“O’ZBEKISTON TEMIR YO’LLARI“ JSC

Tashkent institute of railway engineering

Protection

Permitted

Head of the department

“___”__________2018 y

Department “Electrical communication and radio”

GRADUATION QUALIFICATION WORK

Theme: Organization of trunking system of communication

Student. Jaulibaev E.N ____________________

Tutor: Ortiqov M.S _________________________

Consultant of language :

Filimonova L.Yu_______________________________

Consultant of labor protection:

Krivoruchko B.V. ___________________________

Reviewer: _________________________________

Tashkent – 2018 y

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Head of the department “EC and R”

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“___”___________2018 y

THE TASK RECEIVED ON GRADUATION QUALIFICATION WORK

Student:____

full name

1. The theme of graduation work: Organization of trunking system of communication «____» __________ 2018 at the meeting session of department.
2. Deadline ______________________________
3. Initially information and basic resources for qualified graduation work: course job and several literatures
4. Should be solved in the following problems
    1. Introduction
    2. Fixed-Assignment Access for Voice-Oriented Networks
    3. Comparison of Trunked radio, TETRA and Radiocommunication trunk technologies (RCTT)
    4. Performance of Fixed-Assignment Access Methods
    5. Devices
    6. Labor protection
    7. Conclusion
    8. Literatures

Section consultants of graduation work

SECTIONS	CONSULTANTS	Sign,date	
		Task given	Task received
Labor protection.	KrivoruchkoB. V.		
Main part	Ortiqov M.S		
Language consultant	Filimonova L.Yu		

The plan of graduation work

№	Sections of graduation work	Expiration date	Sign
1.	Introduction		
2.	Trunking system features and principles of operation		
3.	Trunked radio system in the railway transportation		
4.	Terrestrial Trunked Radio		
5.	Inspecting fire hazardous electrical appliances		
6.	Literature		

Tutor: ass Ortiqov M. S. _______________

(full name) sign

Accepted to accomplishing: Jaulibaev E.N.______________

(full name) (sign)

Task given date ___________________ 2018 year

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ANNOTATION

My graduation work consists of four parts. In the first part, the principle of operation and standards of the trunked radio system and its advantages from a simple radio system are shown. There is also information on the trunk communication.

In the second part, it provides information on the role of the trunked radio system in railway communication. There are guidelines for ensuring security, remote vehicle control, and providing passenger comfort.

The third part deals with the TETRA, basic standard of the trunked radio system. It provides information on the principle of operation of TETRA standard, its advantages and disadvantages. In addition, TETRA and GSM-R are compared.

The fourth part provides information on fire safety. In this part, fire occurrence in radio equipment is mainly calculated through mathematical method.

This graduation work has been actualized on a technical task, text size 68 pages, 16 pictures, 11 tables, 7 literatures.

INTRODUCTION

President of Uzbekistan Shavkat Mirziyoyev signed a decree "On Uzbekistan's Development Strategy ".

The document has approved Uzbekistan's Five-Area Development Strategy for 2017-2021 which was developed following comprehensive study of topical issues, analysis of the current legislation, law enforcement practices, the best international practices.

The Decree establishes that the timely and effective implementation of the Development Strategy shall be the top priority of all government bodies and their officials.

In the decree, the state bodies and entities, responsible for the implementation of measures envisaged in a state program, have been instructed to pay particular attention to:

- improving the system of handling of letters from natural and legal persons, introducing of new effective tools and methods to establish an open dialogue with ordinary people, putting in practice of a system of reporting to the public, strengthening among the public the trust in authorities;
- inadmissibility of bureaucratic barriers and obstacles when handling of letters from natural and legal persons and inadmissibility of transforming the process of dialogue with ordinary people into "window-dressing";

The Strategy is to be implemented in five stages, each of which provides for approval of a separate annual State program in accordance with a declared name of the year.

Radio communications and broadcasting are not only a part of communication, but also a vital part of the overall telecommunications network. It includes cities, villages, interregional, mainstream radio communication lines, computer networks, data transmission networks, and so on. It is composed of air transmission lines, cables, radios and space lines. For example, it also allows the transmission of any kind of information received from a radio through a wired network.

It also serves as a key tool in linking rural areas with large numbers of people living in remote areas and areas that are hard to deal with.

The role of the radio in the communication with mobile, radioactive moving objects, is rising, from year to year, the need for radio communication with ships, airplanes, cars, expeditions, polar stadiums and others.

One of the first personal mobile communications systems can include a personal messenger called “Multiton”. In such a system, the dispatcher calls the employee through a personal (private) receiver. After accepting an acoustic call, the employee finds the TF and calls the dispatcher. Due to the improved level of service, the employee will only see the TLF number of the subscriber calling on the screen of the individual receiver, but only with the stationary TLF (Paiging Systems).

An example of such a highly similar system is that it interacts with individual radiotelephone and allows the public to access the TLF network through a dispatcher. Similar types of systems are provided by some enterprises, hospitals, manufacturing complexes and others (PMR, PAMR). Understandable as a specific type of mobile radio communication system, PMR can not provide uninterrupted communication on the subscriber crossing the borders of the radiofrequency zone, does not have automatic roaming, and other system subscribers can not provide the same set of communication services available, including payment. In contrast to PMR, PAMR provides subscribers in motion with connection to commonly used telephone network subscriptions. The main driver for the design of mobile systems is the high concentration of radiotelephone messages, which has led to significant progress in this area, and has brought the mobile communication to the quality of information received at the TLF communication string. This has led to the fact that the massive increase in the number of radio users has ended the frequency resource allocated to mobile communication. As a result, it has entailed the creation of systems with a high level of design capacity and a thorough research into the effective use of the allocated frequency spectrum. In this regard, the principal new structure has a structure and connection, meaning that many base stations (BTSs) are commonly considered to be more promising than the one-sided portable communication system (KSAT). In the migration process, the subscriber station is "transmitted" from one BTS to another, which automatically connects to the required frequency channel in the command signal control, thus ensuring uninterrupted communication. Frequency channels allocated at KSAT frequently are repeatedly used by subscribers who are placed in the protective range. Based on this structure, the number of active channels is increased so that higher bandwidth and frequency spectrum are used more effectively. (Cellular Radio Systems).

CHAPTER 1. TRUNKING SYSTEM FEATURES AND PRINCIPLES OF OPERATION

1.1 The main conception of the trunked radio system

A trunked radio system is two-way radio system that uses a control channel to automatically direct radio traffic. Two-way radio systems are either trunked or conventional, where conventional is manually directed by the radio user.

Trunked radio systems are complex radio systems that were developed to improve the efficiency of the use of available radio spectrum. In conventional (nontrunked) radio systems, a radio frequency is dedicated to a single function or workgroup. When the radio frequency is not in use, it cannot be used by another function or workgroup. Trunking borrows technologic concepts from telephone systems to assign radio frequencies to active calls, improving the efficiency of frequency use.

Like a conventional repeated radio system, trunked radios communicate with each other through two or more repeaters. In a trunked system, the radios often are known as **subscriber units** and a voice communications exchange is know as a **call**. A basic trunked radio system has a system controller that controls the assignment of the repeaters, called voice traffic repeaters, to individual calls. The radios communicate with the system controller, for example to request the use of a voice traffic repeater, by sending data messages to the system controller on a special dedicated channel called the control channel. The system controller acknowledges these communications and sends information to the radios using the control channel as well. The radios also can communicate some information using the voice traffic channels after a call has been terminated.

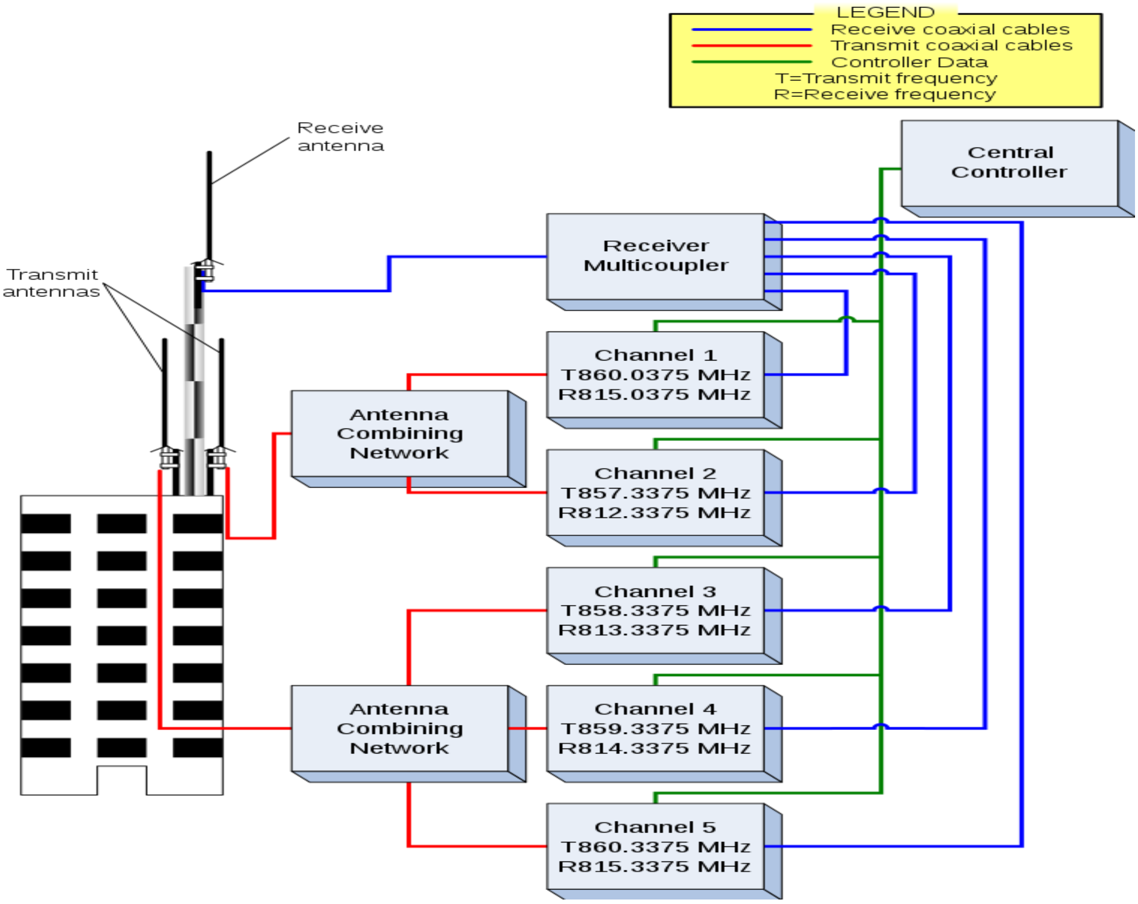
Trunking is a more automated and complex radio system, but provides the benefits of less user intervention to operate the radio and greater spectral efficiency with large numbers of users. Instead of assigning, for example, a radio channel to one particular organization at a time, users are instead assigned to a logical grouping, a "talkgroup". When any user in that group wishes to converse with another user in the talkgroup, a vacant radio channel is found automatically by the system and the conversation takes place on that channel. Many unrelated conversations can occur on a channel, making use of the otherwise idle time between conversations. Each radio transceiver contains a microcomputer to control it. A control channel coordinates all the activity of the radios in the system. The control channel computer sends packets of data to enable one talkgroup to talk together, regardless of frequency.

The primary purpose of this type of system is efficiency; many people can carry many conversations over only a few distinct frequencies. Trunking is used by many government entities to provide two-way communication for fire departments, police and other municipal services, who all share spectrum allocated to a city, county, or other entity.

The voice traffic repeaters are shared among all users of the system; they also are known as resources. In complex systems that use encryption and dispatch consoles, other equipment is necessary for the operation of these features, and they are considered shared resources.

Control channels. In essence, a trunked radio system is a packet switching computer network. Users' radios send data packets to a computer, operating on a dedicated frequency — called a control channel — to request communication on a specific talk-group. The controller sends a digital signal to all radios monitoring that talkgroup, instructing the radios to automatically switch to the frequency indicated by the system to monitor the transmission. After the user is done speaking, the users' radios return to monitoring the control channel for additional transmissions. This arrangement allows multiple groups of users to share a small set of actual radio frequencies without hearing each other's conversations. Trunked systems primarily conserve limited radio frequencies and also provide other advanced features to users.

The system controller and other parts of the trunked radio system maintain a log of all activity that occurs in the system, as well as statistical information on the operation of the system. These system logs can be used in the event of a suspected anomaly in the operation of the system to help determine the cause.



Picture 1.1. A central-controlled trunked system uses a control channel

Talkgroups. A *talkgroup* is an assigned group on a trunked radio system. Unlike a conventional radio which assigns users a certain frequency, a trunk system takes a number of frequencies allocated to the system. Then the control channel coordinates the system so talkgroups can share these frequencies seamlessly. The purpose is to dramatically increase bandwidth. Many radios today treat talkgroups as if they were frequencies, since they behave like such. For example, on a radio scanner it is very common to be able to assign talkgroups into banks or lock them out, exactly like that of conventional frequencies.

Scanning. Most scanners that can listen to trunked radio systems (called trunk tracking) are able to scan and store individual talkgroups just as if they were frequencies. The difference in this case is that the groups are assigned to a certain bank in which the trunked system is programmed. In other words, the talkgroups are stored on the trunked bank.

Comparison with telephone trunking. The concept of trunking (resource sharing) is actually quite old, and is taken from telephone company technology and practice. Consider two telco central office exchanges, one in town "A" and the other in adjacent town "B". Each of these central offices has the theoretical capacity to handle ten thousand individual telephone numbers. (Central office "A", with prefix "123", has available 10,000 numbers from 123-0000 to 123-9999; central office "B", with prefix "124", the same.)

If all 10,000 subscribers in "A" were to simultaneously call 10,000 subscribers in "B", then it would be necessary to have 10,000 lines (in telco parlance "trunk lines", or simply "trunks") to connect the two towns. However, the odds of that happening are remote, as the number of simultaneous phone calls is usually much lower. Erlang-B is a common formula that predicts the optimal number of trunk lines actually needed under normal conditions.

This concept has simply been applied to radio user groups, to determine the optimal number of channels needed, under normal conditions, to accommodate given number of users. In the event of a widespread emergency such as a major earthquake, many more users than normal will attempt to access both the telephone and radio systems. In both cases once the trunking capacity of the systems is fully used, all subsequent users will receive a busy signal.

In our example of police dispatch, different talk-groups are assigned different system priority levels, sometimes with "preempt" capability, attempting to ensure that communication between critical units is maintained.

Multigroup Call. A multigroup call is a call that transmits to two or more talkgroups simultaneously. The system can be configured to wait for all talkgroups in the multigroup to become available before initiating the call, or configured to begin the call immediately, with busy talkgroups joining when their calls are complete. During the call, all associated talkgroups act as a single talkgroup. Because of this, after the initial multigroup transmission completes, a user in one of the associated talkgroups can call all users in the associated talkgroups. In a busy system, this can keep the multigroup call in progress for a significant amount of time, severely disrupting operational communications.

Private Call. The **private call** feature allows one radio to call another radio and to carry on a conversation without any other radios hearing the conversation. The radio user initiating the call must select the called radio from a list, or know the numerical ID of the called radio. Some more advanced radios allow the user to change numbers in a cell-phone-like phone book, making this feature more usable.

A problem with the private call is that it is very difficult to predict the capacity or loading impact of this feature during system design. When the system is in operation, high private call usage can cause other system users to experience more talkgroup busy signals than the design would predict. Some system operators prohibit the use of private call to eliminate the possibility of these calls affecting more critical operations.

EmergencyAlarm. There are two different emergency features in trunked radio systems: **emergency alarm** and **emergency call**. When a radio user presses the emergency button on the radio, the radio switches to the control channel and transmits an emergency alarm message. This message is processed by the system, and an indication of the activation of the alarm is presented to any dispatchers using radio consoles. The benefit of the emergency alarm feature is that it is possible to send the alarm message even when all repeaters in the system are busy. Thus, even when the talkgroup is in use, an emergency alarm can be sent by a firefighter in trouble.

EmergencyCall. An **emergency call** is similar to a normal talkgroup call or a multigroup call, but the radio initiating the call is in emergency mode after having its emergency button pressed.

Emergency calls are initially processed in the same way as talkgroup calls or multigroup calls. The difference in processing occurs when resources are not immediately available for assignment to the emergency call. If resources are not available, the emergency call can be processed in two ways: top-of-queue or ruthless preemption, depending on the configuration of the trunked radio system.

If the system is configured for top-of-queue, the request for resources is placed on the busy queue in front of all other requests. When the resources become available, the emergency call is assigned the newly-available resources immediately.

If the system is programmed for ruthless preemption, the request for resources is not queued and instead the voice repeater for the lowest-priority existing talkgroup is reassigned to the emergency call. To accomplish this, the receiving radios on the existing lower-priority call are instructed to terminate that call, and the radios on the emergency call are instructed to tune to the frequency of that voice repeater. Unfortunately, the transmitting radio on the lower-priority call cannot be instructed to terminate the call. This can cause the emergency radio to compete with the lower-priority radio, resulting in distorted audio or no audio.

Telephone Interconnect. The **telephone interconnect** feature allows system users to answer or make calls to telephone users from the user's radio, similar to a cellular phone. The difference between telephone interconnects and a cell phone is that the trunked user cannot transmit and receive simultaneously. Telephone interconnect was a much more valuable feature before the cell phone became commonplace. In addition, similarly to private call, it is difficult to predict telephone interconnect usage during system design. This can cause telephone interconnect use to affect operational use of the system.

Dynamic Regrouping. The **dynamic regrouping** feature allows an authorized system administrator to assign a radio to a specific talkgroup remotely. The purpose of this feature is to allow multiple radios to be grouped together on a talkgroup for operational purposes. This feature is limited in function due to the potential delays while the radio is assigned to the new talkgroup; because of this, few agencies use this for critical operations.

1.2 Types of trunked radio systems and differences from conventional two-way radio

"Trunked" radio systems differ from "conventional" radio systems in that a conventional radio system uses a dedicated channel (frequency) for each individual group of users, while "trunking" radio systems use a pool of channels which are available for a great many different groups of users.

For example, if police communications are configured in such a way that twelve conventional channels are required to permit citywide dispatch based upon geographical patrol areas, during periods of slow dispatch activity, much of that channel capacity is idle. In a trunked system, the police units in a given geographical area are not assigned a dedicated channel, but instead are members of a talk-group entitled to draw upon the common resources of a smaller pool of channels.

Advantages of trunking. Trunked radio takes advantage of the probability that with any given number of user units, not everyone will need channel access at the same time, therefore fewer discrete radio channels are required. From another perspective, with a given number of radio channels, a much greater number of user groups can be accommodated. In the example of the police department, this additional capacity could then be used to assign individual talk groups to specialized investigative, traffic control, or special-events groups which might otherwise not have the benefit of individual private communications.

To the user, a trunking radio looks just like an "ordinary" radio: there is a "channel switch" for the user to select the "channel" that they want to use. In reality though, the "Channel switch" is not switching frequencies as in a conventional radio but when changed, it refers to an internal software program which causes a talkgroup affiliation to be transmitted on the control channel. This identifies the specific radio to the system controller as a member of a specific talkgroup, and that radio will then be included in any conversations involving that talkgroup.

This also allows great flexibility in radio usage - the same radio model can be used for many different types of system users (i.e. Police, Public Works, Animal Control, etc.) simply by changing the software programming in the radio itself.

Since the talkgroups are constantly transmitting on different frequencies, trunked radio systems makes it more difficult for a scanner listener without a programmed trunk tracking scanner to keep up with the conversation.

This is not designed to be a list of manufacturers equipment types, it is intended as a list of air protocol types unless significant vendor specific modifications have been made which violate the published standard.

Trunked radio technologies today have generally diverged into three distinct types or "tiers". These are not "official", but are clearly defined within protocol types.

Entry-level. These systems are extremely primitive in their operation and only just about meet the requirements to be defined as a "trunked" radio system. They generally do not have enhanced features such as data communications or registration awareness. They will only provide simple trunking facilities for voice calls only.

1)SmarTrunk

2) Ericsson GE

3) Logic Trunked Radio

Standard. These systems exhibit some of the characteristics of a high tier trunked radio system but not all features. Therefore, they are suitable for small deployments where users are expected to use the entire network available (such as a private system covering a campus or town). Because of their lack of advanced features they generally are not suited to mission critical deployments, PAMR type operation or uncoordinated shared user types.

It must be noted that DMR/dPMR true Tier 3/Mode 3 protocols are intended eventually to migrate into the "Advanced Mature high end" list below but today (2015) cannot be classified as such due to major interoperability issues, lack of mature protocol and lack of clearly defined user interface protocol.

1. OpenSky System
2. APCO Project 16
3. dPMR Mode 3 - Has equipment manufacturer interoperability issues.
4. DMR Tier III - Has equipment manufacturer interoperability issues.
5. NXDN
    a) Kenwood NEXEDGE Digital trunked radio
    b) Icom IDAS Digital trunked Land Mobile Radio

1.3 Advanced mature high end systems

Some trunked radio protocols are of special merit since they clearly stand out from the others for the following reasons:

- Proven technology used on numerous mission-critical applications around the world
- Mature, thereby only undergoing minor revisions rather than major feature changes and this must have been case for at least several years
- Designed for mission-critical applications
- Suitable for networks in excess of 150 sites
- Suitable for large numbers of users (in excess of 500 differing user group types)
- Support for "subset" coverage areas whereby a particular customer can be restricted to a smaller area of coverage
- Network level call confirmation (rather than end to end success/failure detection)
- Seamless roaming based upon "vote now" procedures controlled from a central controller, based on RSSI hysteresis or similar
- Registration upon site change
- Graceful failure modes defined at protocol level
- Data transfer facilities

- Presence awareness at network level which only invokes the transmitter sites necessary for call establishment
- Centralized control with a degree of over-air control of terminals (such as barring units, etc.)
- ESN based terminal security or similar
- True and proven interoperability between manufacturers dictated by an open standard
- Little flexibility for custom deviations from standard, ensuring all terminals comply with standard
- Uniform user terminal standard with respect to user interface, tones, dialling schemes, etc.

1.4 Trunk communication systems

Communication network equipment for intelligent transportation systems can be divided into two different categories: analog and digital. Analog technology conveys data as electronic signals of varying frequency or amplitude that are added to carrier waves of a given frequency. Broadcast and phone transmission has conventionally used analog technology. Digital describes electronic technology that generates, stores, and processes data in terms of two states: positive and non-positive. Positive is expressed or represented by the number 1 and non-positive by the number 0. Thus, data transmitted or stored with digital technology is expressed as a string of 0's and 1's. Each of these state digits is referred to as a binary digit, or "bit" in short. A string of bits that a computer can address individually as a group is a byte.

Within each of these categories are Voice – typically radio communications, but can include PBX telephone type systems between centers, Data - elements from system detector stations, ramp meters, dynamic trailblazer assemblies, and variable message signs, which do not require large bandwidth (i.e., small packages of data). Video - elements require transmission of full-motion video for incident verification and traffic surveillance, such as closed-circuit television cameras or local agency video (large bandwidth/transmission requirements). The majority of ITS equipment requires data or video transmission requirements. Hence, these communication system elements will be the primary focus of this chapter.

There are numerous types of carrier technologies. This ranges from regular telephone service, one of the most basic forms of communication, to optical carrier (OCx) levels up to OC-48. A sampling of various communication types, data rates, and media are discussed in this section and summarized in Table 1.1. In discussions of "carrier systems", the following definitions are presented:

- **T-Carrier** - The T-carrier system, introduced by the Bell System in the U.S. in the 1960s, was the first successful system that supported digitized voice transmission. The original transmission rate (1.544 Mbps) in the T-1 line is in common use today in Internet service provider connections to the Internet. Internet service providers also commonly use another level, the T-3 line, providing 44.736 Mbps. Another commonly installed service is a fractional T-1, which is the rental of some portion of the 24 channels in a T-1 line, with the other channels going unused. The T-carrier system is entirely digital, using pulse code modulation and Time-Division Multiplexing. The system uses four wires and provides duplex capability (two wires for receiving and two for sending at the same time). The T-1 digital stream consists of 24 64-Kbps channel that are multiplexing. (The standardized 64 Kbps channel is based on the bandwidth required for a voice conversation.) The four wires were originally a pair of twisted pair copper wires, but can now also include coaxial cable, optical fiber, digital microwave, and other media. A number of variations on the number and use of channels are possible.
- **Synchronous Optical Network** - SONET is the U.S. (American National Standards Institute) standard for synchronous data transmission on optical media. The international equivalent of SONET is synchronous digital hierarchy (SDH). Together, they ensure standards so that digital networks

can interconnect internationally and that existing conventional transmission systems can take advantage of optical media through tributary attachments. SONET provides standards for a number of line rates up to the maximum line rate of 9.953 gigabits per second (Gbps). Actual line rates approaching 20 gigabits per second are possible. SONET is considered to be the foundation for the physical layer of the broadband ISDN (Broadband Integrated Services Digital Network). SONET defines a base rate of 51.84 Mbps and a set of multiples of the base rate known as "Optical Carrier levels (OCx)." Asynchronous transfer mode (ATM) runs as a layer on top of SONET as well as on top of other technologies.

- **Optical Carrier Levels** (OCx) SONET includes a set of signal rate multiples for transmitting digital signals on optical fiber. The base rate (OC-1) is 51.84 Mbps. OC-2 runs at twice the base rate, OC-3 at three times the base rate, and so forth. Planned rates include OC-1, OC-3 (155.52 Mbps), OC-12 (622.08 Mpbs), and OC-48 (2.488 Gbps). Asynchronous transfer mode (ATM) makes use of some of the Optical Carrier levels.
- **Asynchronous Transfer Mode (ATM)** - ATM is a dedicated-connection switching technology that organizes digital data into 53-byte cell units and transmits them over a physical medium using digital signal technology. Individually, a cell is processed asynchronously relative to other related cells and is queued before being multiplexed over the transmission path. Because ATM is designed for easy implementation by hardware (rather than software), faster processing and switch speeds are possible. The pre-specified bit rates are either 155.520 Mbps or 622.080 Mbps. Speeds on ATM networks can reach 10 Gbps. Along with (SONET) and several other technologies, ATM is a key component of broadband ISDN.

Table 1.1

Carrier Technology	Data Rate	Primary Medium
Voice-grade telephone	56 kbps	twisted pair

T-1	1.544 Mbps	twisted pair or fiber optic
T-3	44.736 Mbps	twisted pair or fiber optic
OC-1	51.84 Mbps	fiber optic
OC-3	155.52 Mbps	fiber optic
OC-12	622.08 Mbps	fiber optic
OC-48	2.488 Gbps	fiber optic

Various communication system mediums (types) are associated with ITS deployment, and include the following:

- **Fiber optic communication -** Fulfills communication requirements for voice, data, or video devices
- **Twisted-pair communication cable -** Typically reserved for communication with voice or data communication only
- **Spread-spectrum radio -** Most applications of spread-spectrum radio are reserved for data devices, however higher bandwidth technologies of spread-spectrum radio may apply to video devices
- **Leased communications -** Depending on the type of leased communication chosen, any of the communication categories may apply. Typically, leased video communication alternatives are substantially higher in cost than those available for data devices.

The overall communications network configuration has a major impact on the design of communications network. Network configuration falls into two main categories: centralized and distributed.

- **Centralized Communications** – All processing is performed at the control center. Communications in this manner are handled directly from trunk lines, and connected directly to each surveillance and control element in the field. This concept allows the greatest control over the system, and permits all communications trouble-shooting and maintenance to be handled at one physical location. Its primary disadvantage is that direct connections between the control center and the ever-expanding amount of field equipment require an extremely complex and expensive communication network. Moreover, the system is slightly more susceptible to wide-area disruptions.

- **Distributed Communications** – This network uses a concept identical to that of the central system, in that most information and control is processed at a single point (i.e., control center). The major difference is that the communications network is distributed to several key locations (i.e., "hubs") throughout the network. A local distribution network is used for each section of a freeway, and all of the communications for that area are concentrated at the "hub" within the area. At the communications hub, the data are concentrated (i.e., multiplexed) for transmission to the control center over long-haul, high-speed, large bandwidth trunks. Similarly, trunk communications from the control center are split into multiple low-speed channels at the hubs, and then transmitted over the local distribution network to the field devices. Depending on the distance involved and the data concentrations, a distributed network may include multiple tiers of hubs. For example, at the first level, the data may be concentrated into T-1 or T-3/OC-3 channels and transmitted to a second level node. At this hub, the T-1/T-3/OC-3 channels from several first nodes may be concentrated into higher bandwidth channels (e.g., OC-24 or OC-48); and so on until the data reach the control center.).

The distance requirements of the system area, coupled with cost and reliability considerations, dictate the distributed configuration with one or two tiers of hubs; although higher-level tiers may also be required if the video transmissions are digitized using coder-decoder (otherwise known as CODEC) hardware.

The distributed configuration will require the placement of communication hubs at locations in the field to gather/distribute field data. These hubs divide the network topology into two basic divisions:

- **Trunk circuits** (i.e., “backbone network”) for hub-to-hub and hub-to-control center communications. The data transmissions are high-speed conforming to T-carrier or SONET (synchronous optical network) standards. Analog video communications (if used) will be multiplexed at the hub, providing multiple video images on a single trunk channel. If digital video communications are used, they too will be multiplexer at the hub and combined with the digital data, thereby requiring a larger bandwidth trunk and multiple tiers of hubs.
- **Distribution circuits** are used for the exchange of digital data messages between the hubs and field elements. These are typically low-speed channels (i.e., 1200-9600 baud). The hardware devices are usually aggregated on multi-drop lines in a polled network, both to take advantage of the connectivity economics and to have the system in control of the timing.

Several segments will consist of WisDOT-owned fiber optic and twisted-pair cables - the fiber optic cable being used for video transmissions and for high-speed data trunks between communication “hubs” and the control center; and the twisted-pair cable being used for low-speed data transmissions between the hubs and the various field components, although fiber or alternate communications methods (wireless) may also be used for this function. The communications cables are all installed in conduit. Additionally, conduit will be necessary for control cables between field components and their respective field devices (e.g., between ramp signals and the ramp meter controller), and for 120 VAC power feeds. This report addresses the configuration of the network’s main trunk line.

Freeway resurfacing / modernization programs offer excellent opportunities for installing the conduits required for the ITS communications networks and for the control cables. Performing this work during freeway rehabilitation work will result in reduced installation costs, as well as minimize disruption to traffic flow. Moreover, given its long life expectancy, conduit can be installed several years before it is actually needed. Assuming that the conduit network is designed and constructed properly, any rehabilitation effort during system implementation will be minimal - at the very worst, the existing conduits may require cleaning.

CHAPTER 2. TRUNKED RADIO SYSTEM IN THE RAILWAY TRANSPORTATION

2.1 Radiocommunication system trunk technologies (RSTT)

Railway transportation is a mean of conveyance of passengers and goods (freight). It is also commonly referred to as train transport. Various radiocommunication systems/technologies have been used for many years for railway operational applications. There are various degrees of implementation of numerous technologies among countries. Radio-communication networks are critical to train operations including stringent requirements for reliability, availability, safety and security for these operations. Different security measures are considered based on the assumption of transmission error or communication blackout in RSTT.

In general, radiocommunication for railway operations are considered as “mission critical” for train operations in general and the management of train emergency situations. Furthermore, railway radiocommunication systems require the support of legacy technology and to have a long life cycle.

RSTT provide improved railway traffic control, passenger safety and security for train operations. RSTT carry train control, voice dispatching, command, operational information as well as monitoring data between on-board radio equipment and related radio infrastructure located along trackside. To date, RSTT have included narrowband wireless technologies for carriage of train control, command, and operational information, as well as monitoriing data between on-board equipment and related radio infrastructure located along the trackside.

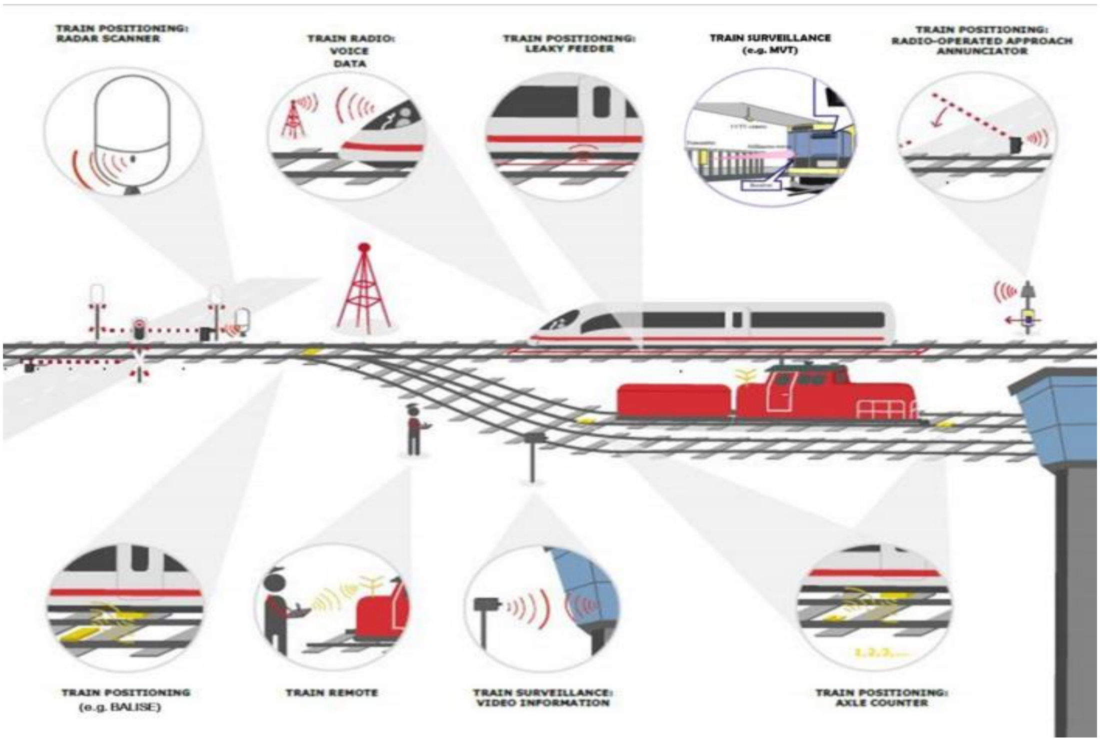
Such legacy systems also usually took the form of dedicated mobile radio systems for dispatching, train control and other operational safety-related and efficiency needs of railway transportation systems.

Radiocommunication systems supporting RSTT generally need system interoperability and seamless continuity, especially for tracks crossing borders or tracks operated by multiple railway network entities. As such, regional and global standardization and harmonization efforts of the railway industry become essential.

2.2 Main applications and common architecture of the RSTT

The main elements of the RSTT may consist of on board radio equipment, radio access units and other trackside radio infrastructure. Other systems, such as the core network, etc., are supporting systems for the RSTT.

- Radio access unit: including antenna and base station, to provide radio access to the terminals (especially cab radio)



Pic 2.1. A diagram of the main applications of RSTT

- On board radio equipment: Radio equipment installed on train as well as handsets (for example, mobile terminals of automatic train control – ATC)
- Other trackside radio infrastructure: Radio infrastructure operating along trackside (for example: shunting radio devices)

A diagram of the main applications of RSTT is illustrated in Pic.2.1. Main applications consist of.

1)Train radio. The train radio application is a part of a railway radio-communication system used for communication between train and track side for signalling and traffic management with the aim to contribute to safe train operation. Train radio provides mobile interconnect to landline and mobile-to-mobile voice communication and also serves as the data transmission channel within various bearer services. For voice communication Train radio provides call functions (point to point / group / emergency / conference) with specialized modes of operation (e.g. location depending addressing, call priorities, late-entry, and pre-emption).

Train radio comprised of:

- Voice/Dispatch
- Maintenance
- Train Control (Interlock/movement authorization)
- Emergency
- Train information

Voice/Dispatch. System for voice/dispatch includes point-to-point voice calls, public emergency voice calls, broadcast voice calls, group voice calls and multi-party voice calls.

One of the main functions of RSTT is to provide dispatching communication, which is to provide specific voice communication features for railway shown in Table 2.1.

Table 2.1

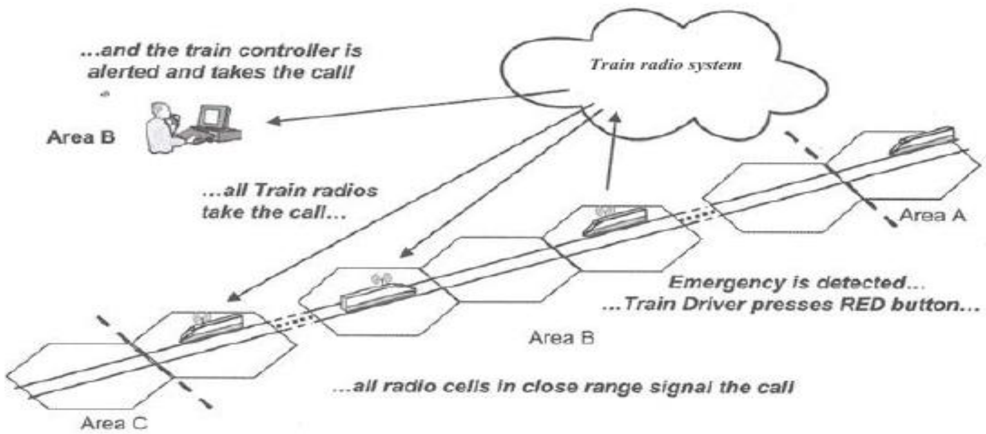
Service type	Feature Description
REC/enhanced REC	Railway emergency call/ enhanced REC
eMLPP	Enhanced multi-level precendence and premption
FA	Funcional Adressing

LDA	Location dependent Adressing
VGCS	Voice Group Call Service
VBS	Voice Broadcast Service
PTT	Push To Talk

Maintenance. This application provides voice communication (point-to-point, point to multi-point call, or group-call) and data communication for maintenance services in railway infrastructure.

Train Control (Interlock/movement authorization). This application provides reliable communication bearer for train control system in order to ensure efficient data transmission between the on-board equipment and trackside equipment. The limitations of the trains distance to run are sent in the form of a Movement Authority1 from the trackside.

The train control application can be categorized into decentralized and centralized modes. In a decentralized operation, the train movements are controlled by local interlocking stations. The operator of neighbouring interlocking stations communicate with each other by means of communications. In a Centralized Traffic Control (CTC) as one way of train control, all points and signals inside the



Pic.2.2. Principle of Railway Emergency Call

controlled area are directly controlled by the dispatcher.

Emergency. Emergency applications allow an authorized user setting up an emergency communication to other users within an automatically configured area or group, which is based upon the originator's location or characteristics and those users likely to be affected by the emergency (pic 2.2).

Train information. Generally, railway information transmitted by RSTT could be classified into two categories:

- Delivery of railway data for train operators, operational condition of trains, mobile tickets and discounts;
- to provide relevant railway transportation information for passengers, such as travel information.

2) Train positioning information. The knowledge of the positions of all trains and other vehicles on the tracks in normal and high-speed operations is one of the essential information to provide for railway traffic control, passenger safety, and security of train operations and therefore systems and applications providing information on the intermittent train positioning or constant train tracking are an integral part of RSTT.

These systems gather all kind of train positioning information (exact location of all units on trackside) relevant to train operations. This includes line- and

Pic.2.3 Example of railway balise

location-oriented information. The information about the position of the train can be obtained by detection systems. These include following specific active communication devices.

Balises. A passive or active device normally mounted in proximity to the track for communications with passing trains. Balise is a vital spot transmission based system conveying information between train and trackside. The system consists of the balise and the transmission equipment. Balises can provide fixed or variable content. The on-board transmission equipment consists of the antenna unit and the Balise Transmission Module (BTM). The relevant positioning information can be repeated also by other means, e.g. train radio.

Loops/Leaky cable. Euroloop is a component based on leaky cable and a modem that is providing signalling information in advance of the next main signal. The relevant positioning information can be repeated also by other means, e.g. train radio.

Annunciators. Annunciators control level crossings when a train route has been set and the indication point is passed by an approaching train.

Radar. The radar systems measure the motion parameters of the approaching rolling stock (speed, distance) and transmit that data into a comprehensive system of safety on the dead-end paths, passenger stations for high-speed, passenger, suburban trains and shunting. Such radar is installed on a stationary object on the railway track (e.g. track focus stalled on railroad tracks).

One of the radar applications is to detect the threat of a dangerous convergence with an obstacle and to send data and commands to the speed reduction or forced stop the locomotive or the head of an approaching motor car of rolling stock (Pic.2.4).

Axle counters. Axle counters are systems that control the integrity of trains in all operations by counting the number of axles at a given position and sending the data to the control center.

Pic.2.4 Example of radar

- **Train remote.** This application provides data communication between a locomotive and a ground based system in order to control the engine. The remote driver can operate the locomotive via the ground system. This application enables and allows remote controlled movement of trains typically for shunting operation in depots, shunting yards and/or for banking. This application provides a point to point localized functionality to control trains in an assemble/disassemble operation.
- **Train surveillance.** Train surveillance systems enable the capture and transmission of video of the public and trackside areas, driver cabs, passenger compartments, platforms and device monitoring.

Train surveillance contributes to analysis of the railway environment, improvement of maintenance services, and gathering of information on infrastructure.

A set of cameras at specific locations (front, interior, rear view) is used in low to high resolution, low and high frame-rates depending on the event. Data may be either stored on-board/locally or streamed (e.g. real-time video) to control centres via dedicated radio communication system.

2.3 Examples of current technologies for RSTT

Radio-communication systems technologies consist of:

1) Technologies used for train radio application

a) Analogue Radio based. Analog radio used for RSTT that utilizes analogue modulation and constitute a set of mobile-to-mobile(s), mobile-to-fixed operating on common channel(s) without control channel typically in narrow band channels. Analog trunked radio systems used for RSTT that utilizes analogue modulation and constitute a set of mobile-to-mobile(s), mobile-to-fixed on common channel(s) and a control channel for control or resources and dispatch.

b) Digital Radio based.

Digital radio based consist of :

- Conventional Digital Radio
- TETRA based
- B-TrunC based

Conventional Digital Radio use digital modulation for communications between mobile-to-mobile(s), mobile-to-fixed including repeaters sharing common channel(s) without control channel for resource management. Conventional Digital Radio in RSTT are used in some countries for wagon tail communications, shunting operation and intercom communication. Onboard staff, locomotive driver and people involved in maintenance and management are normally participating.

Terrestrial Trunked Radio (TETRA) is a professional land mobile radio standard specifically designed for use by government agencies, emergency services, public safety networks, rail transport, transport services and the military. TETRA is a European Telecommunications Standards Institute (ETSI) standard, first version published 1995. TETRA uses Time Division Multiple Access (TDMA) with PI/4 QPSK modulation with four user channels on one radio carrier and 25 kHz channel raster. Both point-to-point and point-to-multipoint transfer can be used. Digital data transmission is also defined in the standard.

TETRA mobile stations can communicate direct-mode operation (DMO) or using trunked-mode operation (TMO), using switching and management infrastructure (SwMI) made of TETRA base stations (TBS). As well as allowing direct communications in situations where network coverage is not available, DMO also includes the possibility of using a sequence of one or more TETRA terminals as relays. This functionality is called DMO gateway (from DMO to TMO) or DMO repeater (from DMO to DMO). In emergencies, this feature allows direct communications underground or in areas of bad coverage.

In addition to voice and dispatch services, the TETRA system supports several types of data communication. Status messages and short data services (SDS) are provided over the system's main control channel, while packet-switched data or circuit-switched data communication uses specifically assigned channels. TETRA provides for authentication of terminals towards infrastructure and vice versa. For protection against eavesdropping, air interface encryption and end-to-end encryption is available. The common mode of operation is in a group-calling mode in which a single button push will connect the user to the users in a selected call group and/or a dispatcher.

TETRA has been successfully deployed in a number of high-speed and a large number of METRO projects around the world 2 and is being considered in many European countries as well.

Studies conducted on TETRA train communication systems at speeds of up to 500 km/h show that the performance of the channels at higher speeds is not significantly different from that at lower speeds. This is due to the forward error correction applied, which has better performance at higher speeds. Fade causes bursts of errors for the duration of a fade, and TETRA compensates for this by interleaving bits over a timeslot so that the error bits during a fade are spread out in between 'good' bits before the error correction mechanism operates on the decoded information. As speed increases, whereas the fades become closer together, the duration of each fade becomes shorter, affecting fewer bits. TETRA systems are also used for High speed Train communications in some countries and operate at speeds of 300 km/h.

B-TrunC is a professional trunking system which can support emergency call, voice group call, video group call, private voice call, private video call, real-time short data, floor control, late entry, dynamic regrouping, etc. The B-TrunC standard is developed by the CCSA and published by the Ministry of Industry and Information Technology of the People's Republic of China. B-TrunC system has been used in some countries for railway shunting and freight train inspection in shunting yards, providing voice communication and data communication. Also, it is used for control and voice/dispatch applications in some metro lines.

c) GSM-R based. GSM-R supports mobile radio connectivity between train and track and serves terminals mounted on or integrated in trains from base stations along the trackside.

GSM-R, Global System for Mobile Communications – Railway or GSM-Railway is a wireless communications standard for railway communication and applications. As a sub-system of European Rail Traffic Management System (ERTMS), it is used for communication between train and the track. GSM-R is built on GSM technology, and benefits from the economies of scale of its GSM technology.

The specifications were finalized in 2000, based on the European Union-funded MORANE (Mobile Radio for Railways Networks in Europe) project, The specification is being maintained by the International Union of Railways (UIC) project ERTMS. GSM-R is a secure platform for voice and data communication between railway operational staff, including drivers, dispatchers, shunting team members, train engineers, and station controllers. It delivers features such as group calls (VGCS), voice broadcast (VBS), location-based connections, and call pre-emption in case of an emergency. This will support applications such as cargo tracking, and passenger information services.

d) LTE based. LTE supports mobile broadband radio connectivity between base stations (eNBs) and terminals (UEs). Hence LTE is able to serve terminals being mounted on or being integrated in trains from base stations along the trackside. In addition, relaying and direct device-to-device (D2D) communications are also supported.

A description of LTE features up to and including Release 12 can be found in Recommendation ITU-R M.2012. In addition 3GPP has been working on the following LTE enhancements, which might be relevant also for RSTT:

- RSTT performance enhancements for high speed scenario, where the target moving speed is at least 350 km/h and at most 750 km/h, depending on candidate solution.
- Coverage enhancements with up to 2048 repetitions leading to ~20 dB coverage extension.
- Narrowband operation with a minimum channel spacing of 200 kHz. Multi-antenna transmissions with up to 32 steerable antenna ports, which can be used for beamforming to reach far away receivers.
- Latency reduction reducing both signalling and data transmission delays.

Examples LTE Based Enhancements are shown in Table 2.2 below.

Table 2.2

Parameter	LTE
Frequency Range	From 450 Mhz up to 6Ghz
Channel separation	1.4; 3; 5; 10; 15; 20 Mhz carrier bandwidth
Transmission data rate (Mbps)	75 Mbps-10 bandwidth
Modulation	Dl: OFDM Ul: single tone FDMA
Multiplexing method	FDD, TDD

e) Leaky Coaxial Cable (LCX) based. In general mobile communications, the spaced wave method is commonly used, where base stations and mobile stations communicate with each other by antennas through some distance of space. But in closed spaces such as a tunnel, radio waves are weakened rapidly and radio propagation becomes very short range. In order to solve this problem, LCX is commonly used in such spaces. In LCX based RSTT, LCX systems are laid at trackside all along the line and base stations are connected to the cables and transceivers. Through the cables and onboard antennas, radio communications between base stations and mobile stations are enabled. The most distinctive feature of this system is to use the cable even at no-tunnel area. The close distance between LCX and onboard antennas mitigates the effect of interference which results in much lower noise level compared to other spaced method, and it is possible to maintain stable communication regardless of the location of train, even in open-site or inside of tunnels. The LCX based RSTT can be applied to any applications, like analogue train radio, digital train radio, and so on. Applying LCXs to RSTT enables high quality communication service areas in almost all the line and it contributes safety of railway.

2) Technologies used for train positioning application

Technologies used for train positioning application consist of:

a) **Radar based.** Radars, particular short range radars, are used for measuring train movement parameters. Such RSTT radar systems could provide information on the motion parameters of the approaching train (speed, distance) to determine position to avoid collision with obstacles or other moving trains. The measured motion parameters are transmitted to the train control center to be used to reduce speed or stop train movement.

b) **Short Range Radio based** Short Range Radio for RSTT is specific technology that limits the electromagnetic field of the transceiver within a certain distance. The ransceiver using short range radio technology is optimized for movement speeds, power consumptions etc., which uses invariable, repeating or oscillating of electromagnetic field to indicate the exact position information of the train.

3) Technologies used for train remote application

Common technologies including but not limited to Analogue Radio, Digital Radio, GSM-R, LTE and RLAN can be used for train remote application. Detailed information of Analogue Radio, Digital Radio, GSM-R and LTE.

RLAN technology is a specific radio communication technology which uses random access method to share the channel without having control channel for resource management. The most popular standard of RLAN technology is constructed by IEEE and published within 802.11 series.

4) Technologies used for train surveillance application

Common technologies including but not limited to RLAN, LTE, B-TrunC and Millimetric wave can be used for train surveillance application.

Millimetric wave radio technologies can provide broadband transmission capabilities to support functions such as multiplexed uncompressed high-definition video transmission from train to trackside and vice versa. The millimetric wave radio technologies can use pencil beam antennas to reduce the frequency interference.

Generic operating scenarios. This section provides a brief overview of RSTT operating scenarios. These scenarios are Railway line, Railway station, Shunting yard, Maintenance Base and Railway Hub. The general service characteristics of RSTT in different operating scenarios are listed in Table 2.

General Service Characteristics of RSTT in different operating scenarios are shown Table 2.3 below.

Table 2.3

	Priority	**Latency**	**Reliable**	**Density**	**Moving speed**
Railway line	High	Low	High	Low	High
Railway station	High	Low	High	High	High/Stop
Shunting yard	High	Low	High	High	Low/Stop
Maintenance base	Low	Medium	High	High	Stop

Railway hub	High	Low	High	High	High/Low/Stop

The train communication between the tracksides and moving trains, in this operating scenario, requires reliable wireless radio-links. It needs to satisfy all train to track communication applications, including voice and data services, for example, the data transmission for the control-command of trains, provided by railway operators.

Pic 2.5. Span in railway transport

Whenever needed, the interoperability requirements of the RSTT should be taken into account during cross-border railway transportation (Pic 2.5). Compatible RSTT system can support international roaming and international data exchange, that is also helpful to improve the efficiency of cross-border transportation and to reduce the relevant cost.

a)Parallel railway lines b) Viaducts c) Tunnel

Pic. 2.6

In addition, there are several specific operating scenarios of railway lines, e.g. parallel railway lines, viaducts and tunnels, etc. (pic. 2.6)

Typical applications in railway stations may include train control, interlock, train surveillance, train radio and train information. One of the main tasks of railway stations is the interlocking which is the central function to ensure that trains move safely. For interlocking, RSTT obtain information about track occupancy and the position of movable track elements (Pic. 2.7).

The RSTT in hub scenario is the N radiocommunication systems and applications with urban rail or other transport systems could be possible (e.g. big hub stations, airports, etc.). It is a diagrammatic sketch in a big city, in which railway stations (including Maintenance base and shunting yard etc.) are connected by different railway lines. Due to the complex operations in the hub, the moving speed of the trains in the hub is quite different, ranging from 0 to high speed level.

Pic. 2.7 Railway station

Shunting operations is the process for assembling and disassembling of trains, moving carriage from one track to another, storing carriages and trains, and similar purposes (Pic. 2.8).

Pic. 2.8 Shunting yard

In shunting mode, the typical applications may include voice and alerting data mixed transmission, monitoring.

The operating scenario of RSTT inn the maintenance bases is similar to that of in railway stations.

In this scenario, RSTT need to support the following applications: monitoring, maintenance information.

The RSTT in hub scenario is the N radiocommunication systems and applications with urban rail or other transport systems could be possible (e.g. big hub stations, airports, etc.). It is a diagrammatic sketch in a big city, in which railway stations (including Maintenance base and shunting yard etc.) are connected by different railway lines. Due to the complex operations in the hub, the moving speed of the trains in the hub is quite different, ranging from 0 to high speed level.

CHAPTE 3. TERRESTRIAL TRUNKED RADIO

3.1 Terrestrial Trunked radio and descriptions, advantages, disadvantages and radio aspects

Terrestrial Trunked Radio (TETRA; formerly known as **Trans-European Trunked Radio**), a European standard for a trunked radio system, is a professional mobile radio and two-way transceiver specification. TETRA was specifically designed for use by government agencies, emergency services, (police forces, fire departments, ambulance) for public safety networks, rail transport staff for train radios, transport services and the military.

TETRA is a European Telecommunications Standards Institute (ETSI) standard, first version published 1995, it is mentioned by the European Radiocommunications Committee (ERC).

Description. TETRA uses Time Division Multiple Access (TDMA) with four user channels on one radio carrier and 25 kHz spacing between carriers. Both point-to-point and point-to-multipoint transfer can be used. Digital data transmission is also included in the standard though at a low data rate.

TETRA Mobile Stations (MS) can communicate direct-mode operation (DMO) or using trunked-mode operation (TMO) using switching and management infrastructure (SwMI) made of TETRA base stations (TBS). As well as allowing direct communications in situations where network coverage is not available, DMO also includes the possibility of using a sequence of one or more TETRA terminals as relays. This functionality is called DMO gateway (from DMO to TMO) or DMO repeater (from DMO to DMO). In emergency situations this feature allows direct communications underground or in areas of bad coverage.

In addition to voice and dispatch services, the TETRA system supports several types of data communication. Status messages and *short data services* (SDS) are provided over the system's main control channel, while packet-switched data or circuit-switched data communication uses specifically assigned channels.

TETRA provides for authentication of terminals towards infrastructure and vice versa. For protection against eavesdropping, air interface encryption and end-to-end encryption is available.

The common mode of operation is in a group calling mode in which a single button push will connect the user to the users in a selected call group and/or a dispatcher. It is also possible for the terminal to act as a one-to-one walkie talkie but without the normal range limitation since the call still uses the network. TETRA terminals can act as mobile phones (cell phones), with a full-duplex direct connection to other TETRA Users or the PSTN. Emergency buttons, provided on the terminals, enable the users to transmit emergency signals, to the dispatcher, overriding any other activity taking place at the same time.

Advantages**.** The main advantages of TETRA over other technologies (such as GSM) are:

- The much lower frequency used gives longer range, which in turn permits very high levels of *geographic* coverage with a smaller number of transmitters, thus cutting infrastructure costs.
- During a voice call, the communications are not interrupted when moving to another network site. This is a unique feature, which dPMR networks typically provide, that allows a number of fall-back modes such as the ability for a base station to process local calls. So called 'mission critical' networks can be built with TETRA where all aspects are fail-safe/multiple-redundant.
- In the absence of a network, mobiles/portables can use 'direct mode' whereby they share channels directly (walkie-talkie mode).
- Gateway mode - where a single mobile with connection to the network can act as a relay for other nearby mobiles that are out of range of the infrastructure.
- TETRA also provides a point-to-point function that traditional analogue emergency services radio systems did not provide. This enables users to

have a one-to-one trunked 'radio' link between sets without the need for the direct involvement of a control room operator/dispatcher.

- Unlike cellular technologies, which connect one subscriber to one other subscriber (one-to-one), TETRA is built to do one-to-one, one-to-many and many-to-many. These operational modes are directly relevant to the public safety and professional users.
- Security TETRA supports terminal registration, authentication, air-interface encryption and end-to-end encryption.
- Rapid deployment (transportable) network solutions are available for disaster relief and temporary capacity provision.
- Network solutions are available in both reliable circuit-switched (telephone like) architectures and flat, IP architectures with soft (software) switches.

Disadvantages**.** Its main disadvantages are:

- Requires a linear amplifier to meet the stringent RF specifications that allow it to exist alongside other radio services.
- Data transfer is slow by modern standards.

Up to 7.2 kbit/s per timeslot, in the case of point-to-point connections, and 3.5 kbit/s per timeslot in case of IP encapsulation. Both options permit the use of between one and four timeslots. Different implementations include one of the previous connectivity capabilities, both, or none, and one timeslot or more. These rates are ostensibly faster than the competing technologies DMR, dPMR, and P25 are capable of). Latest version of standard supports 115.2 kbit/s in 25 kHz or up to 691.2 kbit/s in an expanded 150 kHz channel. To overcome the limitations many software vendors have begun to consider hybrid solutions where TETRA is used for critical signalling while large data synchronization and transfer of images and video is done over 3G / LTE.

Radio aspects**.** For its modulation TETRA, uses $\pi/4$ differential quadrature phase-shift keying. The symbol (baud) rate is 18,000 symbols per second, and each symbol maps to 2 bits, thus resulting in 36,000 bit/s gross.

As a form of phase shift keying is used to transmit data during each burst, it would seem reasonable to expect the transmit power to be constant. However it is not. This is because the sidebands, which are essentially a repetition of the data in the main carrier's modulation, are filtered off with a sharp filter so that unnecessary spectrum is not used up. This results in an amplitude modulation and is why TETRA requires linear amplifiers. The resulting ratio of peak to mean (RMS) power is 3.65 dB. If non-linear (or not-linear enough) amplifiers are used, the sidebands re-appear and cause interference on adjacent channels. Commonly used techniques for achieving the necessary linearity include Cartesian loops, and adaptive predistortion.

The base stations normally transmit continuously and (simultaneously) receive continuously from various mobiles on different carrier frequencies; hence the TETRA system is a frequency-division duplex (FDD) system. TETRA also uses FDMA/TDMA (see above) like GSM. The mobiles normally only transmit on 1 slot/4 and receive on 1 slot/4 (instead of 1 slot/8 for GSM).

Speech signals in TETRA are sampled at 8 kHz and then compressed with a vocoder using *algebraic code-excited linear prediction* (ACELP). This creates a data stream of 4.567 kbit/s. This data stream is error-protection encoded before transmission to allow correct decoding even in noisy (erroneous) channels. The data rate after coding is 7.2 kbit/s. The capacity of a single traffic slot when used 17/18 frames.

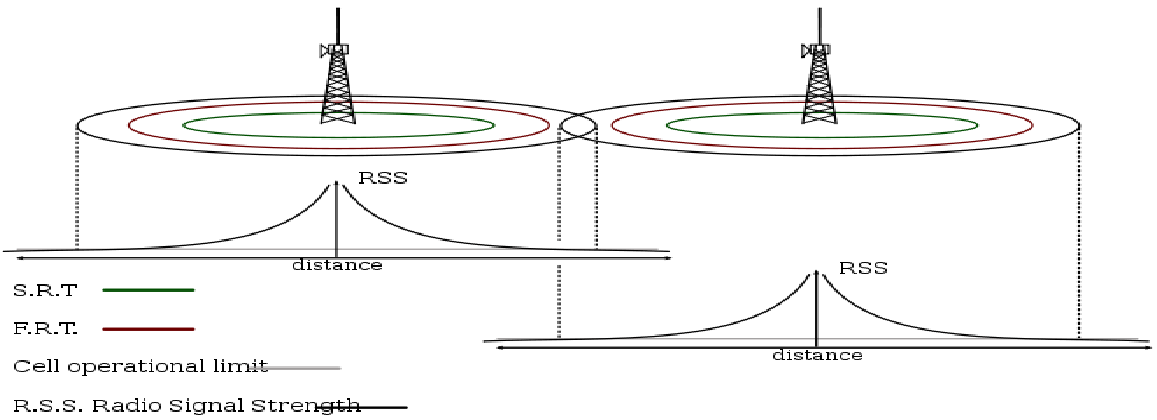
A single slot consists of 255 usable symbols, the remaining time is used up with synchronization sequences and turning on/off, etc. A single *frame* consists of 4 slots, and a *multi-frame* (whose duration is 1.02 seconds) consists of 18 frames. Hyper frames also exist, but are mostly used for providing synchronization to encryption algorithms.

The downlink (i.e., the output of the base station) is normally a continuous transmission consisting of either specific communications with mobile(s), synchronization or other general broadcasts. All slots are usually filled with a burst even if *idle* (continuous mode). Although the system uses 18 frames per second only 17 of these are used for traffic channels, with the 18th frame reserved for signalling, Short Data Service messages (like SMS in GSM) or synchronization. The frame structure in TETRA (17.65 frames per second), consists of 18,000 symbols/s; 255 symbols/slot; 4 slots/frame, and is the cause of the *perceived* "amplitude modulation" at 17 Hz and is especially apparent in mobiles/portables which only transmit on one slot/4. They use the remaining three slots to switch frequency to receive a burst from the base station two slots later and then return to their transmit frequency (TDMA)

3.2 Cell selection and their types

Cell re-selection (or hand-over). This first representation demonstrates where the slow reselect threshold (SRT), the fast reselect threshold (FRT), and propagation delay exceed parameters are most likely to be. These are represented in association with the decaying radio carrier as the distance increases from the TETRA Base Station.

From this illustration, these SRT and FRT triggering points are associated to the decaying radio signal strength of the respective cell carriers. The thresholds are situated so that the cell reselection procedures occur on time and assure communication continuity for on-going communication calls.



Pic. 3.1 Cell re-selection.

Initial cell selection. The next diagram illustrates where a given TETRA radio cell initial selection. The initial cell selection is performed by procedures located in the MLE and in the MAC. When the cell selection is made, and possible registration is performed, the *mobile station* (MS) is said to be attached to the cell. The mobile is allowed to initially select any suitable cell that has a positive C1 value; i.e., the received signal level is greater than the *minimum receive level for access* parameter.

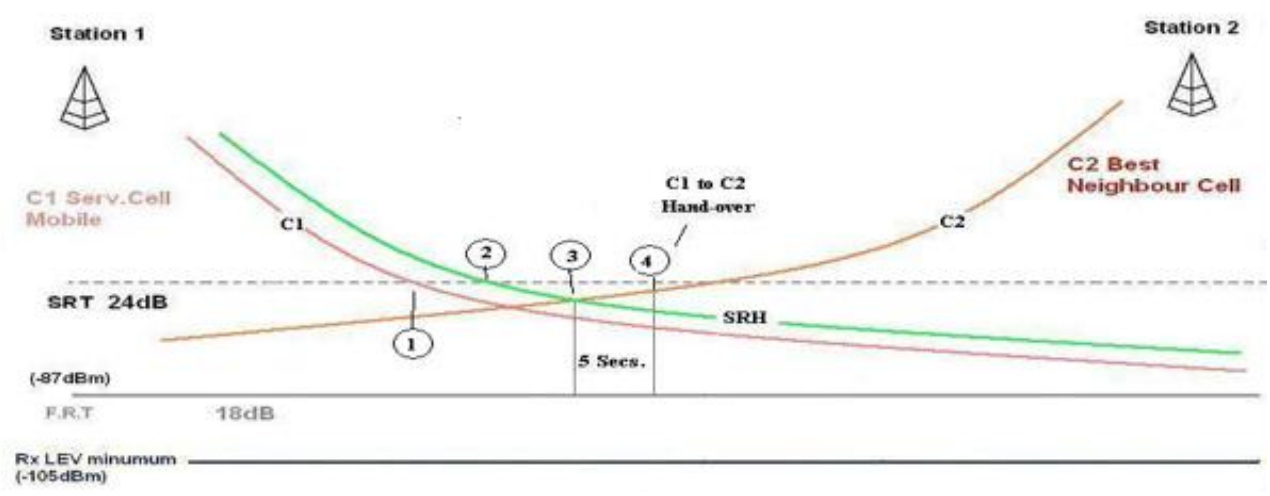
The initial cell selection procedure shall ensure that the MS selects a cell in which it can reliably decode downlink data (i.e., on a main control channel/MCCH), and which has a high probability of uplink communication. The minimum conditions that shall have to be met are that C1 > 0. Access to the network shall be conditional on the successful selection of a cell.

Pic 3.2 Cell initial selection.

Cell improvable. The next diagram illustrates where a given TETRA radio cell becomes *improvable*. The serving cell becomes improvable when the following occurs the C1 of the serving cell is below the value defined in the radio network parameter cell reselection parameters, slow reselect threshold for a period of 5 seconds, and the C1 or C2 of a neighbour cell exceeds the C1 of the serving cell by the value defined in the radio network parameter cell reselection parameters, slow reselect hysteresis for a period of 5 seconds.

No successful cell reselection shall have taken place within the previous 15 seconds unless Mobility Management (MM) requests a cell reselection. The MS-

MLE shall check the criterion for serving cell relinquishment as often as one neighbour cell is scanned or monitored.



Pic. 3.3. Cell improvable.

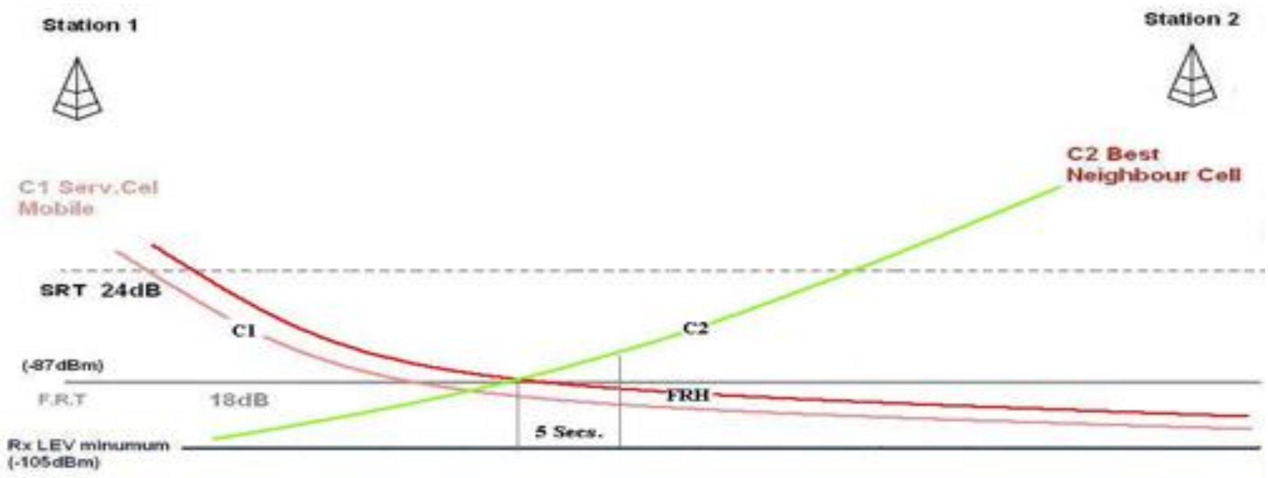
Cell usable. The next diagram illustrates where a given TETRA radio cell becomes *usable*. A neighbour cell becomes radio usable when the cell has a downlink radio connection of sufficient quality.

The following conditions must be met in order to declare a neighbour cell radio usable: The neighbour cell has a path loss parameter C1 or C2 that is, for a period of 5 seconds, greater than the fast reselect threshold plus the fast reselect threshold, and the service level provided by the neighbour cell is higher than that of the serving cell. No successful cell reselection shall have taken place within the previous 15 seconds unless MM requests a cell reselection. The MS-MLE shall check the criterion for serving cell relinquishment as often as one neighbour cell is scanned or monitored.

The following conditions will cause the MS to rate the neighbour cell to have higher service level than the current serving cell:

- The MS subscriber class is supported on the neighbour cell but not on the serving cell.
- The neighbour cell is a priority cell and the serving cell is not.

- The neighbour cell supports a service (that is, TETRA standard speech, packet data, or encryption) that is not supported by the serving cell and the MS requires that service to be available.
- The cell service level indicates that the neighbour cell is less loaded than the serving cell.

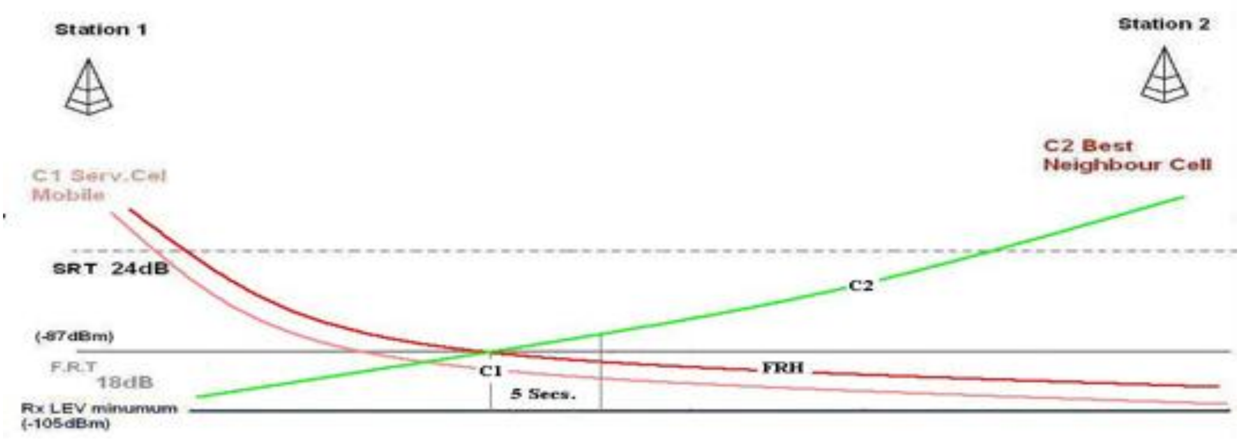


Pic. 3.4. Cell usable.

Cell relinquishable. The next diagram illustrates where a given TETRA radio cell becomes *relinquishable* (*abandonable*). The serving cell becomes relinquishable when the following occurs: the C1 of the serving cell is below the value defined in the radio network parameter cell reselection parameters, fast reselect threshold, for a period of 5 seconds, and the C1 or C2 of a neighbour cell exceeds the C1 of the serving cell by the value defined in the radio network parameter cell reselection parameters, fast reselect hysteresis, for a period of 5 seconds.

No successful cell reselection shall have taken place within the previous 15 seconds unless Mobility Management (MM) requests a cell reselection. The MS-MLE shall check the criterion for serving cell relinquishment as often as one neighbour cell is scanned or monitored.

That is to say, the mobile station is aware that the radio signal is decaying rapidly, and must cell reselect rapidly, before communications are terminated because of radio link failure. When the mobile station radio-signal breaches the minimum receive level, the radio is no longer in a position to maintain acceptable communications for the user, and the radio link is broken.



Pic. 3.5 Cell relinquishable.

Radio down-link failure. When the FRT threshold is breached, the MS is in a situation where it is essential to relinquish (or abandon) the serving cell and obtain another of at least *usable* quality. That is to say, the mobile station is aware that the radio signal is decaying rapidly, and must cell reselect rapidly, before communications are terminated because of radio link failure. When the mobile station radio-signal breaches the minimum receive level, the radio is no longer in a position to maintain acceptable communications for the user, and the radio link is broken.

Radio link failure: (C1 < 0). Using the suggested values, this would be satisfied with the *serving cell level* below −105 dBm. Cell reselection procedures are then activated in order to find a suitable radio base station.

Pic. 3.6 Radio down-link failure.

3.3 Virtual MMI for TETRA radio terminals

Any given TETRA radio terminal using Java (Java ME/CLDC) based technology, provides the end user with the communication rights necessary to fulfil his or her work role on any short duration assignment.

For dexterity, flexibility, and evolution ability, the public transportation radio engineering department, have chosen to use the open sources, Java language specification administered by Sun and the associated work groups in order to produce a *transport application tool kit*.

Service acquisition admits different authorised agents to establish communication channels between different services by calling the service identity, and without possessing the complete knowledge of the ISSI, GSSI, or any other TETRA related communication establishment numbering plan. Service acquisition is administered through a *communication rights centralised service* or *roll allocation server*, interfaced into the TETRA core network.

In summary, the TETRA MMI aims are to:

- Allow any given agent while in exercise, to exploit any given radio terminal without materiel constraint.

- Provide specific transportation application software to the end-user agents (service acquisition, fraud, and aggression control).

This *transport application tool-kit* has been produced successfully and with TETRA communication technology and assures for the public transport application requirements for the future mentioned hereafter.

The *home* (*main*) menu presents the end user with three possibilities:

1. Service acquisition,
2. Status SDS,
3. End-user parameters.

Service acquisition provides a means of virtually personalising the end user to any given radio terminal and onto TETRA network for the duration the end user conserves the terminal under his possession.

Status SDS provides the end user with a mechanism for generating a 440 Hz repeating tone that signals a fraud occurrence to members within the same (dynamic or static) Group Short Subscriber Identity (GSSI) or to a specific Individual Short Subscriber Identity (ISSI) for the duration of the assignment (an hour, a morning patrol or a given short period allocated to the assignment). The advantage being that each of the end users may attach themselves to any given terminal, and group for short durations without requiring any major reconfiguration by means of radio software programming tools. Similarly, the aggression feature functions, but with a higher tone frequency (880 Hz), and with a quicker repetitious nature, so to highlight the urgency of the alert.

The *parameters* tab provides an essential means to the terminal end-user allowing them to pre-configure the target (preprogrammed **ISSI** or **GSSI**) destination communication number. With this pre-programmed destination number, the end-user shall liaise with the destination radio terminal or *roll allocation server*, and may communicate, in the group, or into a dedicated server to which the service acquisition requests are received, preprocessed, and ultimately dispatched though the TETRA core network. This simplifies the reconfiguration or recycling configuration process allowing flexibility on short assignments.

The parameters tab also provides a means of choosing between preselected tones to match the work group requirements for the purposes of fraud and aggression alerts. A possibility of selecting any given key available from the keypad to serve as an aggression or fraud quick key is also made possible though the transport application software tool kit. It is recommend to use the asterisk and the hash keys for the fraud and aggression quick keys respectively. For the fraud and aggression tones, it is also recommend to use 440 Hz slow repeating tone (blank space 500 milli-seconds) and 880 Hz fast repeating tone (blank space 250 milliseconds) respectively. The tone options are as follows: 440 Hz, 620 Hz, 880 Hz, and 1060 Hz.

The *parameters* page provides an *aid* or *help* menu and the last tab within parameters describes briefly the tool kit the version and the history of the transport application tool kit to date.

3.4 The TETRA standard and Enhanced Data Service (TEDS) in the Railway Systems

TETRA Enhanced Data Service (TEDS). The TETRA Association, working with ETSI, developed the TEDS standard, a wideband data solution, which enhances TETRA with a much higher capacity and throughput for data. In addition to those provided by TETRA, TEDS uses a range of adaptive modulation schemes and a number of different carrier sizes from 25 kHz to 150 kHz. Initial implementations of TEDS will be in the existing TETRA radio spectrum, and will likely employ 50 kHz channel bandwidths as this enables an equivalent coverage footprint for voice and TEDS services. TEDS performance is optimized for wideband data rates, wide area coverage and spectrum efficiency.

Advances in DSP technology have led to the introduction of multi-carrier transmission standards employing QAM modulation. WiMAX, Wi-Fi and TEDS standards are part of this family.

TETRA standards. Traditionally the majority of the mainline rail market, particularly in Europe, has been locked out to TETRA in favour of GSM-R as a result of a historical UIC (International Union of Railways) decision to standardize on GSM-R for ERTMS (European Rail Traffic Management System) projects. However other transport sectors such as metros, trams, buses, etc., as well as some mainline train markets outside Europe have enthusiastically adopted TETRA on the basis of its features and facilities for critical applications.

TETRA has been proven in Asia and South America, where it has dominated railway communications, and ETCS6 compliant signaling as well as positive train control have been demonstrated in Asia, the US and South America using TETRA. Moreover, Communication Based Train Control (CBTC) can be seen as a further potential application especially for TEDS. The railway signaling system CBTC requires higher data rate than ETCS (approx. 70 kbit/s). TEDS provides the needed data rate (and higher) and improves security, reliability and cost efficiency. Narrowband data communications over primarily voice mobile networks based on GSM-R are currently the norm for train control in Europe. However GSM-R is seen as an End Of Life (EOL) technology and organizations such as the UIC and the European Railway Agency (ERA) are currently considering the future replacement technology choice. Furthermore in future the safe movement of express trains may depend more on localized high-speed data transfers associated with use of advanced signalling systems such as the European Train Control System (ETCS).

In P3's view the global rail community does not seem to have developed its thoughts on the applicability or not of broadband generally, and LTE specifically, to the same extent as, for example, the Public Safety community. Rail stakeholders do not appear for the meantime at least to have looked for future rail communications requirements very far beyond current group voice and limited signalling needs satisfied by GSM-R. There is an overall impression that "more bandwidth will be needed in future", but no specific requirements, use cases, etc. defined.

With GSM-R replacement unlikely until circa 2030 there is a potential gap for TETRA to fill. This is an especially compelling option where TETRA coverage exists from existing PPDR networks and operators believe that savings can be made. For example, a recent study carried out by the Finnish VIRVE TETRA operator proposed that the Finnish railways GSM-R network could be superseded in future by the VIRVE service with very few technical issues and quite considerable savings to the exchequer resulting from operating one nationwide network rather than two. At the time of writing this proposal is reported to have been agreed by the Finnish Transport Authority, which will seek a derogation from European Union rail authorities to allow use of TETRA in place of GSM-R for train communications.

In view of the foregoing, it is reasonable to expect that the rail sector particularly, but also the transport sector generally, will use the interim period whilst critical broadband standards are being specified, to develop and refine requirements and use cases for broadband applications that transport sector users will require in the future. In the meantime, TETRA may be able to fill the gap in some circumstances, but there is also a risk that proprietary technologies, including but not limited to so-called ‘Trunked LTE’, may be seen by users as an early way into the broadband world. See section 7 herein for further commentary on proprietary solutions.

3.5 A comparison of TETRA and GSM-R for railway communications

Many railways operators face a dilemma when choosing the wireless technology to support their networks’ communications requirements: in 1993, a time when the TETRA standard was just being established, the Union Internationale des Chemins de Fer (UIC) chose the GSM standard as a basis for its future digital mobile system. This led to the specification of the GSM-R (GSM for railway) standard, and the introduction of Voice Broadcast Calls, Voice Group Calls and Priority features as new added services in GSM.

However, the rapid adoption of TETRA technology by the public safety sector has catalysed its use in a growing range of markets: TETRA is now the de

Table 3.1

	GSM-R	TETRA
ETSI standard availability	Early 1997 (based on previous GSM)	Full ETSI status December 1995
Modulation	GMSK	Pi/4 DQPSK
Channel bandwidth	200 kHz providing 8 independent communication channel	25 kHz providing 4 independent communication channels
Frequency Bands (MHz)	876-880/921-925	380-400 410-430 450-470 806-821/851-866
TETRA/GSM-R CEPT SE7 Guard band in 800/900MHz for –60dBc (kHz)	300	25
Receiver sensitivity (dBm)	-104	-103
Maximum terminal speed (km/h)	500	500
Maximum propagation distance (km)	40	58

facto radio technology for public transportationsuch astrams andmetro systems. But why is TETRA so suited to railway operations? What are the factors that have driven its success and led to such exponential growth in its use?

This document looks at both TETRA and GSM-R, and compares the two technologies. It covers aspects relating to their performance and features, showing why TETRA has important advantages in comparison with GSM-R in the following areas:

- Spectrum efficiency
- Coverage
- Cost
- Public safety and mission-critical features
- Future-proofing and future development of the technology

TETRA is a technology that was designed specifically for the private mobile radio market, with public safety features at the fore. GSM-R, however, was modified from GSM, a public radio network standard, for use in railway operations – a private mobile radio environment.

Private mobile radio systems are designed specifically for professionals who require fast communications, simultaneous communication within a work group and mission critical features.

Public radio networks, however, cater to a totally different audience, being designed for general public use and individual calls, with no requirement for fast call set-up times. A comparison between TETRA and GSM-R RF performance is shown in the table 3.1 below.

In terms of frequency usage, TETRA is four times more efficient than GSM. TETRA offers four channels/25kHz, while GSM gives eight channels/200kHz, making TETRA systems more spectrum efficient: more channels are available, therefore there is more capacity to support significantly higher traffic levels.

Having more capacity also allows for future mobile data applications to be implemented without the need for further RF equipment.

TETRA operates in frequency bands 300 MHz and higher. GSM-R, by operating in the frequencies 876-915/921-960 MHz, requires many more base station repeaters than TETRA to obtain the same coverage.Using TETRA will lead to significant savings, not only in radio equipment, but also in civil engineering, such as buildings, shelters and towers.

The 300kHz guard band required to prevent interference between GSM-R and/or analogue FM (GSM-R DMO Solution) is provided from the GSM-R frequency allocation of 2 x 4MHz (20 channels). These requirements could easily inhibit frequency planning in cities where railways terminate and traffic is greatest.

Questions have been raised about the suitability of TETRA for terminals travelling at high speed – an important factor, since the average speed of trains is in excess of 200kph and speed has an effect on the TETRA radio data error rate. This is critical for high-speed rail applications where trains may run at speed of up to 350kph. The GSM-R standard specifies that the radio communication system should support speeds of up to 500kph. Simulations carried out by member companies of the TETRA community have proven that TETRA is effective at 500kph.

The typical cell size of a GSM system in a rural area is around 5 to 10 km radius, whereas TETRA cell sites range between 10 to 25 km radius, depending on terrain. Therefore, fewer TETRA cell sites would be required to cover a given area, typically resulting in fewer RF sites along the track and lower infrastructure costs.

Both TETRA and GSM-R will need special consideration for seamless handover when adjacent cells are busy (all traffic channels in use). However, TETRA is better provisioned to provide seamless handover continuity between cells, because ruthless pre-emption protocols already exist to disconnect lower priority users as part of the emergency call facility. This feature is very important from a safety perspective, as calls should not be dropped during data transmission and voice communication, even when trains are crossing between cells.

This section provides a summary comparing the voice, data and rail specific-features supported by GSM-R and TETRA systems.

Voice call set-up time.GSM-R uses a public network type infrastructure that was inherited from GSM, making it extremely difficult to achieve very fast call set-up times. The set-up times currently achievable by GSM-R systems would not be acceptable in the event of an emergency is shown in the Table 3.2 below .

The GSM-R standard specifies data transmission at 2.4kbps for the exchange of signalling information. This is not a problem for TETRA, as it supports the European Train Control System (ETCS) or Automatic Train Control (ATC) applications – and in fact, even higher data rates.

Table 3.2

Voice Services	GSM-R	TETRA
Call access time	5 - 8.5 sec	500 ms
Group call	Y (5 sec)	Y (0.5s)
Individual call	Y (5 sec)	Y (0.5s)
Broadcast call	Y (5 sec)	Y (0.5s)
Priority/emergency call	Y (2 sec)	Y (0.5s)
Full duplex voice	Yes	Yes
Telephone interconnect call	Yes	Yes
Call busy queuing	No	Yes
Recent user priority	No	Yes
Late entry	No	Yes
Remote monitoring	No	Yes

TETRA, on the other hand, was specifically designed for use in mission-critical environments, where fast response times are essential. The typical response time achieved by TETRA systems is less than 500ms-300ms within a switch, and 500ms between switches much faster than EIRENE specifies for GSM-R is shown in the Table 3.3 below.

Table 3.3

Data services	GSM-R	TETRA
Status messaging	Yes	Yes
Short data messaging	Yes	Yes
Circuit mode data	Yes	Yes
Data terminal interface	Yes	Yes
Simultaneous voice + data	Yes	Yes
Packet data	No	Yes

Data all set-up time. The call setup time also affects the data call handover: due to set-up times currently achievable by GSM-R (around 5-8.5s), the onboard radio design would require the installation of at least two GSM-R radios. The process is as follows:

- A data call between the onboard radio 1 and the RBC 1 in the wayside (Radio Block Centre) is established --> Train control from RBC 1
- When the train control has to be passed to a new RBC, a second data call between the onboard radio 2 and the RBC 2 in the wayside is established
- The train control is assumed by RBC 2
- The first call Radio 1 – RBC 1 can be disconnected

If there was just a single GSM-R radio, the handover between RBCs could take around 5-8.5s (the time to disconnect a call and connect a second one). During this time the train is not controlled, which is obviously not acceptable.

The GSM-R standard does not offer integrated DMO mode. The GSM-R solution for DMO is to use analogue FM within the same radio terminal. Combining both GSM-R and FM requires good frequency separation due to the 300 kHz guard band requirement of GSM-R. To ensure that all GSM-R systems have equal access to DMO, a group of RF channels will need to be assigned from the 876-880/915-921 MHz frequency band, thus reducing GSM-R channel capacity. DMO is included within the TETRA, without the need to integrate any other FM analogue radio.

In railway operations, it is important that emergency communications are maintained – even in times of drastic communication link failure between sites or between main and remote sites. When a remote site is isolated, a degraded mode of operation should allow emergency communications to continue, especially in catastrophic conditions. Within TETRA, radios within coverage of a site can communicate with each other even when site links go down. With GSM, the architecture requires centralized control – thus, when the link between the switch and base station is severed, the site is no longer operational and overage in this area is completely lost.

The GSM-R standard specifies data transmission at 2.4kbps for the exchange of signalling information. This is not a problem for TETRA, as it supports the European Train Control System (ETCS) or Automatic Train Control (ATC) applications – and in fact, even higher data rates.

It is expected that the data requirements for railway systems will, over time, increase significantly beyond the 2.4kbps specified. TETRA would therefore be fully capable of transporting the control application information as well as, or better than GSM-R.

In addition, although GSM-R is evolved from GSM, both systems cannot directly interoperate due to the allocated operating frequency and the fact that additional features incorporated within the GSM-R radio are not supported by the GSM infrastructure. GSM-R radios cannot roam into GSM networks and vice versa.

TETRA has been adopted as the digital radio trunking standard for public safety and private networks in Europe, and this trend has spread to the rest of the world. In the event of an emergency, when multiple agencies need to communicate and coordinate their activities, it is critical that the radio systems are able to interoperate with each other – typically by using the same standard. Without this functionality, railway personnel will not be able to communicate with other agencies in times of need.

In the case of derailment of a train, the emergency services, all using TETRA, can be easily and dynamically configured and placed into new talk groups with the railway operator to facilitate communications to coordinate rescue works, crowd control, etc. This kind of interoperability is especially critical during times of crises, where lives may be at stake.

Economic consideration. GSM-R infrastructure tends to be expensive, as it is based on GSM architecture, which was developed for mobile telephony (public networks), where the infrastructure cost is supported by millions of subscribers. By contrast, TETRA was created for low-density private systems, with a usage profile closer to the requirements of railway systems. This technology profile – GSM for public networks (infrastructure heavy) and TETRA for private networks (infrastructure light) – makes TETRA much more cost-effective than GSM-R (Table 3.4).

In addition, GSM-R terminals are very different – in terms of both features and function – from typical GSM terminals, and do not benefit from the economies of scale achieved by their production. Furthermore, the relatively small market for GSM-R hand-portable terminals does little to drive competition between suppliers, potentially resulting in higher prices and reduced choice for users.

Table 3.4

Economic factors	GSM-R	TETRA
Application	Designed for railways	PMR applications, including rail
Network scalability	No small network capability	Scalable from single site to nationwide network
Infrastructure cost	Slightly higher than GSM (GSM elements + rail specific elements)	Cheaper than GSM-R. TETRA was specifically defined for professional usage, and requires no

		commercial architectural elements
Mobile terminal cost	Higher (due to DMO integration, low volume market)	Competitive (terminals already supporting DMO and PMR features in ruggedised housing)
Customised terminal cost (cab radio)	Same as TETRA (radio control panel, train control interface, DC converter,etc.)	Same as GSM-R (radio control panel, train control interface, DC converter, etc.)
Maintenance cost	Higher (more sites to maintain)	Cheaper than GSM-R
Rural area coverage	High infrastructure cost and low user density in rural areas	Scalable design allows large coverage area for rural users
Bearer circuits	Use at least E1 circuit (30 channels) per base station site	A single TETRA base station requires just one 64kbps channel. Any backhaul between node and base stations is suitable. Reuse of customer-owned elements is possible
Second source security	Limited suppliers	Greater choice of suppliers

TETRA has received greater widespread market acceptance than GSM-R with thousands of projects awarded worldwide, in market sectors including public safety, transportation and utilities. GSM-R projects have so far been limited to European railways only.

Almost all new or upgraded metro and mass rapid transit lines – whose needs are very similar to those of railway operators – are selecting TETRA as their technology of choice when deploying digital trunked radio systems.

Although GSM has many manufacturers supporting it, the same cannot be said of GSM-R. Due to its limited market size, most GSM manufacturers have elected not to support GSM-R. TETRA has significantly greater manufacturer support for both infrastructure and terminals, leading to greater competition and a greater choice of terminals that match users' needs.

TETRA and GSM-R architecture. One of the main differences between TETRA and GSM-R is the architecture. While GSM-R is based on a circuit switching architecture, TETRA, particularly Sepura's infrastructure, is based on Ethernet (packet switching architecture).

Sepura infrastructure for TETRA mobile radio networks delivers excellent coverage, security and reliability in a platform designed for efficient implementation and cost-effective scalability. **Sepura** is the only TETRA system that is fully 100% Ethernet /IP based. A secure and reliable network can be built with distributed switching, distributed intelligence, and complete fault-tolerant redundancy, offering lower network costs due to the use of commercially available off-the-shelf equipment.

The Switching Control Node (SCN) is responsible for providing intelligence to the network, integrating user settings, and providing access to standard PMR services.

Our wide range of base stations, fixed and portable, are built to operate in diverse and challenging conditions delivering the best performance in every operational scenario, indoor or outdoor.

Sepura's Network Management System (NMS) manages and operates the network infrastructure, across TETRA and/or LTE radio technologies.

Table 3.5

Sepura TETRA: 100% Ethernet/IP	Advantages
All modules can be duplicated to achieve complete redundancy	Completely failure-tolerant system; maximum reliability
All elements in the system can be freely distributed	The transport network can use any kind of technology
The control nodes don't need to be geographically centralized	Failure points are avoided
Optimised method for packet data transmission throughout the transport network	Bandwidth requirements between SCNs and SBSs are reduced
Standard network equipment	Reduced obsolescence risk and reduced costs
Standard maintenance IP services	Standard tools: FTP, SNMP, TELNET, HTTP

Obsolescence is a key factor in the selection of the most appropriate technology to support railway communication requirements. A long lifecycle is mandatory, and the chosen technology should have a migration or evolution upgrade path to meet foreseeable future trends.

TETRA has consistently evolved to meet the needs of the professional market; the life of the technology is guaranteed for many years to come.

However, GSM-R's path into the future is less certain. It is not clear how GSM-R will be updated following the evolution of the public networks. The plans for new 3G and 4G public networks do not include the special railway functions of GSM-R, leaving the technology locked in to the initial, 1997 specification. For this reason, GSM-R is considered to be a technology that is near to the end of its life.

Conclusions. The TETRA standard betters GSM-R in terms of performance, features and price – as well as having a more clearly defined future. Flexible and open, the standard allows software application interfaces to be written to address the highly specific requirements of the railway sector.

Although the GSM-R standard was designed to meet the requirements of the railway industry, TETRA is arguably a better standard for railway operators to adopt, offering:

- Better spectrum efficiency
- Better coverage
- Lower cost
- Public safety and mission-critical features

CHAPTER 4. INSPECTING FIRE HAZARDOUS ELECTRICAL APPLIANCES

4.1 The causes if fire in the building of the Regional Railway Unit

Despite the great success in combating fire, the damage caused by fire in the railway is still very high.

Therefore, one of the main tasks in the fight against fire is fire prevention.

For this purpose, it is necessary to develop a continuously systematically identifying the cause of the fire and to identify modern methods and techniques for preventing fire risk.

The cause of the fire is the presence of ORS rooms, residential premises and so on in buildings, service and warehouses as well as other sectors of the national economy.

These include:

- ignition with electro-interlocking work, operation with lamps, heating equipment and devices, heating appliances, smoking in prohibited places, etc.;
- malfunctions of electrical appliances, electrical networks, electrical equipment, violation of rules of their use;
- Failure to observe firewood, burners, equipment, industrial equipment, technological process, fire safety;
- self-flammable lubricants, rubber materials and combustible substances;
- burning of static electricity from stoves;

4.2. Calculation of engine and power to eliminate fire in the building

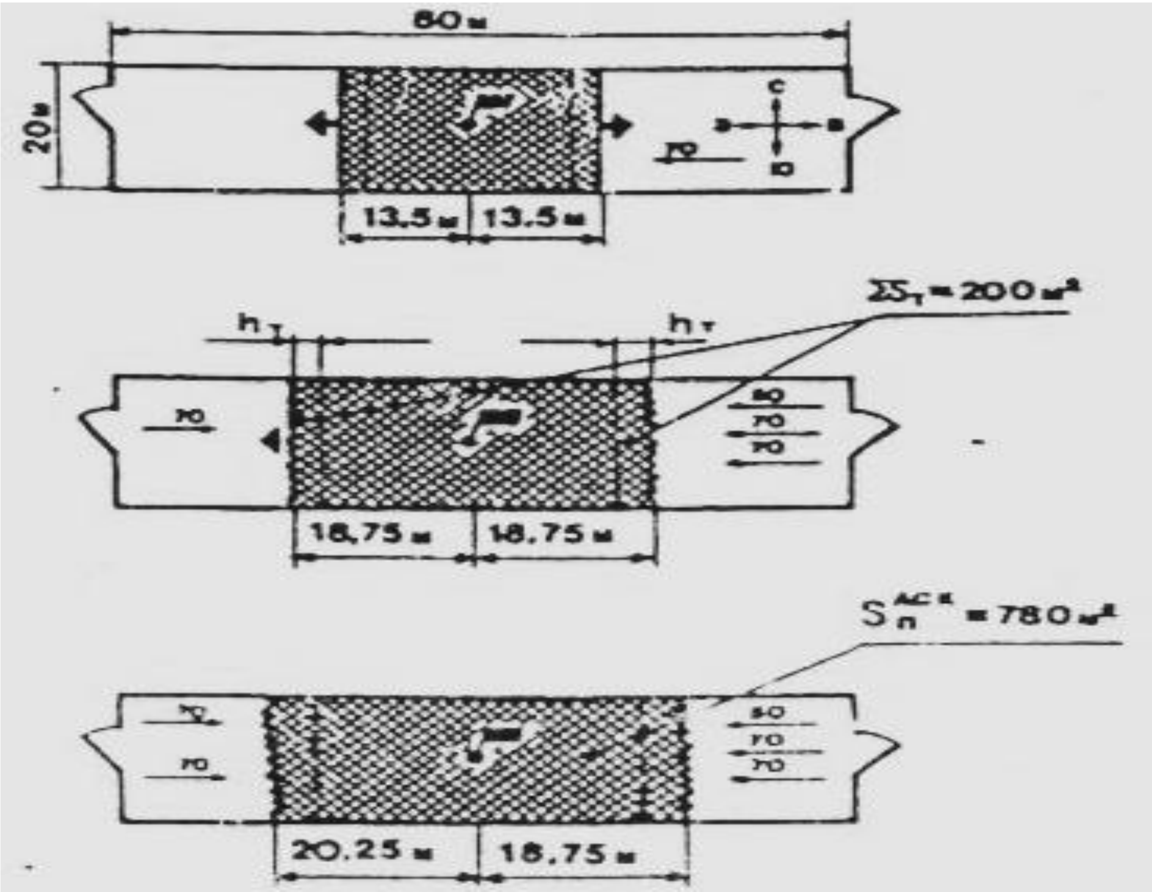
1. Determine the time of the fire (L), the free development of the fire (tsv = 14 min).

   Since the freezing time is more than 10 minutes, we will do the following for 10 min:

$$L^{t = 14min} = 5V_L + V_L * \tau_2 = 5 * 1{,}5 + 1{,}5 * 4{,}0 = 13{,}5m.$$

Here, the linear velocity of the V_L-fire flame front is 1.5 m / min according to the condition of the subject:

$$T_2 = \tau_{sv} - 10 = 14 - 10 = 4 \text{ min}.$$



Pic 4.1 Fire front.

According to the condition of the case, the point of the fire flames is located at the center of the dyeing center, and the fire load spreads uniformly along the uneven floor area to the wall of the building, spreading at a homogeneous rate in all directions L <10 m; (see picture 4.1).

The fire area is circular. Fire front reached the building wall, which affects the fire geometry (L = 10m).

For the case, the fire turns into a circular bias (east and westward) with rounded corners.

Thus, the fire front counter casts at the 14th minute at a distance of 13.5m ($L_{t\,=\,14min}$ = 13.5m) from the previous state.

Therefore, the fire area occupies the right corner shape at this time. The form at the 14th minute is represented by the following formula:

$$S_n^{t=14\min} = nL^{\tau=14\min}a = 2 \cdot 13{,}5 \cdot 20 = 540m^2.$$

Here: a – the width of building, m;

n - the distribution of fire in the double ticking, n = 2.

2. The localization of the fire at the 14th minute of the first unit is on the south side of a stack of RS-70 (diameter 19 mm, q_{stv} = 7,0 l / s).

It is known that the main requirement for fire localization is the fact that the actual consumption of water (fire removal) is required to exceed the level of fire or demand for a certain period of time.

The actual consumption of water is at the 14th minute of fire at 7.0 l / s ($Q_f^{t\,=\,14min}$=7.0 l/s) under the condition of the subject. Define the requested expenditure.

At the 14th minute of the fire, they form the right angle and spread two teeth in the southern and western sides.

The following formula describes the water consumption of localized water:

$$Q_{mp}^{\tau=14\min} = n \cdot a \cdot h_\tau \cdot I_{mp} = 2 \cdot 20 \cdot 5 \cdot 0{,}15 = 30l/s.$$

Here: n is the number of fire exits, n = 2 for today;

a – the width of the room is 20m depending on the condition of the subject;

h - lifting depth, 5 m for handrest, 10 m for tableware;

I - intensity of water transfer, at the condition of the subject is 0.15 l / s

Combined with the fact that the calculations are made and the actual and required parts of the water, the fire engines for the 14th minute can not localize the fire as the actual expenditure is lower than the required level:

$$Q_{mp}^{\tau=14\min} < Q_{mp}^{\tau=14\min}$$

$$7\ l/s < 30\ l/s$$

According to the picture, it is clear that the fire in 14 minutes and its localization is equal in eastern and western parts and has a constant value.

So, the water consumption in this direction is the same.

Thus, τ > 14 min.

$$Q_{mp}^{east}(\tau) = Q_{mp}^{west} = S_t \cdot I_{mp} = a \cdot h_t\, I_{tr} = 20 \cdot 5 \cdot 0{,}15 = 15 l / s$$

Water consumption is 30 l / sec for continuous localization. Comparing the actual consumption value of water, at 14 degrees east, = 7.0 l / s in the east, and 15.0 l / s in the west. In summary, RS-70 (a = 19 mm) can not localize the fire at the 14th minute. Thus, the spread of fire in the first stroke (t = 14 min) will continue in the east and west.

According to fire-technical literature, Q_f (t) <Q_{tp} (t) is 50% (V_l = 0.5V_l) with the linear distribution rate (V_l = 0.5V_l) after the first stroke (V_l = O.).

3. After 14 minutes, the fire pattern will be flat and its shape will be as in picture.

It can be traced that the 21st minute is limited in the southern direction, with two RS-70 stands and one RS-70 state = 15 l / s, and less than 7l / s. Therefore, starting from the 21st minute, the fire spreads in the western direction. The 21st minute fire may be determined by the following formula:

$$S_n^{\tau=21\min} = n\left[5V_l + V_l \cdot \tau_2 + 0{,}5\mathrm{V}_1(\tau - \tau_{0sv})\right] \cdot a = 2\left[5 \cdot 1{,}5 + 1{,}5 \cdot 4{,}0 + 0{,}5 \cdot 1{,}5(21 - 14)\right]20 = 750 m^2.$$

At the same time, the front frontier in the east and west from the initial state of fire:

$$L^{\tau=21\min} = 5V_L + \mathrm{V}_\mathrm{L}\tau_2 + 0{,}5V_\mathrm{L}(\tau - \tau_{sv}) = 5 \cdot 1{,}5 + 1{,}5 \cdot 4{,}0 + 0{,}5 \times 1{,}5 \cdot 7{,}0 = 18{,}75 m.$$

The location of the fire is much higher than the actual value of water consumed in the western direction.

According to the condition, this state takes place at 23 minutes, the summary is Q_f = 17 l / s, the demand level (15 l / s).

That is, in the 23rd minute, the firefighting stops in the east and west directions ($V_l = 0$) and the fire field does not grow.

4. For the 23rd minute of the local area fire, we define the following formula:

$$S_n^{t=23\min} = S_n^{t=21\min} + \Delta S_n.$$

Here, the Sn - Fire field is in the 21st and 23rd minutes.
n - after the 21st minute, the distribution of fire direction is taken as 1.
In this,

$$S_n^{t=23\min} = 750 + n \cdot 0{,}5V_{\text{L}}(\tau - 21)a = 750 + 1 \cdot 0{,}5 \cdot 1{,}5 \cdot (23-21) \times 20 = 780m^2.$$

The flames of fire in the western direction at 23rd local time are as follows:

$$L^{\text{west}} = 5V_L + \text{V}_{\text{L}}\tau_2 + 0{,}5V_{\text{L}}(\tau - \tau_{sv}) = 5 \cdot 1{,}5 + 1{,}5 \cdot 4{,}0 + 0{,}5 \cdot 1{,}5(23-14) = 20{,}25m.$$

It is possible to notice that at the localized moment, the fire front is at different distances (L) in the east and west directions than the initial state.

5. Calculated values are given in Table 4.1 for ease

Localization of fire **Table 4.1**

Time	Fire Area	Area of deduction, sum and	The amount of actual water consumption	Direction and amount of water required	

min.	m2	direction m / m2			in the direction of l / s			m2			Apply
		sum	east	west	sum	east	west	sum	east	west	
14	540	200	100	100	7	7	-	30	15	15	Border Prediction Localization
17	-	200	100	100	14	7	7	30	15	15	
21	750	200	100	100	24,5	17,5	7	30	15	15	
23	780	200	100	100	34,5	17,5	17	30	15	15	
27	780	200	100	100	38	17,5	20,5	30	15	15	
40											

6. Determine the relative consumption of water to close the fire.

As a relative consumption of water, the volume of water that has been consumed in the unit of fire is reported to the unit.

The analytical relative consumption is determined by the following formula:

$$\bar{q}_{ud} = \frac{\sum V_V}{S_P^{loc}}.$$

Here is the summarized volume of water, l;

S_P^{loc} - localized area of fire, m2, because the maximum value of the area is achieved by fire localization.

We define the time of fire in the fire, the difference between the time it takes to start the fire and the time when the fire is extinguished.

Calculate your convenience to Table 4.2.

Working Hours **Table 4.2**

The time it takes to get it min	The number RS - 50 and consumption l / s	The number RS - 70 and consumption l / s	Liquidation time	Stuff time worked min	The amount of water consumed, l
14		1*7=7	40		10 920
17		1*7=7	40	23	9 660
21	1*3,5=3,5	1*7=7	40	19	11 970
23		1*10=10	40	17	10 200
27	1*3,5=3,5		40	13	2 730
					ΣV_B =45 480

The relative consumption of water in the matter of fire extinguishing is as follows:

$$\bar{q}_{\text{ud}} = \frac{\sum V_{\text{V}}}{S_{\text{P}}^{\text{loc}}} = \frac{45480}{780} \approx 58{,}3 l / m^2$$

CONCLUSION

We have to understand that the role of radio communication in the railway industry is high. At the present time it is necessary to maintain a trunked radio system in railway transport. Because this system improving the efficiency of frequency and bandwidth. This system is for high-speed rail applications where trains may run at speed of up to 350 kph. If the train speed exceeds 200 kph, GSM-R can not transmit data at such a speed. Simulations carried out by member companies of the Trunk community have proven that TETRA is effective at 500 kph. This is a very high result. It also trunking is used by many government entities to provide two-way communication for fire departments, police and other municipal services, who all share spectrum allocated to a city, county, or other entity.

For the development of Uzbekistan railway transport, I have searched and used this information in the experience of the foreign communications companies.

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