1. Introduction

The Tokaido Shinkansen, a huge trunk railway line in Japan, has been playing a very important role in transportation. The first priority of railway operations in the Tokaido Shinkansen is to secure the safe and steady transport. Based on this concept, it has been tried to improve the passenger service. In 1989, train radio facilities of the Tokaido Shinkansen were replaced into a Leaky Coaxial Cables (LCX) system. The system had been in service until recently, but it was the time to replace the system owing to its aging. In order to enhance functions of business applications and passenger services with maintenance of independent communication networks, data transmission functions were strengthened through replacing train radio facilities into a digital system which would increase transmission capacity and quality. On February 21 and the next day, 2009 the change-over works to the new system was performed successfully. Besides it was on March 14, 2009 when the train timetable was revised, and the Internet access service using the train radio system started smoothly. This service can be available to all of the Series N700 Shinkansen trains between Tokyo station and Shin-Osaka station, and has been working entirely with little discontinuity of data communication even in tunnels.

2. Overview of the digital train radio system

(1) Train radio communication of the Tokaido Shinkansen

Train radio facilities were originally installed as a train protection system to realize business communication between crew and ground staffs. However, recently the role of train radio was changed largely because the functions of data communication were added to that. Monitoring data of train facilities was able to be transmitted in real time to the ground, and used for operation and maintenance of rolling stock, for instance. And news texts sent from newspaper companies were able to be displayed with telop devices in cars, and then the data communication of train radio was useful for the betterment of passenger services.

(2) History of the train radio system

At the start of the Tokaido Shinkansen operation in 1964, a space-wave system was adopted for train radio facilities. In this system, communication was done between base stations located on mountains, etc., and mobile stations on trains. In 1989, LCX system were introduced when the facilities were replaced. What is called the LCX system is the system in which wireless communication was able to be carried out between LCXs laid alongside railway tracks and mobile stations on trains. The system has such merits as ① high and steady quality of data transmission with little fading which is inherent in mobile communication owing to very short range transmission, ② repeated use of the same frequency because of little interference by over-reach of waves between those in neighboring zones ③ smaller electric power consumption for output signals, and so forth. In 2009, the system was completely replaced into a digital LCX system succeeding to these merits of LCX, and utilizing digital technologies. This is called the digital LCX system in the following.

(3) Composition of train radio system

The train radio system of the Tokaido Shinkansen is composed of ground facilities and onboard ones. The system composition this time is structured based on the allocation of facilities before digitalization (Fig.1). Transmission channels for business use (for railway business) and ones accessing to the Internet for passenger use (for public telecommunication business) are completely separated from each other.
The ground facilities are composed of the central control stations installed in the Tokyo general control center and the Second control center, 4 local control stations located at Tokyo, Shizuoka, Nagoya and Osaka, base stations located in areas (or zones) divided all the line into a few tens, and about 450 repeater units placed along the line.

The onboard facilities are mobile stations installed on the Shinkansen trains, and the Series N700 Shinkansen trains have equipped with devices for access to the Internet. As the Shinkansen trains run though the Sanyo line, the mobile stations are composed both of analog and digital facilities, which are able to be switched over by software-defined radio devices.

(4) Implemented methods

① Radio system
At the selection of a radio system, we decided to adopt the $\pi/4$ shift QPSK (Quadrature Phase Shift Keying) modulation system having its favorable practices in mobile fields considering its environments and reliability.

② Frequency bandwidth in use and channel capacity
In the digital LCX system, in addition to the frequency bandwidth having been used already for railway business use, the 400MHz bandwidth allowed to use for the service of the Internet access after negotiations with the authorities concerned. The maximum data transmission speed realized with its frequency bandwidth is 2Mbps from the ground to cars and 1Mbps from trains to the ground.

③ Channel quality
The bit error rates are equal to or under $1\times10^{-5}$ (with a code correction algorithm), and channel quality is within the quality specification applicable to mobile IP which is mentioned below.

④ Channel control method
The channel control method for voice transmission adopted the circuit switching mechanism to meet the security level of train protection facilities, and the one for data transmission adopted IP to make efficient use of channels. The adoption of this method with IP is the first application in the train radio system in Japan. A hand-over issue which was the technical problem to communicate with such high-speed mobile objects as the Shinkansen trains has been solved with improving the functionalities of mobile IP technology.

⑤ Radio cell system
In order to increase transfer rate per train, the radio cell system where a radio zone was ramified was adapted (Fig. 2). As each cell shares the same frequency bandwidth, the system can allocate more frequency zones to each train. Ramification of zones has been realized adapting optical ROF (Radio On Fiber) between base stations and repeater units.

⑥ Receiving methods
Aiming at attaining higher transmission quality we have adopted the four branch diversity receiving methods (Fig. 3). Each train is equipped with 4 antennas and diversity methods with 4 transmission routes of receiving input from the ground to trains were adopted. Each cable laid on both sides of railway tracks receives 2 types of signals modulated differently, and then four route diversity is attained from trains to the ground.

3. Applications implemented

In the digital LCX system radio channels has been digitalized completely. Consequently, the system can provide functions to implement more applications of data communication types. As is shown in Table 1, the new functions cover the commander
transmission of traffic conditions, phone call among 3 persons, and access to the Internet in trains, together with the enhancement of the conventional functions.

Wireless LAN was adopted as the method of access to the Internet in cars and there are 2 access points in each car (Fig. 4). The protocol is IEEE.802.11g/b applicable to general use, which helps utilize almost any type of devices (PCs or game machines, etc.) presently available. The access points of wireless LAN are corresponded to multiple SSID (Service Set Identifier). Consequently, in order to support the services of telecommunication companies multiple SSID from one access point is sent and is allocated to some wireless LAN service providers.

4. Data communication technology

The data communication system adopts the IP control system, which has introduced to mobile IP technology utilized in mobile communication. However as the Shinkansen trains run at high speed, high-speed hand-over technology developed newly this time by JR central is applied to the mobile IP technology to realize transmission to Shinkansen cars.

(1) Mobile network

A Shinkansen train runs swiching over from cell to cell in high speed. Therefore central control devices must identify the cell which a Shinkansen trains occupies. The mobile network technology utilized in mobile communication performs this function (Fig.5).

(2) High-speed hand-over technology

A hand-over time of Shinkansen cars at swiching from cell to cell is a key factor to improve communication quality because the Shinkansen trains runs 75m per second, when they run at the top speed of 270km/h. Consequently the new technology to shorten the hand-over time is critical.

A middleware was also developed to perform high-speed hand-over in the Tokaido Shinkansen train radio, in addition to the mobile network technology. The middleware applies measures to resend missing packets at high speed though detecting them at swiching from cell to cell, and to compensate time lag in mobile IP routing though sending beforehand the same data to the succeeding base station (data transmit forward technology). In particular, the data transmit forward technology is a must in such a mobile network as of high-speed trains of the Shinkansen. The high-speed hand-over technology of the Shinkansen trains has therefore been realized with the mobile network technology and the middleware (Fig.6).

(3) Improvement of practical throughput

Radio communication is performed through the use of areas named channels divided by time. If channel sizes of the radio communication are not utilized effectively, any unused spaces at the radio communication will be created and low throughput will be incurred. In the passenger service therefore, in order to use radio bandwidth effectively the middleware above mentioned has a function to control the data sizes which meet channel sizes of radio communication for sending data efficiently.

5. Running tests

(1) Preliminary tests performed in specified sections

To digitize the LCX system, the digital LCX system was installed between Shizuoka station and Kakegawa station in
parallel with the conventional one. And the running tests for the digitized LCX system had been performed at nights (Fig. 7).

The first phase was to test basic data transmission between ground test facilities and ones on the Shinkansen test train. At the Shizuoka base station, a central quasi-device was installed and test data were transmitted between the device and mobile stations on the test train through the digital LCX. We set up a server in which mimic-designed Web pages of the Internet were installed, in the central quasi-device for passenger services, and the Web pages sent from PC connected to onboard facilities were identified in the server.

In the second phase, it was identified that the conventional functions such as news texts, telop devices, and the applications of train operation and maintenance information, etc. were able to transmit. The newly installed functions to connect the Internet were tested with linking the Shizuoka base station to telecommunication companies and the preliminary test was carried out with the form which was of almost actual services.

(2) Integrated tests

After the ground facilities were installed in all the way along the Tokaido Shinkansen, the integrated tests were performed at nights by switching the system to the digital LCX one on the ground. The total of 34 trains ran on the Tokaido Shinkansen for the tests. The basic features of the radio were measured at each zone. It was recognized that the specified features were realized. The data transmitting tests were performed by the use of the actual central facilities installed in the Tokyo general control center. All the transmitting procedures were evaluated to be working correctly between the central facilities and onboard ones through every base station. Such values as throughputs of the Internet service, Web site pages’ response time of passenger PCs, etc. were also measured in the tests, and then necessary adjustments were taken for improvement of the performance of the new system.

The tests were performed in limited time of the nights and in limited line sections with limited number of trains. However the integrated tests were completed, including such tests as at crossing of two trains, at passing of boundary zones between the digital LCX system of the Tokaido Shinkansen and the analog LCX one of the Sanyo Shinkansen, etc., and the integrated functions were evaluated by conducting the tests which had been performed aiming at an actual commercial service.

6. Effects of implementation of the system

(1) State after practical use

On February 21 and the next day, 2009, all of the Tokaido Shinkansen line was switched over to the digital LCX system and has started its service. The business use applications such as data transmission of news texts, monitoring of rolling stock, monitoring of train jolt and monitoring of train radio, commander transmission of traffic conditions, etc. were in service on the same day.

Together with the train timetable revision on March 14, 2009, the Internet access service on the Series N-700 Shinkansen trains was started on the same day in between Tokyo station and Shin-Osaka station on the Tokaido Shinkansen trains. Passengers have been able to utilize the service since then and there has been higher traffic in the mornings and evenings on week days. The transmission quality has been always stable on all through the line, and passengers have reputed the service highly.

(2) Technical possibilities

The high-speed hand-over technology developed in the train radio system of the Tokaido Shinkansen will become the basis of mobile data transmission on high-speed running objects to secure high quality and stable communication. The technology will be expected to apply to various mobile fields in the future.

7. Conclusion

The change-over of the train radio system was not only to change the old system into the new one, but to install the digital technology, and to provide with the various new functions. The matters above mentioned were expected to enhance securing train protection and to improve passenger services. Since the inauguration of the system the facilities have been working quite well. It is our desire that more and more passengers will enjoy the Internet service in trains and experience its comfortable state. We understand that the demand for information services will be aiming to the higher speed of data transmission with more variety of services. The task we are facing is to increase the transmission speed. We will make more efforts to provide passengers with better information services and more comfortable car spaces in the Tokaido Shinkansen trains.