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NDN-GSM-R: a novel high-speed railway communication system via Named Data Networking

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Abstract

To keep up with the rapid development of railway and meet the high demand for communication business in China, Global System for Mobile Communications-Railway (GSM-R) based on General Packet Radio Service (GPRS) ahead of Europe has been developed. However, the current data communication mode of GPRS using TCP/IP has some disadvantages, such as poor mobility, lack of security etc. For this reason, there are some problems for GSM-R, like handover, which makes communication service quality undesirable. Named Data Networking focuses on named data, adopts data-facing communication mode, and does not care where the contents are stored but the contents themselves. It can effectively solve the problems caused by TCP/IP. In this paper, a new high-speed railway communication system with Named Data Networking (NDN) named NDN-GSM-R is proposed. Two simulations, called transmission interference time and end-to-end transmission delay of NDN-GSM-R, have been conducted. The simulation results show that NDN-GSM-R has better performance in high-speed mobile communication environment and can make up the insufficiency of the current GSM-R based on TCP/IP framework.

Keywords: Named Data Networking, GSM-R, Handover, Transmission interference time, Transmission delay

1 Introduction

Global System for Mobile Communications-Railway (GSM-R) [1] is the digital mobile communication system specially designed for railway communication. Based on GSM mobile communication system, GSM-R retains the original services of GSM system and adds some railway feature services, like advanced speech call service and dispatch service. In China, GSM-R adopts general packet radio service (GPRS) technology based on TCP/IP to achieve wireless transmission of dispatch command information, checking information transmission of train wireless number etc. However, with the rapid growth of train speed, the packet data communication mode based on TCP/IP makes the GSM-R unable to deal with communication handover and other problems. Besides, the complex environment along the high-speed railway in China makes it urgent to raise a new plan for high-speed railway mobile communication.

In GSM-R, the radius of cell is relatively small and is in a chain-like arrangement. When the train runs on the railway at high speed, frequent handovers [2] occur. Because GSM-R utilizes hardware switching technology [3], communication shall break down for a short time, which affects data transmission service. The break period of handover is the interval when the current cell site sends a switching command to the mobile station and the mobile station sends a switching command to the target cell. During the break period of handover, the link data transmission is not stable at all, which may lead to error code and data loss easily and reduce communication service quality. If handover fails, namely, the mobile station fails to switch to the target cell, the mobile station may go back to the original cell or calls may get dropped. According to the command process of handover, it can be estimated roughly that 300 ms of communication outage shall occur in a successful handover [4]. In order to guarantee train driving safety and reduce handover failure rate, the researchers have made strict

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requirements for quality of service (QoS) standard of GSM-R, as shown in Table 1.

Named Data Networking (NDN) was proposed by Van Jacobson from Xerox Palo Alto Research Institute (PARC) in 2009 to reduce the disadvantages of the data communication mode based on TCP/IP [5, 6]. NDN provides users with all kinds of safe and convenient services and has the ability to expand elastically and innovate continually. Besides, NDN has some required features of the next generation of network architecture, such as high speed, safety, reliability, intelligent control, and reliable bearing.

Different from TCP/IP network architecture, NDN is content oriented and relies on named data to transmit in the network and concerns no user address information. NDN changes the original package structure and addressing mode, namely, the message header does not use IP address as identification but the content name. Therefore, this new network communication model is going to deal with handover caused by high-speed mobile communication better. NDN is driven by data requesters in communication process. Data communication can be achieved by switching interest package and data package. Interest package is a package with the name of content request, and data package is content package with the data. In order to request the data packets, data requesters broadcast interest package including content name in NDN. Through deploying three kinds of data structure on the forwarding plane, interest package forwarding operation is completed. Three kinds of data structure are, respectively, content store (CS), forwarding information base (FIB), and pending interest table (PIT). FIB has a similar routing table with TCP/IP networks, but a set of export is allowed. CS is used to store data package which has been requested. PIT records the interest package transmitted but non-responded as well as its access to interface [7].

In this paper, a new high-speed railway communication system with NDN named NDN-GSM-R is proposed, and the simulations on the transmission interference time of NDN-GSM-R as well as the end-to-end transmission delay [8] have been conducted. The simulation results show that NDN-GSM-R has better performance in high-speed mobile communication environment and can make up the insufficiency of the current GSM-R based on TCP/IP framework.

Table 1 QoS of GSM-R

QoS item	Indicator value
End-to-end transmission delay	≤0.5 s (99 %)
Transmission interference time	<0.8 s (95 %), <1 s (99 %)
Transmission error-free time	>20 s (95 %), >7 s (99 %)

This paper is organized as follows. In Section 2, the related works which are some hot issues of NDN in communication application field are surveyed. In Section 3, NDN-GSM-R is proposed for high-speed railway communication. Simulative results are illustrated in Section 4, and the improvement in the transmission interference time and the end-to-end transmission delay is shown to prove the effectiveness of NDN-GSM-R. In the end, the conclusion is presented in Section 5.

2 Related works

At present, there are some hot issues of NDN in the communication application field. (1) Ad hoc network. With the rapid growth of wireless network, high-frequency mobility of the user nodes may lead to high dynamics of network topology. The routing protocol initially designed for wireless network loses its advantages. Lixia Zhang of UCLA is committed to applying NDN protocol to ad hoc network and improving its efficiency [9]. (2) Unmanned system. Swarun Kumar from Massachusetts Institute of Technology came up with an unmanned system based on NDN [10]. Since unmanned communication system always needs to get the surrounding environment information, such as road information and pedestrian information, NDN can transmit the information more efficiently and safely. Compared with IP network, NDN can be used in an unmanned system better. (3) Vehicle ad hoc network. Since vehicle ad hoc network has short connectivity and high dynamics of network topology, Marica Amadeo and other people suggested using NDN to establish vehicle ad hoc network [11]. For the monitor performance of NDN network caching and data package, vehicle ad hoc network based on NDN can perform better.

In short, the researchers have obtained a lot of progress on various aspects of NDN and have issued some typical essays. However, the relevant research is still in the start-up stage. There are no reports on the research achievement that NDN is tested in the environment of high-speed railway communication.

3 Architecture of NDN-GSM-R

In traditional GSM-R, TCP/IP is adopted in the transport layer between GSM-R communication server and GPRS interface server. GPRS interface server is in charge of the protocol conversion of transport layer and application layer between GPRS and CTC/TDCS systems as well as IP address transformation of two systems. Because NDN relies on named data to transmit in the network, it needs no IP address transformation. Therefore, the packed data of the application layer can be transmitted directly through NDN.

For this, we proposed the NDN-GSM-R framework. And its architecture can be divided into three parts. The application layer, the physical layer, and data link layer still adopt the same protocol as the original packet data communication mode based on TCP/IP. The packed data contents of the application layer enter the NDN protocol layer and are sent to the network further through the data link layer and physical layer. Figure 1 shows the architecture of NDN-GSM-R.

Since NDN-GSM-R is based on the original framework of GSM-R, NDN communication mode replaces the packet data communication mode based on TCP/IP. In this section, the data transmission process of the NDN-GSM-R will be explained in the network layer. Namely, the data transmission process in the application layer and the transport layer remains the same as the transmission process of the original GSM-R. When the user on the high-speed train requests the data provider for some content, its specific communication process of packet domain is as follows.

1) The data requester packs the data of the application layer into the interest package based on the NDN protocol, transmits the interest package into the data link layer and physical layer successively, and sends to the GPRS network finally.
2) When the network router receives interest package, it processes the interest request further based on the NDN forwarding strategy and workflow.
3) If the interest request is different from the original one, the interest package is transmitted to the data provider through GPRS or Ethernet network.
4) The data provider returns the interest request which is related to the data package to the data requester.

4 Evaluations and discussion

Handover is the main challenge for high-speed mobile communication. As stated in Section 1, in terms of the index of QoS, transmission interference time and end-to-end transmission delay are the evaluation indexes of the network layer performance [8]. Therefore, this section shall compare the transmission interference time and end-to-end transmission delay of traditional GSM-R with that of NDN-GSM-R in high-speed mobile handover by the simulations. It is to test the communication performance of NDN-GSM-R in the high-speed mobile environment.

4.1 Simulations settings

The simulations are conducted through a high-performance computer. The core component CPU adopts Intel(R) Core(TM) i5-3470 CPU @3.20 GHz. And each CPU includes four cores. The internal memory adopts DDR3 4 GB frequency of 1600 MHz. The operating system adopts 32 bits Windows 7. The simulation uses ndnSIM 2.0 [12]. The main code of simulation is 327 lines with C++ programming language.

In the simulation, it needs to set the related parameters on the simulation platform of NDN communication to simulate the communication environment of high-speed running train. NDN communication performance is studied for the current GSM-R handover. Based on the QoS index of GSM-R, the data package size is 30 bytes and the data transmission rate is set as 70 Kbps in the network. User node sends 100 interest requests to the data provider node [8].

The network topology of the simulation can be seen in Fig. 2. Rtr7 represents the server; Rtr1, Rtr2, Rtr3, Rtr4, Rtr5, and Rtr6 represent NDN routers; Src1, Src2, Src3, Src4, Src5, Src6, Src7, Src8, and Src9 represent data requests for the high-speed train in NDN-GSM-R, namely, the data applicants; and Dst1, Dst2, Dst3, Dst4, Dst5, Dst6, Dst7, Dst8, and Dst9 represent data which are provided for the high-speed train in NDN-GSM-R, namely, the data providers. The application contents of Src1, Src2, Src3, Src4, Src5, Src6, Src7, Src8, and Src9 are generated from Dst9, Dst8, Dst7, Dst6, Dst5, Dst4, Dst3, Dst2, and Dst1, respectively.

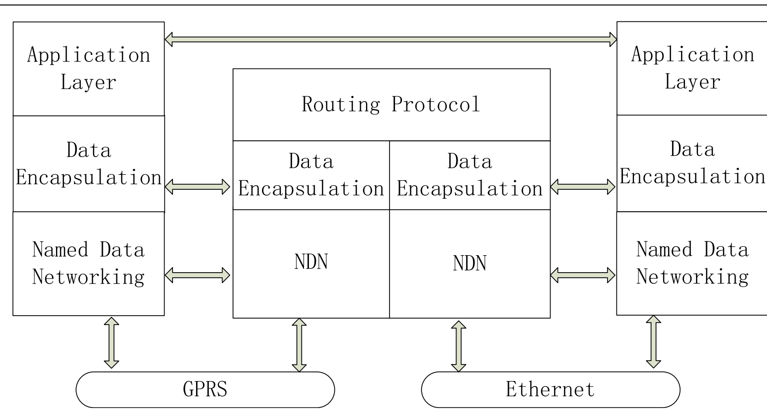

Fig. 1 Architecture of NDN-GSM-R

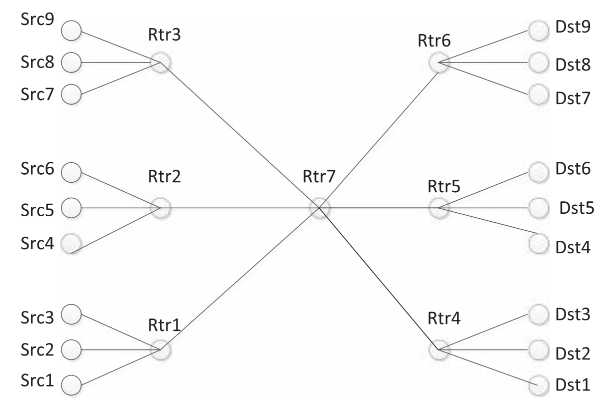

Fig. 2 Topology of simulation

In the current GSM-R, the data transmission rate is 270 Kbps in the data link layer. If the train runs at the speed of 360 km/h and the average distance between base stations is 3 km, three handovers happen every minute. Each successful handover needs 300 ms communication outage. In order to meet the real communication situation of the train, we make data request for train handover to test the network communication performance. Namely, Src9 is set up to disconnect with Rtr3 at 5.0000 s and connect with Rtr3 at 5.3000 s; Src9 is set up to disconnect with Rtr3 at 20.0000 s and connect with Rtr2 at 20.3000 s; and Src9 is set up to disconnect with Rtr2 at 35.0000 s and connect with Rtr1 at 35.3000 s.

4.2 Simulations results

4.2.1 Simulation of transmission interference

In the simulation of transmission interference, Fig. 3 shows that Src9 receives data package sequence number in handover process. Before the communication link breaks, the serial numbers change linearly when Src9 receives data package. It shows that NDN works normally and data transmission is normal. Src9 has received data package No. 491 at 4.9902 s and continues to send interest package to the server in order from 4.9902 to 5.0000 s. When the server receives the request, it returns the corresponding data package successively.

When communication link breaks at 5.0000 s, the requested data package is stored in NDN routers due to NDN network caching function. When Src9 connects with Rtr3 again at 5.3000 s, Src9 starts to receive data package No. 525 at 5.3702 s. Later, the serial numbers of the received data package increases linearly until data package No. 529 is received at 5.4102 s.

Since interest request has a life cycle, only when the life cycle is over can the corresponding interest requests in the PIT table be deleted. Therefore, the serial numbers of data package which is received from 5.4200 to 5.4800 s are fluctuant. It shows that the interest requests from No. 492 to No. 498 have expired. The user can receive the corresponding data package only when he or she transmits these requests again. At the moment, the transmission process of communication link is disturbed. It goes back to normal until data package No. 524 is received at 5.8002 s.

In conclusion, after the communication link is connected again, the transmission process (from 5.3000 to 5.8002 s) of data package is disturbed due to user handover. At last, the data transmission of communication link recovers at 5.8002 s. Therefore, NDN transmission interference time is 502 ms in the process of Src9 handover. Based on the above, we can draw a conclusion that handover interference time of NDN-GSM-R is less than 502 mm. It is a lot better than the service quality index—800 ms.

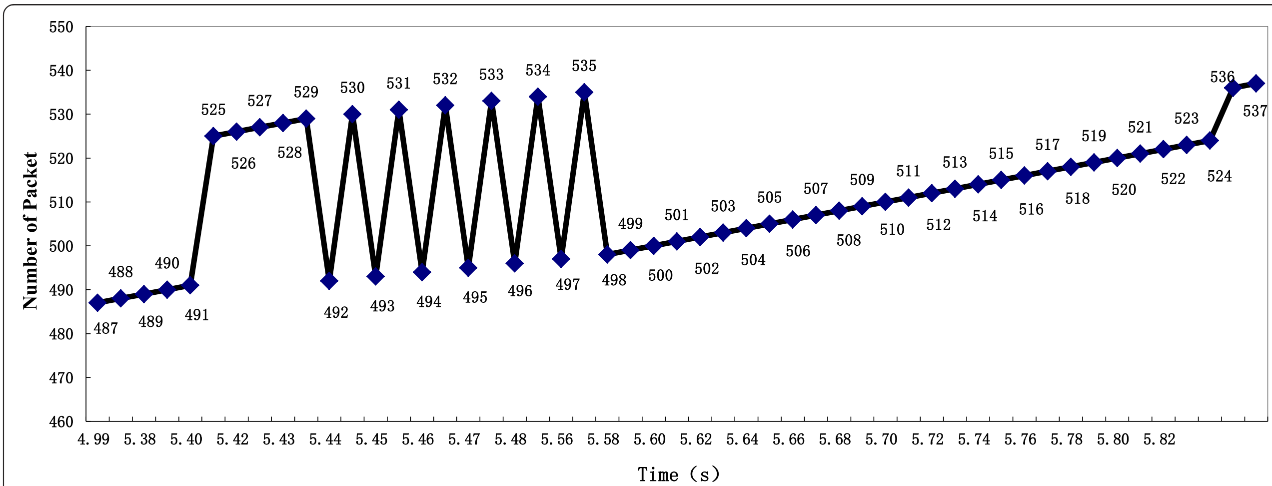

Fig. 3 Transmission interference time of NDN-GSM-R

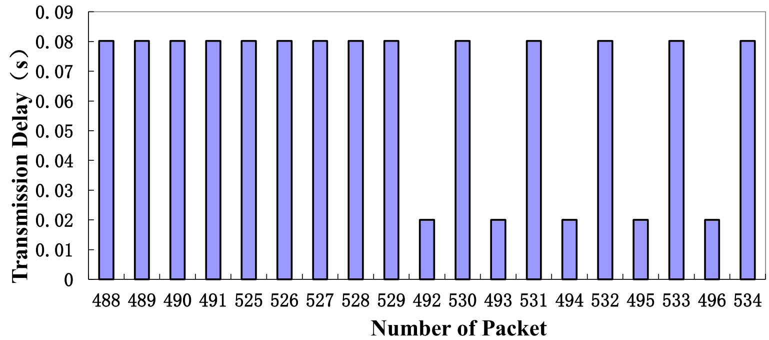

Fig. 4 End-to-end transmission delay of NDN-GSM-R

4.2.2 Simulation of end-to-end transmission delay

The simulation result of maximum end-to-end transmission delay can be seen in Fig. 4. When NDN stable transmission is 30 bytes of data package, namely, a data package has only an interest package. When it fails to be requested again, maximum end-to-end transmission delay of the system is less than 80.2 ms. It is particularly worth mentioning here that when communication link breaks and gets normal, NDN network caching function makes maximum end-to-end transmission delay of the requested data package No. 60 to No. 79 less than 20.0 ms before the link breaks. In conclusion, for data package which is not cached in routing node, the NDN maximum end-to-end transmission delay is less than 80.2 ms. For Data package which is cached in routing node, it is less than 20.0 ms. In this case, it is far lower than 500 ms required by the current GSM-R.

The simulation result shows that compared with the traditional packet data communication mode based on TCP/IP, NDN has better communication performance in high-speed mobile communication environment. Its transmission interference time is less than 80.2 ms, and it is a lot better than the service quality index—500 ms. The caching function of NDN improves data transmission rate and network resources utilization as well as communication reliability. At the same time, NDN transmits data based on content name, which improves communication mobility a lot. Even when the link breaks, the communication can be resumed quickly. The communication losses which are caused by a link break can be reduced to minimum.

5 Conclusions

The paper puts forward a NDN high-speed GSM-Railway communication system (NDN-GSM-R). Two simulations are made to compare transmission interference time and end-to-end transmission delay service quality index with the packet data communication mode based on TCP/IP of GSM-R. The stimulation results show that NDN-GSM-R has better communication performance and can better meet the data communication demands for the future high-speed train running.

Competing interests

The authors declare that they have no competing interests.

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