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An Overview of Digital Trunked Radio: Technologies and Standards

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Abstract

Land Mobile Radio (LMR) refers to the two-way radio communication system that allows users sharing the same range of frequency to communicate with the others. LMR can be roughly classified into two main systems which are conventional and trunked radio systems. In conventional system, a frequency band is permanently dedicated to a voice channel. However, using trunked radio system can increase the spectrum efficiency by having pool of frequencies which are temporarily assigned to a group of users called talk group only when required. In trunked radio system, analog trunked radio is going to be obsolete since digital trunked radio offers better functions and features in terms of voice quality, security, spectrum efficiency and cost. Hence, the commercial applications focus on the digital one. There are many digital trunked radio technologies lunched in the market. However, in this paper, only Terrestrial Trunked Radio (TETRA), Project 25 (P25) and Digital Mobile Radio (DMR) are discussed and compared since they are developed and standardized by international standards organizations. Moreover, these technologies are chosen by many users/operators and mostly deployed in many regions across the world.

Keywords : Terrestrial Trunked Radio, Project 25, Digital Mobile Radio, Digital Trunked Radio, Land Mobile Radio, Private Mobile Radio

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1. Introduction

Land Mobile Radio (LMR) or Private Mobile Radio (PMR) is two-way radio communication system which allows users who share the same range of frequency to communication with each other. LMR networks are mostly operated in either Very High Frequency (VHF) or Ultra High Frequency (UHF) bands, and they are very essential for the successful operation in mission-critical public safety applications, commercial and industrial applications, and business-critical applications.

However, with the increasing demand of frequency spectrum for radio and wireless communications, users or providers implementing (or migrating to) the new radio communication systems decide to select the technology that is more spectrum efficient; that is, users are moving from conventional radio to trunked radio systems.

In conventional radio system, a dedicated radio frequency band is statically assigned to each communication channel, and users who are in vehicle or on foot can talk/listen to the others when they tune their handheld devices or vehicle-mounted mobile radio devices to use on the same frequency channel. If the channel is in use, users who want to communicate with the others are typically blocked and have to wait until the channel is free. Hence, the capacity of this conventional system is limited by number of obtained frequency bands in the system.

On the other hand, frequency bands in trunked radio system are not statically assigned and dedicated to groups of users. However, they are assigned to a pool of frequencies and available for users to access when required. These frequencies are usually controlled and managed by specific equipment known as central controller.

Radio users in trunked radio system are typically assigned to talk group(s) (instead of frequency bands). Moreover, each available frequency band is dynamically assigned to a talk group for a specific period of time in order to allow users in this group to communicate with each other. In trunked system, idle users keep listening to the same shared channel called control channel which is usually used for signaling broadcast to every communication devices in the system. Whenever a user in a particular talk group presses a Push-to-Talk (PTT) button, the requesting message will automatically be generated and sent to a central controller via control channel. This message usually contains identification (ID), talk group, and a request for voice channel assignment. Hence, all users in this talk group will be consequently switched to one of voice channels available in a pool of frequencies. When transmission is finished, all radio devices revert back to the control channel and an assigned voice channel is returned to a pool.

As explained above, in trunked radio system, the spectrum utilization is more efficient compared to the conventional one. It also increases the flexibility of the radio network which allows more number of talk groups to dynamically share a limited number of frequency bands. Moreover, all calls from radio users in trunked system are not blocked by the systems as occurring in conventional system, but they are typically put into a queue which prevents call retries and collisions. In other words, there is no call blocking in trunked system, but call delay could be occurred during the peak period. Hence, Erlang B traffic model is typically applied instead of Erlang C distribution. In addition to system capacity, security in trunked system is also improved since an assigned frequency to a particular talk group is always changed between conversations. This situation makes eavesdropping more difficult.

However, due to the system architecture in trunked radio, time and message complexities are increased since all requests are sent and managed by a central controller. This architecture usually increases the call setup time, and it may cause the single point of failure when a central controller is malfunction. However, trunked system is able to provide fail-soft procedure to allow repeater to manage its local site when controller does not function properly to ensure uninterrupted service.

Trunked radio can be approximately classified into two main types which are analog and digital trunked radio systems. Between them, digital trunked radio usually provides more benefits and better capabilities as illustrated in Table 1. In analog trunked radio, it transmits analog signals over-the-air where the transmitting signal is usually attenuated and interfered by many sources of noises and interferences, and these problems have significant effects on the uplink direction due to the low SNR caused by limited transmitting power at terminal or user equipment. Whereas in digital trunked radio, these noises and interferences can cause transmission errors which can be effectively mitigated by using Forward Error Correction (FEC) technique.

In digital trunked radio, traffic can be effectively compressed and delivered by the system; this consequently results in better throughput. It also supports encryption which typically increases security and privacy level. Furthermore, digital trunked radio can utilize Time Division Multiple Access (TDMA) technique to increase the channel capacity by dividing frequency band into multiple time slots which inherently increases spectrum efficiency. This technique can also prolong the battery life at terminals since data is only transmitted in the assigned time slots or durations. It also provides the cost effective solution for system maintenance due to lower licensing fee and equipment cost.

Because of various benefits stated above, only digital trunked radio system is discussed. In this article, three digital trunked radio technologies i.e. Terrestrial Trunked Radio (TETRA) [1-2] Project 25 (P25) [3-4] and Digital Mobile Radio (DMR) [5-7] are explained, since they are deployed in many countries around the world [8-10]. Moreover, they are also accepted by non-profit standards organizations (i.e. European Telecommunications Standards Institute (ETSI) [11] and Telecommunications Industry Association (TIA) [12]) to be standardized. The other technologies such as Integrated Digital Enhanced Network (iDEN) [13], NXDN [14] and so on are considered to be proprietary technologies and are not reviewed here.

Table 1 Comparison between analog and digital trunked radio systems

Performance Factor	Analog Trunked Radio	Digital Trunked Radio
Voice Quality	Degrade when signal strength is reduced	Better and consistent throughout the coverage area
Non-voice Services	Lower throughput	Better throughput
Security	Less secure since analog systems do not have full encryption feature	More secure due to better encryption features in digital technology
Functions and Features	Application is based on only voice communication, no extra feature is supported	Support advanced features e.g. GPS location, text messaging, emergency call and so on
Spectrum Efficiency	Lower since it is based on only frequency allocation	Better by using both time and frequency allocations with compression technique
Battery Life	Shorter due to full power required for transmission in one radio channel	Lower due to its ability to divide power-intensive transmissions into multiple independent time slots
Cost	Higher maintenance cost	Lower licensing fee and maintenance costs

2. Digital Trunked Radio Standards

Standards are very important in all communication systems including digital trunked radio since they ensure the multi-vendor interoperability and compatibility. They allow users to access to trunked radio network by using the products from multiple vendors or manufacturers, and they also add the flexibility to the operators for equipment adoption, upgrade or replacement. According to digital trunk radio, TETRA, P25 and DMR are the most widely deployed digital trunked radio technologies among the others since they are legally accepted by the international standards bodies for standardization.

Since all of them are digital communication systems, they inherently achieve the advantages of digital transmission such as voice quality by using FEC to correct the transmission errors, security and privacy by using encryption technique, spectrum efficiency by using Time Division Multiple Access (TDMA) technique, and so on as depicted in Table 1. Furthermore, these digital trunked radio standards are discussed and compared in details in the next sections.

2.1 Terrestrial Trunked Radio (TETRA)

TETRA is one of the global open standards for digital trunked radio which has been developed by ETSI and technical specification of TETRA is depicted in Table 2. It is the digital communication system that utilizes TDMA to allow users in multiple talk groups to efficiently access the communication channels. In TETRA, a 25-kHz frequency channel is divided into four equal-sized time slots as shown in Figure 1. Each time slot behaves like a communication channel in analog trunked radio which is temporarily assigned to a particular talk group when required by users. However, one time slot is dedicated for a control channel which is intentionally used for frequency channel control and assignment as discussed in previous section. Hence, the spectrum efficiency of TETRA is four times higher than the legacy analog technology and approximately equal to the other digital trunked radio systems which are P25 and DMR.

TETRA systems mainly operate in UHF band and most of them are used in European countries operated in the 380-430 MHz. However, depending on the spectrum management policy in some other countries such as countries in Asia Pacific and South America, the 800 MHz band (i.e. 870 MHz to 888 MHz / 915 MHz to 933 MHz) is also available to support TETRA.

The modulation technique used in TETRA is $\pi/4$ Differential Quaternary Phase Shift Keying (DQPSK) which is a form of Phase Shift Keying (PSK). In addition, it can support the data rate of 7.2 kbps per time slot. Since a 25-kHz frequency channel in TETRA consists of four time slots, hence, the total data rate provided by TETRA system is 28.8 kbps which is higher than P25 and DMR as illustrated in Table 2.

Terminals or user equipment in TETRA system including mobile and handheld devices normally operate in Trunked Mode Operation (TMO) i.e. base station and terminal communications. However, when the TETRA infrastructure is not presented such as in the situation when base station or repeater is not function properly, terminals devices may operate in Direct Mode Operation (DMO) i.e. terminal to terminal communications. In DMO mode, terminal is allowed to have the direct communication with each other without using the TETRA infrastructure. However, they must be located within communication range of each other. Moreover, to extend the coverage area, terminal can also perform a function called DMO gateway to act as the relay station between DMO and TMO. In other words, this terminal can provide trunked communications for the other terminals that are out of communication range through the DMO. However, TETRA cannot support conventional mode as available in P25 and DMR technologies.

According to coverage area or cell radius of the radio system, the two main factors that affect area/radius are the transmitting power and the antenna gain. In [15], the typical transmitting power at base station of TETRA is around 10-100 W which is approximately the same with DMR. However, in P25, the maximum transmitting power is at 500 W. Hence, the cell radius of TETRA is closely the same with DMR that is about 3.8-17.5 km, whereas the cell radius of P25 can be as far as 35 km away from base station. However, with the limited transmitting power of TETRA compared to P25, one main advantage is that it is better to support the frequency reuse which effectively prevents the co-channel interference caused by the same set of frequencies used in the other cells.

Since TETRA is an open standard, it also supports the interoperability among multiple manufacturers or vendors as in P25 and DMR. However, it is not able to provide the backward compatibility with analog system. Hence, it makes the difficulty for the users with the existing analog trunked radio system to migrate to digital technology. In other words, there is no the smooth migration path from analog to digital trunked radio.

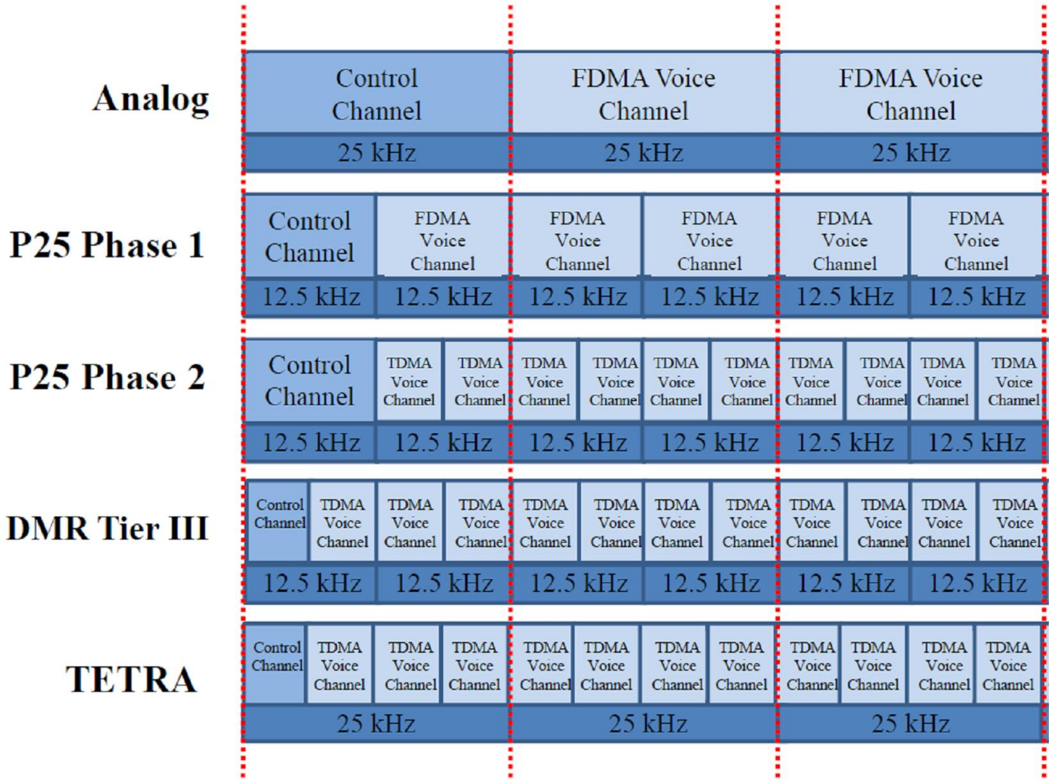

Fig. 1. Spectrum efficiency comparison among multiple digital trunked radio technologies

Table 2 Technical comparison among multiple digital trunked radio technologies

Performance Factor	Terrestrial Trunked Radio (TETRA)	Project 25 (P25)	Digital Mobile Radio (DMR)
Open Standard / Proprietary	Open	Open	Open
Standards Body	ETSI	Initiated by APCO and developed by TIA	ETSI
Access Method	TDMA	FDMA (Phase 1) TDMA (Phase 2)	TDMA
Modulation Scheme	π/4 DQPSK	H-DQPSK / H-CPM	4FSK
Channel Bandwidth	25 KHz	12.5 KHz	12.5 KHz
Number of Time Slots per channel	4 slots	2 slots	2 slots
Supported Frequency Bands	Parts of UHF	Parts of VHF and UHF	Parts of VHF and UHF
Data Rate per Channel	28.8 kbps	9.6 kbps	9.6 kbps
Network Size	Regional and Nationwide	Regional and Nationwide	Local and Regional
Coverage Area	Shorter due to limited transmitting power	Larger	Shorter due to limited transmitting power
Interoperability among Multiple Manufacturers	Yes	Yes	Yes
Backward Compatible with Analog System	No	Yes	Yes
Conventional Support	No	Yes	Yes
Encryption	Yes	Yes	Yes

2.2 Project 25 (P25)

Project 25 or P25 technology was initiated by Association of Public-Safety Communications Officials-International or APCO [16] and continually developed by TIA. This is why some people call this trunked radio technology as APCO-25. P25 is divided into two main phases which are Phase 1 and Phase 2. In P25 Phase 1, it utilizes the Frequency Division Multiple Access (FDMA) technique to obtain 12.5-kHz channel to meet FCC narrowband requirements [17] as shown in Figure 1. Hence, the spectrum efficiency of P25 Phase 1 is two times higher than the analog system; while in Phase 2, it utilizes TDMA technique on a 12.5-kHz channel. In addition, there are two time slots per frequency channel and the spectrum efficiency of P25 Phase 2 is four times higher than the legacy analog trunked radio, and its spectrum efficiency is approximately the same with the other digital trunked technologies which are TETRA and DMR. However, in P25, a 12.5-kHz channel is assigned for a control channel, whereas in the other two technologies, only one time slot is required for a control channel.

P25 is able to operate on both VHF and UHF bands which are 136-200 MHz, 360-520 MHz and 746-870 MHz depended on the spectrum management policy in each country. In addition, the modulation techniques used in Phase 1 is Continuous 4 level Frequency Modulation (C4FM), and two modulation schemes are used in Phase 2 which are H-DQPSK (Harmonized-Differential Quadrature Phase Shift Keying) and H-CPM (Harmonized-Continuous Phase Modulation). Moreover, H-DQPSK and H-CPM are used in outbound and inbound directions, respectively. H-DQPSK is used at base station in order to offer the simpler implementation at the receiving end (terminals or mobile stations), while the H-CPM is used at terminals since it is the simple modulation technique and not complex to be implemented at terminal end. By using these modulation schemes, the peak data rate is at 9.6 kbps per 12.5-kHz channel or 19.2 kbps per 25-kHz channel which is similar to DMR but lower than TETRA.

One important key that makes users or operators to deploy P25 is its scalability to support large coverage area, since P25 is intentionally designed to support the operations of public safety agencies across North America. Hence, its coverage area should be large enough in order to minimize the number of cells/sites implemented throughout the region which results in the lower implementation cost. In P25, the maximum cell radius is 35 km which is typically larger than TETRA and DMR due to the fact that P25 allows higher transmitting power at both base station and terminals.

Another benefit of P25 is that it supports convention mode, hence, each user can communicate with multiple users who share the same set of frequency even when the P25 infrastructure is absent. This is different from DMO in TETRA that only allows the terminal to terminal communications. P25 is also able to support the analog system and provides the simple migration path from legacy analog trunked radio to advanced digital trunked radio.

2.3 Digital Mobile Radio (DMR)

DMR is another digital trunked radio technology developed by ETSI. There are three tiers in DMR technology which are Tier 1, Tier 2, and Tier 3. DMR Tier 1 covers the low-power unlicensed conventional radio, Tier 2 relates to the licensed conventional radio, whereas Tier 3 defines the trunked radio technology in frequency bands 66 - 960MHz. However, nowadays the commercial applications mainly focus on both Tier 2 and Tier 3 which operate on the licensed spectrum.

To increase the spectrum efficiency, DMR also utilizes TDMA technique to divide the 12.5-kHz channel into two slots which is similar to P25 Phase 2. However, only a time slot is required to be a control channel. Moreover, a control channel in DMR can be dedicated control channel or composite control channel. In dedicated control channel, a TDMA slot is dedicated for a control channel; whereas, in composite control channel, it may revert to a traffic channel when traffic is requested and no other channels are available. Hence, spectrum efficiency of DMR is four times higher than the legacy analog system based on 25-kHz channel. In addition, it employs the 4-level Frequency Shift Keying (4FSK) digital modulation to achieve 9.6 kbps data rate per channel. Hence, based on 25-kHz channel, DMR can achieve 19.2 kbps which is approximately the same with P25 but lower than TETRA technology as illustrated in Table 2.

Since both DMR and P25 operate on 12.5-kHz channel, they are able to comply with the FCC narrowband policy; since the FCC mandates all VHF and UHF bands for public safety, industrial, and business licensees who operate on 25-kHz LMR systems to migrate to at least the narrowband 12.5-kHz system by January 1, 2013 [17]. However, in some countries that have not implemented the narrowband plan for LMR, TETRA is more suitable than the other technologies since it operates on the traditional 25-kHz channel. P25 and DMR are able to operate on this 25-kHz channel by partitioning them into two 12.5-kHz channels. However, to use these two partitioned channels in the same cell or nearby cell can possibly cause the adjacent-channel interference.

DMR is able to work backward with legacy analog system; hence, it also provides the smooth migration path for the analog users to migrate to the advanced digital trunked radio. Moreover, it is a reliable communication system since it provides the fail-soft mode in order to guarantee the uninterrupted service by allowing the base station/repeater to control its local site in case that central controller is not reachable. Moreover, if users with DMR technology cannot access the base station, it is still able to operate and connect with other users by using convention mode as supporting in P25; whereas, in TETRA, users can use DMO to connect with another user. Note that all digital trunked radio systems discussed in this paper (i.e. TETRA, P25 and DMR) also provide the fail-soft mode.

However, DMR is suitable for local and regional coverage since there is limitation in number of sites and users per site, whereas TETRA and P25 can be scalable to support the nationwide implementation.

3. Digital Trunked Radio in Thailand

These three digital trunked radio technologies i.e. TETRA, P25 and DMR have been implemented in Thailand. In land mobile radio communications throughout the territory in Thailand, all technologies are suitable and effective to be operated. Among them, less number of base stations is required to service terminals in the same service area for P25 due to its beneficial characteristic in larger coverage area. This may consequently result in cheaper implementation cost. Hence, P25 is suitable for sparse area where users are dispersed over large geographical area.

However, due to the limited coverage area offered in DMR and TETRA, they inherently support the frequency reuse. Because the same set of frequencies can be reused elsewhere without causing interference when they are well planned, both technologies can support more number of users and suitable for dense area. Between them, TETRA also has many attractive features such as higher data transfer rate; hence most of trunked radio operators in Thailand implement TETRA to serve their radio customers.

In maritime mobile radio communications such as communications in offshore terrain, there is limitation in geographical area to construct the base station to service and support radio terminals. Hence, P25 is preferred among all other trunked radio technologies. TETRA is also possible to operate in this area by using DMO gateways to extend coverage area but more number of gateways is required in sparse area, and it incurs high additional cost. Hence, most of oil and gas companies operated in the Gulf of Thailand prefer P25 to service their users over the other technologies.

4. Conclusions

TETRA, P25 and DMR are the digital trunked radio technologies standardized by the international standards bodies. All of them utilize the TDMA technique to increase the spectrum efficiency that is four times higher than the legacy analog system. In addition, TETRA can achieve the higher data rate compared to the other technologies; hence, it is suitable for users who require data transmission in addition to voice communication. Among them, P25 and DMR operate on 12.5-kHz channel which comply with FCC narrowband policy, whereas TETRA operates on traditional 25-kHz channel which is more suitable for country without narrowband plan in terms of spectrum management.

Furthermore, P25 is designed to support large coverage area due to its high transmission power and it consequently has large cell radius compared to TETRA and DMR. However, TETRA can compensate this shortcoming by deploying more number of cells; whereas in DMR, there is limitation in number of cells. Hence, DMR is not suitable for nationwide implementation.

P25 and DMR can operate in conventional mode which ensures the uninterrupted service when radio infrastructure is not presented, while TETRA can use DMO mode to provide back-to-back communications with another. In addition, P25 and DMR are also able to work backward with analog trunked system and there is a simple and smooth migration path from the existing legacy analog system to digital one. Furthermore, since all of them are digital system, they also provide better security and privacy compared to the legacy analog system by using advanced encryption technique.

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