System Manual

Part 1: Introduction to Radio Systems

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Rohill Technologies B.V.
Edisonstraat 12
7903 AN Hoogeveen
The Netherlands
Telephone: +31 528 263355
Telefax: +31 528 271844
Internet: www.rohill.com

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1. Introduction to Radio Systems

Effective communication is fundamental to the way that individuals, corporations and other organizations function in the modern world. Throughout modern history, technological developments have introduced new ways of transferring information between individuals and groups. In the 21st century, communication systems take many forms from hard wired telephones, satellites, optical systems and wireless networks that use specific radio frequencies (RF) to transmit data and voice information. The major advantages of radio communication over other systems are their ability to quickly establish reliable communications over large distances to an almost unlimited number of users that may be static, mobile such as vehicles travelling at high speed, underground or in buildings.

Radio systems that permit communications between fixed and mobile users date back to the early days of Marconi's experiments with ship-to-shore communication in the 1890's. Technological breakthroughs and the increased use of the electromagnetic spectrum have led to the development of higher and higher frequencies where the increased bandwidth available allows more complex usage. The latest generation of Private Mobile Radio (PMR) systems now provides a range of services to meet the demands of users for mission critical voice and data communications. New modulation techniques, trunking methods, standardization, migration to higher frequencies and digital technologies together with the increased use of the Internet Protocol (IP) will all impact the future development of mobile communications as demand for services continues to grow exponentially.

As PMR focuses more on mission-critical communications needs, the public safety and emergency services and the Armed Forces sectors are obvious customers, as well as utilities. However, there is also a strong demand for latest generation PMR networks coming from sectors such as local Government, transport, oil and gas.

As demand for PMR services grows, conventional systems soon start to show their limitations. Trunked systems are now the norm in most countries and increasingly the move is towards digital solutions to provide still further improvements in spectrum efficiency, quality of service and to support new applications.

1.1 Radio Systems

Mobile radio systems provide communication between users within a given geographic coverage area. There are two main types of system:

- Private Mobile Radio or Professional Mobile Radio - also known as Land Mobile Radio.

  These are generally mobile communications systems that are privately owned and controlled by public service and other professional organizations. These entities generally require very specific functionality such as additional security, group and broadcast calls as well as a greater control over communications access and operational costs than is available from public cellular networks.

- Public Access Mobile Radio (PAMR) - also known as Specialized Mobile Radio and Commercial Trunked Radio

  The term refers to PMR-type service offerings and related functionality based on trunked radio networks constructed and operated by commercial companies offering capacity to professional user groups.

PMR networks have traditionally served a wide range of professional user groups with very specific requirements, insulating them to a certain degree from direct competition from public networks. The rise of digital cellular systems has created a much greater challenge for the analogue and digital PAMR operators who must attempt to compete against the much stronger, global cellular operators by offering the specialised, tailored services to specific target segments.

1.1.1 System Configurations

A basic conventional system consists of the mobile terminals (hand portable or mobile e.g. installed in a vehicle) and a central base station which connects the signal via radio. The effective operational or coverage area is governed by a large number of factors including the base station transmit power, antenna height and configuration, receiver sensitivity, terrain, clutter density (buildings etc) and frequency of operation.

In its simplest form, a single frequency channel is used to provide two way simplex communications between the dispatcher and the mobile terminals. Users transmit and receive only on that channel on a first come first served basis. All users and the dispatcher hear one another's calls so that channel access requires effective radio procedure and discipline. The configuration is shown in Figure 1.

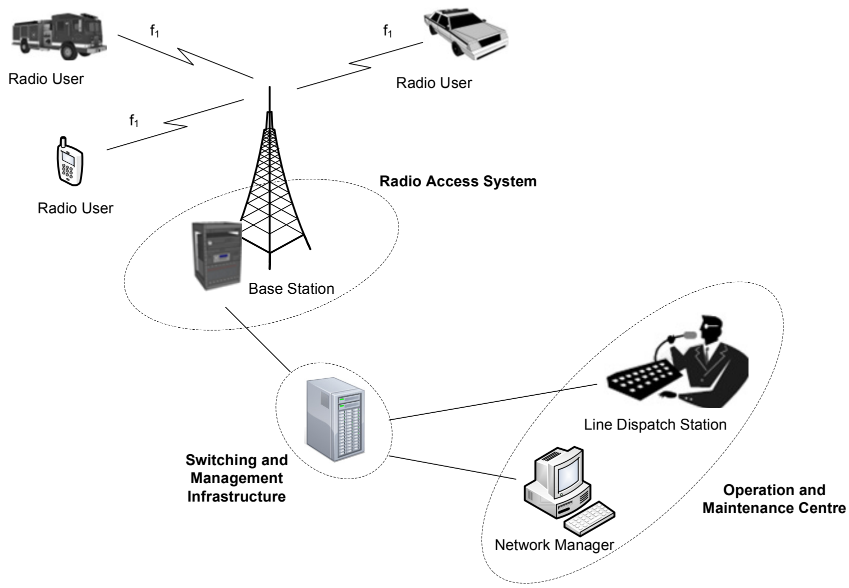

Figure 1 - Basic System

The architecture of a basic system can be viewed as:

- Radio Users

  Radio users can roam within the radio coverage area provided by the system. Access to the network is realised using mobile stations both hand portable and vehicle mounted.

- Operation and Maintenance Centre

  The dispatcher and network manager supervise and control the communications within the network and the performance of the network.

  The dispatcher is a fixed user with access to advanced system features that enables the dispatcher to efficiently communicate with radio users and management the mobile fleet. Access to the network is realised through a Line Dispatch Station.

  The network manager is a fixed user, managing and maintaining the system. Access to the Switching and Management infrastructure and the radio access system is provided through a Network Management Station.

- Switching and Management Infrastructure

  (limited where a single base station is utilised)

  Providing routing to the radio access system and gateways to external systems.

- Radio Access System

The Radio Access System provides the air-interface that enables radio users to access the system. Radio coverage is provided by one or multiple base station systems in a specific geographic area. The base station systems and antenna subsystems form the radio access system of the network.

A major advantage of a conventional radio system is that users equipped with radios from different manufacturers can communicate with one another provided they are programmed to the same frequency. The technology is well proven and equipment and operating costs can be low. Disadvantages include accessibility delays when a channel is being utilized by other users, and security concerns because of the ease of “eavesdropping” on potentially sensitive communications by unauthorized persons since encryption is generally not available.

Where only a small number of mobiles are present in a limited area served by a single base station, a common frequency shared by all users could be sufficient however the limitations of such a system make it impractical for an effective communication system. To provide coverage over a wider area, multiple base station sites are required introducing the need for a switching and management system. To increase the capacity of the network, multiple channels need to be used requiring an appropriate channel access technique to be employed.

A basic multichannel / multisite configuration is shown in *Figure 2*

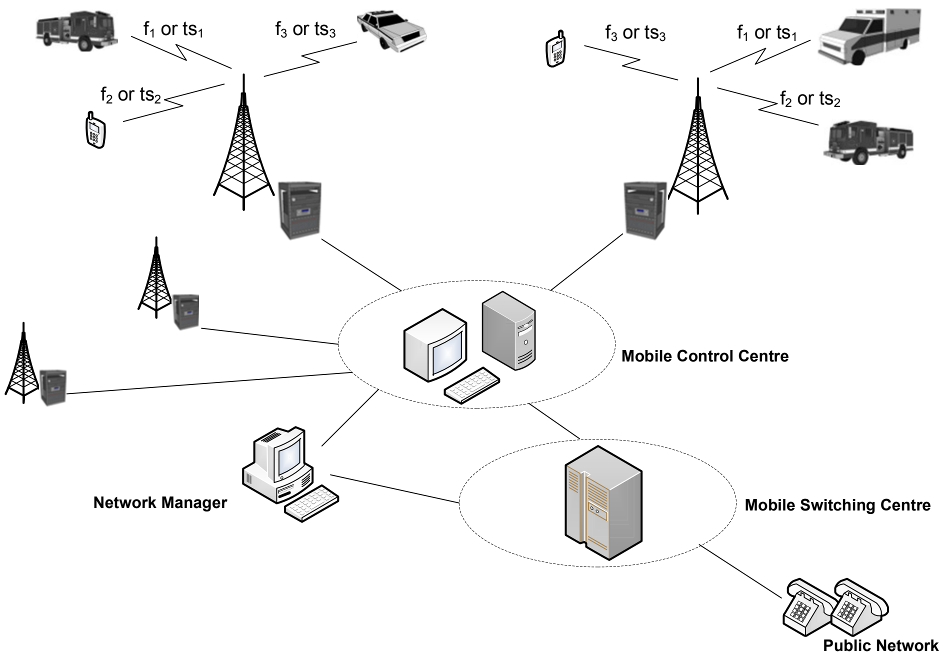

Figure 2 - Multisite / Multichannel Configuration

1.1.2 Multiple Channel Access

Various access techniques are used to allow multiple users to access the available communications channels. The three major access techniques used to share available bandwidth in mobile communications systems are:

- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)

The two most common techniques currently employed in digital mobile radio solutions are FDMA and TDMA. Whilst FDMA has been the access method of choice for PMR networks, TDMA is now becoming the more common in an increasingly digital market and can allow more efficient use of a limited frequency spectrum. Although widely adopted for 3G cellular services, CDMA is not considered a practical option for PMR.

1.1.2.1 Frequency Division Multiple Access

In FDMA, channels are segmented in the frequency domain as shown in Figure 3, the frequency of each channel remains constant. Bandwidths are generally narrow because each channel supports only one circuit per carrier. The most common channel separation is 12.5 kHz and it is not possible to share an FDMA channel with other channels or accommodate variable bandwidth signals.

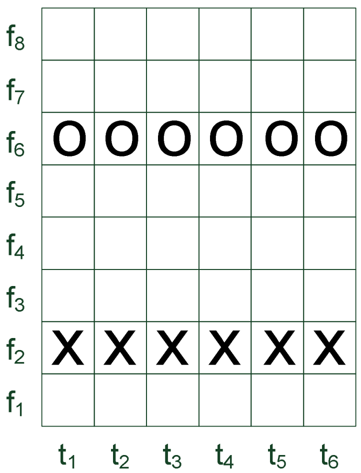

Figure 3 - FDMA

FDMA is used for both the analogue MPT 1327 protocol and also the APCO Project 25 Phase I systems. It has a slight range advantage over the other common access method, TDMA, and is likely to be more cost-effective for the construction of low capacity, conventional PMR networks. However, this method generally limits the overall range of services available to the user and does not scale well for medium to larger, high capacity networks, which is the main reason why TDMA solutions have become more prevalent.

Simultaneous voice and data communications using the same portable unit and carrier are not available in FDMA systems, which also tend to require larger terminals to support full-duplex communications due to the need for a duplexer device and RF screening between the transmitter and receiver.

1.1.2.2 Time Division Multiple Access

In TDMA, channels are segmented in the time domain. One or more time slots, which are repeated once per frame, are assigned to each user in a cell. Although different cells use different frequency channels as in FDMA, with TDMA each frequency channel can support several users (Figure 4 gives an example of two users on the same frequency channel). For example, TETRA technology is based on 4 time-slot 25 kHz carriers. High data rate users can be assigned more than one time slot to produce a faster throughput, but this limits the number of users. TDMA can improve system capacity by a typical factor of 3 to 6 over FDMA. TETRA also enables multi-slot packet data where up to four time slots can be assigned to single packet data session further increasing the available data rate.

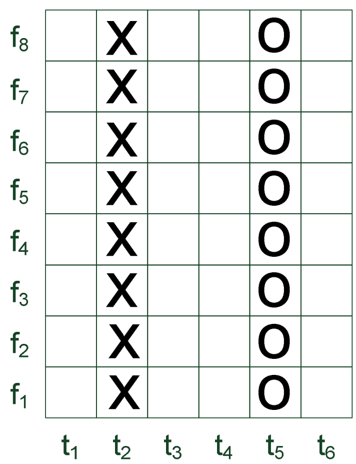

Figure 4 - TDMA

Whilst GSM is the most famous TDMA-based technology, several digital mobile radio technologies also employ this access technique including TETRA and APCO Project 25 Phase II.

TDMA is now a common, well-researched technology, which enjoys a capacity advantage over FDMA particularly in high-density environments. With TDMA, it is possible to provide simultaneous voice and data communications as voice can be assigned one time-slot while data is transmitted at the same time over another time-slot.

1.1.2.3 Code Division Multiple Access

In CDMA, channels are segmented in both the time and frequency domain. All users in a given signal coverage area transmit in the same frequency band at the same time; each user is given a distinct "code" so that a receiver captures all the energy from one particular user and only a small fraction from all other users within a particular cell (see Figure 5).

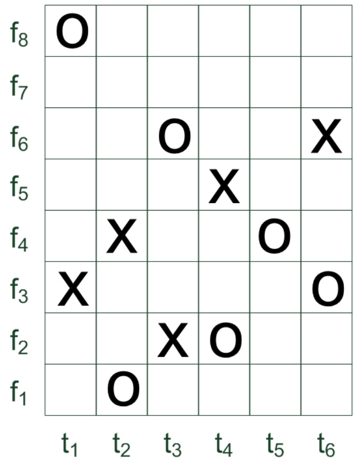

Figure 5 - CDMA

Each CDMA channel uses the whole bandwidth all of the time making it more efficient than FDMA and TDMA for large systems with high capacity requirements. CDMA use FDMA techniques to manage channels so that subgroups can be served by single channels and also hybrid TDMA/CDMA systems can be used where each user is assigned a specific "code" and time slot.

CDMA has been chosen as the core technology for all 3G networks because of its flexibility in bandwidth allocation and capacity advantages when compared to other access methods such as FDMA and TDMA. In theory, service providers could use this additional capacity to offer PMR/PAMR services. However, in general, CDMA technology is best suited to mass-market applications, which are not normally associated with the PMR industry. The flexibility of allocating higher bandwidth only applies to small cells, which is not economical for PMR/PAMR services due to the limited number of terminals serviced.

1.2 Trunked Radio Systems

In most systems, channels are assigned to users as needed rather than giving each user a dedicated channel that is reserved for that user at all times. This is called trunking and allows large numbers of users to be supported with a limited number of available channels, with a small probability that any given call will be blocked because all channels are busy

1.2.1 Trunking Principles

Conventional PMR systems exhibit several operational limitations which impact their effectiveness for many users. These include the inefficient use of radio channels, some of which could be constantly busy at the same time as others were free of traffic; the need to manually switch channels, an almost complete lack of privacy and high levels of interference and noise when data was transmitted over voice channels. Trunking techniques were developed to overcome such limitations and increase the efficiency and effectiveness of modern PMR systems with increased traffic loading. The principle of trunking is to provide a trunk of several channels to a large number of different users in the same way that a telephone subscriber gets a free line from a pool of available trunk lines between public telephone exchanges.

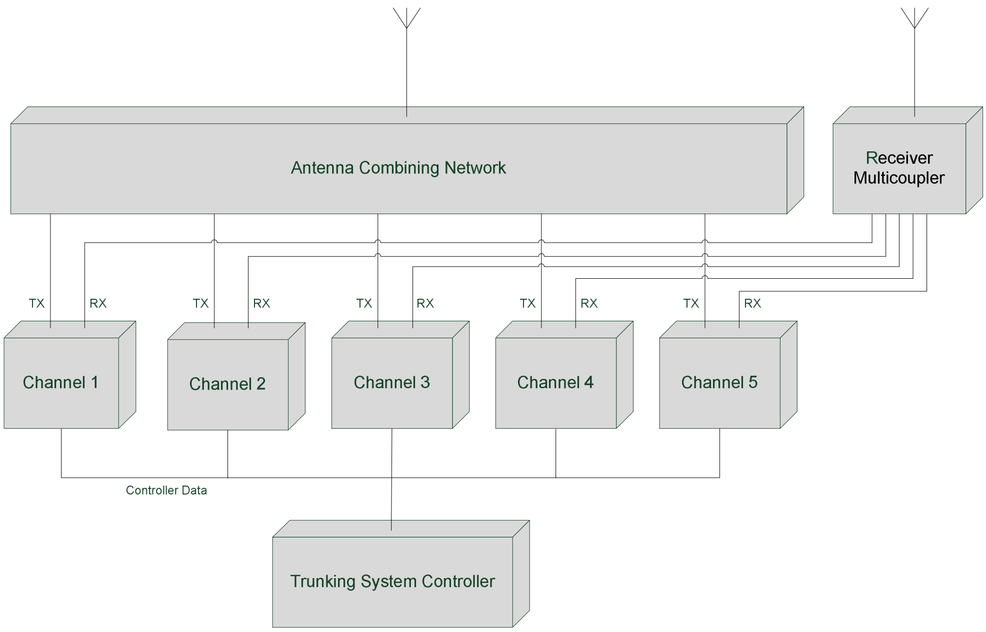

Figure 6 - Trunking System

In a trunked radio system, the Trunking System Controller allocates a free channel for a particular connection just for the period of time required. The channel is selected automatically and all of the radio units are controlled and switched by the Trunking System Controller to that channel. After termination of the call the channel used is switched back to the common trunk of channels and can be used for the next connection.

In radio trunking, there are two basic types of channel:

- Traffic Channel (or Working Channel)

  A channel on which voice or data traffic is handled.

- Control Channel

A channel on which all radio units are controlled (when initiating and receiving calls).

The Control Channel is unique to trunked systems providing the flexibility, which allows a wide range of new types of services to be implemented such as messaging, short data services and call queuing.

Three different methods of trunking can be distinguished according to the way channels are allocated and retained for communications to take place:

- Message Trunking

  A traffic channel is permanently allocated for the complete duration of the call. The channel is de-allocated when the call is released.

- Transmission Trunking

  A traffic channel is allocated every time a member in a call transmits. The channel is de-allocated immediately after the transmission stops.

- Quasi Transmission Trunking

  A traffic channel is allocated every time a member in a call transmits. When the transmission is ceased a certain hang timer is started. The channel is de-allocated when the hang time (also referred to as inactivity or tail time) expires. If a member in the same call transmits within this hang time, the same traffic channel is used.

1.2.2 Benefits of Trunking

Trunking techniques were developed to solve a number of operational limitations observed with conventional radio systems. Since the introduction of trunked systems and the continued development of more advanced trunked solutions, even more benefits of trunking have been discovered. Some of the more important reasons for choosing a trunked radio network are listed below:

- Efficient use of the available frequency spectrum

  Far more users can be accommodated per channel on a trunked system than on a single channel. A free channel is allocated to the subscriber only when a request for a call is made. Generally, the benefits increase as the size of the trunked system grows.

- High Grade of Service

  Since the grade of service is a measure of the quality of traffic handling, a trunked system with one site and 10 channels can accommodate about 50% more traffic per channel than a comparable conventional system.

- User-friendly

Operation is simple from the user's perspective since pushing the call button initiates the connection with the called party - the Trunking System Controller automatically controls channel allocation and the call is placed as soon as there is a channel available.

- Reliability

  Short-term loss of a channel due to interference or other reasons only results in a reduced communication capacity rather than a loss of communication.

- Privacy

  A degree of privacy is obtained, as third parties in the network do not overhear conversations between users or groups accidentally.

- High quality of speech

  Trunking offers high speech clarity. The disturbance because of interruptions has been remarkably reduced.

- Wide range of user facilities

  Types of calls range from priority calls, conference calls; transmit of status messages to connection to public telephone network subscribers.

- Extensive operational coverage areas for the user

  Larger configurations are possible by extending the coverage area enabling an almost unlimited number of subscribers to communicate. Trunking supports this by automated roaming and possibly, handover facilities, which are not available in conventional networks. The coverage area for trunked mobile radio can be anything from local up to nation-wide. No user intervention is required to move from one radio cell to another.

- Easy accommodation of new users

  New users can be accommodated more easily in a trunked system than in one of several single channel sites, all of which may be nearly full. Additional channels can be made available to all users on a trunked system, without the need of modifications to existing mobile or portable equipment.

- Less administrative workload

  The number of required licences can be reduced quite dramatically if they are related to the network instead of to individual users. This means less administrative work for the regulatory authority and simplified frequency planning and channel allocation.

1.2.3 Analogue and Digital Systems

Systems can be distinguished by the type of signal presented to the modulator. An analogue system is designed for transmitting analogue signals and may use analogue or digital modulation whereas a digital system is designed to transmit digital signals and uses digital modulation. An analogue system can transmit digital data signals by using a modem.

A typical system is illustrated in Figure 7.

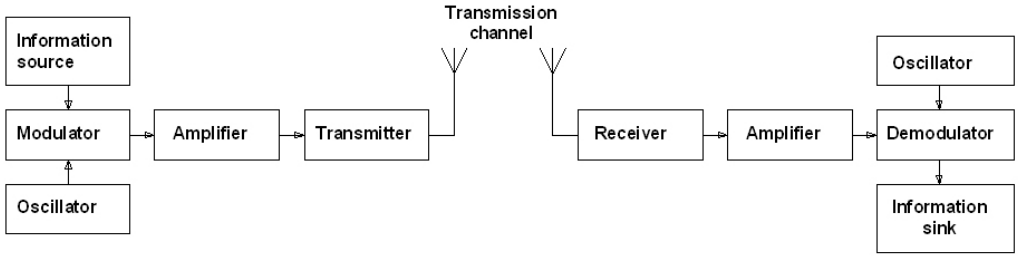

Figure 7 - Radio Communication System

PMR/PAMR systems were predominantly analogue until the uptake of new digital standards such as TETRA and ACPO25 in recent years. In the same way that users moved from conventional radio to trunked networks, the desire for higher security, extra capacity and improved data capability is driving the adoption of the digital systems. Analogue systems are either unable to provide a significant percentage of the services now required by users or cannot provide them in an efficient, cost-effective manner.

Analogue systems allow the transmission of speech very effectively, however they have not been able to handle data effectively or scale to larger, multisite systems. Data transmission is slow at 1.2 kbps, and can use up a large proportion of existing network resources as well as interfering with speech communications.

Digital signals may be transmitted using the same format irrespective of the source of the communication. This allows voice, data and video to be transmitted using the same channel. Most information is now stored in digital format and most communications devices are now basically digital devices.

Common digital PMR/PAMR standards with significant, growing installed bases of end-users are: iDEN, TETRA, APCO 25 and OpenSky. The development of these standards has been motivated by the need to offer customers a wider range of services than those previously available with analogue solutions.

Digital solutions offer a number of significant advantages over the analogue PMR/PAMR including:

- Increased spectrum efficiency for larger systems.

- Increased capacity allows multiple users to share a single network.
- Voice privacy due to voice transmissions being sent in digital form facilitating encryption.
- Superior voice quality in a specified coverage area due to built-in forward error correction with no perceived degradation due to encryption.
- Improved data services and applications, including integrated voice and data.
- Improved signalling features.

Whilst digital solutions have taken some time to be adopted widely by end-users, many of the issues of cost and risk have been overcome as economies of scale and successful deployments have proven both the technology and the business model. Most of the initial concerns have been overcome, particularly through improved RF planning however some issues remain over frequency availability in some territories and backwards compatibility with existing TDMA systems. As is generally the case, no single solution is ever adequate for all applications so that there will be a continuing need for some analogue systems and cross protocol solutions.

1.3 TETRA

TETRA is the standard for digital trunked radio systems developed by the European Telecommunications Standards Institute. It has been designed to meet the demand for more efficient and flexible communication services from both private and public-access mobile radio users. It has also been designed to be capable of addressing many of the technical and commercial problems of mobile radio system development well into the 21st century. It is the core technology in TetraNode.

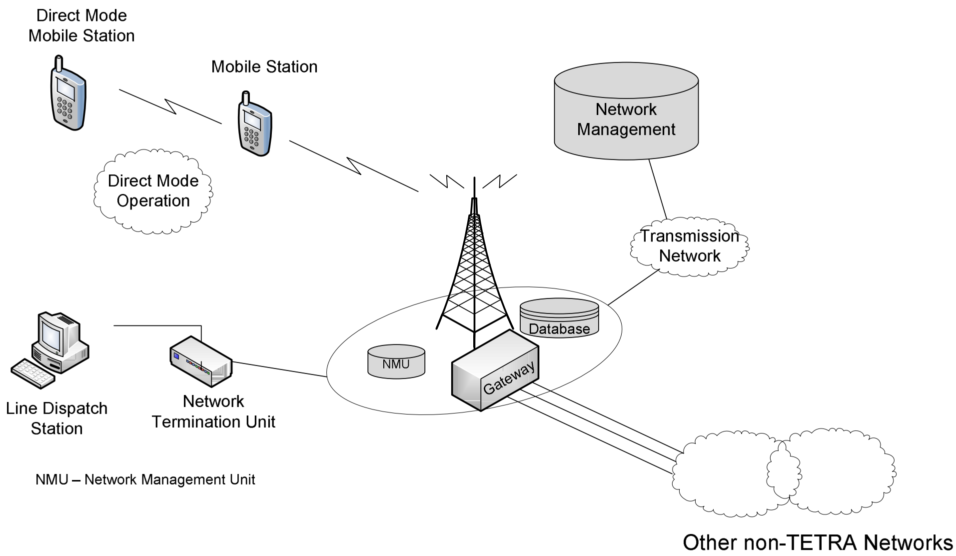

Figure 8 - TETRA Network Configuration

The architecture of a TETRA system can be viewed as:

- Switching and Management Infrastructure

  Provides routing to the radio access system, and facilitates network management.

- Gateway

  Enables calls to be made or data transferred to and from an external network such as a public telephone system.

- Mobile Station

  Mobile terminals, both hand portable and vehicle mounted.

- Direct Mode Operation

  Mode of operation where mobile terminals connect directly with one another without using the infrastructure. The mobile terminal operating in Direct Mode is sometimes also referred to as Direct Mode-Mobile Station.

- Line Dispatch Station

  Comprises the Line Termination Unit and the associated Terminal Equipment - typically the dispatcher or control room console.

1.3.1 TETRA Standards

TETRA was devised by European Telecommunications Standards Institute as a multi-sourced standard for public safety, differentiating itself from standards such as GSM with a strong emphasis on traditional PMR functionality such as fast call set-up times and efficient group call facilities The TDMA access method adopted uses 4 user channels on one radio carrier and 25 kHz spacing between carriers making it inherently more efficient than its predecessors in the way that it uses the assigned frequency spectrum. Data and voice is transmitted at gross 7.2 kbits per second for a single channel.

Initially developed for use in the 380-430 MHz band, TETRA has also expanded into the 320-360, 450-470 and 800 MHz band with hundreds of networks now in operation or are currently being deployed. The trunking capability of TETRA provides a pooling of all radio channels that are then allocated on demand to individual users, in both voice and data modes.

The TETRA standards define a number of key interfaces that allow a large number of suppliers of core infrastructure and terminal manufacturers to develop products providing users with choice.

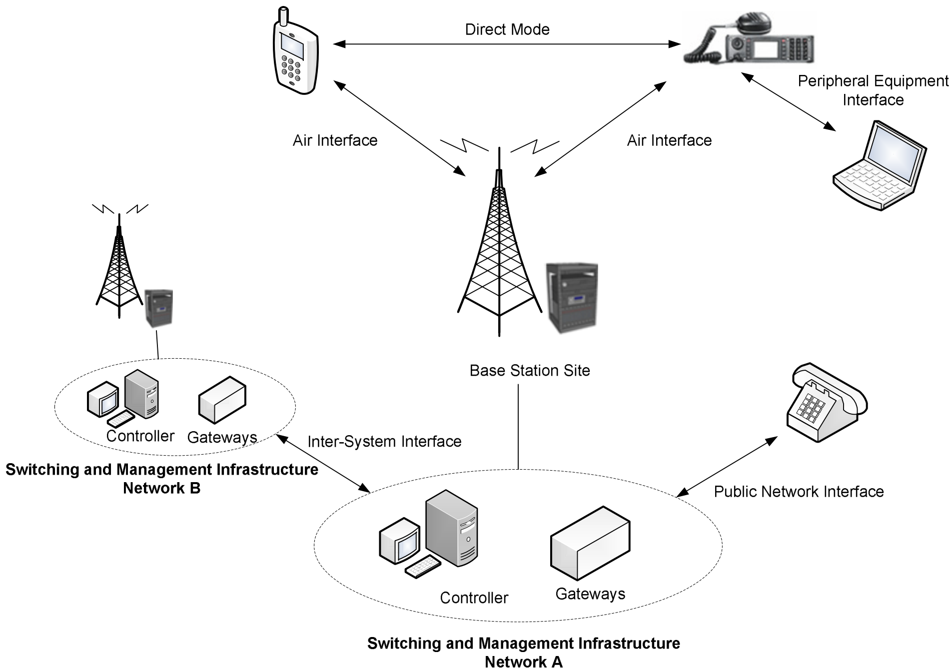

Figure 9 - TETRA Standard Interfaces

The key interfaces defined by the standard are:

- Air Interface

  Ensures the interoperability of terminal equipment from different manufacturers.

- Peripheral Equipment Interface

  Standardises the connection of the radio terminal to an external device, and supports data transmission between applications resident in the device and the connected terminal. Additionally it supports certain elements of control within the radio terminal from the external device and/or applications.

- Inter-System Interface

Enables the interconnection of TETRA networks from different manufacturers. The ETSI standardised Inter-System Interface uses circuit switched links.

- Direct Mode Operation

  Guarantees communication between terminals and beyond the fixed network coverage.

- PSTN/ISDN/PABX

  Enables TETRA to interface with the PSTN, the ISDN and/or PABXs as required.

1.3.2 Interoperability and the TETRA Association

The TETRA Association (previously known as the TETRA MoU) was established as a forum that could act on behalf of parties with an interest in TETRA including manufacturers, integrators, application providers, operators, users, test houses and telecom agencies. The TETRA Association represents more than 150 organisations worldwide.

One role of the Association is to ensure that infrastructure suppliers conform to the standards and that they can interoperate with TETRA terminals and thus form the base of a multi-vendor communications network. This is demonstrated through compliance with interoperability profile (IOP) test procedures, whereby different manufacturers' mobiles and handhelds are tested on various infrastructures. The current certification body for TETRA IOP is the Istituto Superiore delle Comunicazioni e tecnologie dell'Informazione, (ISCTI) which is responsible for the independent testing and certifying of manufacturers' equipment.

The IOP testing procedure proves that the system and terminal suppliers understand and have correctly implemented the TETRA standards. The interoperability profile procedure however only covers a limited number of TETRA features so cannot guarantee full interoperability since this also relies on a number of other important network and terminal features not always specified in the TETRA standard.

1.3.3 TETRA Applications

One of the main advantages of the TETRA standard is its ability to offer a wide range of applications to meet users' demands for feature rich, integrated communications networks.

The basic Voice services of TETRA are:

- Group Call

- Individual Call
- Duplex Call
- Broadcast Call
- Clear of encrypted mode

TETRA allows the following basic Data services:

- Status messaging
- Short Data Service
- IP Packet Data
- Circuit-switched Data

TETRA also supports a comprehensive suite of supplementary services, complementing the basic Voice and Data (V+D) services. Functionality is offered for specific demands in the profession mobile radio environment, for identification purposes of involved parties during a call, for enhancing telephony call functionality and others.

Based on these services, TETRA provides an almost unlimited number of applications for specific user groups; from automatic vehicle location, through email and paging to database queries.

Please refer to part 7 Radio Services for a detailed listing and description of the comprehensive set of TETRA services offered by TetraNode.