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# Integrating 5G and Terrestrial Trunked Radio into Railway Communication System for Railway Safety and Information Security

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It is necessary to develop innovative communication technologies to ensure efficient operation and effective data transmission in "smart railway" systems. For these systems, information security is of paramount importance. Fifth-generation (5G) technology is safe, reliable, and cost-effective for wireless communication in transportation systems. However, the robustness of the links between devices in a 5G network needs to be ensured for the safety of railway operations. Thus, Terrestrial Trunked Radio (TETRA) must be used with 5G technology for secure data transmission and communication. Safety monitoring, early warning, inspection patrols, and passenger services are required in smart transportation systems to prevent accidents and increase operation efficiency. TETRA and 5G technology have been integrated into an international airport in Japan and the railway system of Taiwan. In this study, we analyzed the advantages of the application of 5G technology and TETRA in a system. The integrated system with 5G technology and TETRA allows various applications and cost-effective smart railway systems.

## 1. Introduction

In 2022, an alleged system failure delayed and halted many trains in China, causing major railway hubs across the country to stop or postpone train services.(1) The incident was caused by failures in the Cab Integrated Wireless communication equipment and Global System for Mobile Communications – Railway (GSM-R) systems. These failures were due to multiple cyberattacks. Because GSM-R is used for the railway system in China, the interference with GSM-R disrupted the entire railway system, posing a significant threat to operations. Railway transportation is an important part of the transportation industry; thus, system security and smooth operation are required. By using secure and stable data transmission and communication, incidents such as the one in China can be prevented. Therefore, in this study, we reviewed the use of fifth-generation (5G) technology and Terrestrial Trunked Radio (TETRA) for data security and fast and stable digital communication in a railway system. Both 5G technology and TETRA can be implemented

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in modern transportation systems, including railway systems, as numerous sensors are used in the systems, leading to the construction of wireless sensor networks. In addition, transmission rates must be sufficiently high to prevent delayed data transmission and enable large amounts of data to be transmitted. As wider coverage and interconnectivity are essential for sensor networks, appropriate technologies must be used to manage the sensor networks.

Owing to its capabilities and lower energy consumption than traditional technologies, 5G technology has been used for the railway system of Taiwan. This technology enables real-time monitoring and preventive measures against various risks in the operation of the railway system. There are diverse requirements for “smart railway” systems with 5G to improve the safety and reliability of their operation, one of which is information security. In the development of the European Union Smart Railway Project, interconnection to enhance the comfort and security of services has been seriously considered.

The World Rail Association has released World Radiocommunication Conference (WRC)-19, the railway train-to-ground communication protocol for the 3rd Generation Partnership Project (3GPP), and a series of standards for the Future Railway Mobile Communication System (FRMCS) to improve railway communication.[2,3] FRMCS is the worldwide telecommunication system designed by the International Union of Railways in close cooperation with different stakeholders from the rail industry. It succeeded the previous GSM-R for digitalized rail transportation.[4] Taiwan’s railway system has been reformed with new safety regulations to ensure information security and enable big data use for intelligent operation. Smart railways require next-generation technologies (Fig. 1) with secure train communication and intelligent management.

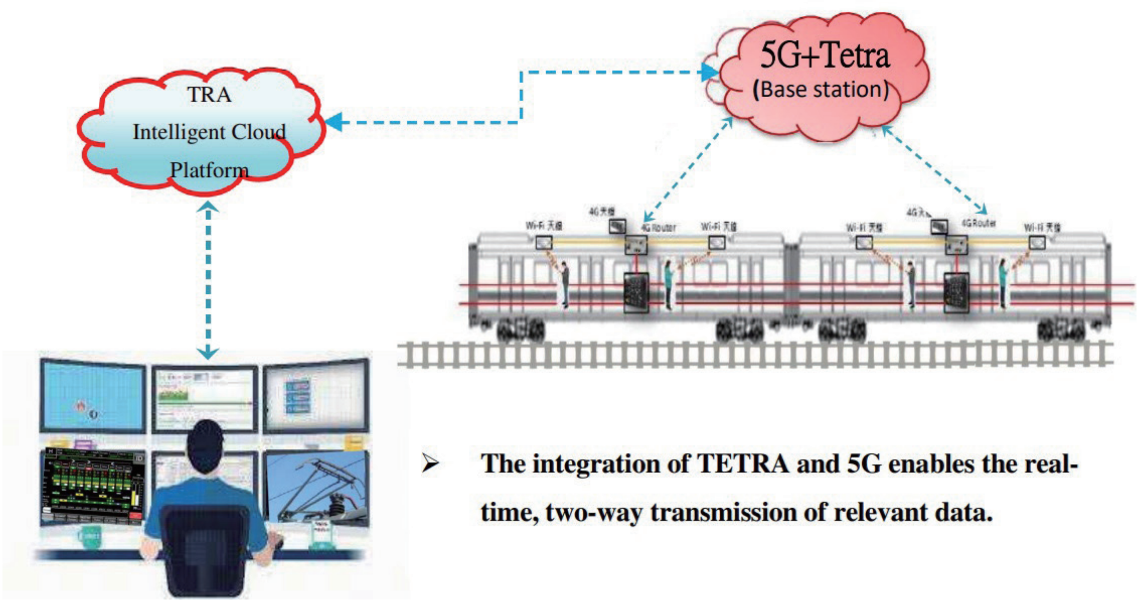


Fig. 1. (Color online) Requirements for train communication in 5G+TETRA platform and integration of TETRA and 5G for real-time two-way transmission of data.

Recently, information security has been critical for the rail industry; thus, 5G technology is being integrated into systems. For Taiwan's railway system with 5G technology, it is important to include security mechanisms and sufficient protection measures. TETRA supports the standardization of mission-critical voice services. TETRA networks for integrated communications in the railway system are constructed on an innovative and compact platform. The network provides cost-effective and reliable digital communication including group and individual calling, texting, and preprogrammed messaging for multiple groups. TETRA allows comprehensive services by using various databases, geolocation systems, and information integration. Location data is obtained from integrated global positioning systems (GPS) and transmitted to the network management service center to track personnel and trains, allocate resources, and dispatch short data services. TETRA enhances safety and reduces work pressure, leading to operational benefits. The control center accesses all information on operating trains and can share it with operating agents.

Owing to its advantages, the TETRA system is expected to become the standard for the railway communication system of Taiwan. Therefore, it is necessary to optimize TETRA standards and equipment for the effective operation of a 5G-TETRA system.(5) Therefore, we investigated how to apply a 5G-TETRA system in the railway system effectively in this study. The results provide a basis for the development of the railway system in many countries.

## 2. 5G and Its Applications

First, we reviewed the goals and requirements of the smart railway to adopt 5G technology. Owing to its higher speed, shorter latency, and wider coverage, 5G has been used for smart transportation for years. 5G exhibits low latency, a high speed of data transmission, wide bandwidth, and high connection density. However, more investment in research and development is required to develop products and services for Taiwan's railway system with appropriate policies and strategies (Table 1).

Table 1
Requirements of smart railway development.

| No. | Goal | Requirement |
|---|---|---|
| 1 | Smart rail maintenance | 1. Operational efficiency<br>2. Early warning<br>3. Reduced the number of siloed solutions<br>4. Operational safety |
| 2 | Automated train operation | 1. Operational and energy efficiency<br>2. Train density and punctuality increase<br>3. Human error decrease and safety |
| 3 | Smart railway | 1. 5G IoT environment<br>2. Automatic patrol inspection<br>3. Cloud platform |

Railways are constructed in urban areas, plains, valleys, and tunnels. Therefore, meticulous planning of station deployment and long-term signal adjustment are required to meet relevant requirements and ensure a wide radio signal coverage. Although 5G networks are mainly public, private networks can meet the needs of private enterprises. According to the definition of 5G Alliance for Connected Industries and Automation (5G-ACIA), private networks are deployed in different scenarios, as shown in Table 2.

Because of the previous implementation of 4G networks, a sudden change to a 5G network would not be plausible for the railway system. Therefore, 4G networks, 5G non-standalone networks, and 5G standalone networks are used together in different infrastructures. In many 5G standalone networks, data is not encrypted, which may make all links of a network vulnerable to cyberattacks.(6)

## 3. 5G and TETRA

Advanced information and communication technology has been integrated into transportation in the Internet of Vehicles and People. Artificial intelligence (AI) image recognition and the analysis of related data enable innovative services. However, such advanced technologies also highlight the importance of cybersecurity. To use the developed transportation technology, it is necessary to develop smart technology based on 5G technology.(7)

As a mobile broadband-ready technology, FRMCS is the global standard for railway communications, helping to improve safety and operational efficiency, support innovative passenger services, and accelerate digital transformation. It also minimizes network latency by employing cloud technology and is used to automate the operation of the railway system through broadband machine-to-machine communication (Fig. 2). In the use of FRMCS, 5G is critical, as it offers high capacity, excellent performance, and reliability and supports massive machine-type communication (MTC) and the Internet of Things (IoT). FRMCS with 5G supports highly reliable and low-latency mission-critical communications and platforms for innovative applications such as group video calling, automated train control, predictive maintenance, and a fast onboard Wi-Fi service, thus reducing operating costs and enhancing passenger experience.(8)

Table 2
Four scenarios where private networks are deployed in railway infrastructures.

| No. | Scenario | Description |
|---|---|---|
| 1 | Train-to-ground solutions | • Unified broadband solution for safety and security, entertainment, and mission-critical telemetry<br>• High availability with seamless switching across redundant links |
| 2 | Mission-critical communications | • MC-PTT/PTV integration<br>• TETRA legacy interworking |
| 3 | Tunnel solutions | In-tunnel connectivity solutions |
| 4 | Integrated operations centers | • Actionable intelligence platform<br>• Complete situational awareness and real-time contextual response |

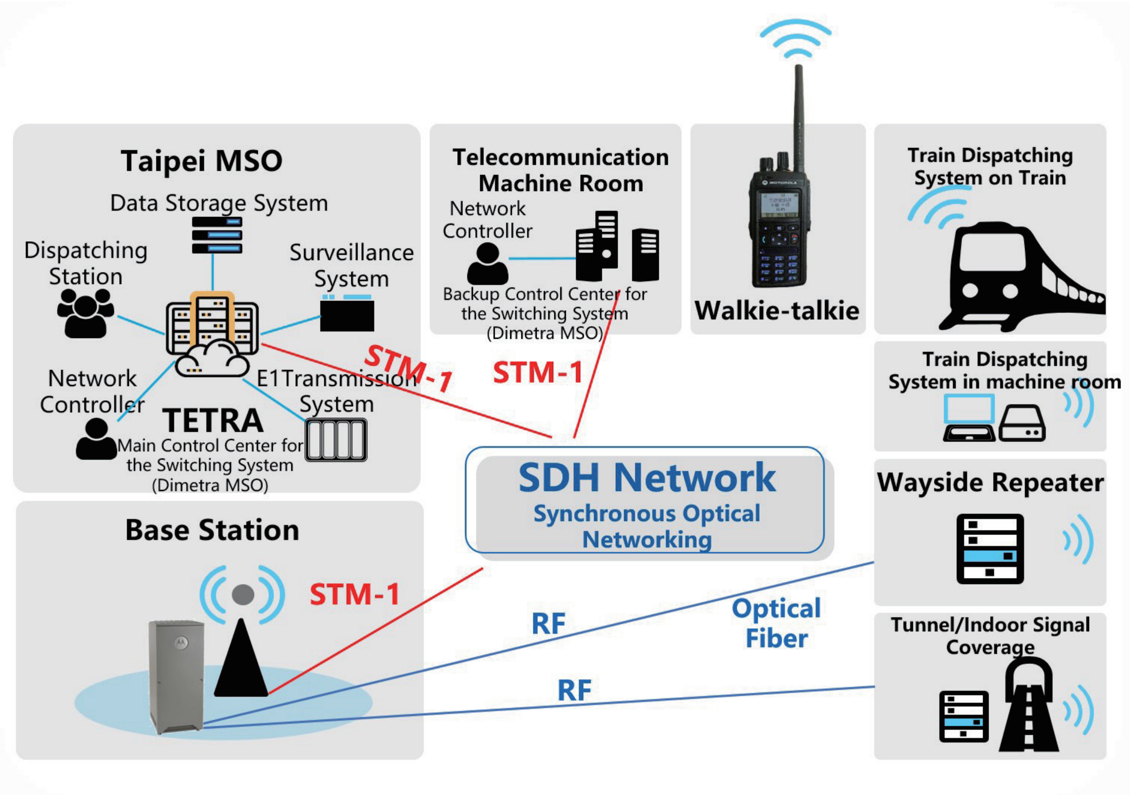


Fig. 2. (Color online) Structure of the TCS in Taiwan.

The train communication system (TCS) is an essential component of a smart railway, which requires reliable and safe communication. In the TCS, GSM-R and TETRA have been used for decades, as they have common railway-specific functions. The TCS allows the virtualization of circuits and block signals and transforms trackside signals into cab signals. Although GSM-R equipment is no longer available, the Level 2 European Train Control System (ETCS) still requires the installation of an ERTMS/GSM-R standard device and wireless base stations along the trackside. Trackside signals are monitored and controlled by the Radio Block Center (RBC), which connects the signal interlocking system to the train via wireless base stations and by using the cab signal function. Ground-based transponders serve as electronic units to locate trains using TETRA in the wireless railway communication system for railway communication, train operation, safety monitoring, maintenance, and customer/passenger service. TETRA is currently used in newly built railway communication projects, and the TCS in Taiwan has adopted TETRA for scheduling and voice dispatching owing to its stable and reliable operations (Fig. 2). In an emergency, passengers on a train can send messages via the emergency button, and the train conductor can contact the station through the TCS.(9) TETRA in the TCS transmits optimized data packets as an advanced all-digital trunked radio system to support individual and group calls between wireless devices and to control data transmission for various operations.(10) The largest TETRA network, consisting of over 300 base stations and 42,000 terminal users, is deployed by the South Korean government. The network is used for wireless communications between the police, fire departments, forestry service providers, and public administrators.(10)

Taiwan Railways (TRA) has designed a TETRA data transmission system for secure, accurate, and stable communication and services (Fig. 3).[11] To enhance the precision of automatic train protection (ATP), TRA connects its TETRA-based train dispatching radio system (TDRS) to the third-generation centralized train control (CTC) system. The third-generation CTC system locates trains and provides the TDRS with information for data comparison. The TDRS transmits alert messages for ATP surveillance to the third-generation CTC system for real-time alerts and recording. The TDRS monitors the train's onboard system, and any malfunction of the ATP is reported in a message to the third-generation CTC system (Fig. 3). The TDRS thus ensures the stability and functionality of the TETRA system.[12,13]

Communication in the railway system does not require Mb/s data transmission. Thus, 3GPP has been conducted to develop the railway system in Taiwan. Because 5G technology has been implemented in most applications, all the railway systems will soon need to adopt 5G technologies to reduce costs and enhance efficiency and performance.

The 5G network costs 10 times more to construct than TETRA owing to its high-frequency band and short communication distance, whereas TETRA operates in a low-frequency band and with a longer communication distance (Table 3). The 5G network is more susceptible to interference from high-power radio waves and ambient noises than TETRA. For railway communication systems, the integration of 5G and TETRA is in line with the needs of railway communication, as 5G is efficient for high-volume data transmission and TETRA is effective for voice communication and positioning applications.

The driving system of trains is important for public safety. For the driving system, TETRA

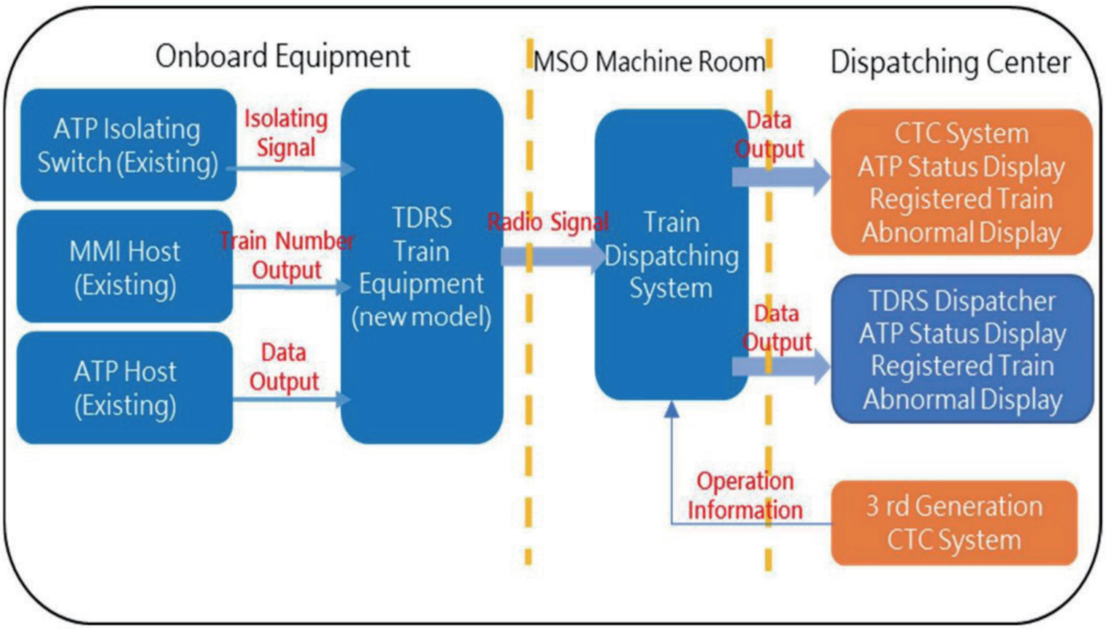


Fig. 3. (Color online) TDRS and CTC system architecture.

Table 3
Comparison of 5G and TETRA.

| | |
|---|---|
| 5G (5th-generation mobile networks) | Ultralow latency, ultrahigh data transmission volume, ultrahigh speed, ultrawide band, and ultrahigh connection density. Used for large-traffic data transmission. |
| TETRA (Terrestrial Trunked Radio) | The digital trunked mobile radio standard is widely used in radio communication applications on railway tracks around the world. |

and the 5G network must be integrated to maximize their respective advantages.(13) In a smart railway, high (GB/s) data transmission rates through a 5G network are required for the high-definition surveillance and remote maintenance of trains. In addition, a wide coverage and interconnectivity are required for sensor networks for trains, cargo, and passengers. Therefore, a dedicated wireless network is required for a large number of sensors, and this network must have ms-level latency, ultrahigh reliability, and GB/s transmission rates for trains operating at speeds of over 300 km/h. Appropriate infrastructure requires the management, services, seamless data transmission, and information security of a smart railway. It must also incorporate mobile networks, IoT, cloud computing, big data, and AI. Dedicated railway frequency bands must also be allocated. Therefore, 5G technology is used in railway communication systems (Fig. 4).(14)

## 4. Example of Integration of 5G and TETRA

NTT East and its group company Nippon Airport Radio Co., Ltd. (NAR) announced successful 5G interconnection using their “Giga-Raku 5G” local 5G service and TETRA for digital communication for commercial purposes. Giga-Raku 5G offers 5G standalone functions at affordable prices and provides end-to-end IT outsourcing to design, construct, and operate 5G services. Giga-Raku 5G and TETRA were integrated into the communication system of an airport by the Airport Restricted Area Automated Driving Realization Research Committee in 2020. For the first time, a voice communication system was established between 5G-compatible devices for mission-critical push-to-talk (MCPTT). The devices are flexibly and seamlessly connected to wireless devices within the airport. In the future, TETRA will be used to integrate the local 5G networks of airports, factories, and warehouses to provide improved and integrated services (Fig. 5).

At Narita International Airport, Japan, a consortium including NTT East demonstrated the use of local 5G networks to operate autonomous buses remotely. They used local 5G networks as a stable and secure communication infrastructure. TETRA, operated by NAR, was used for the airport’s ground-to-ground radio communication to conduct daily operations such as ground control and emergency management and to ensure secure communication. To advance airport operations, airport radio infrastructure must be included in the communication system. Therefore, it is crucial to interconnect different systems and devices, thus enabling smartphones to be used for communication as well as various operations. NAR uses the non-commercial MCPTT system WAVE to connect TETRA to the calling and messaging system of the airport, including mobile phone networks and local 5G networks. By interconnecting WAVE with the local 5G network Giga-raku-5G, communication between 5G-compatible smartphones and

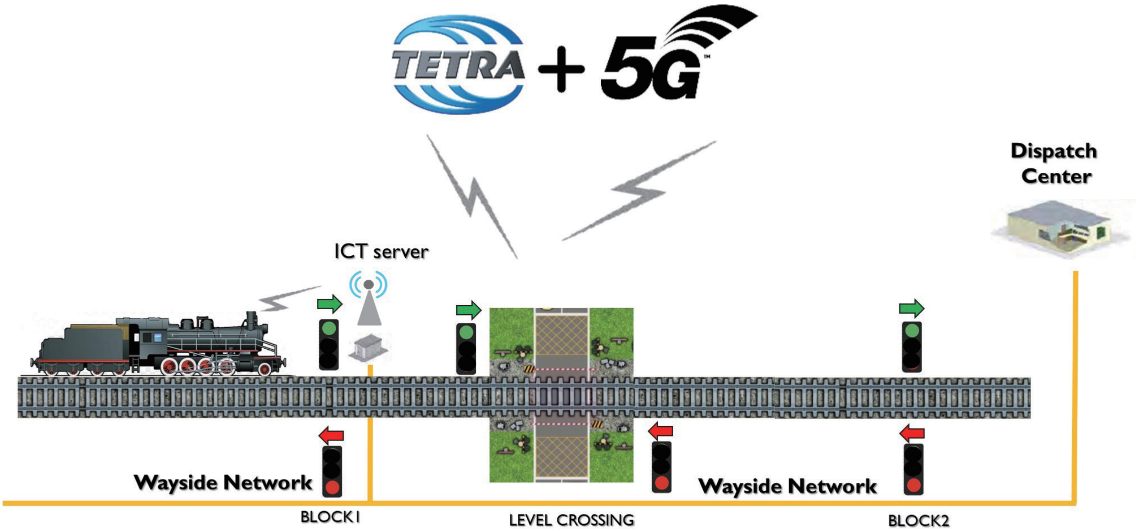


Fig. 4. (Color online) Example of integration of 5G and TETRA.

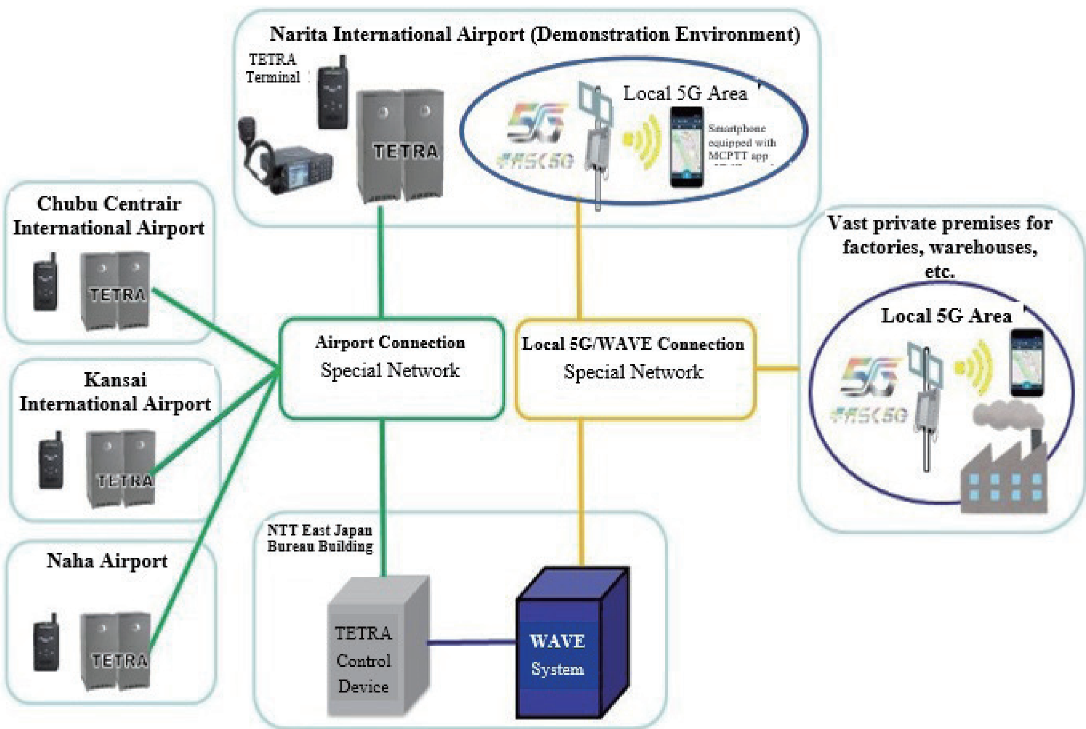


Fig. 5. (Color online) Integration of 5G and TETRA in Japan.

TETRA devices is improved and enables a stable environment. In the system, the integration of WAVE and TETRA resulted in high-quality and stable functions. The integrated system was not affected by mobile network failures or congestion and was readily available in emergencies.

The successful integration of 5G and TETRA at Narita International Airport[15] suggests that they can also be integrated in a railway communication system in which numerous IoT devices are used without efficient management, making them vulnerable to cyberattacks.[16] Such integration would prevent malicious scripts from being downloaded into operating systems including kiosks. It would also become easier to implement security measures with regular updates using the information obtained during the operation. In addition, network connections of devices can be managed and monitored to prevent unexpected malfunctions.[17]

TRA has improved safety and punctuality as a result of using a 5G network to ensure effective network operations and information security based on the integration of 5G and TETRA (Fig. 6 and Table 4). By adopting 5G, AI, and IoT, the safety of passengers and trains has been enhanced and operational costs have been reduced while increasing decision-making efficiency. Innovative services or applications can be used to provide smart transportation solutions and improve the travel experience for passengers.

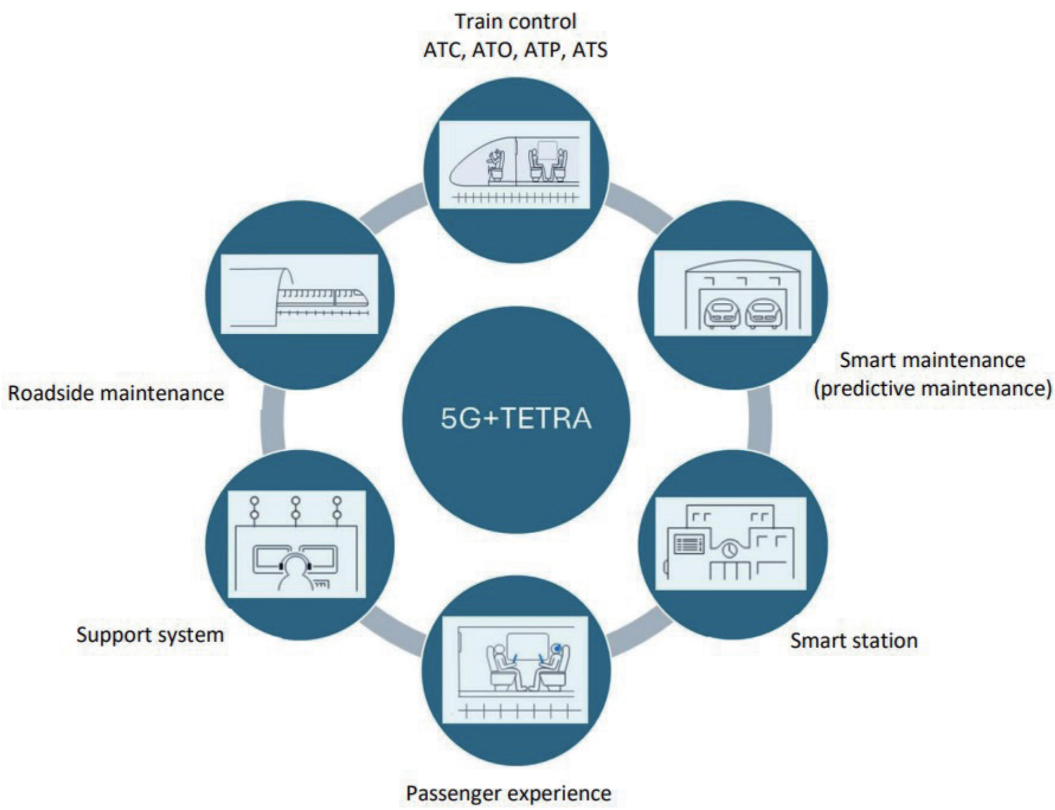


Fig. 6. (Color online) Integration of 5G and TETRA by TRA.

Table 4
Targets for smart railway operation by TRA.

| No. | Target | Description |
|---|---|---|
| 1 | Instant messaging | Using TETRA, trains can communicate with signals and traffic control systems in two directions without interruption. |
| 2 | Continuous monitoring | The train control platform continuously transmits real-time and forward signal conditions to the vehicle through the base station, and uses the positioning system and speed detector to check the train position and speed to ensure that violations such as speeding do not occur. |
| 3 | Precise positioning | An onboard GPS can be installed to monitor the coordinates of trains, tracks, and signal equipment. |
| 4 | Cab signalling | The speed limit and signals in front of the train, the real-time train position, the track alignment and configuration before and after the train, and temporary notices are monitored. In addition to being a necessary package for increasing the speed to 160 km/h, it is also an important item for Level 2 ETCS. |

## 5. Conclusions

Owing to its wide bandwidth, large number of connections, and low latency, 5G technology is used in smart transportation systems. The huge amount of data obtained using 5G technology enables the application of big data analysis to improve transportation services. Both 5G technology and TETRA have been demonstrated to be stable and efficient with certain limits. Therefore, their integration increases information security and allows new applications to be used for reliable, safe, and effective system management and to eliminate possible risks. AI applications can be used with 5G technology to analyze real-time image data to improve safety and operation efficiency. TETRA's stability and wide communication coverage can lower costs significantly. TETRA has been used for over 30 years and its technological maturity and a long lifecycle were proven. It can be used for communication including calling, text messaging, and risk alerts. The integration of 5G technology and TETRA can be employed to significantly improve railway communication systems, as observed in the example of Narita International Airport in Japan.

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