TAIT radio communications

Technologies and Standards for Mobile Radio Communications Networks

TAIT: THE RIGHT FIT

CONTENTS

INTRODUCTION

Many organisations are finding that they need to consider investing in a new or upgraded mobile radio communications network. Dedicated radio networks for use by specific organisations are called land mobile radio (LMR) in the US and professional mobile radio (PMR) elsewhere. This white paper explores various PMR/LMR technologies and standards.

Organisations may be faced with any or all of the following:

- The existing infrastructure is ageing and needs replacement or a last-time buy
- The network uses 25 kHz channels and there is pressure from regulatory agencies (for example FCC in the US) to move to 12.5 kHz or narrower channels.
- Network capacity needs increasing but additional frequencies are not available. Digital networks give more capacity from the same number of frequencies.
- A new digital network promises more features and capabilities, for example through the integrated use of data and voice.

These organisations have a range of options: they can upgrade their existing network, procure a new network, join with other organisations in a shared network, or subscribe to a commercial provider. This white paper explores the choices for those who opt for a new network, to help them decide which is the right fit for them. Before looking at the standards themselves, it looks at the technologies they use. It also looks at other options that are not standards-based. Finally, it lists criteria for assessing the different standards and technologies and provides a summary table. Although the white paper names products that use the standards described, it only evaluates the standards and technologies and not the products themselves.

This white paper is primarily aimed at those who need wide-area or campus-based systems. It is less concerned with public safety organisations, which have their own specific high-end requirements. Small organisations with compact premises could find license-free two-way radios sufficient for their needs, so they may not require a network infrastructure.

TECHNOLOGY OPTIONS

A set of technology choices underlies each PMR/LMR standard. The following aims to explain these technologies and describe their benefits and limitations.

Access Methods: TDMA or FDMA

TDMA (Time Division Multiple Access) and FDMA (Frequency Division Multiple Access) are alternative methods for obtaining the desired spectrum efficiency from RF channels. Some standards use TDMA and others use FDMA.

- TDMA is used by TETRA in 25 kHz channels to obtain four logical channels from each RF channel, and by DMR and P25 Phase 2 to obtain two logical channels from 12.5 kHz.
- FDMA is used by P25 Phase 1 in 12.5 kHz channels, and by dPMR in 6.25 kHz channels. It is also used by MPT 1327 and other analogue systems (TDMA requires digitised voice).

FDMA and TDMA are different ways of enabling multiple users access to communication channels. FDMA does this by dividing the available bandwidth into separate RF frequency channels. TDMA subdivides each RF frequency channel into a number of timeslots. TDMA actually uses FDMA to provide an initial set of RF frequency channels, but then further subdivides them into a number of timeslots. (There is a third multiple access method – Code Division Multiple Access (CDMA). This is used in cellular networks but not in standards-based PMR/LMR radio networks.)

The choice between FDMA and TDMA has been controversial, with debates within standards bodies. Only after many years was the TIA able to decide on TDMA for P25 Phase 2. ETSI opted for TDMA, when it defined DMR Tier II and III, but has also defined another standard (dPMR), which uses FDMA.

TDMA is well established, having been used in GSM, TETRA, OpenSky, and iDEN installations for many years, while FDMA for 6.25 kHz is new. Fears that using FDMA with this narrow bandwidth would be technically too difficult have not been substantiated, although the following issues for FDMA still exist:

- Channels will experience problems when users are travelling at speed, caused by the Doppler effect shifting the carrier frequency. This is more significant at higher frequencies, because the same percentage frequency shift involves a greater number of kilohertz. Increasing the user’s speed will have twice the effect on BER in a 6.25 kHz channel as compared with a 12.5 kHz channel.
- It is technically difficult to restrict transmitted energy to such a narrow channel. As a result, the FCC’s emission mask (Mask E) for the 6.25 kHz signal is very broad and tolerates a lot of adjacent channel interference.

This interference reduces the selectivity of any adjacent analogue channel by almost 10 dB more than if the adjacent channel was analogue. (Digital channels are also affected, but not to the same extent, as their channel filter excludes more of the interfering signal.)

- At higher frequencies (700 and 800 MHz), oscillator drift in mobiles and portables may increase adjacent channel interference and increase BER.

Advantages of TDMA

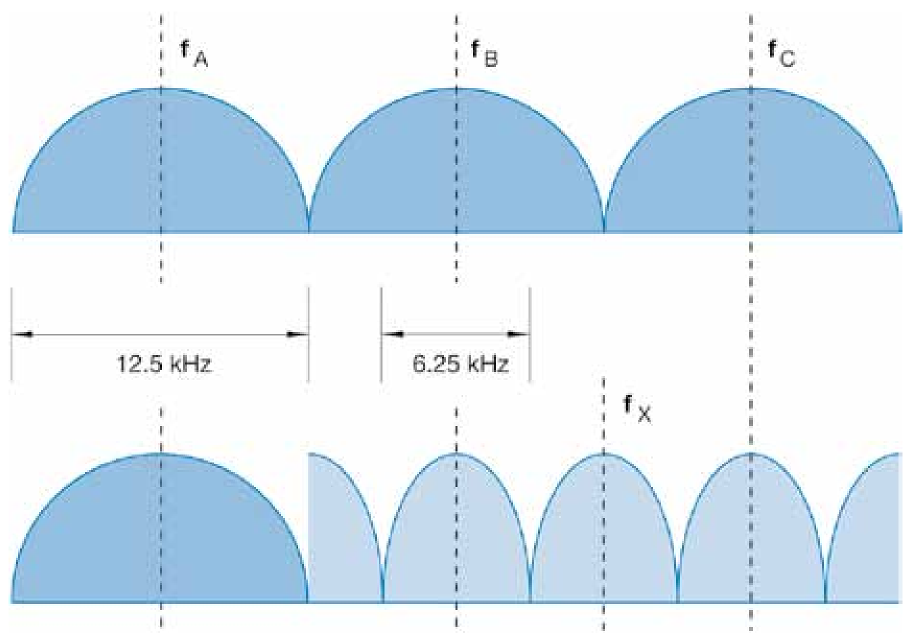
While it may be true that the one technology is not in principle superior to the other, it can have distinct advantages in practice. The following explores advantages that TDMA may have in practice. They are often specific to two-slot TDMA.

Minimizing Frequency Plan Churn

If the organisation already has licenses for 12.5 kHz channels, it can move to a TDMA-based network with no frequency plan churn. Each channel can be used as is without any licensing change.

By contrast, moving to an FDMA-based network with 6.25 kHz channels requires rebanding and relicensing. The way this works in jurisdictions such as the US (FCC) is that new 6.25 kHz channels are assigned, each with the same *centre* frequency as the old licences. This leaves half-channels on either side, which revert to the licensor and can only be used if the other half has also been freed through re-licensing of the adjacent channel for 6.25 kHz.

In the diagram below, three 12.5 kHz channels, fA, fB, and fC, belong to users A, B, and C respectively. Users B and C change to 6.25 kHz channels. This frees up one additional channel, fX, which reverts to the FCC. It also results in half of a 6.25 kHz channel, between fA and fB, which cannot be used. A similar process occurs when moving from 25 kHz to 12.5 kHz channels.



Improving Battery Charge Duration

Modern radios are able to turn their transmitter on and off rapidly. A TDMA radio that is using timeslot 1 to carry a call can turn its transmitter on for each timeslot 1 and off for each timeslot 2. This dramatically reduces battery power consumption, as transmitting is by far the most power-intensive activity of the radio. In a standard operating pattern, consisting of 5% transmitting, 5% receiving, and 90% idle, power consumption would be reduced by around 40%. This greatly extends the duration of a battery charge and increases the amount of talk time. Radios can operate over the longest shifts without battery recharging or replacement.

These improvements are relative to analogue FM or to APCO P25 Phase 1.
The improvements relative to 6.25 kHz FDMA are not so large and not so easily quantifiable. A radio transmitting FDMA with 6.25 kHz bandwidth is transmitting its RF energy into half the bandwidth of a 12.5 kHz TDMA radio. In theory, the transmit power of a dPMR radio could be halved and still obtain the same signal-to-noise ratio as the equivalent TDMA radio. In practice, however, the FDMA radio would not be able to compress the signal into the narrow bandwidth as efficiently. FDMA radios will therefore have higher power consumption than TDMA radios with an equivalent operational range. How much higher will vary with product design.

Ease of Migration

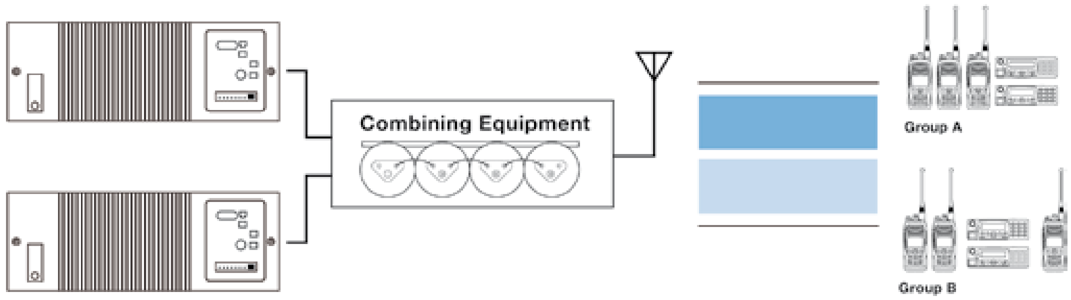
It is easier to migrate from a legacy analogue network to a digital network if that network is TDMA-based and supports backwards compatibility. Existing 12.5 kHz antenna and combining equipment can be used unchanged, as the TDMA channels will use the same RF frequencies as the old network.

TDMA technology may also make a gradual migration possible. If dual mode is supported, equipment can operate on a 12.5 kHz channel either in analogue mode or in digital TDMA mode.

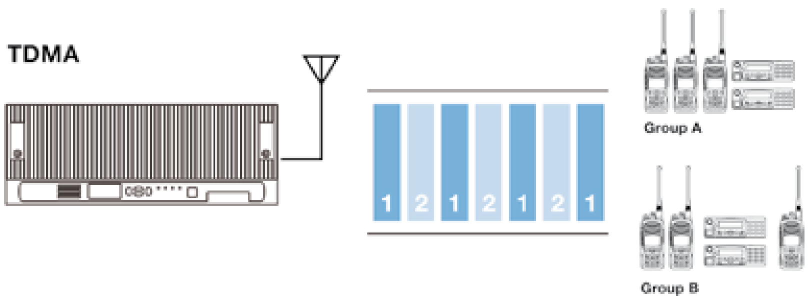
Lower Equipment Costs

Two-slot TDMA means that one repeater makes two logical channels (timeslots) available. This halves the required number of repeaters and reduces the amount of antenna and combining equipment.

FDMA



TDMA



Additional Features

The presence of two timeslots in the channel opens up possibilities for additional features. For example, the second timeslot can contain reverse channel signalling (signalling on the same channel, but which goes in the reverse direction, from receiving equipment to the sending equipment). Reverse channel signalling can be used to tell a transmitting radio to stop, because an emergency call is waiting, or to inform it of its signal strength, so that it can turn its transmit power down or up accordingly.

Disadvantages of TDMA

The following disadvantages are particularly focussed on two-slot TDMA.

- Multipath interference may affect call quality. We can expect that for the same basic receiver design, TDMA will not be able to handle as much multipath as FDMA.
- Not as spectrum-efficient for direct mode (repeater talkaround). In some cases, radios may simply use both timeslots when in direct mode.
- Cannot have two direct mode calls on the one RF channel. This is because time cannot be coordinated between radios that are not in the same call, when a base station is not providing the timing.

Modulation Schemes

Different standards use different types of modulation. Digital modulation schemes modify the frequency, the phase, or the amplitude or any combination thereof, in order to carry the digital data. Amplitude changes require a linear transmitter, which is a more expensive and less power-efficient technology.

Digital modulation schemes are chosen for their data throughput and for their robustness in the face of noise and multi-path fading. Generally speaking, the greater the data throughput, the less robust a modulation scheme is. The raw data rate of a standard results from the modulation scheme chosen.

Modulation schemes can be represented by mathematical equations, I/Q plots, and eye diagrams.

FFSK

The MPT 1327 standard mandates FFSK (Fast Frequency Shift Keying) as the digital modulation scheme for sending data on the control channel. FFSK is also used by EDACS and Motorola's SmartNet and SmartZone. This modulation scheme uses frequency to carry information: 0s and 1s are represented by two frequencies in the audio range. These audio frequencies are then used to modulate the carrier, using FM modulation, in the same way that analogue FM uses voice.

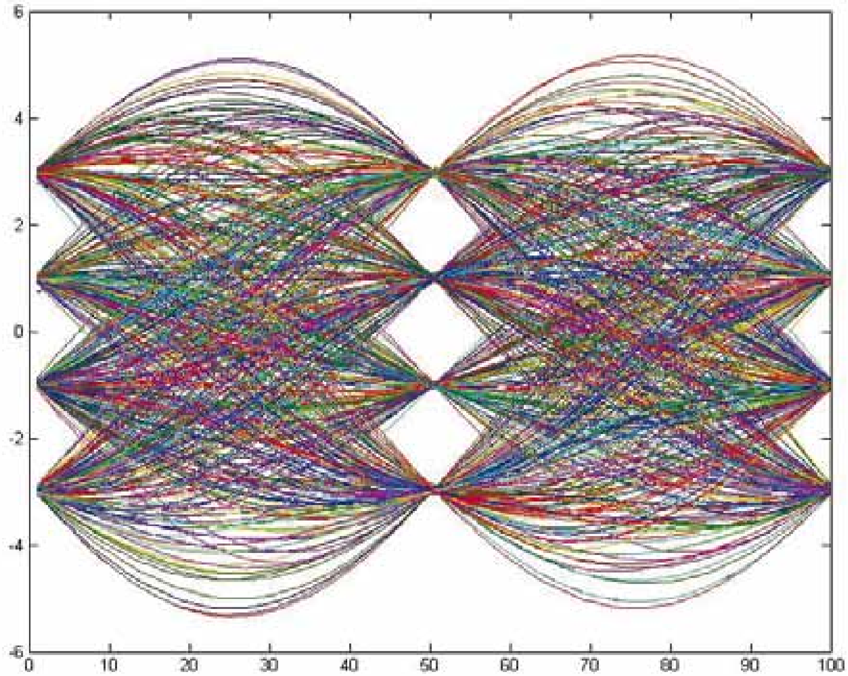
C4FM

The P25 Phase 1 standard mandates C4FM (Compatible 4-Level Frequency Modulation). It also permits an alternate modulation scheme, which is compatible with C4FM: CQPSK (Compatible Quadrature Phase Shift Keying). While CQPSK has not been implemented by manufacturers, Motorola did use it as the basis for developing a proprietary modulation scheme (LSM - Linear Simulcast Modulation) for P25 simulcast networks.

In the C4FM modulation scheme, each set of two bits (dibit) is represented as a fixed deviation from the transmit frequency:

Information	Frequency Deviation
01	+ 1.8 kHz
00	+ 0.6 kHz
10	- 0.6 kHz
11	- 1.8 kHz

The eye diagram for C4FM shows four positions, representing the different dibits:



At each position, the repeated oscilloscope traces pass through the same location, resulting in an eye-shaped hole among the various traces.

4FSK

The DMR Tier II and III standards (as well as dPMR and NXDN) mandate the 4FSK (4-level Frequency Shift Keying) modulation scheme. This is the same basic type of modulation scheme as C4FM: it uses frequency modulation to communicate the information and there are four different frequency deviation levels, each of which communicates two bits.

π/4 DQPSK

The TETRA standard mandates π/4 DQPSK (Differential Quadrature Phase Shift Keying). In this modulation scheme, information is encoded in the phase and in the amplitude. It therefore requires a linear transmitter. 'π /4' means that the phase of each symbol is shifted by π /4. This is done so that phase transitions from one symbol to another do not pass the origin and reduce the peak to mean power ratio in the transmitter.

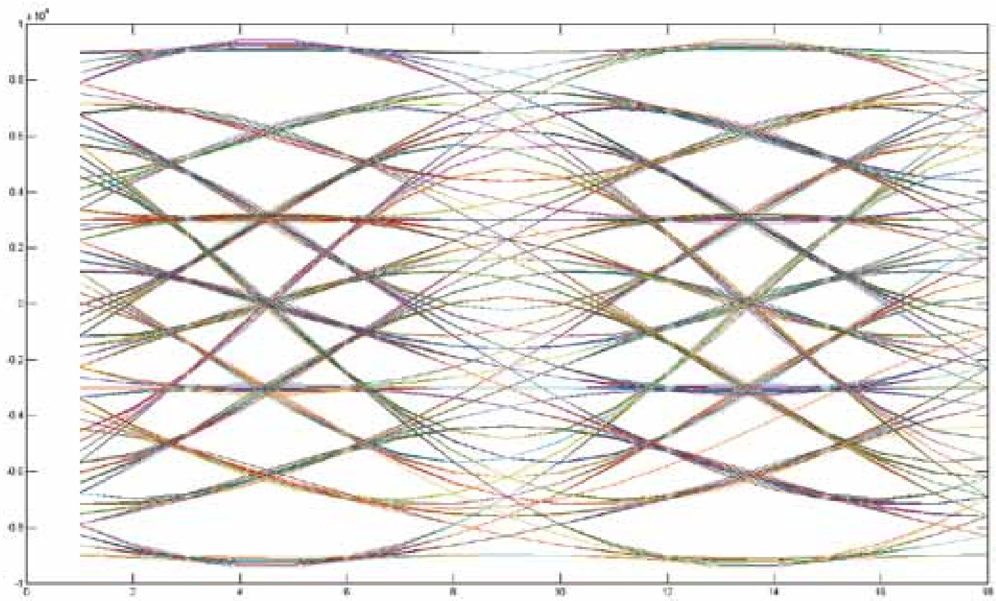
Modulation for P25 Phase 2

Phase 2 of the P25 standard mandates the following modulation schemes:

- HCPM (Hybrid Continuous Phase Modulation) for the uplink.
- HDQPSK (Harmonised Differential Quadrature Phase Shift Keying) for the downlink.
- Alternatively, H-D8PSK can be used for the downlink; this modulation scheme is intended for simulcast systems.

Uplink and downlink use different modulation schemes so as to have the complexity in encoding and decoding in the base station. DQPSK is easier to decode but requires a linear transmitter. HCPM suffers more from I.S.I (InterSymbol Interference) and requires a more complex decoder.

All Phase 2 modulation schemes result in a raw data rate of 12 kbit/s. This increased data throughput results in a more complex eye diagram, as seen in the following example for HCPM.



Vocoder

Digital radios convert the analogue signals from a microphone to a digital form and then compress them using a vocoder (voice encoder). At the receiving end, the process is reversed, producing analogue signals for driving a loudspeaker. Different digital standards use different vocoder technologies. A full-rate vocoder compresses voice sufficiently for it to fit in a narrow-band (12.5 kHz) channel. A half-rate vocoder is necessary to compress the signal sufficiently so that the bit rate is low enough to fit in a 6.25 kHz channel or in one 12.5 kHz TDMA timeslot.

Vocoder	Rate	Used By	Description
ACELP (Algebraic Codebook Excited Linear Prediction)	4.567 kbit/s	TETRA	Older vocoder technology. More recent standards have preferred other vocoders.
IMBE (Improved Multi-Band Excitation)	Full rate (4.400 kbit/s)	P25 Phase 1	
AMBE (Advanced Multi-Band Excitation	Half rate	DMR	The DMR standard itself does not specify a vocoder, but the DMR MoU members agreed on AMBE, to ensure interoperability.
	Dual rate	P25 Phase 2	A dual rate vocoder is able to operate at half rate or full rate, for backwards compatibility with P25 Phase 1.
AMBE +2	Dual rate	Because it is backwards compatible, conforms to DMR and P25 Phase 2.	Slightly more recent and more advanced vocoder, but backwards compatible with AMBE.

Trunked or Conventional

Trunking is a system option for larger networks. Instead of allocating each channel to a set of users, trunking intelligence makes it possible for any available channel to be assigned to any user. The following table shows which standards offer trunked and conventional options.

	Conventional	Trunked
DMR	Yes (Tier II)	Yes (Tier III)
dPMR	Yes	Yes
TETRA	No	Yes
APCO P25 Phase 1	Yes	Yes
APCO P25 Phase 2	No (will be developed)	Yes
MPT 1327	No	Yes

Advantages of trunking

- More users per channel, once the number of channels per site exceeds a certain number. This number will vary, depending on the way the network is used. (Many trunking designs use a dedicated control channel and the increased trunking efficiency needs first to offset the use of a channel for call setup and control.)

- Control of who gets to use the network and what services they are permitted to access.
- More suitable for calls involving more than one site, because intelligence in the trunking controller only includes those sites which have participants in the call.
- Sophisticated handling of failure scenarios (most vendors offer systems which degrade gracefully if equipment or links fail). For example, the loss of one traffic channel only reduces the capacity of the network by one call; no users lose service.

Advantages of conventional

- Simple and cost-effective for smaller numbers of users
- Fast call set-up
- All-informed (however, signalling schemes can segregate groups of users or enable unit to unit calls)

IP-based Backbone

Linking sites in a legacy analogue network can be expensive, with a separate leased line for each voice channel and additional links for control signalling. Modern radio networks now generally use an IP-based backbone. Voice and signalling are transported as IP packets over a network that uses data-capable lines and off-the-shelf building-blocks such as routers and switches. This makes it possible to multiplex control signalling and multiple voice calls over the one link. Standards may not specify line interfaces but there is an advantage to having a network that uses an IP-based backbone.

Look for networks whose elements were designed to work with an IP-based backbone. Some networks can only use an IP-based backbone if they have additional equipment to carry out the necessary protocol conversions from older circuit-switched technologies.

Data

Although PMR/LMR networks have primarily provided voice call services, the importance of data is likely to increase. Networks can have dedicated data channels or dual-purpose channels that can handle voice and data, generally giving voice the priority. They are well-suited to provide low-bandwidth data services and to integrate them with voice. Data services can be used by applications such as the following:

- Vehicle location and tracking
- Encryption key updates (OTAR - Over The Air Rekeying)
- Real time passenger information
- Work force management database access and updates (form based data terminal usage)
- Interactive data messaging (status and text messages).
- Vehicle telematics

- Some simple forms of SCADA (supervisory control and data acquisition)
- Fixed sign updates

Some standards may define the data services which a network can provide and leave the applications that actually use the data services for proprietary solutions. Others may define protocols for particular applications; for example, P25 has defined OTAR and is currently defining services for AVL (Automatic Vehicle Location - GPS-based positioning information).

PMR/LMR networks use a much smaller bandwidth than cellular networks. They are therefore less suitable for applications that require significant data capacity, such as photographic images, video, or complicated web pages. The discrepancy in data capability between PMR/LMR and cellular networks is likely to increase with the rollout of fourth generation cellular networks, which will use adaptive modulation schemes (LTE for example).

The raw data rate of many PMR/LMR standards is 9k6 bit/s, which, after providing forward error correction, slot formatting, headers, and framing, leaves approximately 2000 - 6000 bit/s for the data application. Unlike voice, data cannot have any errors; the data may have to be re-sent, reducing the throughput. Coverage for data applications is likely to be less than for voice; data communications will work well with good coverage but may not work at all at the edges of voice coverage.

The extent to which the different standards have defined data services varies considerably. DMR defines status messaging, short data messaging, and a packet data service. TETRA provides circuit data and packet data services that can be used for IP. TETRA has a raw IP packet data rate of 7.2 kbit/s for one timeslot of a TDMA channel; combining timeslots can provide a raw data rate of up to 28.8 kbit/s, of which approximately 9 kbit/s is available to applications. P25 has a raw data rate of 9.6 kbit/s and offers mainly confirmed and unconfirmed data services. It is also in the process of defining location services (TSB-102.BAJA gives an overview). Tier 1 is completed and Tier 2 is in development.

For system integrators and application developers, an IP-based data service is highly desirable. Applications can then communicate with each other over IP and need not concern themselves with the air interface at all. To support an IP-based packet data service, the network needs to be able to handle radios moving from one location to another. This can be accomplished by routers that support mobile IP. In some P25 systems, radios register with the router using SNDCP (Sub Network Dependent Convergence Protocol). This establishes the context for the radio and enables the router to send IP packets along the right path to it. Because of the limited bandwidth available, the IP data may be compressed. Applications may need to be carefully designed to minimise the amount of data they need to send.

Both the P25 and TETRA standards bodies have been developing standards for high-speed data. Both ETSI and the TIA have agreed to work collaboratively on Project MESA (Mobility for Emergency and Safety Applications), with the aim of developing specifications for a mobile broadband technology. Several TEDS (TETRA Enhanced Data Services) “proof-of-concept” systems have been demonstrated. Although TEDS was standardised as early as the end of 2005, as of this writing no TEDS systems have been commercially deployed. It remains to be seen whether manufacturers will offer solutions based on these standards.

STANDARDS

Successful standards bring real advantages. When vendors work to agreed standards, those managing radio systems have a choice of supplier, which tends to bring down prices and improve quality, and they are not at risk of being unable to source products for replacement or expansion through the demise of a sole supplier. GSM in the cellphone area, APCO P25 in US public safety and TETRA in Europe are examples of successful digital standards.

To properly qualify, a standard needs to be non-proprietary, that is, not under the control of one vendor. The standard needs to be defined and controlled by an independent body, and there needs to be a proper process for resolving conflict between interested parties over the decisions to be made. Some standards only define the air interface, while others cover line interfaces as well.

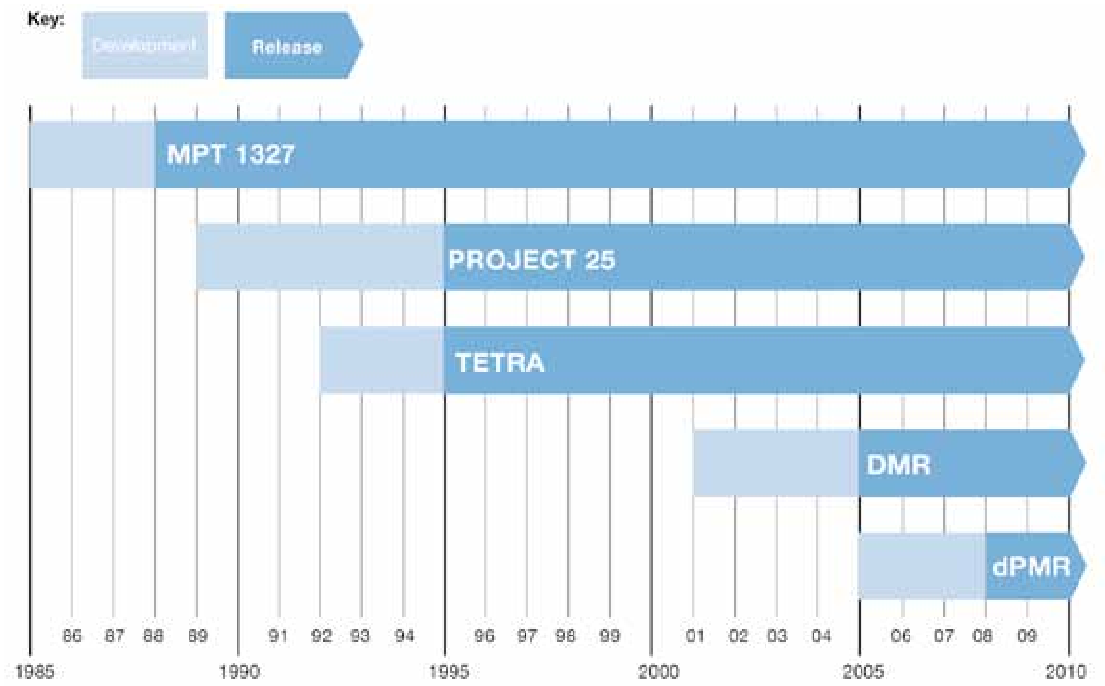
Equipment from one vendor designed and produced to a standard should be interoperable with equipment from another vendor. However, caution is appropriate; there is often room for differences of interpretation of a standard, and vendors can add proprietary features not covered by the standard itself. Look for standardised interoperability test procedures or results from certified interoperability laboratories.

The advent of digital radio has increased the importance of standards.
With conventional analogue FM, interoperability for basic features is a given.
With digital, equipment cannot interoperate at all, unless the same protocols are used. If different vocoders are used, speech cannot be understood. If different control signalling is used, users cannot communicate call setup information.

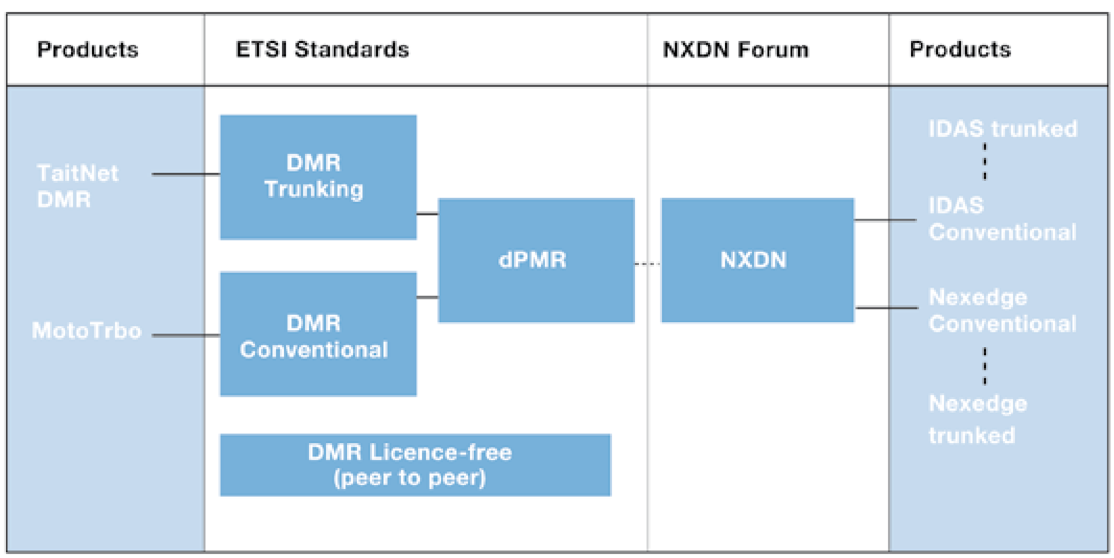
Recent Developments in Standards

In 2000, there were only two non-proprietary open digital PMR/LMR standards: TETRA and APCO P25. TETRA (TErrestrial TRunked Radio) had been developed by ETSI (European Telecommunications Standards Institute). TETRA was designed for large, national networks run by government agencies and used by public safety organisations and others as well. APCO P25 was designed primarily for public safety users. While TETRA comes from Europe and APCO P25 from the US, both standards have been widely adopted outside their area of origin.

However, recent years have seen the emergence of new standards. In 2006, ETSI published the DMR (Digital Mobile Radio) standard. This standard was designed for business and professional users and aimed to make available digital systems with low complexity and low cost levels. The standard defined three different tiers. ETSI has since also defined dPMR (digital Professional Mobile Radio) standards. dPMR was initially an FDMA variant for DMR Tier I but has evolved to provide equivalent FDMA standards for DMR Tier II and Tier III.



NXDN, a set of proprietary but open protocols, has been developed based on the Tier II dPMR conventional standard, but it is not compliant with it. Icom and Kenwood offer conventional products that conform to NXDN. However, their trunked offerings are not based on dPMR trunking requirements and are also not compatible with each other.



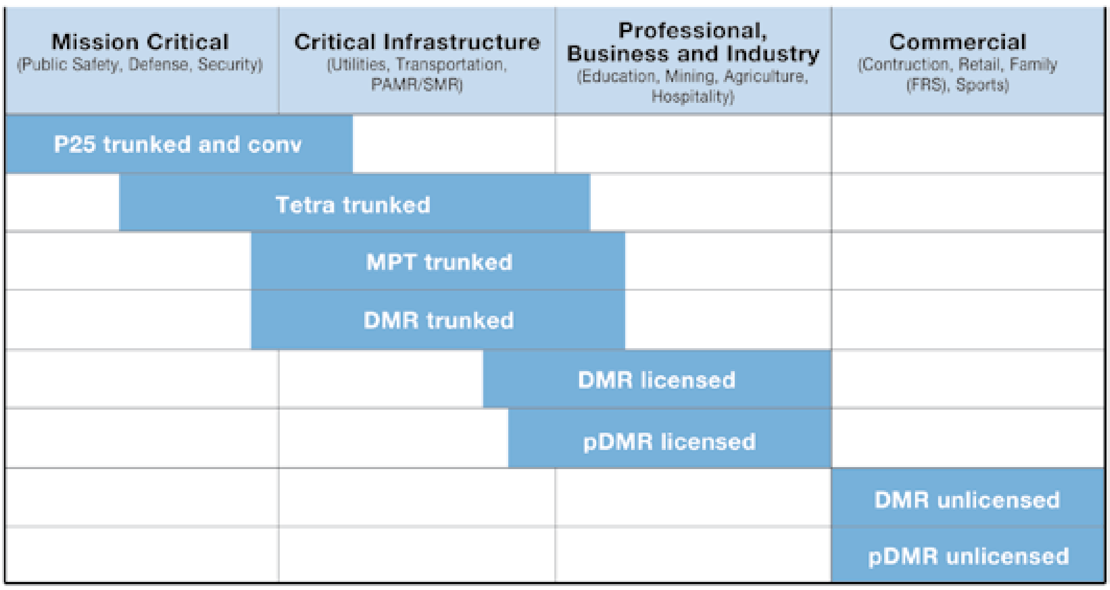
Standards and the Market for Mobile Radio Communications

Standards are generally targeted at particular market needs. Mobile radio communications networks can be divided into the following types, each reflecting the different needs of the organisations that use them:

- Public Safety or Mission Critical (fully featured and highly available networks for police, fire, first responders).

- Critical Infrastructure (wide area networks that are essential for business, for utilities, transport, and for public access mobile radio).
- Professional or Business and Industrial (smaller “campus” networks for a variety of organisation types).
- Commercial (peer-to-peer communications that don’t require any infrastructure).

The following diagram gives an overview of the different standards and the system types they are targeting. The features and capabilities of a standard will generally be closely matched to the targeted system types and the needs of the organisations that use them.



DMR

DMR (Digital Mobile Radio) is a standard defined by ETSI (European Telecommunications Standards Institute). It was first published in 2005 and now provides a full set of standards covering voice, data services and conformance tests. The standards describe the air interface only.

DMR aims to provide a low-cost, low-complexity digital standard to replace analogue radio. It defines three different tiers.

Tier I is aimed at the low end of the market, for applications such as sport, family vacations, and perhaps for commercial enterprises such as retail. It is license-free and permits up to a maximum of 500 mW transmit power output. Operation is peer-to-peer, that is, there are no repeaters. Tier 1 uses FDMA.

Tier II is digital conventional and uses 12.5 kHz two-slot TDMA. It is for licensed operation with higher transmit power. It is aimed at business and industry: mining, manufacturing, and any organisations with campuses that suit single-site coverage.

Tier III is tier II plus trunking and can be thought of as a digital replacement for MPT 1327. It is aimed at applications that will benefit from trunking efficiency. These include organisations responsible for critical infrastructure, such as utilities, transportation, oil, and gas.

While TETRA (also an ETSI standard) and Project 25 were developed with high end systems in mind, but are starting to penetrate the middle ground, DMR began with simple peer-to-peer operation and added functionality to create the higher tiers.

Advantages of DMR

- Non-proprietary open standard.
- Commercially attractive alternative to TETRA and P25 for those who do not need a high-end system.
- Gives 6.25 kHz channel efficiency, four times that of legacy 25 kHz analogue channels, which complies with all current and likely future FCC mandates.
- Doubles network call capacity when replacing an analogue network with 12.5 kHz bandwidth.
- TDMA extends radio battery charge duration, when compared with P25 or 12.5 kHz analogue FM radios. (See Improving Battery Charge Duration on page 6.)
- 12.5 kHz channel size allows re-use of existing frequency licences and site infrastructure (combiners, antennas).

Disadvantages of DMR

- Line interfaces are not part of the standard.
- Vendors are likely to offer additional, proprietary features that are not covered by the standard.

dPMR

Digital Professional Mobile Radio (dPMR) is also an ETSI standard, developed after DMR. While DMR uses TDMA to obtain 6.25 kHz spectrum efficiency, dPMR uses FDMA. Just as there are three tiers of DMR, so there are three modes of dPMR. Mode 1 is peer-to-peer, Mode 2 is conventional (repeaters and infrastructure), Mode 3 has managed sites, each with a beacon channel (dPMR terminology for trunking with control channels). However, it seems that dPMR itself is now only of academic interest, as its main supporters, Icom and Kenwood, have developed NXDN (see NXDN on page 24), their own protocols, which are based on dPMR but incompatible with it.

TETRA

TETRA (TErrestrial TRunked RAdio, formerly known as Trans European Trunked RAdio) is an ETSI standard. Work on it began in 1989 and full European Telecommunication Standard status was obtained in 1995. TETRA provides a full set of standards for air and line interfaces. It is established as the default standard for public safety networks in the UK and in Europe but there are intellectual property and regulatory hurdles that need to be overcome for it to gain a foothold in North America. While this is likely to occur, it will take time.

TETRA was developed to meet the requirements of diverse kinds of end users (not only public safety users). ETSI envisaged networks provided by national organisations, with nationwide coverage, operating usually in urban environments. Consequently, TETRA is more like a cellular telephone system than other PMR/LMR standards and is suited to areas with high volumes of radio traffic. It relies on high user numbers to share the infrastructure cost. Most of TETRA's differences in features from other standards arise from this different purpose.

TETRA does not define an analogue mode of operation. There is no migration path from legacy analogue networks. Operation is trunked; there is no conventional mode. Initially, TETRA had no direct mode (repeater talkaround), but this has since been rectified, with a number of direct mode options.

TETRA equipment is generally comprehensively tested for interoperability. From the beginning, the TETRA Association commissioned an independent certification body (ISCOM) to test interoperability against TETRA Interoperability Profile specifications and test plans. The certification body issues TETRA Interoperability Certificates containing the results of its tests and makes them publicly available. The TETRA association is now looking for ways to simplify these procedures.

TETRA uses four-slot TDMA. Receivers must reply to a downlink signal in time for the next timeslot with the same slot number as the downlink slot. The guard time is the gap between the end of one timeslot and the beginning of another, and effectively determines the allowable time delay which increases with the distance from the base station. For TETRA, the guard time is 0.389 ms (compare DMR: 1.25 ms); the shortness of this interval is the fundamental reason for the limited size of a TETRA cell (see Coverage on page 27).

Advantages of TETRA

- Non-proprietary open standard.
- High level of interoperability between TETRA products from different vendors.
- Fully featured.
- TDMA gives 6.25 kHz channel efficiency (four timeslots in 25 kHz channels).
- Radios have a lower transmit power and therefore can be smaller, less expensive, and more cellphone-like.
- Encryption.

Disadvantages of TETRA

- TETRA systems require clean blocks of contiguous spectrum, which may not be available from the relevant regulatory authority. This is in part because TETRA channels cause interference on existing analogue channels and in part because the standard requires that the transmit and receive frequencies of a channel are 10 MHz apart. For example, if the transmit frequency is 381.0000 MHz, the receive frequency must be 391.0000 MHz. A "clean" block of spectrum is needed, so that no already licensed frequencies interfere with the TETRA channel plan.

- TETRA requires 25 kHz channels and this may conflict with narrowbanding plans. Many countries are considering plans to refarm their spectrum into 12.5 kHz channels, to increase the number of available channels. This may cause practical difficulties in licensing 25 kHz channels.
- TETRA is not designed for backwards compatibility or migration from legacy analogue networks. Those who opt for a TETRA system will need to completely replace their radios because TETRA radios will not interoperate with analogue FM radios. Moreover, TETRA infrastructure cannot operate in an analogue FM mode to provide services to legacy radios.
- TETRA coverage is significantly less than for other PMR/LMR standards, which means that many more site installations are required for a given area. This is an important consideration for networks in areas with a low population density. It may also mean that more channel licenses are required.
- The lower TETRA coverage may mean that more channel frequencies are needed to prevent interference from adjacent channels.
- TETRA is not available as a conventional network.
- The lower power of TETRA radios (1 W) restricts the range between peer-to-peer (direct mode) users to as little as three kilometres (two miles).
- TETRA base stations must be linear, which adds to their cost.
- The TETRA vocoder is older than and probably not as effective as the new half-rate vocoders.

APCO P25

APCO P25 is an open standard initiated by APCO (Association of Public Safety Communications Officials) and developed by the TIA. It has had strong end user input and although it is US-based and primarily oriented towards public safety requirements, many countries outside the US and commercial organisations are also choosing it.

One of the important aims in developing the standard was to ensure interoperability between different agencies, as proprietary systems had prevented this in the past. Accordingly, Project 25 has established a Compliance Assessment Program (CAP). Each vendor publishes a Suppliers

Declaration of Compliance (SDoC) as an output of the CAP process. CAP has approved test laboratories from E F Johnson, Motorola, Harris, and Tait, as well as from two independent laboratories.

The standard initially only defined the air interface, but has evolved to cover dispatch interfaces and interfaces between trunking subsystems, allowing networks from different vendors to be interconnected.

APCO P25 Phase 2 is in development and will provide 6.25 kHz channel equivalence through 12.5 kHz two-slot TDMA and modulation schemes that give a raw data rate of 12 kbit/s. It will be backwards compatible with Phase 1.

Note: Motorola has developed a 9.6 kbit/s TDMA solution with 6.25 kHz channel equivalence. However, the TIA did not approve this design for P25 Phase 2; it opted for 12 kbit/s. It will be important to make sure that Motorola product offering 6.25 kHz channel equivalence actually complies with the TIA P25 Phase 2 standard.

Advantages of P25

- Non-proprietary open standard.
- Fully featured.
- Conventional, trunked, and simulcast options. Combinations of these options can be optimised to reflect customer requirements. For example, trunked in high-density urban areas and conventional in rural areas.
- Designed for gradual, phased migration from analogue FM. Equipment can operate in analogue FM mode, in digital P25 mode, or in dual mode.
- Supports simplex mode (repeater talkaround) for direct communications outside network coverage.
- Very secure end-to-end encryption.

Disadvantages of P25

- Only 12.5 kHz channel efficiency (FDMA). However, Phase 2 of the P25 standard provides an upgrade path to 6.25 kHz channel equivalence.
- While P25 radios can be dual mode (analogue FM or digital P25), trunked P25 networks cannot offer analogue FM services.

MPT 1327

MPT 1327 is a trunked radio standard published in 1988 by the Ministry of Post and Telecommunications in the United Kingdom and widely used in Europe and beyond. There is a tendency to assume that this is an old standard with no future in the digital age. In fact, it dates from the time when work on TETRA began, uses digital signaling and is worthy of serious consideration. It is one of the world's most widely-used radio trunking standards and provides a comprehensive feature set at low cost. Many different vendors offer mature and fully featured product ranges. However, those considering this option should make sure that equipment purchased offers a smooth migration path to a standard such as DMR, as this may be required in future to conform to regulatory requirements for spectrum efficiency. MPT 1327 networks are scalable from a single site with just a few channels to a wide area system covering a whole nation.

MPT 1327 is a recent arrival in North America, where patents previously blocked its use. It is highly suitable for networks that need to cover large geographical areas with low population density. People in North America are familiar with transmission trunking, which is used by several proprietary trunked systems, but not with message trunking, which MPT 1327 uses. In transmission trunking, each time a call participant presses PTT, the system assigns a channel. This is designed for dispatch communications, which are largely one way, but two-way conversations can place a strain on the call control system. In message trunking, the system assigns a channel for the duration of the conversation, making it more suitable for two-way conversations.

MPT 1327 uses 12.5 kHz channels (20 kHz and 25 kHz are generally also available). Control signalling (on a dedicated control channel) is digital and uses FFSK modulation. Voice is analogue over the air but may be converted to the digital PCM format for switching and for sending over the line to the PSTN or to other sites.

Advantages of MPT 1327

- Non-proprietary open standard.
- Low cost of ownership
- Ease of integration with third party equipment.
- Wide coverage.
- Proven technology.

Disadvantages of MPT 1327

- Spectrum efficiency is limited to one channel per 12.5 kHz.
- Generally circuit-switched, so requires additional equipment to use an IP backbone. Alternatively, it may need costly leased analogue lines for intersite links.
- Users requiring privacy are limited to analogue scrambling, which is inferior to digital encryption.
- Talking party ID for group calls requires a proprietary extension.

PROPRIETARY OPTIONS

Alongside the open standards, there are proprietary protocols. Some of them are open, which means that the originators publish them, so that other vendors are able to design and produce compatible products.

EDACS

EDACS is a Swedish-based trunking technology, and is used globally. It supports transmission and message trunking. Because of the success of TETRA in Europe and P25 in the US, the future of EDACS is unclear. If you are considering EDACS, it will be important to obtain guarantees of ongoing support and maintenance from the vendor.

Advantages of EDACS

- EDACS is versatile in terms of the frequencies it can be applied to, with VHF, UHF, 800 MHz, and 900 MHz all being options. It also conforms to international spectrum planning conventions with channel widths of 12.5 kHz or 25 kHz.
- As is common in trunking systems, a range of call types is offered – group, individual, and emergency. Status messaging is possible and talk groups may be formed.
- EDACS systems are available as “EDACS digital” or “EDACS analogue” and are data-capable.
- Systems may also be encrypted with the encryption format known as “AEGIS”.
- At repeater sites the hardware architecture is “fault tolerant”, with a level of fall-back should any hardware fail. Adding to this robustness is the ability for an individual repeater site to “stand alone” and maintain operation should the linking to other sites fail.
- There is a hardware interface available which allows EDACS systems to interface with radio systems of other types.

Disadvantages of EDACS

- Only one vendor.
- There is no “direct mode” (simplex) interoperability between radios, and unless a hardware interface has been put in place between the EDACS network and the network of any other organisation, there is also no communication possible between them.
- While EDACS does have the ability to handle present channel widths of 12.5/25 kHz it does not provide (presently) a 6.25 kHz mode for future spectrum efficiency.
- EDACS systems are limited to a maximum of 24 channels at a single site.

OpenSky

OpenSky is a proprietary radio system used in the USA which targets public safety customers. It uses two-slot TDMA 25 kHz channels. It provides a data rate of 19.2 kbit/s over a 25 kHz channel.

Advantages of OpenSky

- OpenSky networks are IP based. Radios have IP addresses, which are used to identify the destination for a message.
- OpenSky networks use interface cards to interconnect with other networks and this is how OpenSky achieves interoperability. This form of interconnection provides a customer with an easy migration path during a fleet changeover.
- OpenSky technology is versatile enough to be used in a trunked or a conventional mode. When used in the trunked mode, no control channel is needed, which is an advantage in site planning.
- When a user switches on their radio, they are able to enter a PIN number which causes their own personalised radio profile to be downloaded into that radio. The advantage is that any user, can personalise any radio very quickly in terms of channels and set ups.
- Encryption is available.

Disadvantages of OpenSky

- Only one vendor.
- The ability to interoperate with other technologies, including existing analogue radios, is not built into each OpenSky subscriber unit but is provided as an interface ability of the OpenSky network.
- Whilst OpenSky subscriber units can communicate between themselves on direct (simplex) channels, they cannot communicate with any non-OpenSky units on simplex channels; no network means no interoperation.
- OpenSky subscriber units do not have a “dual-mode” for analogue operation to achieve this.
- Limited to 700, 800, and 900 MHz operation.

TETRAPOL

TETRAPOL is a trunking technology that was developed by EADS (formerly MATRA) and is mainly in use by police and military in Europe. It pre-dates TETRA, as its first implementation was for the French National Gendarmerie in 1988. The core design criteria have been trunking, encryption, and wide area coverage. TETRAPOL is well-proven having enjoyed a successful rollout over some years, and although it is a proprietary system, the system interfaces are publicly available.

TETRAPOL uses FDMA 10 or 12.5 kHz channels. Future third generation TETRAPOL is expected to make provision for two 6.25 kHz channels in a single 12.5 kHz channel. Present TETRAPOL systems are switch-linked, however very large TETRAPOL systems may be linked via IP.

Advantages of TETRAPOL

- TETRAPOL has been well planned from the outset, with initial consensus from the users, and with all specifications available and stable for vendors to use in their product designs. Consequently there has been no uncertainty for vendors about features or operation.
- As is usual in trunking systems, a range of services is available. These include status messaging, and call types such as individual, group and emergency calls.
- TETRAPOL systems also provide a “direct” or simplex mode.
- A data speed of approximately 4.8 kbit/s is achieved right out to the limit of radio coverage.
- The available data speed does not deteriorate as the signal weakens.

Disadvantages of TETRAPOL

- TETRAPOL radios themselves offer no conventional mode operation, and it is necessary to use a SCC (Single Channel Converter) to communicate with analogue radios. (This interface can also provide an interface with other types of radio networks.)

NXDN

NXDN (Next Generation Digital Narrowband) is a set of proprietary, but open protocols that have been jointly developed by Icom Incorporated and Kenwood Corporation. NXDN is based on the dPMR standard, but is intentionally non-compliant, in order to bypass intellectual property issues relating to the dPMR standard. The initial driver has been to meet the requirement of 6.25 kHz channel efficiency. Both companies have released products (IDAS from Icom and Nexedge from Kenwood) based on these protocols. Each has both conventional and trunked options. The trunked options are not currently compatible with each other.

The basic outline of the NXDN specifications is completed. The developing companies hope that other vendors will provide products designed to these specifications.

Advantages of NXDN

- Complies with FCC requirements for 6.25 kHz channel equivalence.
- Low cost of ownership.
- Backwards compatible with analogue and with LTR (Logic Trunked Radio) networks.

Disadvantages of NXDN

- Trunked NXDN products from different manufacturers (Icom and Kenwood) are not compatible with each other.

SUBSCRIBING TO A COMMERCIAL CELLPHONE PROVIDER

There is the option of not having a dedicated network at all and instead using the services of a commercially provided cellphone network. This may look attractive in that a large, up front capital investment is not required, however, shared use on a commercial network may not be able to satisfy an organisation's requirements for reliability and availability. Moreover, a dedicated network has a fixed cost, whereas the cost of a commercial provider increases with increased use.

Advantages

- No up-front capital investment.
- Cost is based on the amount that the network is actually used.

Disadvantages

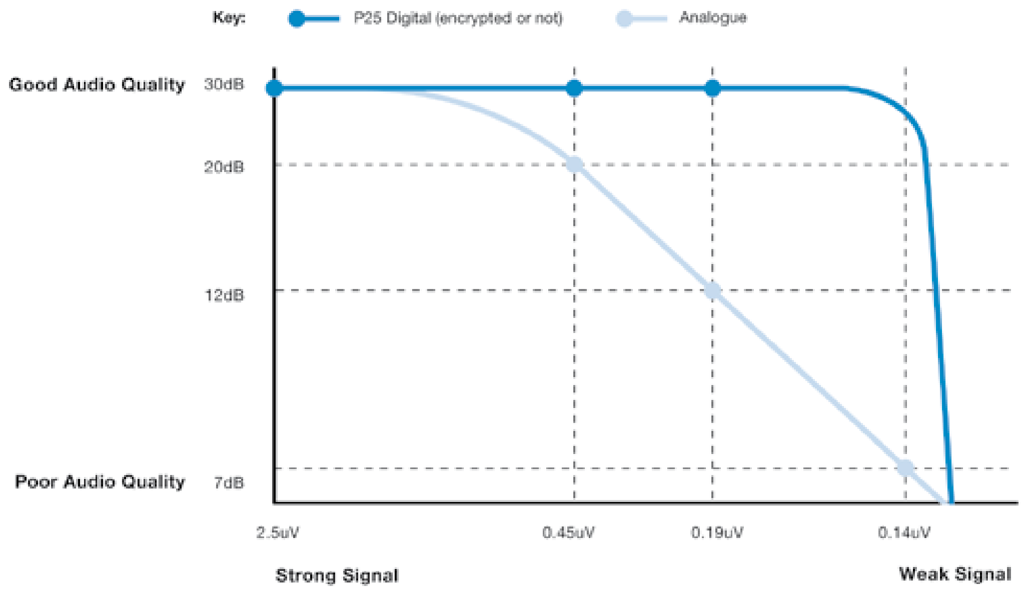
- No direct mode means no communications outside network coverage or in the event of major network failure.
- Call setup is slow.
- Group calls may be possible but are necessarily channel-intensive.
- No priority access to the network during a disaster or emergency. In these situations, where radio communications are of critical importance, public networks are likely to suffer system overload or at least poor quality of service, making mission-critical calls difficult or impossible.
- Increased use brings increased cost.
- Coverage may be poor outside urban areas. It is determined by the goals of the network provider rather than the operational needs of your organisation.

ASSESSMENT CRITERIA

Audio Performance

The general consensus is that digital radios provide better audio quality than analogue ones. While the quality of analogue audio declines as the received signal strength reduces and the signal to noise ratio increases, digital radios operate with binary digits and generally either correctly decode the signal as a 0 or a 1 or they fail. This means that the signal that the receiving radio reconstructs is exactly the same as the transmitted signal. Digital radios can cope with a certain amount of noise and static, through forward error correction processes that are defined in the standards.

As a result of this, what users experience with digital radio is high voice quality right to the edge of coverage. Beyond this, voice quickly breaks up once the signal level is close enough to the background noise level that FEC can no longer cope or the radio is unable to decode frame synchronization. The following diagram compares the digital and analogue voice quality of typical radios as signal strength declines.



One caveat applies to the general statement that digital voice is superior to analogue. The Phoenix Fire Department concluded after its own testing that analogue voice was slightly better than digital and decided to use analogue simplex communications in the fireground. (http://www.ci.phoenix.az.us/FIRE/radioreport.pdf.) If you have the luxury of 25 kHz channels and users will be in environments with high noise levels, analogue might be superior. Because vocoders are designed to compress human speech, background noise can cause distortions in the vocoder output.

The improvement of digital over analogue is even more marked for secure voice communications. While digital encryption has no effect on voice quality, analogue scrambling or encryption techniques degrade it.

Different digital standards mandate different vocoders. Half-rate vocoders generally entail a reduction in voice quality compared with full rate vocoders, as they compress voice into half the bandwidth.

Ease of Migration

To move to a TETRA system means a complete break with the previous network. Existing infrastructure equipment and user radios cannot function in a TETRA network. By contrast, P25 and DMR are designed to enable a smooth migration from analogue systems. Both infrastructure and radios must support the legacy analogue FM mode as well as the new digital mode. This means that networks can be upgraded in stages, and that the fleet of radios can be upgraded as radios reach the end of their useful life. Users with new digital radios can talk with those on analogue FM radios, using analogue channels.

Those considering a new P25 Phase 1 network or upgrading an existing MPT 1327 network need to work on the assumption that they will be required to move to 6.25 kHz channel efficiency sooner or later. It will be important to check with the vendor to ascertain how straightforward such a migration will be.

Reliability and Availability

The reliability and availability of a network is only partly a question of the technology and standards that it is based on. The use of redundant links and backup controllers is a major consideration. Trunked networks are generally fault-tolerant. Standards designed for public safety applications are required to have high availability.

Coverage

Building new sites and antenna towers is the most costly part of installing a radio network, so the coverage of the new system is of crucial importance. There are advantages in selecting a standard that enables a digital upgrade without needing to add sites to obtain the same coverage. The International Telecommunication Union, in its 2006 report M.2014-1, quoted the following comparative coverage figures for P25 Phase 1 and TETRA:

	Mobile/Rural Coverage Cell radius (km)	Handheld/Suburban Coverage Cell radius (km)
APCO P25 Phase 1	35	7.6
TETRA	17.5	3.8

While DMR has similar coverage to P25, and both are approximately the same as conventional analogue, TETRA coverage is much smaller. It is important to realise that halving the cell radius results in a requirement for roughly four times the number of sites.

Spectral Efficiency

Exponential growth in the use of the radio spectrum means that radio systems will be required to optimise their use of radio bandwidth. In the long term, organisations can expect that they have to move to 6.25 kHz channels or to larger channels with an equivalent spectrum efficiency.

In the US, the FCC has mandated the following:

VHF/UHF (150-174 MHz & 421-512 MHz)

1/1/2011	Applications for new systems using 25 kHz channels, or modification applications that expand the authorised contour of an existing 25 kHz station, will not be accepted.
1/1/2013	Radio systems must operate in 12.5 kHz or narrower channels.
No Date Set	Modifications to existing systems – must employ equipment capable of operating in 6.25 kHz channels or demonstrating an equivalent spectrum efficiency.
No Date Set	Radio systems must operate in 6.25 kHz channels or demonstrate an equivalent spectrum efficiency.

700 MHz

1/1/2015	700 MHz voice systems operating before this date can continue to operate in 12.5 kHz channels until 12/31/2016. All new systems must operate in 6.25 kHz channels or demonstrate an equivalent spectrum efficiency.

1/1/2017 All 700 MHz systems must operate in 6.25 kHz channels or demonstrate an equivalent spectrum efficiency.

Similar requirements are to be expected in other jurisdictions.

TETRA, DMR, dPMR and NXDN offer 6.25 kHz spectrum efficiency. P25 Phase 2 also offers this efficiency and P25 Phase 1 provides a migration path from 12.5 kHz FDMA to Phase 2 two-slot TDMA. MPT 1327 networks, and some proprietary networks, will need to migrate to digital to obtain the required spectrum efficiency.

Interoperability

Organisations may be called on to interoperate with other organisations, especially in emergency situations. For example, an electricity utility may need to be in communication with police when dealing with storm damage. Once the procedures for dealing with such situations are clear, any interoperability needs will emerge. Having a network based on the same standard as the organisations that you interoperate with may become important. Standards that offer an analogue FM mode of operation may offer advantages. Direct mode may be of use to provide interoperability at the scene.

Privacy

Standards oriented towards public safety have highly secure encryption options, offering a very high level of privacy. DMR does not yet define the means of encryption, so vendors are likely to provide proprietary options, which means that radios may not be able to interoperate using secure communications.

SUMMARY

This table summarises basic properties of the different standards.

	Standard	Business Targeted[1]	Network Size	Analogue or Digital?	C or T[2]?	Modulation	TDMA/FDMA	Vocoder	Vendor: System Name[3]
Conventional Analogue	Yes		Local, Regional	Analogue	C	FM			All
NXDN	No	C	Local, Regional	Digital	C	4FSK	FDMA	AMBE + 2	Icom: IDAS, Kenwood: Nexedge
DMR Tier II	Yes, ETSI	C	Local, Regional	Digital	C	4FSK	TDMA 2 slots	AMBE + 2	Motorola: Mototrbo, Selex: ECOS, Radio Activity
DMR Tier III	Yes, ETSI	B, C	Local, Regional	Digital	T	4FSK	TDMA 2 slots	AMBE + 2	Tait: TaitNet
MPT 1327	Yes (British)	B, C	Nationwide	Digital signalling, Analogue voice	T	FM			Tait, Fylde, Motorola, Simoco
OpenSky	No	A, B	Regional, Nationwide	Digital		4-GFSK	TDMA 4 slots	AMBE	Harris (formerly M/A-COM, Tyco
P25 Conventional Phase 1	Yes, TIA	A	Regional	Digital	C	C4FM	FDMA 12.5 kHz	IMBE or AMBE + 2	Motorola: Smartzone P25, Tait: TaitNet, Harris, Simoco, EF Johnson, Daniels Electronics, Raytheon
P25 Trunking Phase 1	Yes, TIA	A, B	Regional, Nationwide (ISSI)	Digital	T	C4FM	FDMA 12.5 kHz	IMBE or AMBE + 2	Motorola, Tait, Harris, Spectra Engineering, Simoco, Daniels Electronics, EF Johnson, Raytheon, EADS, Teltronic
P25 Phase 2	Yes, TIA	A, B	Regional, Nationwide (ISSI)	Digital	C or T	CQPSK	FDMA 12.5 kHz (backward compatible) and TDMA 2 slots		We expect that Phase 1 providers will develop Phase 2 product.
TETRA	Yes, ETSI	A, B	Nationwide	Digital	T	π/4-QDPSK	TDMA 4 slots	ACELP	Motorola, EADS, Teltronic, Rohill, Rhode & Schwarz and more
TETRAPOL	No	A	Nationwide	Digital	T	GMSK	FDMA 12.5 kHz	CELP	EADS

1. A = Public Safety or Mission-Critical, B = Critical Infrastructure, C = Professional or Business and Industrial. See Standards and the Market for Mobile Radio Communications on page 15.
2. C = Conventional, T = Trunking
3. Examples only: list not exhaustive

CONCLUSION

Recent years have seen an increase in the number of radio standards and proprietary options. Those who are considering investing in a new or upgraded network have the benefit of an increased range to choose from but also the risk of making an inappropriate choice. A careful analysis of actual communications requirements, followed by an exploration of the available options, assisted by this white paper, will facilitate the choice of the best fit for your organisation.

FOR FURTHER READING

Associations

TETRA Association: www.tetra-association.com/

DMR Association: www.dmrassociation.org/

dPMR Forum: www.dpmr-mou.org

NXDN Forum: www.nxdn-forum.com/

Project 25 Technology Interest Group: www.project25.org/

Vendors

Tait Radio Communications: www.taitradio.com

Motorola: www.motorola.com
MotoTrbo : http://mototrbo.motorola.com/

Kenwood
NEXEDGE : http://nexedge.kenwood.com/index.html

Icom: http://www.icomamerica.com/en/landmobile/

Harris
OpenSky: www.pspc.harris.com/products/opensky/default.asp

More Detailed Documents

Of Cars and Digital PMR by Bryan Seedle, Chairman of Fylde Microsystems. LandMobile Magazine February 2008

(Description of DMR and dPMR)

DMR vs TETRA Comparison: http://www.radioactivity-tlc.it/documenti/ENB26-DMR-vs-TETRA%20comparison.pdf

MPT 1327 Trunked Radio Standard: http://www.radio-electronics.com/info/cellulartelecomms/private-mobile-radio/trunked/mpt1327-trunking-radio-standard.php

Which Technology for your Organisation? http://www.radioandtrunking.com/What-technology.htm

Fact Sheets on TETRA and on Tetrapol from OFCOM (Swiss Federal Office of Communications): http://www.bakom.admin.ch/themen/technologie/01397/index.html?lang=en

EDACS Explained: http://scanneraudio.com/edacs.pdf