Railway Association of Canada
Association des chemins de fer du Canada

Canadian Rail Communication:
Beyond 2020

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NOTE: The author of this white paper made every effort to identify sources of information, which are indicated throughout the report by citation.

EXECUTIVE SUMMARY

The Canadian Railway Industry

The Canadian rail network is the 5th longest in route-miles operated[1]; freight rail moves more than $280 billion worth of goods across our country each year, while passenger railways transport close to 82 million passengers annually[2]. The Railway Association of Canada (RAC) and its members are currently examining ways to improve railway communication and railway safety using modern communication technologies. This requires looking at various options, such as wide-band spectrum to accommodate train control applications and to increase its voice and data capability in railway yards and rights of way in congested areas.

Train Control Requirements

In June 2013, the Transportation Safety Board of Canada (TSB) released its investigation report (R12T0038) into the derailment of VIA Rail passenger train no. 92 near Burlington, Ontario, in 2012. One of recommendations in the report was the following:

“The Department of Transport require [sic] major Canadian passenger and freight railways implement physical fail-safe train controls, beginning with Canada’s high-speed rail corridors.[3]” (Recommendation R13-01)

Following this recommendation, Transport Canada’s Advisory Council on Railway Safety (ACRS) established the Train Control Working Group. It was given the mandate to study existing and developmental fail-safe train control systems—also known as Enhanced Train Control (ETC)—and evaluate their suitability for Canada’s railway operations, with a special focus on high-speed rail corridors. The Working Group was tasked to summarize its findings with a focus on how technologies and systems could best address TSB Recommendation R13-01. Although no specific technology or combination of technologies have yet to be determined, a common factor among all technologies reviewed by the Working Group was the need for a reliable wireless communication infrastructure to support ETC.

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1 https://data.worldbank.org/indicator/IS.RRS.TOTL.KM?end=2015&locations=CA&name_desc=false&start=2013.
2 http://www.industryandbusiness.ca/sustainability/pulling-canada-towards-a-cleaner-future.
3 http://www.bst-tsb.gc.ca/eng/rapports-reports/rail/2015/r15v0183/r15v0183.asp.

Current Situation

In term of mobile wireless communication technologies, with a few exceptions, Canadian railways still rely on decades old technologies for their operations; the North-American standard for voice communication is FM voice analogue, which is very reliable and well suited for rail, but also spectrally inefficient. Even as we introduce new technologies such as narrow band and digital very narrow band modulation to increase spectrum efficiency, the very nature of rail's main radio spectrum band, a 1.41 MHz block of contiguous spectrum in the VHF band, will never allow any room to grow.

High Speed Mobile Data

High Speed Mobile Data (HSMD) is a commodity that every citizen takes for granted: anyone within the coverage area of a commercial service provider, a smartphone and a data plan has access to this service.

- In Europe and in many Asian countries, various partnerships between rail and Commercial Service Providers (CSP) allows for railways to benefit from HSMD since the early 1990's, mainly through a technology derived from Global System for Mobile communication (GSM) called GSM-R (R is for railway). CSPs and manufacturers are phasing out this second-generation cellular technology (2G) to move to the fourth generation of broadband cellular network technology (4G), also known as Long Term Evolution (LTE).
- **In Canada**, GSM-R and full reliance on CSPs for rail communications was never considered as a viable alternative to the existing VHF radio network, for obvious geographic, demographic and operational reasons. However, the current private telecommunication infrastructure built along right of ways and in rail yards that allows train operation from coast-to-coast-to-coast could, with a few modifications, support a nation-wide LTE-based HSMD network.

Radio Spectrum Requirements

HSMD over LTE can be achieved through broadband spectrum, at minimum 3 + 3 MHz, more than four times the spectrum currently assigned to rail in Canada. The standard block size assigned by Innovation, Science and Economic Development Canada (ISED) is 5 + 5 MHz.

Furthermore, railways must seek spectrum in a band that is compatible, as much as possible, with existing network infrastructures. The propagation characteristics of the spectrum must also be compatible with railway operations. There are currently two "available" bands that meet those requirements: 600 MHz and 700 MHz.

Next Steps and Recommendations

1. **Look at the 600 MHz band**

Through its October 2nd, 2017 response to the Consultation on a Technical, Policy and Licensing Framework for Spectrum in the 600 MHz Band[4], the RAC indicated the railway industry's interest in acquiring a block of 5+5 MHz spectrum for rail HSMD[5]. Although ISED's intent is to auction all seven blocks to CSPs, auction of 600 MHz is probably at least two to three years away, so there is room for discussion on the possibility of allocating a spectrum block at 600 MHz for railways. RAC is currently waiting for a response from ISED.

2. **Look at the 700 MHz band**

ISED allocated two contiguous 5+5 MHz of spectrum in the 700 MHz to the Public Safety community earlier this year[6], and indicated that they were open to suggestions on how this spectrum could be shared with non-public safety organizations, such as rail, as well as how the private industry could contribute to the development of a nation-wide shared public safety network. The railway industry should also consider this option, although it could prove to be challenging for both the rail industry and the public safety community to share not only spectrum, but also material infrastructures. A face-to-face meeting between Transport Canada (TC), ISED and the RAC should be organized to discuss the issue.

3. **Look for and facilitate partnerships between railways and with vendors, Communication Service Providers and the Public Utility Sector**

The RAC should initiate discussions with potential partners outside the railway industry. Through a LTE capability known as "network slicing", which allows multiple logical networks to be created on top of a common shared physical infrastructure[7], networks can be shared seamlessly amongst different services and competing entities (such as CN and CP). Furthermore, ISED looks favorably at initiatives that can both maximize the utilisation of radio spectrum and the sharing of infrastructures, especially antenna towers. The RAC should seek the support of both TC and ISED on the issue of partnership.

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4 https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11316.html.

5 https://www.ic.gc.ca/eic/site/smt-gst.nsf/vwapj/SLPB-005-17_comments_RAC.pdf/$file/SLPB-005-17_comments_RAC.pdf.

6 Decisions on Policy, Technical and Licensing Framework for Use of the Public Safety Broadband Spectrum in the Bands 758-763 MHz and 788-793 MHz (D Block) and 763-768 MHz and 793-798 MHz (PSBB Block).

7 https://www.ericsson.com/en/networks/topics/network-slicing.

1. Introduction

This white paper was commissioned by the Railway Association of Canada (RAC) to examine current railway radiocommunication systems and report on advances being made globally to improve railway traffic control, passenger safety and security. It also examines current spectrum usage and future needs, as well as the possible use of global or regional harmonized frequency bands. This white paper is also designed to support the railway industries' discussions with ISED on future spectrum needs for Canadian railways.

2. Present System

2.1 Canada's Railway Network

Canada's rail network stretches from coast-to-coast-to-coast. The country's two Class 1 railways, CN and CP, run separate networks, although they sometimes share tracks. (CN and CP's rail network are shown in Appendix A.) VIA Rail Canada, the national passenger railway, also uses both CN and CP's networks for passenger trains. Some of its routes are seasonal, while others are year-round. (All VIA routes are also shown in the map in Appendix A.)

As VIA considers introducing high-speed service in its Québec City–Windsor corridor, it is essential that communication requirements are assessed well in advance as it may take time to negotiate additional radio spectrum to support new technologies.

2.2 Wireless Technologies

Today's trains make use of wireless technologies ranging from Wi-Fi to GSM-R to satellite to 4G cellular. In the last decade, commercial wireless technologies have evolved from voice-centric 2G systems (such as GSM) with limited data transmission capabilities to 4G broadband multi-service systems (LTE) that offer users several tens of Mbit/s of data. In fact, the broadband capability of 4G is sparking the creation of new services and applications that are changing the way consumers entertain themselves, communicate and get information.

For many years, the rail industry has relied on wireless systems for operational applications. Initially, they depended mainly on voice systems that used VHF frequencies. But since then, many mainline railway operators—particularly in Europe—have deployed GSM-R and Terrestrial Trunked Radio (TETRA) networks for both operational voice communications between train drivers and train controllers, as well as for train signalling (communications-based train control/European Train Control System). Urban transport authorities have also deployed various specialized, and often proprietary, wireless systems, as there is usually a system for signalling and control in unlicensed bands and another for operational voice. However, these systems have limited data capabilities. This significantly limits their potential to enhance operational efficiency and passenger security and, ultimately, the quality of transport[8].

[8] http://www.etsi.org/technologies-clusters/technologies/rail-communications.

Figure 1.1 provides a simple structure of mobile communications technologies. Typically, all modern mobile wireless technologies have three main components:

- the **core,** which provides user management and user functionalities and manages the mobility
- the **Radio Access Network (RAN),** which connects the core with the user's equipment using wireless communications
- the **user equipment (UE)**, which provides the user services and user experiences as ordained by the core

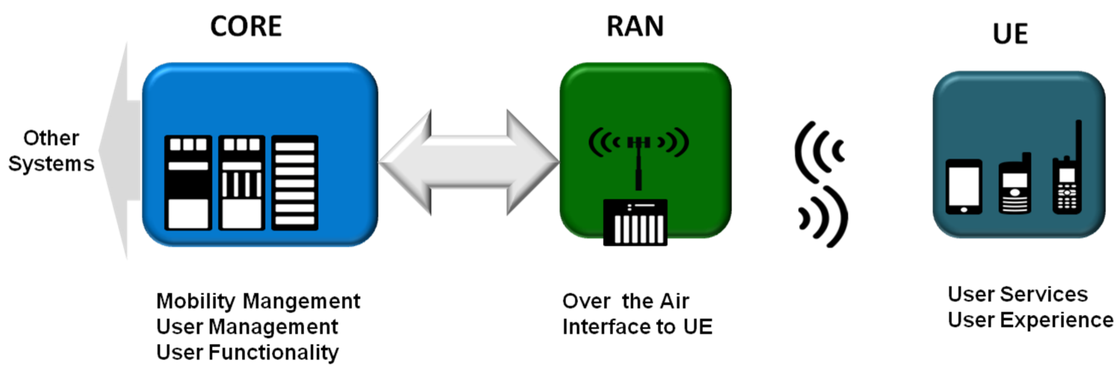

Figure 1.1 Typical Three Components of Radio Network[9]

All trains with radio equipment currently comply with North American railway radio system requirements. The rail industry has an allocated block of dedicated frequency band (VHF frequencies 160.1700 MHz to 161.5000 MHz) which is managed by the RAC in Canada. In addition to VHF, VIA Rail uses UHF (450-470 MHz) for its yard operations and also has a second radio in the locomotive to use to communicate with onboard crew. CN and CP both deploy VHF frequencies according to North American railway radio requirements. In addition, they also deploy:

- 452 and 457 MHz channels for End of Train Devices, which report when the train is moving, air pressure and emergency status of the air valve along with a specific radio ID
- 450MHz frequencies to control trains using DP or Distributive Power (remotely controlled locomotives) and to transmit information, such as power or brake setting, unit ID and other status information[10]
- 900MHz for train control and 450 MHz for Locotrol
- 2.4 GHz and 5.8 GHz for Wi-Fi on passenger trains as well as freight trains in yards
- GPS for time and location
- 911.5 MHz to 921.5 MHz for freight tracking used for Automatic Equipment Identifiers (AEI), a robust version of RFID implemented on rolling stock
- 220 MHz spectrum for PTC operations on all locomotives travelling to the US (see Section 2.3)

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[9] Motorola Solutions

[10] http://www.radioreference.com/apps/db/?aid=7747.

Although each of the above frequencies serve a specific purpose, none have the ability to grow enough to accommodate HSMD.

GO Transit, the regional public transit service for the Greater Toronto and Hamilton Area, complies with the North American VHF railway plan and also uses UHF frequencies to coordinate between its bus and train fleets. Since there are two different radios in their locomotives, a special integrated control unit is provided to manage both UHF and VHF radios. Microwave and fibre connect the remote radio sites; the network also has Digital Vehicle Repeaters, which are used for enhancing portable radio coverage.

2.3 Positive Train Control in the US

Positive Train Control (PTC) is a set of highly advanced technologies designed to make freight rail transportation safer by automatically stopping a train before certain types of accidents occur. At this time, PTC is only used in the US. However, because of trans-border crossings, many Canadian locomotives are also equipped with PTC radios. Although there is no dedicated service for PTC by the Federal Communications Commission (FCC), railways have selected the 220MHz spectrum to operate it.

The technology was originally developed to prevent train-to-train collisions, derailments caused by excessive speeds, trains from entering sections of track where maintenance activities are taking place, or a train moving through a track switch left in the wrong position. However, PTC **will not** prevent accidents caused by track equipment failure, improper vehicular movement through a grade crossing, trespassing on tracks, or some types of train operator error.

There are three main elements of a PTC system, which are integrated by a wireless communications system[11]. They are:

- **the onboard or locomotive system**, which monitors the train's position and speed and activates braking when necessary to enforce speed restrictions and unauthorized train movement into new sections of track
- **the wayside system,** which monitors railway track signals, switches and track circuits to communicate authorization for movement to the locomotive
- **the back-office server,** which stores all information related to the rail network and trains operating across it—such as speed limits, track composition, speed of individual locomotives, and train composition—and transmits the authorization for individual trains to move into new segments of track

The PTC220 radio is a time-division duplexing (TDD) simplex radio operating on 25 KHz channel. It is capable of supporting three different modulation schemes depending upon the requirement and the device. There is one common channel which uses CSMA modulation and the remaining TDD channels will be either full rate (32 Kbits) or half rate (16 Kbits). Figure 2.1 details the characteristics of the three main elements of a PTC system.

[11] https://www.aar.org/policy/positive-train-control.

	Wayside Radio	Locomotive Radio	Base Radio
Application	Fixed remote installations	Mobile remote installations	Base station installations
Frequency Band	217.6 - 222.0 MHz	217.6 - 222.0 MHz	217.6 - 222.0 MHz
TX Modulation	4FM, 16kbps	4FM, 16kbps π/4DQPSK, 32kbps	4FM, 16kbps π/4DQPSK, 32kbps
RX Modulation	4FM, 16kbps π/4DQPSK, 32kbps	4FM, 16kbps π/4DQPSK, 32kbps	4FM, 16kbps π/4DQPSK, 32kbps
Channel Spacing	25kHz	25kHz	25kHz

Figure 2.1 Characteristics of PTC Radio[12]

2.4 CELLULAR/ WI-FI

In recent years, cellular communications have become one of the most popular platforms railways are using due to its convenience, ease of use and relatively low maintenance. For example, CN uses cellular to download information from wayside locations, pull information from wayside equipment inspection systems, or access base radio stations off main and branch lines. Workers also use a cellular connection to obtain track authorities, access emails and track inspection requests. Furthermore, some of CN's locomotive systems—such as GE Transportation's Trip Optimizer, and New York Air Brake Corporation's Locomotive Engineer Assist/Display and Event Recorder, and Wi-Tronix L.L.C.'s Fuel Efficiency Monitor—operate with a cellular connection[13].

As for almost every place of business today, Wi-Fi is widely used by the railway industry to access corporate networks and the Internet. However, due to the nature of this widely used, unlicensed radio band, its reliability and latency are not compatible with mission critical rail applications.

[12] Provided by Enzo De Benetti, CN.
[13] http://www.progressiverailroading.com/csx_transportation/article/Railroad-communications-technology-from-cellular-to-radio-to-satellite-to-Wi-Fi--30947

On board Wi-Fi for passenger rail

Via Rail introduced the first generation of Wi-Fi in the late 1990s. These were experimental systems that connected trains to networks via satellite links and were introduced as a service to passengers in 2006. Although the service worked reasonably well, it had some technical issues, which were resolved in time. The map below shows where this service is available.

Figure 2.2 Wi-Fi Service Area[14]

In January 2011, VIA Rail introduced a new state-of-the-art Wi-Fi system along the Québec City–Windsor corridor. Since then, all trains running in this corridor have been equipped with Wi-Fi. This system keeps passengers connected with a 99.5 per cent coverage rate between Québec City and Windsor.

14 http://www.viarail.ca/en/travel-information/board-services/free-wifi.

One of the front-most cars of each train set (otherwise known as the "brain car") carries eight antennas on its roof that transmit the Wi-Fi signal (Figure 2.3). If the signal is weak around one antenna, it will often be strong around one of the other seven, translating into fewer dropped signals and faster downloads. Each of the other cars in the set is connected to the "brain car" via a high-speed inter-carriage link, which results in a strong connection from the front to the back of the train and reliable service for all passengers in every car.

Figure 2.3 VIA's Antenna Configuration

A key reason for the reliability of VIA's system is the fact there are three wireless service providers along the Québec City–Windsor corridor. Instead of depending on any single provider, VIA aggregates all three. The train's Wi-Fi system is constantly scanning the signals and choosing the strongest one in any given area. As a result, there are virtually no "black holes" along the route[15].

3. Global Outlook

In 2015, the International Union of Railways (UIC) began working on the user requirements specification (URS) for its Future Railway Mobile Communications System (FRMCS), which will replace GSM-R. The UIC was motivated to replace GSM-R due to its obsolescence, narrow band performance and issues of adjacent band interference.

The requirements necessary for FRMCS are being developed by the 3rd Generation Partnership Project (3GPP) standardization bodies (3GPP is a collaborative project aimed at developing globally acceptable specifications for third generation, or 3G, mobile systems) to ensure the entire URS is covered within the LTE standards. Under the current plan, GSM-R's replacement will be available from 3GPP Release 15, which is expected to deliver the first set of 5G standards sometime in the second half of 2017.

[15] Info provided by: Frederik Chevrier, VIA Rail.

Figure 3.1 shows all the technologies currently being used in Europe, China, Japan, and South Korea, as well as the technologies used for different requirements of railway operation[16].

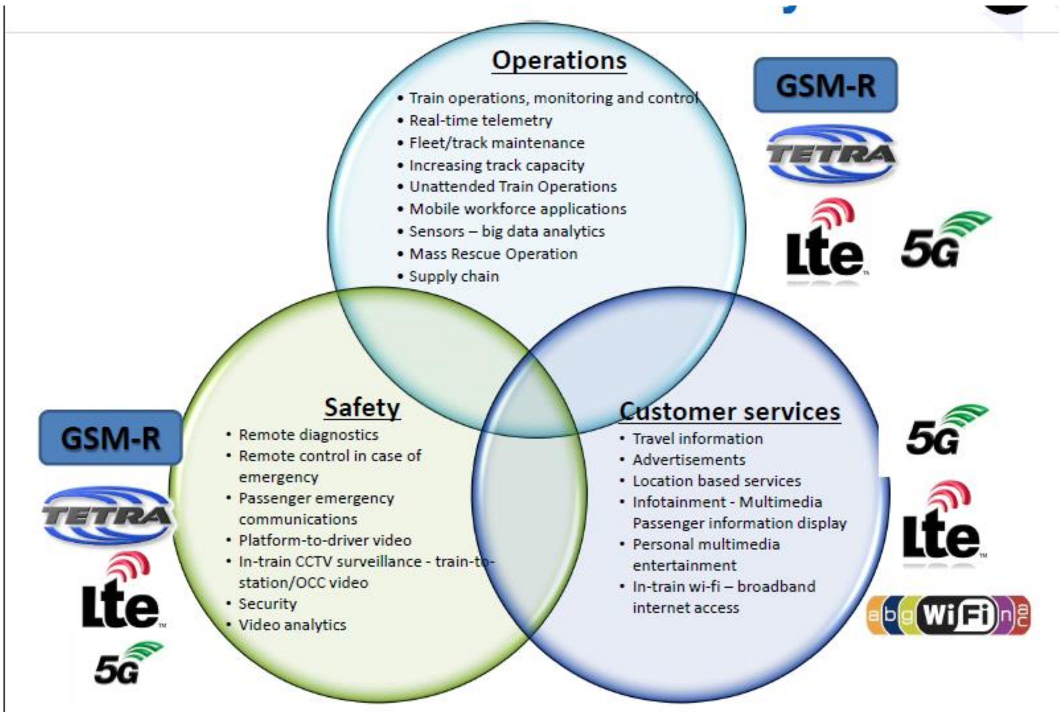


Figure 3.1 Current Global Railway Technologies[17]

There is no doubt 5G offers great opportunities for railways around the world. It will enable business travelers in particular to remain connected, accessing not just their email but also video, and enabling large data transfers. Leisure travelers will be able to download movies or play online games—even virtual reality on passenger trains will be possible in the future. With VIA Rail looking to introduce express service here in Canada, this increased connectivity, and the additional services it will allow, will appeal to passengers. However, these new technologies do not just offer passengers more flexibility and services when they travel. They will also greatly improve train efficiency and enhance rail safety.

[16] http://uic.org/gsm-r.
[17] Presentation Bharat Bhatia, Motorola Solutions to 38th WWRF Meeting.

4. Potential Spectrum for Railway Communication Beyond 2020

4.1 700 MHz – Public Safety

The 108 MHz of spectrum from 698 to 804 MHz was a block of 18 television channels that became available for mobile use after Canada switched from analogue to digital television in August 2011. Lower in frequency than the other radio bands already in use, it has longer wavelengths and better radio propagation characteristics.

While not necessarily faster, this spectrum has the advantage of better penetrating objects with less attenuation than the existing spectra. It is also able to travel longer distances, which reduces the need for expensive infrastructure such as base stations (including radio towers) for cellular networks. This can translate into lower costs for providers such as mobile network operators.

As previously stated, ISED held an auction of this spectrum in 2014 and it was bought by various service providers. It had been divided into seven licensed blocks in 14 areas, creating a total of 98 licences to sell. The band plan is shown below (Figure 4.1):

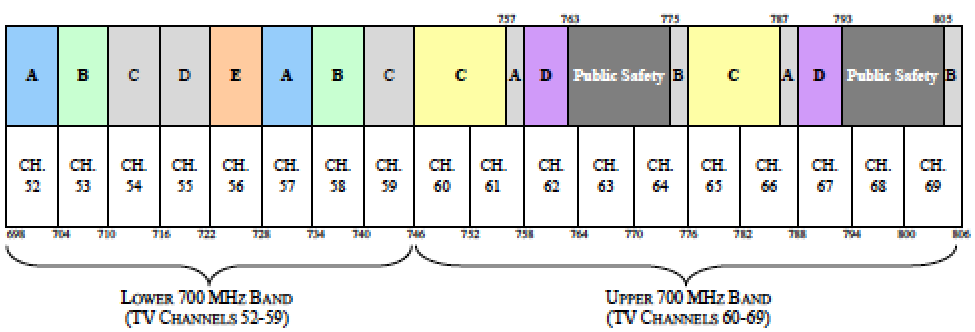


Figure 4.1 700 MHz Band Plan

However, ISED did not auction off D Block of the spectrum, deciding to instead carry out further consultations to determine how to best allocate it. ISED had already designated a 5 + 5 MHz block of spectrum in the 700 MHz band—known as the PSBB Block—for public safety broadband use. As the PSBB Block and the D Block are adjacent to one another in the 700 MHz band, ISED decided the two could be combined to form a paired 10 + 10 MHz block of spectrum, known as the “700 MHz public safety broadband spectrum” (see Figure 4.2).

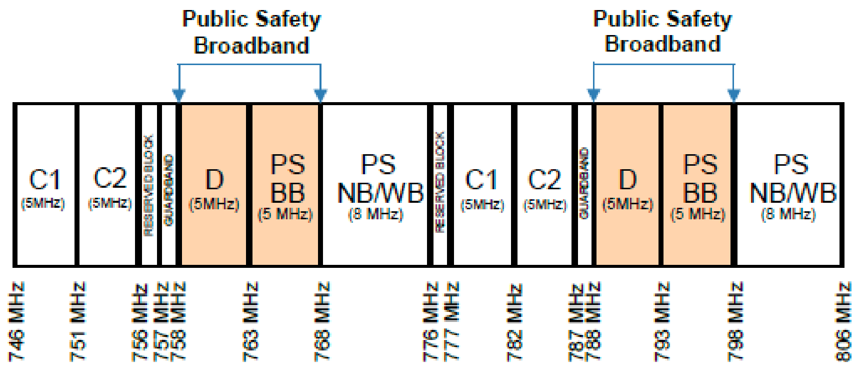


Figure 4.2 700 MHz Public Safety Band[18]

In June 2017, ISED published a Gazette Notice in which it made the following points regarding the shared use of this spectrum[19]:

- Permitting commercial usage of excess capacity from public safety spectrum could be a timely and affordable means to achieve public safety broadband requirements.
- Partnering with commercial service providers would enable infrastructure sharing and avoid unnecessary tower and cell site proliferation, since these operators already possess the necessary infrastructure to operate a broadband wireless network.
- Permitting commercial usage of excess capacity would make effective use of spectrum, although priority must be given to public safety users.
- Priority and pre-emption should be given to police, fire and emergency medical service agencies, but there is an opportunity to offer services to public safety users, such as utilities, transit, and health organizations.
- A technology-neutral approach is necessary to ensure national and cross-border interoperability. Priority and pre-emption capability for public safety services would provide flexibility to a licensee(s) to accommodate different technological solutions.
- Discussions must be held among all interested parties, including the FPT IWG, service providers and manufacturers, to develop recommendations with respect to the sharing of unused capacity of the 700 MHz public safety broadband spectrum with commercial users, priority and pre-emption criteria, and technical requirements to ensure nationwide interoperability, etc.

[18] http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11289.html.
[19] Ibid.

ISED Decision

For the public safety spectrum:
D-4: Commercial use of unused capacity will be allowed provided that public safety users will have priority and pre-emptive rights over any form of commercial usage.

D-5: ISED will not mandate specific technology, though any technology employed on the 700 MHz public safety broadband spectrum must ensure national and cross-border interoperability and ensure priority and pre-emption capability for public safety services and must be consistent with the interoperability solution "sharing standards-based systems.[20]"

It is important to note that D-4 and D-5 do provide a window of opportunity for the RAC to begin discussions with ISED and Public Safety to use the 700 MHz spectrum. However, the Canadian policy differs from the US approach when it comes to public safety spectrum. In the US, the government set up a body called FirstNet, which was responsible for building the public safety network. It negotiates with each state to build the network, although each state has the right to opt out and build its own. Canadian and US policy differences could create challenges when working with US railways.

Although ISED has published the Gazette Notice, no budget has been allocated by Public Safety, nor by provincial or municipal governments to deploy a public safety network. Current discussions are revolving around the possibility of a private public partnership (3P). Although it is believed that three major service providers are in discussions with the public safety community, no firm plan has yet to be decided upon. However, since three major service providers cover most urban and suburban areas of Canada with their 700 MHz spectrum, there is an opportunity for railways to roam onto their network.

Countries around the world, such as South Korea, already share spectrum between railways and public safety agencies (the Korean government allocated 10 MHz for public safety to be shared by railway operators), and in Europe, this possibility is being discussed. Other countries, like China, have dedicated spectrum for railways. Allocating a dedicated spectrum for railways would be a challenge in Canada—especially in the North—as operators have little or no resources to deploy LTE over their entire respective geographic areas. But sharing public safety spectrum would provide an opportunity for "like-minded" operators to meet common goals.

In addition, Canada's railways typically already have a communications infrastructure, whether fibre or microwave, as well as equipment rooms spread across their operating area (including tunnels). By sharing spectrum, the public safety agencies would gain coverage from the railway over areas which they could not otherwise afford to cover. In return, the railways would benefit by gaining use of the spectrum. The railway train control and CCTV application could fall under the umbrella of "public safety" and warrant the same level and quality of service as emergency public safety communications traffic[21].

[20] http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11289.html.
[21] Improving Rail Connectivity Through 3GPP Technology, Proceedings of the 2017 Joint Rail Conference JRC2017 April 4-7, 2017, Philadelphia,
PA, USA (ERICSSON PAPER).

RAC, along with Canada’s major railways, has an opportunity to take on a leadership role when it comes to discussions with ISED as well as Public Safety about spectrum use. It also has the opportunity to engage in a dialogue with ISED through a Request for Information based on the following four pillars:

- Business and operational models for an affordable and sustainable PSBN
- Meeting user and system requirements (e.g., national interoperability, coverage, priority and pre-emption)
- Policies, regulations and governance model
- Applications, services and device eco-system for PSBN

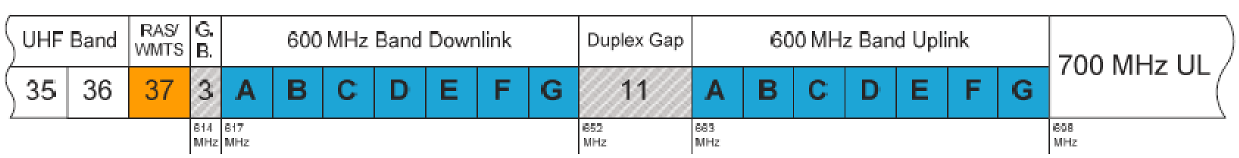
4.2 600 MHz

4.2.1 600 MHz Policy Issues

In 2014, ISED also issued a Gazette Notice for public consultations to repurpose spectrum in the 600 MHz band to mobile use. The spectrum was being used by over-the-air (OTA) TV broadcasting, remote rural broadband systems (RRBS), low-power apparatuses (such as wireless microphones and camera systems), television white space (TVWS) devices and wireless medical telemetry systems (WMTS). The goal of this consultation was to reallocate significant amounts of spectrum from broadcasters to mobile operators. (This spectrum is also used for radio astronomy service (RAS), but ISED is not considering any change to the allocation of spectrum to the RAS, band 608-614 MHz, at this time.[22])

In the US, the FCC has already auctioned 600 MHz. This auction brought in a total of USD$19.8 billion—the majority of which came from T-Mobile, which paid $7.9 billion to acquire 45 per cent of the new spectrum. As the carrier with the third-highest number of subscribers in the US, T-Mobile will initially use the spectrum to cover rural areas, since lower frequencies propagate further in distance than higher frequencies[23].

Canada’s 600 MHz Band Plan includes 70 MHz, or seven paired five MHz blocks, of licensed spectrum. The Plan (614-698 MHz) is comprised of an uplink band (663-698 MHz) and a downlink band (617-652 MHz) for the 600 MHz licences, a duplex gap (652-663 MHz) between these bands, and a guard band (614-617 MHz) between the downlink band[24]. Figure 4.3 shows the Plan.



[22] https://www.ic.gc.ca/eic/site/smt-gst.nsf/vwapj/SLPB-005-14E.pdf/$file/SLPB-005-14E.pdf.
[23] http://www.telecomtv.com/articles/5g-world/the-challenges-of-deploying-5g-15762/.
[24] https://apps.fcc.gov/edocs_public/attachmatch/DA-17-314A1.pdf.

Figure 4.3 600 MHz Band Plan[25]

4.2.2 600 MHz Propagation Properties

The higher the frequency of the radio signal, the shorter the distance it can travel through air. Conversely, the lower the frequency, the further it travels. Lower-frequency signals are also able to better penetrate things such as buildings, windows and trees. Mobile operators generally like higher frequencies because it is easier to control the propagation and keep the cell "small." More small cells over a given area means more capacity than a single cell. So, when an operator needs to increase the capacity in a given area, it will usually first add sectors to the macrocells and then try to put in small cells of one type or another.

4.2.3 Opportunities for Railways

The Canadian auction of 600 MHz is probably still at least two or three years away, but it presents an opportunity for RAC to begin discussions with ISED regarding the possibility of allocating a spectrum block at 600 MHz for railways. Access to this spectrum block would give Canadian railways the additional spectrum capacity needed to create a more modern rail communication system. However, negotiations and discussions will still have to take place with the US to address the fact they have already auctioned some of the 600 MHz.

5. Available and Potential Technologies for Railway Communication Beyond 2020

The latest wireless systems include many capabilities that exceed the possibilities envisaged when trunking radio systems and cellular radio were introduced in the early 1980s. These new wireless systems have capabilities for high-quality multimedia applications within a wide range of services and platforms, providing a significant improvement in performance and quality over previous services.

These systems work in low-to-high mobility conditions and a wide range of data rates in response to user and service demands in multi-user environments. Such systems provide access to a wide range of telecommunication services, including advanced mobile services supported by mobile and fixed networks. These systems are being supported by LTE technology that has been implemented across Canada and around the world. Carriers have upgraded their networks to advanced LTE (LTE-A) in large urban areas, with moderate to significant coverage in rural areas.

[25] http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11215.html.

Figure 5.1 shows the progression of technologies since 1980. Figure 5.2 shows how the capabilities of each generation have progressed, and Figure 5.3 demonstrates that data speed has increased with each generation.

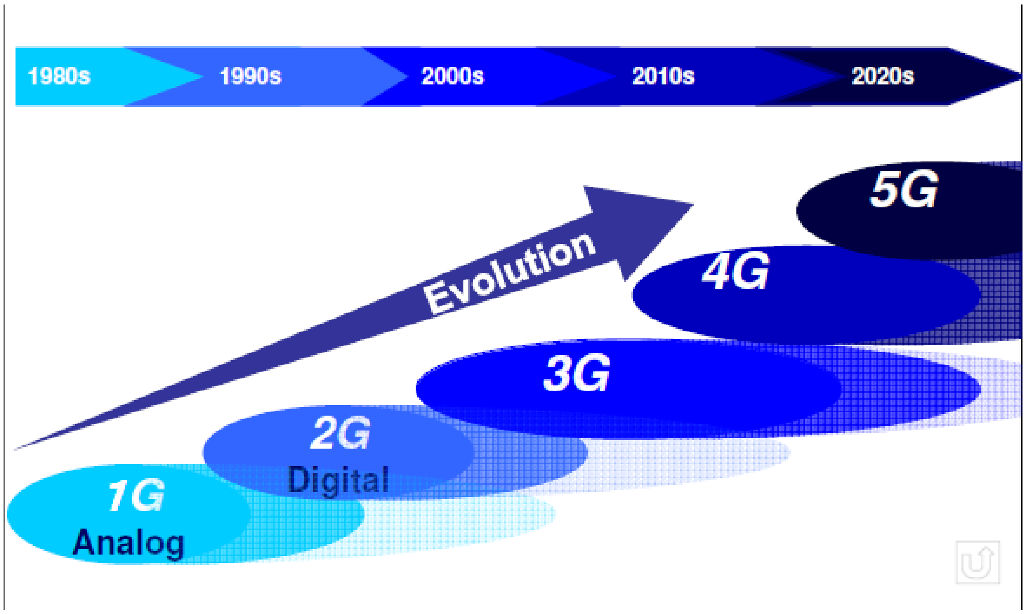


Figure 5.1 Progression of Technologies[26]

[26] NTT DoCoMo

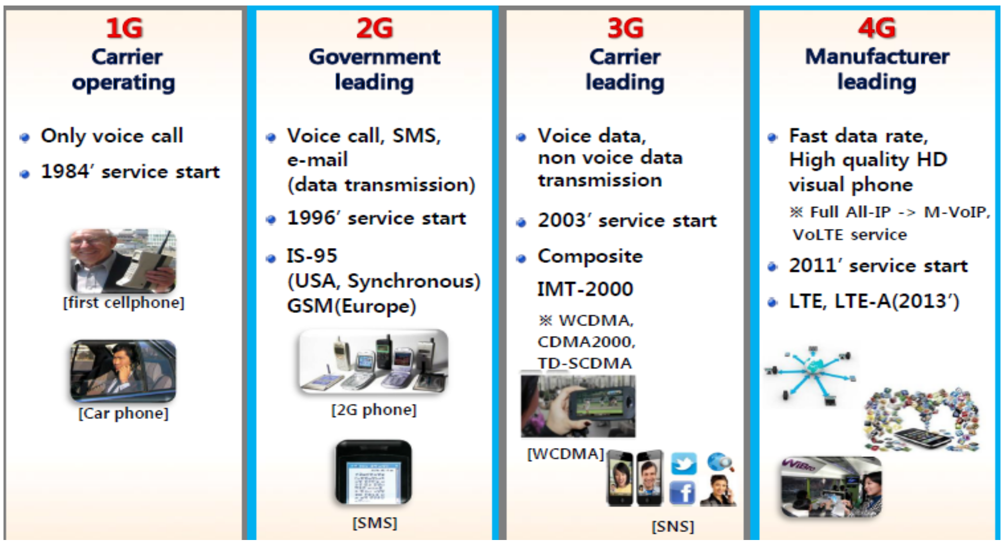


Figure 5.2 Technology Capability Progression[27]

Market impact	2003	2006	2009	2010	2016
Peak rate	384 kbps	7 Mbps	42 Mbps	~150 Mbps	~1 Gbps
Typical user rate downlink	~200 kbps	1–2 Mbps	2–10 Mbps	10–20 Mbps	~30–100 Mbps
Typical user rate uplink	64 kbps	64–884 Mbps	0.5–4.5 Mbps	5–10 Mbps	~10–60 Mbps

Wifi for supporting hot spot coverage

Figure 5.3 Data Speeds Over Generation

[27] 5G Forum Korea

In the last year, there has been growing interest in 5G, known as IMT 2020 in ITU. Vendors and service providers are trialling this technology with an expectation of early deployment in 2020.

The following sections outline some of the technologies that have already been deployed around the world or are being considered for deployment in the next decade.

5.1 GSM-R

GSM-R (or Global System for Mobile Communications – Rail) is used by railway systems around the world, particularly those in Europe, as an interoperable radio communications network for voice communications. In Europe, GSM-R is also used to provide the data communication bearer for European Train Control Systems (ETCS). Voice and data communications are also used for a number of other applications.

In North America, GSM technology was not considered until the mid-1990s. When cellular systems were introduced in Canada, the initial technology was analogue. Cellular networks evolved to digital before time-division multiple access (TDMA) was introduced. The first GSM network was introduced in Canada in 1996[28].

GSM-R is a modified technology based around GSM and designed to deliver specific railway communication requirements. Due to the product modifications required to provide "R" (or railway) functionality, and the need to utilize non-commercial radio spectrum, much of the equipment utilized for GSM-R comprises special-build equipment and/or software variants. The use of modified off-the-shelf technology for GSM-R has proven expensive for the railways, both in terms of capital and operational expenditure.

It is collectively accepted that GSM-R will be obsolete by 2030. The European railways have already produced a user requirements document and initiated work to identify a successor for GSM-R. The successor technology should integrate learnings from past experiences and comply with railway requirements. This document is one of the first steps in identifying and defining users' needs in a consistent and technology-independent way. It will also provide the foundation for next steps on defining the Future Railway Mobile Communications System (FRMCS)[29]. At the recent 3GPP plenary, a study item was also approved to investigate the requirements for a new railway communication system to succeed the GSM-R service[30].

With new requirements for railways, GSM-R is already facing many challenges, such as:

- The system life cycle is coming to an end, with vendor support uncertain beyond 2030
- Extra capacity is required in some areas to support railway operations

[28] http://www.fido.ca/consumer/aboutus.
[29] International Union of Railways – Future Railway Communication Requirements.
[30] 3GPP TSG-SA WG1 Meeting #74 S1-161588 Venice, Italy, 9 - 13 May 2016.

- The rollout of the European Rail Traffic Management System has increased strain on the GSM-R network

In an attempt to have a successor technology in place for trials by 2020, and ready to deploy by 2022, the UIC has published a user requirement specification in its paper, *Future Railway Mobile Communication System – FRMCS*. In response, 3GPP, the standard body (Working Group SA1), has begun an initial study that will pave the way to identify which FRMCS requirements are within their scope and to complete a gap analysis of existing functionality in Rel-14 and identify the work needed in 3GPP Rel-15[31].

5.2 TETRA

TETRA is an open standard developed by the European Telecommunications Standards Institute (ETSI). Its main purpose is to define a series of open interfaces, as well as services and facilities, that will enable independent manufacturers to develop infrastructure and terminal products that will be interoperable and meet the needs of traditional Private Mobile Radio (PMR) user organizations.

Although the prime responsibility of ETSI is to develop standards for Europe, many of its standards are also adopted worldwide, (as evidenced by the uptake of GSM, the first wireless technology standard to be developed by ETSI). The initial responsibility of ETSI Project TETRA, now known as ETSI Technical Committee (TC) TETRA, was to deliver a set of standards for a Digital Trunked PMR communications system that could be deployed in Western Europe. Since that time, TETRA has been deployed in many regions and nations outside Europe, resulting in TETRA becoming a truly global standard. In fact, it has been most recently used in Canada by Montreal Transit[32] and the Toronto Transit Commission (TTC)[33].

The technology solutions contained in the TETRA standards have been, and continue to be, developed primarily by well-known and respected manufacturers such as Motorola, Airbus, and Kenwood. These companies have been serving the PMR market with products and services for several decades. It is expected that the TETRA standard will continue to evolve beyond Release 1 and Release 2 to provide additional enhancements that are driven by user needs, technology innovations and other parallel standard developments.

In summary, TETRA will evolve in a similar way to other open standards such as GSM II+, GPRS, EDGE, etc. to UMTS/3G/4G supporting powerful multimedia applications and high-speed data. Also, the focus and technology solution for next-generation networks will primarily be for public networks. Since analogue MPT 1327 trunking networks are still being deployed across the world 28+ years after the technology was first developed, TETRA networks are expected to be available for at least another 25 years. This will ensure a very good return on investment for user organizations as well as manufacturers and suppliers[34].

[31] 3GPP TSG-SA WG1 Meeting #74 S1-161588, Venice, Italy, 9 - 13 May 2016.
[32] https://www.rrmediagroup.com/News/NewsDetails/newsID/15529.
[33] http://www.sepura.com/news-events/news/2013/sepura-delivers-tetra-system-to-toronto-transit-commission/.
[34] https://tandcca.com/tetra/tetra-standard/.

5.3 Long-Term Evolution

Long-term evolution (LTE) is a fully Internet Protocol (IP)-based technology and therefore differs from the traditional circuit based approach of current systems. The protocol uses packets, like the Internet, and a LTE radio channel is shared by many users simultaneously. Therefore, unlike switch-based circuits, LTE sidesteps the problem of simultaneously busy circuits. It enables the introduction of priority, eliminating the concept of pre-emption.

Since LTE is based on IP, the network can fully rationalize all communication networks into a single mobile LTE and fixed IP/Multiprotocol Label Switching (IP/MPLS) network. LTE's benefits include:

- Savings on network design, management, and maintenance
- Low latency (down to 10ms), enabling it to support critical, time-sensitive applications and provide high levels of quality of service management
- Bit rate, latency, maximum packet loss, priority and all other key transmission parameters which can be set up for each application and each user. These settings can also easily be changed as required, for example, in support of incident management
- Flexibility: It can be deployed in many different frequency bands and accommodate different channel bandwidths
- Security and resiliency: The LTE standard includes multiple features related to encryption and authentication, rendering this technology secure by default. In addition, when properly designed, an LTE network has several mechanisms for auto-reconfiguration in case of network failure—vital for an always-on railway communication network[35]

LTE users will be able to obtain Ethernet-class performance and the network can be configured to satisfy the more stringent requirements of users, such as higher-priority performance and response time. LTE can replace business landlines due to higher bandwidths, low latency and high capacity. These characteristics will contribute to more efficient networks for real-time video and information. Public safety agencies are already considering deploying LTE technology to fulfill their operational needs.

There is already a convergence of technologies taking place between public safety requirements, and corporate and consumer needs. The only distinction is that public safety in North America has been allocated 20 MHz at 700 MHz. There are discussions in other parts of the world to do the same.

5.3.1 VoLTE

Originally, LTE was a completely IP cellular system solely used for carrying data, and operators could only carry voice either by reverting to 2G/3G systems or by using VoIP. However, a standard, called Voice over LTE, or "VoLTE," has been developed to provide service providers a standardized system for transferring voice traffic over LTE. With rapid deployment of LTE, most operators are looking toward VoLTE as a next step and all major service providers in Canada have begun their deployment of the technology[36].

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[35] LTE-in-Rail-Public-Transport-StraWhite paper-NOKIA.

[36] Feasibility Study - Wireless Priority Services on the Next Generation of Networks in Canada by Vino Vinodrai.

LTE technology has been deployed in almost all service areas in Canada. These overlays will still emphasize interoperability with existing 3GPP technologies like UMTS and GSM to ensure that HSPA+ and LTE coexist.

5.3.2 Advanced LTE

There is now also Advanced LTE or LTE-A, which is able to offer higher data speeds as the result of carrier aggregation. Normal LTE channels are 5 MHz wide, but by combining them into 10 MHz or 20 MHz blocks, higher data speeds are achieved. For example, Bell users can now access peak theoretical download speeds of up to 750 Mbps (expect average speeds 25-220 Mbps) in select areas. That is up to two times faster than before but it requires a LTE-A handset to perform this function.

LTE also offers capacity management capabilities which are not available in circuit based systems. It goes further in its ability to provide pre-emption, offering the ability for highest priority communications to go through. There are 16 levels of priority in LTE; certain levels can be reserved for high-priority users.

5.4 IMT-2020 (5G)

The ever-increasing demand for wireless and the exploding number of applications has created a demand for higher speed and low latency services. As a result, there are many research projects and trials being undertaken around the world to address these needs. These projects are often referred to as 5G (for 5th Generation) or in ITU terms: International Mobile Telecommunications (IMT) 2020. Some manufacturers also have public technology half way between today's 4G and the future's 5G technology: 4.5 or 4.9G.

5G is positioned to address the demands and business contexts of 2020 and beyond. It is expected to enable a fully mobile and connected society. Wireless devices will be embedded in cars, machines, transportation systems, and even the human body. Governments are discussing "smart cities" that will embed communication systems in everything from traffic lights and garbage collection to parking and transit systems.

Figure 5.4, created by ITU vision, identifies the capabilities that will be required of 5G (IMT2020).

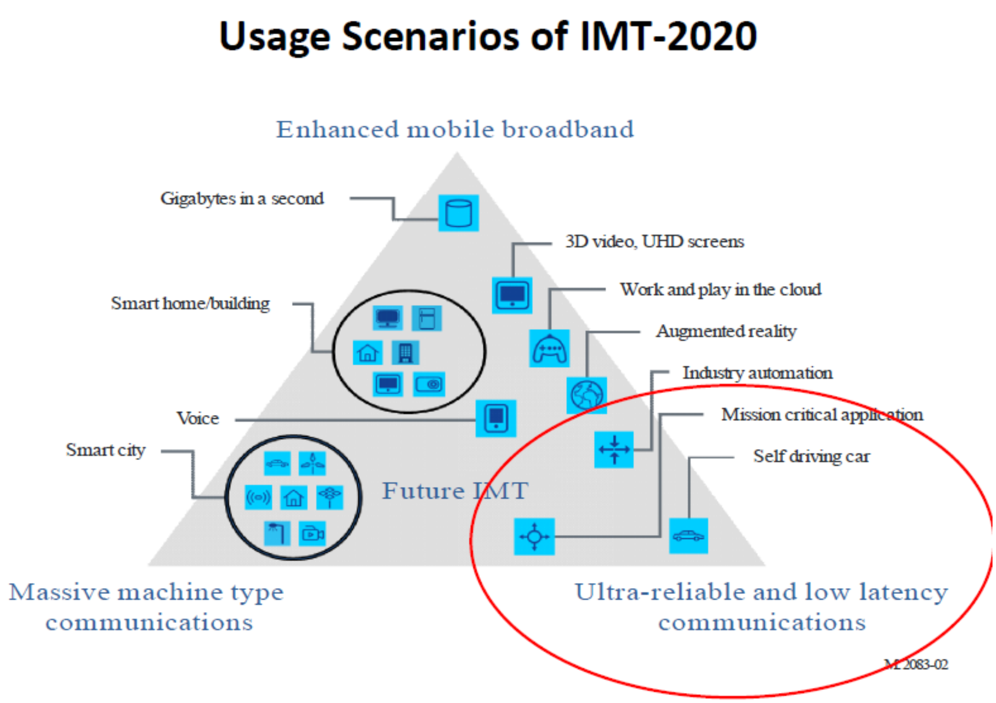

Figure 5.4 IMT 2020 Capabilities[37]

More explicitly, Figure 5.5 shows the need for different data speeds, reliability, and latency for different applications. Latency is critical in applications where there is a need for instant action such as in remote surgery.

[37] ITU Document Vision.

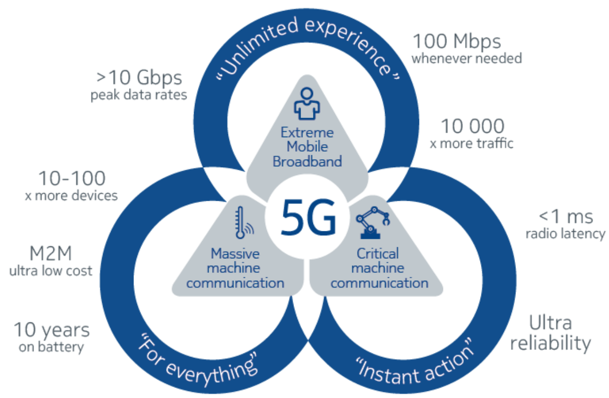

Figure 5.5 5G Diversity of Services[38]

5.5 MESH TECHNOLOGY

Mesh technology, such as fixed wireless technology (such as WiMAX, a technology standard for long-range wireless networking, for both mobile and fixed connections) can be used by railways for connecting wayside stations and Wi-Fi access points to a central location. Wikipedia[39] defines mesh technology as follows:

> *A wireless mesh network is a* communications network *made up of* radio nodes *organized in a* mesh topology*. Wireless mesh networks often consist of mesh clients, mesh routers and gateways. The mesh clients are often laptops, cell phones and other wireless devices while the mesh routers forward traffic to and from the gateways which may, but need not, connect to the Internet. The coverage area of the radio nodes working as a single network is sometimes called a mesh cloud. Access to this mesh cloud is dependent on the radio nodes working in harmony with each other to create a radio network. A mesh network is reliable and offers redundancy. When one* node *can no longer operate, the rest of the nodes communicate with one other, directly or through one or more intermediate nodes. Wireless mesh networks can self-form and self-heal and be implemented with various wireless technology including* 802.11*,* 802.15*,* 802.16*, cellular technologies or combinations of more than one type.*

Mesh technology can be used as an alternative to, or in conjunction with, fibre connection. If no fibre facility exists in the area, a mesh network can be set up to provide coverage, with the main node connected to the nearest fibre point. The cost of installation and maintenance of the network can be shared with other users in the area. An excellent application for the technology could be for surveillance cameras installed at remote or unattended railway properties.

[38] NOKIA: 5G Mission Critical Communication.
[39] https://en.wikipedia.org/wiki/Wireless_mesh_network.

5.6 SATELLITE

Satellite technology potentially has a role to play in railway communication with the introduction of new generations of satellite systems. Low orbiting satellites that use constellation technique (clusters of satellites) offer greater coverage.

Currently, there are four types of satellite systems:

- **low Earth orbit (LEO)**: Geocentric orbits ranging in altitude from 180 km - 2,000 km (1,200 mi)
- **medium Earth orbit (MEO)**: Geocentric orbits ranging in altitude from 2,000 km (1,200 mi) - 35,786 km (22,236 mi). Also known as an intermediate circular orbit
- **geosynchronous Orbit (GEO)**: Geocentric circular orbit with an altitude of 35,786 kilometres (22,236 mi). The period of the orbit equals one sidereal day, coinciding with the rotation period of the Earth. The speed is approximately 3,000 metres per second (9,800 ft/s)
- **high Earth orbit (HEO)**: Geocentric orbits above the altitude of geosynchronous orbit 35,786 km (22,236 mi)

Figure 5.6 below shows the difference between the different systems.

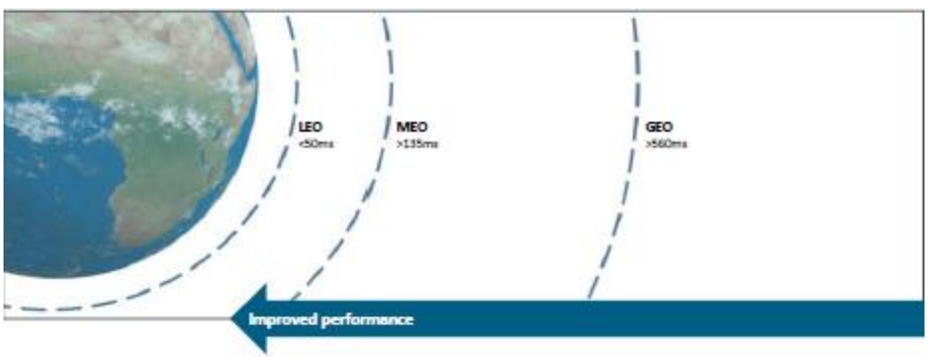

Figure 5.6 Various satellite orbits

MEO and LEO have overtaken the earlier GEO and HEO, providing opportunities for improved communication to mobile operators. Companies like Iridium, Globalstar, BComm and OneWeb are all launching constellations that will further improve communications. These constellations can consist of 36, 42 or more satellites[40].

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[40] http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=8&ved=0ahUKEwiZ7prUt-nWAhXFilQKHUJRCa4QFghhMAc&url=http%3A%2F%2Fbwn.ece.gatech.edu%2Fee4823%2Fnotes%2FCHAPTER11.ppt&usg=AOvVaw3-ZJ-fEc3ztsuBwdCP1nUN.

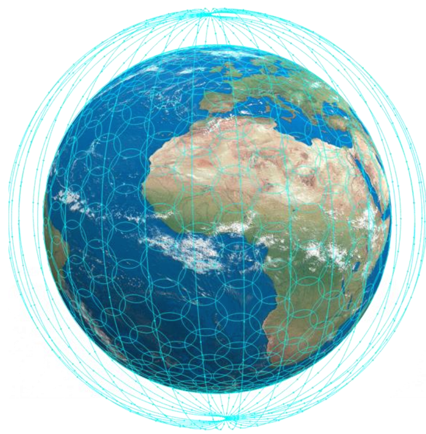

Figure 5.7 LEO[41] Orbits

For example, OneWeb's satellite, consisting of approximately 648 individual communication satellites, expects to provide global Internet broadband service to consumers as early as 2019. The 648 satellites will operate in circular low Earth orbit, at approximately 750 miles (1,200 km) altitude. The first 10 satellites are already under construction by Airbus.

The disadvantage of satellite systems is its latency, which can be 20ms to 25ms compared with the 1ms proposed for 5G. This means that satellite is not suitable for critical control system operation but can be used for video transmission, data collection and connecting onboard communication back to a central point. However, it is too early to understand the full scope of this technology.

6. The Internet of Things

The concept of the Internet of Things (IoT) embraces a multitude of applications. There are numerous interpretations of how it can be broken into various key verticals of adoption as well as horizontal considerations. The most common key verticals of adoption include: connected wearable devices, cars, homes, cities, and the industrial IoT[42].

The GSM Association (GSMA), is a trade body that represents the interests of mobile operators worldwide. GSMA predicts that IoT will allow M2M (machine to machine) connections to grow from five billion in 2014 to 27 billion in 2024 using both licensed and unlicensed spectrum.

Figure 6.1 shows IoT, from short range applications using unlicensed spectrum to long-range IoT using licensed spectrum. Although trains appear under "long-range," there are a number of train transportation applications that also fall under short range.

[41] OneWeb.
[42] http://www.5gamericas.org/files/3514/8121/4832/Enabling_IoT_WP_12.8.16_FINAL.pdf.

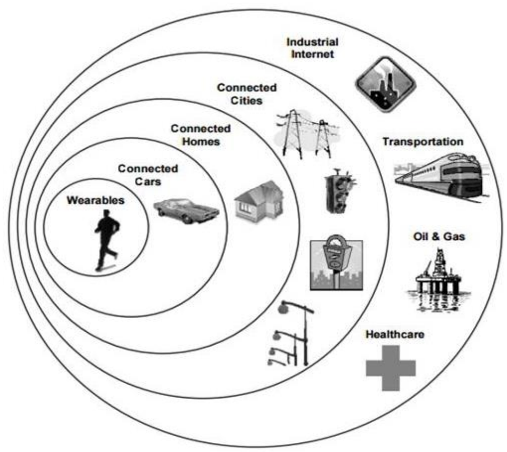

Figure 6.1 Internet of Things

Figure 6.2 outlines a roadmap for the progression of IoT. Radio-frequency identification (RFID) was an early incarnation of IoT, but with the advancement of technology and miniaturization, new applications have become available. The health industry has been an early adopter of wearables. GSMA says that with extended battery life and reduced costs, IoT technology is finding new applications. Since some batteries will last 10+ years, they become attractive options for remote locations or unattended sites.

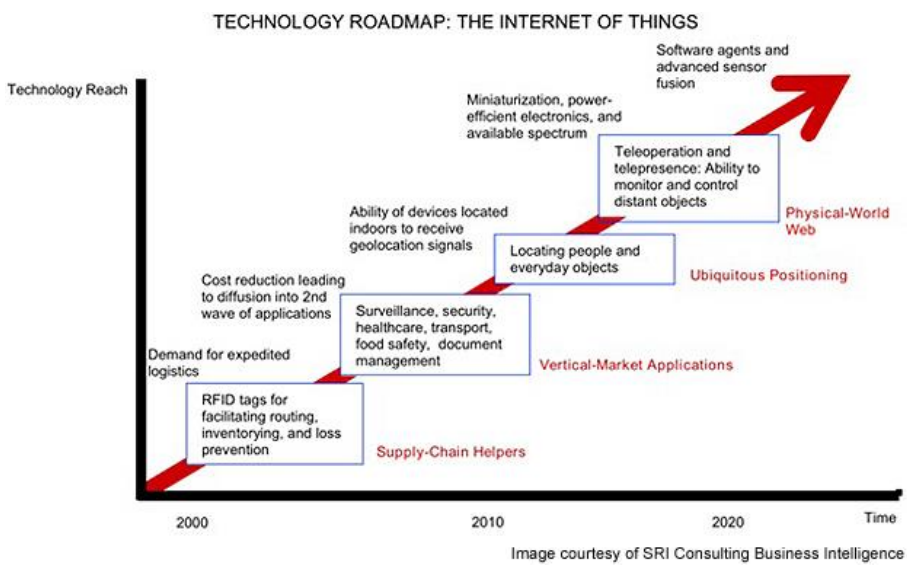

Figure 6.2 Progression of the Internet of Things[43]

[43] Image courtesy of SRI Consulting Business Intelligence.

The industrial IoT has also had a major impact on the transportation industry with the advent of innovations like autonomous vehicles and improved cargo management. Sensors can be deployed on railway tracks to monitor air and track temperatures and stress gauges. The introduction of IP networking will also allow more sensors to be deployed. The trackside network will provide data on track status, including faults and obstacles. Other connected devices will interact independently with sensors on the network to measure things such as water table levels, which can affect railway embankments should the ground become waterlogged and in-ground sensors will detect actual and potential landslides.

Railways in many parts of world, especially in Japan, Korea and Europe, adopted IoT early on. However, deploying IoT systems on trains operating at high speeds, through tunnels and extreme weather conditions, has presented challenges. Fortunately, networking advances have made smart trains a reality. With the introduction of IoT, the efficiency, safety and sustainability of the passenger experience—and the operators' return on investment—will undoubtedly improve.

According to a recent report by Cisco, almost $27 billion will be spent in the next 15 years on IoT projects in the railway industry[44].

6.1 IoT for Passenger Trains

The IoT offers Canadian passenger railways such as VIA, Metrolinx and other transit systems, as well as future high-speed trains, potential opportunities to improve passenger comfort and efficiency[45].

For example, an integrated journey planner application could recommend the fastest or most comfortable trip, allowing for road conditions to the station, live train times, available car parking capacities, passenger loading, etc. Passengers would be able to make informed choices about what would provide them with the best experience according to their personal circumstances. The inclusion of historic data would enable evaluation for current trips as well as for future trips in a predictive way, based upon what is normal for the planned travel day and time.

Social networking apps could also be used in conjunction with passenger loading information from trains to help spread demand peaks. The same base of information could be shared at a terminal to help passengers select the destination platform efficiently, considering the loadings of other inbound trains. Sharing the same information on the train could enable a more even distribution of passengers within the carriages, potentially allowing standing passengers to find a seat.

[44] https://www.ibm.com/blogs/internet-of-things/smart-trains-connected-railway/.
[45] https://www.ibm.com/blogs/internet-of-things/smart-trains-connected-railway/.

The IoT could also allow passenger railways to:

- provide food menus and entertainment selections
- install intelligent closed-circuit TV cameras that would provide a record of events in case of an incident and provide real-time alarms for potential problems, allowing for more timely interventions and potentially reducing service outages
- collect information about categorization of faults that could be analyzed across multiple assets—even multiple operators—to spot trends and identify areas for preventive maintenance

6.2 IoT for Freight Trains

IoT also offers benefits for freight trains[46]. It could allow for each freight car to be monitored and data transmitted, allowing for the manifest of each car to be identified. The monitoring system on freight cars can now provide the data necessary to determine each freight car's location to within a meter. This makes it possible to seamlessly track and monitor rail transport activities. Furthermore, the sensors located inside the freight car can provide data on variables such as temperature and air humidity. Because of this, transport conditions can be monitored at each point along the route, ensuring that items such as foodstuffs in refrigerated wagons always arrive fresh at their destination. If critical temperature limits are exceeded, the system will immediately sound an alarm and notify the control center.

Providing data information on car doors that have been opened would also increase the security of goods in transit. In addition, shock monitoring functionality can be added for monitoring heavy shocks during maneuvering, or during transfer of freight onto railway cars. This makes it possible to properly assess the causes of damage to freight cars and freight, in addition to analyzing transport conditions.

The mileage of railcars is a matter of great importance. Providing the precise mileage for each car would help in the planning of repair and maintenance work. Figure 6.3 shows some of the different ways IoT could be used on freight cars.

[46] http://blog.bosch-si.com/categories/projects/2016/02/connected-freight-trains-will-revolutionize-freight-traffic/.

Figure 6.3 Internet of Things on Freight Car[47]

6.3 IoT and Rail Safety

Safety is a key element of IoT applications and solutions for train management[48]. For example, onboard train location and detection systems enable trains to be "aware" of the positions of other trains. This reduces the risk of collisions by allowing trains to operate safely in close proximity to one another. This is essential for transit systems such as GO Transit.

Speed monitoring and control is another important safety application. Systems have been developed that can display train velocity for drivers and report speeds back to central control systems. Onboard monitoring systems are interconnected with outdoor signaling systems that can regulate train speeds and remotely command trains to stop based on track conditions, the positions of switches, and/or the presence of other trains on the track.

Other benefits from automation and the IoT include:

- signaling
- interlocking
- level crossing control

As automated trains become commonplace, signaling systems will control the movement of a train by remotely adjusting train speed and braking. IoT can help to decrease accidents at level crossings by deploying cameras and sensors for increased safety.

[47] http://blog.aeris.com/locomotive-management-creating-smart-rail-lines-with-iot.
[48] https://www.ibm.com/blogs/internet-of-things/smart-trains-connected-railway/.

7. Network Sharing

Since Canada's rail communication network will be shared by competitors such as CP and CN, it is important to develop network architecture that ensures that privacy/divisions can be maintained between railways. Research is underway on how to accomplish this and an early version of proposed approaches is available from manufactures including Nokia and Ericsson.

A brief overview of the network architecture options has been compiled in consultation with experts from the Wireless World Research Forum. The network can use:

- adaptive (de)composition and allocation of mobile network functions
- software-defined mobile network control
- multi-service and context-aware adaptation of network functions
- mobile network multi-tenancy (read multiple users)
- network slicing

Figure 7.1 shows an example of how network sharing could work.

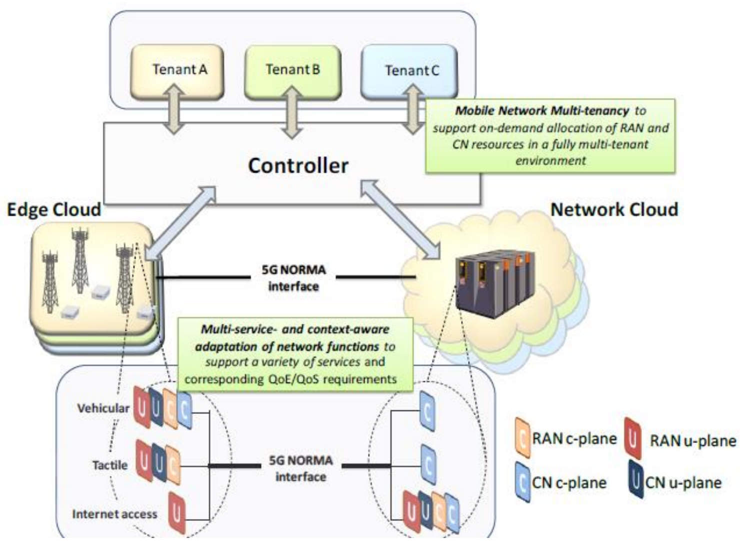

Figure 7.1 Network Sharing[49]

[49] https://5gnorma.5g-ppp.eu/wp-content/uploads/2016/11/5g_norma_d2-1.pdf.

8. LOOKING AHEAD: THE NEXT TEN YEARS

As Canada works to improve passenger and freight rail travel, there will be a growing need for better voice communication. High-speed trains need good communication systems to reduce journey time and passengers will demand to remain connected. On the freight side, if Canada is to achieve its emission goals, there will be a move toward more environmentally friendly transportation systems.

The TSB investigation of the 2012 VIA Rail derailment near Burlington, Ontario, led the Advisory Council on Railway Safety (ACRS) to set up a working group on rail safety. One of the TSB's recommendations in the investigation report was as follows:

"The Department of Transport requires that major Canadian passenger and freight railways implement physical fail-safe train controls, beginning with Canada's high-speed rail corridors.[50]" (R13-01)

The mandate of the working group was to study existing and developmental fail-safe train control systems to evaluate their suitability for Canada's railway operations, with a special focus on high-speed rail corridors. The working group was tasked to summarize its findings with a focus on how technologies and systems could best address TSB Recommendation R13-01. This report made many recommendations including setting up a Canadian version of PTC to be called Enhanced Train Control (ETC). Many of the recommendations also parallel those described in this white paper. The Train Control Working Group report looks in depth at railway safety issues but the underlying technology to support it can be found within these pages.

To ensure today's trains are safe, onboard real-time video surveillance is needed to monitor and assess any critical or abnormal situation inside the engine and the coaches, alongside the track, and on platforms. Onboard, real-time information is also becoming mandatory for train operators. Many recent incidents on high-speed lines have left passengers dissatisfied after being stuck for hours without being properly informed of the situation.

Technology obsolescence—particularly in the telecommunications domain—occurs quickly and is often not in line with the life cycle of rail systems. The technology North American railway communication systems depend on is now 30+ years old. GSM-R will approach the end of its life toward 2030, which is already a concern for infrastructure managers even though the industry has committed to maintaining the current systems until sometime between 2020 and 2025. Railway infrastructure owners view the very limited number of GSM-R manufacturers and GSM-based technology obsolescence as a threat[51].

[50] http://www.bst-tsb.gc.ca/eng/recommandations-recommendations/rail/2013/rec-r1301.asp.
[51] ASIA-PACIFIC TELECOMMUNITY AWG-20/INP-29.

Discussions are already underway on the next evolution of train to track communications technologies. 4G LTE and 5G technologies with low latency are good candidates to complement the existing mission-critical technologies. In future, an IP based Radio Access Network (RAN) will replace the existing circuit radio based network for train to track communications as shown in Figure 8.1 below:

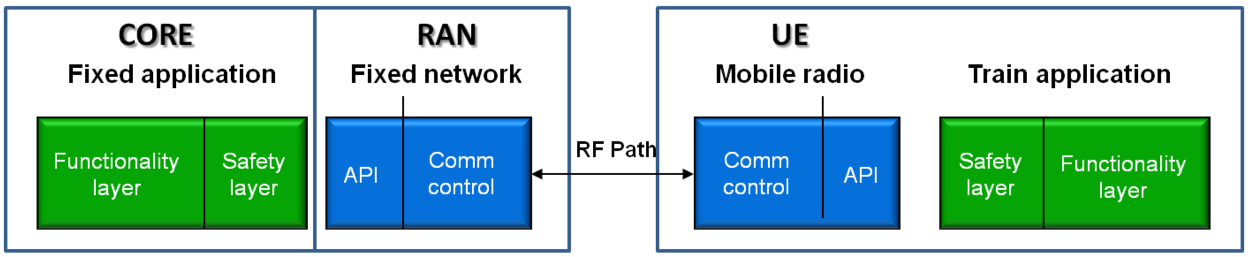

Figure 8.1 IP Based RAN[52]

LTE and LTE-A are the ideal candidates for a next generation of communication that would be able to support many new train communications services. An example of this can be seen in Annex C, which is based on the Paris Metro.

9. Recommendations

There is no question, it is time for railways to start planning for a new generation of radio communication system. As demand for real-time data grows, there is a convergence between IT and radio. This is evident from the explosive growth of smartphones, both for business use and pleasure. This white paper provides an overview of technology progression that is taking place in the railway industry around the world. Canada is not the only country looking at meeting rail's future needs. In fact, the ITU's 2019 World Radio Communication Conference (WRC 2019) has an agenda item to:

> *…take necessary actions, as appropriate, to facilitate global or regional harmonized frequency bands to support railway radiocommunication systems between train and trackside within existing mobile service allocations, in accordance with Resolution 236 (WRC-15)*[53]. (The full resolution can be found in Appendix B.)

This illustrates that railways around the world already recognize the importance of radiocommunication in ensuring future rail efficiency and safety.

[52] Technologies and Spectrum considerations for High Speed, freight and Metro Trains by Bharat Bhatia.
[53] https://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A00000C0012PDFE.pdf

When it comes to choosing the “best” technology, a proprietary solution can be brought to market in less time than a solution conforming to a recognized open standard. However, large user organizations, especially those in the public sector, have recognized that while some proprietary solutions can meet their needs, a “tie in” to a single supplier can have significant disadvantages. Although not a perfect solution, the main advantages and benefits of adopting an open standard are:

- economies of scale provided by a large harmonized market served by several independent manufacturers and suppliers competing for the same business resulting in competitively priced solutions
- second source security if existing suppliers exit the market
- evolution (instead of revolution) of the technology standard ensuring longevity and good return on investment for both users and suppliers
- choice of manufacturers for new products keeping prices down
- greater choice of products for specialized applications
- increased responsiveness to future needs because of competition between suppliers

Because there are several independent manufacturers of both TETRA and LTE network infrastructure and radio terminals, all the benefits of standardization listed above also apply both to the TETRA and LTE.

Globally, UIC is moving toward the next generation wireless communication technologies for rail operations to replace GSM-R. To that end, UIC:

- published a set of technology-independent user requirements for the Future Railway Mobile Communication System (FRMCS)
- cooperated with TCCA to define the next generation broadband communications for railway operations
- plans to use standard technologies, like LTE and 5G, and not a specialized system like GSM-R

At the same time, the 3GPP standard body is now working on FRMCS. This is an ongoing activity in which they are:

- performing mission-critical LTE standardization work
- coming up with a mission-critical broadband solution for rail that has many components—not just 5G—and includes multiple specialized applications, devices, interoperability and services
- initiating a rail dispatch solution that has 5G mission-critical features that will be able to support rail operations
- identifying that Rail User Equipment (UE) needs to be ruggedized to meet environmental requirements

But the challenge remains increasing data capacity to meet railway's needs for 2020 and beyond. This can be done by obtaining new broadband spectrum compatible with existing and future HSMD technologies. Therefore, it is recommended that the following should be considered by RAC and its members:

1. Approach ISED with an evidence-based argument that additional spectrum is needed for the efficient and safe operation of railway systems. Rail must be viewed as an essential service and should be considered within the scope of public safety. A modernized railway system can help Canada achieve and exceed its emission requirements and will help boost the Canadian economy. The Transport Canada report, *Final Report of the Advisory Council on Railway Safety's Train Control Working Group*, will help in preparing these arguments. As mentioned earlier in this document, 600 MHz and Public Safety 700 MHz are the best options available right now.

2. Open discussions with Canadian service providers and manufacturers in extending their present network to areas where they do not have coverage with a view to build a joint network.

3. Start discussions with public safety agencies about how sharing spectrum with railways (700 MHz) can help to build their network, especially in remote areas.

4. Set up a small working group immediately to prepare a user requirements document for Canadian railways. This document should address freight and passenger trains, as well as LRTs.

ACRONYMS

3GPP	3rd Generation Partnership Project
3P	Private Public Partnership
AAR	Association of American Railroads
ACRS	Advisory Council on Railway Safety
CSMA	Carrier Sense Multiple Access
ETC	Enhanced Train Control
ETCS	European Train Control System
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FPT IWG	Federal, Provincial, Territorial, Interoperability Sub-Working Group
FRMCS	Future Railway Mobile Communication System
GSM-R	Global System for Mobile communications - Railways
HSPA+	Evolved High Speed Packet Access
IP	Internet Protocol
IP/MPLS	IP/Multiprotocol Label Switching
ISED	Innovation Science and Economic Development
ITU	International Telecommunication Union
LTE	Long Term Evolution
OTA	Over The Air
PBSN	Public Safety Broadband Network
PMR	Private Mobile Radio
RAC	Railway Association of Canada
RAN	Radio Access Network
RAS	Radio Astronomy Service
RRBS	Remote Rural Broadband Systems
TDMA	Time-Division Multiple Access
TETRA	Terrestrial Trunked Radio
TSB	Transportation Safety Board of Canada
TTC	Toronto Transit Commission
TVWS	Television White Space
UE	User Equipment
UIC	International Union of Railways
UMTS	Universal Mobile Telecommunications Service
URS	User Requirements Specification
VoLTE	Voice over LTE
WMTS	Wireless Medical Telemetry Systems

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SUGGESTED READING

1. http://www.cisco.com/c/en/us/solutions/industries/transportation/rail.html
2. http://www.cisco.com/c/dam/en_us/solutions/industries/docs/trans/rail-aag.pdf
3. Technology Evolution Toward 5G & Beyond, Seizo ONOE, CTO and EVP, NTT DOCOMO, INC
4. Final Report of the Advisory Council on Railway Safety's Train Control Working Group
5. 5G For Rail – Bharat Bhatia Presented at 38th Meeting WWRF in Taiwan
6. Mobile Internet on Taiwan High Speed Rail, Sean Hsien-Wen Chang, Ph.D Senior Engineer, Information and Communications Lab, Industrial Technology Research Institute
7. Akyildiz, I.F. and Jeong, S., "Satellite ATM Networks: A Survey," IEEE Communications Magazine, Vol. 35, No. 7, pp.30-44, July 1997.
8. OneWEb
9. LTE-in-Rail-Public-Transport-Stra-NOKIA
10. Description of Railway Radiocommunication Systems between Train and Trackside (RSTT) ITU -Annex 16 to Document5A/469 8 June 2017
11. NOKIA: Paris metro LTE trial: the SYSTUF project and its results
12. The Gigabit Train -techUK Seminar, March 21st 2016
13. Improving Rail Connectivity Through 3GPP Technology, Proceedings of the 2017 Joint Rail Conference JRC2017 April 4-7, 2017, Philadelphia, PA, USA (ERICSSON PAPER)
14. RAC- Ericsson Presentation – February 1st, 2017
15. IEEE Communications Magazine, August 2017, Vol. 55 No 8

APPENDIX A - MAPS

Figure A1 CP Rail Network

Figure A2 CN Rail Network

Figure A3 VIA Rail Network[54]

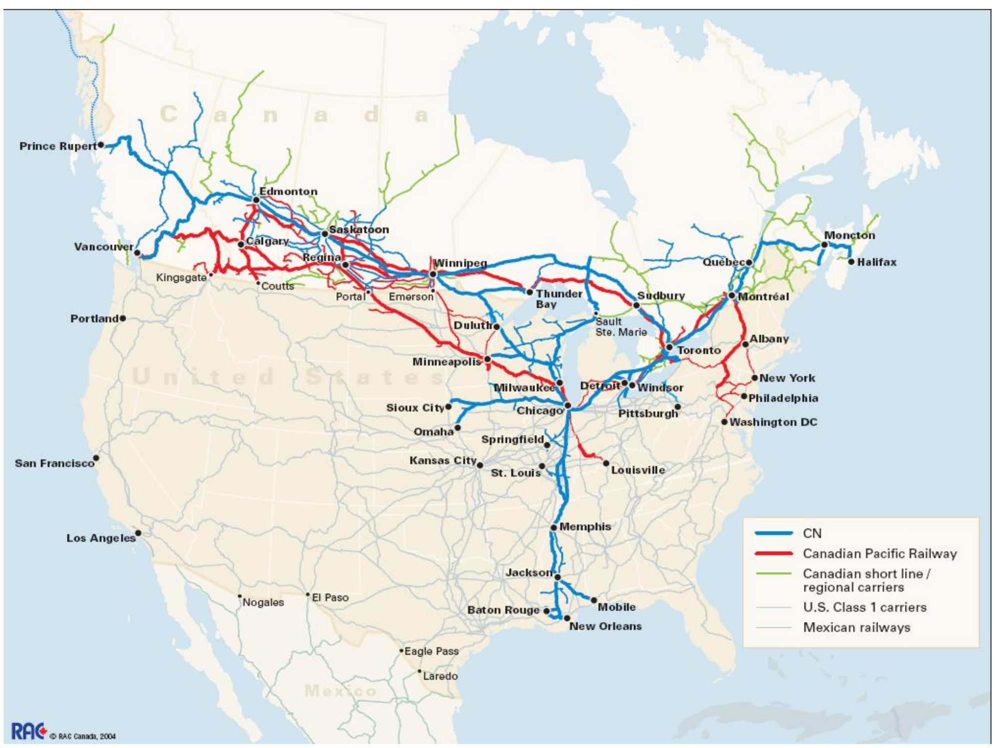

Figure A4 Integrated Railway Map[55]

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[54] http://www.viarail.ca/en/explore-our-destinations/trains.

[55] http://cnebusiness.geomapguide.ca/.

Figure A5 GO Transit Train Map[56]

56 http://www.gotransit.com/timetables/en/schedules/maps.aspx.

Appendix B – WRC 2019 Resolution

RESOLUTION COM6/12 (WRC-15)

"Railway radiocommunication systems between train and trackside

The World Radiocommunication Conference (Geneva, 2015),

considering

a) that railway transportation systems are evolving;

b) that there is a need to integrate different technologies to facilitate various functions, for instance dispatching commands, operating control and data transmission, into railway train and trackside systems to meet the needs of a high-speed railway environment;

c) that the current railway radiocommunication systems supporting railway train and trackside are narrowband systems;

d) that the deployment of railway radiocommunication systems between train and trackside requires infrastructure investment,

recognizing

a) that information and radiocommunication technologies in railway radiocommunication systems between train and trackside provide improved railway traffic control, passenger safety and improved security for train operations;

b) that timely studies are required on technologies providing for railway radiocommunication;

c) that international standards and harmonized spectrum would facilitate worldwide deployment of railway radiocommunication systems between train and trackside and provide for economies of scale in railway transportation for the public;

d) that there is a need to benefit from the experiences in achieving compatibility between current railway radiocommunication systems between train and trackside and other radiocommunication systems,

noting

a) that railway transportation contributes to global economic and social development, especially for developing countries;

b) that some national and international railway organizations have begun investigations on new technologies for railway radiocommunication systems;

c) that ITU Radiocommunication Sector (ITU-R) Study Group 5 is studying relevant technical and operational characteristics for railway radiocommunication systems;

d) that, in some countries, railway radiocommunication systems may assist in providing passenger services,

emphasizing

a) that, in the frequency bands in which these current and future systems operate, railway radiocommunication systems between train and trackside should be compatible with a variety of other systems;

b) that the provisions of Nos. **1.59** and **4.10** do not apply for railway radiocommunication systems,

resolves to invite the 2019 World Radiocommunication Conference

based on the results of ITU-R studies, to take necessary actions, as appropriate, to facilitate global or regional harmonized frequency bands, to the extent possible, for the implementation of railway radiocommunication systems between train and trackside, within existing mobile-service allocations,

invites ITU-R

to study the spectrum needs, technical and operational characteristics and implementation of railway radiocommunication systems between train and trackside,

invites Member States, Sector Members, Associates and Academia

to participate actively in the study by submitting contributions to ITU-R,

instructs the Secretary-General

to bring this resolution to the attention of International Union of Railways (UIC) and other relevant international and regional organizations.[57]"

[57] https://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A00000C0012PDFE.pdf.

APPENDIX C – NOKIA PARIS TRIAL

This an example taken from Nokia on their white paper: *Paris metro LTE trial: the SYSTUF project and its results***.**

“As metro networks become busier, more capacity is required — not only for passengers, but also for operational applications and services. Conventional siloed radio networks, with their limited capacity, are not able to answer this need. A promising solution lies with a unified ground-to-train radio networks based on 4G LTE technology. Nokia, within a consortium called SYSTUF, conducted a trial project in real-world conditions on Paris metro line 14. This white paper presents this project and its results.[58]”

EXTRACT:
A single urban railways operator may consequently be hosting seven or eight separate networks (see Figure 1), which inevitably increases costs. This situation is almost certain to worsen as more applications are added. Building out new networks for each application is therefore becoming increasingly untenable. The separate infrastructures have a cumulative effect on maintenance and cost over time as the number of services and their associated networks multiplies.

Figure 1: Traditionally, multiple communication applications have run on separate networks.

The primary characteristics of LTE are high-speed, security, and capacity, with the capability to carry voice and data for train control, onboard video surveillance and passenger information simultaneously on a single IP network. (See Figure 2.)

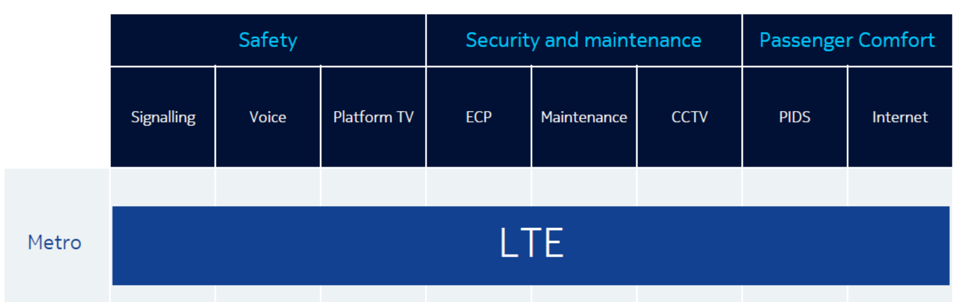

Figure 2: LTE can carry all necessary communications data with high speed, security and capacity.

58 http://asia.blog.terrapinn.com/rail/2017/03/07/paris-metro-lte-trial-the-systuf-project-and-its-results/.

Railway Association of Canada

Association des chemins de fer du Canada