Transit Agency Implementation of, or Migration to Digital Trunked Radio

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INTRODUCTION

It is difficult for transit agencies to keep pace with the range of communication technologies available, the emergence of digital radio and the rapid evolution in broadband technologies in order to plan for the future. Recent developments in North America have seen the growth in digital trunked radio applications with several technologies now available.

The Association of Public Safety Communication Officials (APCO)[1] Project 25 (P25) technology is emerging as the predominant digital trunked radio system in North America, providing both voice and low bandwidth data, and while primarily used by Public Safety and Security agencies it is now appearing in Transit applications as a replacement for aging and obsolete analog systems.

In a revision to its rules, the FCC[2] has now allowed the European TETRA[3] digital radio technology governed by the ETSI[4], to be licensed and used in the USA, offering an alternative to P25 for voice and data applications to provide narrowband voice and data channels. There has been an immediate response with the use of TETRA to support both bus and rail transit applications.

In addition to TETRA and P25 the ETSI Digital Mobile Radio (DMR) technology has been approved for use in North America and offers a lower cost alternative for digital trunked radio. Its functionality and features are also far more limited than either TETRA or P25 and are not therefore considered as a suitable replacement for TETRA or P25 in the transit sector.

The future is also expected to see the 4G LTE (Forth Generation - Long Term Evolution) wireless data standard used for Public Safety broadband applications, with the standard also able to offer voice over Internet Protocol (VOIP) capabilities.

This paper using information provided by several industry sources including the P25 Interest Group (PTIG) and the TETRA + Critical Communications Group (TCCA), will help explain the different technologies and provide agencies with some guidance when planning a new or replacement Private Mobile Radio (PMR) system that will meet both their current and future transit needs including increased broadband capabilities.

Digital Trunked Radio

Trunked radio systems allow a limited number of channels to be shared between multiple users and dynamically assign frequencies to both users and call groups. In conventional land mobile radio (LMR) systems when a user is assigned a channel, that channel is unavailable for other users until the call is completed. Trunked radio systems, on the other hand, allocate channels dynamically taking advantages of "silent" times in conversations. The radio controllers may allocate different channels each time the user speaks which introduces a slight delay. Trunked radio systems are able to make most efficient use of available channels. The voice channels can be encoded in analog or digital.

TETRA and APCO-P25 both utilize a digitally encoded voice signal which as shown in the following Figure provides a better audio quality over a wider range of received signal strengths than analog radios.

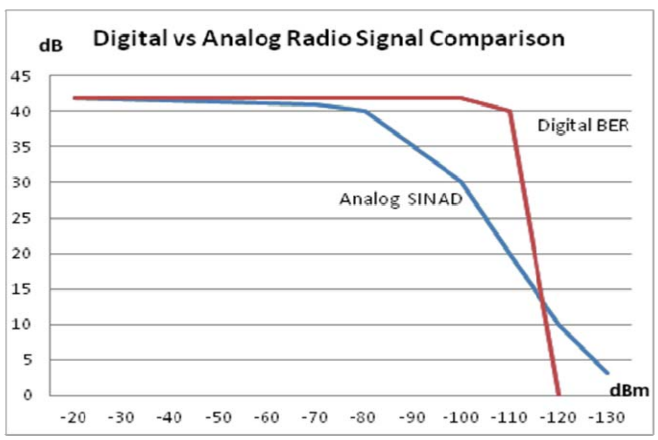

Figure 1. Digital / Analog Radio Signal Comparison

Figure 1 (indicative only) shows that the signal quality remains consistent over a wide range of received signal strengths and then drops off sharply when the signal strength reaches a threshold, whereas in analog radios as the received signal strength decreases the audio quality also degenerates.

Analog systems are also more susceptible to the effects of phase distortion or multipath fading which lead to the deterioration of the voice signal. By comparison for digital systems such as P25 and TETRA the only concern is the Bit Error Rate (BER) which can to some degree be mitigated by forward error correction. A BER of 2% equates to a Digital Audio Quality (DAQ) figure of 3.4 which has become the established norm for transit operations voice quality[5].

Digital Trunked radios therefore offer the following advantages when compared with analog radios:

- Improved Voice Quality;
- Expanded RF Coverage with acceptable voice quality;
- Non-Voice Services;
- Improved Security;
- Lower Cost;
- Spectrum efficiency.

APCO P25

Project 25 represents the American Public Safety community's overall strategy to develop a digital radio solution and achieve the FCC spectrum efficiency mandates requiring migration to narrowband channel spacing in the VHF and UHF bands.

This strategy is an effort to ensure more efficient use of the VHF and UHF spectrum by requiring all VHF and UHF Public Safety and commercial LMR systems in the US to migrate to 12.5 kHz per voice channel. Further migration to 6.25 kHz channel bandwidth is also expected.

Project 25 addresses the FCC's mandate with a phased implementation program:

- The Phase 1 (P25-1) initial implementation, offered the necessary technologies and standards to provide for channel reduction from 25 kHz to 12.5 kHz.
- Phase 2 (P25-2) systems entered service in 2011; they are gradually replacing Phase 1 systems and offer an additional 50-percent reduction in voice channel size to 6.25 kHz equivalency.
- A future Phase 3 is expected to address the growing need for high speed data.

P25-1 requirements include standards for a digital common air interface (CAI) based on an FDMA[6] protocol using a 12.5 kHz channel.

P25-2 requirements also provide a digital CAI but employ a TDMA[7] protocol for voice using a 6.25 kHz equivalent channel, with two slots per 12.5 kHz channel. Phase 2 radios also provide Phase 1 functionality to remain backwards compatible with Phase 1 equipment and allow interoperability with Phase 1 radios. For example:

- Phase 2 data communication continues to employ FDMA techniques using one or more 12.5 kHz channels;
- The Phase 2 control channel is compatible with the P25-1 implementation; and
- Data channels continue to utilize the full 12.5 kHz spectrum allocation.

The P25 suite of standards were established in 1989 in the US through a collaboration of APCO, NASTD[8], NCS[9,] NTIA[10] and NSA[11], and were developed as a set of open of standards under the TIA[12], they exist in the public domain and are managed and maintained by APCO.

The standards define key interfaces and functions. This allows multi-vendor sourcing with any manufacturer able to produce compatible radio equipment. Manufacturers are able to demonstrate through a set of standardized tests and a compliance assessment program (CAP) that their equipment meets the P25 standards and are interoperable in accordance with these standards.

By defining key interfaces, manufacturers are able to develop products or system elements that match their capabilities and that allow users to procure a system or replace or upgrade a subsystem or equipment based on their specific their needs. For example, one manufacturer may provide the fixed radio base stations with another providing the mobile or portable radios.

P25 compliant radios can communicate with legacy analog radios, and in either analog or digital mode with other P25 radios.

P25 systems are frequency agnostic and therefore the standards can be applied to all applicable radio bands including Public Safety and Transit. A base station site requires a control channel and can accommodate multiple Tx/Rx carrier pairs. Base station equipment can be expanded to accommodate additional carriers as licenses permit.

P25 System Architecture

The following Figure 2 shows the components of a P25 radio system including the key subsystems and the primary interfaces.

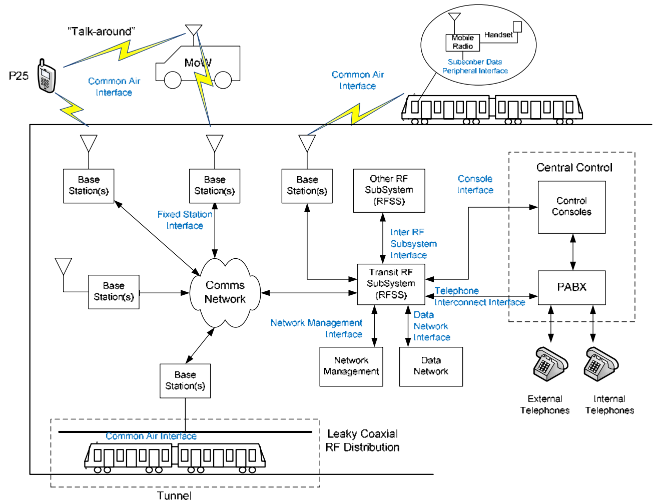

Figure 2. Typical P25 System Architecture

Figure 2 includes each of the following elements and primary interfaces:

RF Subsystem (RFSS) – This represents the core infrastructure with multiple radio sites

Common Air Interface (CAI) - Radio to radio protocol; this interface defines the wireless access between mobile and portable radios and between the subscriber (portable and mobile) radios and the fixed or base station radios.

Inter-System Interface (ISSI) - RFSS to other system (e.g. agency) IP based interface. This interface permits users in one P25 system to communicate with users in a different P25 system, from one jurisdiction to another, from one agency to another, from one city to another, etc.

Telephone Interconnect Interface - This interface (analog or digital) between the RFSS and the Public Switched Telephone Network (PSTN) allows field personnel to make connections through the PSTN by using their radios rather than using cellular telephones, and can also be used to interface to other non P25 radio systems such as TETRA.

Network Management Interface - Interface between network management system and the RFSS. This interface to the RFSS allows administrators to control and monitor network fault management and network performance management.

Data Host or Network Interface - Computer Aided Dispatch (CAD) or other data network to RFSS. This interface describes the RF subsystem's connections to computers, data networks, external data sources, etc.

Data Peripheral Interface - This interface describes the data transfer protocol that must take place between subscriber radios and any data devices that may be connected to the radio

Fixed Station Interface - Base Station to RFSS / Console IP to analogue voice infrastructure. This interface (either digital, IP over Ethernet or analog) describes the signaling and messages between the RFSS and the fixed station by defining the voice and data packets (that are sent from/to the subscriber(s) over the CAI) and all of the command and control messages used to administer the fixed station as well as the subscribers that are communicating through the fixed station

Console Sub-System Interface - Console and RFSS Interface with Fixed Station support. This interface is similar to the fixed station interface but it defines all the signaling and messages between the RFSS and the dispatch console used by a dispatcher or Transit controller to direct and support field personnel.

It is important to note that manufacturers have developed proprietary implementation with value added features which are not included in the standards. In order to interface systems and take advantage of these "proprietary" features addition system design and customization is required for full inter-operability

P25 Call Capabilities

P25 supports voice and data communications modes using the trunked radio and with the exception of the "Talk-around" function, individual and group calls operate in full duplex mode, with channels assigned by the system based on the resources available. In the "Talk-around" mode the radios manage the channel assignments jointly. The following call types are supported:

System All Call - a pre-programmed "special call" in a supervisory radio allows a supervisor to communicate immediately to all radios within the assigned system.

Group Call - The standard call on a P25 trunked radio system and may operate in one of two different modes: P25 voice or P25 data. P25 Trunked radios can automatically scan between the different modes.

Group Emergency - When a P25 Trunked system receives a group emergency call request the dispatcher is notified immediately and the call is assigned to a free working channel. If all working channels are busy, the system assigns the call to the next available working channel.

Individual - Addressing for individual voice or data calls may be accomplished by a dispatcher or another radio unit and can be pre-programmed into a radio.

"Talk-around" - Allows direct radio to radio communications without need for a repeater or radio tower. This function, equivalent to the DMO feature of TETRA, operates on a single channel in a simplex mode. Using P25 radio standards this is accomplished via the Phase 1 features so both mobile and portable radios support both Phase 1 and may support Phase 2.

Interagency Communications - P25 systems provide interoperability via the ISSI interface, audio PSTN patch panel and radio to radio communications. The ISSI interface will provide integrated radio system control whereas the audio link will enable voice patching via the PSTN interface between different systems and system technologies. Groups from different systems may also be connected together and controlled through the dispatcher and the console functions and features.

P25 Technology Migrations

P25 Phase-2 has been designed to allow migration from Phase 1 to Phase 2 as follows:

- Phase 1 is compatible with analogue trunked systems, whereas Phase 2 is not;
- Phase 2 systems and radios support both P1 and P2.

Since Phase 2 is a migration and not a replacement for Phase 1, and as a result of the need for backwards compatibility from Phase 2 to Phase 1, then some features of Phase 1 are maintained with the migration. For example the "talk-around" function uses the P1 technology. As a result terminal equipment is designed to support Phase 1 or Phase 1 and 2 (supporting both FDMA and TDMA technologies). Repeater mode is supported in P25 for both Phase 1 and Phase 2 handsets. Repeaters are also available which support legacy analogue radios as well.

P25 Phase 1 can facilitate backwards compatibility towards legacy analog networks, since it is based on a FDMA air interface and with compatible channel spacing to analogue. P25-2 is based on a 2-slot TDMA trunked air interface, providing two speech traffic channels in a 12.5 kHz channel allocation, and hence mirrors TETRA which uses a 4-slot TDMA in 25 kHz.

While P25-2 improves spectrum efficiency compared to Phase 1, a system may still be required to support FDMA transmission (dual-mode transmission sites) termed dynamic dual-mode operation. P25 Phase 1 terminals that are "Phase 2 capable" are available on the market. As an option some vendor equipment designs therefore provide both Phase 1 and Phase 2 capability with automatic mode detection to provide seamless and transparent interoperability between equipment.

Phase 3 of the P25 radio standards is expected to address the growing need for high speed data.

P25 Simulcast Capabilities

The P25 architecture provides both multicast and simulcast capabilities. Multicast systems are configured with adjacent repeater sites using different frequencies to avoid interference. Simulcast systems use the same radio channels at each base station site location. Transmissions from all sites are synchronized to form a composite coverage area composed of all sites in the simulcast system. The resulting simulcast zone is perceived by the users as a single site.

No site selection or roaming is performed by the users or their terminals. Similarly, transmissions from field users may be received by one or more of the base station receivers.

Within a simulcast system the system selects (votes) the best quality signal received and reroutes to all sites to be transmitted (repeated) to all field units. Transmit timing and frequency stability is critical to ensure that the sites function as a synchronized group without destructive interference in areas of coverage overlap from multiple sites.

P25 Deployment

P25 has seen extensive global deployment in the Public Safety domain; however there have been limited applications for Transit Systems. Some key points to be noted are:

- Significant implementations, mostly for first responders in North and South America and Australia;
- Limited Transportation use – key where large geo-graphical areas require coverage; for example GO Transit (providing commuter transit in Greater Toronto Area) and the Ministry of Transportation of Ontario.

Other Transportation applications include:

- Dallas Area Rapid Transit (DART), which uses P25 for both voice and data application;
- The Golden Gate Bridge Highway and Transportation District of San Francisco including the Golden Gate Bridge, the Golden Gate Ferry and Golden Gate Transit. This includes a public-safety radio communications component, automatic vehicle location, transit fleet mobile data capabilities, new computer-aided bus dispatch systems and new real-time announcement and information systems.

TETRA

TETRA is very similar to P25 in that it is an open, interoperable and continuously evolving set of standards. Developed by the ETSI, TETRA provides a digital trunked radio system for voice communications. The main purpose of the TETRA standards was to define a series of open interfaces, as well as services and facilities, in sufficient detail to enable independent manufacturers to develop infrastructure and terminal or subscriber products that would fully interoperate with each other as well as meet the needs of traditional PMR user organizations.

The TETRA suite of standards covers different technology aspects, for example, air interfaces, network interfaces and its services and facilities. The continuous evolution allows benefits from innovation and new technologies to be incorporated as they evolve.

The TETRA standard is based on a digital trunked TDMA technology that, similar to P25, provides a number of inherent advantages and benefits compared with legacy private radio networks.

The TETRA TDMA uses four time slots, providing 4 independent communications channels in a 25 kHz RF bandwidth Channel as shown in Figure 4 below.

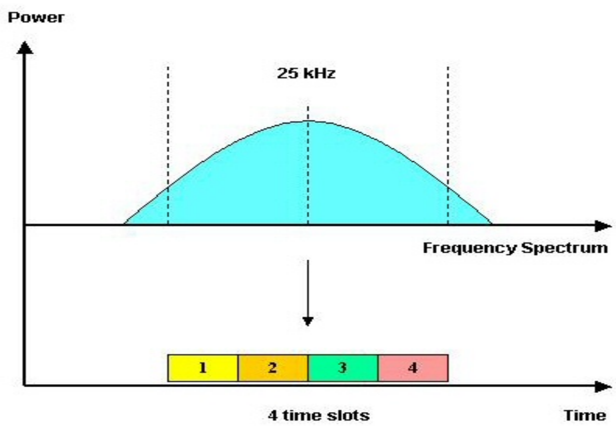

Figure 4. TETRA TDMA

RF Spectrum efficiency is a combination of three main factors being the occupied bandwidth per communication channel, the frequency re-use factor determined by the Carrier to Interference protection ratio C/I in dB's and the trunking technology used.

Key features of the technology are as follows:

Data Throughput - The net data rate in TDMA is better than FDMA in poor RF propagation conditions. This is because Automatic Repeat Requests (ARQ's) are required when received data is corrupted as a result of RF fading. As TDMA terminal devices effectively operate in full duplex ARQ's can be sent efficiently after each time slot transmission instead of waiting until the end of each voice transmission, as is usually the case with FDMA.

Data Bandwidth on Demand – Up to four slots per 25 kHz channel slots up can be combined to increase data throughput as required for specific applications. For higher data rates the TETRA Enhanced Data Services (TEDS) uses multiple 25 kHz channels to provide 25, 50, 100 and 150 kHz bandwidths that will support data rates up to 500 kb/s.

Concurrent Voice and Data - The TDMA time slot structure allows one time slot to support voice and the next time slot to support data in a two slot transmission from radio terminals. This capability effectively allows a single radio terminal to concurrently transmit or receive voice and data at the same time.

Full duplex Voice Communications - TDMA technology inherently supports full duplex communications.

Trunked (TMO) and Direct Mode Operation (DMO) - The TETRA system normally operates in trunked mode, through the base station site, however there is also a need for users to operate in independent local groups. DMO provides the ability for TETRA radio terminals to communicate directly with each other independent of the TETRA network infrastructure in a simplex mode on the same channel. A mobile terminal unit can also act as a DMO Repeater to extend the range of DMO operation, and can also act as a gateway between DMO and trunked mobile operation (TMO).

TETRA System Architecture

The standard TETRA system elements and interfaces are illustrated in the following Figure for a Transit implementation.

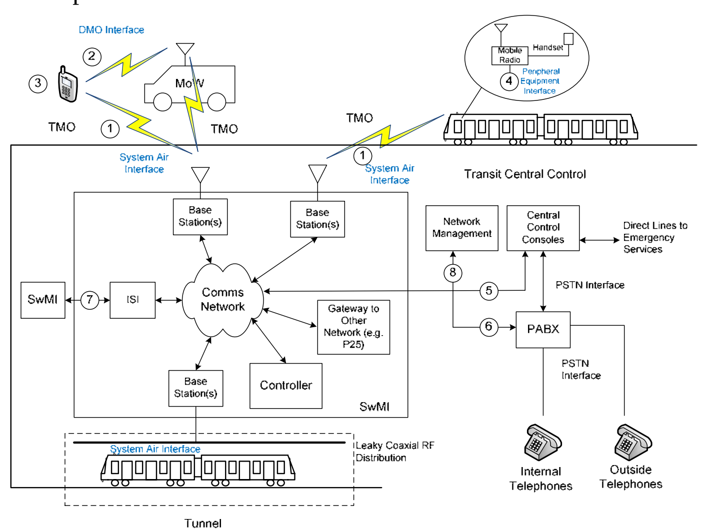

Figure 5. TETRA Architecture

The core element of a TETRA system is the Switching and Management Infrastructure (SwMI). The SwMI includes all the equipment and sub-systems that comprise a TETRA network, including base stations. The standards allow flexibility in design as long as the interfaces are respected. This means that new technologies in the areas of transmission and networking can be used without having to go through a long standardization process.

A control channel is used for each base station location (can be multiple base stations) to provide a signaling communications link with mobile radio terminals operating on the system. This allows the system and usage to be controlled and monitored with:

- The individual and group identity of all radio units registered on the system;
- The individual identity and time at which the radio units registered on the system;
- The individual identity and time radio units de-registered from the system;
- The individual and group identity, time and duration of all messages;
- Different levels of call priority can be set by the Network Manager; e.g. routine users would be set with lowest priority while highest priority would be set for emergency use.

The key TETRA interfaces shown in Figure 5 are described as follows:

Air Interfaces (**1 & 2**) – The interface between the base station and radio terminals (1) and the Direct Mode Operation (DMO) interface (2) described below.

Peripheral Equipment Interface (PEI) (4) - This interface supports data transmission between the radio terminal and an external device. The PEI also supports certain elements of control within the radio terminal from the external device and/or application. The PEI can be used to provide a gateway to radios using different technologies.

PSTN/ISDN/PABX (6) - This interface enables TETRA to interface with the PSTN, via an ISDN interface and/or a PABX. This interface can also be used to interface to other non-TETRA radio networks such as a P25 network.

Inter-System Interface (ISI) (7) - This interface allows infrastructures supplied by different TETRA manufacturers to inter-operate with each other allowing interoperability between two or more networks.

Network Management Interface (8) – A common network interface does not currently exist which is at present a limit to full interoperability.

Besides these interfaces, the many services and facilities available on TETRA are also standardized. The most significant of these being:

- Advanced group call services - clear and encrypted;
- Individual calls - clear and encrypted;
- Short Data Services (SDS) - clear and encrypted.

TETRA Call Capabilities

The following key voice services and facilities are offered by TETRA:

- Group Call (commonly called ‘all in formed net’ and ‘talk group call’);
- Pre-Emptive Priority Call (Emergency Call);
- Call Retention;
- Priority Call;
- Busy Queuing;
- Direct Mode Operation (DMO);
- Dynamic Group Number Assignment (DGNA);
- Ambience Listening;
- Call Authorized by Dispatcher;
- Area Selection;
- Late Entry;
- Voice Encryption.

Group Call - The most common call type, a one-to-many group call is generally set-up within 0.5 seconds and typically less than 300 ms for a single node call. The origin of the call does not affect the call set-up time.

Pre-emptive Priority Call - This call service, of which the highest priority is the emergency call, provides the highest uplink priority and highest priority access to network resources. If a network is busy, the lowest priority communication is dropped to handle the emergency call. Unlike typical three digit (e.g. 9-1-1) public network emergency calls (which can also be supported on TETRA) the TETRA emergency call can be initiated by using a dedicated switch located on the terminal.

Activating the emergency call automatically alerts the associated control room dispatcher and other terminal users in that persons talk group.

Call Retention - This service protects selected radio terminal users from being forced off the network as a result of pre-emptive calls (emergency calls) during busy periods. When emergency calls are supported in a network, it is essential that only a small number of radio terminal users are provided with this facility as the objective of retaining important calls during busy periods could be lost.

Priority Call - During network busy periods, that service allows access to network resources in order of user terminals call priority status. As there are 16 levels of priority in TETRA, this service is very useful in providing different Grades of Service (GoS) during busy periods.

For example, front line officers would be provided with the highest priority levels in a Public Safety network to maintain the highest level of service access whilst routine users would be provided with lower priority levels.

Busy Queuing - In TETRA a queue is provided in the trunking controller during network busy periods to store and handle calls on a "First In First Out" (FIFO) basis for each user priority level.

Direct Mode Operation (DMO) - Direct Mode Operation (DMO) provides the ability for TETRA radio terminals to communicate directly with each other independent of the TETRA network infrastructure. DMO is not new and has been a facility mandated and used by many traditional PMR user organizations for several decades. The DMO function provides a simplex mode of operation using a single 25 kHz channel. The requirement for this mode of operation by Transit and Utilities Agencies makes the use of public cellular networks unsuitable.

Dynamic Group Number Assignment (DGNA) - This service allows the creation of unique User Groups to handle different communication needs and may also be used to group participants in an ongoing call. This service is be extremely useful in Railway Operations, for example; for incident management, allowing set up of a common talk group for incident communications. Selected users from the various groups can be interconnected where close co-ordination is required. A user can belong to and switch to multiple groups, or can exit a group to make an individual call.

Ambience Listening - A Dispatcher may place a radio terminal into Ambience Listening mode without any indication being provided to the radio terminal user. This remote controlled action allows the dispatcher to listen to background noises and conversations within range of the radio terminal's microphone.

This is an important service where operations could be 'hijack' targets such as onboard a rail vehicle in the passenger compartment or driver's cab.

Call Authorized by Dispatcher - This service allows the dispatcher to verify call requests before calls are allowed to proceed. This is a useful service to utilize when radio user discipline needs to be maintained. This service also reduces the amount of radio traffic on a network as only essential work related calls are permitted.

However, the frequent need for all informed net group communications between terminal users and the time delay experienced in authorizing calls can make this service unacceptable for some user organizations.

Area Selection - Area Selection defines areas of operation for users and can be chosen on a 'call by call' basis. This service basically simulates the ability for a dispatcher to select different base stations to make a call as was possible in conventional networks. This service also helps to improve network loading and overall spectrum efficiency by restricting the area of operation for selected group calls.

Late Entry - This service provides continuous call in progress updates to allow latecomers to join a communication channel. This feature allows a trunked radio terminal to behave in a similar way to conventional PMR terminals. For example, if a user turns on their TETRA terminal the control channel will automatically divert the user's terminal to a talk group call, if a call is already in progress. Similarly, if the user's terminal has been outside radio coverage, for example in a tunnel, the control channel will also divert the user's terminal to a talk group call assuming a call is already in progress.

Voice Encryption - The TETRA standard supports a number of over the air TETRA Encryption Algorithms (TEA's), further described below; the differences being the types of users who are permitted to use them.

The TETRA standard also supports 'end to end' encryption using a variety of other encryption algorithms as deemed necessary by national security organizations.

TETRA Data Services

To meet the needs of traditional PMR user organizations, a wide range of voice plus data services and facilities have been provided in the standard. The voice services are described above. The following data services are also supported:

Short Data Service (SDS) - SDS can provide up to 256 bytes of data, which can be used for basic status messaging, location information and free form text message applications in either 'point to point' or 'point to multipoint' call set-up configurations. Because of the relative short duration of each data message, this service is supported on the TETRA control channel TDMA time slots. SDS messages can be acknowledged depending on message type to ensure message delivery. If the data requirements exceed the capacity of the Main Control Channel then Secondary Control Channels can be provided, however these will occupy allocated bandwidth using one of the four timeslot per Secondary Control Channel.

Packet Data Service - The packet data service can be supported on one TDMA time slot with a gross protected bit rate of 4.8 kb/s or multiple TDMA time slots up to a maximum of four. The use of multiple TDMA time slots is often referred to as bandwidth on demand and can be used to increase gross protected data throughput up to 19.2 kb/s, thus increasing the number of non-voice applications that can be supported on TETRA.

TETRA Enhanced Data Service (TEDS) – In the current release TETRA can provide enhanced data services. TEDS can use multiple RF channel bandwidths (25, 50, 100 and 150 kHz) with alternative TDMA modulation schemes that can provide increased data up to 500 kb/s depending upon the bandwidth allocated. TEDS applications may include provision of video or telemetry.

P25 AND TETRA COMPARISON

Both the P25 and TETRA standards offer the following benefits:

- Interoperability between vendors;
- Cost competition and economies of scale with a large market served by numerous independent manufacturers and suppliers;
- Second source security if existing suppliers exit the market;
- Evolution of the technology standard ensuring longevity and good return on investment for both users and suppliers;
- Choice of manufacturers for new products keeping prices competitive;
- Wider choice of products for specialized applications, with competition driving innovation to meet future needs.

P25 and Tetra Security

Encryption is required for voice and data communications for Transit applications. TETRA and P25 both provide high levels of encryption to protect all signalling and identities as well as user speech and data. The levels of encryption provided by both TETRA and P25 are more than sufficient for transit use as demonstrated by their implementation for both Public Safety and transit agencies.

TETRA Security

TETRA has extensive security capabilities, as it needs to provide different levels of security ranging from what is acceptable on commercial networks to what is acceptable on a national Public Safety network. The security mechanisms in the standards are covered through Authentication, Air Interface Encryption (AIE) and End to End encryption. The threats to Confidentiality, Authenticity, Integrity, Availability as well as Accountability are covered with those three mechanisms.

The TETRA standard supports four AIE TETRA Encryption Algorithms (TEAs), these being TEA1, TEA2, TEA3 and TEA 4. There are differences in the intended use and the exportability of equipment containing these algorithms. For example, TEA2 is intended for use by Public Safety users in European countries only; the others have wider applications ranging from general commercial use to Public Safety use in regions where TEA2 is not used. The main benefit of over the air encryption is that it protects all signalling and identities as well as user speech and data.

This provides an excellent level of protection from traffic analysis as well as from eavesdropping. The encryption system is closely bound to the TETRA signalling protocols and the algorithms can (if desired) be implemented as software within radio terminals and base station equipment, instead of using encryption modules, which consume space and increase cost.

The TETRA standard also supports End to End encryption using a variety of encryption algorithms as deemed necessary by national security organizations.

Beside these core security capabilities, TETRA can also support a wide range of security management capabilities such as those used to control, manage and operate the individual security mechanisms in a network.

The most important of these is Encryption Key management, which is fully integrated in TETRA standard functions. Even though security functions are integrated in a network this does not automatically imply that a network is fully secure. However, what is normally achieved is that the security risks are “condensed”, that is they are concentrated to specific elements in the network, which can be adequately controlled.

P25 Security

P25 is specifically designed for Public Safety and security use. It has therefore been developed with high levels of encryption with four types available:

Type 1 - defined for U.S classified material (national security);

Type 2 - defined for general U.S federal interagency security;

Type 3 - defined for interoperable interagency security between U.S. Federal, State and Local agencies. For interoperability purposes, all P25 equipment implementing Type 3 encryption are required to employ the Advanced Encryption Standard (AES) standard with a key length of 256 bits. Type 3 encryption is generally used for Transit applications.

Type 4 – reserved for use by proprietary solutions.

P25 and TETRA Grade of Service (GoS)

The Grade of Service (GoS) required by a Transit Agency from a digital radio system can be defined by:

- The coverage area; with complete radio coverage provided for both above ground and below ground areas;
- Voice quality and data error rates which are compatible with maintaining a 3.4 or better delivered audio quality (DAQ) Availability of voice and data channels when required.

Voice quality and data error rates for both P25 and TETRA radio will be very similar, since performance of the voice codecs (convert analog voice signal to digital signal) used are comparable. In both cases a DAQ of 3.4 or better will be achieved with a corrected bit error rate of between 2% and 5 % which will be determined by the carrier to noise ratio based upon the base station locations and ERP. In either alternative the engineering design will be able to meet the signal quality requirements.

The availability of a communication channel in a trunked radio system is determined by the number of simultaneous conversations, gaps in the communications, duration of communications and the number of available channels (spectrum). This is calculated during the design phase based upon an analysis of users and their communications needs.

Either technology allows an integrated management of its own users including allocation of priorities and establishing call groups (drivers, security, maintenance, operators, etc.).

Potential Interference Issues

For both P25 and TETRA technologies, frequency/channel coordination and allocation to each base station must be coordinated by the system integrator, who must address any possibilities of co-channel interference through filtering and other techniques available. No significant differences in interference potential have been identified between P25 and TETRA.

As digital technologies, both P25 and TETRA are designed so that RF channels occupy only their assigned 25 kHz or 12.5 kHz channels with specified limits placed on interference with adjacent channels. For either technology, guard bands are not required between channels.

The US Federal Communications Commission (FCC) amended their rules, to accept TETRA for use in the US in the 450-470 MHz and 809-824/854-869 MHz bands.

In its ruling the FCC, concluded that TETRA has a lower interference potential to adjacent channel users than other radio technologies currently in use including analog FM and Project 25 Phase 1. However both technologies meet FCC interference requirements.

For a 25 kHz channel not to overlap a 12.5 kHz channel, the center frequencies must be separated by at least 18.75 kHz. The centre frequency of a 25 kHz TETRA signal is offset 18.75 kHz from the center frequency of a 12.5 kHz analog FM signal.

The FCC concluded that TETRA offers adjacent channel protection that is often better than other narrowband systems currently operating in the LMR bands. However the FCC has not allowed TETRA operation in the narrow band Public Safety channels (700 and 800 MHz)

The regulator will assign the frequencies for all radio users in the band and ensure frequency co-ordination between all users. Once applications for frequencies have been made and frequencies have been assigned, then studies must be conducted to ensure that C/I values between adjacent cells and other interfering sources are within specification and where necessary other mitigating measures such as filters are applied. Multipath issues with digital radio are far less that with analog as illustrated in Figure 1 above.

It is therefore not expected that there would be any interference issues between different technologies or users in adjacent channels.

P25 and TETRA Cost Comparison

Cost comparisons between TETRA and P25-2 systems and equipment are not widely available, especially since P25-2 equipment is relatively new. However the body of evidence, including Agency procurement information in the public domain suggests that TETRA equipment costs are lower, although with increased competition P25-2 costs are becoming more competitive.

Based on cost and capability, some utilities in North America are now switching to TETRA. New Jersey Transit recently adopted TETRA for transit communications following a procurement approach based on specification that did not stipulate which digital technology should be used, but based on functional and performance requirements. Although a Utility application, not a Transit application, British Columbia Hydro selected a TETRA solution based upon an open tender. In both cases the TETRA solution was determined to be best able to meet the requirements and was also more cost competitive compared to P25 alternatives. The Toronto Transit Commission has recently begun tendering for a replacement radio system based on TETRA to replace its obsolete MPT technology rather than using the P25 technology with cost concerns being one of the factors.

P25 and TETRA System Expansion

The networked, modular and distributed architectures of both TETRA and P25 allow inherent expansion.

Both technologies are also governed by interoperability standards supported by many global equipment manufacturers and independent and recognized standards bodies (ETSI for TETRA and TIA for P25). The standardization and the certification process followed to demonstrate interoperability will ensure systems are supported through their design life allowing upgrade and expansion by multiple vendors. However it should be noted that most vendors provide enhanced features beyond the standard set which may be unique or differ from other vendors.

P25 and TETRA Failure Management

With both TETRA and P25 systems, fall back modes of operation are available in the event of system failures. In addition system architectures allow for dual redundant base station configurations with redundant network architectures to ensure high availability. When combined with redundant power supplies including uninterruptible power supplies (UPS), the overall infrastructure availability can be extremely high.

It is recognized however that mechanical and electrical failures can occur due to other factors; for example, weather related damage to antennas, cable breaks, etc. In such cases individual sites can act as stand-alone repeaters allowing group call communications managed by the local site database.

TETRA DMO and P25 talk-around functions also allow local communications in the event that users are isolated from the network.

Broadband Applications for P25 and TETRA

One concern with both TETRA and P25 is that they do not support broadband applications. As described above TETRA (TEDS) can provide data rates of up to 500 kb/s if sufficient bandwidth is available, and P25 can provided increased data capabilities by aggregating the 12.5 kHz data channels. However the resulting data capabilities are low compared to other technologies such as 4G. The UHF spectrum for both TETRA and P25 technologies are also heavily utilized with little capacity for significant levels of data transmission, whereas broadband technologies utilize the higher frequency bands that allow higher data transmission rates.

It should be noted that 4G including LTE and WiMax, and other similar technologies are driven by a much larger commercial market with the focus on data rather than voice function, and as a result do not meet the requirements for a mission critical PMR such as TETRA or P25, including reliability, availability, call access times, group call, DMO and other features.

P25 and TETRA have focused on voice communications with minimal data capacity, and the need for high speed data is typically addressed by ancillary data service providers. TETRA Phase 3 is expected to extend the available data capacity however it will still be limited by the spectrum available and bandwidth constraints. Activities will encompass the operation and functionality of a new aeronautical and terrestrial wireless digital wideband/broadband Public Safety radio standard that can be used to transmit and receive voice, video and high-speed data in wide area, multiple-agency networks. The ETSI and TIA are working collaboratively on future migrations, with a joint project known as Project MESA (Mobility for Emergency and Safety Applications). Current P25 systems and future Project MESA technology will share many compatibility requirements and functionalities. It is not known at this stage what the migration strategy will be from either P25 or TETRA Phase 2 to Phase 3.

In some rural areas, 4G may never be a cost-effective solution compared to narrowband LMR networks, which can provide greater coverage on lower frequencies, thereby requiring fewer sites that need to be deployed and maintained.

Key Public Safety features, such as talk-around or group call that are also used in Transit applications are also unlikely to be implemented in the LTE standard within the near future. One key reason for this is that the standards bodies for the technology are driven by the needs of commercial wireless carriers that want customers to remain on their networks. For a number of reasons therefore it is unlikely that LTE will replace either P25 or TETRA for Public Safety, however technologies may emerge including dual mode radios that also provide LTE capabilities, and so the future of both P25 and TETRA based on the current levels of deployment appears to be assured, with a likely migration path integrating LTE.

TETRA and P25 Comparison Summary

P25 has been designed and developed for Public Safety and security applications which have a requirement to cover large geographical regions (State and National), whereas TETRA has a far wider range of applications and is more widely used in Transit. As a result the experience of TETRA with Transit is far greater. However the comparison provided demonstrates that P25 can also meet the voice and data needs of a Transit Agency and the two technologies are very similar in capabilities.

Both TETRA and P25-2 provide digital trunked voice and data capabilities suitable for Transit operations. Similarities between the two technologies include:

- Functionally equivalent to meet transit voice communication requirements including group call, individual calls, emergency calls and direct modes;
- Call prioritization;
- High availability and reliability;
- Fast call set-up times;
- Both use Time Division Multiple Access (TDMA) to divide the voice channels into time slots;
- Both P25 and TETRA are inherently compatible with their earlier equipment standards;
- Interoperability providing multiple sources of equipment within each technology group;
- Allow interfaces to different external communication networks (PSTN, other radio systems, etc.);
- Equal spectral efficiency (4 channels per 25 kHz);
- Operate in same frequency band and provide similar geographical coverage;
- Comparable quality of service.

Differences between the two technologies include:

- P25-2 is not yet widely deployed and interoperability specifications are not yet fully developed;
- With more suppliers and market maturity TETRA can currently offer lower cost solutions for a stand-alone system compared to P25;
- P25 supports simulcast operation with benefits for frequency utilization over larger geographical area, this is important for national and multi-agency applications. P25 is optimized for wider area coverage with low population density;
- TETRA has higher data capabilities (though limited compared to broadband) than P25;
- TETRA has been far more widely used in Transit applications, whereas P25 is more widely used in Public Safety and security applications, in particular when very large geographic coverage is required such as in North America.

Interface To Public Safety Agencies

A Transit Agency may not need or wish to integrate with other radio systems such as Public Safety, and a standalone system may be sufficient. However there are an increasing number of examples where integration is desired. Such integration would allow Transit subscribers to interface directly with Public Safety subscribers in the field, and could allow Public Safety dispatch to interface directly with transit field staff over radio.

Many agencies are reluctant to allow such integration however, where for example police can command a train to stop at a station to conduct a search, since this can have significant affects on the transit system operation. Instead it may be preferable to limit the interface to that between Transit and Public Safety dispatchers (central contro). In addition, in the event of a serious security or safety incident it may be necessary for field Transit staff to evacuate the scene of the incident with coordination only at central control and incident management.

However should integration be required, several methods of interface are available with both TETRA and P25 networks.

Although TETRA is extensively used for Public Safety applications in other parts of the world, it is unlikely that TETRA would be selected for Public Safety application in North America due to the development of P25, and so only the following scenarios are considered:

- Interface between a P25 Transit network and a P25 Public Safety network;
- Interface between a TETRA network and a P25 Public Safety network.

P25 Transit Agency Interface to P25 Public Safety Network

The types of interface employed to interconnect P25 Transit Agency users with P25 Public Safety users will depend upon the operational needs, and could include any of the following:

- Interface at the dispatch (control) level using 9-1-1 calling, this is the most simple interface and most often used;
- PSTN or ISDN interface allowing field personnel to use their radios to call users from another agency or organization;
- Similarly the ISSI interface will connect two networks together at the core infrastructure level, again allowing field personnel to use their radios to call users from another agency or organization;
- If required, the use of mobile gateways in the field to support communications in the field between users of different agencies.

Complete integration could also be considered, with Transit Agency channels and coverage being provided as part of a wider Public Safety network. In this case the Transit Agency would be allocated call groups and priority levels would have to be defined for essential and non-essential Transit Agency channels. Levels of guaranteed service and performance would have to be defined and agreed.

TETRA Transit Agency Interface to P25 Public Safety Network

Any interface should be selected based on the operational scenarios anticipated and the level of interaction required between the transit and Public Safety agencies.

The first, most simple and direct method is to utilize the PSTN interface that is provided by both TETRA and P25 standards, which would provide an identical interface to that used between two separate telephone exchanges. Several suppliers provide dispatch console equipment that is compatible with, and can provide interfaces to both TETRA and P25 networks. This would allow a transit control operator at a dispatch console to patch in emergency services to transit operators in the field, or for individual users from one network to call a user or group from the other.

A second method supported by several suppliers is to develop a TETRA / P25 gateway that would provide a bridge between the TETRA and P25 using IP.

Mobile gateways also exist, using the peripheral interface, to allow portable subscribers on both P25 and TETRA to communicate locally in the field.

CHOSING A TECHNOLOGY

The complexity needed to support the group and other call types described above is one of several reasons that would make public cellular networks unsuitable for Transit operations; simply because they were originally designed to support "One to One" calls, unlike TETRA or P25 which have been designed to support group calls as a primary function.

While some differences do exist, either P25 or TETRA technologies can be used in Transit applications:

- Both provide a level of service reliability, security and functionality not provided by public carriers;
- While TETRA is more mature than its P25 equivalent, both sets of standards provide open architectures, allowing interoperability with multiple supply options;
- Both technologies can be expected to be supported for the design life of a Transit Agency's radio system, with upgrades and future migration paths that will support future additional demands.

Public Safety and security are typically less constrained by economics, whereas Transit is typically more cost constrained. Hence the lower cost TETRA technology provides considerable cost benefits for Transit applications. However since P25 is becoming more widely deployed within North America then costs are expected to fall

Opportunities may exist within a jurisdiction for the P25 Public Safety infrastructure to extend to Transit applications. There are several advantages to this, primarily that:

- Both are typically funded from the same tax base, and therefore where infrastructure can be shared then it represents better value for money;
- Both would typically require coverage over the same geographic area.

However the disadvantages to this are that:

- The Transit Agency may find its access to radio usage at a lower priority than the Public Safety users;
- The Transit Agency would be tied to the Public Safety system which may include more expensive subscriber sets, with significant costs over the lifetime of the system;
- APCO-P25 has been designed specifically for security applications and standards are therefore tied to security/Public Safety functions and requirements;

- Transit functions and needs do differ – and could require some level of customization to an APCO-P25 system. For example some Transit Agencies may have found that earlier MPT 1327 analog systems have had to be customized to support their transit needs;
- Maturity – P25 is still fairly new, with Phase 2 (TDMA) just emerging.

As described above, if communication is required between Transit Agency and Public Safety subscribers, then several options described above exist to interconnect the P25 and TETRA networks that should not constrain the choice of technology.

There is not a simple answer that will suit each Transit Agency, but any selection process should include the following criteria:

- Whole life-cycle costs; not just initial capital costs but considering equipment maintenance costs including periodic replacements and upgrades;
- The degree of independence required by the Transit Agency, including ownership of infrastructure and considering the future needs of the Transit System (growth, expansion, obsolescence management, integration with other systems or equipment, etc.);
- While sharing infrastructure may appear attractive, in the long term the institutional issues may be problematic, therefore the conditions of a Service Level Agreement (SLA) between the parties will be critical;
- Regardless of an SLA, whether a shared infrastructure will provide the Transit users with the channels and functionality necessary to meet the needs. If needs cannot be met, perhaps a stand-alone dedicated Transit infrastructure should be considered;
- Performance requirements including channel coverage, availability and audio quality;
- Functional requirements such as the need for data communications – data requirements may be more extensive for Transit applications, such as requirements to interface to on-board passenger information systems.

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[1] Association of Public Safety Communication Officials

[2] Federal Communications Commission

[3] Terrestrial Trunked Radio System

[4] European Telecommunications Standards Institute

[5] DAQ 3.4 is defined as speech understandable with repetition only rarely required, but with some noise/distortion

6 Frequency Division Multiple Access

[7] Time Division Multiple Access

[8] National Association of State Telecommunications Directors

[9] National Communications

[10] National Telecommunications and Information Administration

[11] National Security Agency

[12] Telecommunications Industry Association