Digital Radio Standards Uncovered

An introduction to digital radio standards and related technology platforms

White Paper

CONTENTS

WHAT WILL YOU LEARN FROM THIS PAPER?

This paper provides technical information on currently available open standard, digital technologies. For organizations seeking to replace existing networks, or considering an initial purchase of a communication solution using land mobile radio (LMR), this paper will seek to inform those decisions.

The paper will explain the different modulation schemes and multiple access methods used in radio technology as well as comparing the performance of a range of digital standards against pre-determined criteria. The criteria used in this comparison reflect the requirements of a typical wide area network, suitable for Public Safety organizations and Utilities organizations.

The technology platforms included in this paper are DMR, P25, MPT1327, Tetra and dMPR. However, the information presented on dPMR can also be applied to FDMA systems like NXDN.

MORE CAPACITY AND GREATER VOICE CLARITY WITH DIGITAL RADIO

Compared with legacy analog systems, digital radio networks provide:

- **More capacity from the same number of frequencies.** Digital radio provides superior Spectral Efficiency[1] than analog radio. This is a result of the modulation methods used.
- **Greater voice clarity at low received signal levels near the edge of coverage.** Generally, digital radios provide better audio quality than analog ones. Analog audio quality steadily declines as the received signal strength gets weaker. Digital radios however, code speech as a stream of binary digits and either correctly decode the signal as a 0 or a 1, or it fails. This means the signal that the receiving radio reconstructs is exactly the same as the transmitted signal. Digital radios can cope with a level of noise and interference, through Forward Error Correction (FEC) processes defined in the radio standards. As a result, the digital radio user experiences high voice quality right to the edge of coverage. Beyond this, voice quickly breaks up once the signal level reduces and the FEC can no longer cope.

It is a common misconception that 'digital radio' only refers to the transfer of digital data, in the same way it is that analog radio is limited to voice. In fact both options can transfer either voice or data. Data is generally not defined in analog standards, and therefore analog data implementations are proprietary. In comparison, data transfer is well defined in digital radio standards.

***"Both analog and digital* radio can transfer either voice or data, *however* data is generally not defined in analog standards... leading to proprietary implementations"."**

Footnote:
1 Spectral Efficiency is a term relating to the amount of information that can be conveyed in a given bandwidth.

tait communications

UNDERSTANDING MODULATION, MULTIPLE ACCESS AND TRUNKING FOR RADIO STANDARDS

This section explains the common technology attributes that underlie each PMR or LMR standard as a basis to understanding the radio standards themselves.

MODULATION

In traditional analog modulation schemes, the frequency, amplitude or phase of the radio signal is continuously varying. In digital modulation schemes however, only certain states of frequency, amplitude and/or phase are defined. These states are called ***Symbols***, and each symbol conveys several bits of data, such as digitized voice). If the modulation contains amplitude changes, a linear transmitter is required; a technology that is more expensive and less power-efficient.

Digital modulation schemes have superior spectral efficiency and robustness in the face of interference and multi-path fading. Generally speaking, the greater the data throughput, the less robust a modulation scheme is. In simple terms, this means that the greater the ***Symbol Rate,*** the more prone to interference the channel will be and the poorer the coverage will become.

While there are only three main types of analog modulation (Amplitude Modulation, Frequency Modulation and Phase Modulation), many more types of digital modulation exist. The following section covers the more common digital modulation methods.

FFSK Modulation

FFSK (Fast Frequency Shift Keying) uses frequency to carry information: 0s and 1s are represented by two frequencies in the audio range. These audio frequencies then modulate the carrier, using FM modulation, in the same way that analog FM uses voice. As the modulation contains no amplitude content, simple transmitters similar to their analog FM predecessors can be used.

MPT 1327 uses FFSK Modulation as the digital modulation scheme for sending data on the control channel.

C4FM

C4FM (Compatible 4-Level Frequency Modulation) has four frequencies (four symbols), each used to convey two bits of data. For example:

INFORMATION	FREQUENCY DEVIATION
01	+ 1.8kHz
00	+ 0.6kHz
10	- 0.6kHz
11	- 1.8kHz

NOTES

C4FM contains no amplitude content, so simple transmitters similar to analog FM systems can be used.

P25 Phase 1 is a digital open standard that uses C4FM.

4FSK Modulation

4FSK (4-level Frequency Shift Keying) is a very similar type of modulation to C4FM, essentially being frequency modulation that employs four frequency deviation levels, each of which communicates two bits of data. The key difference is that C4FM refers to particular symbol frequency deviations (+/-600Hz and +/-1800Hz), whereas the term 4FSK can refer to a variety of different symbol frequency deviations.

4FSK modulation contains no amplitude content, so simple transmitters similar to analog FM systems can be used.

Standards that mandate 4FSK modulation include DMR Tier 2 and 3, dPMR and NXDN.

π/4 DQPSK

Like FFSK, C4FM and 4FSK, QPSK (Quadrature Phase Shift Keying) conveys two bits of data per symbol. In this case however, this is done by four symbols separated by amplitude and phase. During transitions between symbols, the amplitude of the signal can reduce to zero, so the transmitter may produce significant unwanted energy in neighboring channels.

DQPSK (Differential QPSK) limits the amplitude content of the signal and therefore reduces the energy in neighboring channels.

'π/4 DQPSK' refers to the phase difference between neighboring symbols; π/4 radians or 45 degrees.

Given that the signal has amplitude content, more complex, expensive and power-hungry linear transmitters are required for π/4 DQPSK.

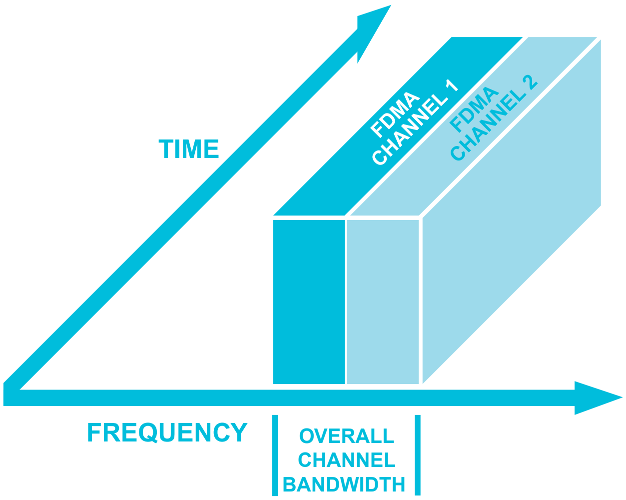
TETRA mandates the use of π/4 DQPSK.

MULTIPLE ACCESS METHODS: TDMA OR FDMA

We now understand that digital modulation provides greater ***Spectral Efficiency*** than its analog predecessors. FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access) can further improve spectral efficiency so that more than one 'conversation' is accommodated on a single radio channel, at the same time.

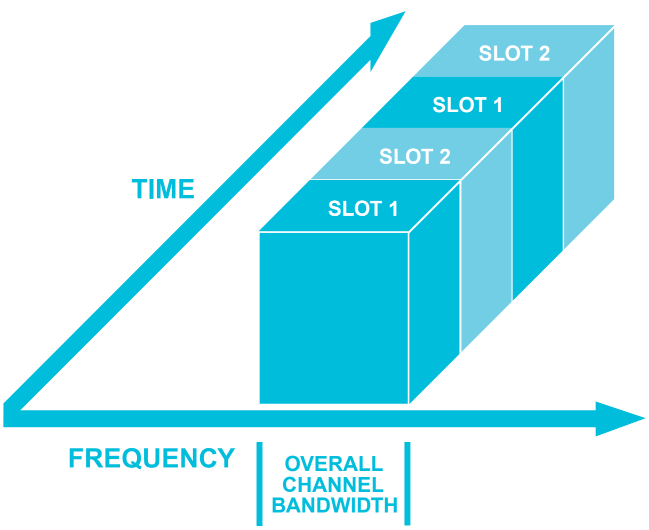
NOTES

FDMA divides the available bandwidth into separate RF frequency channels, as shown below.



FDMA
FDMA divides the available bandwidth into separate RF frequency channels

In comparison, 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, as shown below.



TDMA
TMDA further subdivides the RF frequency channels into a number of timeslots

A third axis 'Code' – Code Division Multiple Access (CDMA) is used in cellular networks but not in radio standards-based networks.

The choice between FDMA and TDMA has been controversial, prompting debates within standards bodies. Some standards use TDMA and others FDMA. Only after many years did Telecommunications Industry Association (TIA) decide on TDMA for P25 Phase 2. The European Telecommunications Standards Institute (ETSI) used TDMA for TETRA, but with the latest standards they selected TDMA when defining DMR Tier 2 and 3, and defined another standard - dPMR - which uses FDMA.

TRUNKED OR CONVENTIONAL RADIO NETWORKS?

Trunking is a system option for larger networks. Trunking essentially makes it possible to allocate any radio channel to any user, maximizing the possible radio 'traffic' within any set of channels. The following table shows which radio standards offer trunked and conventional options:

STANDARD	CONVENTIONAL	TRUNKED
DMR	Yes (Tier 2)	Yes (Tier 3)
dPMR	Yes (Mode 2)	Yes (Mode 3)
TETRA	No	Yes
APCO P25 Phase 1	Yes	Yes
APCO P25 Phase 2	No (will be developed)	Yes
MPT 1327	No	Yes

Advantages of trunked radio

- More efficient use of frequencies due to the dynamic channel allocation at the call setup.
- Greater control with authenticated user access to the network and its services.
- Suitable for calls involving more than one site, as the trunking controller only includes sites which have participants in the call.
- Sophisticated handling of failure scenarios. For example, the loss of one traffic channel only reduces the capacity of the network by one call; no users lose service. Most vendors offer systems which degrade gracefully if equipment or links fail.

Advantages of conventional radio

- Simple and cost-effective for sites with a small number of channels.
- Fast call set-up.
- All-informed feature (however, signaling schemes can segregate groups of users or enable unit-to-unit calls).

OPEN DIGITAL RADIO STANDARDS

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

"To properly qualify, a standard needs to be non-proprietary, so not under the control of one vendor."

To properly qualify, a standard needs to be non-proprietary, so not under the control of one vendor. It should be defined and controlled by an independent body with a proper process for resolving conflict between interested parties.

Some standards only define the air interface, while others cover line interfaces as well.

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

The advent of digital radio has increased the importance of standards. With conventional analog FM, interoperability for basic features is inherent. However digital equipment cannot interoperate unless the same protocols are used. For example, if different vocoders are used, speech cannot be understood; if different control signaling is used, users cannot communicate call setup information.

DIGITAL RADIO STANDARDS DEVELOPMENTS

In 2000, there were only two non-proprietary open digital PMR or LMR standards; TETRA and APCO P25. TETRA (TErrestrial TRunked Radio) was developed by the European Telecommunications Standards Institute for large, national networks run by government agencies for public safety organizations and others. APCO P25 was designed primarily for public safety users. While TETRA originated in Europe and APCO P25 in the United States, both standards have been widely adopted outside their area of origin.

In 2005, European Telecommunications Standards Institute (ETSI) published the DMR (Digital Mobile Radio) standard with three tiers for business and professional systems with low complexity and low cost. ETSI has since defined dPMR (digital Private Mobile Radio), an FDMA variant for DMR Tier 1, which now provides equivalent FDMA standards for Tier 2 and Tier 3.

DIGITAL MOBILE RADIO (DMR)

DMR now provides a full set of air interface standards covering voice and data services, and conformance tests. Current developments will add interfaces, encryption and application protocols to the standard.

DMR provides a low-complexity digital standard to replace analog radio. DMR is promoted as a data and voice standard that can operate in 6.25kHz channel equivalence mode.

- Tier 1 is aimed at applications such as sport, family vacations and commercial enterprises such as retail. It is license-free and permits up to 500mW transmit power output. Operation is peer-to-peer, so it requires no repeaters.
- Tier 2 is digital conventional. It achieves 6.25kHz channel equivalence through 2-slot TDMA on an existing 12.5kHz narrowband FM channel. Designed for easy migration of analog to digital, the output spectrum must fit in to the existing 12.5kHz narrowband FM channels used by legacy analog systems.

DMR Tier 1 - commercial enterprises such as retail

DMR Tier 2 - digital conventional

DMR Tier 3 - digital trunked replacement for MPT 1327

The choice of modulation scheme and associated symbol rate are critical. 4FSK modulation is used with an associated symbol rate of 4800symbols/sec. Each symbol carries 2 bits of data, so the equivalent data rate is 9600bits/sec. Both the downlink (base station to terminal) and uplink (terminal to base station) use this modulation.

- Tier 3 DMR Trunked is a digital replacement for MPT 1327, aimed at applications that will benefit from trunking efficiency. These include organizations responsible for critical infrastructure, such as utilities, transportation, oil, and gas.

dPMR

Digital Private Mobile Radio (dPMR) is an ETSI standard developed after DMR, and using FDMA to divide the 12.5kHz channel into two 6.25kHz sub-channels. The implications of this are covered later in the ***Key Comparisons of the Standards*** section. Just as there are three tiers of DMR, 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, dPMR is only offered outside the United States. In the United States its main supporters, Icom and Kenwood, have developed NXDN as their own protocols, which are based on dPMR but incompatible with it. Early 2012 (at IWCE) they announced NXDN will become an open standard.

"dPMR is an ETSI standard developed after DMR and *uses* FDMA *technology*"

TETRA

TETRA (TErrestrial TRunked RAdio, formerly known as Trans European Trunked RAdio) is an ETSI standard. Work on this began in 1989 and the 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. Two years ago the intellectual property hurdles were removed for the United States and TETRA is now aiming to enter the market. TETRA is now fully approved in Canada with an outcome on FCC rulings expected in the coming months. TETRA was developed to meet the requirements of diverse kinds of end users (not only public safety users). ETSI envisaged networks provided by national organizations, with nationwide coverage, operating usually in urban environments. Consequently, TETRA is more like a cellular telephone system than other professional or land mobile radio 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* is established as the default standard for public safety networks in the UK and in Europe".

TETRA does not define an analog mode of operation. There is no migration path from legacy analog networks. Operation is trunked; there is also 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 Association is now looking for ways to simplify these procedures.

TETRA uses π/4 DQPSK modulation with an associated symbol rate of 18000symbols/sec (36000bits/sec). These choices of modulation method plus the relatively high symbol rate mean the resulting radio signal has a bandwidth too wide to be accommodated in a 12.5kHz narrowband FM channel. Instead, a 25kHz wideband channel is required. Within this, 6.25kHz channel equivalence is achieved through the use of 4-slot TDMA. These choices have far reaching implications, which will be described in the Key Comparisons of the Standards section of this paper.

APCO PROJECT 25 (P25)

APCO Project 25 is an open standard initiated by the Association of Public Safety Communications Officials (APCO) and developed by the Telecommunications Industry Association (TIA.) It has had strong end user input and although it is United States-based and primarily oriented towards public safety requirements, many countries outside the United States and commercial organizations are also choosing it.

"P25 has had strong end user input and although it is United States-based and primarily oriented toward public safety requirements, many countries outside the United States and commercial organizations are also choosing it"

One of the important aims in developing the standard was to ensure interoperability between different agencies at an emergency scene, as proprietary systems had prevented this in the past.

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

P25 was designed to enable ease of migration from analog to digital. Therefore P25 mandates two 'phases', in effect, each providing one step along the way between existing narrowband FM analog systems, with the desired end result of a digital system with 6.25kHz channel equivalence.

As a first step, P25 Phase 1 mandates the use of C4FM with a symbol rate of 4800symbols/sec (9600bits/sec). These choices result in a radio signal that fits nicely in to the existing narrowband FM channel. To ease the upgrade, P25 Phase 1 radios must be backwards compatible with existing narrowband FM systems, so it is not necessary to upgrade the entire network in one go.

The second step of the migration is provided by P25 Phase 2. Here, 6.25kHz channel equivalence is achieved for voice operation only, through the use of 2-slot TDMA. The modulation schemes are also different. The uplink uses HCPM (Hybrid Continuous Phase Modulation) and the downlink uses HDQPSK (similar to π/4 DQPSK).

The reason behind the use of different modulation schemes is to simplify the design of the terminals (mobile and portable radios) and to have the complexity in the base station/repeater. Essentially, DQPSK is easier for the terminals to decode but requires a linear transmitter in the base station, whereas (having no amplitude content) HCPM eases the design of the terminal transmitter, but requires a more complex decoder in the base station. Both the uplink and downlink operate at an increased symbol rate of 6000symbols/sec (12000bits/sec).

P25 Phase 2 radio standard will be backwards compatible with P25 Phase 1.

Note: Motorola have developed a 9600bit/s TDMA solution with 6.25kHz channel equivalence. However, the TIA did not approve this design for P25 Phase 2; instead, it opted for 12000bits/sec. It will be important to make sure that Motorola product offering 6.25kHz channel equivalence actually complies with the TIA P25 Phase 2 standard.

MPT 1327

MPT 1327 is a trunked radio standard published in 1988 by the Ministry of Post and Telecommunications in the United Kingdom and is 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.

"There is tendency to assume that this is an old standard with no future in the digital age. In fact, *MPT 1327* uses digital signaling and is worthy of serious consideration."

MPT 1327 entered North America later than the rest of the world, as 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 12.5kHz channels (20kHz and 25kHz are generally also available). Control signaling (on a dedicated control channel) is digital and uses FFSK modulation. Voice is analog 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.

KEY COMPARISONS OF THE STANDARDS – WHAT DOES IT ALL MEAN IN PRACTICE?

NOTES

We have worked through digital modulation methods, multiple access schemes, and the main open digital radio standards that exist. All this is necessary background, ***but what does it mean in practice?*** What performance differences would the end user experience when using one radio standard versus another? Perhaps the best way to illustrate this is to compare some key standards, and show the implications of the different modulation methods, symbol rates, and multiple access schemes that were chosen.

ASSESSMENT CRITERIA FOR STANDARD COMPARISONS

First, let us define the following assessment criteria against which to benchmark the performance resulting from the following standards:

- Spectral efficiency
- Ease of migration from existing analog systems
- Coverage
- Choice of frequency bands

Using these assessment criteria, we will first compare DMR to dPMR.

DMR VERSUS dPMR COMPARISON

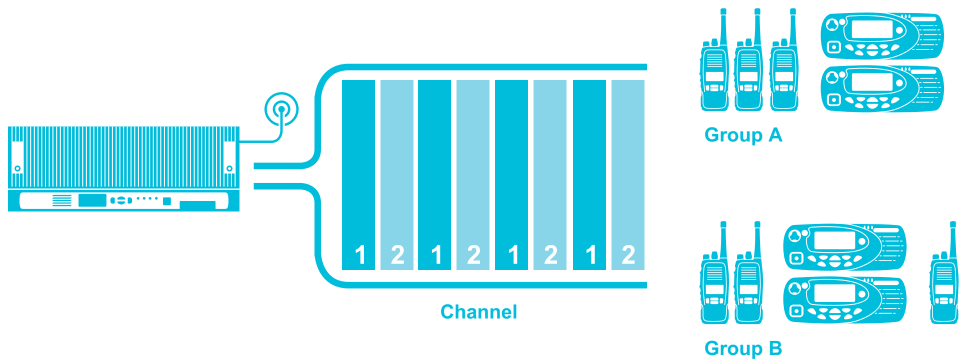
The open digital radio standards section reveals that the major difference between DMR and dPMR is the choice of multiple access scheme. DMR uses 2-slot TDMA to achieve two communication paths per 12.5kHz channel, whereas dPMR uses FDMA to divide the 12.5kHz channel in to two 6.25kHz sub-channels.

Therefore, the comparison of these two systems very much comes down to understanding the relative advantages and disadvantages of TDMA versus FDMA.

In theory there appears to be little difference. In Spectral Efficiency terms, both achieve 6.25kHz channel equivalence. Coverage-wise, the modulation methods and symbol rates mean coverage would be almost identical to existing narrowband FM systems in both cases. While the resulting radio signals do look quite different (DMR appears similar to narrowband FM, whereas the dPMR signal appears as two individual signals each with 6.25kHz bandwidth), both fit within existing 12.5kHz narrowband FM channels. So the choice of frequency bands may be made according to the application and terrain to be covered.

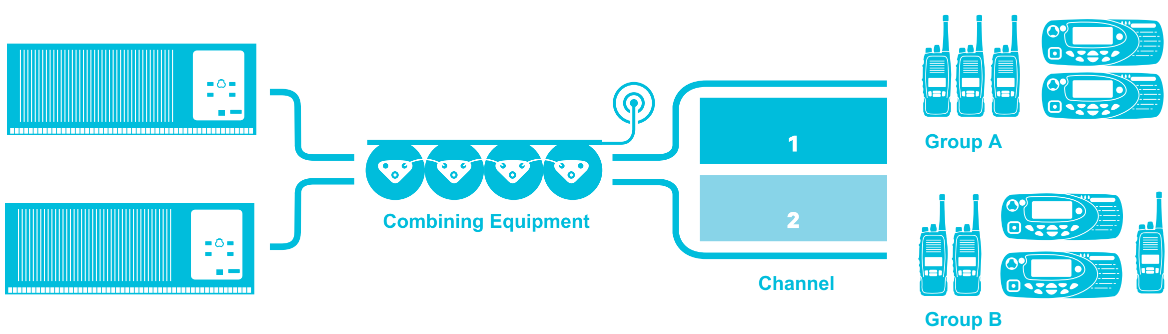
Ease of migration from existing analog systems

The obvious difference is the ease of migration from analog systems. With DMR, because the TDMA slots are operating on the same frequency, the resulting infrastructure is much the same as for a narrowband FM system, effectively reducing the cost of system infrastructure. In effect, you only need one repeater, one antenna and a simple duplexer, as shown in the diagram below.



TDMA
TDMA DMR system representation

Contrast this with infrastructure for an FDMA dPMR system. As both 6.25kHz sub-channels must operate simultaneously, two repeaters (one for each 6.25kHz sub-channel) are required, plus expensive combining equipment for multiple frequencies to share the single base station/repeater antenna, as shown below.



FDMA
FDMA dPMR system representation

FDMA infrastructure costs are considerably higher than for 2-slot TDMA DMR. In addition, the losses of the extra combiners may require additional RF Power Amplifiers to maintain the transmitted power level and therefore coverage.

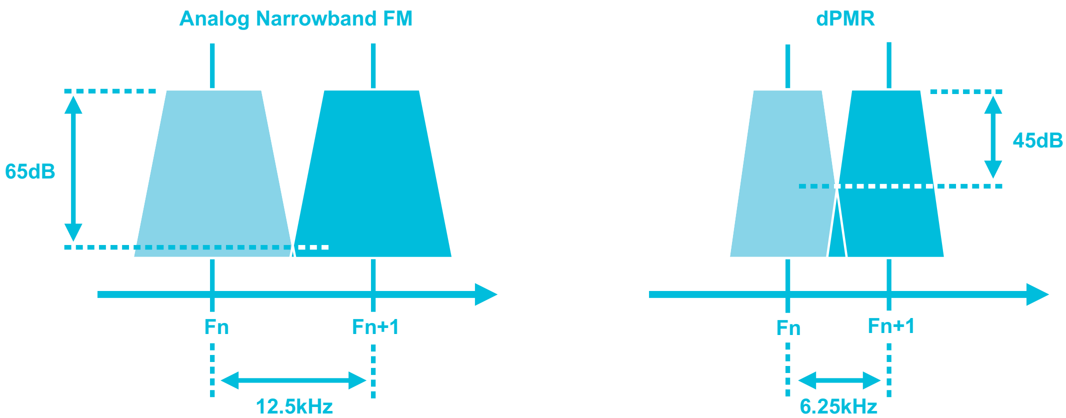
To summarize, 2-slot TDMA DMR makes efficient use of expensive infrastructure and simplifies migration. Compared to FDMA, 2-slot TDMA allows you to achieve 6.25kHz efficiency while reducing investment in repeaters and combining equipment. Much of the combining equipment used in the previous analog FM system can be re-used by a new DMR network.

This is the obvious advantage of a TDMA system such as DMR, over an equivalent FDMA counterpart like dPMR. However, if we look beneath the surface, other differences appear that have consequences in terms of other assessment criteria.

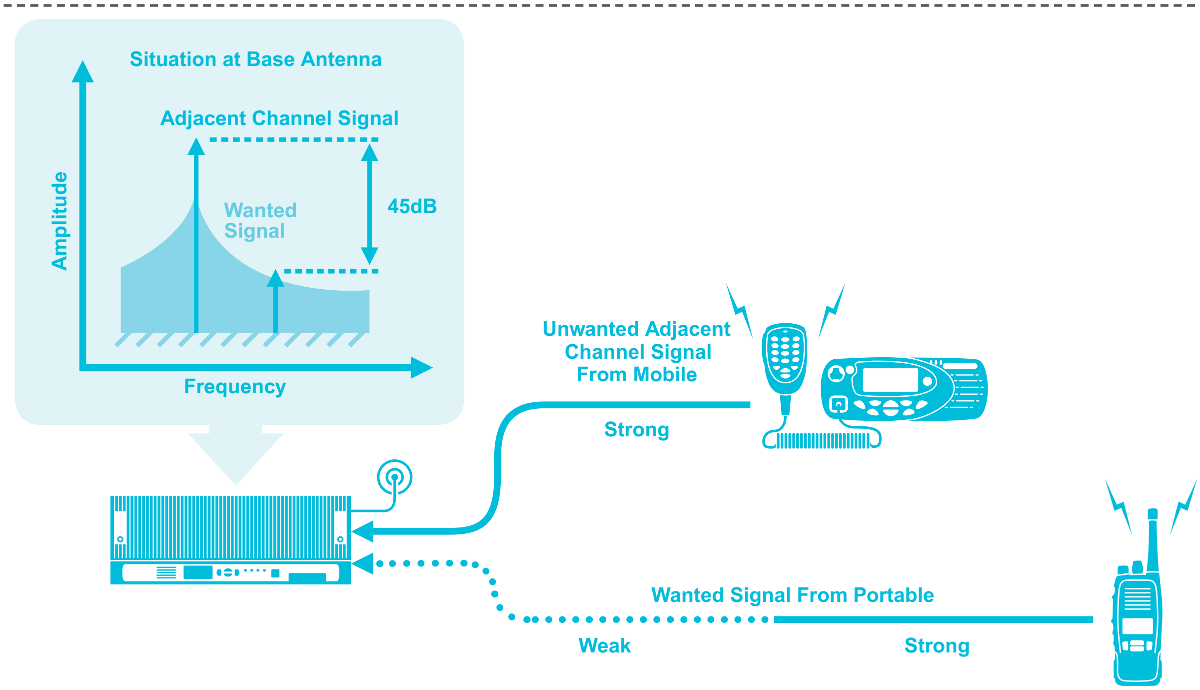
Spectral efficiency

What happens to dPMR FDMA when we try to combine two 6.25kHz sub-channels in to an existing 12.5kHz channel? In narrowband analog FM, a signal in the adjacent channel is 12.5kHz away. As transmitted signals are not pure, some energy from the transmission in the adjacent channel (Fn+1 in the following diagram) is present in the desired channel (Fn). For example, if the signal amplitudes are the same, the noise in the desired channel (Fn) generated by the transmitter operating in the adjacent channel (Fn+1) would be about 65dB down.

Now consider the same situation using FDMA dPMR. As the signals are now only 6.25kHz apart, if we assume transmitter noise performance is the same, we can see the overlap now occurs at typically 45-50dB.



What does this mean in practice? The effect of this increased adjacent channel noise is that transmitters operating close by in one 6.25kHz slot could easily prevent reception of weak signals from distant transmitters operating in the other slot.



This effect would be most noticeable if the adjacent channel was analog. If two 6.25kHz spaced FDMA sub-carriers existed in the same 12.5kHz channel, the effect isn't as bad as a result of the channel filter of the digital radio excluding more of the interfering signal. However, the customer would experience noticeably worse interference than with analog FM. For a busy system, this can mean you can only operate one 6.25kHz slot per 12.5kHz channel, meaning spectral efficiency advantages of dPMR can be lost altogether.

Also, 6.25 kHz systems have lower tolerance for frequency accuracy, and drift over time. The crystal oscillators that set transmitter frequency stability and accuracy drift away from the desired centre frequency over time. This can result in the two 6.25kHz channels drifting even closer together, leading to worse adjacent channel interference. This effect can be seen when users are travelling at speed, caused by the Doppler Effect shifting the carrier frequency.

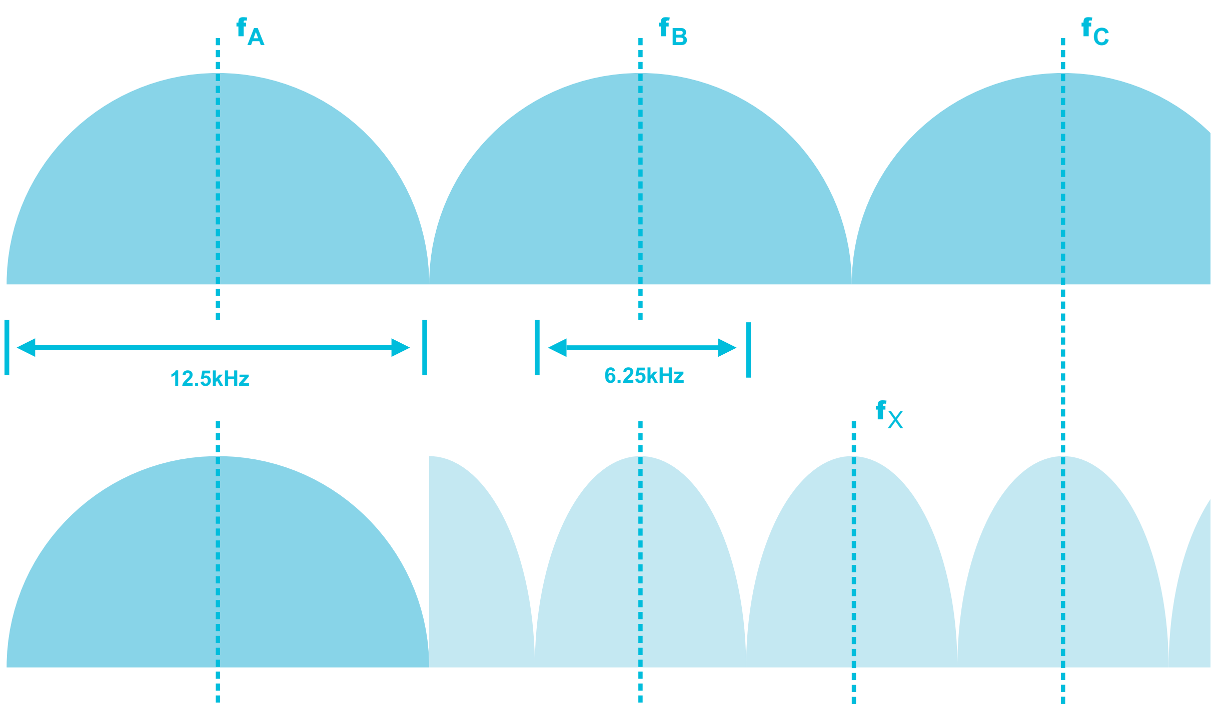
Contrast this with TDMA on DMR. Like legacy narrowband FM systems, there is only one signal occupying the 12.5kHz channel at any one point in time. Therefore, the adjacent channel performance, and the probability of interference is no worse than for the analog system.

Minimizing frequency plan churn

If an organization already has licenses for 12.5kHz channels, it can move to a TDMA-based network, such as DMR, with no frequency plan churn because each channel can be used without any licensing change.

By contrast, in the United States, moving to an FDMA-based network with 6.25kHz channels requires re-banding and relicensing, where new 6.25kHz channels are assigned by Federal Communications Commission (FCC), each with the same centre frequency as the old licenses. 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 6.25kHz.

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



Longer portable radio shift life

Compared with an analog FM radio, a 2-slot TDMA radio using one timeslot is only transmitting for half the time. For portable radios, this dramatically reduces battery power consumption, as transmitting is a very power-intensive activity. In a standard operating pattern, (5% transmitting, 5% receiving, and 90% standby), power consumption is reduced by around 40%, greatly extending the battery charge duration and increasing talk time. Radios can operate over the longest shifts without recharging or replacement.

The improvements relative to 6.25kHz FDMA are not so large or so easily quantifiable. A radio transmitting FDMA with 6.25kHz bandwidth is transmitting its radio frequency energy into half the bandwidth of a 12.5kHz TDMA radio. In theory, transmit power of a dPMR radio can be halved and still obtain the same signal-to-noise ratio as the equivalent TDMA radio. In practice however, the FDMA radio cannot compress the signal into the narrow bandwidth as efficiently so will therefore have higher power consumption than TDMA radios with an equivalent operational range.

Opportunity of reverse channel signaling

Two-slot TDMA channels opens up possibilities for reverse channel signaling. This refers to signaling on the same channel, which goes in the reverse direction, from receiving equipment to the sending equipment. For example, where the second timeslot contains reverse channel signaling it can 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

We have focused on the advantages TDMA brings in comparison to FDMA. However, there are disadvantages that we should be aware of on 2-slot TDMA.

- Multipath interference may affect call quality. For the same basic receiver design, TDMA cannot handle as much multipath as FDMA where there is more than one 'propagation' path between the transmitter and receiver. This can cause the received signal to be artificially strengthened or weakened.
- Direct mode (repeater talkaround) is not as spectrum-efficient. In some cases, radios may use both timeslots.

DMR VERSUS TETRA COMPARISON

We can compare DMR and TETRA to show the implications of modulation method, symbol rate and multiple access schemes.

The descriptions in the Open Digital Radio Standards section show the major points of difference between DMR and TETRA are:

- The choice of multiple access schemes.

NOTES

- DMR uses 2-slot TDMA to achieve two communication paths per 12.5kHz channel, whereas TETRA uses 4-slot TDMA to achieve 4 communication paths in a 25kHz channel.
- The modulation schemes and symbol rates used.
- DMR uses 4FSK modulation with a symbol rate of 4800symbols/sec (9600bits/sec), whereas TETRA uses π/4 DQPSK modulation with an associated symbol rate of 18000symbols/sec (36000bits/sec).

Spectral efficiency

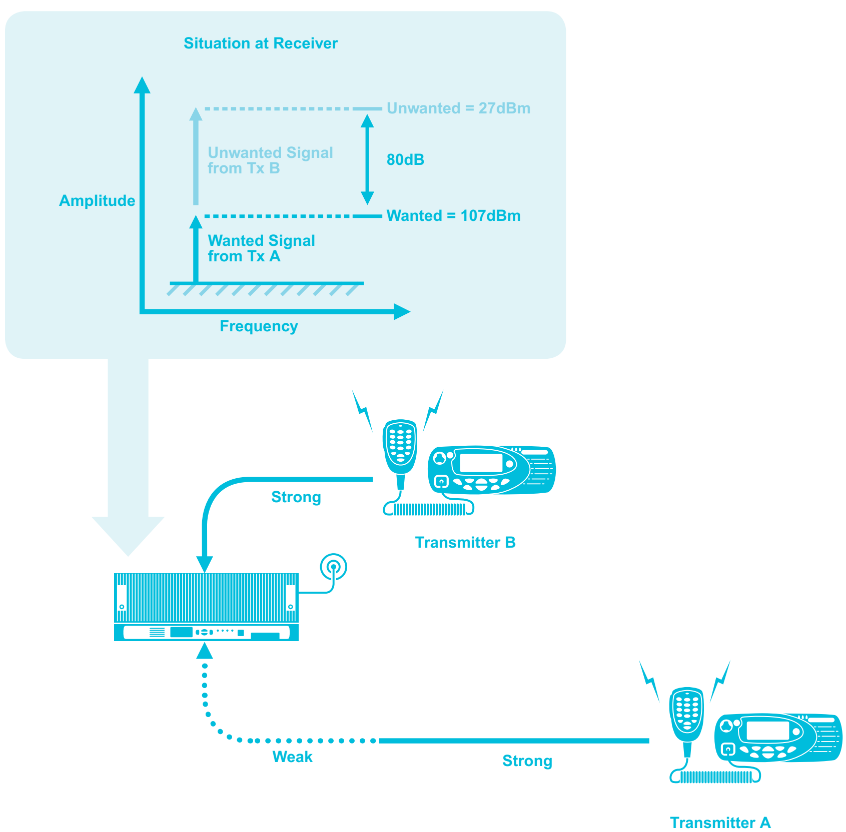
Both DMR and TETRA can achieve 6.25kHz channel equivalence. However, one of the four TETRA TDMA slots is largely used for control information, leaving only three slots available for end user communication.

Coverage

Building new sites and antenna towers is the most costly part of installing a radio network. So there are considerable financial advantages in selecting a digital standard that upgrades without the expense of additional sites.

The difference in coverage between DMR and TETRA is the result of different modulation methods, symbol rates and TDMA slot structures.

The diagram below shows the coverage implications of the TDMA slot structure:

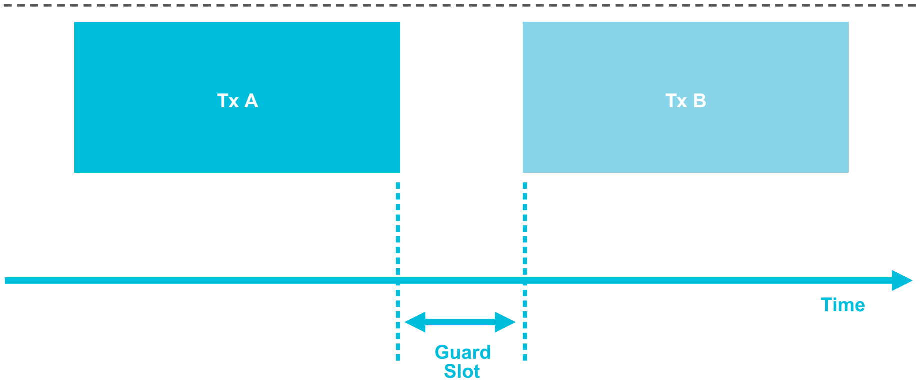


Imagine you are talking to someone 20 feet away. If you are both in a quiet, empty room, then conversation is quite easy at normal voice levels. Now imagine someone else enters the room, stands much closer to the other person and starts talking in a normal voice. The person you were originally talking to would predominantly hear them, so what you are saying is reduced to background noise and the original conversation is lost.

It is the same with radio communication. Imagine a receiver listening to a distant transmitter (Transmitter A). The received signal level is weak, but if it is above the receiver's sensitivity threshold, communication is possible. Now imagine another transmitter (Transmitter B) starts transmitting much closer to the receiver. The signal from Transmitter B (the nearer transmitter) swamps the weaker signal from Transmitter A and makes it undetectable.

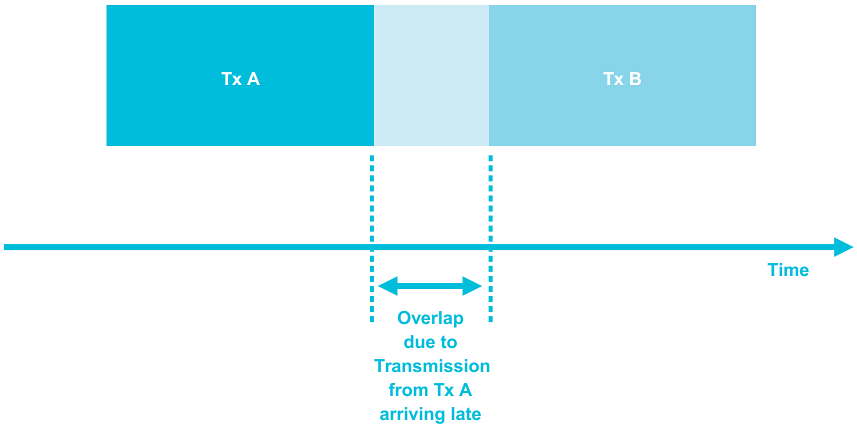
In TDMA systems, although transmitters never transmit at the same time on the same frequency, there is a fundamental limitation which sets the coverage the system can achieve.

In TDMA, we want to receive both transmissions, as Transmitter A and Transmitter B are transmitting on the same frequency, but not at the same time. DMR has a 2.5mS 'guard slot' between the time slots that different transmitters can use, as shown below. The guard slot is the gap between the end of one time slot and the beginning of another.



1.5mS of the guard slot is used for ramp up at the beginning of a slot, and ramp down at the end, so this leaves only 1mS true quiet time. There is also the issue that the clock frequencies running the Digital Signal Processors (DSP) in Transmitter A and Transmitter B may be different, so the respective transmissions could start slightly earlier or later than they ideally should. Typical DSP Clock accuracy accounts for another 0.5mS, so the true guaranteed quiet period between adjacent DMR TDMA slots is only 0.5mS.

Remembering that Transmitter B was very close to the receiver, the time taken for the signal to reach the receiver is very short. In contrast, Transmitter A is more distant, so the time taken to reach the receiver (propagation delay) is longer. If we increased the distance, eventually the signal from Transmitter B would be received before the delayed signal from the distant Transmitter A had finished.



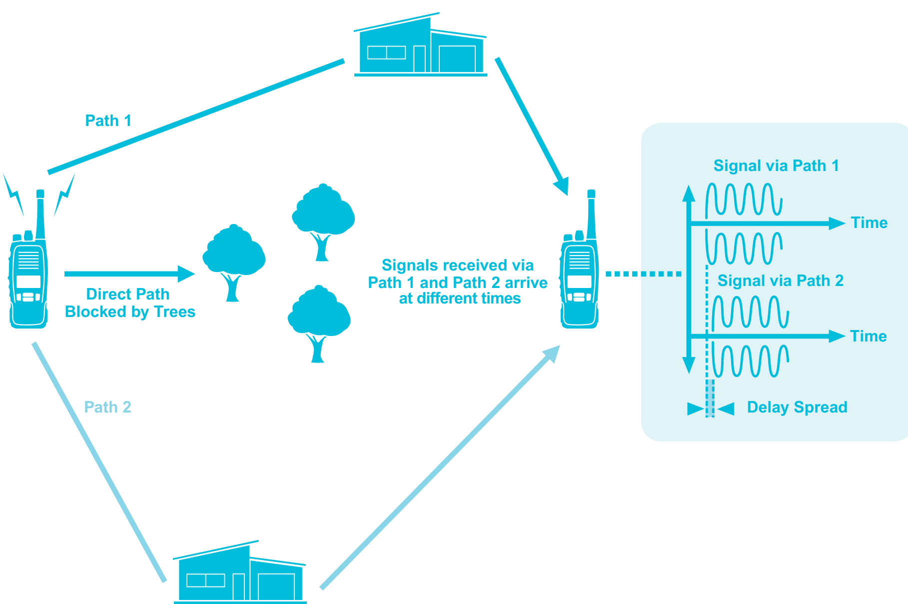
As the signal from Transmitter B is much higher (as it is nearer to the receiver), the end of the transmission from Transmitter A is lost.

Contrast this with TETRA TDMA slot structure. For TETRA, the guard time is only 0.389mS. To appreciate the implication of this, we need to understand that propagation delay increases as the distance between the transmitter and receiver becomes greater. The overlap only begins when the propagation delay exceeds the guard time, so in the case of DMR, Transmitter A can be much further away from the Receiver before this occurs. The implication is that TETRA requires more infrastructure than DMR to achieve comparable coverage.

Coverage implications of symbol rate

Also significant is TETRA's higher symbol rate (18000symbols/sec) compared to 4800symbols/sec for DMR.

The implication on coverage can be seen if we consider ***delay spread.*** Delay spread measures the multi-path effects of a channel. It is the time difference between the arrival of the first and last multipath components of the wanted signal. Multi-path signals can arrive from the same transmitter via different paths (due to reflection, as shown on the diagram below) or from different base stations transmitting the same information on the same frequency.



The two received signals contain exactly the same information modulated onto a radio frequency carrier of the same frequency. But, what is obvious is that once these signals are added together within the receiver, the result will not 'look' like either of them and so the contained information is lost.

If the delay spread becomes too great, then the information cannot be detected and communication is lost despite the signal level being well above the Receiver's sensitivity level. Delay spread of about 30% of a symbol time is generally the limit before the system falls over.

The symbol rate of the DMR system is 4800symbols/sec, meaning the symbol time is 1/4800 = 208uS, so 30% of this is 67mS.

In the TETRA case, the symbol rate is 18000symbols/sec, meaning the symbol time is 1/18000 = 55uS, so 30% of this is 17mS.

Therefore, as delay spread increases with distance from the Transmitter, it is clear the coverage of the DMR system will be superior.

Overall coverage comparison

Generally, these factors indicate that coverage of DMR is superior to TETRA. However, because no two situations are the same, there are situations where TETRA systems could achieve greater coverage. For example, in a TETRA system with light usage, where the 'distant' transmitter was using TDMA slot 1 and the 'near' transmitter was using TDMA slot 3, there would be greater guard time between the slots allowing the 'distant' transmitter to be further from the base station before overlap occurs. .This cannot be guaranteed, and with a busier system it becomes less likely; with coverage consequences. It is also possible that a TETRA system over flat rural terrain with minimal multi-path might achieve greater coverage than a DMR system installed in multi-path rich urban terrain operating at the same frequency and transmitter power.

As a general rule DMR systems have superior coverage.

Ease of migration

A TETRA system means a complete break from the previous network, because existing infrastructure and radios cannot function on a TETRA network. By contrast, P25 and DMR can migrate smoothly from analog FM systems. Both infrastructure and radios must support the legacy analog 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 they reach the end of their useful life. Users with new digital radios can talk with those on analog FM radios, using analog channels.

Any new P25 Phase 2 network or upgrade from an MPT 1327 network will require a move to 6.25kHz channel efficiency. It is important to confirm with the vendor how straightforward the migration will be.

NOTES

Choice of frequency band

DMR radios operate in the same 12.5kHz channel bandwidth as existing narrowband analog radios. There is no need for re-banding or re-licensing as DMR fits the existing analog professional or land mobile radio band plan. Network operators can choose the best frequency band for their application and terrain.

TETRA requires 25kHz channels. In Europe these are only available from 380-430MHz, so it is not possible to choose the best frequency band for the application. TETRA systems cannot operate next to 12.5kHz narrowband FM channels, so TETRA users need to buy the adjacent channels too.

DIGITAL RADIO STANDARDS CONCLUSIONS

TETRA is a good choice if you need to provide high data throughput over a relatively small coverage area, and if you can acquire the required wideband channels. However, migration from analog is not easy. Customers should be aware of the high replacement infrastructure costs.

Public safety and utilities require wide area coverage, and P25, DMR and dPMR are designed to provide coverage similar to existing analog FM. However, customers looking to upgrade from analog FM to digital dPMR need to be aware of the increased repeater complexity and costs, and of the potential spectral efficiency consequences that may arise on a busy system.

P25 and DMR are better choices for existing customers for public safety and utilities respectively, looking to upgrade from analog FM to digital radio. P25 and DMR allow much of the legacy analog infrastructure to be re-used. DMR and P25 Phase 2 also guarantee one channel per 6.25kHz of spectrum.

"Public safety and utilities require wide area coverage, and P25, DMR and dPMR are designed to provide coverage similar to existing analog FM"