INTRODUCTION

“Overcoming increasing traffic, ensuring passengers’ safety and security during their journey, improving travel comfort, providing real time multimedia information and access to social networks in stations or in motion”: here are some of the key challenges that train/metro operators are facing today.

To meet all those requirements, train operators need to put in place broadband telecommunication networks, using a variety of technologies whether fixed or wireless. Heterogeneity of these networks is becoming a real headache for train operators and infrastructure managers: WI-FI, GSM-R, Satellite, 3G / 4G networks. What are the characteristics, limitations and evolutions of these technologies?

In the last decade, commercial wireless technologies have been evolving from voice centric 2G systems (e.g. GSM) with limited data transmission capabilities to 4G broadband multiservice systems (LTE) that offer several 10s of Mbit/s to the end-users. And, the broadband capability of 4G is actually fostering the creation of new services and applications for mass consumers to improve the way they communicate, keep informed and be entertained.

The railways industry has also been using wireless systems for operational applications for many years. Indeed, many mainline railway operators have deployed GSM-R networks both for operational voice communications between train drivers / train controllers and also to carry train signaling (ETCS level 2).

Urban transport authorities have also deployed various specialized, and often proprietary, wireless systems: there is usually a system for signalling and control in unlicensed bands and another system for operational voice.

But these systems are limited in their data capabilities. This therefore significantly limits the possibility to enhance the operational efficiency, the passenger security and ultimately the quality of transport.

The proposed paper addresses how the innovative commercial wireless technologies can enhance the quality and reliability of railway transport in the near future.

1. Alongside this paper we will tackle different aspects related to wireless technologies for railways and metro:
   - New application demands and expected benefits
   - Comparisons of different technologies
   - Introduce LTE technology: the 4th Generation of wireless networks enabling high bandwidth connectivity

GROUND-TO-TRAIN COMMUNICATION: WHAT’S AT STAKE FOR RAIL?

In a context of deregulation, Telecommunications is becoming a key component in the strategy of railway operators and infrastructure managers, since it has been realized that it can bring significant cost savings and a better operational efficiency, in particular in the 3 following domains (figure 1)

- Operation of the transportation system
- Safety and security
- Passenger experience

Telecommunications also contribute to the brand image of transport operators and in some cases even add to revenue (Utilities telecom business model).
Figure 1: Communication as the backbone for converged rail operations

Both fixed and mobile communication networks are part of these missions. A secured, robust, reliable and converged telecommunications network is therefore essential to support different information exchanges, whether man-to-man, man-to-machine or machine-to-machine. This helps transport operators to fulfill their mission while keeping the highest level of global security and increasing passenger satisfaction (through outstanding punctuality and more services).

Rail operators are not only going to compete against each other but also with other means of transportation, such as planes or cars, and in this context offering more comfort and entertainment to passengers is not an option. Amongst the different applications (or « services ») to be carried by the telecom network, one can distinguish two main families with very different constraints and specifications:

Vital Applications related to signalling and control/command of equipment. Such applications require generally a low bandwidth (some 10 to 100 kbps) but a very high degree of availability (at least 99.99%), robustness and liability (typically a packet error rate of $10^{-3}$ for an approximately 200 byte packet length). Such performance indicators have equally to be fulfilled under high speed mobility (handover timing when a mobile terminal must change its connexion from one fixed base station to another). These vital applications are typically CBTC (Communication Based Train Control) in case of metros or ETCS (European Train Control System) in case of mainline trains.

Non-vital applications related to Passenger Information, remote maintenance, on-board video surveillance, CCTV for track or platform monitoring, internet access, etc. Such non-vital applications generally require much higher bandwidth (several 10s of Mbits/s in both direction train-to-ground and ground-to-train), together with lesser robustness constraints (a packet error rate of $10^{-2}$ for an approximately 1Mbyte packet length).

3 EXISTING TRAIN-TO-GROUND COMMUNICATION SOLUTIONS

A moving vehicle cannot obviously be connected to ground based infrastructure by any other mean than radio communication. Such radio systems have long been based on analogue technology, dedicated to voice and not adapted to carry data. Then digital technology became available in the market, with various bandwidth capabilities and distance ranges, supplied to different standards or even totally proprietary protocols.

Rail operators have implemented such technologies alongside their track and inside their vehicles, but without necessarily being interoperable, or with specific adaptation to match vital application requirements.
Consequently, related CAPEX and OPEX (with high maintenance costs and rapid obsolescence) are desperately increasing, whilst non optimized use of scarce radio spectrum is being seen, particularly in urban areas...

It is quite common to see operators deploying several radios with different purposes in the same rail network and geographical area: ETSI TETRA / 3RP, IEEE 802.11a/n WiFi, ERTMS GSM-R

3.1 TETRA, 3RP technologies:
In Urban areas, train-to-ground communications have initially relied on UHF (Ultra High Frequency) in the 420-470 MHz band.

Professional Mobile Radio (PMR, also known as Private Mobile Radio) and TETRA have had a considerable expansion and success, particularly in Europe, thanks to the development of train-to-ground radio equipment in the 450 MHz band. Initially they were used mainly for voice communication with controllers or shunting function. Then came the development of data communication dedicated to remote control and maintenance of vehicles, and it was natural to connect devices through these radios. However two major limitations hamper this type of technology:

- Very limited bandwidth
- UHF spectrum is now overloaded and the trend is to go in the upper frequency band in order to increase the number of available communication channels.

Similar Land Mobile Radio system (P25) has been developed in North America by the APCO association and is mainly targeting the Public safety application in the 700 MHz band.

3.2 WiFi and CBTC DCS technologies

WiFi technology offers high performance and some advantages:

- A very large bandwidth (typically 10/20 Mbps uplink and downlink)
- Low packet loss rate (depending on data rate, link budget, OFDM Modulation)
- Fast roaming (hard/soft, background scan, active scan)
- Operating mode: non-line of sight
- Light core network infrastructure

However, it also has some disadvantages:

- Range limitation: radio coverage from 250m to 450m due to limited authorized power emission and problems associated with Dynamic Frequency Selection (DFS) mode (Radar protection)
- Unlicensed band: 2.4GHz and 5.xGHz show some drawbacks, in particular the possibility of jamming or interference that may be coming from other users of this technology
- Non standard roaming solution: every vendor develop its own non interoperating hand-over flavour.

DCS radio systems, used by CBTC (metro signalling systems) use proprietary adaptation of WiFi standards that considerably reduces bandwidth in order to increase radio link robustness and jamming/interferences risks.

3.3 GSM-R

Finalized in 2000, based on the European Union-funded MORANE (Mobile Radio for Railways Networks in Europe) project, GSM-R is derived from GSM (2G+) technology and part of the new European Rail Traffic Management System (ERTMS) standard. It carries both signalling information (in case of ETCS L2) and voice communication.

Based on GSM, this technology offers:

- Low bandwidth (TDM based, with GPRS packet base expected in the near future)
- Fast handover (specified up to 500 km/h)
- Operating in Frequency band of 2x4Mhz (one uplink and one downlink) in 800/900 MHz band
- Imbedded voice rail specific features (at application level) such as group, broadcast or emergency calls
• Typical range of 7-15 km between 2 base stations

Due to its very specific nature and market only a very few number of equipment manufacturers offer this product.

3.4 Wireless technology comparison

The selection of an optimal wireless communication system for railways and metros need to consider many performance parameters and service attributes such as voice support, vital traffic, priority, availability, frequency band, commercial maturity. Figure 2 compares these different technologies in term of performance and industrial support.

<table>
<thead>
<tr>
<th>Technology comparison</th>
<th>GSM-R</th>
<th>TETRA</th>
<th>P25</th>
<th>WiFi</th>
<th>LTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational voice support</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>VoIP</td>
<td>VoIP</td>
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<tr>
<td>Broadband data support</td>
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<td>&lt; 10kb/s</td>
<td>&lt; 100kb/s</td>
<td>&gt; 10Mb/s</td>
<td>&gt; 10Mb/s</td>
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<tr>
<td>All IP (native)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Vital traffic support</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P21 call set up time</td>
<td>1 to 5 s</td>
<td>250ms</td>
<td>800ms</td>
<td>100ms</td>
<td>100ms</td>
</tr>
<tr>
<td>Priorities / pre-emption</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>3 levels / no</td>
<td>9 levels / yes</td>
</tr>
<tr>
<td>Choice for operating frequency</td>
<td>900MHz UIC</td>
<td>400MHz PMR</td>
<td>700MHz + VHF</td>
<td>2.4 / 5 x GHz</td>
<td>400MHz to 3.5GHz</td>
</tr>
<tr>
<td>Market support (vendors)</td>
<td>3 vendors</td>
<td>+</td>
<td>limited (US specific)</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Maturity</td>
<td>End of Life 2025</td>
<td>Mature</td>
<td>Mature</td>
<td>Widely adopted</td>
<td>Emerging</td>
</tr>
</tbody>
</table>

Figure 2: Wireless technology comparison

4 NEEDS FOR A NEW GENERATION OF TRAIN TO GROUND COMMUNICATION

To reach the necessary safety level Metro line automation projects (driverless metros) demand on-board real time video surveillance to monitor and assess any critical or abnormal situation inside the coaches, alongside the track or platforms.

Non vital applications contributing to a better passenger comfort and journey experience such as on board Internet access (passengers are likely not to accept loosing connection any longer in the coming years), but also video on demand or other entertainment, will probably soon be must-have application in order to attract or retain customers, as well as contributing to a high level of transport companies brand images. Trains (and more specifically high speed trains) are more and more considered as a mobile office by many passengers. A survey for the Swedish national operator found that the train journey is widely considered as an integral part of the working day. At the same time, higher comfort is also a key reason for the shift of passengers from airlines to high speed trains. To keep up with this trend and maintain competition with air travel, mainline railways operators need to enhance passenger experience with high-speed Internet access based services across the complete journey (from hospitality rooms in stations to on-board the train), both for professionals to extend their mobile office to the train and also to other passengers for infotainment.

On board and real time information is also becoming mandatory to train operators: recent delay incidents on some European High Speed lines can testify of passenger dissatisfaction of being stuck for hours without being informed of the situation.

Technology obsolescence – particularly in the telecommunications domain – is coming fast and often not in line with rail system lifecycle. GSM-R systems are still under deployment today, with the maturity of deployment varying according to countries and networks. However GSM-R end of life is already a concern for infrastructure managers even though industry has committed to maintain the systems until 2025: the very limited number of GSM-R manufacturers and GSM based technology obsolescence are seen a threat by Railway Infrastructure owners.

Preventive maintenance is a more and more common tool used by railways operator to significantly enhance their operational efficiency. By permanently and remotely monitoring the status of key elements of the rolling stock, maintenance actions can be planned in advance upon detection of warning information before the fault becomes an actual problem. Today, the remote monitoring is usually performed using commercial low speed 2G technologies. Such services are driving the huge increase in bandwidth requirement, and consequently a new
generation of train-to-ground transmission will soon have to address these needs, while following telecom industry standards with minimum (or no) rail specific adaption in order to avoid costly solution and rapid obsolescence.

**LTE seems to be the ideal candidate** for this next generation of communication that would be able to support such new services, as well as vital applications at the same time.

5  **LTE ARCHITECTURE**

LTE is composed of a core network: Evolved Packet Core (EPC) and an access radio network UMTS Terrestrial Radio Access Network (E-UTRAN).

EPC is a native « all IP » based and multi-access network that enables the deployment and operation of a common network for every kind of 3GPP access network (2G, 3G and LTE), and even non 3GPP (WLAN).

E-UTRAN LTE is connected to the EPC core network in packet mode.

Protocols and user plans have been designed in order to support high bandwidth applications together with real-time constraints, Quality of Service (QOS) and high availability.

The main components of LTE architecture are therefore (Figure 3):

- E-UTRAN composed of eNodeB (LTE base stations)
- EPC is composed of :
  - service gateway (SGW)
  - Packet Gateway (PGW)
  - Mobility manager (MME)
  - Policy and Charging Rules Function (PCRF)
  - Home Subscriber Server (HSS)
  - IP Multimedia Subsystem (IMS)

![LTE Architecture](image)

6  **LTE : Long Term Evolution**

LTE (Long Term Evolution) is the 4G wireless technology standardized in 2008 by the 3GPP. The main benefits of this technology are:

- LTE is the 4G convergence standard worldwide,
- LTE provides state-of-the art broadband performance,
- LTE provides flexibility of deployment,
- LTE is open, secure, reliable and easy to operate.
Today, the LTE standard is embraced by most wireless service providers across all continents. The two predominant standardization bodies 3GPP and 3GPP2 (standardization body for mobile systems that represent more than 99% of worldwide mobile subscriptions) have selected LTE as the evolution of their current 3G standards. LTE is then the first true convergence standard for mobile communications worldwide and a number of commercial networks are already live and running: in particular Verizon in US has already deployed its 4G network and sold more than 1.4 million LTE compatible terminals.

3GPP has already undertaken definition of next LTE version—called LTE advanced or “release 10”—and that will bring significant improvements:

- multiple LTE carriers aggregation in channels of up to 100 MHz and therefore enable a higher bandwidth
- Better radio performance at the cell level to be able to serve more terminals, thanks to MIMO evolution
- Cell coverage extension thanks to low cost radio relays
- Network self optimization functions (SON)

7 LTE FOR RAIL

We have seen several elements driving the demand for the next generation of communication system for Rail, namely:

- New services demanding more bandwidth
- Life duration and anticipated obsolescence of existing systems
- Cost of rail specific systems, both in terms of CAPEX but also in OPEX with high level of maintenance

In this context we can consider LTE as a good candidate for this next generation given the very stringent specificities of rail constraints:

- Network High availability and robustness demanded by signalization and control
- A Quality Of Service being able to carry and prioritize both vital and non-vital services
- A bandwidth able to carry very “greedy” application such as video surveillance
- Fast handover between cells compatible with High Speed
- Communication robustness in urban environment

LTE standard therefore offers all needed features of a radio access system to match transport specific needs without specific adaptation. This will avoid developing any “LTE-R” while taking advantage of the huge telecommunications mass-market effect.

A typical LTE architecture for Railway is given in Figure 4 where both vital and non vital traffics are delivered between servers in the OCC (Operation Control Center) and applications running onboard vehicles.

In the fixed infrastructure, the radio system can use either directive antennas or radiating cables to exchange the wireless signals with the OBU (Onboard Board Units).
7.1 Better spectrum efficiency, increased link capacity and automated network operations

Thanks to OFDMA (downlink) and SC-FDMA (uplink) access technologies, LTE can support flexible spectrum allocation, augmenting uplink radio coverage and downlink peak traffic up to 300 Mbps with MIMO 4x4 antennas and 20MHz large channel. Besides, LTE can increase cells sector spectral efficiency by a factor ranging from 2 to 4 and therefore enable a better use of radio spectrum while guaranteeing performances matching transport needs: the LTE standard offers a wide variety of channel width (from 1.4 MHz up to 20 MHz). Consequently, telecommunications operators will be able to reallocate part of their spectrum to LTE.

Finally SON (Self Organized Networks) technology makes operation, configuration and optimization of the network extremely simple, managing in a automated way all resources, handovers, frequencies and relay function of LTE.

Figure 5 summarizes these different technologies

**Figure 4 : Example of LTE architecture for transport**

**Figure 5 : Key technologies involved in LTE**
7.2 Which frequency band for LTE in rail?

LTE is not only addressing the need of commercial mobile operators for improved capacity at lower cost per byte. LTE also addresses the need of professional users that requires broadband wireless communications system for their operations.

Large bandwidth are available in upper bands (2.6GHz and above), giving a higher data rate. Such bands fit well with urban rail needs that require high bandwidth on medium distance range and at medium speeds (less than 100 km/h).

Lower frequency bands (700 MHz, 800MHz) offer longer distance coverage and present the advantage of reusing existing infrastructure already invested for radios in the same range. In the USA, FCC and APCO have endorsed LTE as the next generation interoperable broadband LMR system. There, Public Safety LTE networks will be deployed in a dedicated spectrum (2x5 MHz in the 700 MHz band); the public safety agencies will then benefit from a dedicated interoperable mission critical broadband wireless network and will also be able to roam to commercial LTE networks deployed in other bands if needed. Other countries are considering following a similar strategy. However, in some countries or regions, dedicated spectrum can be difficult to obtain. To that end, Alcatel-Lucent and Cassidian have decided to commonly develop a LTE solution at 400 MHz for all professional users (Public Safety, Transportation, Defense, Energy and other industries) with data transmission performance well beyond the capabilities of the existing narrow-band technologies. The operation in the 400MHz band is already well adopted by the rail industry where dedicated bandwidth for professional use can still be allocated from the local regulators. Therefore this future LTE 400 solution should also be considered to support train-to-ground applications.

8 CONCLUSIONS

For basic single service requirements (e.g. CCTV only of Voice only) basic WiFi and TETRA solutions are still economically implemented today.

The advent of the next generation of railways and metros wireless communication systems is pulled by the demand of new services – whether safety or business related - requiring much higher bandwidth, technology obsolescence facing and O&M (Operation and Maintenance) cost containment.

The emergence of LTE, the 4th generation of wireless communication, is definitely an opportunity for Public transportation since it is the only radio access technology that combines high bandwidth, hierarchical Quality of Service and low latency, therefore capable to carry both vital and non-vital traffics and we have already seen public transport operators requesting LTE.

However the choice and the allocation of frequency band is one of the questions to be tackled carefully and early by train operators willing to go for this technology.