COMMUNICATION REQUIREMENTS OF RAIL SIGNALING APPLICATIONS, BENEFITS OF TETRA FOR THAT USE AND COMPARISON WITH OTHER DIGITAL STANDARDS AVAILABLE
Based on the vast experience obtained and dominant position achieved in the transportation sector over the past decade, TELTRONIC continues to strive to introduce its widespread solutions based on TETRA technology into other application areas. One such area is that of railway signaling applications, which, for various reasons, up to now has relied on other systems such as GSM-R for communication. TELTRONIC is working hard behind the scenes with several key players including train manufacturers, railway signaling companies, system integrators, railway operators, etc., to transmit to them the advantages of TETRA technology to cover the different communication requirements for this sector. This activity is now beginning to bear fruit, and today, there are several on-going projects in which TELTRONIC is designing TETRA solutions for railway signaling applications. The white paper tries to summary the communication requirements of rail signaling applications, the benefits of TETRA for that usage and the comparison with other digital standards available in the market. Finally, three real success stories are presented.
The operation of a railway system requires the integration of numerous different subsystems, such as:

- Rail line infrastructure
- Energy systems
- **Signaling systems**
- **Communications networks**
- Traffic operation and management
- Rolling stock
- Maintenance
- Telematic applications for passenger services
- Freight management

Although with slightly different requirements in each of the various railway environments (metro, tram, light rail, conventional rail, high-speed lines, etc.), signaling systems include all necessary equipment to ensure safety and command and control of the movement of trains within the rail network.

The communications network, in addition to supporting data transmission for the signaling system, also facilitates voice communication for network users (drivers, maintenance crews, passengers, etc.).

The signaling and communications subsystems are related, often being contracted as a package. In actual practice, however, the design, management, and deployment of each is usually carried out independently, thereby leading to additional costs for the end user, as well as perhaps not resulting in the most efficient solution from the operational point of view.

One of the keys of the TELTRONIC proposal is the **optimized integration of both worlds (Signaling & Communications)**, which has allowed the following general objectives to be attained:

1. Cost optimization → Economic feasibility.
2. Integration of railway services into a single communications network → Obtain maximum efficiency from the investment.
3. Flexibility of the technical solution → Ensure capacity for evolution and future growth.
4. Maintaining and improving system performance for the users → Both for the railway operators (efficiency in operation) and end-users or passengers (safety and convenience).
RAILWAY SIGNALING APPLICATIONS

Railways are used by millions of people every day, for example, in urban environments with high traffic densities and frequency of trains, as well as for long-haul and high-speed lines where punctuality is important, and also therefore, the speed of the trains.

When speaking of railway signaling systems, there are two types of basic applications, known as safety systems and protection systems, which are responsible for ensuring the required standards of comfort, punctuality, availability, and safety for passenger and freight transport.

Safety Systems

Rail safety systems are based on continuous and real-time communication involving a variety of distributed sensors and track elements and other centralized units known as "interlockings", which process all incoming data and are responsible for sending orders to the driver.

A railway line is controlled by several interlockings each one responsible for a specific line section. As a train travels along the line, the interlockings communicate among themselves to assure traffic safety for the train along the various sections.

Furthermore, the interlockings likewise are remotely supervised by a command center known in railway jargon as Centralized Traffic Control (CTC). The interlockings, knowing the origins, destinations, and routes of the trains, are responsible for managing the railway infrastructure to permit them to arrive to their destinations according to their defined schedules.

Two requirements of a railway signaling system therefore are:

- Communication between interlockings
- Communication between interlockings and the control centers

Traditionally, these types of communication have been carried out by means of copper wire or fiber optic cable systems. Due to the long distances of the rail lines, these solutions significantly increase the installation cost of railway signaling infrastructure. That is the reason because of transport operators look for wireless efficient alternatives that substitute to those solutions.

Protection systems

Safety systems (interlockings) are complemented by other systems called protection systems, which are responsible for automatically processing the signaling information and execute the safety commands to prevent errors and accidents due to human factors.

There are two types of associated equipment:

- Ground equipment, which processes the information received from the interlockings and is responsible for passing operating instructions (speed, stop orders, emergency brake activation, etc.) to the train.
- On-board equipment, which is responsible for executing the driving orders received from the ground equipment according to the transmitted safety parameters.
The transmission of the information from the ground equipment to the on-board equipment can be accomplished in two ways:

- By physical elements arranged along the railway line (such as beacons, or "balises", and track circuits). In these systems, the train receives information only when it physically passes over these elements.
- By radio systems. In this case, radio coverage ensures that any train located on the line receives the information transmitted by the ground equipment at any location.

The three systems currently most used for train protection system are:

- For high-speed lines or conventional lines in Europe, **ERTMS - Level 2** (European Railway Traffic Management System) is used, which employs a protocol known as ETCS and, for the communications, a variant of the GSM system (GSM-R) supported by track's signals. This method facilitates radio interoperability for cross-border traffic, but GSM-R systems also carry very high associated roll-out and maintenance costs (on the order of tens of millions of Euros), which can be difficult to justify. In these environments, in the near future is expected to have **ERTMS-Level 3** on the field that relies almost exclusively on radio communications.

- For Automatic People Movers (APM), metro systems and other mass transit transportation systems, **Communications-Based Train Control (CBTC)** is used and incorporates automatic train protection (ATP) systems. Proprietary radio systems, mainly operating in the 2.4-2.5 GHz range, are most often used.
For long-haul distance trains or freight and mining trains, Positive Train Control (PTC) is used. This is an advanced system designed to automatically stop a train before certain accidents occur. It uses communication-based train control technology that provides a system capable of reliably and functionally preventing train-to-train collisions, overspeed derailments, incursions into established work zone limits. The communication technology currently used is WiFi or even proprietary solutions working above 2 GHz.

The TELTRONIC communications solution based on TETRA technology provides an alternative means for data transmission instead of GSM-R and other radio systems employed in various train protection systems.

One basic feature of the TETRA solution is the use of standard Ethernet/IP interfaces, for both on-board equipment as well as ground-based systems, which thereby facilitates the end-to-end interchange of information between railway signaling applications.

The solution also provides for a unified multiservice system for all communications requirements, resulting in lower deployment costs compared to GSM-R systems.
What are the basic requirements requested for a railway communications system?

- To be based on an international standard that incorporates railway-related applications.
- Demonstrated performance in mobile communications network operation.
- Economically viable roll-out and operation.
- Standard system components, identical to those available in the rest of the market (multi-vendor, open market environment to facilitate competition and choice).
- Support for railway-specific services.
- Integration of railway-related services into a single communications network.
- High system reliability and availability, and quality of communications (voice and data) at different speeds, including up to 500 km/h (300 mph) for high-speed lines.
- Capacity for future expansion and addition of new services.

TETRA technology satisfies this set of basic requirements and also possesses other key aspects that differentiate it from solutions based on technologies such as GSM-R:

**Frequency bands and spectral efficiency:**

TETRA operates between the 300 MHz and 800 MHz frequency bands, meanwhile GSM-R operates in 900 MHz and 1800 MHz. As radio propagation losses are directly proportional to the square of the frequency, GSM-R requires many more repeater stations than does TETRA to obtain the same coverage. Choosing TETRA therefore results not only in a savings for radio communications equipment, but also in civil engineering and site preparation costs (fewer towers, equipment shelters, etc.).

TETRA is four times more spectrally efficient than GSM-R, providing four channels within a bandwidth of 25 KHz, compared to eight channels over 200 KHz for GSM-R. Consequently, use of the radio spectrum, a natural resource that is limited in availability today, is greater optimized with TETRA.

**Profile of use:**

GSM is a standard developed by ETSI for mobile telephone systems, in which frequency reuse is a key factor (even to the extent that propagations losses can be considered as an advantage), and where overall infrastructure cost is of lesser relevance since it is supported through the use of millions of subscribers.

GSM-R, which is an adaptation of GSM that include group call capability and a degree of protection for data transmission, is therefore obviously not cost-efficient for low user density systems such as for railways.
### Standard TETRA functionalities useful for railways:

Some of the functionalities found in TETRA technology that are particularly applicable for railway environments include:

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleet and group management</td>
<td>Definition of fleet configuration and call groups that can be adapted to different operational groups in the railway network, for example, line groups, depot groups, station groups, etc.</td>
</tr>
<tr>
<td>Group calls</td>
<td>Made between two or more users. All users can speak in the conversation. The speaking party identity is indicated to all group members at any given time.</td>
</tr>
<tr>
<td>Broadcast calls</td>
<td>Made between two or more users unidirectionally, that is, only the sender of the call can speak meanwhile the other users can only receive and are not allowed to respond. This type of call can be configured to be sent only to certain groups or to the entire network (system-wide call).</td>
</tr>
<tr>
<td>Call set-up</td>
<td>The call establishment times for TETRA, for both individual and group calls, are the order of 300 msec (call set-up in GSM-R can be from 7 to 9 seconds).</td>
</tr>
<tr>
<td>Priority management</td>
<td>TETRA provides up to 15 call priorities assignable to the different services.</td>
</tr>
<tr>
<td>Emergency calls</td>
<td>Calls which have assigned the highest level of priority (15) and which may interrupt other ongoing calls with lower priority, if there are no other network resources available to allow the call to pass.</td>
</tr>
</tbody>
</table>
| Data services                      | Wide range of data services to cover different needs:  
  - Packet data  
  - Circuit mode data  
  - Short Data Service  
  - Status messages |
| Dialing and call routing services  | TETRA provides several methods for dialing and call routing to access to TETRA services and external networks such as PABX/PSTN.  
  These may be complemented by other special procedures such as user login, which can be required at the beginning of daily operation. |
| Dynamic Group Number Assignment (DGNA) | Supplementary service which enables assigning groups dynamically n a temporary basis, which is useful for the management of special operations. |
| Ambience listening                | Supplementary service that, after an emergency request by the |
user, can automatically place the TETRA terminal in a kind of special voice call, in which will transmit but without giving any indication to the user (visual or audible). This allows the control center to hear what is happening around the equipment that reported the emergency.

<table>
<thead>
<tr>
<th>Duplex calls</th>
<th>Possibility of making full duplex calls, which can be managed by drivers in &quot;hands free&quot; mode without the need to use &quot;push to talk&quot; function.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct mode</td>
<td>Direct communication between terminals without calls being passed through the main network. Especially useful in railway operations (&quot;Shunting&quot; mode).</td>
</tr>
<tr>
<td>Roaming</td>
<td>Cell change and restoration of the call transparent to the user. Mechanisms for configuration and selection of different cells: cell change parameters and thresholds, neighbor cell information, call permissions, etc.</td>
</tr>
</tbody>
</table>

All these services are integrated within a standard TETRA communications system and, hence, in the TETRA solution from Teltronic.

**Integration of services:**

TETRA can fulfill all of the communication needs identified for a railway environment in a single communications network:

- Voice communications between drivers, stations, depots, control centers, PA systems, etc.
- Voice communications between maintenance staff
- Voice communications between security staff
- Voice communications with other organizations in special circumstances (police, firefighters, etc.)
- Location applications (trains, maintenance vehicles, ground personnel, etc.)
- Passenger information systems
- Monitoring applications, diagnostics, management of alarms and incidents.
- Railway signaling applications (safety and protection systems)
DIGITAL COMMUNICATIONS SYSTEMS COMPARISON

To complement the analysis carried out in this white paper, we could mention other narrow band digital standards that could serve voice and data needs to professional market. One of them is DMR (Digital Mobile Radio). This section will review its capabilities in comparison with the recommended TETRA standard for the transportation usage case.

Digital Mobile Radio (DMR) is an open digital mobile radio standard defined in the European Telecommunications Standards Institute (ETSI) Standard and mainly used in commercial products around the world. DMR was designed with three tiers. DMR tiers I and II (conventional) and DMR III (trunked). The primary goal of the standard is to specify an entry-level, digital radio system with low complexity, low cost and interoperability across brands, mostly intended for non-mission-critical users as for instance retail, businesses or sporting event.

On the other hand, Terrestrial Trunked Radio (TETRA), a European standard for a trunked radio system, is a professional mobile radio 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. It is also a European Telecommunications Standards Institute (ETSI) standard.

Both communications solutions provide an alternative means for data transmission to GSM-R, WiFi and the other radio systems employed in various train protection systems.

As follows, a comparison of the radio services and general features commercially available and provided at present by both technologies are listed, to evaluate advantages and disadvantages or each of the technologies:

<table>
<thead>
<tr>
<th></th>
<th>TETRA</th>
<th>DMR Tier III</th>
<th>DMR Tier II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VOICE SERVICES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individual call, full duplex</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Individual call, half duplex</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Group call</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Emergency call</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Broadcast call</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Pre-emptive priority call</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>All call</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Telephone call, full duplex</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Telephone call, half duplex</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Roaming</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Handover (restoration of ongoing calls after roaming)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>DATA SERVICES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Status messages</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Short data messages (text messages)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Short data read and delivery receipt</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Simultaneous voice and data</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Packet mode data monoslot</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Feature</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>-----------------------------------------------------------</td>
<td>-----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Packet mode data multislot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circuit mode data monoslot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circuit mode data multislot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum data rate, circuit mode data (gross rate)</td>
<td>28.8 Kbps</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Maximum data rate, packet mode data (gross rate) (*)</td>
<td>14.4 Kbps (multislot)</td>
<td>2.4 Kbps (monoslot)</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Secondary control channels for enhanced zone capacity</td>
<td>Yes (up to 4 control channels)</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

**SECURITY SERVICES**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Yes</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authentication of terminals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mutual authentication</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Air interface encryption</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>End to End encryption</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Temporary disabling of terminals</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Enabling of terminals</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Permanent disabling of terminals</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**ADVANCED SERVICES**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Yes</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late entry</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Dynamic group number assignment (DGNA)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Call forwarding</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Call authorized by dispatcher</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Ambience listening</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

**SYSTEM ARCHITECTURE**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed/cabinet-based base stations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outdoor base stations</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Transportable base stations</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Mast Mounted Base Stations</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Double diversity receiver</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Triple diversity receiver</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Double link to backhaul network</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Full redundancy of all network active elements</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Voice recording system</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>VoIP telephony gateway</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Analogue telephony gateway</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>ISDN telephony gateway</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>E2EE telephony gateway</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Telephony gateways placed in both base stations and control node</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>SNMP monitoring</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Backup and restore tool for advanced system maintenance</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Future-proof evolution/upgrade to broadband radio technologies as LTE</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

(*) Data rates indicated above may change depending on the protection level applied to the data channel in DMR.
The table above highlights that TETRA systems provide more features and functionalities than DMR Tier II and DMR Tier III systems. In fact, features described in next paragraphs are essential for the rail sector and especially for signaling scenarios:

- **Variety of data services:** TETRA offers several data transmission services, whereas DMR data services range is more limited, not to say basic in DMR Tier II. This delivers a great flexibility for signaling application suppliers to choose the TETRA data service that best fits their needs and application traffic model, adapting the radio system to the signaling application rather than the signaling application to the available radio services. Additionally, the enriched offer of TETRA assures that multiple data needs may be satisfied in parallel each using the most appropriate data service, as for instance continuous transmission of signaling packets and on-demand transmission of GPS position.

- **Simultaneous voice and data:** Signaling scenarios demand dedicated data channels for managing signaling data, that is vital information. The reception of such data must be assured while minimum QoS (Quality of Service) values are secured. At the same time, these scenarios usually require voice communications between drivers and Control Centre operators. Thus, it is essential that the system is able to provide both services simultaneously on the basis that the quality of them is not undermined.

- **Pre-emptive calls:** pre-emptive calls are those calls where the system will release radio resources or/and radio users engaged in other calls for the establishment of a new critical call. TETRA provides the necessary mechanisms to alert users that a new pre-emptive call has been made, and thus specific users engaged in existing calls must automatically switch to the new one. Whereas this feature is not currently in place in commercially available DMR systems, it allows guaranteeing that no critical communication will be missed by any user who should participate in it, which is one of the main goals of mission-critical systems: full awareness.

- **Bandwidth:** As TETRA is a 4-TDMA technology, it provides up to 4 communication channels fitting into a 25 KHz physical channel. However, DMR being a 2-TDMA technology provides 2 communications channels fitting into a 12.5 KHz physical channel. This means that both TETRA and DMR radio technologies deliver the same spectral efficiency of 6.25 KHz per communication channel, although relevant differences arise when comparing the rates in data transmission, as shown in the table above. Maximum bandwidth provided by TETRA is 28.8 Kbps by using the circuit mode data service (gross rate), whereas maximum DMR bandwidth is 2.4 Kbps by using the packet mode data service (gross rate). It is worth remarking that TETRA can offer up to 14.4 Kbps if using packet mode data service (gross rate), and DMR lacks circuit mode data service.

- **Duplex calls:** In a normal operation between the On-board Signaling Computer and the Zone Controllers in the wayside, it is essential to have a simultaneous exchange of information between both ends. This is the key of all the signaling systems based on radio communications. Meanwhile the Zone Controller sends Limit Movement Authorities (LMA), the On-board Computer sends its location information. For that purpose, TETRA provides the possibility to establish full-duplex calls.

- **Handover:** In signaling projects based on PTC and ETCS long distances are travelled. Therefore, more than one radio site is required and consequently handover capabilities are mandatory in order to transfer and recover and ongoing call when a radio roams between sites. For the
proper performance of signaling applications, it is of utmost importance to always maintain active the ongoing voice calls and data transmission sessions if there is a roaming process between neighbor sites of the communication system, which is known as handover. If the TETRA terminal is involved in the transmission or reception of IP packets immediately prior to performing a roaming process, the transmission or reception of data will continue from where it finished on the previous site, with no loss of data. If circuit data are sent, an instantaneous loss data happens, similarly to GSM-R, accepted by the signaling application. With regard to voice calls, TETRA defines the necessary mechanism for handover to successfully occur, based on allocating radio services and transferring the ongoing call to the destination site. Not including handover mechanisms, DMR lacks one of the radio services demanded in any truly professional, cutting-edge radio communication system, which could lead an ongoing communication (whether voice or data transmission) to be suddenly interrupted, lost or sharply degraded, even without notice from the calling party.

- **Encryption:** Transportation systems including buses, tramways, metros, railways and commuters are defined as mission-critical systems since they move millions of passengers per day worldwide. That is the reason why they require different encryption methods to assure the confidentiality and the security of their operations. Whereas E2EE is mostly used in military scenarios, TETRA also offers air interface encryption (AIE) as a means to deliver the highest privacy and security, which is not deemed to be as complex to manage as E2EE.

System design and architecture is also a key point to consider when assessing the radio technology of choice. Among others, next differences between TETRA and DMR systems can be underlined:

- **Number of radio repeaters required:** TETRA is a 4-TDMA technology, whereas DMR presents a 2-TDMA structure. This means that for the same number of trains and traffic load expected, which leads to a recommended number of communication channels for the systems, twice as many radio repeaters will be required in a the DMR system, incurring in higher cost.

- **Overlapped coverage:** Overlapped coverage is distinct requirement in transport and signaling scenarios, where a uniform signal level is required to maintain both the bandwidth and the minimum QoS parameters in signaling applications. Simulcast DMR systems prove to be inappropriate to secure an acceptable overlapping level among neighbor sites, as using the same frequencies for all sites could entail a harmful level of downlink interference in terminals place on the cell boundary, if no global system synchronism is used (which is uncommon in DMR system looking to pare down the system complexity).

- **Variety of base station models:** Main lines, freight and mining trains run across long distances, where train stops, shelters or technical rooms are not always available. Consequently, it is not always possible to deploy any kind of telecommunication infrastructure and equipment, and additionally it is crucial to count on the enough flexibility from the radio system supplier and the technology itself to provide those network elements best adapting to each scenario. TETRA systems do not only feature cabinet or rack mounted base stations, but also outdoor and transportable units which bring several advantages such as being fully prepared to withstand extreme weather conditions (up to 60 ºC), no need for shelter, mast installation, fanless design for easy maintenance, light weight, reduced power consumption...
Availability: being truly mission critical, TETRA systems incorporate mechanisms for avoiding points of failures and assuring the continuous service of the system like the double link to backhaul network and the full redundancy of all network active elements. This is extremely important in transport scenarios (urban and railway) where the trains are running almost 24/365 and the availability figures demanded are extremely high.

Maintenance: being truly mission critical, TETRA systems incorporate more advanced tools and capabilities with which to manage, monitor and maintain the infrastructure. For instance, backup and restore tools allow making copies of current system configuration, operating parameters and fleets, groups and terminals added on to the system, to be restored on-demand upon an accidental system misconfiguration.
SUCCESS CASE 1: MOATIZE-NACALA CORRIDOR, MOZAMBIQUE

With a mission to transform natural resources into prosperity and sustainable development, VALE is a global mining company with headquarters in Brazil which is part of Mozambique’s history, contributing to the development of the country’s mining industry, since 2004, when it won a concession to implement its first greenfield project in the country – the Moatize Coal Project.

In its first full year of operation (2012), Moatize Mine produced 3768 million metric tons: 2501 million metric tons of metallurgical coal and 1267 million metric tons of thermal coal.

VALE is investing heavily in the area in order to transport Moatize’s output. It is building the Nacala Corridor, which will link Moatize to the Port of Nacala and work with a TETRA communication system to provide voice and data functions.

The Nacala railway corridor project is intended to provide a logistics solution for the transportation of coal from the Moatize Mine, in Mozambique’s Tete province, to the maritime terminal in Nacala, on the Indian Ocean, through a new 912 km-long railway corridor which pass through Mozambican jungle and Malawi. The corridor will be able to carry more than 20 million tons of coal a year whose prior destinations will be India, America’s, Europe and Eastern Asia among others.

THE CHALLENGE: MOATIZE-NACALA CORRIDOR READY IN 2014

The first challenge is assuring that TELTRONIC and Siemens engineers carry out a coordinated project to provide VALE an innovative and integrated solution as it is demanded.

Given the strategic importance of both lines, the main challenge is providing systems that would allow security and train speeds to be increased, and thereby reduce operating costs for freight transport. These railway control systems require the support of a robust and reliable communications system, which shall be based on radio technology in order to reduce the wayside equipment, which, given the characteristics of the environment it is difficult to deploy and presents high maintenance costs.

At that point, TELTRONIC and Siemens will participate in the project by providing the TETRA communications system and the signaling Positive Train Control (PTC) system respectively. Thus, PTC equipment will use TETRA digital radio communications network to communicate its wayside and mobile parts and hence, monitor and control train actions.

Apart from managing signaling data, it is necessary to use more TETRA equipment in order to:

- Manage voice communications between drivers and Control Center operators.
- Manage data sent from the derailment sensors to the wayside application of the Control Center to the train.
- Manage data sent from wheel bearing temperature supervision system to the wayside application of the Control Center to the train.
THE SOLUTION

The Siemens signaling system uses train-to-ground communication to transmit vital information regarding trains movement.

The signaling application uses GPS and speed sensors to locate the train relative to an on-board track database. This equipment continuously monitors train speed and location against the speed limits and movement authorities (LMA). By predicting the train braking distance, the system warns the crew of potential safe movement violations. If no action is taken, the locomotive brakes are activated automatically.

The final solution must allow getting the maximum performance of the system and operate with the maximum efficiency as VALE demands. By means of a single and unified communications infrastructure with maximum availability must be provided service to all applications and railway systems such as signaling applications, wheel bearing temperature supervision system, derailment system and voice services to provide communications between drivers and other groups of users.

The solution deployed in Nacala Corridor is based on the NEBULA TETRA infrastructure. 100% Ethernet IP architecture provides high flexibility in the solution design, as well as an easy management and maintenance.

The infrastructure part is composed of a central node which controls more than 50 TETRA base stations installed along the 912 km-long rail line. The Mobile 10W Coverage is 99.6% and Overlapping Mobile 10W Coverage is 90.2%. The base stations backbone network is based on microwave links.

It is worthwhile pointing out that the TETRA base stations has been integrated within a special cabinet ready to support extreme environmental conditions. Additionally, in order to provide a higher availability level of the network, a satellite communications system has been installed to be used in the case of failure of the TETRA system.

The on-board TETRA equipment provided has been designed following the recommendations of several signaling systems manufacturers. It presents an Ethernet link to be connected to the vital on-board computer and then, establish data transmission sessions with the object controllers and interlockings distributed along the tracks.

The second range of on-board TETRA equipment supplied for Nacala Corridor will be used by the drivers to be in communication with the 3 operators of the Control Center, located on Nacala Port, which will manage the communications with the trains running along the line.

The control center user interface is based on TELTRONIC’s CeCo-TRANS system, which is designed for the railway environment, and allows displaying and interaction with the trains by means of a synoptic line display. The application allows operators to display the train fleet positions in real-time.

Finally, portable terminals have been supplied as for Moatize Mine and Nacala Port workers as for maintenance staff working along the line to be in communication with the Control Center operators and other users.
CONCLUSION

Based on the vast experience obtained and dominant position achieved in the transportation sector over the past decade, TELTRONIC has got to introduce its widespread solutions based on TETRA technology into other application areas. One such area is that of railway signaling applications, which, for various reasons, up to now has relied on other systems for communication.

With Nacala Corridor project, TELTRONIC has proven TETRA technical viability to offer safe and efficient communications in the railway environment, providing voice, operational data (location, alarm and event management) and PTC signaling data over a single infrastructure. This experience may be applicable to other transportation environments with signaling systems based on different existing protocols such as ETCS or CBTC.

The new railway line will benefit from the return on investment of the TELTRONIC TETRA, being an attractive technology in economic terms (multi-vendor technology with economy of scale in production), in functionality (multi-service integrated systems), and in guaranteed capacity for future growth and further development (long life cycles and open standard system with flexible and scalable architecture).
SUCCESS CASE 2: NORTHERN RAILWAYS OF COLOMBIA (FENOCO) COLOMBIA

FENOCO (Ferrocarriles del Norte de Colombia S.A.) is responsible for the administration, operation and maintenance of railway infrastructure and rolling stock of the Atlantic Railway Concession in northern Colombia.

The company already operated a voice-centric TETRA network supplied by Teltronic, part of the Sepura Group, supporting simultaneous voice and data transmission on the Chiriguaná-Santa Marta line. Used principally for the transportation of coal from La Loma mine to ports on the northern coast, the 246km line has 17 stations and sees the transportation of 156,000 tons of coal per day.

In 2014 Teltronic’s U.S. subsidiary PowerTrunk entered into a frame contract with General Electric Company for the purpose of testing and validating a data-centric TETRA solution intended to support GE’s Incremental Train Control System (ITCS) rail signaling. To such purpose a testbed was set up at GE’s facilities in Melbourne, Florida. The solution proved compliant with Positive Train Control (PTC) requirements established by the Federal Railroad Administration (FRA) in the United States. Once the final specifications were defined, GE proposed Teltronic’s TETRA technology to implement ITCS over TETRA for FENOCO in Colombia following directives issued by the Colombian government to ensure the highest safety standards for railways.

“The agreement with General Electric Company served as frame contract with GE Transportation Systems, today merged with Alstom Transport, for the purpose of delivering a data-centric TETRA solution and optical fiber backbone to FENOCO specifically designed to meet PTC-compliant ITCS rail signaling”, said Jose Martin, Sepura Group Regional Director for the Americas. “We leveraged the local engineering capabilities of our subsidiary Teltronic Andina, headquartered in Bogota, to supply and commission the entire communications network for the La Loma-Santa Marta railway line operating 3km-long trains with several locomotives. This successful experience is evidence of the Sepura Group’s capabilities to deliver turnkey TETRA-based solutions for rail signaling worldwide”.

THE CHALLENGE

The existing system provided voice communication, GPS location information, and short data messages for the management of maintenance operations and traffic regulation of the three freight companies working on the line.

FENOCO wanted to leverage the power of this TETRA system to implement a PTC system on a 193km section of the track, running from Ciénaga to La Loma.

THE SOLUTION

The existing network was expanded and upgraded to support an ITCS system for railway operations.

ITCS is a Federal Railroad Administration (FRA)-approved PTC rail signaling system which uses train-to-wayside wireless links and a vital communications protocol to monitor and control train actions. ITCS
provides a variety of safety and operational functions such as track occupancy, speed limits and restrictions, and enforces their execution via an onboard computer.

This proven technology is approved by the FRA for operation at speeds up to 110MPH (177KM/hr) and is already in use – or in development – worldwide, in territories such as North America, China, Australia and South America.

Delivered in conjunction with GE Transportation, a division of the General Electric Company, the custom solution included:

- additional TETRA carriers installed on all existing sites to provide extra radio resources and support ITCS data
- three Mast-Mounted Base Stations installed along the line to boost coverage
- 84 specially designed onboard radios – compliant with railway (EN50155) standards – using ITCS technology, to allow vital information to be exchanged from ground to train along the route
- centralized traffic control (CTC) and onboard signaling applications

**BENEFITS OF THE OVERALL SOLUTION**

- Single network for simultaneous voice and data
- Minimizing maintenance operation costs and maximizing the RoI of the previously installed voice-oriented TETRA network
- Enhanced coverage in critical areas including overlapping for redundancy
- Proven TETRA technical viability to offer safe and efficient communications in railway signaling environment
- This experience may be applicable to other transportation environments with signaling systems based on different existing protocols such as ETCS, CBTC or PTC.
(KTZ), Kazakhstan passenger and freight rail operator company, is an essential part in the transport infrastructure development program in the country, defined for the period 2010-2014 and framed within the national strategic plan up to 2020.

The Kazakhstan geographical conditions, with vast areas without direct access to the sea, the production structure of raw materials and poorly developed road network, give rail transport an extremely important role in that strategic plan.

The company is facing a major challenge of modernizing their systems, rail infrastructure, locomotives and control and operational systems, which, for sure, will help to improve the competitiveness of Kazakh transport system for both passengers and freight transportation through the euro-asian international routes.

PROJECT CONTEXT

Within this program of modernization, the first two projects planned by KTZ are described below:

Uzen – Bolashak line: Section of 150 km between these cities in the southwest of the country. It is the beginning of a long railway line linking Kazakhstan, Turkmenistan and Iran meant to enhance trade between the countries.

Zhetygen – Khorgos line: 300 km line linking two cities located close to the Chinese border. This railway will be important to promote political and economic relations between the two countries and establish a new access route between China and Europe.

Given the strategic importance of both lines, it was essential to provide them with control systems that would allow security and train speeds to be increased, and thereby reduce operating costs for freight transport.

These railway control systems require the support of a robust and reliable communications system, which shall be based on radio technology in order to reduce the wayside equipment, which, given the characteristics of the environment it is difficult to deploy and presents high maintenance costs.

TECHNOLOGICAL CHALLENGE: ETCS OVER TETRA

Due to the many good references available in Europe, the railway signaling system chosen by the customer KTZ was ETCS (European Train Control System). A key aspect in the solution design was the selection of a communications system for supporting the signaling system. It was needed to find a safe, reliable, and cost efficient system to support at least the following requirements:

- To be based on an international standard that incorporates railwayrelated applications.
• Support for railway-specific services: Group calls, ambience listening, emergency calls, priority management, data transmission services, remote management and monitoring system, fast set-up and registration times, etc.
• Availability of equipment in UHF frequencies
• Integration of railway services into a single communications network
• High level of reliability, availability and quality of voice communications and data integrity
• Economic and technical feasibility (CAPEX)
• Low maintenance costs (OPEX)
• Capacity of the company providing the radio solution to adapt it and integrate it with the vendor of ETCS signaling system.

Competing against the current GSM-R technology mandatory in Europe, TETRA technology and specifically the TELTRONIC equipment were chosen to cover extensively the above requirements.

Kazakhstan’s national railway has been the first to rely on the implementation of an ETCS (European Train Control System) railway signaling system over TETRA, being the security level implemented equivalent to that defined in the standard as ETCS Level 3. In addition, with this solution, KTZ has available through a single communications infrastructure data services to support railway signaling and voice services for communications with drivers and maintenance staff.

PROJECT DEPLOYMENT

The solution deployed in both lines (Uzen- Boloshak and Zhetysu- Khorgos) is based on the NEBULA TETRA infrastructure. 100% Ethernet IP architecture provides high flexibility in the solution design, as well as an easy management and maintenance.

Every project is composed of a central node and several base stations which cover the train lines. Each train is equipped with an on-board RTP-603 terminal and accessories to manage voice and data communications. Furthermore, DT-410 desktop units have been supplied in order to manage communication with drivers and other walking users.

The extreme terrain conditions required a big effort from the TELTRONIC staff, who worked especially in the tasks of installation and deployment of the radio infrastructure.

On the other hand, TELTRONIC engineers and staff from the company responsible for the signaling system carried out a coordinated integration project, which consisted of several stages: analysis of alternatives, definition of interfaces and communication protocol, implementation and validation tests.

The validation tests were divided into two phases, the first of them in the laboratory, where the correct operation of the radio equipment was validated through rail traffic simulation tools, and a second phase of testing in the tracks, which verified the behavior of the complete solution on the customer’s real scenario. The system was commissioned in June 2012.
CONCLUSIONS

TETRA technology is spectrally more efficient, has a greater range of functions, and is significantly cheaper than the commonly deployed technology in the European signaling systems, GSM-R.

With this project, TELTRONIC has proven TETRA technical viability to offer safe and efficient communications in the railway environment, providing voice, operational data (location, alarm and event management) and ETCS signaling data over a single infrastructure.

This experience may be applicable to other transportation environments with signaling systems based on different existing protocols such as ETCS, CBTC or PTC.
SUSTAINABILITY OF THE COMMUNICATIONS SYSTEM

In the previous sections, the various technical aspects comprised in the railway communications solution have been analyzed. However, another essential factor for project success also needs to be mentioned: the sustainability of the business model associated with the system.

Each company has different operational needs, different management models, and even different financing capacity. Each particular business case should therefore be based on a rigorous economic and financial analysis to ensure efficient and safe operation, and must be adequately adapted to the operating environment (urban, rural, etc.), varying traffic densities (metro systems, railways), and operating model (passenger vs. freight transport).

The Teltronic TETRA solution is the bet for the return on investment, being an attractive technology in economic terms (multi-vendor technology with economy of scale in production), in functionality (multi-service integrated systems), and in guaranteed capacity for future growth and further development (long life cycles and open standard system with flexible and scalable architecture).