Development of a Function for Timetable Transfer via WiMAX

When the train to which a crew is assigned is changed due to operation rescheduling in transport disruptions, the timetable of the new train is sent by fax and handed to the crew. With an aim of easing the work involved and speeding up such notification to crew of the change due to operation rescheduling, we developed a function for timetable transfer via WiMAX and a tunneling function where data of multiple applications is transmitted using just one WiMAX device. Development was completed by the end of fiscal year 2010, and we confirmed that the function works correctly. In tests on handling of the function, we confirmed that the data transfer speed via WiMAX and the time until the timetable is shown on the cab monitor are almost equal to the time from data input to data display with the current method using IC cards. Starting in 2011, we have been selecting the antenna to be equipped to cars in practical use, and we will carry out field tests of the developed functions.

Keywords: Crew scheduling, vehicle and crew operation rescheduling, timetable, WiMAX, TIMS

1 Introduction

In the event of transport disruptions due to situations such as accident or disaster, we change the scheduled operation of trains and crews in line with train delays and cancellations (for example, the crew returns by a train different from the scheduled one at arrival at the station). In such a case, crews have to work on a train it is not originally assigned to, but crews do not carry with them timetables of trains other than those they were originally assigned to.

In addition to the train schedule, a timetable has the number of vehicles in the train set, number of power vehicles, special notes and other information necessary for train operation. So, it is impossible for a crew to operate a train without its timetable (excluding trains in some designated lines).

Crews thus must receive the timetable of the new train if the train they are to work on is changed.

At present, the crew is handed the timetable by staff at the station or the crew office. Timetables are managed, however, only at the crew section of the crew originally scheduled to work the train. So, if the crew receives the timetable outside of that crew section, the timetable must be faxed, and notification/confirmation of such fax transmission must be done over the phone. And as such tasks require relay work by the station staff, much time and labor is involved. Due to those circumstances, it takes time for the crew to receive the timetable, and there are sometimes cases where a train cannot depart because the timetable of the train is not available at the departure time even if the train and crew are available.

Appropriate and quick operation rescheduling is necessary for early recovery from transport disruptions in abnormal situations. However, it is also important to build a method for quick notification and implementation of planned operation rescheduling.

2 Purpose of Development

The Transport System Group of the Advanced Railway System Development Center, Research and Development Center of JR East Group is proceeding with development of a crew operation rescheduling support system that supports crew operation rescheduling in transport disruptions. The system uses mobile terminals (PDAs) for locating crews and transmitting information. In fiscal 2004, we developed a function for transferring timetables to crews and trains. With this function, the timetable is downloaded to the PDAs of each member of the crew via mobile phone line if they are to work on a different train than that for which they were originally scheduled. That data is also transferred to and displayed on the cab monitor (Train Information Management System, TIMS) via an onboard Wi-Fi access point.

With advances in radio technology, communications equipment such as digital radio and WiMAX has been put in place as a means of data communications between onboard and wayside devices. In particular, WiMAX is capable of high-speed and large-volume mobile data communications, so it is expected to expand as communications infrastructure along railway lines.

In light of future expansion of deployment of WiMAX, we decided to develop a new timetable transfer function in this development. Specifically, we changed the Wi-Fi method of timetable transfer we had already completed development for to a WiMAX method and changed the location for displaying the timetable from PDAs to driver’s cab monitors.
3 Development Overview

We planned the following development stages.

Step 1:
1) Development of a timetable transfer function via WiMAX
2) Development of a V-LAN capsuling/tunneling function

Step 2:
3) Field tests of the developed functions

We focused on 1) in particular in this development. So, instead on using PDAs developed in past, we adopted a system structure where the crew requests timetable data by the existing cab monitor (TIMS) and the data is sent from a wayside server.

From a viewpoint of cost reduction, we used existing devices as onboard devices needed for WiMAX communications, avoiding work such as vehicle modification as much as possible. For series E259 rolling stock (rolling stock for Narita Express trains) that has been deployed since 2009, WiMAX transceivers have been installed and are already in use since March 2010 for update of content of the Visual Information System (VIS) of the train. We conducted this development to achieve a timetable transfer function without additional vehicle modification by utilizing that WiMAX transceiver.

For onboard equipment, we also revised the TIMS program to allow the crew to request timetable data. And for wayside equipment, we built a server that sends timetable data at request from onboard equipment (Fig. 1).

3.1 System Configuration

3.1.1 Onboard Equipment (WiMAX Controller, TIMS)

WiMAX onboard equipment was originally intended to be the same as the existing equipment. In these tests, however, we needed to change the settings of the WiMAX onboard equipment before the tests to differentiate the test domain from the domain of VIS in practical operation.

We therefore prepared test WiMAX onboard equipment of the same model as the existing equipment and completed settings in advance. That way, we could carry out the tests on the scheduled day simply by switching with the existing WiMAX antenna (Fig. 3). In this way, we shortened the preparation time on the test day.

We modified the software so inputting the train number on the cab monitor and selecting the current station and end station would output a data transmission request to the WiMAX controller. Fig. 4 demonstrates the procedure to call up timetable information using the modified TIMS.

1) Activate TIMS cab monitor
2) Input train No.
3) Input (select) current station and duty end station
3.1.2 V-LAN Capsuling/Tunneling Function

One (fixed) IP address of the WiMAX network is assigned to the onboard WiMAX controller. The WiMAX controller has a routing function that routes data on the WiMAX side and the onboard equipment side. Currently, the WiMAX controller has only one application, VIS. Thus, to access the onboard device (VIS onboard device) under the control of this controller from outside, the VIS onboard device IP address is translated into a single address by the Network Address Translation (NAT) function of the WiMAX controller, with that WiMAX controller having a fixed IP address. The NAT function cannot allocate different IP addresses to individual applications because that function can translate the IP address of a device connected to the WiMAX controller into only one address for the fixed IP address of the WiMAX controller. This will be a problem in practical use.

One solution is installing a WiMAX controller and an antenna for each additional application, but this entails vehicle modification for every addition of an application. Moreover, in order to take full advantage of the high-speed and large-volume communications feature of WiMAX communications, it is more efficient to make one WiMAX controller transmit and receive the data of multiple applications.

Thus, as a system to achieve that, we developed a function to transmit the data of multiple applications (timetable data, VIS data). That was done by building virtual tunnels on the WiMAX network (tunneling) and making each of those into a virtual network (V-LAN) as a mechanism for sending and receiving data of a multiple applications by just a single WiMAX controller.

As the tunnel protocol, we adopted Layer 2 Tunneling Protocol version 3 (hereinafter, “L2TPv3”). This protocol is an expansion of L2TP (ver. 2), which is mainly a VPN protocol for remote accessing. It allows connection of all types of packets including Internet Protocol (IP) packets between LANs. With L2TPv3, application data can be separated from each other, allowing future expansion. There are two tunnel creation methods: a dynamic method where tunnels are created and deleted and a static method where fixed tunnels are statically created. In this development, we adopted the static method on the following reasons.

- Considering that the system is used in moving trains, the static method can reduce the time lag of tunnel restoration when recovering from a section without WiMAX service.
- As it is a private network, there are a few security concerns.
- As the number of train runs is limited to some extent, there are relatively few restrictions on the maximum number of tunnels.

3.1.3 Wayside Equipment (Train Timetable Information Transmission Terminal)

In the building of the Tokyo Branch Office (at Tabata, Tokyo), we temporarily installed a terminal that searches the train timetable at request from onboard equipment and sends back the relevant timetable information. In this development, we created virtual timetable data in advance and stored that in the terminal. We applied the data format for PDAs that we had developed in the past crew operation rescheduling support system to cover all information needed to display TIMS operation information.

4.1 Advance Check Tests

Before tests using the test system introduced in the previous section using an actual train, we tested to check whether the wayside equipment in the Tokyo Branch Office building could create a correct virtual LAN structure through L2TPv3 tunneling. We built in the factory of the manufacturer an onboard system of the same configuration as that of the planned practical system. Then we established communications via WiMAX between the wayside equipment in the Tokyo Branch Office building and the onboard equipment in the manufacturer’s factory.

The communications check results confirmed that L2TPv3 tunneling successfully created the virtual LAN and that the onboard equipment could be used during communications. We also verified that devices in use nearby were not affected.

4.2 Tests Using an Actual Train

Based on the results of the advance check, we carried out transmission tests using an actual series E259 Ne004 train set in the Kamakura Vehicle Maintenance Depot of the Yokohama Branch Office. The tests were conducted with the train stationary, and we made timetable requests at the cab monitor of TIMS and measured the time until the requested data was displayed on the screen. In the tests, we measured the timetable transfer time via WiMAX with no other data load on the WiMAX line (low load condition) and with data load equal to that when transmitting and receiving VIS data (high load condition) for comparison. Results for the cab monitor with the WiMAX onboard device in car No. 6 were transfer times of 5.5 to 8.5 seconds in low
load condition (average of 6.7 seconds), and 5.1 to 8.5 seconds in high load condition (average of 5.9 seconds). For the cab monitor in car No. 1, the times were 6.1 to 9.1 seconds in low load condition (average of 6.9 seconds) and 6.3 to 9.1 seconds in high load condition (average of 7.3 seconds) (Table 1).

Table 1  Time from Request to Display of Timetable Data (in seconds)

<table>
<thead>
<tr>
<th>Transferred data</th>
<th>Car No. 6 (with WiMAX transceiver)</th>
<th>Car No. 1 (without WiMAX transceiver)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train No.</td>
<td>Section</td>
<td>Low load condition</td>
</tr>
<tr>
<td>2022M Narita Airport - Shinjuku</td>
<td>5.9</td>
<td>5.5</td>
</tr>
<tr>
<td>2001M Rebekuku-Narita Airport</td>
<td>8.5</td>
<td>5.1</td>
</tr>
<tr>
<td>2029M Rebekuku-Narita Airport</td>
<td>5.5</td>
<td>5.3</td>
</tr>
<tr>
<td>2051M Rebekuku-Narita Airport</td>
<td>6.1</td>
<td>5.7</td>
</tr>
<tr>
<td>2045M Rebekuku-Narita Airport</td>
<td>5.9</td>
<td>5.3</td>
</tr>
<tr>
<td>2050M Narita Airport - Shinjuku</td>
<td>8.1</td>
<td>8.5</td>
</tr>
<tr>
<td>Average</td>
<td>6.67</td>
<td>5.90</td>
</tr>
</tbody>
</table>

For reference, we also measured the time until timetable display on the TIMS monitor in the current method using IC cards. The time from selecting the train number on the screen to reading the timetable data from the IC card and displaying the data on the TIMS monitor screen was approx. 4.5 seconds.

Consequently, the tests showed the following results.
1) The time from request to display of the timetable was between roughly 5 and 9 seconds.
2) There is no difference of processing time between low and high load conditions.
3) We found a difference between cars No. 1 and 6 (with and without the WiMAX transceiver) of approx. 1 second in the time from request to display.
4) The time from request transmission to display varied a little.
   At the longest, it took approx. 3 extra seconds in cars No. 1 and 6. This tendency was seen both in low and high load conditions.

Our comments on those were as follows.
Concerning 1), the results demonstrated that timetable transfer via WiMAX has sufficient potential compared to the method using IC cards. Timetable transmission over the high-speed and large-volume network of WiMAX has sufficient leeway for further use, while the data capacity of IC cards is currently around 256 Kbyte.

Concerning 2), one of the reasons for the results is that the test environment (Kamakura Vehicle Maintenance Center) was relatively good for WiMAX sending and receiving, with no significant hindrance due to signal strength and WiMAX use by others users. There remains the possibility of communications being affected by changes in the environment such as transmitting or receiving large volumes of data by multiple users to and from the WiMAX base station used.

Concerning 3), the WiMAX transceiver is installed only at one end of the train, in the driver’s cab of car No. 6, due to series E259 train specifications. Timetable data request and transmission is carried out through TIMS and data on TIMS is conveyed by transmission between vehicles. Thus, if timetable request/transmission is made at a cab monitor without a WiMAX transceiver, TIMS data transmission time becomes longer. That explains the results found this time.

Concerning 4), in the investigation of cases where transmission took a long time, the data log revealed that retries occurred during transmission. This is because most of the timetable data already sent was omitted before the arrival of the Address Resolution Protocol (ARP) response and the onboard equipment had to request the omitted data be resent (retries). The ARP response was sent to the ARP request that the wayside equipment made before sending data.

ARP request/response transmission is fairly common on the IP network. The reason for obvious variation of the transmission time in these tests is most likely the large delay on the WiMAX network. Some suggestions for countermeasures in practical use are (1) adjusting the timeout period in applications, (2) making ARP static registration of between the sending and receiving terminals, (3) setting longer ARP expiration time between the sending and receiving, and (4) performing steady communications in the background in applications so ARP is not unresolved.

Putting emphasis on the effect of introduction the system, we chose Shonan-Shinjuku Line, Tohoku Line, Takasaki Line and Tokaido Line as the field test lines. Those have through-service and long-distance trains, so transport disruption in those easily affects other lines.

Before the field tests, we set up measurement devices in the driver’s cabs of the trains in commercial service and measured the in-and-out signal environment in the lines shown below. One purpose of that was to check the train stopping point for stations where crew on duty changes, the location where the developed function will be used. Another is to identify the signal environment between stations when conducting tasks such as retrying.
- Shonan-Shinjuku Line train: Takasaki - Shibuya, Ikebukuro - Zushi
- Tohoku Line: Ueno - Utsunomiya
- Takasaki Line: Ueno - Takasaki
- Tokaido Line: Tokyo - Atami
(Line sections are those where actual measurements were made.)
5.1 Measurement Details

1) PING
Identifies points without signal reception by requesting response from onboard to wayside

2) RSSI
Measures strength of signals received onboard

3) CINR
Measures ratio of interference and noise in the carrier wave

4) Throughput
Measures onboard data reception speed

5.2 Measurement Results

As the present capacity of IC cards that store data such as timetables is around 0.3 MB, we thought that the throughput should be at least 0.3 Mbps to secure stress-free transfer speed. But, taking into account communications data increase in future studies of functions, 2 Mbps would be better. The result was more than 2 Mbps of throughput at the stations of crew change other than Atami Station, exceeding our expectations. The results at Atami Station were as expected since the station is located out of the WiMAX service area. We therefore need to further consider the reception method for field tests. (Fig. 5 and 6)

6 Antenna Performance Tests

No trains with WiMAX antennas are operated on the lines where field tests were performed, so an antenna had to be installed to the test train. We thus faced the problem of high vehicle modification costs as currently only rooftop type WiMAX antennas are available.

To reduce costs, we decided to choose an antenna that can be easily installed in the driver’s cab. Possible options were a non-directional sleeve antenna that had already been used in train radios and a new directional patch antenna. We therefore decided to compare those two.

6.1 Antenna Types and Measurement Items

(1) Train used for measurement
- MUE-Train (series 209)

(2) Measurement line section
- Tohoku Line: Hasuda - Kuroiso

(3) Antennas type
- Non-directional sleeve antenna
- Directional patch antenna

(4) Measured Data
1) PING
Identifies points without signal reception by requesting response from onboard to wayside

2) RSSI
Measures strength of signals received onboard

3) CINR
Measures ratio of interference and noise to the carrier wave

4) BSID
IDs of connected base stations

5) Frequency
Frequencies of connected base stations

6) Throughput
Onboard data reception speed
From wayside to onboard with 2 MB load, from onboard to wayside with 1 MB load

7) GPS latitude and longitude
Identifies location of train in latitude and longitude
6.2 Test Results

Fig. 8 to 12 show comparisons of measurement results of RSSI, CINR and connection rate, average communications throughput from wayside to onboard and average communications throughput from onboard to wayside for the non-directional sleeve antenna and the directional patch antenna.

We found differences in the characteristics of the antennas when the BSID was changed while the train was running, i.e. when the communications level of the connected base station lowered. At the lower communications level, the sleeve antenna relatively easily changed the connection to another base station of higher communication level. It was able to do that because the sleeve antenna receives signals at a wider angle than the patch antenna does. In contrast, the patch antenna receives signals at a limited angle, so it could not find another base station of higher communications level in a direction horizontal to the antenna. We thus found that this delayed the connection changeover with the patch antenna.

The sleeve antenna was more effective in mobile communications, while there was no obvious difference between the two antennas when stopped at stations. We therefore decided to adopt the sleeve antenna for the field tests.

Conclusion

We were able to confirm that developing a WiMAX transceiver, TIMS and other onboard equipment and developing wayside equipment that sends timetable data would allow a timetable transfer function via WiMAX. We also confirmed that we could develop technology for efficient and simultaneous sending and receiving of data of multiple applications via one WiMAX line.

In 2011, we further proceeded with work such as measurement of the signal environment ahead of field tests. We are also studying items such as use of a tablet terminal in addition to cab monitors in the field tests.