established for VoIP, setting timeouts for closing the wireless channel resources can reduce latencies. For example, call-setup time would apply to the first transmission by a PTT user, but if a 30 s timeout is specified for wireless network resources, then the latency contribution due to call-setup time would be eliminated for subsequent transmissions made within 30 s of the most recent transmission in the PTT conversation. Other solutions to mitigate latency include buffering voice samples in the handset until the data connection is set up.

Additionally, CDMA PTT-enabled handsets may experience reduced battery life because they are not allowed to enter sleep mode to conserve power. Normally, idle handsets wake up every few seconds to determine whether they are being

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paged by the network. PTT handsets, on the other hand, are always awake, as sleep periods would contribute even more latency to call setup.

Still, latency is a primary concern for VoIP implementations of PTT. Traditional LMRs use circuit switching and can support lower call-setup times.

U.S. operators that currently provide PTT service or have announced their intention to do so in the near future include Verizon Wireless, Sprint PCS, Alltel Communications, Cingular, and T-Mobile [5]. These service providers appear eager to integrate PTT into their networks because of the success of Nextel's existing Direct Connect service. Evidence of the broad interest in PTT VoIP is seen in the number of companies involved in development of wireless VoIP technologies, including L.M. Ericsson, Sonim, Dynamicsoft, Qualcomm, Togabi Technologies, Comverse Technology, and Mobile Tornado; these companies claim to be in talks with major service providers regarding tests and trials. Commercial PTT service has also been introduced in some international markets. For instance, Indian wireless carrier Tata Indicom is introducing PTT service powered by Qualcomm's BREW software platform.

The Open Mobile Alliance has recently chartered a working group on PTT over cellular (PoC) to specify an open standard, in cooperation with other organizations such as the 3rd Generation Partnership Project (3GPP) and the Internet Engineering Task Force (IETF). Objectives of the working group include defining PoC requirements, designing an architecture for PoC, addressing interoperability requirements, and creating test suites for the service. Architectural elements of PoC include the user equipment, the PoC server (which serves as the endpoint for SIP signaling and reports to the billing system), the IP multimedia system (which contains SIP registers and SIP proxies), and a group and list management server.

INTEGRATION WITH 2.5G/3G WIRELESS SYSTEMS

VoIP applications will also be deployed on CDMA networks. When VoIP operates on a CDMA network, the probability of detection is lower due to the spreading of the transmitted spectrum, which results in a noiselike signal. The use of long pseudo-noise (PN) codes and available encryption reduces probability of interception of transmissions. QChat, as well as other wireless VoIP implementations, will be supported by the wireless data capabilities on IS-2000 1xRTT CDMA networks. These CDMA networks are widespread throughout the United States and Canada and are operated by service providers such as Verizon Wireless and Sprint. QChat and other VoIP applications on CDMA networks will compete with Nextel's TDMA Direct Connect® PTT feature.

Another emerging wireless network is the CDMA-2000 1xEVDO network, which is designed to be a high-speed, widespread data network for mobile communications. The 1xEVDO is an evolution ("EV") of today's CDMA networks but is designed for data-optimized ("DO") applications. Since VoIP traffic is viewed as any other IP traffic on networks, voice applications are not excluded from 1xEVDO networks. Companies such as Winphoria (recently acquired by Motorola) and Airvana Inc. released news that PTT capabilities were to be demonstrated on 1xEVDO and 1xRTT networks. These applications will initially use pocket-PC devices as the user equipment instead of a handset. However, new handsets are including capabilities of PDA and pocket PC devices, blurring the line between wireless telephone handsets and personal computing devices.

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COMMERCIAL PTT IN THE TRADITIONAL LMR ARENA

Always-on services such as PTT have emerged as strong revenue potential for wireless service providers, who may see them as a way to recoup some of the large investments made in infrastructure for 2.5G and 3G systems.

Nextel leads the other service providers, using its Integrated Digital Enhanced Network (Iden®) and employing mobile devices manufactured by Motorola. Other service providers (Sprint, Alltel) and software and hardware vendors (Ericsson, Qualcomm) have already announced current or upcoming support for their own PTT capabilities in a cellular environment. These services also position providers to complement the LMR networks operated by federal, local, and state agencies.

The attractiveness of commercial PTT service has been so strong that government employees often purchase the service on their own, without official financial support from their employer. The demand has been a grass-roots phenomenon when competing with traditional LMR. With the press of a button, the call is set up and a connection (directly peer-to-peer or through base stations and the network) is made, providing walkie-talkie style service. There is no need to keep track of frequency assignments, channels, and so forth when roaming, as is required in LMR systems. The ability to contact a teammate almost instantly can be extremely valuable when quick decisions or reactions are required, as in public safety and emergency response.

PTT commercial systems make use of a handset that is virtually indistinguishable from general cell phones. Individuals who do not want to be quickly identified as law enforcement personnel (for instance, individuals working undercover or in surveillance) find this a big advantage relative to using a traditional LMR, which still relies on bulky and easily recognizable radios. There is a substantial enough private customer base using PTT for business purposes such that government employees can easily blend into the population. This also means that the electronic traffic also blends into commercial traffic, thus providing a measure of privacy (one might say, camouflage) that is not present with LMRs.

Limited support for traffic prioritization, preemption, and encryption in current commercial PTT service is a barrier for its adoption in the law enforcement arena. Many law enforcement agencies currently adopt commercial PTT as a complement to their own LMR networks. It is unlikely that commercial PTT can replace existing LMRs for those applications unless and until security and QoS support are strengthened.

Cost Issues

Low cost, coupled with ease-of-use, may drive the PTT market beyond individual subscribers. There is the potential for organizations that currently operate their own LMR network to increasingly make use of PTT services.

Traditional LMR handsets are expensive. Although there are several different types of handsets in use, Motorola's popular ASTRO® and Spectra® radios may run up to US$4000–5000 each. One of the factors that increase the cost is the high level of encryption. Certainly one of the other important cost factors is the lack of competition in the provision of handsets for some types of users. Proprietary technologies tend to lock-in a single vendor for future purchases by the user.

In contrast, the price of commercial PTT handsets currently ranges from below US$100 to as high as US$350. This affordability is certainly a factor driving the adoption of commercial PTT by some public safety agencies. Given tight budgets for communications, the ability to acquire as many as 40 or 50 handsets where only one is possible using LMR is a strong incentive for offices to adopt a PTT commercial service.

In addition, a switch to PTT commercial service essentially outsources to a commercial vendor the cost of maintaining and upgrading the backbone infrastructure. This transfers the costs for the LMR user to another party in exchange for monthly service charges that spread the cost over a longer period. For smaller organizations, the outsourcing of this potentially temperamental technology is very attractive.

Another cost component is training. In many organizations, the ability to take time away from current tasks to attend training on the use of LMR equipment is severely limited. PTT commercial systems, by virtue of their user-friendly operation and similarity to cell phones, require far less training. However, to set up talk groups and take advantage of other advanced features of the system, some training is required for efficient operation. The time required is nonetheless substantially smaller than for LMRs. The ability to use the handset "right out of the box" also motivates employees to quickly learn other features.

Finally, some government agencies find that the adoption of PTT commercial service can streamline back-office operations. Although this is not truly a function of the PTT capabilities, the advantages and versatility of PTT commercial service have driven this source of savings. First, if commercial service is officially sanctioned and paid by the employer, other devices are eschewed and the number of bills and tracking of accounts are simplified. Although this is not an advantage for offices that solely use LMR (unless they extensively track employee usage), the reduction in paperwork in other offices with mixed uses is potentially substantial, if difficult to quantify.

Commercial PTT vs. LMR: Additional Considerations

The decision by an organization, such as a law enforcement agency, to operate and upgrade its LMR rather than adopt a PTT commercial service must weigh the trade-offs between the two alternatives. In this section the application of some basic but crucial considerations in financial decisionmaking highlights some of those trade-offs and suggests ways of quantifying some of their relative effects.

A newly implemented LMR system will require the establishment of towers and relays. These are typically quite expensive to construct. In some cases, the expense can be reduced through the leasing of space on existing towers. However, in organizations with thousands of employees, the larger cost is the acquisition of radios for individuals. LMR handsets cost 10–50 times more than handsets from commercial vendors of cell or PTT services. On the other hand, a commercial service requires payment of monthly service fees, hence presenting substantial recurring costs. So, in part, the consideration between the two is determined by the ability of the purchaser to acquire financing for a single-stage capital investment versus for a continuing expenditure. In other words, if the cost of capital is low, the future operating expenses loom larger and thus an immediate investment in LMR is more palatable, even if it represents a larger dollar amount.

When considering replacing an existing communications system with a new LMR or a PTT commercial service, the "with and without" principle of comparison must be applied. The principle is that the comparison of alternatives must consider the cash-flow consequences of adopting the new system versus not adopting the new system. Cash flows that would have occurred in the absence of a replacement are the basis for a comparison with the replacement system. Thus, for example, training costs that would occur regardless of which system is adopted are not a factor, except to the extent that the training could be shorter or longer (cheaper or more expensive) than existing efforts. Training will occur in either case, and PTT training will likely be less time-consuming but may involve more people because of the affordability of the handsets. The *difference* between what would have been spent on training under LMR versus spending on training for PTT commercial service is the critical factor, not the dollar spending on PTT commercial training. Similarly, if the purchase of additional LMR handsets would have been required even in the absence of a switch to PTT commercial service, then that additional dollar expenditure is the basis for comparison. Because the cost of PTT commercial handset is much lower, a cost savings (the differential)

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Typically, from the user's perspective, the consideration of LMR versus PTT commercial service involves a tradeoff between substantial early investments in LMR with low future operational costs against almost no early investments but with larger future expenditures for service using a PTT provider.

accrues to the PTT commercial service — a positive factor in decision-based computations.

One additional factor that is relevant to the decision is the risk. The risk of the various alternatives may differ. The cash flows associated with continuing with an LMR system are relatively well known. There will be some upgrade and maintenance expenses and the cost of handsets is predictable (on a percentage basis). Given hiring forecasts, the dollars expended are easy to forecast. With a PTT commercial system, the expenditures are much less certain and less controllable by the user. Vagaries about the cash flows include the cost of handsets (which are uncertain in the downward direction — it is unlikely that the cost of handsets will rise over time unless new features are added), the monthly service costs, and most troubling, whether the commercial vendor will remain in business. It would be reasonable to use a different discount rate for each category to reflect the different risks. Predictability and control issues make a PTT commercial option a riskier alternative in general. However, a countervailing risk advantage is the greater robustness to obsolescence, because PTT commercial handsets can be inexpensively upgraded to newer technology (by replacing them with new handsets).

Typically, from the user's perspective, the consideration of LMR versus PTT commercial service involves a tradeoff between substantial early investments in LMR with low future operational costs against almost no early investments but with larger future expenditures for service using a PTT provider. Thus, there is an important time dimension to the consideration. With high financing costs (e.g., an inability to borrow against future cash inflows), the advantage is strongly toward PTT commercial service. This avoids large initial expenditures that are more heavily weighted against distant expenses when the cost of capital is high. But even at low financing costs, the PTT commercial service is often the better alternative financially, unless the cost of capital is close to zero. The added consideration of technological flexibility against obsolescence also tends to favor PTT commercial service, whereas control issues weigh against it.

CONCLUSIONS

The continued success of PTT services depends to a large extent on its ability to seamlessly integrate with other emerging technologies, such as 2.5G/3G wireless networks (and, in turn, with popular IEEE 802.11-based WLANs) and multihop mesh networks and to support, with adequate QoS, real-time IP-based voice, text, image, and video. Solutions thus far have been proprietary, with details not published in the open literature. We believe there is room for research on the integration and optimization of PTT services with WLAN and mobile/cellular networks.

In addition to the individual subscriber market, PTT providers are increasingly positioning themselves to compete for the traditional LMR market, including safety and law enforcement. The attractions of PTT commercial service are substantial for traditional LMR users. The risks are in some ways greater with a commercial service, but the added safety of field workers who can have immediate connectivity can outweigh the administrative risks, especially for emergency response workers. The small (in some cases negligible) initial investment for a PTT commercial service can provide a financial incentive to avoid LMR deployments.

We expect LMR to survive for critical law enforcement and disaster response applications, since for some organizations it is crucial to maintain control of their own radio network. There are advantages for public safety agencies to own and administer their own LMR networks. By controlling coverage of the network, these organizations do not depend on the PTT service provider to fix dead spots. Also, traffic load from a single agency is typically low; as capacity is not a primary concern, network planners can build fewer base-station sites at much higher-radiation centers. However, if encryption and pre-emptive priority become available in commercial PTT, those services will seriously challenge current LMR networks and may gain a significant portion of market share in the public safety arena.

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BIOGRAPHIES

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GEORGE E. MORGAN (gmorgan@vt.edu) is the SunTrust Professor of Finance at the R. B. Pamplin College of Business at Virginia Tech. His research interests are in financial institution management and regulation, valuation, and commercialization of wireless and space technology, regulation, and risk management. He and his colleagues across the university developed, under NSF funding, interdisciplinary teaching materials for design and layout of broadband wireless systems, with a focus on commercial and financial

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CHARLES W. BOSTIAN [F] (bostian@vt.edu) received his B.S., M.S., and Ph.D. degrees in electrical engineering from North Carolina State University in 1963, 1964, and 1967, respectively. After a short period as a research engineer with Corning Glassworks and service as a U.S. Army officer, he jointed the Virginia Tech faculty in 1969 and is currently the Alumni Distinguished Professor of Electrical and Computer Engineering. His research interests are in cognitive radio, wireless and satellite telecommunications, and RF design. His teaching has been recognized by a number of awards. He is the co-author of two textbooks, *Solid State Radio Engineering* and *Satellite Communications* (both, Wiley).

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If encryption and pre-emptive priority become available in commercial PTT, those services will seriously challenge current LMR networks and may gain a significant portion of market share in the public safety arena.