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Report ITU-R M.2395-0

(11/2016)

Introduction to railway communication systems

M Series

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REPORT ITU-R M.2395-0

Introduction to railway communication systems

(2016)

1 Scope

This is a technical Report which focuses on a case study of measurement results of radio communication characteristics between train and ground stations in the millimetric wave frequency ranges for some railway deployment scenarios in Annex 1, in order to assess, among others, the impacts of 1) future broadband transmission and 2) high mobility of more than 300 km/h in millimetric wave frequency ranges, on current and future railway radiocommunication systems.

Annex 2 is provided for information and includes other types of radiocommunication systems used in railway communications.

2 Measurement results and related deployment issues in millimetric wave frequency ranges

As a case study from Japan, measurement results of radio communication characteristics between train and ground stations in the millimetric wave frequency range for some railways deployment scenarios are given in Annex 1, which demonstrate key technical characteristics of railways communication systems and operational features in millimetric wave frequency ranges, in environments such as 1) broadband transmission, and 2) high mobility.

According to Annex 1, the following issues should be taken into account for optimal deployment scenarios.

– shorten distances between ground stations in section containing gradient change,
– enlarge distances between ground stations in tunnel condition, rather than open-site,
– impact of Doppler effects on railway communications in high speed cases is not severe as expected, as shown in § 4, but further study would be required for both bandwidth and frequency ranges.

Technical characteristics and operational features of the system for mobile communications with railways in Japan and Korea are given in Annex 2 for information, including other types of radiocommunication systems.

Annexes: 2

Annex 1

Measurement results of radio communication characteristics between train and ground stations in the millimetric wave frequency range for some railway deployment scenarios – a case study from Japan

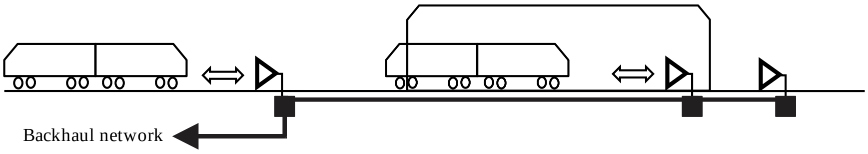
1 Introduction

Considering future demand of mobile phone and wireless local area network (LAN) access, wireless link between ground station and train should be broadband and require more bandwidth, e.g. the order of 40-500 MHz bandwidth. Meanwhile, the millimetric wave band, such as the over-30 GHz band, is not used heavily in commercial mobile applications and is expected to facilitate the broadband communication systems.

Figure 1 shows a conceptual image of the broadband wireless transmission system between moving trains and the backbone network using over −40 GHz band. Typical deployment scenarios for railway communication links are 1) open-site, and 2) tunnel channel. Both scenarios further include line-of-sight and non line-of-sight[1]. The propagation characteristics are generally critical for establishing the wireless communication link. Therefore, this section investigates propagation characteristics for these deployment scenarios based on filed measurements, so that technical issues can be identified for developing future robust railway systems.

FIGURE 1

Conceptional image of the broadband wireless transmission system



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2 Open-site scenario

Open-site is a major deployment scenario in railway communication. In this scenario, both line-of-sight (LoS) and non line-of-sight (NLoS) cases are investigated by field measurements. This section discusses their impact on railway communication systems.

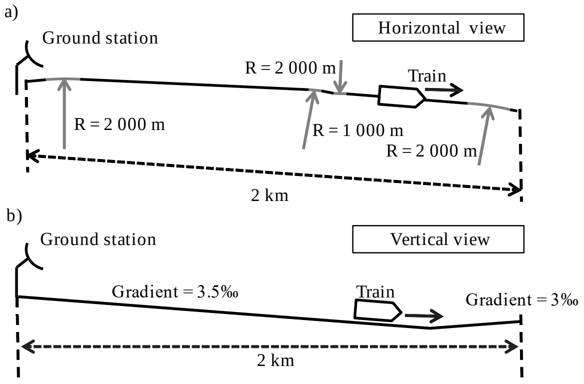
2.1 Line-of-sight link case

2.1.1 Descriptions of test conditions

A propagation measurement was conducted between two train stations, which was a 2 km long typical LoS straight section as shown in Fig. 2.

FIGURE 2

Sectional view of LoS straight section
(a) Horizontal view, (b) Vertical view



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[1] In some other Recommendations and Reports, the term “beyond line-of-sight” is also used in other applications.

A transmitter with a horn antenna on the train transmitted a signal with beam width of 17 degrees in vertical polarization and the transmitted signal was received by a Cassegrain antenna at the ground station placed beside the railway line. The train moved at a velocity of 310 km/h on the rail. The height of the receiving antenna was set at 2 m above the ground. Table 1 shows the other measurement conditions [1].

TABLE 1

Measurement conditions

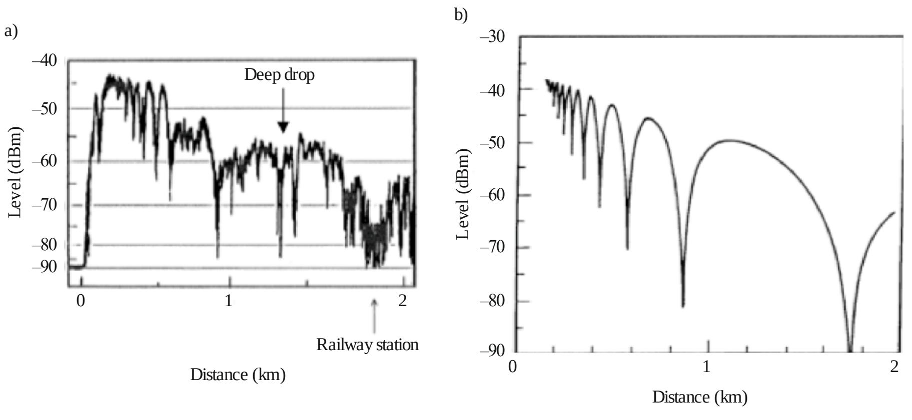
Station	Parameter	Value	Note
	Frequency	50 GHz	
	Polarization	Vertical	
Train station (transmitting side)	On-board transmitter power	12 dBm	15 mW
	Antenna gain	40 dBi	30 cm diameter Cassegrain, 1.5 degrees beam width
		20 dBi	2.5 cm diameter conical horn, 17 degrees beam width
	Velocity	310 km/h	
Ground station (receiving side)	Receiver Sensitivity	−70 dBm	BER = 10^{-7} (2 Mbit/s]
	Antenna gain	40 dBi	30 cm diameter Cassegrain, 1.5 degrees beam width

2.1.2 Measurement results

Figure 3(a) shows the results of the obtained propagation behaviour in this measurement, and Fig. 3(b) shows the result of theoretical calculations using a 2-wave interference model under the same conditions as these measurements.

FIGURE 3

Propagation behaviour in LoS link
(a) measurement results, (b) calculated result using 2-wave interference model



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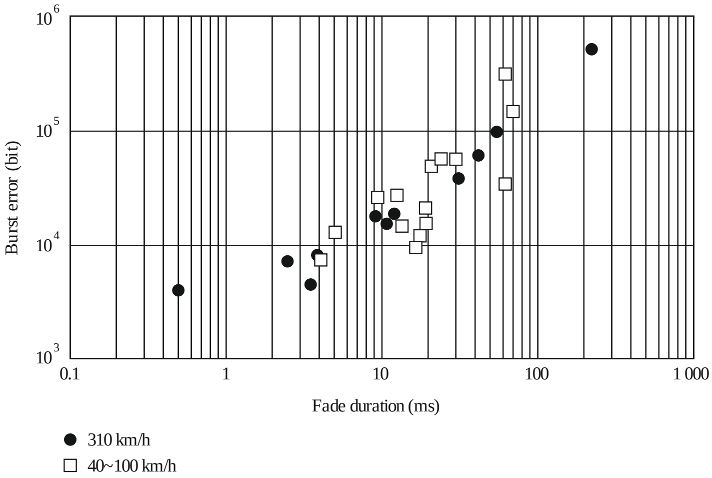
Comparison of Figs 3(a) and (b) shows that the results of the reception level obtained in these measurements give close agreement with the calculated regular fading pattern. A deep drop in the receiving level described by "↓" in Fig. 3(a) is thought to be the effect of the null pattern of the antenna mounted on the train due to the meandering path of the railway track. Figure 4 shows the relationship between fade duration and burst error. The trend of the relationship between fade duration and burst error is almost the same whether the train speed is high or not [1].

FIGURE 4

Relationship between fade duration and burst error



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2.2 Non line-of-sight link case

Non line-of-sight (NLoS) case can be further categorized in two cases: 1) terrain obstruction, and 2) curved section. Terrain obstruction is such a case that LoS is not established due to the propagation beyond top of mountain, as shown in Fig. 5. Curved sections are a case that the sidewall on curved section hinders LoS of communication, as shown in Fig. 6.

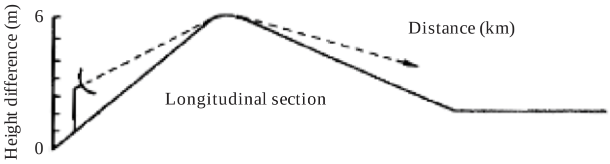
2.2.1 Terrain obstruction

2.2.1.1 Descriptions of measurement conditions

Propagation over curved sections or in situations when there is an obstruction (like mountain, etc.) between the transmitter and receiver, are typical cases of NLoS links. A propagation measurement was conducted on a railway track including a slope change as shown in Fig. 5. The other measurement conditions were the same as Table 1 [1].

FIGURE 5

Sectional view of NLoS area



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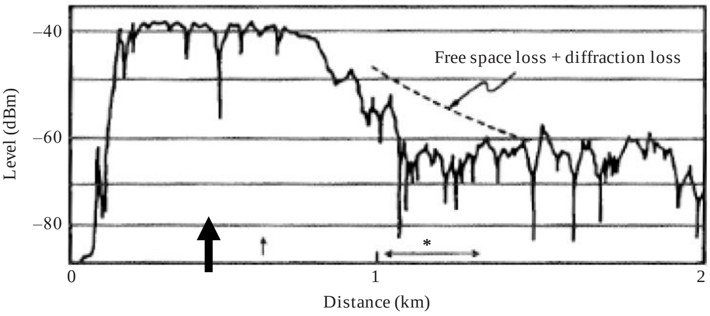
2.2.1.2 Measurement results

Figure 6 shows the results of the obtained propagation behaviour in this measurement. This result shows that the reception level in this measurement agrees with the calculated values with knife-edge diffraction propagation at the 800 m mark or farther from the receiver, described by "↑" in Fig. 6.

A large amount of propagation loss at the area indicated by the point "*" in Fig. 6 was thought to be the effect of diffracted waves [1].

FIGURE 6

Measurement results of propagation behaviour in NLoS link



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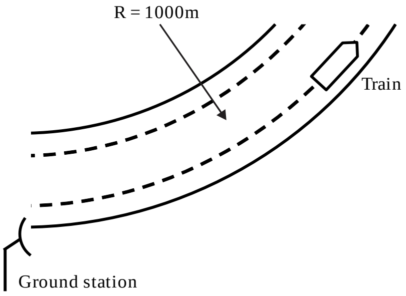
2.2.2 Curved section

2.2.2.1 Descriptions of measurement conditions

On the curved sections, diffraction and reflectance are major factors in considering the propagation. The propagation measurement was conducted in a curved section with side walls, as shown in Fig. 7. The other measurement conditions were the same as Table 1.

FIGURE 7

Sectional view of curved line



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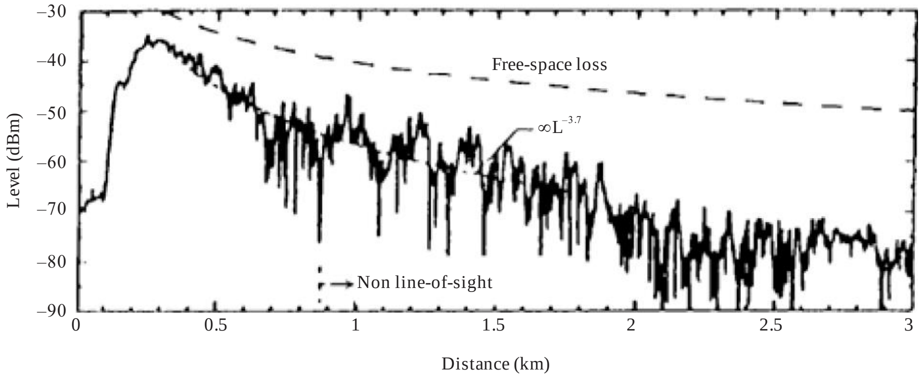
2.2.2.2 Measurement results

Figure 8 shows the results of the obtained propagation behaviour in this measurement. This result shows that the reception level in this measurement are still enough for establishing the communication link in NLoS condition. This is because diffraction by electrical poles and reflectance by the ground and the side walls prevented the propagation loss.

FIGURE 8

Measurement results about propagation behaviour in NLoS link



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2.3 Summary of measurement results

The results of these measurements mainly present propagation characteristics of millimetric wave, which are important elements for system design of railway mobile communication.

In considering keeping the quality, further efforts would be required against the deep drops, such as use of diversity for transmit and received antenna, optimized arrangement of distance between Base Stations, and increasing transmit power, etc.

In the case of NLoS link with gradient changed points and/or curved line, diffraction propagation over curved sections or slope changed sections and reflection by side-wall should be considered for the arrangement of Base Stations. In curved section, there is little influence of LoS because of those reflections. However, in the case of gradient changed section, drop of received power by diffraction loss cannot be negligible for link quality. In order to avoid these phenomena, Base Stations should be located on the gradient changed points.

3 Tunnel scenario

This scenario needs to be also considered for both LoS and NLoS. Propagation characteristics are different from the open-site scenario, in that the frequency-dependency becomes dominant factor. This section discusses their impact on railway communication systems.

3.1 Mixture of LoS link and NLoS link cases

3.1.1 Descriptions of system architecture and communication equipment

A propagation measurement was conducted in a tunnel site [2]. The deep fading effects are expected due to the multipath signals in tunnel. Therefore, in order to mitigate the deterioration of transmitting and receiving signals from this multipath effects, antenna diversity or similar techniques are required. Therefore, two-antenna arrays were used for both the transmitter (Tx) and receiver (Rx) in these measurements in tunnel in order to evaluate antenna diversity effect.

Figure 9 shows the configuration of the measurements. The antenna units of Tx and Rx were oriented to be faced each other. The Tx was mounted on a road-rail vehicle and moved in the broadside direction linearly. Between Tx and Rx, 100 Mbit/s signals were consecutively transmitted. The measurement conditions are shown in Table 2.

FIGURE 9

Measurement setup of Tx and Rx

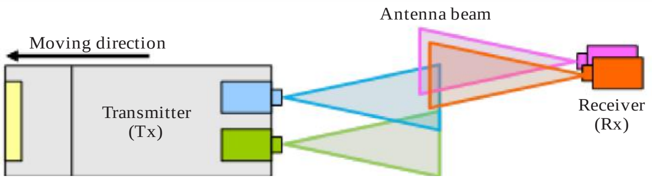

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TABLE 2

Measurement parameters

Station	Parameter	Value	Note
	Frequency	46.8 GHz	
	Polarization	Circular	
	Modulation scheme	64QAM-OFDM	
	Maximum throughput	100 Mbit/s	
Train station (transmitting side)	On-board transmitter power	10 dBm	10 mW
	Antenna gain	32 dBi	Cassegrain, 1.0~1.5 degrees beam width
Ground station (receiving side)	Antenna gain	32 dBi	Cassegrain, 1.0~1.5 degrees beam width

The measurements in a tunnel scenario were carried out in Iiyama Tunnel of Hokuriku Shinkansen, Nagano, Japan, of which the sectional view is shown in Fig. 10. The Tx (transmitter on a road-rail vehicle) moved at a velocity of 15 km/h on the rail, and received signal strength indicator (RSSI) and bit error ratio (BER) were measured at the Rx (receiver at a side of the rail). The distance between the Rx and the Tx was measured by Radio-Frequency Identification (RFID) tags uniformly located alongside the rail and pulse signals from an axle shaft of the vehicle per one wheel rotation. Two antennas at the ground station were installed vertically. On the other hand, two antennas at the train station were set vertically or horizontally depending on the measurement case, where the former and the latter are hereafter referred to as "vertical case" (Fig. 11) and "horizontal case" (Fig. 12), respectively. The test parameters for the tunnel scenario are shown in Table 3.

FIGURE 10

Sectional view of Iiyama tunnel

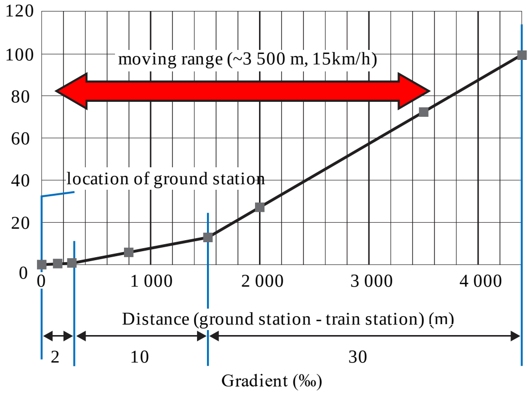

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FIGURE 11

Antenna setup in tunnel scenario (vertical case)

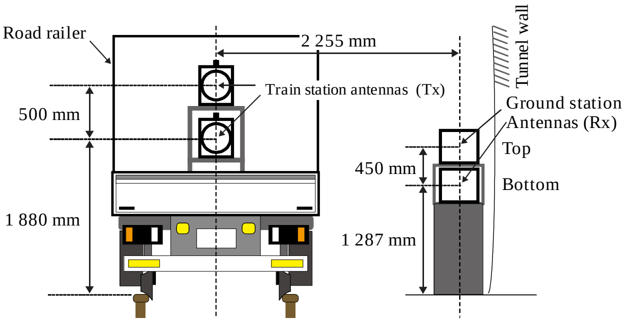

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FIGURE 12

Antenna setup in tunnel scenario (horizontal case)

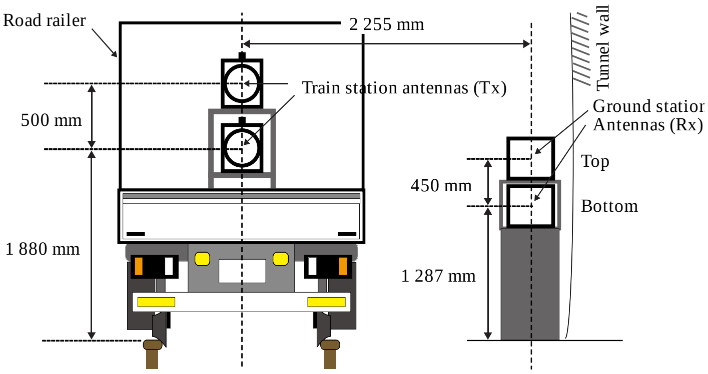

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TABLE 3

Test parameters (tunnel scenario)

Parameter	Value
Carrier frequency	46.8 GHz
Number of antennas	Tx: 2, Rx: 2
Moving range	3 500 m from Rx
Velocity	15 km/h
How to get Tx’s location	RFID and pulse signals from an axle shaft

3.1.2 Measurement results

This subsection shows the results in the tunnel scenario.

3.1.2.1 Performance of Diversity Effect

Figures 13 to 16 show the results of RSSI and BER performance for the vertical case depending on the number of antennas; the performance without any diversity schemes (1 Tx and 1 Rx) in Fig. 13, that with transmit diversity (2 Tx and 1 Rx) in Fig. 14, that with receive diversity (1 Tx and 2 Rx) in Fig. 15, and that with both transmit diversity and receive diversity (2 Tx and 2 Rx) in Fig. 16. As a reference, the free-space propagation loss is also shown in each RSSI figure. Here, the Tx moved away from the Rx. It can be seen that in the tunnel scenario all RSSI performances are similar to or less than the free-space propagation loss within transmission distance of 3 500 m. Furthermore, it can also be seen that BER performance is drastically improved with an increase of the number of antennas, because of the alleviation of received power degradation by diversity effect.

FIGURE 13

The RSSI and BER performance for the vertical case depending on the number of antennas in the tunnel scenario (Tx = 1, Rx = 1)

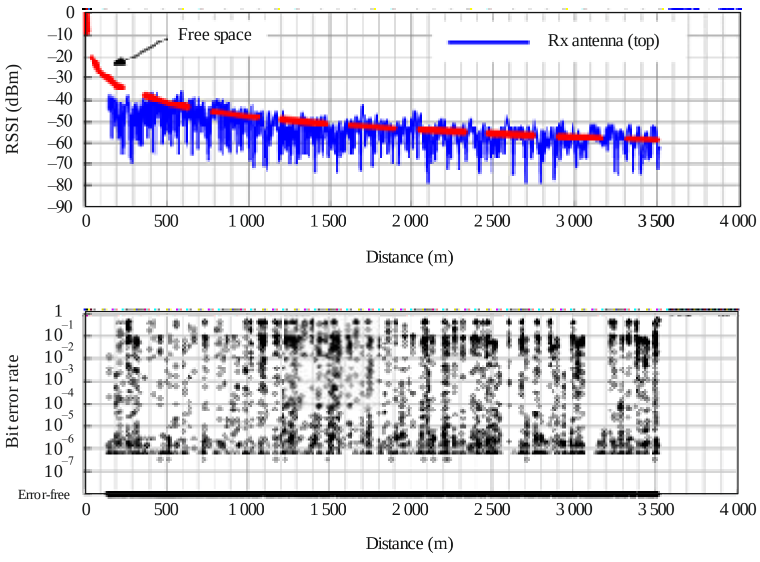

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FIGURE 14

The RSSI and BER performance for the vertical case depending on the number of antennas in the tunnel scenario (Tx = 2, Rx = 1).

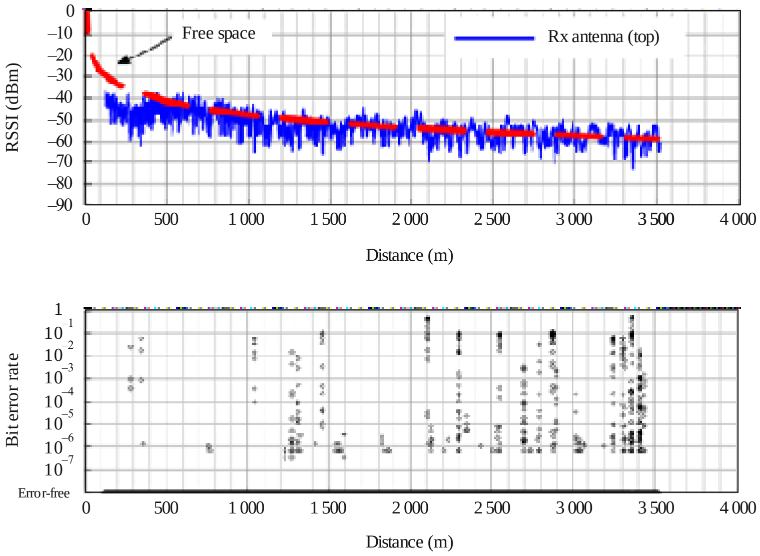

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FIGURE 15

The RSSI and BER performance for the vertical case depending on the number of antennas in the tunnel scenario (Tx = 1, Rx = 2)

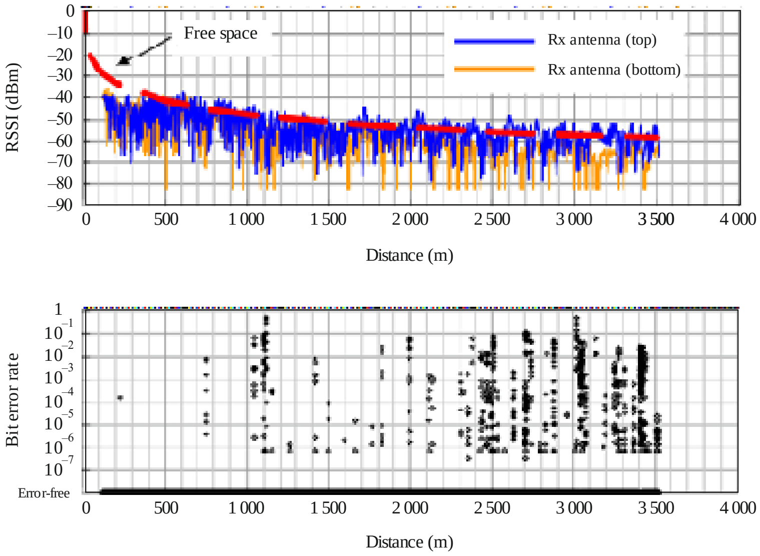

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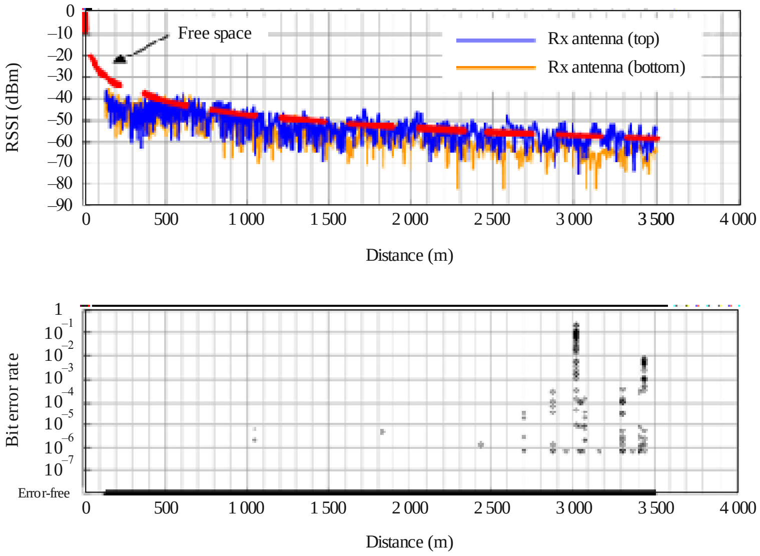
FIGURE 16

The RSSI and BER performance for the vertical case depending on the number of antennas in the tunnel scenario (Tx = 2, Rx = 2)



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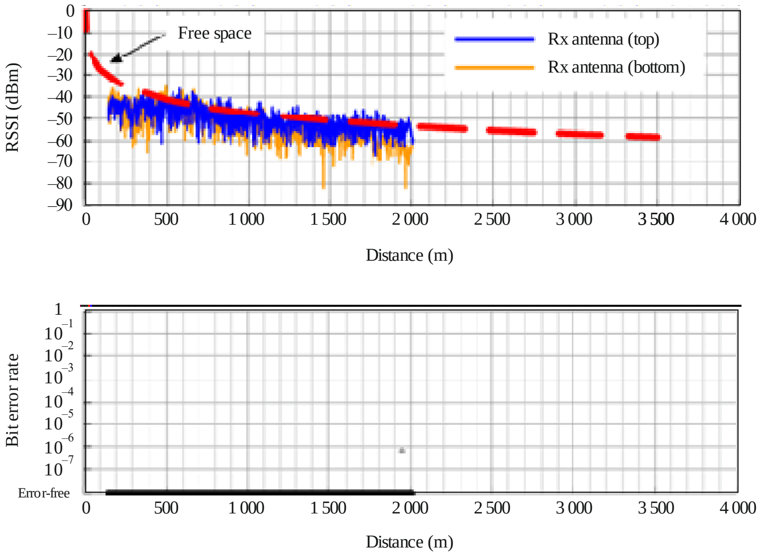
3.1.2.2 Comparison between vertical and horizontal cases

The performance for the different installations of Tx antennas is evaluated. Here, the number of antennas at the Rx and the Tx is commonly set to 2. Figure 17 shows the RSSI and BER performance of the horizontal case (Fig. 12) while the performance of the vertical case is already shown in Fig. 16. It can be noticed that the performance of both the cases are similar despite the difference in antenna configurations. This tendency irrespective of the antenna configuration may be due to rich multipath and a wave-guide phenomenon in the tunnel.

FIGURE 17

Measurement results (horizontal case) in the tunnel scenario



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3.2 Summary of measurement results

These results confirm that the maximum throughput of 100 Mbit/s in almost all the measurement area of the tunnel can be achieved. The transmit distance by keeping enough link quality was over 3 500 m distance from Base Station, which is longer than the distance in similar case in open-site. This shows that the millimetric wave propagation is suitable for condition of tunnel. Moreover, the use of antenna diversity technique can mitigate the deep drop of received power from interference and/or multipath effects.

4 High speed train scenario

Transmittance scenario of high speed train over 300 km/h is different from cases of normal speed train such as regional and local trains, due to consideration of Doppler effects, etc. This section deals with the high speed train scenario and investigates its impact on railway communication system, e.g. Doppler effects.

4.1 Descriptions of trial conditions

The trial was conducted in an open-site curve section (R = 4 000 m) of Tohoku-Shinkansen near Ninohe station in Japan, using a high-speed bullet train known as Shinkansen train [3]. The train with receivers moved at a velocity of 320 km/h on the rail. The measurement conditions are shown in Table 4.

TABLE 4

Measurement conditions (high speed train)

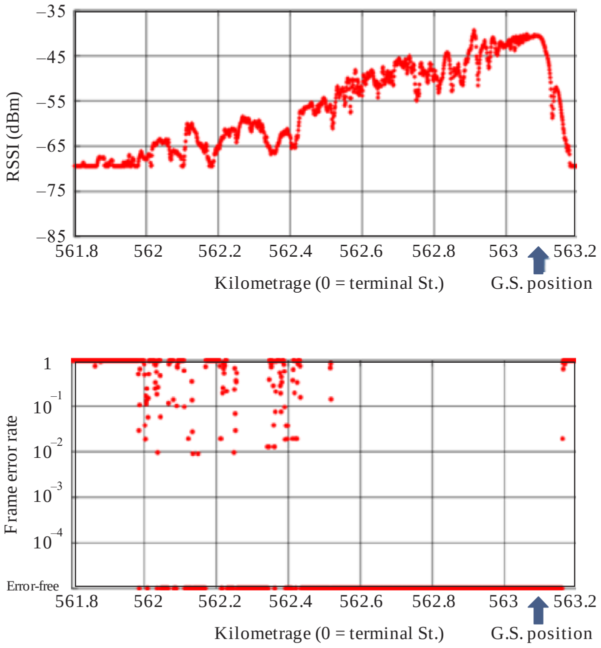
Parameter	Value
Frequency	40 GHz Band
Number of antenna	Ground Station: 2(TX) Train Station: 2(RX)
Modulation scheme	64QAM-OFDM
Data transmission speed	100 Mbit/s
Transmitter power	10 mW
Antenna gain	32 dBi
Beam width	±1.0～1.5 degrees
Vehicle	Shinkansen train
Vehicle speed	Approx. 320 km/h
Propagation environment	Open-site

4.2 Measurement results

Figure 18 shows the measured RSSI and the corresponding Frame Error Rate, where “E.F.” at the vertical axis means Error Free, providing both 100 Mbit/s transmission and error-free connection. The Error Free can be achieved when enough RSSI level is obtained.

FIGURE 18

Measurement results (high speed case) in curved area



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Under the restricted measurement conditions that the location of ground station was installed apart from track, the desired measurement scenario, that main lobes of ground-side and train-side antennas faced directly each other, could not be configured. Furthermore, because the train-side antennas were experimentally installed in driver's room for this measurement, the received signal was attenuated by the front glass of the room. Due to these unfavourable conditions, the range of communication distance was limited. Considering practical use case that the train-side antennas are installed outside, the communication range is expected to be longer than this measurement result.

4.3 Summary of measurement results

These results present that the radio communication between ground and train could be established even under high speed condition in which there is degradation due to the Doppler effects, as shown in the result of frame error rate. This shows the millimetric wave propagation has possibility to be used for high speed train communications.

Annex 2

Specific systems for mobile communications with railways in Japan and Korea

1 Introduction

In Japan and Korea, there are mobile communication systems with railways currently in operation. These are described in the sections below.

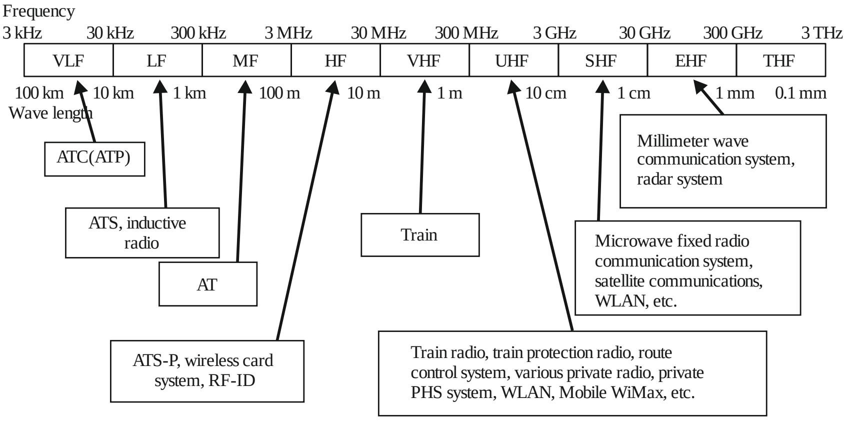
2 Communication systems in Japan

2.1 Introduction

Demand has increased for mobile phone and wireless local area network (LAN) access for passengers on trains in particular for broadband applications. In general, the telecommunication infrastructure for public network for broadband cellular phones and Wi-Fi network have not been sufficiently equipped in tunnels, and the more high speed communication links between ground and trains would be required for adapting various types of wireless communications. Now, many kinds of radio communication systems with railways have been used in Japan, as shown in Fig. 19.

FIGURE 19

Various radio communication systems used in railway systems in Japan



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In Fig. 19, the term THF stands for Tremendous High Frequency; this terminology is used only in the context of this Report.

In Japan, radio communication systems with railways are generally categorized into two types based on applications; train operation and passenger services. Several train companies have started Wi-Fi network service inside the train cabin in order to provide stable and high-speed network service for the passengers. Furthermore, LCX operated in Shinkansen has been used for not only train operation but also passenger service, which can be defined as integrated system.

The following sections address the existing and planned communication systems between ground stations and train stations in Japan for each of three systems; integrated system, train operation system and passenger services system.

2.2 Integrated systems

2.2.1 Shinkansen LCX train radio system

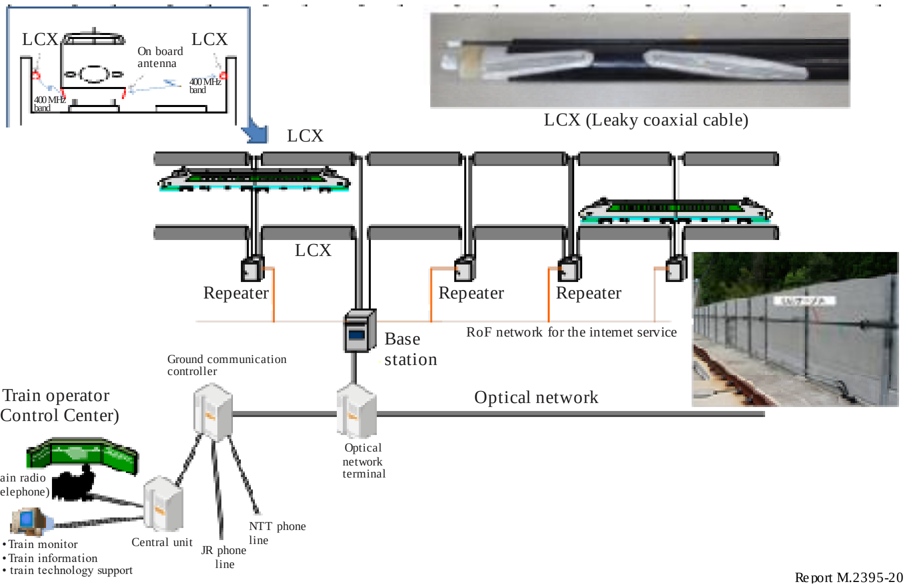
The Shinkansen train radio system equipped with leaky coaxial cables (LCX) as shown in Fig. 20, which is laid at each side of railway tracks all along the Shinkansen line, is used for direction call, direction message, train monitoring information, character-based news, and travel information by radio transmission. Tokaido Shinkansen provides internet access as well for passengers via LCX. A high-quality communication between high speed train and ground with reliable handover connection, is the most distinctive feature of the system.

A Central Unit in Control Centre accommodates Ground Communication Controllers which are located in the major railway stations. The Ground Communication Controllers take handover through accommodated Base Stations. Base Stations are located in almost every station and repeaters which compensate for LCX propagation loss, are located at every 1.3 km intervals along track between Base Stations (2.6 km intervals only at Sanyo Shinkansen). Four antennas installed at body side of the front vehicle, receive radio waves from LCX.

LCX which was developed in 1967 as a type of coaxial cable, has holes called “slot”, to gradually leak radio waves to outside of the cable. Information is transmitted by 400 MHz band radio waves propagated between the slots and antennas installed at the “skirt” of the vehicle. LCX method allows the distance between LCX and antennas on board to be so close constantly that the affection of interference or noise can be minimised and it is possible to maintain stable communication regardless of the location of train, open-site or inside of tunnels. Applying the whole LCX method to train radio systems makes it possible to achieve more than 99.99% connections throughout the entire line even when trains are running at high speed (above 300 km/h).

FIGURE 20

Total system of LCX along Shinkansen tracks



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2.2.2 Millimetric wave

In Japan, 50 GHz band has been used for convenience radio stations of the Shinkansen systems, and 60 GHz band was examined in some measurements for the operation of Shinkansen. On the other hand, recently verification measurements of high capacity wireless communication using 40 GHz band for high speed train has been conducted considering public mobile communication for passengers in the near future. These measurements verified high connectivity in the range of over 3 500 m from Base Station in 100 Mbit/s in tunnel. This millimetric communication system can have high degree of expectation for application in Japan, which has many tunnel areas on the line of high speed trains because there are many uphills, downhills, and mountains all over Japan.

2.3 Train operation communication systems

2.3.1 Railways radio system for conventional railways

The railways radio system for conventional railways is a private communication tool between train operators on the ground and crews on board for safety and stable train transportation. In the past, an analogue radio system is used mainly for direction call. Recently a digital radio system is deployed in order to meet the needs of direction message transmission or train monitoring information transmission [4].

The system consists of a Central Unit in Control Centre, Base Stations located at every approximately 2 to 3 km distance along the track, and Mobile Stations on board. Each radio zone covers approximately 20 to 30 km. Since all Base Stations in a zone transmit the same frequency radio it causes a beat interference at Mobile Stations when RSSI of the front Base Station and RSSI of the rear Base Station are almost the same. It is considered to be a disadvantage of the analogue radio system. This problem was solved in the digital radio system.

In the digital radio system, a Base Station transmits two types of waves; the preceding and delayed. The transmission timing of delayed wave is delayed by one-symbol compared to the preceding wave. Base Stations transmit these two types of waves one after another and Mobile Stations demodulate the waves by using adaptive equalizer to suppress a beat interference and realize high quality radio communications.

2.3.2 Radio communication for train control system

Radio communication for a train control system is an automatic train control system that makes use of telecommunications between Mobile Station (train) and Base Stations (ground) for traffic management and infrastructure control. In Japan, from the latter of 1980s to the 1990s, a system called “CARAT” (Computer and Radio Aided Train control system) had been developed for Shinkansen system experimentally. At the system trial of CARAT by Shinkansen train, a part of the Shinkansen LCX train radio system described in § 2.2.1, had been utilized for telecommunications of train control commands. As a result of the system trial, it was confirmed that the safe and flexible train control could be achieved by the system. Based on some essential techniques developed in CARAT, a new system called “ATACS” (Advanced Train Administration and Communication System) has been developed for conventional railways. ATACS has been in practical use since October 2011, as the first train control system based on radio communications without using whole LCX along the track.

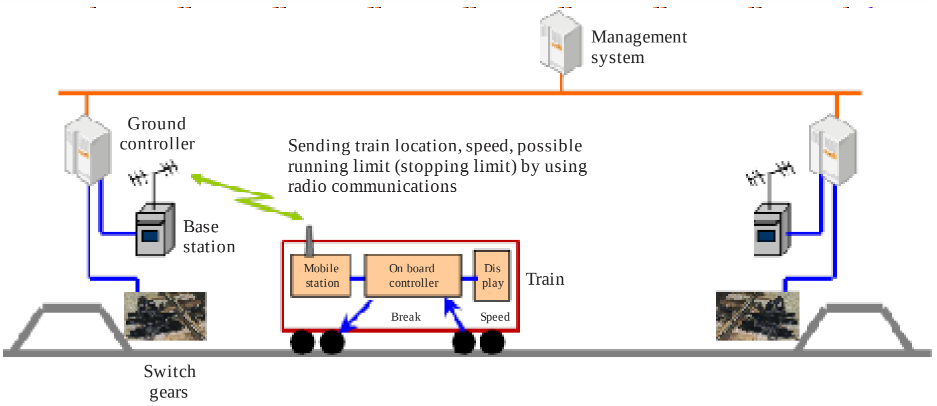
These systems developed in Japan, are called “JRTC” (Japan Radio Train Control system) as shown in Fig. 21, and requirements of basic function and system construction have been defined in Japanese Industrial Standards as JIS E 3801. JRTC corresponds to the train control system of ERTMS/ETCS Level 3 in Europe.

The basic architecture of JRTC consists of 3 sub-systems, i.e. wayside sub-system, on-board sub-system, and train to wayside communication sub-system. The train detects its own location and location information is transmitted to the Ground Controller. With the location information, condition of electric switch machine, and condition of level crossing, the Ground Controller calculates the limit in which the train could run safely and sends the stopping limit to the train. The Ground Controller controls the ground equipment as well, such as electric switch machines, level crossings, etc.

On the train, the on-board controller calculates a brake pattern and an upper limit speed curve, by using its own brake performance to stop at the running limit directed by the Ground Controller. The on-board controller directs adequate train-speed to the train-driver and if train-speed exceeds the brake pattern, the on-board controller makes the train slow-down or stop by controlling the brake automatically.

FIGURE 21

Basic architecture of JRTC system



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In ATACS, Base Stations are located at every 3 km intervals along the track. In the system, FDD method is used and four pairs of radio frequencies for ground-to-train communications and train-to-ground communications are prepared. These frequency pairs are assigned to each Base Station one by one repeatedly to prevent interference at any place along the track. Therefore eight radio frequencies, a pair of frequencies x4, are used in each railway section. The bandwidth of the radio wave is 6.25 kHz and data rate is 9 600 bit/s. TDMA method is used in the system and each Base Station can control 12 trains at a time. Location information of the train is used for handover between Base Stations. The Base Station communicates with each train every 1 second in the same radio zone and the train will make an emergency stop automatically if communications between a Base Station and the train stopped for more than 3 seconds. Emergency stop caused by malfunction of radio communication, has never happened since 2011 in practical use.

2.3.3 Train protection radio system

The train protection radio system is used to notify the approaching trains of emergency, and in order to prevent a secondary accident. When train crews are confronting an emergency situation on track such as line blocked objects, a train derailment, and a fire, the crews should use the train protection radio system and the emergency radio signal is directly transmitted to approaching trains. The system started its operation in the late 1980s in Japan as an analogue system and now the systems have been replaced with a digitalized system in many railways in the nationwide [5].

The protection radio equipment on board consists primarily of private radio equipment, a transmission button, and an antenna. When the transmission button is pressed, the emergency radio of 150/400 MHz band is transmitted to the approaching trains. When the approaching train receives the emergency signal, the crew hears alarm and should take necessary actions such as stopping the train. The emergency radio signal reaches nominally within 1 km radius. If it is difficult for the emergency radio signal to reach to the approaching train because of geographical conditions, such as in tunnels, repeaters are installed on trackside in order to expand the coverage of radio propagation.

The followings are some extended examples of the system.

1) The emergency radio signal is transmitted to other trains through the network via Base Stations and Central Unit.

2) The emergency radio signal is also triggered by input signal from other equipment on board.

3) The train protection radio equipment is installed at stations, or railroad crossings in order to notify the approaching trains of the emergency situation.

4) The train protection radio equipment is set up in an equipment room on the ground. It may send signal to other systems such as power cut-off system when it receives the emergency signal from the train. The other system utilizes the signal to improve safety.

2.4 Passenger service systems

2.4.1 WiMAX

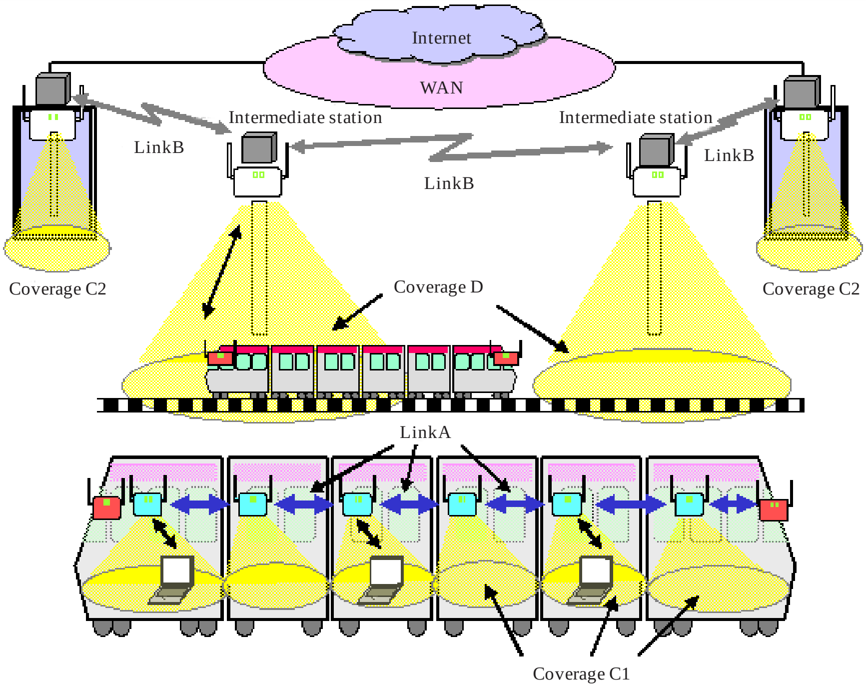
Narita Express trains connecting between Narita international airport and the Tokyo metropolitan areas provides Internet access service that communicates with WiMAX Base Stations using antennas on the train roof and converts data into that for Wi-Fi at on-board repeaters to communicate with passengers' terminals. WiMAX already has many Base Stations in operation along railway lines in the greater Tokyo area, and small Base Stations and relay stations are installed in railway stations. On the other hand, use of WiMAX on Shinkansen trains faces the issues of transmission in tunnels and the number of Base Stations required along the lines. The transmission speed is 40 Mbit/s in 2.5 GHz band, and the transmission range is 1 km [6].

2.4.2 WiFi access for travelling train

Tsukuba Express railway line connecting Tokyo and Tsukuba, Ibaraki prefecture at 130 km/h uses Wi-Fi access system inside the car. A Base Station installed in each compartment of the train provides internet services to passengers, and a Base Station at each end of the train communicates with relay Base Stations installed at stations or along the railroad. The detailed information on this system is provided in Report ITU-R F.2086-1. Figure 22 shows the overview of this Wi-Fi access system.

FIGURE 22

WiFi services for train



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2.4.3 Contents transmission

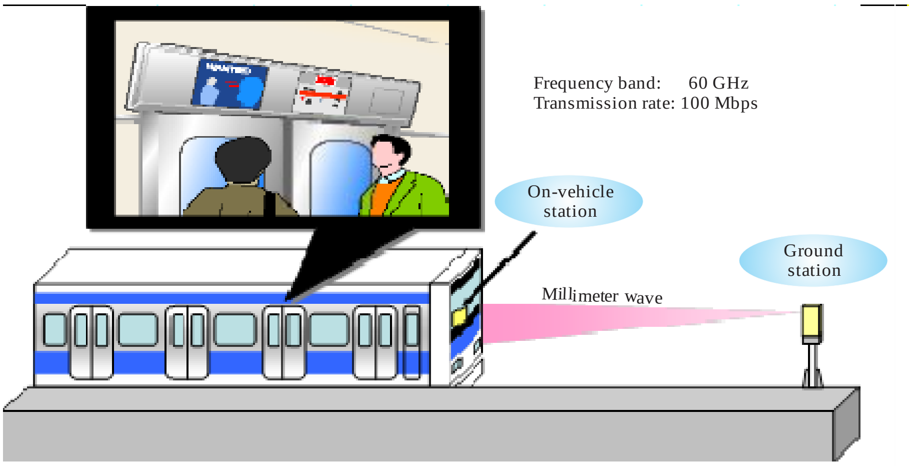
Recently, digital signage in cabin, which displays advertisements, news, etc., is becoming popular. Millimetric waves are used for contents transmission. The contents transmission system consists of

Ground Stations and On-Vehicle Stations. 60 GHz band radio is used for 100 Mbit/s transmission. Contents are transmitted to the train when it stops near the Ground Station [7].

It becomes possible to renew instantaneously large-volume information of contents such as the latest news and advertisement with video by using high-capacity communication by a millimetric wave. Figure 23 shows the image of the millimetric wave system.

FIGURE 23

Millimetric wave system of contents transmission



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3 Communication systems in Korea

3.1 Introduction

The Republic of Korea has been running conventional railway and high speed railway systems, so called KTX, whose speed is about 300 km/h. Mobile internet services such as mobile video on demand, internet broadcasting, and social networking are steadily increasing and expanding. According to a recent survey, one of the most preferred places to use mobile internet is the moving vehicle, such as subway and train. The passengers in the subway trains and high speed trains called KTX can use Wi-Fi access points (APs) as well as 3G/4G cellular networks. Specifically, to make use of the Wi-Fi APs, the backhaul lines between tracksides and trains are important. In this regards, this section describes an existing mobile wireless backhaul based on WiBro and on-going development work that expands the existing backhaul capacity per train with a millimetric-wave-based system. Additionally, it describes the present and near future railway communication systems related to a couple of signal control systems.

3.2 Mobile internet services

3.2.1 WiBro

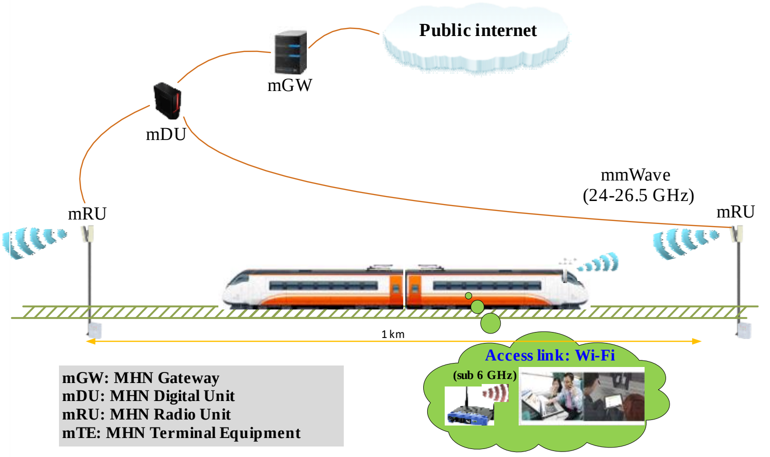
WiBro is the service name for IEEE 802.16e international standard. In Korea, the WiBro systems have been widely deployed at tracksides of subways in Seoul and Busan for the mobile wireless backhauls. The passengers can access the Internet through Wi-Fi APs inside the train cars, and their aggregated data are pipelined into the WiBro backhauls. The maximum capacity of the deployed WiBro-based backhauls is less than 10 Mbit/s where 2.4 GHz bands are utilized. On the other hand, the passengers inside the carriages can directly access 3G/4G networks of three operators. Therefore, the WiBro backhauls play the key role in performing offloading for these networks on rush hours in the carriers’ point of view. However, the backhaul capacity limitation is still too low to accommodate the ever-increasing demands for data. In the meantime, the Korean bullet trains, KTX provide the passengers with some limited free Wi-Fi services by using 4G-network-based backhauls.

3.2.2 Mobile Hotspot Network (MHN) using millimetric wave

In Korea, a communication system for fast moving vehicles, named as mobile hotspot network (MHN), is under development. Figure 24 shows an overall system architecture where backhaul links with the millimetric waves and user access links inside the car are drawn. A goal of backhaul capacity is 1 Gbit/s, which corresponds to 100 times larger than that of the currently deployed WiBro based backhaul in Seoul. However, the service scenarios are likely to be expanded into normal and high-speed trains, and even route-unpredictable fast moving transportations. Particularly, the expected mobility supported by the MHN system is up to 500 km/h. A prototype of the MHN commercial system will emerge soon. The prototype system will use 24~26.5 GHz frequency bands. The capability of supporting ultra-high data capacity and mobility will enable the MHN system. And this can make it an alternative evolutional path to the high-speed region of upcoming 5G systems.

FIGURE 24

Overview of MHN system



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3.3 Train communication

3.3.1 VHF

VHF (Very High Frequency) system provides point-to-point communication scheme between control centre/Base Station and a train crew or inter-mobile station communications in conventional train. VHF system uses four channels for exchanging data at 153 MHz frequency band. Since the communication is established by voice call depending on propagation range, appointment for intercommunication is required. Due to point-to-point scheme, various communication functions such as group communication, priority communication are not supported. Furthermore, the main requirement for railway wireless networks, i.e. safety, reliability, and security, are not guaranteed. Table 5 represents frequency band assignment for VHF system station.

TABLE 5

Frequency band assignment for VHF

Item	**CH**	**Wideband (MHz)**		**Narrowband (MHz)**	
		Tx	**Rx**	**Tx**	**Rx**
Portable terminal	1 (Normal)	153.440	Same as Tx	150.4250	Same as Tx
	2 (emergency)	153.250		150.4500	
	3 (Work)	153.280		150.4625	
	4 (Work)	153.660		150.4375	
Portable terminal	1 (Normal)	153.440	Same as Tx	150.4250	Same as Tx
	2 (emergency)	153.340		150.4875	
	3 (Work)	153.740		150.4125	
	4 (Work)	153.660		150.4375	
Mobile terminal	1 (Normal)	153.440	Same as Tx	150.4250	Same as Tx
	2 (emergency)	153.520		150.4500	
	3 (Work)	153.590	153.110	150.4750	150.3750
	4 (Work)	153.620	153.200	150.5000	150.4000
Base Station	1 (Normal)	153.440	Same as Tx	150.4250	Same as Tx
	2 (emergency)	153.520		150.4500	
	3 (Work)	153.110	153.590	150.9750	150.4750
	4 (Work)	153.200	153.620	150.4000	150.5000

3.3.2 TRS

Korea is using two TRS (Trunked Radio System) schemes, i.e. TRS-ASTRO and TRS-TETRA. Table 6 represents TRS-ASTRO technology.

TABLE 6

Characteristics of TRS-ASTRO

Property	**Characteristics**
Frequency range	800 MHz
Channel access	FDMA
Bandwidth	12.5 kHz
Data rate	9.6 kbit/s
Modulation scheme	C4FM

Table 7 represents TRS-TETRA technology. TRS-TETRA provides four channels.

TABLE 7

Characteristics of TRS-TETRA

Property	Characteristics
Frequency range	800 MHz
Channel access	TDMA
Bandwidth	25 kHz
Data rate	7.2~36 kbit/s
Modulation scheme	π/4 DQPSK

TRS-TETRA provides voice service such as one-to-one call, one-to-multi call, group call, emergency call, and direct call as well as data service such as message and packet transmission. TRS-TETRA has versatile availability for railway wireless network, being compared with TRS-ASTRO and VHF systems. TRS-TETRA has limitation of localization due to proprietary technology and high speed data transmission.

3.3.3 LTE

Based on a governmental policy, it was decided to develop LTE railway communication system in 2010. To support high speed transmission and new functionalities (group communication, data service, quality of service, direct communication, etc.), various wireless communication technologies are considered for railway communications. As LTE systems are capable of supporting voice, critical data, and video applications, a pilot test has been conducted between Iksan station and Jeongeup station to verify their communication performance.

FIGURE 25

Configuration of railway communication system

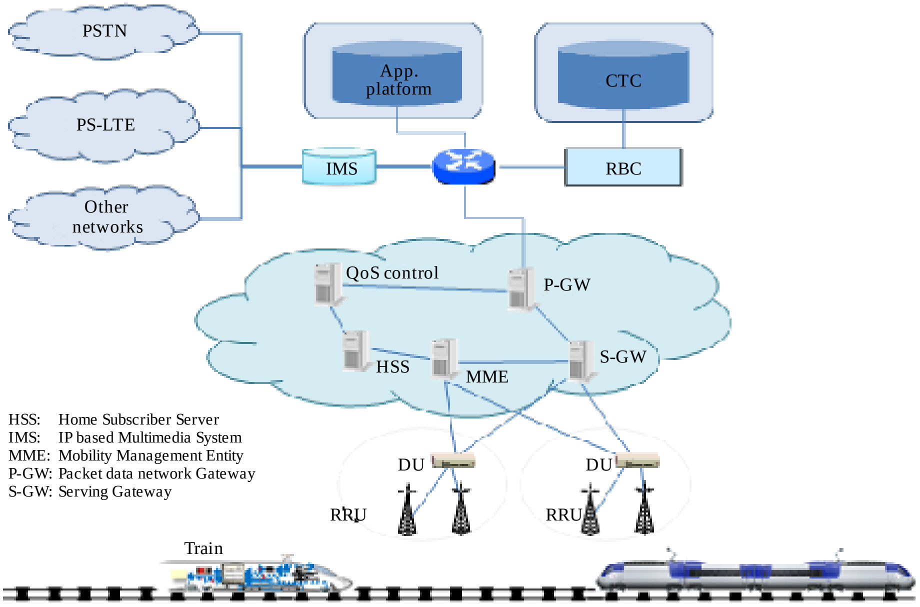

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Figure 25 shows the configuration of LTE railway communication system which consists of radio access networks, LTE core system, application platforms (App. Platform) and centralized train control center (CTC) including radio block center (RBC). Radio access networks consist of digital units (DU) and remote radio units (RRU). LTE core system includes QoS control system, P-GW, S-GW, HSS and MME, etc. The technical characteristics of LTE railway communications system are as follows:

TABLE 8

Technical characteristics

Item	**Technical characteristic**
RF frequency	Uplink: 718 ~ 728 MHz Downlink: 773 ~ 783 MHz
RF channel bandwidth	10 MHz
RF Transmit power (Max)	23 dBm (Mobile) 46 dBm (RRU)
Modulation type	Uplink: SC-FDMA Downlink: OFDMA
Data rate (Max)	Uplink: 37 Mbit/s Downlink: 75 Mbit/s (2X2)
MIMO	2×2
Duplex	FDD (Frequency Division Duplex)

This system will be installed between Wonju station and Gangneung station for PyungChang Winter Olympic Game in 2018. This is the first high speed railway using LTE communication systems in Korea. Starting from the installation in Wonju-Gangneung route, LTE based railway communication system will be gradually deployed. Besides applying of new communication system, interworking technologies among different communication networks, i.e. LTE-VHF, LTE-TRS-TETRA and LTE-TRS-ASTRO are also under developing. Although various communication schemes are currently used in railway communication, LTE based system will be mainly used for the major railway communication system. In addition, Busan City first deploys an LTE based Metro system for railway communication services in 2016.

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