On 5G Projects for Urban Railways

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***Abstract*—The paper is devoted to 5G project proposal for urban railways. It is obvious, that all the developments in 2018 should follow the digital railway model. As per the European Commission, it means the creation of connected railways by providing reliable connectivity for safe, efficient and attractive railways, enhancing customer experience, value added for customers, increased capacity by enhanced reliability, efficiency, and performance of railways, and making the most of transport data. For all the above-mentioned goals, the connectivity presents a foundation allowing the digital transformation of railways. Therefore, 5G deployment here could be a critical issue. As a practical example, we discuss the upcoming Moscow urban railways project.**

I. Introduction

In this paper, we would like to discuss the future 5G deployment for urban railways in Moscow. In 2017, Moscow announced plans to create links between the existing radial rail routes into the city. At least five such routes are to be developed, with existing lines upgraded and large diameter tunnels bored where required (Fig 1).

Fig. 1. Moscow Central Diameters

The first phase would cover two ground routes, branded Moscow Central Diameters [1]. End-to-end journey times would be about 1 hour on both routes, with services running every 6 minutes, compared with less frequent and less regular services on the current lines [2].

Undoubtedly, this new development, which began in 2018, should follow the model of the digital railway. The European Commission defines the objectives of making railways digital [3]:

- offering connected railways by providing reliable connectivity for safe, efficient and attractive railways
- enhancing the customer experience by offering better and added value for customers
- increasing capacity by enhancing reliability, efficiency, and performance of railways
- boosting rail competitiveness by making the most of transport data

Here connectivity presents a foundation allowing the digital transformation of railways. The aim is to provide connectivity across the entire rail network and on all the different railway lines. Railways operators need highly available, stable and reliable network connectivity. What is important for urban railways, the technical requirements should cover tunnels connectivity and avoid any form of interference and cyber-threats.

Technically, Russian railways somehow missed GSM-R stages (at least, in mass adoption). So, the development of new 5G networks will offer a great opportunity for them by enabling the digital signaling, Internet of Things and better internet services for clients. In this paper, we discuss 5G prospects for Moscow Central Diameters.

The rest of the paper is organized as follows. On Section II, we discuss 5G and railways. In Section III, we target railway communication scenarios. In Section IV, we discuss so-called connected train. And in Section V, we describe the current proposal for Moscow urban rail.

II. 5G and Railways

It is no doubt, that safety-critical train operations require an evolution. The widely used GSM-R has already a predicted obsolescence by 2030. Keeping in the mind the five-year standard migration, rail industry will need a next-generation solution by 2025. Of course, the preferred options for railways operators are COTS solutions operated on a dedicated spectrum. Railways, as an industry, provides an own set of safety-related services. The better connectivity, of course,

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should be a key for increasing passengers comfort via better QoS for Internet inside trains.

In general, 5G follows the same design roadmap as 4G has from 3G and 3G from 2G. It means the improvements in data rate, delays and the number of connected devices. It is how we should move from 3G delivered 100Mbps in 3G to 10Gbps in 5G. For end-users, it is a pure speed increase, but for industrial applications, it could be an enabling technology for critical control applications (e.g. massive Internet of Things deployment).

European Rail Infrastructure Managers (EIM) is a sector association that represents the interests of European rail infrastructure managers. EIM provides a set of requirements for Future Railway Mobile Communication System (FRMCS). It should [4]:

- Be cost effective and use "Commercial off the shelf" solutions
- Ensure vendor independence and bearer independence
- Be future proof, and provide a long-term evolutionary solution for railways
- Offer flexibility in network usage and modeling (i.e. offer possibility to use private mobile networks, public mobile networks, Wi-Fi - networks, other technology networks with mobility, or hybrid solutions between those systems)
- Allow flexibility at the application level for the applications which are not critical for interoperability
- Ensure high availability of service at least equivalent to GSM-R
- Offer high robustness (also under mobility conditions) including robustness against interference
- Be interoperable (i.e. allow trains to function on mobile networks between countries, and allow co-existence between GSM-R and future technologies)
- Allow a seamless migration of voice and ETCS services to the new communication technology and allow efficient, effective and flexible usage of spectrum
- Be compatible with multiple harmonized types of technologies to allow the same train to run on different type of networks
- Be IP Based (Internet technology) to allow an easy and standardized interfacing with applications

In general, the train-specific service requirements are provided in technical report TR 22.989 'Study on Future Railway Mobile Communication System' as part of 3GPP SA1, which focuses on a gap analysis between existing 3GPP functions and Future Railway Mobile Communication System (FRMCS) user requirements [5]. Fig. 2 below describes a general architecture.

As per this document, railway communication services can be categorized into

- Train control services
- Maintenance services
- Railway specific services (such as Railway Emergency Call, functional addressing, and location-based addressing)
- Other services (providing train crews or train Drivers with information of train operation and internetworking with the existing railway communication systems)

This study categorizes all the use cases by considering inherent characteristics of railway applications. Specifically, the following categories of use cases are considered.

- Basic functionality
- Critical communication applications
- Performance communication applications
- Business communication applications
- Critical support applications
- Performance support applications
- Business support applications
- FRMCS System principles

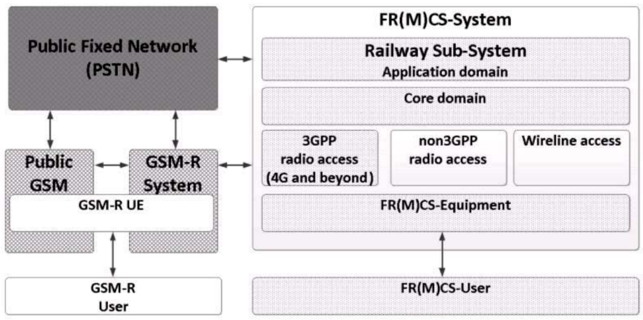

Fig. 2. TR 22.989 architecture [5]

In addition, there is the technical report TR 38.913 '5G RAN Scenarios and Requirements' [6]. It describes the various train-specific deployment scenarios for a future 5G radio access network (RAN). For example, it provides the requirements for radio parameters, such as carrier frequency, inter-site distance, user density and maximum supported mobility speed. It describes also the critical train communications as part of a high-speed scenario analysis.

There are three groups of beneficiaries for 5G on railways. Firstly, the consumers (passengers) will get reliable and consistent network experience. 5G will provide higher rates, better and more resilient system designs as well as lower costs to the operators due to flexible architectures. Also, 5G can act as a backhaul system for Wi-Fi in trains [7].

For railways operators, 5G lets traditional corporate services to work natively within the train ecosystem. It is what the above-mentioned use-cases from TR 22.989 are about. And higher rates (low delays) and reliability here are the key factors for IoT deployment. In particularly, it means the possibility to replace proprietary SCADA systems with some universal IoT data persistence layer shared with Smart City systems. Thus, the sensors and actuators from railway operators could be combined with those from Smart City systems. It is a very important unification for urban railways. It opens also the possibility for third-party vendors to use this information as well as offer own services to railways operators. So, third-party vendors are last group benefited from 5G deployment.

III. RAILWAY COMMUNICATION SCENARIOS

The picture below (Fig. 3) describes railway communication scenario [8]: train to infrastructure, infrastructure to infrastructure, inter-car, inside the station and wireless sensor networks.

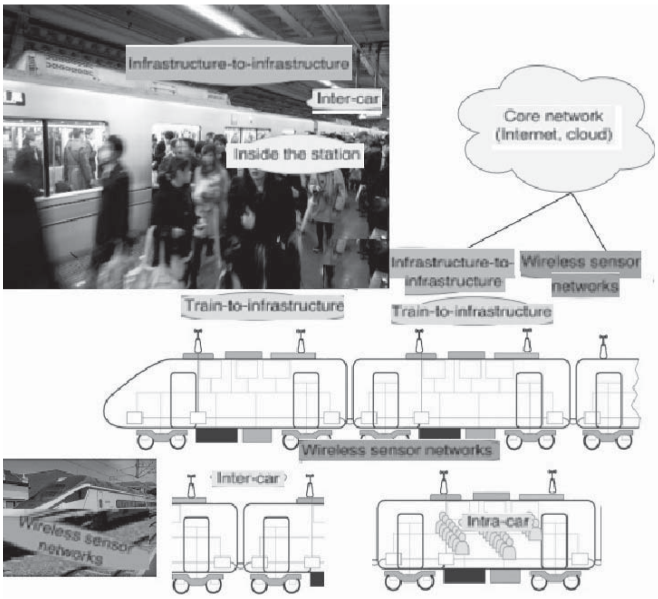

Fig. 3. Communication scenarios [8]

Technically, there are different types of communications. For example, train to infrastructure scenario requires two types of links among the Access Point (AP) transceivers located in the train and the fixed network infrastructure. Both links must be bidirectional, with high data rates and low latencies (e.g. lower than 100 ms) while AP is moved at speeds up to 100 km/h (for urban railways).

Inter-car communications could be wired (e.g. optical cable) or wireless. The APs could be placed in each wagon. In this case, every placed station acts as a client station for the AP in the previous car. Currently, the main technologies for inter-car communications are Wi-Fi (see remarks above for 5G backhaul).

Inside the railway station communications usually assume APs provided wireless connectivity to the users, who are typically interested, at the first hand, in broadband communication services. For such a purpose, a fixed/wireless communication infrastructure has to be deployed in the stations [8]. In this connection, massive MIMO technology is an appropriate choice for providing such kind of communications [9]. Actually, massive MIMO technology is a good choice for inside cars communications. Also, the transmission modes in massive MIMO can be adapted dynamically to the presence of multiple simultaneous users.

Infrastructure to infrastructure communications for railways assumes real-time modes with bi-directional links. The typical examples are data transfers between the IoT infrastructure and the APs deployed on the trains, and stations.

Wireless sensor networks are used in the various scenarios, where sensors can be on trains, stations, infrastructure, etc. In the connection with 5G deployment, we should note here the importance device to device (D2D) communications in 5G deployments [10].

D2D communications options let two devices exchange data without the involvement of the base station or with just a partial aid from the base station [11]. Dislike to Wi-Fi and Bluetooth technologies, which can support peer to peer capabilities in the unlicensed band, with D2D communications the Quality of Service is controllable due to use of the licensed spectrum. It opens the door for a new generation of scenarios and services in 5G systems. We could name here the following services: device relaying, context-aware services (e.g. context-aware data discovery) [12], mobile cloud computing, etc.

D2D communication leads to dense spectrum reuse. The base station is no longer the traffic bottleneck between the source and destination.

Technically, four different types of D2D communications can be distinguished:

- Device relaying with operator controlled link establishment. In this case, any device can broaden the coverage of the base station and act as a relay node.
- Direct D2D communication with operator controlled link establishment. In this case, any pair of devices (network nodes) can directly communicate via D2D link, which is set up under the control of the operator.
- Device relaying with device controlled link establishment. In this case, both sides (both devices) are in charge of setting up a relaying infrastructure.
- Direct D2D communication with device controlled link establishment. In this case, any pair of devices can exchange messages via a link, which is established without an operator.

In our opinion, the first two options could form a base for a new IoT solution. As it is constantly mentioned, enabling IoT communications in the licensed band is essential to strengthening the support to mission-critical applications and group communications.

Railway-Specific Services and Requirements include:

- Voice Group Call Service (VGCS). It is about conducting group calls between trains or Base Stations, or between station staff and trackside workers.
- Voice Broadcast Service (VBS). It is about broadcasting recorded messages or to announce operations to certain groups of trains or Base Stations with the strong requirements to call set-up time.

- Functional addressing (FA). So, a train can be addressed by a number identifying its function.
- Location dependent addressing (LDA). So, calls from a train can be addressed based on its location.

Railway specific features include the set-up of urgent or frequent calls through single keystroke or similar; display of functional identity of calling/called party; fast and guaranteed call set-up; seamless communication support for high train speeds; automatic and manual test modes with fault indications; control over mobile network selection; and control over system configuration [8].

In Fig. 4, we present so-called European Rail Traffic Management System (ERTMS).

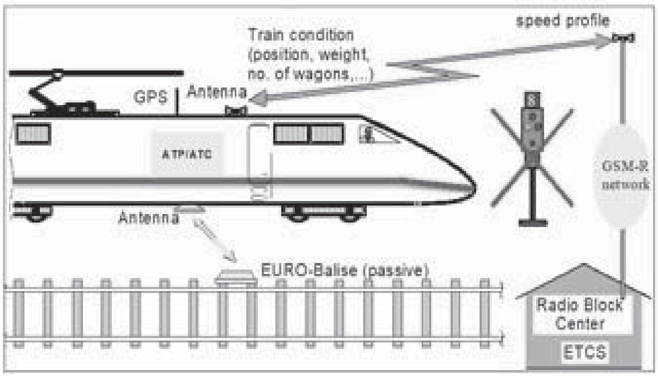

Fig. 4. ERMTS

It includes several elements, such as EURO-Balise - beacons tag that allows accurate positioning of the train, EURO-Cab - on-board management system that includes European Vital Computer, Driver-Machine Interface, and measurement devices such as odometers, etc. It has several levels, where Level 3 is a complete radio-based system with tags for position reference, but with the removal of track circuits / axle counters. Also, it facilitates moving block that allows trains to be close up when running at slower speed.

And sub-system of ERMTS is GSM-R (GSM-Railway). It is an international wireless communications standard for railway communication and applications. It is used for communication between train and railway regulation control center. As we have already mentioned, the life-time of the GSM-R has been determined until 2030.

IV. Connected trains

This term is used in two meanings. Firstly, it is a designation for supporting the Internet of things on trains. It is illustrated in Fig. 5.

This figure illustrates the various points of connection of monitoring systems in the train. Like many other elements for railways, this is also standardized.

Another interpretation, which is often used in conjunction with the word 'platform' (Connected train platform) describes a high-speed network (actually – networks) in the train. It is illustrated in Fig. 6.

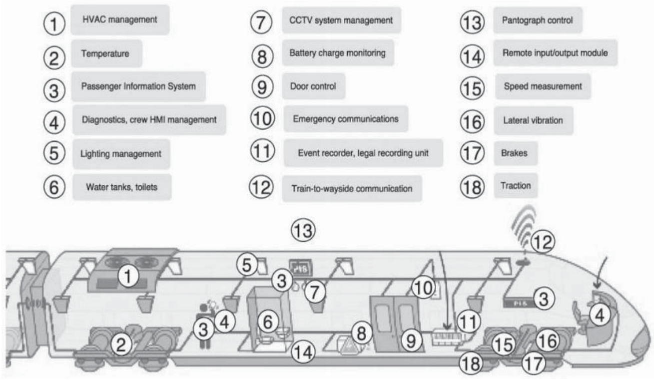

Fig. 5. Connected train [8]

It is a popular ATOS platform [13]. It supports three networks in the train. The Control Area Network (CAN) sends safety critical messages between the different components of the train such as the brakes or doors. Additionally, there is a network for the crew and separate network for the passengers. The crew and passenger networks may not have physical separation but instead may be virtual local area networks (VLAN). The crew and passenger network service is distributed around the cars using Wi-Fi access points. Today ATOS relies on IEEE802.11ac protocol, which should allow up to one gigabit per aggregate cell.

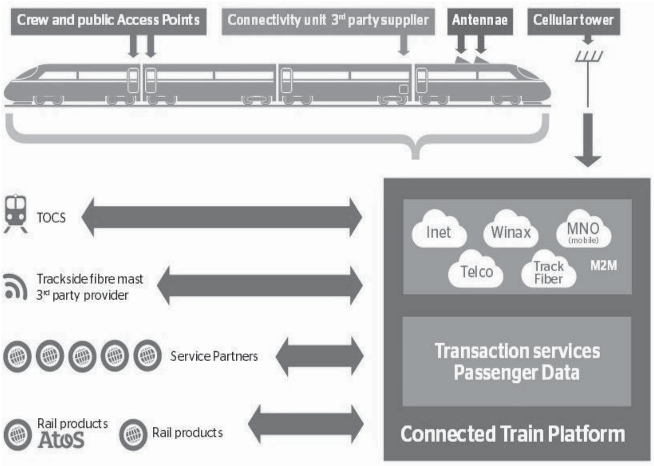

Fig. 6. Connected train platform [13]

All of these networks come together at a "connectivity unit". Connectivity unit is the component of the train that connects via radio communications to a fixed infrastructure. Data that is emitted or consumed by the train flows through this connectivity unit, which has read-only access to the CAN.

In terms of bandwidth, the Connected Train platform ATOS must offer 12 Mb/s to each passenger.

V. 5G and Moscow Diameters

In 2014, ETSI published two European Standards for Intelligent Transport Systems (ITS): the specification of Cooperative Awareness Basic Service - EN 302 637-2, and the specification of Decentralized Environmental Notification Basic Service - EN 302 637-3. They define the message sets needed for running Cooperative ITS safety-critical applications [14].

The Cooperative Awareness Service enables the exchange of information between road users and roadside infrastructure, providing each other's position, dynamics, and attributes. Road users here may be cars, trucks, motorcycles, bicycles or even pedestrians, while roadside infrastructure equipment includes road signs, traffic lights or barriers, and gates. Awareness of each other is the basis for several road safety and traffic efficiency applications, and it is achieved by regular exchange of information from vehicle to vehicle (V2V), and between vehicles and road side infrastructure (V2I and I2V) based on wireless networks. This specification defines the syntax and semantics of the Cooperative Awareness Message (CAM), as well as provides detailed specifications on the message handling.

The second standard, EN 302 637-3 defines the Decentralized Environmental Notification (DEN) Basic Service that supports road hazard warning. The Decentralized Environmental Notification Message (DENM) contains information related to a road hazard or an abnormal traffic condition, including its type and position. Typically for an ITS application, a message is disseminated to ITS stations that are located within a geographic area through direct V2V or V2I communications, in order to alert road users of a detected and potentially dangerous event.

So, the modern development for urban rail should follow the standards. For urban rails, ETSI Technical Committee Railway Telecommunications presents a solution for the shared use of spectrum between Communication Based Train Control (CBTC) and ITS applications based on ETSI ITS-G5 in the band 5 855 MHz to 5 925 MHz [15].

The primary public objective of CBTS system is to provide urban rail and regional railway operators with a means to control and manage the train traffic on their own networks. Metro lines which are operated at a high level of performance and short intervals between successive trains are now installing CBTC systems.

CBTC is a wireless Automatic Train Control (ATC) system, more flexible and cost-efficient than traditional ATC. CBTC systems are deployed on urban and suburban train on dedicated tracks. The standard IEEE 1474.1 gives the following definition:

A CBTC system is a continuous, automatic train control system utilizing:

- high-resolution train location determination, independent of track circuits;
- continuous, high-capacity, bidirectional train-to-wayside data communications;
- train borne and wayside processors capable of implementing automatic train protection (ATP) functions, as well as optional automatic train operation (ATO) and automatic train supervision (ATS) functions.

CBTC application requirements are defined in the standard IEEE 1474.1.

CBTC systems allow running trains only 90 seconds apart with total safety for the passengers and the staff (or even less, the headway depending upon time spent by the train at every station for passengers to leave and board trains, the distance between stations and profile of the line as well as the possible acceleration, maximum speed and deceleration of the train) [14]. So, for urban rail with the interval schedule, it is a critical system.

In the band 5 905 MHz to 5 925 MHz all sharing proposals assume that CBTC urban rail safety-related applications will have a prioritization over the C-ITS applications. In the band 5 875 MHz to 5 905 MHz C-ITS will have the priority. In the band 5 855 MHz to 5 875 MHz both systems are treated equally.

ETSI TR 103111 [16] defines spectrum requirements for Urban Rail Systems in the 5.9 GHz range. The requirements depend on the type of urban rail application (Fig. 7): safety/non-safety.

The required power level (EIRP) range is from 3 dBm to 33 dBm to achieve communication distances of up to 1 000 m. The related maximum power spectral density (EIRP) is 23 dBm/MHz.

In this connection, we should mention such technology as network slicing. By slicing a physical network into several logical networks, network slicing can support on-demand tailored services for distinct application scenarios at the same time using the same physical network. The main idea is that with network slicing support, network resources can be dynamically allocated to logical network slices according to QoS requirements and demand.

As the promising techniques for network slicing the scientific community mentioned mostly Software Defined Networks (SDN). The slicing could be implemented on the base of Network Function Virtualization (NFV). NFV replaces the traditional network elements (e.g. mobility management entity, policy and charging rules function, packet/service-gateway, etc.) with software servers, which also host the functions of dedicated physical infrastructures.

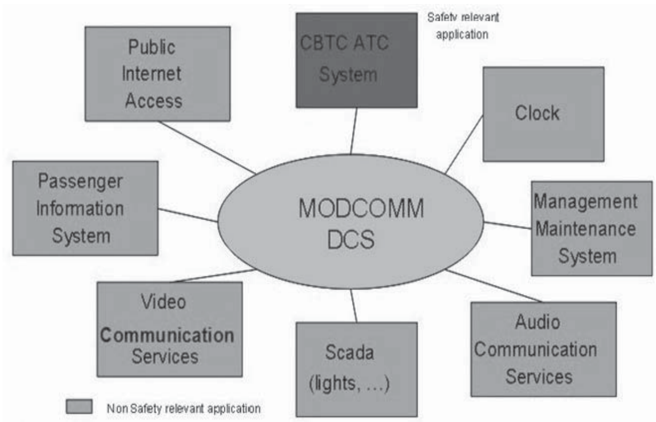

Fig. 7. Urban rail applications [15].

Also, all researchers agree that Ultra-dense network is a promising technique to satisfy the requirements of explosive data traffic in 5G mobile communications. E.g., when overlaid on top of the macro-cells, low power small cells (such as femtocell and pico-cell) can improve the coverage and capacity of cellular networks by exploiting spatial reuse of the spectrum [17].

Low power small cells can improve the coverage and capacity of the 5G systems by shortening the distance between a transmitter and receiver.

So, in terms of infrastructure, the current version of the project follows to proposals presented in [18]. The shared pico-cell layer could provide benefits of future passenger-oriented deployment by telecoms along railways tracks. And additional antennas on millimeter wave bands will offer enough capacity (Fig. 8).

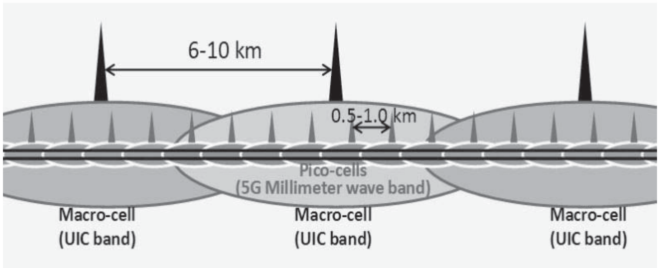

Fig. 8. Pico-cells [18]

Main QoS requirements could be not worse than current GSM-R requirements. For example:

Connection establishment delay	<8.5s (100%)
Connection establishment error ratio	$<10^{-2}$ (100%)
Connection loss rate	$<10^{-2}$/h (100%)
Maximum end-to-end transfer delay	<0.5 s (100%)
(30 bytes data)	
Error free period	>7s (100%)
Call setup time	<10s (100%)

VI. Conclusion

In this paper, we describe the current state of telecom proposals for railways. Undoubtedly, 5G technology is critical for the railway in terms of supporting the technology of a connected train and, more broadly, of the Internet of Things technologies. The positive point is that in the case of urban railways, a high-speed network is needed to support a limited and often even physically separate territory. Another positive aspect is the availability of a clear specification of the required services.

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References

[1] Namiot, Dmitry, et al. "On the assessment of socio-economic effects of the city railway." *International Journal of Open Information Technologies* 6.1 (2018): 92-103.

[2] Moscow REP http://www.metro-report.com/news/single-view/view/putin-approves-moscow-rer.html Retrieved: Feb, 2018.

[3] A roadmap for digital railways http://www.cer.be/sites/default/files/publication/A%20Roadmap%20for%20Digital%20Railways.pdf Retrieved: Feb, 2018

[4] Future Railway Mobile Communication System EIM expectations and key challenges http://www.eimrail.org/uploads/news/2016-12-EIM-FRMCS%20position%20paper.pdf Retrieved: Feb, 2018

[5] TR 22.989 'Study on Future Railway Mobile Communication System https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3109 Retrieved: Feb, 2018

[6] TR 38.913 '5G RAN Scenarios and Requirements' http://www.etsi.org/deliver/etsi_tr/138900_138999/138913/14.02.00_60/tr_138913v140200p.pdf Retrieved: Feb, 2018

[7] Zhang, Haijun, et al. "Coexistence of Wi-Fi and heterogeneous small cell networks sharing unlicensed spectrum." *IEEE Communications Magazine* 53.3 (2015): 158-164.

[8] Fraga-Lamas, Paula, Tiago M. Fernández-Caramés, and Luis Castedo. "Towards the internet of smart trains: a review on industrial IoT-connected railways." *Sensors* 17.6 (2017): 1457.

[9] Elijah, Olakunle, et al. "A comprehensive survey of pilot contamination in massive MIMO—5G system." *IEEE Communications Surveys & Tutorials* 18.2 (2016): 905-923.

[10] Palattella, Maria Rita, et al. "Internet of things in the 5G era: Enablers, architecture, and business models." *IEEE Journal on Selected Areas in Communications* 34.3 (2016): 510-527.

[11] Tehrani, Mohsen Nader, Murat Uysal, and Halim Yanikomeroglu. "Device-to-device communication in 5G cellular networks: challenges, solutions, and future directions." *IEEE Communications Magazine* 52.5 (2014): 86-92.

[12] Namiot, Dmitry, and Manfred Sneps-Sneppe. "Context-aware data discovery." In *Intelligence in Next Generation Networks (ICIN)*, 2012 16th International Conference on. IEEE, 2012.

[13] ATOS Connected train platform https://atos.net/wp-content/uploads/2017/10/01042013-AscentWhitePaper-ConnectedTrain.pdf Retrieved: Feb, 2018

[14] ETSI publishes European Standards for Intelligent Transport Systems http://www.etsi.org/news-events/news/851-2014-12-press-etsi-publishes-european-standards-for-intelligent-transport-systems Retrieved: Feb, 2018

[15] Railways Telecommunications (RT) Shared use of spectrum between Communication Based Train Control (CBTC) and ITS applications http://www.etsi.org/deliver/etsi_tr/103400_103499/103442/01.02.01_60/tr_103442v010201p.pdf Retrieved: Feb, 2018

[16] Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference document (SRdoc); Spectrum requirements for Urban Rail Systems in the 5,9 GHz range http://www.etsi.org/deliver/etsi_tr/103100_103199/103111/01.01.01_60/tr_103111v010101p.pdf Retrieved: Feb, 2018

[17] Zhang, Haijun, et al. "Fronthauling for 5G LTE-U ultra dense cloud small cell networks." *IEEE Wireless Communications* 23.6 (2016): 48-53.

[18] David Mottier. How 5G technologies could benefit to the railway sector: challenges and opportunities. https://docbox.etsi.org/Workshop/2016/201611_MANAGING_RAIL_MOBILE_COMMS/S03_ATTRACTIVENESS_FUTURE_OTHER_TECHNO/BENEFITS_5G_TECHNO_RAILWAY_SECTOR_MOTTIER_MERCE.pdf Retrieved: Feb, 2018.