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Broadband communication in the high mobility scenario: the WiMAX opportunity

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1. Introduction

Nowadays, the emerging broadband wireless access technologies face the long term challenge to properly address the air link channel limitations with the growing demand on services, fast mobility and wide coverage. One of the most demanding and challenging scenarios is the high mobility scenario; scenario that matches the railway domain.

The International Telecommunication Union (ITU) – radio division (ITU-R), in its standardization global role, has recently identified the IMT-Advanced family as those mobile communication systems offering technical support for such high mobility usage scenarios. In October 2007, ITU-R decided to include the WiMAX technology in the IMT-2000 family of standards; and, in the near future, the next IEEE802.16 specification, the IEEE802.16m project, will cover the mobility classes and scenarios supported by the IMT-Advanced, including the high speed vehicular one.

This chapter covers the WiMAX opportunity in this low dense, full mobility and high demanding railway scenario. In order to do so, this chapter is structured as follows:

Section 2 presents and characterizes one of the most typical high speed vehicular scenario: the railway scenario. Subsection 2.1 describes the existent data communication networks in the railway domain. Subsection 2.2 introduces the current trends in the railway domain regarding IT services .

Section 3 describes the current telecom context. Section 4 provides an analysis on the open WiMAX network specification as a valid player for matching the railway requirements previously specified in section 2. The currently set of technical, regulatory, and market aspects that contribute to identify the mobile WiMAX access technology as a competitive solution in the railway context are shown.

2. The Railway Context

Traditionally, railway transport is one of the industry sectors with a greatest demand on telecom services due to the intrinsic mobile nature of the resources involved.

However, the railway domain introduces quite specific and challenging requirements to a general wireless communication architecture, system or technology, such as: high mobility, high handover rate, compatibility with legacy or non-conventional applications, stringent quality of service (QoS) indicators and reliability. These legacy applications are related to signalling and train control and command systems. Such signalling systems highly demand communication availability; if there is any communication loss, the signalling system is disrupted and trains stop. The embedded information within these systems is related to control train movement and is based on very strict safety rules. Moreover, railway environment is also a really harsh environment from the electromagnetic point of view; high vibration, thermal noisy, high number of different radio systems everywhere, cohabitation between high power (traction) and low power systems (electronic)…

On the other hand, and once exposed the challenges, it is also fair to outline some facts that may turn the railway domain in a favourable scenario from the telecom point of view. In normal conditions, not in busy yards, the railway network is not a heavy loaded telecom network as it can be considered a traditional one. Secondly, from the operational railway point of view, the supported services are pretty well defined. Not only is the mobile node's mobility pattern predictable but also its data traffic profile. Being that way, it is possible to identify and predict the most complex and challenging use cases to be supported by the network architecture.

2.1 Railway Communication services

From a general point of view, three main types of communications flows exist in the guided transport context (railway and underground):

- Train to ground communications (vehicle to infrastructure communications).
- Train to Train communications (Vehicle to vehicle communications).
- In train communications (Intra vehicle communication).

The requirements for train to ground communications in the guided transport field are generally divided in two main families related to **safety** and **non safety** applications. The first family is quite demanding in terms of robustness and availability, but the amount of information exchanged is generally low. In order to attend these safety applications, railway communication dedicated architectures have traditionally been deployed. On the contrary, non safety applications require high data rate. They use dedicated communication architectures, shared communication architectures or, even sometimes, they rely on public and commercial communication systems. The number of these non-safety applications keeps growing.

Following the traditional UIC (Union Internationale des Chemins de Fer or International Union of Railways) classification, it is possible to classify the fundamental Train to ground communication needs in the following application fields.

Safety applications

- o Voice and data communications between CCC (Command Control Centre) and drivers. This application consists in providing voice and data communications in order to control, ensure and increase the safe movement of trains.

- Data communication for Automatic Train Control (ATC) systems.
- Data communications for remote control applications such as: remote control of engine for shunting, remote control of trains at line opening and closure, remote control of customers information systems, remote control of interlocking, remote control of electrical substations, remote control of lighting, electrical stairs, lifts, emergency ventilation installations, etc…
- Voice communications for broadcast emergency calls, for shunting in depot areas and for workers during track maintenance activities.

Non safety applications

- Voice and data communications in depot, maintenance and yard areas.
- Voice and data communications from and towards a train for staff, customer's services, diagnosis and maintenance message. These information exchanges aim to increase operation efficiency.
- Voice and data transmission for crew members
- Voice and data transmission for security applications
  These applications consist of: the supervision with discreet voice listening inside trains from a central control room to the surface (Centralized Control room, Security Control room); supervision of trains with discreet digital video record for trains from a central control centre on the surface; digital video broadcast in the drivers' cabin of the platform supervision at stations
- Voice and data communications for passenger services
  Passengers on public transport (underground, train or plane) or private transport (car) expect the information they usually receive in day-to-day life, whether professional or private, to be available to them during their journeys. These demands will increase significantly with the growing market of mobile telecommunications. The main needs identified in general are listed here: public phone, fax, passenger call service, connection to external networks and computers, entertainment videos, live radio channels, live TV channels, video-on-demand, tourist, multimodal and traffic information, information panels at the platforms and inside the units, database queries for passengers or staff, E-mail, Internet browsing, other Internet services, VPN secure connection to company's Intranet, Audio and video streaming, Video-conference..

2.2 Railway Trends regarding IT services

The increasing complexity of railways systems, the new European directive regarding the separation between track owner and train operators and future deregulation regarding maintenance, push the development of a huge variety of information systems. In addition, the following current trends can be pointed out:

A. Suppress cables and discontinuous data communication equipment installed between the tracks in order to avoid vandalism and to decrease maintenance costs.
B. Use of open technology and IP equipment interoperability, avoiding protocols and proprietary solutions.
C. Utilization of telecommunication technologies that have been proven and validated in other industries (Component Off the Shelf –COTS). Essentially, well proven and cost-effective solutions are the main goal.

D. Minimize obsolescence. Due to the high cost of a telecommunication system deployment along a railway, all equipments and systems installed along the railway net are expected to have a working life of around 30 years. Currently this requirement is being slightly loosened.
E. Migrate from a dedicated network infrastructure towards an infrastructure supporting critical and complimentary services with prioritization.
F. Increase data acquisition from the train and from wayside equipment involving high capacity broadband networks (Fibre, Gigabit backbone networks) and then enhance safety through complimentary services.

Having into account these trends regarding IT railway services, a set of general requirements can be identified for the communication technologies in the railway domain.

1. Broadband Wireless Digital Radio Access Support

Railway technologies shall be based on wireless digital communication technology, minimizing cable deployments and this way lowering maintenance cost and contributing to higher availability indicators.

2. Support for Full Mobility and High Speed Vehicular Scenario

Railway communication technologies shall support the high speed vehicular profile (up to 500km/h), solving the mobility management and re-attachment problem, and providing low latency and seamless handover between cells without data loss.

3. High Data Rate Support

Railway communication technologies shall provide broadband communication in both uplink and downlink communication. It shall provide higher capacity (traffic volume/number of users) than second and third generation of mobile communication technology. This way the architecture shall provide support for the previously identified trend related to increase the high quantity of data acquisition from train and wayside equipment and high capacity network utilization.

4. Low Latency

Railway communication technologies shall cater for low end-to-end latency able to support high demanding real time applications in full mobility.

5. End-to-end Quality of Support

Railway communication technologies when making use of packet or connection oriented based technologies shall provide end-to-end QoS support. This means that, it shall be possible to provide support for critical applications prioritization. Emergency support and priority access is one of the important requirements for critical railway services. The radio access technology should be able to provide differentiated levels of QoS – coarse grained (per user) and/or fine-grained (per service flow per user). It will be able to implement admission control and bandwidth management.

6. Advanced Security Scheme

Railway communication technologies shall support a security scheme with mutual authentication, able to cope with the critical services messages vitality, integrity and authenticity. The mobility scheme chosen should support different levels of security requirements, such as user authentication, while limiting the traffic and time of security process, i.e., key exchange.

7. Scalability, Extensibility, Coverage

Railway communication technologies shall support incremental infrastructure deployment. The railway communication architecture may accommodate a variety of backhaul links, both wireless and wire line and be able to be integrated in a fibre deployment.

8. Operate at Licensed and Licensed exempt frequency bands

The railway communication technology shall work at licensed and licensed exempt frequency bands. This requirement is aligned with another demand that is commonly manifested by railway operators. As seen before, due to the safety and critical nature of the train control communication service, railway operators have typically eschewed shared public and commercial network solutions and have been responsible for designing and maintaining their own telecom network. Railway operators normally demand the possibility of totally controlling the communication architecture due to the inherent responsibilities that failures, malfunctioning or low performance indicators in this architecture, may represent on railway operators´ own safety and performance.

9. Cost-effective Deployment Based on Open and Standard Based Technology

The railway communication technologies shall facilitate a cost effective deployment. In order to do so, these technologies will follow the international standardization framework, which further enhances the economic viability of the solution proposed. The architecture shall provide support for IP equipment interoperability.

There are some other important features such as maturity and mesh support that have to be taken into account when choosing the railway access technology. Mesh support is related to the demanded "direct mode" communication; in this case, every connection is not necessarily performed via the network.

The standards that define the new wireless digital communication technologies cover only the PHY and MAC layers. And just specifying these layers is not sufficient to build an interoperable broadband wireless network for railway critical services. Rather, it is necessary to propose an interoperable network architecture framework capable to deal with the end-to-end service aspects such as QoS and mobility management. A full railway communication architecture that may serve as a valid alternative to the existing GSM-R deployments shall be a full stack end-to-end architecture. It shall also provide robustness and redundancy, this way increasing availability. Mechanisms such as support for hot standby configuration and redundant coverage deployments shall be implemented.

Additionally, the architecture shall support a broad set of mobility, deployment and use case scenarios and co-existence of fixed, nomadic, portable and mobile (and full mobile) usage models. Last, but not least, and as a general good telecom practice, the communication architecture shall allow a functional decomposition and support management schemes based on open broadly deployable industry standards.

3. Telecom Context

In the last few years, traffic profile in Wireless Mobile Networks has changed abruptly. Figure 1 shows the data services as the key service driving the bandwidth demands in Wireless Mobile Networks, together with the migration from a circuit switching traditional approach towards a packet switching strategy where packets are routed between nodes over data links shared with other traffic. In each network node, packets are queued or buffered, resulting in variable delay.

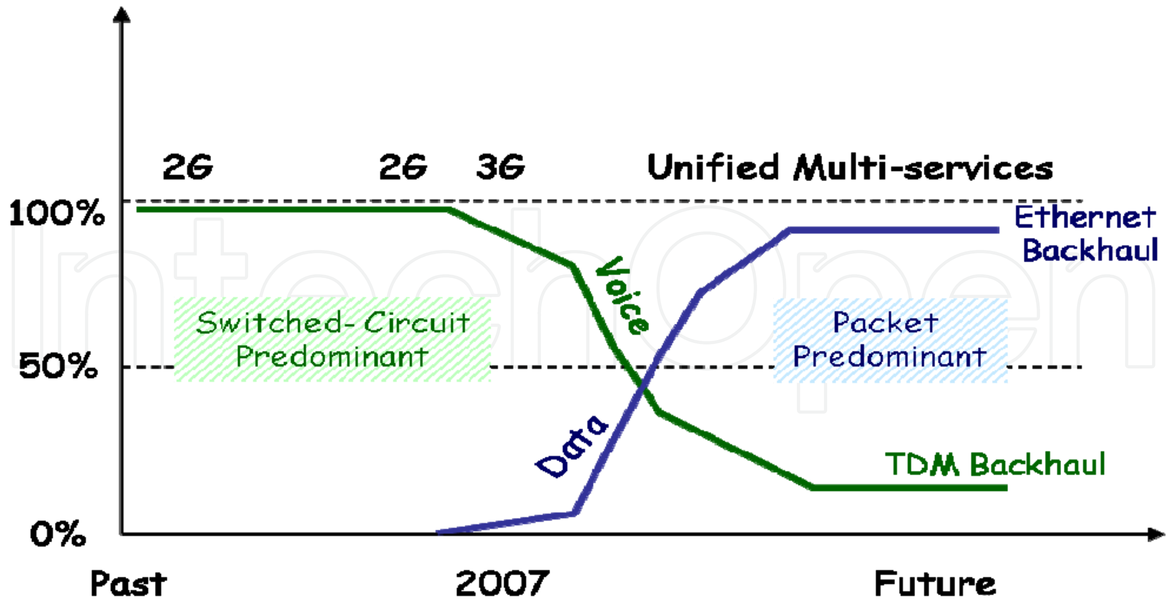

Fig. 1. Voice and data trends in mobile networks (Source International Wireless Packaging Consortium IWPC Milan 2008)

It is foreseen that the development of IMT-2000, the ITU global standard for third generation wireless communication, will reach a limit of around 30 Mbps. In the vision of the ITU [ITU-R M.2072], there may be a need for new wireless access technologies capable of supporting even higher data rates.

The ITU-R has recently proposed the International Mobile Telecommunications – Advanced (IMT-Advanced) technical requirements; one of the most demanding and challenging scenarios covered by the IMT-Advanced is the high speed scenario. The new capabilities of these IMT-Advanced systems are envisaged to handle a wide range of supported data rates according to economic and service demands in multi-user environments. Target peak data rates are up to approximately 100Mbit/s for high mobility, such as mobile access, and up to approximately 1 Gbit/s for low mobility such as nomadic/local wireless access. However, it is necessary to take into account that IMT-Advanced is a long term endeavour. The specification of IMT-Advanced technologies will probably not be completed until at least 2010.

Until recently, there was a technological gap regarding access techniques which could offer high transmission data rates and high interactivity (low latency) able to support real time applications in high mobility environments. However, research community efforts are underway to develop new generation wireless mobile networks that provide broadband data communication in this high speed vehicular scenario and new technologies capable of fulfilling the aforementioned technology gap have been developed, Figure 2. Currently, there are a number of initiatives that aim to provide ubiquitous connectivity at different mobility profiles.

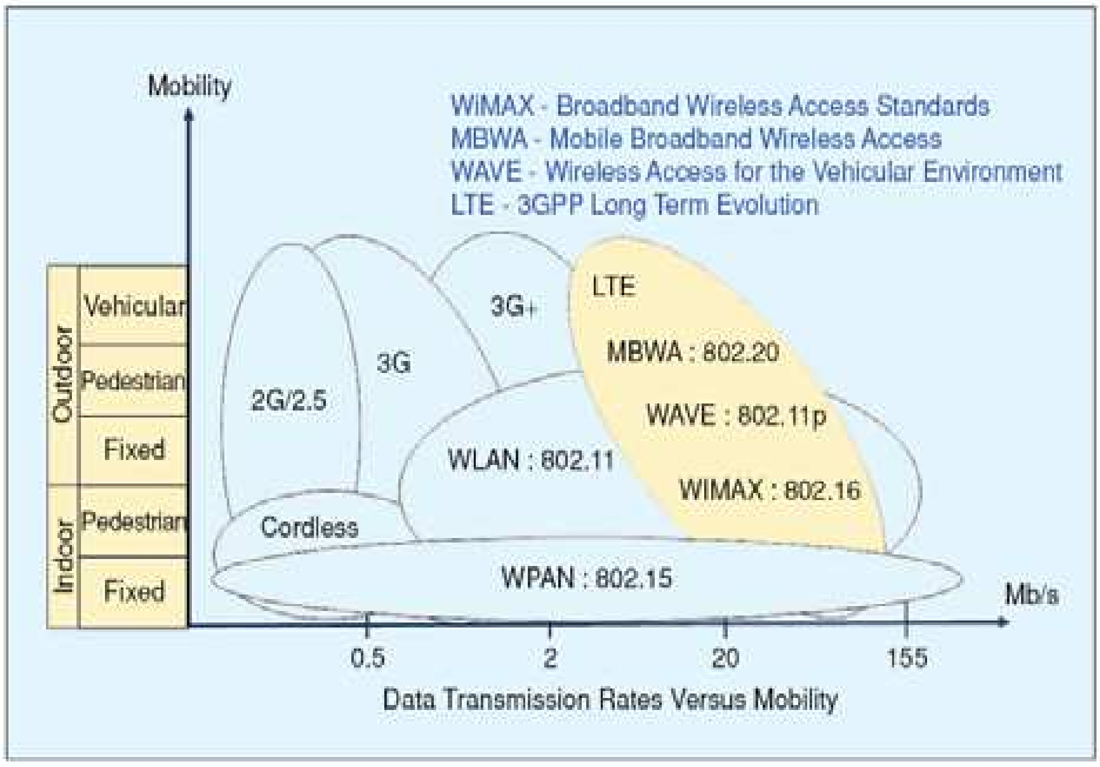

Fig. 2. Radio access technologies scenario: mobility versus data rate.

The *standard based* broadband wireless technologies able to support the vehicular mobility profile while offering a high transmission data rate are:

- IEEE802.11p or Wireless Access for the Vehicular Environment (WAVE),
- IEEE802.20 or Mobile Broadband Wireless Access (MBWA),
- IEEE802.16,
- Third Generation Partnership Project (3GPP) Long Term Evolution (LTE)

These emerging broadband and mobile access wireless technologies have some common features such as QoS support, low latency and advanced security mechanisms. They are also designed to support QoS and real-time applications such as voice-over-Internet protocol (VoIP), video, etc. They also may offer deployment bandwidth on the order of 40 to 100Mbps per base station.

OFDM and higher order MIMO antenna configurations are the core enabler for scaling throughput of these wireless mobile technologies. IEEE802.16, 3GPP and 3GPP2 standards bodies are all adopting OFDM & MIMO for 4G (WiMAX Forum, 2008). Figure 3 shows how all the three 4G candidates are based on OFDM and MIMO, consequently their major features are similar.

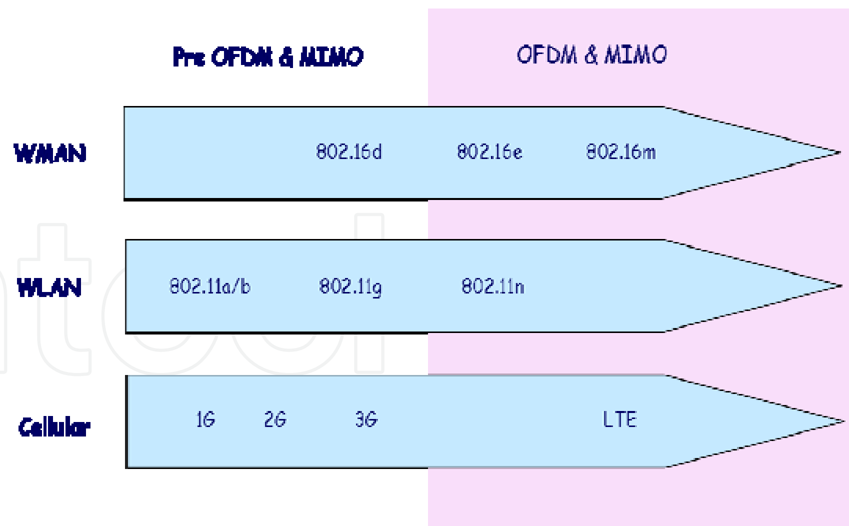

Fig. 3. All roads lead to OFDM and MIMO (WiMAX Forum, 2008)..

The IEEE802.16.m specification and the Third Generation Partnership Project (3GPP) long term evolution (LTE) specification are currently the only two candidates to cover the IMT-Advanced requirements.

4. The WiMAX opportunity in the railway domain

The scope of the IEEE 802.16 family is to develop the air interface technology for Wireless Metropolitan Area Networks (WirelessMAN), by specifying the medium access control layer (MAC) and the physical layer (PHY), of combined fixed and mobile *broadband wireless access* system providing *multiple* services. (IEEE 80216e, 2005)
The IEEE 802.16 standard has evolved from a fixed scenario IEEE802.16d towards a mobile typical vehicular (up to 120km/h) with IEEE802.16e. The group is now working on the revision of IEEE std 802.16-2004 (IEEE P802.16Rev2). WiBRO, the WMAN South Korean initiative, began to align itself with the WiMAX Forum implementation in 2004. Currently both approaches are harmonized in current WiMAX profile.
The IEEE 802.16 is focused on filling the existent gap between very high data rate wireless local area networks and very high mobility cellular systems. The next standardization effort in which the IEEE 802 is involved, *the IEEE 802.16m project*, follows this line. The IEEE 802.16m amends the IEEE 802.16 WirelessMAN-OFDMA specification providing an advanced air interface that meets the requirements of next generation mobile networks targeted by the cellular layer of IMT-Advanced. The purpose of this standard is to provide performance improvements necessary to support future advanced services and applications, such as those described by the ITU in Report ITU-R M.2072 [ITU-R M.2072].
IEEE 802.16m specification supports the mobility classes and scenarios supported by the cellular systems IMT-Advanced, including high speed vehicular scenario (up to 350km or even up to 500km/h). (P80216MPR2007)
Regarding the economic viability of IEEE 802.16, the proposed amendment is done within the framework of international standardization, which will further enhance the economic viability of the standard. Because IMT-Advanced is intended to be a globally deployed

system, it is expected that cost effective performance can be achieved through large economies of scale. (P80216M2006). IEEE 802.16e was first released in December 2005. Currently, the standard and its certification programs have clearly demonstrated its maturity.
IEEE802.16 specification provides mobile to mobile infrastructure-less communication. IEEE802.16j specification (to be included in next IEEE802.16 release) expands IEEE802.16 current deployment alternatives PTP, PTMP and mesh topologies by supporting a relay topology, this way enhancing the IEEE802.16 support for backhaul and last mille deployments. It specifies multi-hop relay capabilities and functionalities of interoperable relay stations and base stations.
IEEE802.16 standard supports license exempt profile operation. Additionally, it is currently working in the P802.16H/D8a proposal. This amendment provides measures to increase the efficiency and robustness of license exempt operation, specifies improved mechanisms as policies and medium access control enhancements and facilitate the coexistence of such systems with primary users.
The IEEE802.16 supports public safety first responders, military and emergency services such as call-prioritization, pre-emption and push-to-talk. (P802.16M2007). The involved tools to obtain this feature are the contention-based and the allocation-based radio resources.
Currently, WiMAX Forum plots a mobile profile in the 700MHz band, the recently identified by the ITU as the digital dividend spectrum; this spectrum is starting to be abandoned by TV broadcasters moving to all digital delivery, all around the world. WiMAX-700 specifications are already concluded (WiMax Forum, 2008B). The activities related to the operation of TDD and FDD in the 700MHz band are included in the development of the Release 1.5 profile. The certification of Release 1.5 based products, IEEE802.16REV2 compliant, is currently projected to begin in Q4 of 2009.
There are several interesting technical considerations from the railway low density context point of view regarding the 700MHz UHF frequency band:

- Lower path loss (26.5 dB lower than in the 2.5GHz or 3.5GHz bands)
- Lower Doppler Shift
- Better building penetration or indoor propagation to be taken into account inside the train composition and building stations.
- The enhanced signal processing reach (up to 65km) leads to the fact that the number of base stations necessary to cover the same area is about 10% of those at 3.5GHz profile. This represents an enhanced cost effective deployment when compared with 3.5GHz deployments.

A 700MHz PHY profile can compliment 2.5GHz and 3.5GHz networks. In dense environments such as the busy junctions situations, with higher subscriber density and high capacity demand small cells are necessary. In this case the optimal recommended deployment proposed is to deploy 700MHz umbrella cells for coverage and compliment then with 2.5GHz and 3.5GHz macro or micro cells to meet capacity requirements.
Most of the current implementations of IEEE802.16 in the access network are pre-WiMAX versions, such as the internet access provided along the 96km London-Brighton route with T-Mobile and Nomad Digital initiatives (Conti JP, 2005). There are also other research initiatives considering IEEE802.16 technology in the access network such as the European Research projects BOSS and also early studies like the one found in (Ritesh Kumar, 2008).

5. Conclusions

The access network between the train and the fixed network is definitely the most challenging one. Table 1 matches the railway requirements identified in Section 2 for each of the access technologies under study.

Nowadays, the most commonly used technologies are 2nd generation cellular-based (trackside) and satellite solutions. 2nd generation cellular systems, PMR included, and satellite solutions cannot be considered as an appropriate solution because either they are quite limited in bandwidth or suffer from an unacceptable delay and high cost.

The IEEE802.11 proposal for high speed vehicular scenario, IEEE802.11p, has a too limited coverage. Apart from that it is no mature enough. RoF and LCX solutions demand quite of an extended wired deployment. IEEE802.22 is not intended to provide support to mobile end users. HAPs do not support handover capability. The three technologies to be considered for the access network in the railway domain are HSPA, LTE and IEEE802.16.

4G technologies, LTE and IEEE802.16, are a step forward from HSPA technology when comparing data rate and latency features (Krapichler,C., 2007) , (Arthur D Little, 2007). Then, when considering LTE and IEEE802.16, mainly IEEE802.16m, both PHY layers are similar, OFDM and MIMO support and consequently there is no doubt about their capacity to cover the data rate and low latency needs of all emerging and future communication applications for the railway domain. Major LTE constraints are related to LTE maturity, cost and LTE operators' interest in low density, and consequently low return of investment, deployments.

There are some other identified features in the IEEE802.16 specification (mobile to mobile support, license exempt operation, public emergency services support and 700MHz profile), that currently contribute to consider the IEEE802.16 access technology as the best competitive access technology for the railway domain.

	Satellite	GSM-R	HSPA	LTE	PMR	DVB-H	IEEE 802.11p	IEEE 802.16	HAPs
High Speed Veh. Support	■	■	■	■	■	■	■	■	■
HO capability	□	■	■	■	■	■	■	■	□
High Data Rate Support	□	□	■■	■■■	□	■	■■	■■■	varies
Low Latency	□	■■	■■	■■■	■■	■	■■■	■■■	■
Wide Radio Coverage	■■■	■	■	■■	■	■■■	□	■■	■■■
Advanced Security Scheme	■	■	■	■	■	■	■	■	■
End2End QoS Support (MAC layer)	NA	NA	■	■	NA	NA	■	■	varies
Maturity	■■■	■■■	■■	□	■■■	■■■	□	■■	■
Cost	□	■	■	■	■	■■	■■■	■■	■
Mesh Support	□	□	□	□	□	□	■	■	□
Licensed exempt operation	□	□	□	□	□	□	■	■	□
Wireless	■	■	■	■	■	■	■	■	■
Full stack E2E Arch. (all IP)	□	□	□	■	□	□	□	■	□
Data Rate	Varies from few Kbps up to few Mbps	9.6Kbps	Useful: 10.8/4.3 Mbps	Useful: 75/37.5Mbps	7.2kbps	Downlink 30Mbps	10-20Mbps	.16e Useful: 42/14Mbps .16m twice .16e	varies

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WIMAX New Developments

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WiMAX (Worldwide Interoperability for Microwave Access) is a wireless broadband access network named by industry group called the WiMAX forum formed in June 2001. It is Wireless MAN with IEEE 802.16 family standards. Loosely, WiMAX is a standardized wireless version of Ethernet that enables the last mile, intended primarily as an alternative to wire technologies (such as Cable Modems, DSL and T1/E1 links) to provide broadband access to customer premises. Mission of the WiMAX forum is to promote and certify compatibility and interoperability of broadband wireless products. This book touches most of the above issues in form of 22 individuals' papers containing research work in WiMAX domain in particular. WiMAX has two important standards/usage models: a fixed usage model IEEE 802.16-2004 for Fixed Wireless Broadband Access (FWBA) and a portable usage model IEEE 802.16e-2005, which is mainly concentrated on Mobile Wireless Broadband Access (MWBA). Both are released as standards and amendments are available in form of drafts. Higher data rate transmissions (@ 100 Mbps) are achieved in IEEE 802.16-2004 WiMAX through LOS communications which incorporate a stationary transmitter and receiver but IEEE 802.16e supporting NLOS communication is much complicated and little less bit rate is achieved. 2-11 GHz licensed band is the range of frequencies with TDD and FDD supports. The book will provide a wide horizon to visualize the WiMAX technology and its developments leading towards 4G systems. It will provide a good platform to the researchers with clues to the innovative ideas in WiMAX domain. I wish all the best to the authors and readers of this book in their successful research of WiMAX technology.

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