Contents

Executive Summary .................................................................................................................. 3
Introduction ................................................................................................................................. 4
Communications requirements for rail ......................................................................................... 5
Tests & Trials ................................................................................................................................. 5
Delivering LTE Solutions .......................................................................................................... 7
    Quality of Service .................................................................................................................. 8
    Network robustness ............................................................................................................. 8
    Safety and security ............................................................................................................. 8
    Spectrum & LTE licences .................................................................................................... 9
    Stakeholders ....................................................................................................................... 10
    Cost effectiveness .............................................................................................................. 10
LTE as an evolving bearer ......................................................................................................... 10
Conclusion .................................................................................................................................. 12
List of Abbreviations ............................................................................................................... 13
About Thales ............................................................................................................................... 14
About the author ......................................................................................................................... 14
Executive Summary

This paper presents Thales’s positioning with respect to the mobile cellular standard, Long Term Evolution (LTE) and describes LTE trials undertaken by Thales and also what transport solutions/ projects Thales is currently delivering with the use of LTE as the radio bearer. The paper also describes how LTE fits in with the broader Thales vision of delivering signalling/communications solutions and measures taken to address some of the sort comings of LTE with respect to transport implementation.

LTE brings both opportunities and challenges to transport solutions. The challenges, such as cyber vulnerability, spectrum availability and new stakeholder alignments are discussed, along with the Thales response to these challenges.
Introduction

Long-Term Evolution (LTE) is the latest cellular communications standard that has achieved global acceptance. It is standardised by the 3GPP and has been acknowledged by the ITU as a 4th generation (4G) mobile system.

LTE offers performance and bandwidth capabilities that make it an attractive technology for transport applications.

Thales is a world leader in the delivery of transport solutions and has engaged fully in the assessment of LTE as a suitable radio bearer for these solutions.

There are market factors influencing the pace at which the transport sector is embracing and orientating itself to LTE. For mainline rail, the existence of the GSM-R standard, and its protected spectrum within the EU, can be seen as a factor moderating the pace of probable migration to an LTE bearer solution for operational rail requirements. The pace of migration may be quicker for non-operational requirements such as passenger connectivity, or indeed for market areas outside the EU.

Conversely, the lack of a common radio standard with protected spectrum for the metro/urban rail sector can be seen as a motivating factor, among other factors, in the uptake of LTE as a radio bearer in this sector.

The uptake of LTE bearer solutions in the Light Rail / Tram (LRT) sector will be more aligned to the metro sector than the mainline sector, but there are other influencing factors here, such as the relative small size of LRT networks compared with metro networks, probably mitigating against dedicated LTE networks for LRT.

What is clear is that LTE implementation in the rail transport sector is set to grow.
Communications requirements for rail

The three main rail transport modes, urban, mainline and light rail have similar communication requirements spanning signalling, operational voice & data and passenger communications.

The main communication requirements and associated radio bearers currently used in the rail sector include:

<table>
<thead>
<tr>
<th>Application</th>
<th>Rail mode</th>
<th>Bearer Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signalling</td>
<td>Metro/Urban/LRT</td>
<td>WiFi</td>
</tr>
<tr>
<td>Signalling</td>
<td>Mainline</td>
<td>GSM-R</td>
</tr>
<tr>
<td>Signalling</td>
<td>LRT/Mainline</td>
<td>Tetra SDS (not widespread)</td>
</tr>
<tr>
<td>Voice</td>
<td>Metro/Urban</td>
<td>Tetra</td>
</tr>
<tr>
<td>Voice</td>
<td>Mainline</td>
<td>GSM-R</td>
</tr>
<tr>
<td>CCTV</td>
<td>Metro/Urban</td>
<td>WiFi (wayside to train)</td>
</tr>
<tr>
<td></td>
<td>Mainline</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LRT</td>
<td></td>
</tr>
<tr>
<td>Passenger Information</td>
<td>Metro/Urban</td>
<td>WiFi</td>
</tr>
<tr>
<td>(On board)</td>
<td>Mainline</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LRT</td>
<td></td>
</tr>
<tr>
<td>Passenger connectivity</td>
<td>Metro/Urban</td>
<td>-On board WiFi.</td>
</tr>
<tr>
<td></td>
<td>Mainline</td>
<td>-Public Cellular (if</td>
</tr>
<tr>
<td></td>
<td>LRT</td>
<td>coverage available)</td>
</tr>
</tbody>
</table>

Table 1

LTE offers the potential to act as a single bearer for signalling, voice and telecoms services between the train and ground. This is an attractive option for transport operators and infrastructure owners because of the broadband communications capability of LTE and also because of the potential reduction in infrastructure deployment and hence maintenance costs over the operational life of the infrastructure.

Tests & Trials

Tests and trials are the necessary prerequisite to implementing LTE as a bearer for signalling and communications solutions for transport. Testing is needed to assess the suitability of LTE to meet the particular transport communications requirements. The chief parameters of interest include:

- Signal latency
- Data throughput
- Dropped data packets
- Quality of Service (QoS)
- Network security
- Failover time of backbone network

Thales has undertaken in depth LTE tests – both lab tests and live tests on operational lines. The tests and trials undertaken are shown in Table 2 below:
<table>
<thead>
<tr>
<th>Application</th>
<th>Rail mode</th>
<th>LTE supplier</th>
<th>Status of the tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signalling &amp; Telecoms</td>
<td>Metro/Urban</td>
<td>Huawei eLTE and MPLS backbone</td>
<td>Test with Huawei eLTE equipment and MPLS backbone. Simulated signalling traffic. Result: Passed.</td>
</tr>
<tr>
<td>Signalling &amp; Telecoms</td>
<td>Metro/Urban</td>
<td>Huawei eLTE and MPLS backbone</td>
<td>Live LTE trials for signalling (Seltrac™ CBTC) and telecoms on Shanghai Line 6 using Huawei eLTE and MPLS backbone. Result: Passed</td>
</tr>
<tr>
<td>Signalling</td>
<td>Metro/Urban</td>
<td>Fiberhome LTE TD</td>
<td>Wuhan Line 7 using Fiberhome LTE TD solution. Result: Passed</td>
</tr>
<tr>
<td>Signalling</td>
<td>Mainline</td>
<td>Vodafone Public LTE</td>
<td>Simulating ETCS data communications between OBU and RBC using antennas mounted on road vehicles and laptop signal simulator. Vodafone’s public LTE was used as the bearer. Result: Passed</td>
</tr>
</tbody>
</table>

Table 2

An extensive live trial using LTE trials was conducted on Shanghai Line 6. The trials and results analysis and reporting period lasted from January 2015 through to December 2015. The trial network comprised a dedicated Huawei eLTE network with radiating cable infrastructure and an MPLS backbone. Load testing, QoS and radio signal characteristics were tested for combined signalling and telecoms operation. A section of the test track and the cover page of the results report are shown in Figure 1 and Figure 2 below.

Figure 1 Shanghai Line 6 Test Track

Figure 2 Shanghai LTE Trial Report
Delivering LTE Solutions

Having undertaken the necessary urban rail field trials with positive outcome, Thales and its joint venture, TST, have already been awarded urban rail signalling projects delivering SelTrac™ CBTC solution either using LTE as the only communication bearer, or in dual mode with 802.11 FHSS (both active) or LTE serving as fallback, as described in the text boxes below.

**WiFi as Primary and LTE as fallback CBTC communication bearer**

Seven lines, Hong Kong, China (January 2015)
- High redundancy configuration of the main Wi-Fi based DCS system.
- Thales’s high anti-interference 802.11 FHSS using Software Defined Radio (SDR) will be used as primary system.
- Commercial LTE network to be selected and provided by the customer will serve as a fall-back radio communication medium if primary radio communication medium fails.
- Two separate commercial LTE networks

Thales to supply all train equipment for primary and fallback radio communication.

Common interoperable LTE train radio modem

On Board Internet Security Device (OISD) provides security functions required for LTE communication on CBTC

**LTE as sole bearer - primary & fallback CBTC communication bearer**

Line 7, Wuhan, China (Dec. 2015)
- 48 km track length, 26 stations
- Dedicated 1.8 GHZ LTE.
- Fiberhome LTE TD (1.8 GhZ)
- Thales JV to supply all train equipment for primary and fallback radio communication.
- On Board Internet Security Device (OISD) provides security functions required for LTE communication on CBTC
- The line is to be opened by end of 2017.

**WiFi and LTE both active as primary CBTC communication bearer**

- Line 5, Shanghai, China (2016)
- 34 Km track, 20 stations
- High redundancy configuration of the Wi-Fi based DCS system. Thales’s high anti-interference 802.11 FHSS using Software Defined Radio (SDR)
- Huawei eLTE
- Thales JV, TST, to supply all train equipment for primary and fall-back radio communication.
- On Board Internet Security Device (OISD) provides security functions required for LTE communication on CBTC.
- The line is to be opened in 2018.
In delivering LTE solutions, there are a number of factors of particular importance in determining how and with what kind of business model a particular customer is provided for. The factors are:

- Quality of Service
- Network robustness
- Safety & Security
- Spectrum
- Stakeholders
- Cost effectiveness

**Quality of Service**

LTE allows service prioritization and for a dedicated LTE network, the QoS value available can be allocated in the range of 1 to 9. Signalling would be allocated level 1, corresponding to the criticality of the service and a likely prioritization for services would be as follows:

- Level 1 = CBTC signalling
- Level 2 = Voice
- Level 3 = Passenger Information
- Level 4 = CCTV

If the LTE network was not a dedicated network for the transport service, clear arrangements for assuring the required prioritization would have to be put in place with the network owner/operator.

**Network robustness**

The next factor of high importance is the robustness of the network. There are two factors to consider here, there is the architectural robustness of the network, such that the required RAMS are achieved both at delivery and during operational life. The meeting of life time RAMS would likely be achieved as part of a service offering.

An important point for operational rail requirements, signalling in particular, is the high network availability requirement. This can be addressed at network design stage by the use of high availability network architecture and knowledge of redundancy protocols. In considering the use of public cellular LTE for rail signalling, two separate networks would be required to achieve the required network availability. Thales would not consider delivering a rail signalling solution using a single public cellular LTE network, as they are currently implemented, as the radio bearer.

The other factor to do with overall robustness is the ability of the solution to resist cyber-attacks, either a deliberate attack or an accidental attack (such as staff infecting the network inadvertently.) The increasing threat of cyber-attacks means that measures to protect networks against an attack are necessary rather than optional (see following section, Safety and Security.)

**Safety and security.**

It is important to understand that a bearer such as LTE is a means and not an end. It is a means of supporting the operation of signalling and communications solutions. However, the top priority for Thales operational rail solutions is safety. Thales signalling solutions must and will always perform safely, even if the communications bearer is compromised either deliberately or by accident.

Using LTE as the bearer brings new challenges in terms of the cyber threat profile. The LTE standard has many features related to encryption and authentication. For the air interface
(trackside antenna to the train, for example) these are defined and mandated by 3GPP. For the network core however (the non-air interface part of the end to end communications path), specific cybersecurity measures are not mandated.

There are therefore different needs and requirements for addressing LTE security, partly depending on the implementation model and whether the LTE network is a dedicated or a shared network.

In the case of a dedicated LTE network, ‘security by design’, is the optimal approach. This is the approach adopted by Thales’s own LTE PMR solution, Nexium. Thales has developed new techniques that include deploying security enforcing functionality at key points in the mobile network, which allows protection to LTE hosting platforms, and to secure interfaces to backbone networks and peering with roaming partners. Thales can also offer enhanced protection against DDoS attacks through our hybrid architecture solutions.

In the case of a shared network, which will probably be the more likely scenario in transport applications, a different approach needs to be adopted.

The 3GPP does not mandate particular cyber security measures for the LTE network core. The cyber vulnerabilities of the core must be mitigated against however. For the critical signalling requirement for urban rail systems, Thales has developed an ‘On Board Internet Security Device’, with which the Thales CBTC is hardened against potential cyber-attacks. The security device is independent from the “communication bearer” to provide end-to-end encryption using IPSEC tunnels to the CBTC signalling network. This mitigates any encryption gaps in the LTE provider wired infrastructure such as mandated “law enforcement” taps.

(Interested readers can find further information on the Thales approach to cyber security in our transportation white papers covering urban rail, mainline rail, integrated communications and supervision and revenue collection systems.)

**Spectrum & LTE licences**

LTE operates in licensed spectrum bands. There will be a couple of scenarios envisaged for solution delivery.

In the first scenario, the spectrum will be made available through the national spectrum regulatory entity of a country. An example here is China, where the government released a dedicated LTE spectrum band for Metro, in 2015.

The other scenario is that protected spectrum is not available and so the spectrum owner, usually a Public Cellular Operator, will likely be a stakeholder in the solution delivery.

Another possible option is using the LTE service as a regular customer, with a network SIM. The Thales approach to security will ensure that this approach can be implemented safely and in a cyber-secure manner. This approach would need analysis as to how the required QoS and RAMS could be guaranteed, and this would need to be addressed on a case by case basis. It is likely that RAMS requirements for operational rail will require duplicated network coverage, as discussed above in *Network Robustness*.

License fees will need to be planned for as part of any solution using LTE. License fees for LTE equipment will also need to be accommodated and ways of optimizing the quantity of equipment
deployed addressed. Such optimization should be normal practice for an experienced integrated solution provider.

**Stakeholders**
Implementing LTE solutions in rail transportation involves different stakeholders each with an important role. The stakeholder list includes:

- The rail operator
- The rail infrastructure owner
- The LTE spectrum owner
- The solution provider

In addition to robust and secure technical solutions, the close collaborative working of stakeholders will be key to project delivery success.

**Cost effectiveness**
It goes without saying that the cost effectiveness of implementing a radio bearer solution is of paramount importance. It would however be too simplistic to assume that because LTE offers the potential to be a ‘one bearer for all applications’ option, it promises to be the most cost effective solution, if not in capital expenditure terms, at least in operational expenditure terms.

In practice, the most cost effective solution will depend on several factors – spectrum availability; spectrum cost; the part of the LTE spectrum being used (the higher the LTE frequencies being used, the more trackside radiating infrastructure required); whether the LTE network is dedicated or shared, and so on. It may be that the best solution, cost wise, is one that uses LTE as the fall-back bearer, with WiFi as the primary bearer or vice versa.

The key point here is that each solution requirement needs to be assessed to ensure that what is delivered to the end customer offers the best cost effectiveness, while also meeting the required functional and safety requirements. Such assessments require in depth knowledge and experience of radio/backbone networks design and delivery in the rail environment; Thales is well positioned in this area.

**LTE as an evolving bearer**
LTE offers opportunities to rail operators for a standardized, broadband bearer for all of their radio based services, once spectrum has been secured. LTE, however, as the ‘Evolution’ bit of its name attests, is a standard that will always be in a state of transition. Known also as ‘4G’, LTE was preceded by 3G and will be succeeded by 5G. The first operational 5G network is planned to be in operation by 2020 to a defined programme as illustrated in Figure 4.
This evolution certainly brings benefits for transport operators as they will be able to benefit from a technology standard that is tailored, by design, to offer increased communications capability to users both in terms of bandwidth and also in terms of global interconnectivity between entities, be they humans or machines. This is the vision built into the standard, a vision that has transportation as a major ‘connector’ in a world of interconnected, ‘smart cities’, Intelligent Transport Systems and other advanced communication entities. It is a vision that will increasingly be at the heart of the strategic thinking of transport planners.

One clear implication of this vision is that transportation solutions incorporating radio bearers need to be ‘bearer independent’, from the product perspective.

The Thales approach addresses this by providing secure and bearer independent signalling and communications products. ‘Bearer independence’ is ‘built into’ the respective Thales product plans. This means that from the customer perspective, as the bearer technology changes, (e.g. WiFi being superseded partially or completely by LTE as a bearer for metro signalling, or GSM-R being superseded by LTE, or 4G being superseded by 5G), these changes should be transparent to the user, from the perspective of the signalling and communications products that are being used.
Conclusion

In spite of the very many powerful attributes of LTE, its implementation as a bearer in an operational rail environment demands careful attention to detail, to ensure that the long term needs of the rail operator / infrastructure owner are met.

Thales understands LTE technology through its activities and experience in design, testing and delivery. Thales is positioned to deliver, together with the other necessary stakeholders, safe and secure signalling and telecoms solutions over LTE.
## List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>3GPP</td>
<td>3rd Generation Partnership Project</td>
</tr>
<tr>
<td>CBTC</td>
<td>Communications Based Train Control</td>
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<tr>
<td>DCS</td>
<td>Data Communications System</td>
</tr>
<tr>
<td>DDoS</td>
<td>Distributed Denial of Service</td>
</tr>
<tr>
<td>ETCS</td>
<td>European Train Control System</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FHSS</td>
<td>Frequency Hopping Spread Spectrum</td>
</tr>
<tr>
<td>GSM-R</td>
<td>Global System for Mobile communications - Railways</td>
</tr>
<tr>
<td>IP</td>
<td>Internet Protocol</td>
</tr>
<tr>
<td>ITU</td>
<td>International Telecommunication Union</td>
</tr>
<tr>
<td>JV</td>
<td>Joint Venture</td>
</tr>
<tr>
<td>LRT</td>
<td>Light Railway Transit</td>
</tr>
<tr>
<td>PMR</td>
<td>Private Mobile Radio</td>
</tr>
<tr>
<td>SDS</td>
<td>Short Data Service</td>
</tr>
<tr>
<td>TD</td>
<td>Time Division</td>
</tr>
<tr>
<td>MTR</td>
<td>Mass Transit Railway</td>
</tr>
<tr>
<td>RAMS</td>
<td>Reliability Availability Maintainability Serviceability</td>
</tr>
<tr>
<td>SDR</td>
<td>Software Defined Radio</td>
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<tr>
<td>TST</td>
<td>Thales Saic Transportation</td>
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</table>
About Thales

Thales is a global technology leader for the Aerospace, Transport, Defence and Security markets. With 62,000 employees in 56 countries, Thales reported sales of 14 billion euros in 2015. With over 22,000 engineers and researchers, Thales has a unique capability to design and deploy equipment, systems and services to meet the most complex security requirements. Its exceptional international footprint allows it to work closely with its customers all over the world.

Transportation Systems activities

Thales is a global transportation systems provider with a proven track record in greenfield projects and infrastructure modernisation. Thales offers the most extensive portfolio of critical IT systems to national railways and urban operators: Signalling, Supervision, Communications, Security and Revenue Collection.

Independently from rolling stock, Thales delivers all rail systems integrated for maximum efficiency and reduced operational costs. Using Thales transportation systems, operators can be trusted to offer the best experience and journey to passengers using their network: safe, secure, seamless, connected and reliable.

As railways become more and more Digital, Thales accompany operators and infrastructure owners in their Digital transformation by developing the solutions that address today’s needs and prepare for future requirements. We invest in the technologies and develop the solutions that will deliver maximum efficiency in digitalised railways of tomorrow: big data analytics, autonomous trains, cloud computing and most importantly cyber security without which no rail digitalization is possible.

With Thales, rail and metro operators can be confident of getting the most out of your infrastructure and deliver seamless, safe and secure transportation of goods and people, now and in the future.

About the author

Timothy Murphy is Global Solution Leader, Radio, for the Ground Transportation Systems activities of Thales. He is also the Product Line Manager for Networks and the Cybersecurity Authority for Integrated Communications and Supervision Systems.