2 Modern Security Requirements in Private Mobile Communications Systems

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2.1 Introduction

Having discussed the main objectives of the book in the previous chapter, we shall now embark on showing the basic features of the class of systems to which TETRA belongs, their basic configurations, the different technologies used and the problems that present in their usage as security tools in the Private Mobile Radio (PMR) communications field. Actually, even though these systems have been designed as the security alternatives of their public equivalents such as the GSM, still they have limitations which are pointed out. As the best candidate to satisfy modern security requirements, we present TETRA. It is shown, by identifying the elements on which a comparison of the requirements with its special features of the evolving standards and the improvement that are possible for TETRA, that TETRA can play a major role in the next generations of PMR systems. An area which requires special attention is the interoperability functional requirements based on both technical and operational issues The superiority of TETRA is then proven in chapter 3 comparing TETRA with its closest competitor which is GSM. This superiority becomes then the basis for using TETRA as the building block in many applications that involve implementations of secure integrated designs.

2.2 PMR Systems [1]

2.2.1 PMR Configurations

The simplest PMR configuration is point-to-point direct terminal communication. Such a system has no infrastructure, and in most cases all terminals within range receive messages as shown in figure 2.1. It is possible, however, to conduct private conversations through the use of signaling tones or messages which mute terminals which the message is not intended for so that it is not heard. Either a single common frequency is used, or different frequencies can be used for different call groups. Communication is only possible between terminals when they are in range of each other, and given the power limitations on battery operated portable devices, this may be a significant restriction.

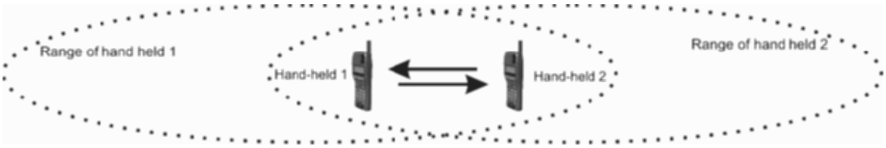

Fig. 2.1. Simple direct mode PMR configuration

One of the most common PMR configurations is the dispatch operation. At least two channels are used, one for uplink communications between terminals and the base station, and one for the downlink to the terminals. Messages from the dispatcher on the downlink can be received by all terminals (although again individual addressing is possible), whereas messages from the terminals can only be received by the dispatcher. Mobile to mobile communication is possible via the dispatcher. Links with the public switched telephone or data networks are possible, again via the dispatcher as shown in figure 2.2.

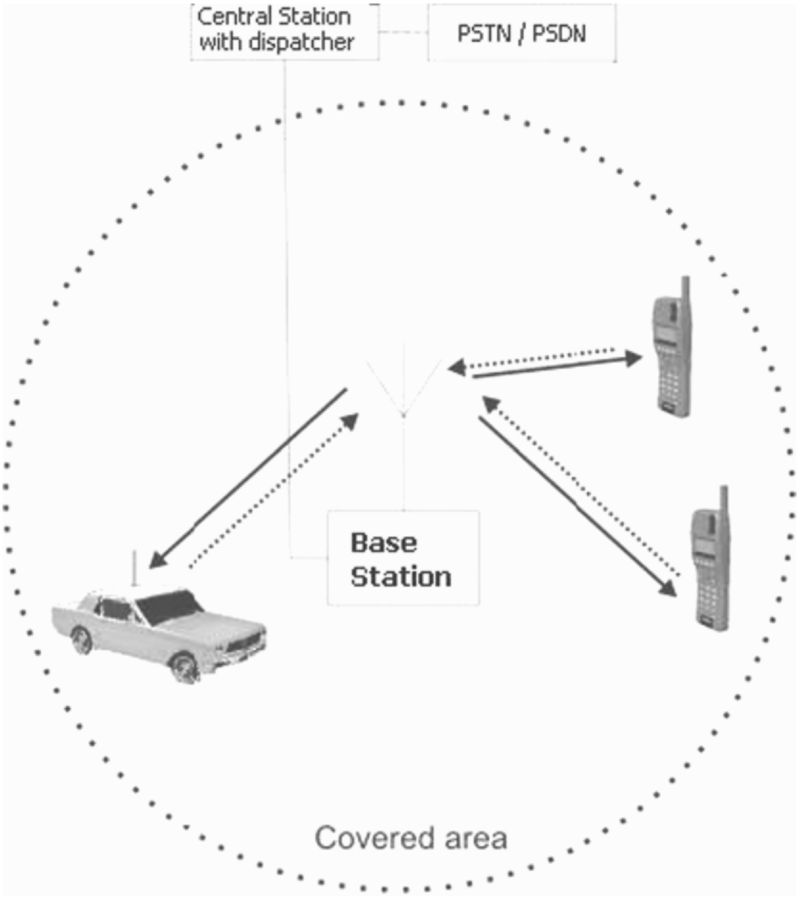

Fig. 2.2. Dispatch mode PMR configuration

A number of refinements to this basic system are possible. If extended coverage is required, but central dispatch or PSTN network access is not necessary, the base station can be connected as a repeater. This is called “talkthrough” mode where any uplink messages are retransmitted on the downlink, effectively extending the range of mobiles to that of the base station. In Figure 2.3, the transmission from mobile 1 is received by mobiles 2 and 3, even though they would not have been in range if the message had been transmitted directly.

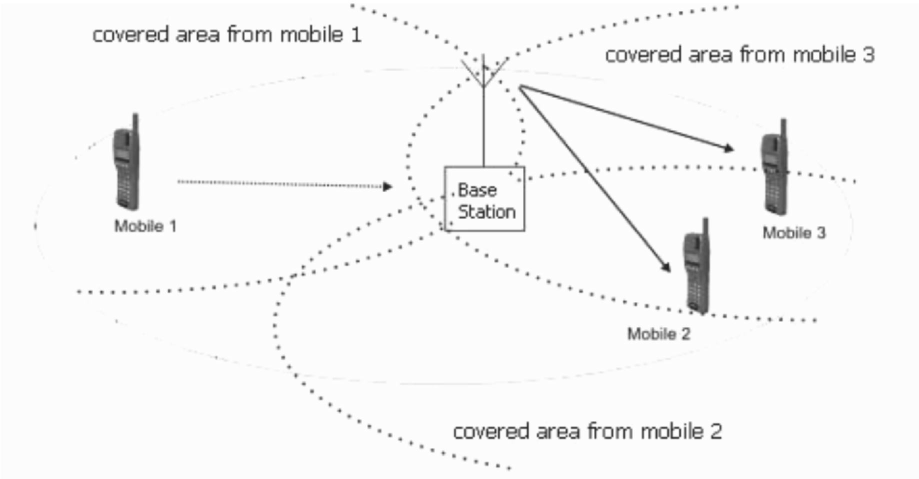

Fig. 2.3. Talkthrough repeater operation

Different organizations can share repeaters (so-called "community base stations" or "community repeaters") if the different users have signalling to identify their messages. The signalling is retransmitted by the base station, so that users in other groups are muted and privacy maintained. Since users in groups do not hear all the messages it is necessary to keep usage low to ensure access. Such systems therefore include time outs to ensure that users do not hog a channel.

A better option, although one which requires more complexity, is trunked operation. In this case, several channels are available, pooled between different PMR operators. This allows trunking efficiency and makes it more likely that a free channel will be available.

In many cases, a single base station will not be able to cover the entire service area. If the uncovered area is limited to relatively small areas, such as in the shadow of a building, a remote radio port can be provided to illuminate this area.

Since hand-held terminals usually have lower power than mobile terminals mounted in vehicles (due to battery and safety restrictions), mobiles can receive signals at greater ranges than hand-held. Portable vehicle-mounted repeaters can therefore be used to provide hand-held coverage to users working near to their vehicles. This mode of operation is commonly used by the emergency services.

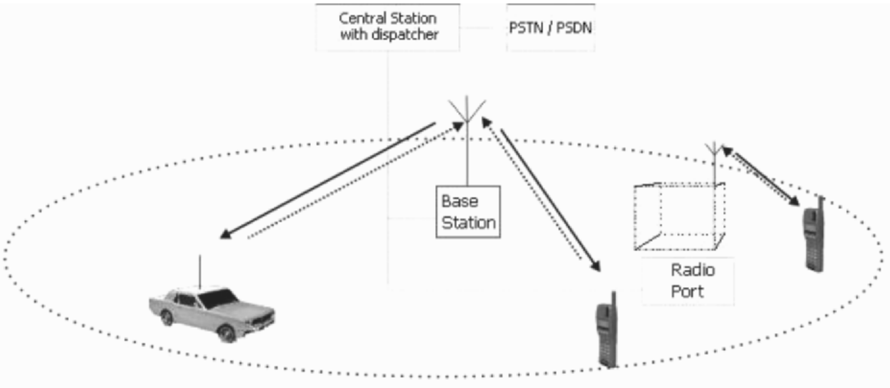

Fig. 2.4. Using a radio port to fill a coverage black spot

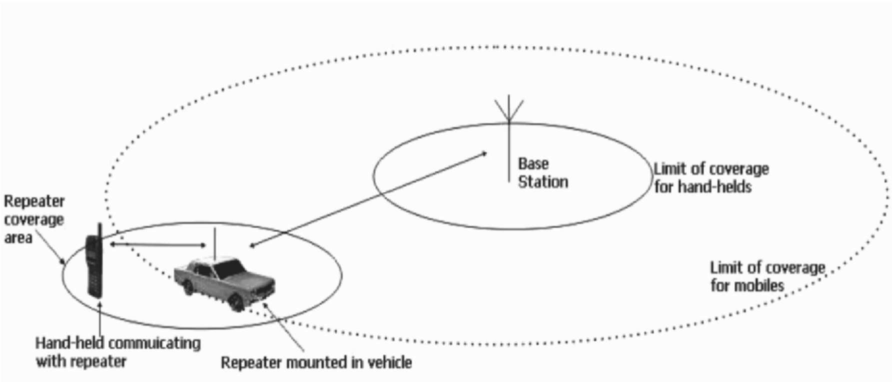

Fig. 2.5.

If larger areas have to be covered, several base stations must be used as shown in figure 2.6. If only a relatively low capacity is required, these can all transmit the same signal in a system known as simulating, and the system acts in the same way as one large cell. In analogue systems the frequencies used in the different cells vary by a few hertz which reduces problems in the overlap regions that receive signals from two or more cells. In digital systems, this is not possible, and systems have to be carefully designed to ensure that terminals can receive an adequate signal in the overlap region.

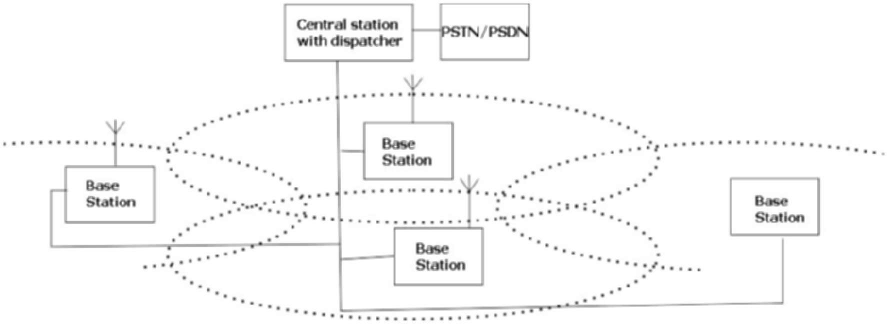

Fig. 2.6. Wide area coverage using several base sites

Larger capacity systems would require the use of multiple cellular re-use. Such systems are considerably more complex than other configurations, requiring switching between the base stations and handover of mobiles between cells as shown in figure 2.7. However, large PMR operators, and PAMR operators, need to use cellular configurations to give them sufficient capacity. Even large PMR or PAMR systems do not have as much traffic as public cellular systems, and so will have a relatively flat architecture compared to the complex hierarchical network architecture of GSM. The next section compares PMR and cellular operation more generally. A more detailed comparison will be given when TETRA will be compared technically with GSM in chapter 3.

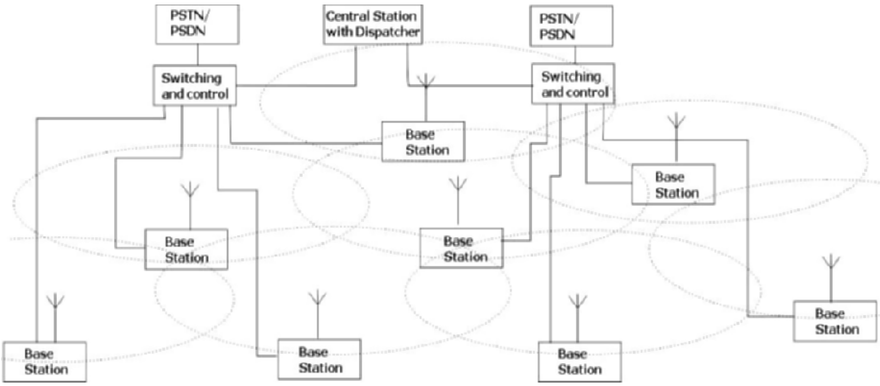

Fig. 2.7. Cellular PMR Configuration

2.2.2 Comparison Between PMR and Cellular [2]

PMR systems are in many ways similar to the public cellular systems. However, there are some significant differences between the two types of system which means that their design requirements are very different. The differences contribute to the security advantages of PMR over the cellular public systems as we shall see in chapter 3. The main differences between PMR requirements and the requirements of cellular systems are as follows.

Group calls.

Cellular users have a much lower requirement for group calls than PMR users, and such requirements can usually be covered by having some sort of conferencing facility to link calls. PMR systems, on the other hand, must have flexible group call facilities, including allowing parties to enter and leave groups, and the ability to contact all users in a particular area.

Dispatcher operation

Many PMR systems have a centralized dispatcher controlling and monitoring the system. This facility is not required in a cellular system.

Decentralized operation

PMR systems are often required to work in a direct mode, where mobiles contact each other directly rather than via fixed base stations and network infrastructure. This allows operation outside the coverage of the fixed infrastructure and also in an emergency. Cellular systems must route all communications through the fixed infrastructure to allow for control and billing.

Fast call set-up

Cellular users dial a number, and wait for their call to be connected. This may take tens of seconds depending on the call's destination and call handling issues such as billing. In contrast, PMR users with a push-to-talk expect to do exactly that -press and talk- without delay.

Supplementary services

Supplementary services are additional call services over and above the basic communication service. Examples include call forwarding for a voice call. PMR users are more likely to want supplementary services tailored to their particular needs, such as variable priorities for different users, the ability to break into or monitor conversations, and so on. Cellular operators, on the other hand, have a much broader user community and will wish to offer a fixed range of simpler services which they can be confident will be commercially viable.

Traffic patterns

With a PMR system which operates without dialing (i.e. a push-to-talk to contact the dispatcher or other users), calls are very short, consisting of a sentence or two. Usage regulations request a limit on shared PMR channels of 15-20 seconds, and the system may include a time out limiting the length of activity periods to 30 seconds or one minute so that one user is not able to hog a channel. In contrast, cellular calls will consist of a conversation, and so be longer. The average length of cellular calls is just under two minutes. Another difference between PMR and cellular is the destination of calls. Most cellular calls originate or terminate outside the mobile network, with only a small proportion of mobile to mobile calls within the operator's network. On the other hand, PMR calls are usually intended for other users on that network, and the facility to route calls to other networks may even be absent as shown in figure 2.8.

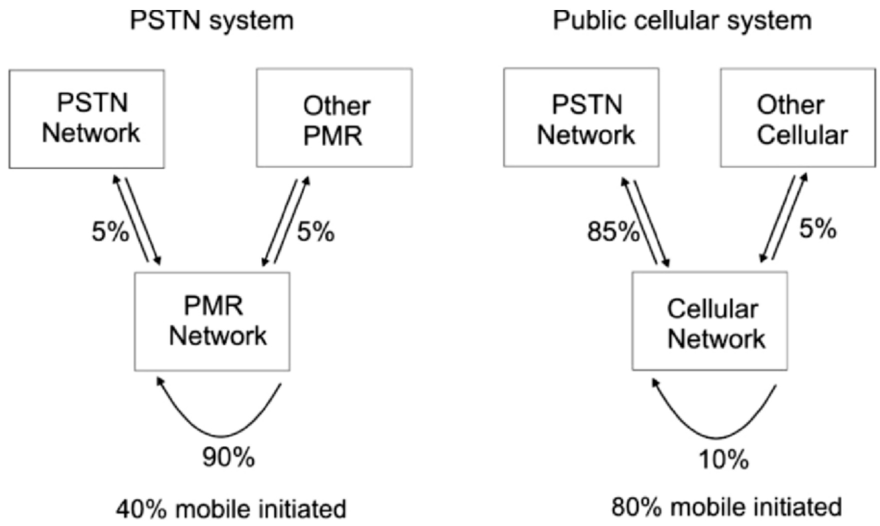

Fig. 2.8. Sources and destinations of calls in PMR and cellular networks

Capacity

Cellular operators have a fixed allocation of frequency and they wish to maximize the number of users on the system to maximize their revenue. Their user base is large compared with their spectrum allocation and there is therefore an incentive to provide a large number of base stations, small cells, high re-use and efficient air-interface techniques to increase the number of simultaneous users supported. A PMR system is likely to have a much lower user base and the traffic is lower due to shorter calls, so capacity for the PMR operator is not likely to be an issue. PMR operators with their lower capacity requirements will want to minimize infrastructure costs, and so will have much larger cells, in the order of tens of kilometers. Cellular operators usually have cells limited to a few kilometers in radius at most. Capacity does affect PMR operators in another way when it comes to obtaining licenses. In many urban areas there are so many PMR operators that there are no spare frequencies and channels have to be shared. A PAMR system allows trunking of calls and results in a more efficient use of the spectrum.

Frequency planning

In a cellular system, frequencies are planned throughout the whole system. This is not the case in PMR, where frequencies will be allocated to users for specific areas and there may be no co-ordination between users in a particular area. This means that a PMR system must obey strict interference limits with regard to neighboring earners, whereas cellular systems can tolerate adjacent carrier interference because neighboring cells can be planned with this in mind.

Control, billing and authentication

In a cellular system the user is authenticated and billed for each call. This is in contrast to a PMR system where permitted users may use the system at will. The PMR operator has to pay for the infrastructure but this is effectively a standing charge and there is no per call charge.

Relationship between the service provider and the user

In a PMR system the users are providing their own service, or will employ someone to provide the service on their behalf. The quality of the service is therefore directly within the control of the user. A cellular system provides a standard service, though perhaps with some amendments. The user therefore has much less control. A PAMR system falls somewhere between these two extremes.

Coverage

A cellular operator will provide coverage where it is economic to do so, which is where people who want to make mobile phone calls are. Cellular operators normally quote coverage in terms of the percentage of the population rather than the land mass, as complete coverage of the land mass of a country would be extremely expensive, and unless external factors such as government support are involved, may not be undertaken. On the other hand while cellular users may be able to operate their system at capacity in some areas, judging that the extra infrastructure costs would not be recovered by the additional traffic served. PMR operators may not have the option of dropping or queuing high priority calls, and will therefore have to provide additional capacity to meet worst-case, rather than average, traffic load.

PMR operators usually require coverage over predefined areas of operation. Cellular users must be able to use their phones over as wide an area as possible, including internationally. PMR users may not be interested in use outside their specific location, although in the case of police services or truck drivers this might still be a considerable area requiring roaming between mobile networks. It is then obvious that there is need for the following peer standards.

2.2.3 PMR Standards [1]

The Need for and Development of Standards

With the move towards digital PMR systems, there has been a trend away from proprietary systems toward a public standard with which equipment must conform, thus allowing equipment from different manufacturers to be used together. Moves towards public standards have come from manufacturers and operators, as in the case of TETRA, or the user community, as in the case of APCO25. The attitudes of governments to the standardization process are quite varied. A hand off approach has been taken in the United States of America, where it has been decided not to insist on the APCO25 system but to allow the market to dictate which system is used. In contrast, in Europe, the European Commission is far more proactive in setting standards and even defining them at a technological level through

ETSI. This insistence that for certain government contracts systems conforming to ETSI proposals must be used is one of the reasons cited for the opening of the Matra PMR system resulting in the TETRAPOL standard.

Public standards have a number of advantages, as was shown by the success of GSM in the mobile radio sector. Public standards enlarge the market, allowing an economy of scale as well as opening the market for niche players in more specialized areas. All the various standards include defined interface points allowing users to source different parts of the system from different suppliers. As well as forcing more competition between providers, it means that suppliers are no longer required to produce all the components of the system, although turnkey .solutions are still certain to be required by some users.

Public standards also allow users more freedom to move equipment between networks. This is less of an advantage than it would be in the case of public cellular systems, where some users want a high degree of mobility and roaming between networks. However, it can still be seen to be an advantage to many PMR users, especially those, such as the emergency services, who co-ordinate with each other.

Analogue PMR

Early PMR systems were analogue and proprietary. However, a wish to share infrastructure costs and a need to share spectrum led to the development of trunked radio systems, and with this development came the need for standards so that equipment could be sourced from different suppliers. The earliest such system, which is still available from a number of different suppliers, is LTR (logic trunked radio) developed by E F Johnson. A number of these systems are in operation worldwide.

Another major analogue PMR standard is MPT1327 (Ministry of Post and Telecommunications), which developed in the UK in the late 1980s, but has been adopted by manufacturers and implemented worldwide. It is the most widely used PMR standard, common everywhere except the United States of America, where proprietary systems by Motorola, and to a lesser extent Ericsson, dominate. Although MPT1327 is more complex and expensive than some simpler analogue systems, it is relatively efficient in terms of spectrum use (digital systems are still better by a factor of two), and offers some data capabilities as well as the normal PMR voice call features such as group calls, fast call set-up, and priorities.

PMR networks are expensive, and decisions to replace or upgrade are not taken lightly. Analogue systems arc likely to remain until capacity, maintenance or required features force a replacement. At the time of writing in 1999, manufacturers of LTR and MPT1327 equipment were still promoting their analogue systems, in particular for use in countries or areas without spectrum capacity constraints.

Digital PMR [4]

Digital systems offer a large number of advantages over analogue systems. A major advantage is the ability to recover the signal completely as long as the noise level is below particular threshold. This compares with the analogue case, where noise is always and degrades the quality of the signal. There is a disadvantage in that when level approaches the threshold of a digital system, the system performance falls off very rapidly, whereas in an analogue system the quality falls off steadily, giving clear of the system's limits as shown in figure 2.9.

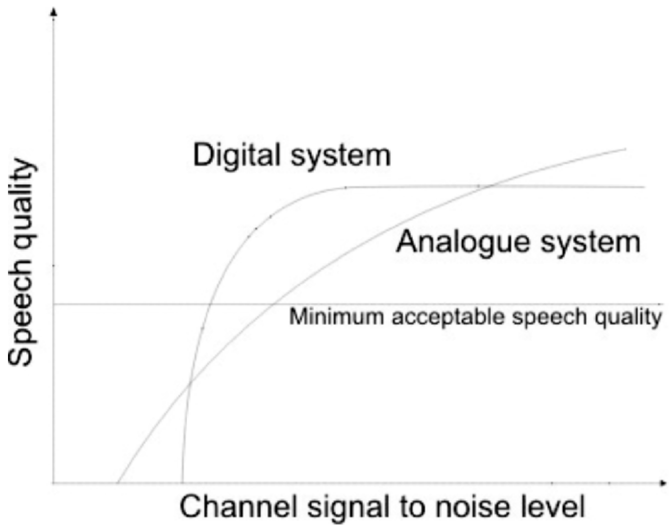

Fig. 2.9. Comparison of analogue and digital speech quality ith differing signal to noise level

Additional advantages relate to the sending of data, which can be sent directly in a digital system the requirement for a modem, and for trunking, as a digital signal can be manipulated more easily than an analogue one. While digital modulation is more easily than analogue systems, the transformation of a speech signal into digital form use of very efficient compression techniques so that the spectrum required for a speech signal is lower with digital modulation and good speech coder than with an modulation scheme.

Digital systems are more complex, and therefore more expensive. However, the increased flexibility, availability of services, and efficiency, in combination with the increased quality of service, means that the PMR market is now moving towards digital in the same way as the cellular market five years ago. A short description of the ones which made an impact are summarized in the following.

1. EDACS

EDACS (Enhanced Digital Access Communications System) is a proprietary digital PMR system from Ericsson. The first systems were installed in the late 1980s, and the system has found application in the military field, as well as its principle use in public safety. When the system was launched, a major selling point was its data services, which were unusual for a mobile radio system of that time, and the system has achieved considerable success, particularly in the USA.

2. Geotek-FHMA

Geotek-FHMA is a digital system which uses slow frequency hopping on an FDMA structure. The technology employed is novel for the civil mobile radio environment, being more common for secure military communications. As well as developing the system through its Israeli subsidiary, Geotek operated a limited number of digital networks itself in the USA, but the system suffered from limited take-up. A link up with IBM in 1997 failed to raise fortunes, and Geotek withdrew from digital network provision in 1998. The system itself, which has been installed in about half a dozen countries, is promoted as the PowerNet system for public safety applications along with Rafael, the Israeli defense firm which was a partner in its development. National Band 3, a UK PAMR operator owned by Geotek, was going to adopt Geotek-FHMA, but this network is now owned by Telesystem International Wireless of Canada, which through its Dolphin Telecom subsidiary is using TETRA for new digital PAMR operations in the UK and France

3. APCO25

APCO25 was an initiative by the Association of Public-safety Communications Officials - International, Inc. (APCO) to try to create a standard PMR system for public safety applications. While the emphasis in Europe has been to create a cross-border standard for such systems, the United States has a more market-orientated culture and different countries may have incompatible systems from different suppliers. The idea of a federally required standard has since been watered down, but the system has continued to be developed with Motorola, which owns lights to much of the key technology, licensing this to other manufacturers. Motorola's Astra system was the first APCO25 system, launched in 1996.

Recently APCO25 and TETRA agreed to cooperate on future developments. In its current form, APCO25 is an FDMA system with 12.5 kHz carrier spacing, which is compatible with existing analogue channel spacing. However, future plans foresee halving the bandwidth requirements for speech channels to make more efficient use of spectrum. A narrow-band FDMA approach with 6.25 kHz carrier spacing has been proposed to allow this, but this is being reconsidered in the light of TETRA developments which may see a TDMA approach being employed for this development has had a presence in the market for a couple of years before the roll out of TETRA systems, and has been adopted by users in 15 countries, mainly in the public safety area.

4. TETRAPOL

Tetrapol faces a problem in terms of take-up in the EU, since although it is recognized by the ITU, it is not a formal standard approved by ETSI, and moves to convert the TETRAPOL PAS (Publicly Available Specification) to an ETSI standard have recently stopped. Most European Union countries are planning to use TETRA, although TETRAPOL has been recognized by Schengen Group along with TETRA, and it is in use by security forces in France, Spain and Austria, as well as other European countries such as Romania, Slovakia and the Czech Republic.

5. TETRA

The main focus of this book is the TETRA standard as used in security applications. More technical details are given in chapter 3 in the forum of a comparison between TETRA and GSM. the appendix we summarizing the technical characteristics of TETRA. TETRA was developed from the start as an open harmonized digital PMR standard within ETSI. As an ETSI approved system, it has a significant commercial advantage within Europe, both from the point of view of manufacturer and operator support, and from the point of view of governments, which in Europe will specify ETSI approved systems for their contracts. The wide user and producer base should provide significant economies of scale. However, the PMR market has a number of existing 2^{nt} generation digital systems in operation already, and with 3^{ld} generation cellular systems only a few years away it is important that TETRA gets off to a good start if it is to establish a dominant position in the marketplace.

TETRA is a feature-rich system, providing everything from specialized safety services to cellular operating modes. It also has a wide selection of data services. The trunked TDMA access technique allows more efficient use of the radio spectrum, but means that an operator must be assigned a minimum of at least four voice channels. However, the system has a number of operating modes, which allow wide area coverage with a single radio carrier without resorting to cellular frequency reuse schemes that would increase radio carrier demands still further. Of more potential concern is that the complexity of the system will make the infrastructure and terminals relatively expensive, which should be offset by the economies of scale if the system becomes popular.

6. Mobile Satellites

Although it is uncertain as to when satellite communications will be practical and economical for use by public safety agencies, it is critical to discuss these important emerging technologies in this handbook.

The United States has a fleet of geosynchronous earth orbit (GEO) satellites at approximately 22,500 miles above the equator providing wideband transponders to connect telephone and television circuits around the world. There are several GEO systems used for general mobile services available today. However, they require a briefcase full of equipment, including a highly directional antenna. In addition, there is a delay of about 1/4 second for the transmission, which slows down interactive voice and data transmissions considerably. Because of this, the service is not yet appropriate for the use of simple handsets as used for cellular or PCS radio.

7. Voice Communications Satellites

Besides GEOs, medium earth orbit (MEO) and low earth orbit (LEO) satellites have been proposed for relaying radio transmissions. MEO and LEO satellites require less output power from phones and have less time delay than GEO systems. The relationship of GEO, MEO, and LEO satellites so that in a full implementation of GEOs, MEOs and LEOs, there will be three discreet bands over the eath where the satellites will be located.

Iridium®[5].

In 1987, Motorola engineers proposed their Iridium satellite system for wireless communications to allow a person with a small handset anywhere on the earth's surface to communicate with another person's handset anywhere else on the earth's surface. This satellite system was the first of a number of systems that would not only receive signals from the earth (which are converted in frequency, amplified, and re-transmitted as commonly done in transponders) but would also contain switching and routing processors.

Iridium system was constructed and functioned as planned; however, Iridium, LLC, filed for bankruptcy in February, 2000, because of a failure in their business plan. In December, 2000, Iridium Satellite, LLC was formed and acquired the operating assets of Iridium LLC including the satellite constellation, the terrestrial network, Iridium real property and the intellectual capital. A new management team was installed and the company sold their services in March, 2002, to the U.S. Department of Defense as a stable customer.

The Iridium system consists of 66 satellites placed in LEO orbits with seven spares to fill in should the company loose the service of a satellite. The system is composed of 6 planes of 11 satellites equally spaced in a low-elevation orbit with an orbit altitude of 421.5 nautical miles, as shown in figure 2.11. Each satellite provides a set of 48 separately controlled spot beams to cover the earth's surface so that (with the 66 satellites) there will be 3,168 cells covering the entire earth. The system may be thought of as a type of cellular radio system where the "cellular base stations" and cells are constantly rotating so the earth signals are handed off from one satellite to another as they pass over an individual's handset.

L-band frequencies (1616 - 1626.5 MHz) are to be used for the communications between the earth and the satellites and the Ka-band frequencies (23.18 - 23.38 GHz) are used for intercommunications between the satellites. Ground segment frequencies to gateways and control facilities use Ka-band frequencies (downlinks, 19.4 - 19.6 GHz, uplinks, 29.1 - 29.3 GHz). Figure 2.10 shows Motorola's concept of this system. Iridium will support voice and data up to 4800 bps.

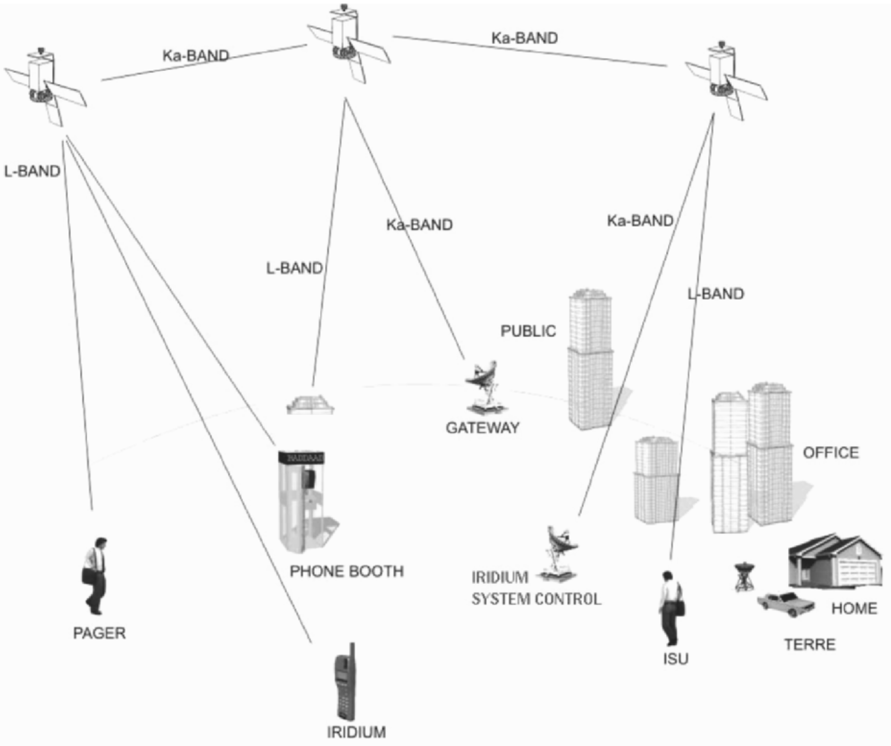

Fig. 2.10. Iridium System Overview

Other voice satellite systems.

The other commercial LEO system in orbit is Globalstar, which is now a wholly owned subsidiary of Vodafone Group PLC. The system consists of 48 satellites allowing for seamless coverage anywhere on the earth. The system utilizes CDMA technology with path diversity and the company provides light weight, 12 oz. phones for voice communications.

Other companies have stated an interest in LEO and MEO narrow band systems. Mobile Communications Holdings' Ellipso™ and ICO Global Communications' ICO satellites are in MEOs, spaced at about 6,000 to 10,000 miles above the earth's surface.

There are tradeoffs between the LEOs and MEOs. Far fewer satellites are required in the MEO system than in the LEO system, but higher effective power is required for transmissions by the subscriber units, and time delays are greater.

8. Data Communications Satellites

Since 1992, American Mobile Satellite Corporation, now Motient Corporation, has offered satellite service employing geosynchronous satellites. Motient has recently transferred it's operating interest in satellite communications to a partnership called Mobile Satellite Ventures LLC (MSV). Motient retains approximately 25% interest in the partnership.

The MVS system provides coverage to North and Central America, parts of South America and the Caribbean via a single geosynchronous satellite using "L-band" technology. Both voice and data may be handled on the same system, with communication of data up to 4800 bps. The equipment used includes both mobile and transportable units. The mobile units use a steerable antenna to allow use on a moving vehicle.

The system provides three different services. The first is a satellite telephone service that allows calls to be made to any phone through the PSTN and unit-to-unit calls to be made through the satellite without use of any ground stations.

The second service provided is a radio-like service that allows unit-to-unit calls via a talk group. Satellite units can have multiple talkgroups, and operate using the system as a satellite-based trunked radio system. Some rural fire and EMS agencies use this system for radio communications over very large areas. In addition, several local and US government agencies use these talk groups to coordinate task force disaster responses.

The final service is a packet data service. This service is relatively low speed and useful primarily for fleet tracking and equipment control.

Motient provides dual mode services allowing mobile units to use their terrestrial service when within their coverage area and to automatically switch over to the MVS satellite system when the terrestrial system is not available.

Wideband, data-oriented LEO and MEO PCS satellites are being studied and proposed at this time, as shown in table 2.2. These satellite systems will have the ability to carry high-speed data around the world at up to 10 Gbps.

9. High Altitude Long Endurance (HALE) Platforms and High Altitude Platforms (HAPS)

In this proposed network, relay of signals would be accomplished using large blimp-like repeaters at several miles (20,000 meters) above the earth. The devices would cost less than the big satellite systems and could be recalled to earth for maintenance. Multi-beam, phased array antennas would support both mobile two-way communications and broadband video. Although not considered HALE/HAPS, the U.S. is presently performing surveillance over the U.S.-Mexican boarder using low altitude tethered balloons carrying electronic equipment.

Four types of HALE platforms have been proposed, which include helium-filled robotically controlled dirigibles stabilized by ion engines units powered by solar or fuel cells; piston-driven platforms; and jet engine-driven platforms. The biggest challenge faced by all of them will be power requirements versus refueling requirements. The first two types need little or no refueling but may not produce the transmit power needed, whereas the latter two types will have plenty of power but will need to be refueled every few days.

Sky Station International was the commercial initiator of this technology in the United States and filed with the FCC in March 1996 for use of the 47 GHz band. Sky Station claims a blimp repeater can offer many advantages over satellites, including less time delay and lower power at a considerably lower cost. The concept was also introduced at the 1997 World Administrative Radio Conference, and a portion of the 47 GHz band was tentatively allocated. The 47 GHz band is severely limited by rain, so space diversity ground circuits will most likely be required.

The basic concept is to have "very high antenna towers" allowing for very wide-area communications. This might be an alternative to backbone microwave terrestrial systems. Sky Station indicated that one could start with communications in local areas, expand to regional areas, and eventually cover the country. The FCC has made no decisions at this time. The concept has many technical and political challenges, and its development should be interesting to watch as it evolves.

Since the first edition of this book much greater consideration has been given to HALES/HAPS by many countries throughout the world. NASA has proposed a schedule for testing systems by 2003 using manned and unmanned aircraft and balloon type platforms[23]. The HALE/HAP systems at a height of 25 Km appears to have the least amount of wind speed and a coverage is about 200 Km.

Among the multitude of technical problems to be solved are:

1. Developing stability systems to hold the HALE/HAPS at station keeping locations and stabilize microwave antenna positions.
2. The testing of aerodynamics and aircraft structures.
3. The development of additional light weight, high strength materials.
4. Making sure the altitudes of HALE/HAPS will not interfere in any way with normal air or military air travel.

10. Ultra Wide Band (UWB) Devices

Microcircuit advances in the last year or so have made it possible to create ultra wideband (UWB) radio and radar equipment having very narrow digital pulses, in the nanosecond range, to transmit and receive very high rate data information. The bandwidths are very large and cover a great amount of the licensed frequency spectrum. The FCC and NTIA have studied and made tests to determine that the use of UWB at low power levels will not cause objectionable interference to those licensed services.

In February, 2002, the FCC enacted rules under Part 15 to assign certain frequency ranges for UWB and to quickly allow for the development of commercial devices using this new technology. The UWB research has already yielded a number of new devices which will assist public safety groups as soon as the equipment is developed. These include:

- High Speed in Building Radio Communications - High speed digital transmission with rates in the gigabit range for computer networks using work stations or handheld devices within buildings. The transmissions must take place in the 3.1 - 10.6 GHz spectrum.
- Building Penetration Radar - Radar has been developed for firefighters to look into buildings through walls to find the position of people trapped during a fire. Similarly police surveillance may utilize this radar to determine the number and locations of people within buildings. Operation is limited to law enforcement and fire and rescue operation. The radar emissions must be kept within the 3.1 - 10.6 GHz frequency domain.
- Ground Penetrating Radar Systems - Public safety personnel may use ground penetrating radar (GPR) to determine the location of buried objects including the locations of people within the rubble of fallen buildings. Operation of the GPR is restricted to law enforcement, fire and rescue operations, scientific research institutions, commercial mining companies and construction companies. GPRs must be operated below 960 MHz or between 3.1 - 10.6 GHz.
- Surveillance Operations - Surveillance operations, as opposed to the wall penetration systems, are defined by the FCC operate as “security fences” to establish stationary RF perimeter fields to detect the intrusion of people or objects. Operations of these devices are limited to law enforcement, fire and rescue organizations, public utilities and industrial entities. The frequency band established is 1.99 - to 10.6 GHz.
- Vehicular Radar Systems - Licensed in the 24 GHz band, this UWB technology using directional antennas on road vehicles will detect and locate

the movement of objects near the vehicle to enhance crash avoidance systems, improve airbag activation and suspension systems that will respond better to road conditions.

All the above uses of UWB are licensed under Part 15 of the FCC Rules and are subject to power restrictions as well as the frequency restriction discussed previously.

11. Software Defined Radio (SDR), Cognitive Radio, Wireless Mesh Networks

Public safety radio systems have changed over many years from simplex radios, to single repeaters, to trunked radio systems in both analog and digital configurations. Current radio systems make use of digital circuitry to emulate a number of these earlier configurations, allowing for efficient interoperability within single frequency bands.

However, the next big change in radio design is the use of software to dynamically change a radio's configuration to emulate a multitude of protocols and modulation waveforms using the same hardware.

Microprocessors are already used in today's radio systems at specific frequency bands to set up the transmitting and receiving frequencies, as well as for other functions including user configurations for different talk groups. Software Defined Radio (SDR) promises to integrate entire radio functions (including transmitting, receiving, signal processing and networking) to allow for specific hardware to be dynamically reconfigured to all types of public safety radio systems across multiple bands with a simple change of the "channel" switch. The resulting product will be the ultimate solution to the interoperability problem, giving the field officer a radio "on-the-belt" that can access many different systems on different bands, depending upon the configuration authorized by his agency. Additionally, this radio hardware platform should be easily upgradable to new technologies as they develop, reducing equipment obsolescence as new features, functions and systems are introduced.

An example of early software controlled radio is the use of multimode cell phones which allows a subscriber to automatically switch from the 800 to 2000 MHz frequency bands and emulate the present TDMA, FDMA, and CDMA standards without using several different cell phones. The third generation of cell phones is already utilizing as many as seven independent standards to automatically accommodate different transmission modes. Although the software for these technologies is embedded in chips, SDR promises to allow dynamically updated changes so that it will not be necessary to purchase new hardware every time an update to more efficient technology is made.

These systems can support a number of military and public safety waveforms, and covers the public safety bands from 30 MHz to 512 MHz. While the radio does not yet protocols, there is significant interest by the manufacturer and governmental agencies to add these protocols to the radio. While this radio currently costs about twice as much as a similarly featured single band radio, if it replaces radios on three different bands (as it is capable of doing), it today provides significant savings. As with all new technologies, prices should drop significantly as market penetration increases.

There is a trend, in general, that these systems as they are also coined as cognitive radio, to be combined with PMR and have as a building block the TETRA system. This bring us the prospect of using the rich functionality of TETRA and create TETRA extensions to include integration with WLANs and wireless mesh networks as explained in chapters 6 and 7 be able to use TETRA as the integration component of any possible technology that is being used for emergency, public safety and security communications used even in antiterrorist applications. Therefore the title of the book: TETRA – A Global Security Tool is well justified.

12. Voice Over Internet Protocol (VoIP)

Using the Internet for wireless information applications is one of the latest technology developments to hit the telecommunication world. Voice delivered using the Internet Protocol, or IP, is simply a way of sending information from one device (a desktop computer, for example) to another (radio) over the Internet. To do this, voice information is converted into digital form and then sent in discrete packets over the internet to a receiving device on the other end Changes in technology enable more information to be sent at higher speeds, including voice, fax, video and data through a single large pipeline.

With the passage of IEEE’s 802.11e standard, more network managers will be administering wireless voice over IP. This can mean private radio or cellular wireless or both. The standard is focused on supporting video on demand and audio on demand.

Multimode devices (such as NIC cards) are being developed that will work with a choice of 802.11e wireless LAN or cellular wireless LAN. Other researchers are working on multimode for 802.11 and CDPD. These multimode devices will likely be targeted towards users, such as business people in airports, who need to make cellular voice calls as well as send data over the Internet using a wireless IP link.

In public safety applications, portable radios could receive pager-like text messages, reducing the demand on voice traffic, mug shots could be sent from headquarters to the field officer, video footage can be sent from a crime scene to a dispatch center for assistance in resolving highly volatile situations, and GPS tracking is available for the added safety of officers in the field.

13. Private Wireless Wideband Data Systems

Private Wireless Systems can be extended to cover mobile video, voice and data transmissions simultaneous at as low as 460 kbps data takes. One such application has been demonstrated successfully by Motorola in Florida by the "Greenhouse Project" This experiment proved that applications conducted at one's personal computer may be accessed wirelessly in the field and teleconferencing may be conducted wirelessly from a field facility to another field or fixed facility. Tests were being conducted from patrol cruisers, surveillance vans, ambulances, fire engines and fire district vehicles equipped with Greenhouse equipment.

Greenhouse supports the following technologies and applications:

- Video (Streaming IP video: 2-way video, 1-way video, video pull, video push)
- Voice (Voice over IP - Internet Protocol, Full Duplex - both users can talk at the same time)
- Data (high-speed mobile access to intranet and internet)
  Some applications include:
- Automatic Vehicle Location (AVL) through GPS - vehicles locations appear on map
- Electronic Mail - instant messages including attachments
- Computer Aided Dispatch - facilitates quick deployment of public safety officials
- National and State Crime Database Access - ability to check drivers licenses, etc.
- The ability to distribute a picture of a missing child, or criminal suspect/sketch to all equipped vehicles in the field
- Robbery videotapes can be distributed shortly after an event
- Enable fire department access to building plans and hydrants
- Transmit fingerprints
- Transmit live video feeds for police officer pursuits
- Remote situation analysis

For example, at a crime scene, an officer may take a digital camera mug shot and crime scene pictures; digitize finger prints; select driver's license signature and picture information and send messages (wirelessly) over such a system to obtain crime analysis data from NCIC as well as infrastructure information if required.

2.3 PMR Limitations [4]

Conventional PMR communications systems as we have seen bring many benefits to user organizations but they also create many operational problems for the radio user. Even the most simple of systems comprising a single base station operating on one RF channel and using open channel 'all informed net' operation has some annoying operational problems/limitations. When the size of a conventional system increases and utilizes several base station sites with more than one base station per site, the annoying operational problems are multiplied. Moreover, when large scale PMR systems of different technologies and features are use in security applications and especially when infer organizational or infer country applications are involved interoperability is a major issue and we shall see in section 2.3.3.

For example, operational problems reported are:

- Edge of coverage voice quality
- Contention
- Manual switching of channels
- Inefficient channel utilization
- Lack of privacy
- Abuse by radio users
- Limited data throughput

A detailed description covering each of these operational problems is provided in the following text.

2.3.1 Edge of Coverage Voice Quality

Analogue wireless systems were designed for noise limited range performance, as a trade-off between communication quality and infrastructure cost. This cost versus communication quality trade-off was not unusual as organizations traditionally procured their own private networks. For example, police forces, fire brigades, ambulance services, municipalities, gas utilities, electricity utilities, water utilities and public transportation organizations often had their own private PMR networks covering similar geographic areas, with many of the base station sites being shared to provide coverage.

This cost versus communications quality meant that voice quality at the edge of RF coverage areas was often poor, as received signal levels decreased and noise levels increased. The resulting poor voice quality meant that messages were often repeated and in some cases lost. Also, this poor voice quality placed radio users under increased stress in 'listening out' for voice messages in noisy background signals.

Contention

Radio users wanting to access the system needed to wait until the channel was free of traffic. This meant that they had to monitor the channel waiting for an appropriate time to initiate a call. During busy periods many users were waiting to access the network resulting in several users transmitting at the same time when the channel became free. This simultaneous transmission often corrupted received messages and resulted in users having to contend with each other again in order to access the system. As a consequence, many lower priority calls were never established.

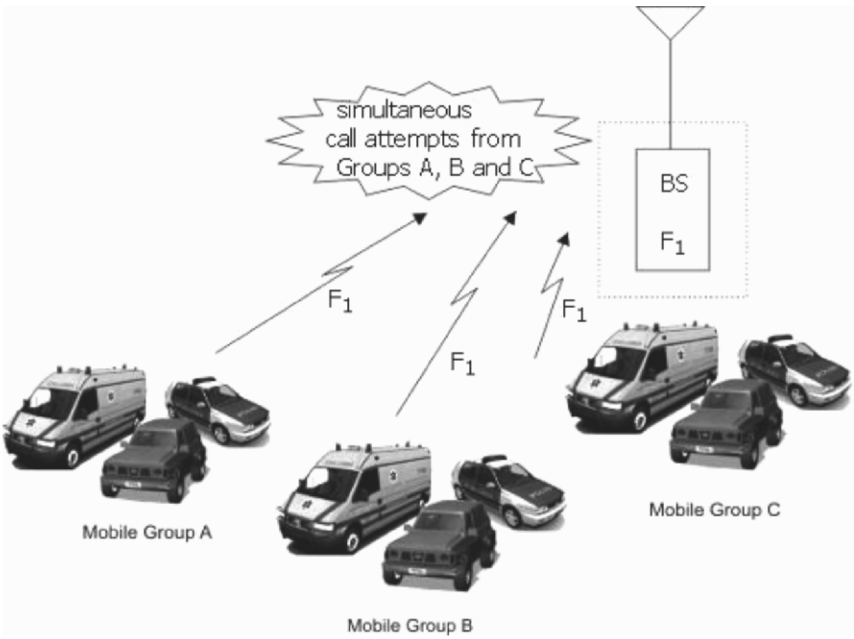

Fig. 2.11. Contention between users accessing a Base Station

The diagram in Figure 2.11 shows contention clashes between three user groups, A, B and C attempting to access a single Base Station (BS) operating on frequency Fl. The high probability of contention clashes during busy periods led to user frustration and also limited the number of radio users that could be supported, which were often as low as 15 to 20 per communication channel.

Manual switching of channels

In systems with more than one base station site to provide wide area coverage, radio users needed to switch to a different radio channel when moving from the RF coverage area of one base station site to that of another. This manual switching of channels was relatively simple to do if the radio user knew when they were out of RF coverage and also knew which channel to switch over to for service. But this need placed the burden on radio users to monitor the channel for lack of coverage and then make the channel changeover decision. As a consequence, radio users were often out of communication without realizing it, until they tried to initiate a call.

Inefficient Channel Utilization

When there were many radio users on a system, more than one base station was provided at a base station site to provide the required capacity. However, for ease of operation and because of technology limitations, radio users in different disciplines of an organization were given only one channel to use, even though more than one channel was available at the base station site.

The diagram in Figure 2.12 shows three base stations, each supporting three independent user groups -groups A, B and C operating on BS Fl, groups D, E and F operating on BS F2 and groups G, H and I operating on BS F3. From the diagram it can be seen that user groups A, B and C attempting to access BS Fl are experiencing contention clashes and resulting poor grade of service whereas Group D has gained access on BS F2 and is experiencing a good grade of service. Base Station F3 is not being utilized because no user groups need communication services at that moment in time.

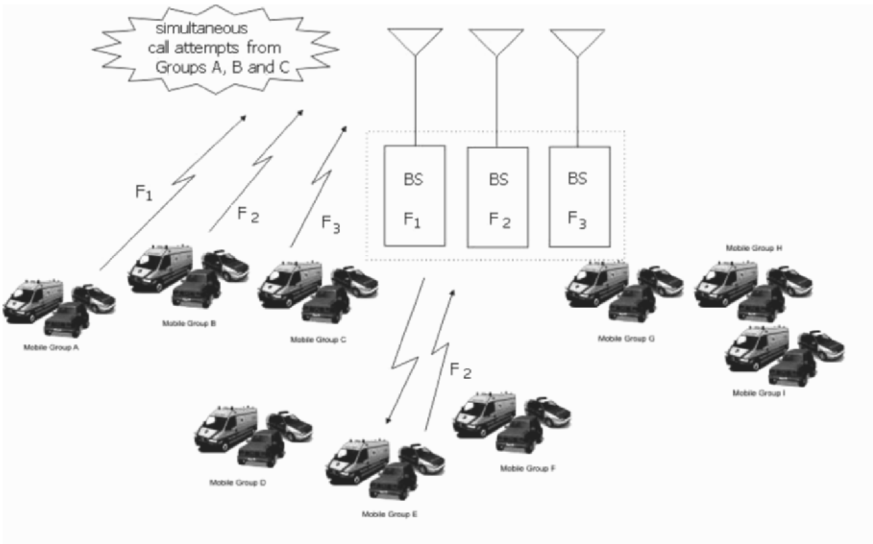

Figure 2.12. Representation of a conventional multiple channel PMR system

This would mean that when one channel was busy with several users waiting to gain access, other channels would normally be free of traffic and could have been used to lessen the load on the busy-radio channel. As a consequence, radio users often encountered unnecessary contention and wasted valuable time through inefficient channel utilization.

Lack of Privacy

Because every radio user listening on a radio channel could hear what everyone else was saying, as anyone can with an easily obtained radio receiver, communications privacy was virtually impossible. This situation had particular implications for the emergency services as well as some commercial organizations.

Abuse by Radio Users

Even in the most disciplined of organizations there will always be individuals who will abuse the system if they can get away with it. This is unfortunately true for radio users. Common examples of abuse by radio users are:

- Ignoring messages and saying that they must have been out of coverage
- Saying they were in one location when they were in another
- Giving verbal abuse over the radio channel knowing that they could not be identified

Limited Data Throughput

The traditional method used by regulators to increase RF spectrum efficiency and utilization was frequency division. For example, over time 50 kHz channels were replaced with 25 kHz channels, 25 kHz channels replaced with 12.5 kHz channels and in some cases 12.5 kHz channels replaced with 6.25 kHz channels. As far as occupied channel bandwidth was concerned, dividing channels by two effectively doubled the number of channels available for a given amount of RF spectrum. Reducing channel bandwidth for voice communications had little effect on quality. However, as a consequence of using narrow band channels, mobile data throughput was limited to relatively low-speeds. The laws of physics meant that the narrower the channel bandwidth, the lower the data throughput.

From a user's operational aspect, this limitation in data throughput meant that practical applications were limited to status messages and short data messages. Users were also particularly concerned about mixing voice and data messages on the same channel, as the data messages were audible and annoyed users.

Problems Solved

Fortunately, identifying problems is a precursor to solutions being provided. In the problem areas described previously there are solutions that have evolved to overcome some of these problems. For example, Continuously Tone Coded Sub-audible Squelch (CTCSS), also known as Private Line (PL), helped to provide some degree of privacy between radio user organizations operating on the same system, but not against eavesdroppers with radio receivers.

Press To Talk (PTT) inhibit, automatically enabled when the channel is busy, helped to minimize transmission clashes and reduce the number of repeated messages.

Selective signaling, such as 5/6 tones sequential, reduced verbal abuse because users can be automatically identified at the start of each transmission. Also, selective signaling provided some degree of individual user privacy, but again not against eavesdroppers with radio receivers.

Automatic Vehicle Location (AVL) provided by Global Positioning System (GPS) and other location technologies, has greatly assisted the operational efficiency of many organizations and has also prevented false location information being provided by radio users.

By far the most beneficial technology solutions are those of trunking and digital wireless communications. Because of the importance and significance of trunking and digital cellular systems in solving many conventional PMR operational problems, a comparison is made between PMR and cellular as well as TETRA and cellular in separate chapters. The clear advantage of TETRA then is proven in chapters 5,6,7.

2.3.2 Requirements of PMR Services

The requirements of a private mobile radio system can be summed up very simply as giving the ability for users to communicate with each other reliably. More specifically, it is possible to identify a number of key requirements of PMR users. In no particular order, these are:

Reliability

Many PMR services are used in safety critical systems. One advantage to the user of being involved in the operation of the service is that they are in the position to ensure reliability and are not dependent on other operators. The lack of public cellular systems to guarantee quality of service or grade of service in all circumstances, or their unwillingness to take liability for safety critical services, may force the use of a PMR system. A survey that looked at the importance of PMR features found that service availability was classed as “extremely important” by two-thirds of those questioned, the highest proportion of any requirement.

Speech and data transmission capability

Mobile data services are increasingly being used for tracking, telemetry or information updating services. Examples of innovative data service use include BT, a national telecommunication operator, which sends daily work orders direct to repair technicians so that the working day can start at the first job rather than with a trip to the depot. Simoco is conducting trials with Langdale Ambleside Mountain Rescue Team in the UK on transmitting medical telemetry, including still images, video, text messages and GPS data to assist in rescue operations. As data services develop, so will the applications which make use of them. A flexible data service provision is therefore essential. In the survey [6], almost 80% of users classed data communications as important, with over half of these saying that it was "very important". 10% of respondents classed data calls as "not important", but all respondents classed speech calls as important to some degree.

Centralized and decentralized operation

In many businesses, PMR is used to organize users, and a central dispatch point is therefore required. However, it may also be important that users are able to contact with each other in the absence of a central control point or even any infrastructure at all. Again the survey [6] found almost 80% of users classed direct mode operation as important, with over half of these saying that it was "very important".

Point-to-point, group calls and broadcast calls

If PMR systems are used, a flexible group call structure is essential so that users can share information directly rather than having to relay it via others. Therefore, group calls, calls involving a number of defined users, and broadcast calls, where the call includes all terminals, are required in addition to point-to-point (single terminal to single terminal) calls.

Fast call set-up

Rather than dialing a number to set up a call, with the called party answering a phone, PMR systems usually have a "push-to-talk" to activate a call to the dispatcher or user group, with the receiving terminal annunciating the message without an answering procedure. Calls may therefore consist of a sentence or two, and users expect to be connected to the called terminal without delay. This is particularly important in the emergency services where the radio may be used to give urgent commands and the dropping of the first few words of the message due to delaying in setting up the call might have serious consequences.

Good coverage

Professional mobile radio users usually have less choice as to where to make a call than a cellular user. The call location is often stipulated by the location of the work the user is undertaking. In the case of a utility this may mean having good coverage over a wide area, and for public safety users, constraints can be even more severe. For example, a mountain rescue service may require coverage in areas where public cellular systems would not be provided, but even in more benign radio environments, as well as overall area coverage, the absence of black spots within a covered area is also very important.

Long battery life

User maintenance costs money in terms of lost work time in PMR systems, and reliability of service is also important. This compares with public cellular systems where the users are responsible for battery charging.

Flexibility

Flexibility takes many forms. Flexibility with regard to services has already been covered, but another input aspect of flexibility is the ability of the system to change with the developing needs of the operator. In particular, the system should be scalable so that growth can be handled, and sufficiently adaptable to allow new services, which were not anticipated when the system was installed, to be added later. Businesses will not want to invest large sums of money in a system which cannot be modified easily once installed.

Low total cost of ownership

Companies using PMR systems will consider cost over the entire life of the equipment, including capital costs for the infrastructure and maintenance costs for the equipment in addition to the "headline" cost of the terminals themselves. Unsurprisingly, no respondents to the survey in (61 classified costs as unimportant, with 95$ classifying them as "important" or "extremely important".

A number of other requirements may not be necessary in all cases but will be needed by a large number of users. Any PMR system will therefore have to take them into account.

Security

Many PMR users have a requirement for high levels of security. Security takes a number of different forms, both in terms of reliability of operation and protection of the transmitted information from tampering and interception.

Call priorities

PMR operators may wish to be able to differentiate between users to give different call priorities or qualities of service to different user or call types. For example, an emergent call may be able to pre-empt other call types to gain access to the network.

Communication between networks

Many companies operate over large areas or with several sites. They may not want to provide the complete network themselves or they may use different networks on different sites due to equipment replacement cycles or regulatory restrictions. Their PMR networks may therefore have to communicate with each other. Also, in many circumstances, communication with general telephone or data networks is a useful Infrastructure

Ease of licensing

This issue involves not just the bureaucratic process of obtaining permission to use a radio channel but also the issues of the availability of channels and any co-ordination which may be required with other users in the same area. The problem of licensing hundreds of different users operating in numerous different areas is much more complex than that of organizing a small number of national cellular operators. It is only possible if the PMR radio channels are as self-contained as possible from the point of view of interference with other users.

In-house control of system

Almost two thirds of PMR users preferred to control their own network, with less than one sixth thinking that control was not an issue. An obvious reason for this is to ensure security, but other advantages relate to cost control and service guarantees.

One requirement not included above is that of capacity, or the efficient use of radio resource. In tact, capacity is not normally an issue to PMR users due to the length of the call, and since licenses have been relatively cheap in most countries. PMR users have only been concerned at a more general level as channels become scare and have to be reused more frequently in high traffic areas such as cities. Of more general concern is the fact that the division of the available spectrum between different PMR users means there is little trunking efficiency. This results in there being fewer channels than required in most large urban areas. The regulatory authorities are therefore likely in insisting that PMR systems are spectrally efficient and use a narrow carrier spacing.

2.3.3 Interoperability [6]

Introduction

As PMR technologies become more far-reaching and interconnected, interoperability has become critical. Interoperability to achieve information superiority is the keystone on which future security systems, logistic, and other government systems will be based on. Interoperability is, therefore, the foundation of effective joint, multinational, and interagency operations. We have seen that for an effective, overall design of a system that will satisfy modern security requirements must be able to utilize the resources of all subsystems that have been used so for emergency security or public safety implementations. In order to integrate all of them for a particular and multifunctional application we can use show the TETRA can accomplish this objective and serve as an integrating system as will explain in later chapters. The general framework that covers such operation is coined interoperability which will be described in the section in more general terms.

Currently, there is a tendency to concentrate on the mechanisms that various systems use to interoperate. However, focusing solely on mechanisms misses a larger problem. Creating and maintaining interoperable systems of systems requires interoperation not only at the mechanistic level, but also at the levels of system construction and program management. Improved interoperation will not happen by accident and will require changes at many levels.

While many systems produced by security agencies can, in fact, interoperate with varying degrees of success, the manner in which this interoperation is achieved is piecemeal. In the worst case, interoperability is achieved by manually entering data produced by one system into another—a time consuming and error-prone process. cross-organizational home. Although technical interoperability is essential, it is not sufficient to ensure effective operations. There must be a suitable focus on procedural and organizational elements, and decision makers at all levels must understand each other's capabilities and constraints. Training and education, experience and exercises, cooperative planning, and skilled liaison at all levels of the joint force will not only overcome the barriers of organizational culture and differing priorities, but will teach members of the joint team to appreciate the full range of Service capabilities available to them.

A proper definition of interoperability is a prerequisite to any discussion followed.

Defining Interoperability

There is a need for precise definition of *interoperability*, because the term can have various interpretations in different contexts. For example, interoperability between a field commander's planning systems and a weather system may be addressed via a simple broadcast email. In contrast, radar reports of objects in the environment that must be shared between complex systems like AWACS may require frequent, automated updates of complex information.

Some of the difficulty associated with defining interoperability is reflected in the many definitions that exist. For example, the IEEE has four definitions of interoperability:

- the ability of two or more systems or elements to exchange information and to use the information that has been exchanged.
- the capability for units of equipment to work together to do useful functions.
- the capability, promoted but not guaranteed by joint conformance with a given set of standards, that enables heterogeneous equipment, generally built by various vendors, to work together in a network environment.
- the ability of two or more systems or components to exchange information in a heterogeneous network and use that information.

Security agencies also use multiple definitions of interoperability, several of which incorporate IEEE definitions:

The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces, and to use the services so exchanged to enable them to operate effectively together.

The condition achieved among communications-electronics systems or items of communications-electronics systems equipment when information or services can be exchanged directly and satisfactorily between them and/or their users. The degree of interoperability should be defined when referring to specific cases. For the purposes of this instruction, the degree of interoperability will be determined by the accomplishment of the proposed Information Exchange Requirement fields. The result that is strived for is (a) Ability of information systems to communicate with each other and exchange information. (b) Conditions, achieved in varying levels, when information systems and/or their components can exchange information directly and satisfactorily among them. (c) The ability to operate software and exchange information in a heterogeneous network (i.e., one large network made up of several different local area networks). (d) Systems or programs capable of exchanging information and operating together effectively.

We may never have agreement on a precise definition due to differing expectations that are constantly changing. New capabilities and functions continue to offer new opportunities for interactions between systems. For the purposes of this report, we define interoperability as: The ability of a set of communicating entities to (1) exchange specified state data and (2) operate on that state data according to specified, agreed-upon, operational semantics.

Models of interoperability

There exist a number of models of Interoperability which will be analyzed below. For the purposes of this book, we shall stress the technical model.

Levels of Information System Interoperability

A widely recognized model for system of systems interoperability is Levels of Information System Interoperability (LISI). LISI focuses on the increasing levels of sophistication of system of systems interoperability.

Five levels are defined:

Level 0 – Isolated interoperability in a manual environment between stand-alone systems: Interoperability at this level consists of the manual extraction and integration of data from multiple systems. This is sometimes called “sneaker-net.”

Level 1 – Connected interoperability in a peer-to-peer environment: This relies on electronic links with some form of simple electronic exchange of data. Simple, homogeneous data types, such as voice, text email, and graphics (e.g., Graphic Interface Format files) are shared. There is little capacity to fuse information.

Level 2 – Functional interoperability in a distributed environment: Systems reside on local area networks that allow data to be passed from system to system. This level provides for increasingly complex media exchanges. Logical data models are shared across systems. Data is generally heterogeneous-containing information from many simple formats fused together (e.g., images with annotations).

Level 3 – Domain based interoperability in an integrated environment. Systems are connected via wide area networks. Information is exchanged between independent applications using shared domain-based data models. This level enables common business rules and processes as well as direct database-to-database interactions. It also supports group collaboration on fused information.

Level 4 – Enterprise-based interoperability in a universal environment: Systems are capable of using a global information space across multiple domains. Multiple users can access complex data simultaneously. Data and applications are fully shared and distributed. Advanced forms of collaboration are possible. Data has a common interpretation regardless of format.

Within a level, LISI identifies additional factors that influence the ability of systems to interoperate. These factors comprise four attributes: Procedures, Applications, Infrastructure, and Data (PAID). PAID provides a method for defining the set of characteristics required for exchanging information and services at each level. It defines a process that leads to interoperability profiles and other products. Scenarios depict the possible uses of LISI in different circumstances throughout the system life cycle.

LISI focuses on technical interoperability and the complexity of interoperations between systems. The model does not address the environmental and organizational issues that contribute to the construction and maintenance of interoperable systems (e.g., shared processes for defining interoperability requirements and maintaining interoperability across versions).

2) Organizational Interoperability Maturity Model

The Organizational Interoperability Maturity Model (OIM), which extends the LISI model into the more abstract layers of command and control support, describes the ability to interoperate. It can cover cases where the organization depends, on one extreme side, on independent sub- groups and on the other extreme side on unified sub-entities.

3) Technical Architecture Reference Model for Interoperability

If we try to develop Technical Architecture Model for Interoperability, we should be able to define four degrees of Interoperability regarding data exchanges.

Degree 1 - Unstructured Data Exchange: exchange of human-interpretable unstructured data such as the text found in operational estimates, analyses and papers.

Degree 2 - Structured Data Exchange: exchange of human-interpretable structured data intended for manual and/or automated handling, but requires manual compilation, receipt and/or message dispatch.

Degree 3 - Seamless Sharing of Data: automated sharing of data amongst systems based on a common exchange model.

Degree 4 - Seamless Sharing of Information: universal interpretation of information through data processing based on cooperating applications.

The degrees were intended to categorize how operational effectiveness could be enhanced by structuring and automating the exchange and interpretation of data. It is obvious that the organizational and technical model must merge as we shall see in the following model which is of major importance in the design of an integrated system that includes TETRA as a building block.

4) The System of Systems Interoperability (SOSI) Model

The models previously discussed address a range of interoperability issues from technical to organizational. The SOSI model, addresses technical interoperability and operational interoperability. However, SOSI goes a step further to address programmatic concerns between organizations building and maintaining interoperable systems.

Interoperation among systems is typically achieved through significant effort and expense. Too often, the approaches used lead to interoperability that is specific to the targeted systems (sometimes called "point-to-point interoperability") and that does not facilitate extension to other systems.

Achieving large-scale and consistent interoperation among systems will require a consistently applied set of management, constructive, and operational practices that support the addition of new and upgraded systems to a growing interoperability web. Improvements in technology alone will not be sufficient. There must be parallel improvements in the ways that current and future interoperability needs are identified, and how organizations pursue interoperability. Applications of these models is made in chapters 5-7.

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