WHITE PAPER

ETCS L2 AND CBTC OVER LTE: CONVERGENCE OF THE RADIO LAYER IN ADVANCED TRAIN CONTROL SYSTEMS
Summary

A general trend in modern Train Control Systems is the use of increasingly similar hardware platforms to implement different applications. More and more, the on-board equipment needed to deploy a mass transit CBTC system is, if not effectively the same, at least equivalent to the equipment used for ETCS Level 2 roll-outs. A similar process is taking place trackside, with Eurobalises being adopted for CBTC and Zone Controllers or Interlockings being revamped into RBCs. It is mostly at the application level where these systems really begin to differ, as if CBTC systems were about to become a series of customised ATO applications on top of what basically is a generic ETCS-like ATP system.

This integration tendency begs a question: what will happen with the radio layer? Today, nearly all ETCS Level 2 systems use GSM-R as their radio carrier technology, with a few anecdotal instances of TETRA usage. At the same time, nearly all CBTC systems use radio networks based on IEEE 802.11 (Wi-Fi). The main reason for this difference is historical – with GSM-R being developed by European authorities as part of the ERTMS specification, and Wi-Fi being chosen as a “cheap and dirty” unlicensed band solution for railways that are mostly underground.

This paper explores the forces that underpin the trend to move away from those radio layers. It also identifies LTE as a technology that seems to be, according to current market trends and to technical reasons, the obvious successor to GSM-R and the best alternative to replace Wi-Fi in safety critical applications. The paper finally presents some of the integration challenges that train control system engineers will face in the coming years in trying to make the transition from their current radio interfaces to the latest radio carrier technology around, and how enhanced capabilities of the radio layer may open the box for oncoming innovations in Train Control Systems.

1. Introduction

In the last 20 years, Train Control Systems have experienced a tremendous growth all over the world. In particular, two technologies (ETCS and CBTC) have come to dominate their respective core markets to the point of becoming, in practical terms, worldwide standards.

ETCS (European Train Control System) is the In-Cab Signalling, Train Protection and Train Control component of the ERTMS (European Rail Traffic Management System) standard. The development of ERTMS was kicked-off by a series of European Union directives in the early 1990s that mandated a number of initiatives to provide interoperability between the Train Control Systems across European borders.

Over the last two decades, a number of ERTMS-compliant systems have been developed by Signalling suppliers, and many of those systems have been deployed over significant portions of the European railway network, as well as in China and in the Middle East. Most ETCS-fitted railway lines are either High Speed Lines or Mainlines.

ETCS can be implemented in different levels with increasing reliance on a radio carrier to act as a train trackside communications link. For the purpose of this paper, we will be discussing ETCS Levels 2 (L2) and 3 (L3), which are in most cases implemented on top of a GSM-R radio network.

In parallel, the Mass Transit market has seen the evolution of a number of Train Control Systems known collectively as Communications Based Train Control (CBTC). Although the IEEE has issued a standard (IEEE 1474.1-2004) that provides generic performance and functional requirements, CBTC systems are still in essence a family of proprietary, non-interoperable technologies. However, almost the totality of these systems makes use of purpose-built IEEE 802.11 Wi-Fi networks to act as the communications link between trackside and on-board equipment.

CBTC systems have been deployed in Mass Transits systems all over the world, and are often manufactured by the same suppliers that also produce and market ETCS systems.

The next sections will discuss some of the latest trends that these two technologies are recently experiencing, and how the authors forecast that things are going to evolve, particularly for radio interfaces.

2. Current Situation

2.1. ETCS – CBTC Convergence

Starting from legacy conventional signalling systems based on Interlocking and Centralised Traffic Control systems, the development of ETCS and CBTC originally responded to different application concepts. ETCS was clearly oriented to Mainline and High Speed railways while CBTC was designed with mass transit networks in mind.

Mainline and High Speed applications are characterised by long distances between stations and complex rail networks interfacing with each other. The ERTMS specification is therefore designed to allow maximum running speed, timetable based operations and interoperability, which was achieved through extensive protocol standardisation.
On the other hand, the performance of a Mass Transit system is measured by line capacity. CBTC systems are designed to achieve optimum performance, enforcing train speed profiles, headways and dwell times in order to move the maximum number of passengers per hour.

Nowadays, there are a number of general trends bringing these two different approaches towards a point of convergence:

→ High Speed operators are demanding constant increases in line capacity, being their requirements closer to those theoretically defined for ETCS L3. It must be noted that, in many ways, ETCS L3 would be functionally equivalent to a CBTC system.

→ Mass Transit operators are increasingly demanding interoperability between CBTC systems in order to connect CBTC run railway networks and to increase the flexibility of their overall systems, as well as to avoid having to rely on a single provider.

→ Vendors are tending to standardise their products, implementing ETCS and CBTC applications over equal hardware platforms.

A clear example of the need for an integrated system is found in suburban, regional and freight systems, where some operators are choosing to change from one technology to the other. The optimal solution in those cases seems to be an ETCS L2 based CBTC, or a CBTC based ETCS L3.

These applications are starting to reveal that there is no real need for two competing in-cab signalling technologies, and that the ultimate optimum system including both CBTC and ETCS benefits and covering the full range of rail applications is a distinct possibility.

2.1.1. Functional convergence

One of the advantages of CBTC over ETCS L2 is the use of moving blocks to minimise train separation. This feature is already specified for future ETCS L3 applications, but it is not part of conventional ETCS L2 systems.

The second feature of CBTC that stands high over ETCS is the implementation of an Automatic Train Operation (ATO) mode. ATO is in high demand from railway operators in need to provide automatic traffic management and an optimisation in travel time and energy resources. ATO is a reality in current CBTC systems and, since it is a non safety-critical application, it would be feasible to implement it over ETCS. In fact, the Thameslink Programme in London (UK) is currently implementing an ATO application on top of an ETCS L2 system for the upgrade of the North-South high capacity section through Central London.

The following tables summarise a functional comparison between the two systems, for both on-board and wayside segments:

<table>
<thead>
<tr>
<th></th>
<th>CBTC</th>
<th>ETCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moving Block</td>
<td>Yes</td>
<td>L3</td>
</tr>
<tr>
<td>Traffic regulation</td>
<td>Yes</td>
<td>Not part of the system</td>
</tr>
<tr>
<td>Track circuits</td>
<td>Not needed</td>
<td>Only for L1 &amp; L2</td>
</tr>
<tr>
<td>Location References</td>
<td>Fixed (all kinds)</td>
<td>Switchable Eurobalises for L1 (LEI)</td>
</tr>
<tr>
<td>Train detection</td>
<td>Position report (track circuit L1 and L2 are secondary)</td>
<td>Position Report in L3</td>
</tr>
<tr>
<td>Radio protocol</td>
<td>Proprietary</td>
<td>Universal</td>
</tr>
<tr>
<td>Speed restrictions</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Maintenance system</td>
<td>Vendor specific</td>
<td>Vendor specific</td>
</tr>
</tbody>
</table>

Table 1: Comparison between ETCS and CBTC wayside functionalities

<table>
<thead>
<tr>
<th></th>
<th>CBTC</th>
<th>ETCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train integrity</td>
<td>Yes</td>
<td>Challenging</td>
</tr>
<tr>
<td>Track data</td>
<td>Onboard map</td>
<td>included in the movement authority Standardised</td>
</tr>
<tr>
<td>Train interface</td>
<td>Application specific</td>
<td>Application specific</td>
</tr>
<tr>
<td>ATP</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>ATO</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Geodetic system</td>
<td>Yes</td>
<td>Under development</td>
</tr>
<tr>
<td>Satellite positioning</td>
<td>No (tunnel)</td>
<td>Under development</td>
</tr>
<tr>
<td>DMI</td>
<td>Application specific</td>
<td>Standard</td>
</tr>
<tr>
<td>Antenna</td>
<td>any</td>
<td>BTM, Eurobalise reader</td>
</tr>
</tbody>
</table>

Table 2: Comparison between ETCS and CBTC on-board functionalities
A quick analysis of Tables 1 and 2 below shows that ETCS L2 and CBTC are, to a very large extent, functionally compatible with each other. Differences in implementation can be overcome by adapting CBTC proprietary applications to work on top of a standard ETCS L2 system.

2.1.2. Platform convergence
Architecturally, both systems are equivalent, and modelled in the following segments:
→ Operation Centre (HMI)
→ Wayside Interlocking
→ Authority Management (RBC / ZC)
→ On-board (ATP / ATO)

Historically, signalling systems supplier companies have developed ETCS and CTBC systems independently, not only because originally there were two different general design approaches, but also because they were aimed at two clearly differentiated markets.

Furthermore, these companies have been going through a series of merging and globalisation processes. At some point, these companies found themselves with more than one product in their portfolio with which to cover a given market need.

As a result, signalling suppliers are spending significant efforts in homogenizing their products by discarding, adapting or merging legacy hardware, creating in the process new versatile platforms suitable for more than one application.

Most signalling suppliers’ portfolios offer CBTC and ETCS as different systems. But the fact is that, in most cases, the only difference now between those systems is in the application software, which has been built through a different approach, and therefore presents differences in functionalities, implemented protocols and functional specifications. Hardware components, however, are in many cases identical for both systems, at least on the “signalling side” of the radio communications interface.

Another trend that points towards platform convergence is centralisation. Suppliers are trying to concentrate the system in a reduced number of hardware elements. While in-cab signalling systems were initially deployed in blocks, one per station, the use of enhanced computing, data storage and processing time has allowed for a significant reduction in trackside equipment, which is now capable of covering wider areas of the railway network.

And in parallel to this centralisation trend in topographical terms, advanced Train Control Systems are also starting to integrate vital wayside functionalities (interlocking, authority management and control interface) in a single platform. It is therefore clear that there is a distinctive trend towards the convergence of in cab signalling systems. But what is happening with the radio interfaces that are providing the train-to-shore communications these systems need?

2.2. Current Radio Interfaces
The two Train Control Systems mentioned in the previous section, in spite of all their commonalities, present, for historical reasons, two very different radio interfaces to “preferred” or “conventional” radio bearers. Additionally, a few ETCS L2 deployments have chosen a different radio technology, sacrificing interoperability in the process. Let us briefly examine these interfaces.

2.2.1. ETCS L2 over GSM-R
As mandated by European Directive 2008/57/EC, the ERTMS standards suite includes the definition of a specific radio technology to provide both interoperable voice services and a data carrier service to ETCS L2.

GSM-R (Global System for Mobile communications – Railway) was originally defined by the European Union-funded MORANE project. Currently, the International Railways Union (UIC) EIRENE Project maintains the EIRENE (European Integrated Railway Radio Enhanced Network) specifications in two documents:
→ EIRENE Functional RequirementsSpecifications (FRS)
→ EIRENE System Requirements Specification (SRS).

The latest official version published by the UIC for EIRENE FRS is 7.3.0. For EIRENE SRS, it is 15.3.1. The EIRENE specifications basically define a version of the ETSI 3GPP Technical Specifications for GSM mobile telephony technology with a number of Advanced Speech Call Items (ASCI) like Voice Group Calls, Railway Emergency Calls or Voice Broadcast Calls.

On the ETCS side, ERTMS/ETCS Class 1 Subset-093 Functional Interface Specification defines GSM-R as the standard radio carrier for ETCS L2 and L3. This means, amongst other things, that full ERTMS interoperability can only be achieved on an ETCS L2 system if it uses GSM-R as its radio carrier.

Subset-093 defines, in addition to EIRENE SRS and the UIC O-2475 Quality of Service test specification, a series of requirements that a GSM-R radio interface has to meet in order to be considered as a viable carrier for an ETCS L2 application.
As a result of all the standards mentioned above, and since interoperability has been considered a very desirable characteristic in most ETCS L2 deployments, all UNISIG suppliers have developed ETCS products based on GSM-R as the preferred radio carrier. Practically all ETCS L2 implementations in the world use GSM-R as a radio carrier, with very few exceptions.

2.2.2. ETCS L2 over GPRS
At the time when the original ERTMS specifications were issued, packet-switched data radios were not considered mature enough to carry safety-critical information. Therefore, all the original ERTMS standards mandate circuit-switched data connections, and all the requirements in Subset-093 have been defined with a circuit-switched data connection in mind.

However, as ETCS L2 roll-out has progressed, it has become evident that a circuit-switched data format has a number of limitations.

In the first place, circuit-switched data makes a relatively inefficient use of the radio spectrum. When an ETCS On-board Unit establishes a connection to the Radio Block Centre (RBC) over a GSM-R circuit-switched link, the on-board data radio reserves a full Traffic Channel out of the eight time slots per carrier that are available in each GSM-R cell.

That means that, in order to transmit a few hundreds of bytes every 3 to 10 seconds (the actual figures depend on the specific implementation), ETCS is making full use of 1/8 (577μs every 4.616ms) of a 270 kHz channel that would otherwise be capable of transmitting up to a rate of 9.6 kb/s. The spectral efficiency, therefore, is in the order of 1%. Because of this, many national spectrum administrators are currently asking the railways to make a better use of the valuable resource they have been allocated.

At the same time, as ETCS L2 deployments approach large urban areas, the GSM-R networks are beginning to experience congestion problems. Since the same frequencies and their adjacent frequencies cannot be reused on a given base station or in its collateral base stations to avoid co-channel and adjacent channel interference, the maximum number of carriers per base stations is limited. This problem is exacerbated in Europe by the narrowness of the 900 MHz GSM-R band, with only 4 MHz (or 19 channels) of total available bandwidth – even though some regions have managed to secure an additional 3 MHz extension to that bandwidth, this extension has not been granted in every European state.

The UIC, together with UNISIG and the ERTMS Users Group, has been developing an Annex to Subset-093 to provide a packet-switched radio interface to ETCS L2 applications. In keeping with the philosophy of ERTMS specifications, the packet-switched radio carrier that is specified in all the drafts of that Annex is GPRS over GSM-R.

ETCS over GPRS offers a number of advantages that go beyond the initial objective of solving the issues with spectral efficiency and frequency congestion. A packet-switched interface will allow a single ETCS data on-board radio to send IP packets to two different RBCs, thus reducing the complexity of RBC to RBC handovers. But more importantly, a packet-switched interface places the ETCS L2 application in the right place to transition to future 4G radio technology, as we will see later on.

ETCS over GPRS is expected to see its first commercial application in Denmark from 2014 onwards. This first deployment will represent the final proof of the viability of the packet-switched ETCS concept.

2.2.3. CBTC over Wi-Fi
Mass Transit CBTC systems have a completely different historical background from ETCS, and that explains the different approach to choosing a radio carrier.

The closest thing to a CBTC standard is IEEE 1474.1 – 2004: CBTC Performance and Functional Requirements (latest version). This IEEE standard, however, is very lax in its requirements, and the CBTC systems that different signalling suppliers have developed are all effectively proprietary systems. No degree of interoperability is guaranteed by the standard, and the few instances where interoperability between different CBTC suppliers has been a requirement from the Operator, it has proved a very challenging subject.

In spite of this lack of standardisation, most CBTC implementations in the world use the same wayside-to-train communications technology: Wi-Fi radio networks based on the IEEE 802.11 standard family.

There are differences, however, in the way this radio technology is used. Depending on the implementation, Wi-Fi can be used exclusively to support CBTC services, or to support multimedia services at the same time. The frequencies that these Wi-Fi networks are using also vary between implementations.

The reason Wi-Fi has become so pervasive in the
CBTC environment is probably a historical one. Most CBTC systems have originally been developed for Mass Transit lines that are mainly underground. In the controlled (from an RF emissions perspective) environment of an underground railway, Wi-Fi represents an excellent option in terms of cost, simplicity, availability of off-the-shelf equipment and familiarity. Some of the obvious drawbacks of using a Wi-Fi radio network – some of which we will discuss further in the following sections – have less impact in underground areas.

Wi-Fi co-channel interference in mass transit tunnels and underground stations can be kept under check by controlling what Wi-Fi networks are deployed in the underground environment, and the small range of Wi-Fi access points is not so crucial in a tunnel that would anyway need leaky feeders and/or frequent repeaters for other technologies. In many cases, the savings introduced by Wi-Fi’s low cost more than make up for the increase in the number of base stations needed to provide coverage to an underground railway.

3. Drivers for change

3.1. Limitations of GSM-R/GPRS

3.1.1. Limited bandwidth

The number of applications in the railway environment that could benefit from having a reliable radio data carrier service keeps growing and growing. From train diagnostics, to remote condition monitoring, on-board customer information displays, public announcements, passenger help points connected to centralised helpdesks... The list grows endlessly.

Many of these applications are actually not very demanding in terms of bandwidth. Diagnostics and remote condition monitoring typically send even less data throughput than modern Train Control Systems, and with less demanding delay requirements. GSM-R and GPRS are perfectly suited to cater for these applications.

However, as ubiquitous data transmission becomes more and more pervasive in our society, there is an ever increasing pressure for railway Infrastructure Managers to provide a number of high bandwidth applications. The most obvious example is the transmission of real time streaming video for both on-board security CCTV and Driver Assisted Video Systems (DAVS) for Driver Only Operation (DOO).

GSM-R, even if augmented with packet switching GPRS or EDGE modules, does not provide a data rate that can support real time video streaming. While GSM-R can reach, on circuit-switched data connections, a maximum of 9.6 kb/s per carrier timeslot, this figure can be expanded by EDGE/GPRS to a theoretical maximum of 61.85 kb/s per timeslot, using an 8PSK modulation instead of a conventional GMSK. However, neither of these figures can match by any stretch of imagination the requirements of high-quality video streams that run well into the several hundreds of kb/s, depending on factors like image definition and video compression. In fact, even certain ATO applications could prove too demanding for this radio technology, with data rates over 100 kb/s.

3.1.2. Limited Longevity

GSM-R technology is, by now, a well proven technology in the railway environment. EIRENE specifications were first issued in 2000, and the first GSM-R implementations started at about the same time. Some GSM-R networks in Europe have been operational for over a decade.

In railway terms, this doesn’t seem like a long time. Railway investment cycles are measured in decades, and human generations sometimes pass without seeing major changes to railway systems. 19th century mechanical interlockings are still a common sight in many parts of the world, for instance.

However, for the telecommunications sector, a decade is a very long time. GSM-R was originally based on the ETSI 3GPP GSM Technical Specifications that triggered the 2G mobile telephony revolution in the 1990s. Since then, and in spite of the 2000 Dotcom Crisis, mobile carrier technology has not only moved on onto GSM’s 3G successors – UMTS and CDMA2000 – but it is clearly leaving them behind, with 4G technology in operational use since 2009.

We also need to understand that, for obvious economical reasons, the railway communications market is a relatively small pie of the telecommunications market. Mobile telephony equipment manufacturers (Ericsson, Huawei, Alcatel-Lucent, Nokia Solutions and Networks, ZTE, Kapsch, etc...) are more interested in selling tens of thousands of new LTE eNodeBs to public mobile network carriers than in maintaining a small niche market of a few hundred GSM-R base stations to provide continuity to the railway market.

The GSM-R Industry Group has made a public commitment to support GSM-R at least until 2025 (1), and that commitment has been extended to 2028 during the UIC GSM-R Conference in Paris last September. But there is still a level of uncertainty about what will happen after those dates. The UIC is currently conducting a study to identify a suitable candidate to be the successor technology for GSM-R (2), with a very clear front-runner: LTE.
3.2. Limitations of Wi-Fi
We have briefly mentioned above some of the limitations experienced by IEEE 802.11 solutions when used for safety-critical communications. This section brings a closer look.

3.2.1. Limited range
Wi-Fi technology was initially developed in order to set up wireless Local Area Networks (WLAN). Because of that, and due to the fact that most of the protocols of the IEEE 802.11 set normally use frequencies in the unlicensed bands of the radio spectrum, transmission powers are not very high, and the maximum range of a conventional Wi-Fi access point is in the order of 250 m, and even that figure is only achieved through MIMO antenna configurations and OFDM modulation in IEEE 802.11n (3).

The only 802.11 standard to go beyond this range, IEEE 802.11y-2008, does so by leaving the unlicensed band and going into the 3.65 to 3.7 GHz band, that currently is only available for that purpose in the US, allowing up to 20 W EIRP and a theoretical maximum range of 5,000 m (4).

This limited range has not proven a major problem in mass transit systems that are mostly underground. The reason is that, due to the physical structure of a tunnel, limited radio propagation is a reality in such a system for any wireless technology. The number of base stations will necessarily increase in such an environment, since it is impossible to cover kilometres of track from an antenna located in a high tower or mast. In this scenario, the lower cost of commercially off-the-shelf Wi-Fi access points makes it a very attractive solution for tunnel coverage.

In overground areas, however, the balance may start to turn against Wi-Fi. When a single base station can generate a cell with a radius measured in kilometres, and once outdoor housing, power supply and transmission equipment are taken into account, economic factors may start to favour other technologies.

3.2.2. Lack of QoS
As we mentioned above, Wi-Fi technology comes from a purely IT TCP/IP background, and its design concept is based on a straightforward “Best Effort” service approach. As such, conventional Wi-Fi does not provide native Quality of Service (QoS) differentiation at lower OSI protocol stack layers.

Some newer IEEE 802.11 standards (5) have added a number of QoS enhancements to the Layer 2 Media Access Control (MAC) protocol. However, these enhancements still do not stop Wi-Fi from using a contention access mechanism. Since all users are competing for the air interface on a random interruption basis, there is no way to guarantee that a given mobile station will be given access with a higher priority than other users.

As a consequence of this lack of native QoS policies, Wi-Fi networks cannot guarantee bandwidth or latency for safety-critical services.

3.2.3. Interference
As we mentioned before, and in most cases, Wi-Fi technology makes use of a series of unlicensed spectrum bands. That is part of its attraction. Deploying solutions based on IEEE 802.11 standards does not entail having to negotiate with ACMA, the FCC or any other national spectrum administrations to obtain expensive spectrum licenses.

However, using an unlicensed band has an immediate drawback: if a railway can use it for free, so does everybody else. What is more; a third party could be transmitting on exactly the same channel as the railway’s safety critical Wi-Fi radio, in a location physically adjacent to railway property. This would potentially cause constant problems with radio interference. But as long as that party’s transmitter does not emit over the maximum power threshold as dictated by the IEEE 802.11 standard – the same power threshold imposed on the railway Wi-Fi network itself - there is not much the railway can do from a legal point of view to stop the interfering party from transmitting.

In other words, the IEEE 802.11 air interface is inherently unreliable for railways safety-critical systems because a railway has no control whatsoever over inter-system interference in a class licensed band. As a consequence, the availability of a Wi-Fi network can not be guaranteed.

3.2.4. Mobility
The IEEE 802.11 standard was initially designed for domestic or office environments; hence, it does not have very good mobility characteristics. Handover between Access Points is a particularly complex factor, and can only be solved effectively at medium speeds by having more than one radio connected to two different Access Points. This solution, however, still does not respond well to high speeds, since the amount of time needed to process this kind of handover is usually quite high.

Additionally, Wi-Fi’s treatment of the Doppler Effect is not very good either. The frequency shift introduced by speeds beyond a few km/h...
is already enough to significantly increase the Bit Error Rate of a Wi-Fi connection (6).

4. Train identification: LTE as a train control carrier

4.1. LTE Overview

As mentioned before, the UIC has already identified one radio technology as the clear front runner to become the successor of GSM-R as the primary railway mobile communications technology.

LTE stands for Long Term Evolution, and it is a standard for high-speed, high-bandwidth radio communications. The LTE standard is owned and developed by 3GPP (3rd Generation Partnership Project), which is a standard development group whose mandate comes from the ITU–R (International Telecommunications Union – Radiocommunications) and that is based at the ETSI (European Telecommunications Standards Institute).

LTE was developed from previous generations of mobile telephony, like UMTS and GSM/EDGE, and it has been designed to eventually replace those technologies while allowing for a phased transition – hence the use of the term “Evolution”.

LTE commercial deployment started in 2009, and it is currently being deployed by public mobile operators all over the world. Private LTE networks, sometimes of a smaller scale than the full-blown carrier networks, are also starting to appear in certain sectors, like mining and emergency services.

4.1.1. LTE building blocks

LTE networks can be split into two main subsystems (7):

⇒ A network of distributed radio stations; in LTE jargon, this subsystem is called Evolved UMTS Terrestrial Radio Access Network, or E-UTRAN.

⇒ A network core that controls all higher level interactions within the network. The core is often referred to as Evolved Packet Core (EPC).

Figure 2 below shows a diagram of the functional architecture of these two LTE subsystems.

![Figure 2: LTE Architecture](image)

The E-UTRAN is composed of a number of radio stations called eNodeBs that handle the physical and link layers of the protocol stack, managing radio resources and controlling transmitting devices.

As shown in Figure 1, all eNodeBs are directly connected to the Evolved Packet Core – there is no equivalent to GSM-R Base Station Controllers. Figure 4 shows the different elements contained in the EPC. The EPC consists of a number of functional blocks that handle mobility management, authentication and policy charging, as well as connectivity with legacy networks and external networks. These functional blocks do not necessarily correspond with physical hardware; they are exclusively software based, and this feature allows for a greater degree of scalability and virtualisation than it was possible with previous 3GPP technologies.

The first functional block after the S1 interface router is the Mobility Management Entity (MME), which handles authentication (via the HSS), ciphering/integrity protection for network signalling, idle mode User Equipment (UE) tracking, paging, retransmissions and mobility to and from 2G/3G radio access networks.

Logically adjacent to the MME is the Serving Gateway (SGW). Its function is to route data packets as well as to manage inter-eNodeB cell re-selections and handovers. It also manages LTE/GSM/UMTS mobility.

The Packet Data Network Gateway (PGW) provides connectivity to and from external data networks.

The Home Subscriber Server (HSS) is a database that contains the information of all registered UEs. It is consulted by the MME to authenticate UEs requesting connection.

The Policy Charging and Rules Function (PCRF) controls the billing function and the rules governing
the Quality of Service parameters experienced by each UE. The connectivity between all these elements is generally based on MPLS over IP services. None of the interfaces is based over an E1 link, as was the case with previous 3GPP technologies. Security is based on 128 bits Advanced Encryption Standard (AES) for the air interface, as well as SIM card (IMEI) identification via MME and HSS. Optionally, the MPLS transmission network can implement IPSec protocol to further augment security.

4.1.2. LTE radio interface – OFDMA and SC-FDMA

The LTE radio interface is based on an Orthogonal Frequency-Division Multiple Access (OFDM) modulation for the downlink that provides up to 300 Mb/s, and in Single Carrier Frequency-Division Multiple Access (SC-FDMA) in the uplink with a maximum rate of 75 Mb/s (7).

These modulation schemes can be used in either Frequency Division Duplexing (FDD), with uplink and downlink frequencies separated by a frequency offset, or Time Division Duplexing (TDD), where downlink and uplink transmission share frequencies at different moments in time. Figure 3 below presents a quick visual comparison between OFDM and SC-FDMA. One feature that makes LTE very different from its predecessors is a very high degree of flexibility in frequency and bandwidth allocation. LTE can be deployed in a number of frequency bands that include 700, 800, 1400, 1600, 1700, 1800, 1900, 2100, 2300, 2500 and 3400 to 3800 MHz, all dependent on regional frequency band allocation, while available channel bandwidths vary between 1.4, 3, 5, 10, 15 and 20 MHz (8).

Figure 4 below zooms into OFDMA and shows how a number of orthogonal subcarrier signals are allocated to different users in a spread spectrum configuration that minimises multipath and narrow-band interference, while maximising frequency reuse and spectral efficiency.

Figure 3 below presents an illustrative diagram of how the concept works. OFDMA divides the bandwidth allocated to each device into subcarriers that are 15 kHz apart and into 0.5 ms time slots. Each time slot contains 7 OFDM symbols. LTE combines 12 subcarriers into one Resource Block.

Therefore, each Resource Block is composed of 84 (12 x 7) OFDM symbols, and takes up 180 kHz (12 x 15kHz) and one 0.5 ms time slot. Every eNodeB, however, needs 4-6 Resource Blocks for network overhead. Hence why the minimum bandwidth that can be allocated to an eNodeB is 1.08 MHz (6 RBs), and the maximum bandwidth is 19.8 MHz (110 RBs).

4.2. LTE vs. GSM-R / GPRS / Wi-Fi / TETRA

So how does LTE compare against current Train Control radio bearers, and against the limitations we identified in the previous sections?

4.2.1. LTE versus GSM-R / GPRS

While GSM-R and GPRS/EDGE would correspond, in terms of 3GPP standards, to the second generation (2G) of mobile telephony standards developed in the mid 1990s, LTE is their late 2000s fourth generation (4G) successor technology. Therefore, in terms of
longevity, it is obvious that LTE will still be around years after the last GSM-R base station is decommissioned.

Not only that; as we will see in a later section, the LTE Evolved Packet Core has been designed to be able to integrate existing GSM Radio Access Network components. LTE’s ability to “cannibalise” an existing GSM-R network by replacing its core will make the transition from existing GSM-R networks relatively straightforward, since the network Core can be effectively be replaced, while maintaining parts of the existing Radio Access Network – GSM-R’s Base Station Subsystem – as long as it is desirable.

As for bandwidth limitations of GSM-R/GPRS, bandwidth is what LTE is all about. Although peak transmission rates are difficult to compare due to the way different technologies allocate bandwidth, a quick comparison of order of magnitude can be seen on Table 2 below:

<table>
<thead>
<tr>
<th>Peak Rates</th>
<th>GSM-R</th>
<th>GPRS</th>
<th>EDGE</th>
<th>LTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>UL</td>
<td>9.6 kb/s</td>
<td>40 kb/s</td>
<td>500 kb/s</td>
<td>75 Mb/s</td>
</tr>
<tr>
<td>DL</td>
<td>9.6 kb/s</td>
<td>60 kb/s</td>
<td>1.6 Mb/s</td>
<td>300 Mb/s</td>
</tr>
</tbody>
</table>

Table 3: Peak Bit Rates Comparison

In summary, and given that LTE has been developed precisely to be the 3GPP 4G successor technology to GSM-R, GPRS and EDGE, it shouldn’t come as a surprise that LTE covers the shortcomings that these technologies are currently experiencing.

4.2.2. LTE versus Wi-Fi
The IEEE’s original technology roadmap included an evolutionary path for Wi-Fi technology to be expanded beyond its original design limitations through the IEEE 802.16 standard family, commercially known as WiMAX.

WiMAX was designed to overcome the shortcomings of Wi-Fi in terms of range, mobility (mobile WiMAX) (9) and use of licensed spectrum. However, WiMAX has been losing the race against competing 3GPP standards, mainly because LTE provides a better transition path forward for mobile telephony carriers from their existing 2G/3G platforms (10).

So how does the apparent winner of the 4G race fare against Wi-Fi? In terms of range, the LTE E-UTRAN radio access network has been designed to provide coverage to a mobile operator. Although effective cell range is dependent on the frequency band in which LTE is deployed, cells radii are in any case measured in kilometres, rather than in hundreds of metres.

Mobility is another major win for LTE, since, once more, LTE has been developed from day one with mobility in mind. In particular, cell-reselection/handover does not need a mobile terminal to de-register from one Access Point and register into another, and can in fact be enhanced with additional LTE features for “seamless handover” where handover time would be measured in the order of tens of milliseconds (11).

As for QoS, LTE does not have an open contention mechanism to allocate radio resources, allowing for different user profiles to be dynamically assigned different radio resources (12). Lastly, LTE uses licensed spectrum bands, which minimises some of the potential interference problems that are so prevalent in Wi-Fi.

4.3. LTE for Railways
GSM-R supporters sometimes claim that LTE technology is not optimised for rail systems, and especially that LTE does not provide the same native voice capabilities offered by GSM-R.

3GPP, however, is both developing the standards to provide Voice over LTE as an eventual replacement for the current 3G Circuit Switched voice service. Voice over IP applications making use of LTE’s IP Multimedia Subsystem (IMS) platform are currently available.

What is even more interesting for the railways is that 3GPP plans to include Push-To-Talk and voice group functionalities in the standard LTE specification, making any sort of “LTE-R” development unnecessary, and further simplifying a future transition of LTE as a voice operational carrier in a railway environment. The specification will include additional features such as group calling, direct call, priority assignment or mobility support. These features conform, in essence, the same differences between GSM-R and conventional GSM.

Additionally, LTE could provide significant improvements in capacity that could be the basis of a new paradigm in future Train Control Systems, and allow further innovations in safety, operation, passenger services and security.

These innovations could include the application of train to train communications to increase radio coverage and availability, bringing safety to its theoretical limits and reducing headways in operations.

The return of investment in LTE technology could be further improved by the use of modern passenger services, train CCTV remote supervision, real time on-board status and energy monitoring for maintenance and operation efficiency.
4.4. LTE Upgrade

The main goal of 3GPP when LTE (Long Term Evolution) was developed was to provide a way forward into 4G technology from existing 3G packet switching infrastructure. Because of this, LTE Evolved Packet Cores have relatively straightforward interfaces with 3G Packet Switching cores, based on sharing a common IP networking layer and on the IP Multimedia System (IMS) architectural framework. Figure 5 below gives a schematic view of how an existing 3G network could be interconnected with a new LTE EPC.

Effectively, this means that 3G and 4G technology can coexist and integrate seamlessly at the core level, while two separate Radio Access Networks are deployed in the field, with the new LTE E-UTRAN overlapping a previously existing 3G UTRAN.

In this fashion, new services using LTE’s bandwidth and data transmission rates can be deployed while older services (like 3G voice) are left undisturbed.

As for Wi-Fi integration, note that Figure 6 above shows how Wi-Fi Access Points can be directly connected to the EPC’s Packet Data Network Gateway by virtue of sharing a common IP Network Layer.

So what would be the migration path from an existing GSM-R network? As long as that GSM-R network has packet switching capabilities through a Gateway GPRS Support Node (GGSN) and a Serving GPRS Support Node (SGSN), that is, as long as a GSM-R network is GPRS-enabled, the GGSN and SGSN can interface the LTE EPC just like a 3G network in Figure 4.

4.5. Future LTE Trends

Future LTE trends include virtualisation and miniaturisation. In fact, several suppliers are already offering commercial solutions that can be implemented in an individual hardware platform – that is, all the functions of the EPC – often excluding the HSS – implemented via software over a single blade. Several suppliers are also already offering “mini-cores” and “micro-cores”, platforms capable of supporting a limited number of eNodeBs for a fraction of the cost of a full-blown EPC.

The 3GPP group is also working on the integration of safety-critical voice communications over LTE. The plans include LTE cores integrating legacy radio systems like P25, TETRA and even analogue radio. At the same time, a Voice over LTE specification is being prepared; Push To Talk operation and some of GSM-R’s safety communications features will be integrated into the standard.

Conclusion

This White Paper has highlighted how and why two of the most widespread modern In Cab Signalling technologies – ERTMS and CBTC – are seeing their hardware platforms converging to the point that the only real difference between them is the software resident at the application level, and even those are becoming functionally identical.

Curiously enough, the one element of both systems that doesn’t seem to be converging on its own volition is the data radio bearer. ERTMS systems still mostly use GSM-R and CBTC systems use Wi-Fi, but they are both facing a number of challenges that could be solved by transitioning to LTE.

Interestingly enough, a convergence on the radio bearer would also represent the final piece in the puzzle. If CBTC and ERTMS moved to LTE, one could finally claim that both technologies are becoming part of a single family of largely equivalent In Cab Signalling Solutions that combines the benefits of both approaches.

However, we have to be realistic. The railway industry is slow in adopting new technology, and there is a worldwide concern in protecting past investments. Who will bite the bullet and blaze the trail that leads to the full integration of ERTMS and CBTC?
Mr Rodrigo Álvarez
Rodrigo has been involved in railway communications in the UK and Europe for over eight years. His comprehensive experience extends to railway radio telecommunications deployment projects, the integration of advanced railway signalling systems and telecommunications technologies and the design and implementation of railway fixed communications networks. He is one of a small number of Engineers based in Australia with experience in the design of GSM-R and ERTMS systems, as well as SDH and Carrier Ethernet networks and the telecoms element of axle counters, Computer Based Interlocking, SIS and DOO systems. Past projects include Network Rail’s Cambrian ERTMS Deployment and Crossrail Programme in London, as well as GSM-R deployment in ADIF’s High Speed Network (Spain). He has also worked on railway research and development projects for the European Commission.

Mr Juan Román
Juan holds over ten years experience in Train Control Systems for high speed, mass transit and heavy haul railways; working across the whole lifecycle of signalling projects, from concept design, specification, design, implementation, integration, testing, safety and commissioning. Following the beginning of his career as a signalling maintenance manager in Metro de Madrid, Juan has attained deep understanding of railway technologies through an extensive involvement in engineering activities for CBTC, ETCS L1 and L2 projects all over the world, including Spain, France, Italy, China, Russia, Turkey and recently Australia, where Juan has been exploring the needs and state-of-the-art solutions for freight systems.

References

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