Fast Handover for High-Speed Railway via NDN

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***Abstract*—Handover is crucial for quality of communication service in high-speed railway. With the speed increases, the handover becomes more frequent in high-speed railway. However, the hard handover of GSM-R will break down the communication service for a short time. To reduce the handover latency, we propose the Fast Handover Mechanism (FHM) in Named Data Networking-Railway (NDN-R). Named Date Networking (NDN) is content oriented, FHM does not need to establish an end-to-end connection after the handover occurs. Therefore, FHM can fast handover to the next-hop node without interrupt the communication service. In addition, the FHM can avoid the ping-pong handover which further improves the quality of communication. Simulation results show that the FHM can reduce about 72% of the handover latency compared to the traditional handover mechanism. The packet loss rate, average delay can be reduced and the throughput can be improved.**

Keywords—Named Data Networking, high-speed railway, fast handover mechanism, ping-pong handover, handover latency

I. Introduction

In recent years, China's high-speed railway has achieved remarkable achievements. The average speed of high-speed train has reached 300 km/h, and the top speed can reach to 350 km/h. With the rapid development of high-speed railway, providing reliable, real-time and efficient wireless network access service for high-speed train's passengers is becoming more and more necessary. However, the current data communication mode of Global System for Mobile communication for Railway (GSM-R) [1] using TCP/IP has some disadvantages [2], such as poor mobility, lack of security, frequent handover etc. Handover is the key technology in the mobility management of GSM-R network and it keeps wireless communication between the base station and mobile station. The effectiveness of handover process in GSM-R network is crucial for improving the overall system and therefore it has become a research hotspot in wireless communication.

In GSM-R, the base stations are in a chain-like arrangement. With the increase of the train's speed, the handover occurs more frequently. GSM-R utilizes hard handover technique [3], communication will break down for a short time, which affects data transmission service. The interruption period of handover is the interval when the current base station disassociate with the current mobile station and the mobile station connect with the target base station. During the interruption period of handover, the link data transmission is not stable, which may lead to data loss[4]. According to [5], the traditional handover time is about 0.1-1s and is definitely intolerable in high-speed railway.

GSM-R cannot reduce the handover latency effectively, the fundamental reason is the disadvantages of TCP/IP architecture. Reference [6] points out that the triangle routing problem cannot be solved effectively in TCP/IP architecture, which increases handover latency. TCP/IP cannot support reliable mobile communication in high-speed environment, Reference [7] considers that the reason is end-to-end communication mode. It requires all handover mechanisms to maintain the latest mapping between the original location and the new location, whenever the mobile station occurs across the network segment.

The development of future internet architecture provides another solution for high-speed railway's frequent handover [8]. Reference [9] indicates that the Information Centric Networking (ICN) is fundamentally different from the traditional IP network, and is not restricted by the end-to-end mode, which is a feasible solution to solve the frequent handover problem. Named Data Networking (NDN) [10] is a kind of ICN, it replaces the named host by named data and implement the transformation from host to content. NDN makes data information and location information independent of each other, and data becomes the element of internet communication. Therefore, the consumer no longer cares about which Producer can get the data, and can avoid the end-to-end connection requirement under TCP/IP architecture. In addition, the cache in NDN can save Data packets with high request frequency, Consumer that requests the same content can be obtained directly from cache. Consumer no longer needs to get content from Producer, which effectively reduces data transmission delay. Therefore, NDN is expected to solve the frequent handover problem under high-speed railway, and improve the communication effect in high-speed movement environment.

This paper makes the following contributions:

- We use the advantages of NDN and propose a fast handover mechanism in Named Data Networking-Railway architecture for high-speed railway.
- The fast handover mechanism can avoid the ping-pong handover and reduce the interrupt time caused by the frequent handover in high-speed railway.

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- The fast handover mechanism combines with direction-aware forwarding strategy which we have been proposed can provide more stable communication service.

II. RELATED WORK

To reduce the handover latency, several mechanisms have been proposed. In order to reduce handover latency by making handover preparation before handover starts, two position-assisted handover schemes are proposed in [11]. Some other enhanced handover mechanisms based on Mobile IPv6 have been proposed to minimize the handover latency[12][13]. Reference [14] proposes a predictive handover protocol, using a combination of a Kalman filter and an online hidden Markov model, to minimize the handover registration time. A predictive handover framework that uses the neighbor network information has been proposed in [15] which makes the required handover procedures can appropriately finish before the current link goes down. In [16][17] handover mechanisms focused on the reduction of the latency incurred in link layer are proposed. The schemes that reduce the authentication latency are proposed in [18][19] so that the mobile node can be authenticated in advance. An efficient handover [20] reduces the number of redundant handovers based on the received signal strength and wireless transmission loss in hierarchical cell networks.

All these handover mechanisms proposed above are based on TCP/IP architecture, they must establish the end-to-end connection after the handover occurs. Although they can shorten the handover latency, they cannot change the hard handover to seamless handover. In this paper, we use the advantages of NDN, and propose a fast handover mechanism. It can reduce the interrupt time significantly and improve the quality of communication service. There is no triangular routing problem or location update process during the handover, because NDN is content oriented and relies on named data to transmit in the network and concerns no user address information. Therefore, the communication between base station and mobile station will no longer establish the end-to-end connection after the handover occurs and the better wireless communication service can be provided.

III. PRELIMINARY WORK

We have already proposed the Named Data Networking-Railway architecture (NDN-R) and the direction-aware forwarding strategy (DAF) [21]. In this section, we will introduce the preliminary works and the importance of multi-channel design.

A. NDN-R Architecture

As shown in Fig. 1, NDN-R architecture we designed includes the following three parts:

⑴ Named Portal Point (NPP): NPP plays the role of high-speed rail station, we consider that only the station can provide reliable internet service. Therefore, only this kind of NPP can generate the Data packets.

⑵ Named Access Point (NAP): NAP is a series of base stations between two NPPs which are evenly spaced. The NAPs are in a chain-like arrangement, and the adjacent NAP uses wired connection to communicate with each other. They are responsible for passing the Interest packets to NPP and sending the Data packets back to the train.

⑶ Train Access Point (TAP): We abstract all information on the train into a unified access point which is TAP. It sends Interest packets to NAP or receives the returned Data packets from NAP via the wireless connection.

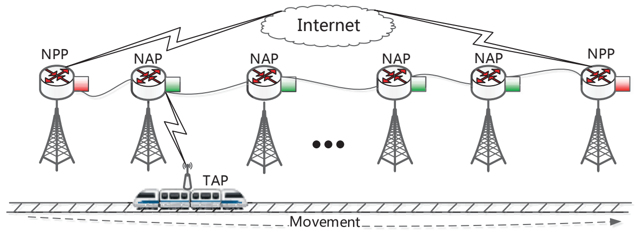

Fig. 1. NDN-R architecture.

In NDN-R architecture, NDN protocol is installed on all nodes (NPP, NAP and TAP). NDN uses named prefix to forward the Interest packets, the NDN-R architecture can avoid the triangular routing problem. There is no network address translation problem or network address management problem in the case of frequent handover between different network segments, because NDN does not care about the address information. Therefore, NDN-R architecture is more suitable for high-speed railway than TCP/IP architecture.

B. Direction-aware Forwarding Strategy

To further improve the performance of high-speed railway networking, we have put forward the direction-aware forwarding strategy (DAF). It ensures that Interest forwarding direction is the same as that of the train. Fig. 2 shows the Interest packets forwarding process of DAF. Compared to the process in traditional NDN model, DAF needs to determine the direction after the Interest packet has been forwarded by FIB. Only in the following two cases the Interest packet will be forwarded: ⑴ the train runs from left to right and the NAP nodes forward the Interest packets to right direction; ⑵ the train runs from right to left and the NAP nodes forward the Interest packets to left direction.

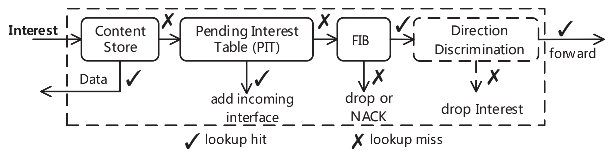

Fig. 2. Interest packets forwarding process.

What we changed in Interest forwarding process does not affect the Data forwarding process. We consider Interest forwarding direction keeping the same way with running train, which reduces the network redundancy. In addition, when the direction-aware forwarding strategy combines with fast handover mechanism, the communication services for passengers can be effectively improved.

C. Multi-channel Design

NDN-R architecture adopts frequency multiplexing technology to improve spectrum utilization. However, when the NAP coverage continues to shrink, the co-channel frequency multiplexing coefficient will increase continuously. And the co-channel interference (CCI) will become more serious, which directly affects the quality of mobile communication. The CCI in high-speed railway means that all access points (NPP, NAP and TAP) are in the same channel and results the media competition. To reduce the problem of CCI, channel multiplexing design is very necessary. As shown in Fig. 3, there are only three channels in the 2.4GHz frequency band of the 802.11b protocol to meet the conditions of no frequency overlap, which are 1, 6 and 11 channels respectively. Therefore, we use these three channels in the experiment to reduce the CCI problem.

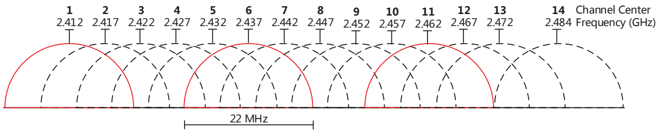

Fig. 3. Channel frequency distribution of 802.11b.

IV. Handover Mechanisms

In this section, we firstly introduce the working principle of the traditional handover mechanism [3] and analyze how the traditional handover mechanism causes the ping-pong handover. Secondly, we put forward two mechanisms for direction-aware forwarding strategy in NDN-R architecture. One is signal strength handover mechanism. The handover is triggered by signal strength. The other one is fast handover mechanism. It can make sure that the train handover to the next-hop NAP as soon as possible.

A. The Traditional Handover Mechanism

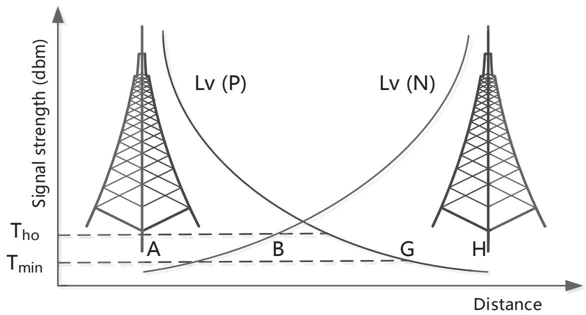

Fig. 4. The traditional handover.

The traditional handover mechanism is widely used in GSM-R network. According to the Hata Model, the two base stations which are adjacent can be shown in the Fig. 4. We denote Lv(P) as the signal strength in the current base station and Lv(N) as the signal strength in the neighboring base station. T_{ho} represents the defined threshold value and T_{min} represents the minimum signal strength that can be received. The distance of AG and BH is the coverage radius of these two base stations respectively. The traditional handover mechanism initiates a handover when the Lv(P) is dropped below T_{ho}, and the Lv(N) is greater than Lv(P).

However the high-speed railway movement environment is complex and changeable, influenced by the mountains and rivers, the change of signal strength is not as stable as Hata Model. As shown in Fig. 5, at the point of A, the handover will be triggered normally. But at the point of B, the Lv(P) is greater than the Lv(N), and the handover will be triggered again. This is so-called ping-pong handover. It causes unnecessary handovers and reduces the quality of communication service.

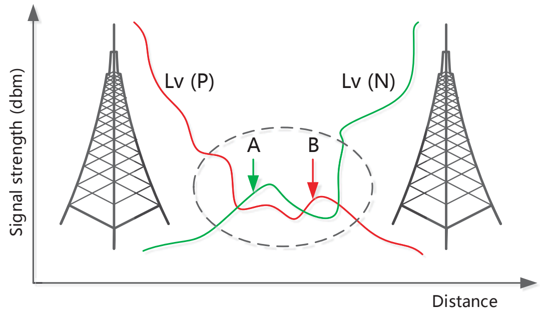

Fig. 5. Ping-pong handover.

B. Signal Strength Handover Mechanism

We implement the signal strength handover mechanism (SSHM) in NDN-R architecture. If the signal strength of the scanned NAP is stronger than the current one in the coverage area, the train will disassociate with the current NAP and associate with the scanned NAP. The detailed process of SSHM is described in Algorithm I. However, similar to the traditional handover mechanism, signal strength handover mechanism cannot avoid the ping-pong handover problem either. In addition, SSHM does not take into account the directional running characteristic of the high-speed train. It cannot reduce the handover latency effectively. Therefore, the SSHM is not suitable for high-speed railway.

Algorithm I: Signal strength handover mechanism

```
1:  Initialize:
      NAP uses active scanning look for NAP
      Pc indicates the signal strength of the current
      connected NAP
      Ps indicates the signal strength of the scanned NAP
2:  while scan different NAP do
3:    if (Ps > Pc ) then
4:      TAP disassociate with current NAP
5:      TAP associate with scanned NAP
6:    else
7:      TAP stays association with current NAP
8:    end if
9:  end while
```

C. Fast Handover Mechanism

In the fast handover mechanism (FHM), the problem of ping-pong handover can be avoid by basic service set identifier (BSSID). It is a 48-bit identifier used by all nodes in the basic service set (BSS). As shown in the Algorithm II, if the scanned BSSID is not in the *S* set, it means that the scanned BSSID is a new BSSID. The train can initiate the handover without ping-pong handover. However, if the BSSID is in the *S* set, it means that the scanned BSSID has been associated before. The train should not trigger the handover which may cause the ping-pong handover. Therefore, we can avoid the unnecessary handover via BSSID.

In addition, the current running position of the train can be obtained by the running time and running speed of the train. We also determine the location of the train to change the association based on the coverage of the NAP, according to the relationship between the current train position and the distance of two NAP nodes. If the handover has not been triggered at the middle position of the *D*, the handover will be enforced. In this case, the robustness of our algorithm can be improved.

```
Algorithm II: Fast handover mechanism
Input: (T, V, D, R, S)
    T, Time
    V, Speed
    D, Distance of two NAP
    R, NAP nominal radio range
    S, BSSID set
Initialize:
    TAP uses active scanning look for NAP
    BSSID_s indicates the BSSID of the scanned NAP
    Let P be the current position of the TAP, P=(T*V)%D
    Let M be the middle position of D, M = D/2
while scan next-hop NAP do
  if (BSSID_s is not in S) || (P > M) then
     TAP disassociate with current NAP
     TAP associate with scanned NAP
     add the BSSID_s to S
  else
     TAP stays association with current NAP
  end if
end while
```

In summary, the purpose of the fast handover mechanism is letting the train trigger the handover as soon as possible. As long as the train finds a new BSSID, the train disassociate with the current NAP and associate with the next-hop NAP. The next-hop NAP must be the front of the train, because of the train's working model and the design of the simulation. As the train only moves forwardly, it will not turn around suddenly, so the new BSSID received by train on the single-path railway must be the BSSID of the front of the train.

We also implement the backward handover mechanism (BHM) in NDN-R architecture which is the opposite of fast handover mechanism. BHM connects with the current NAP as long as possible until the current NAP cannot provide the network service. The direction-aware forwarding strategy ensures that the Interest packets forwarding direction is consistent with that of the train. The Data packets can only be obtained from the NPP in front of the train. In the coverage area of two NAPs, the direction-aware forwarding strategy combines with the fast handover mechanism can save one hop count compares to the direction-aware forwarding strategy combines with the backward handover mechanism. Therefore, the direction-aware forwarding strategy combines with the fast handover mechanism can not only implement the fast handover but also improve the quality of communication service.

V. EVALUATION

In this section, we use ndnSIM [22] to simulate the NDN-R architecture, implement the multi-channel design and handover mechanisms. In addition, we evaluate handover latency, packet loss rate, average delay and throughput for different handover mechanisms.

A. Parameters of Experiment

In the simulation experiment, the main entity of high-speed railway scenario is two NPP nodes and eight NAP nodes. The two NPP nodes are located at the head and tail, and the eight NAP nodes are arranged between NPP nodes. The ten nodes are arranged in a straight line with a distance of 1000 meters, and the TAP node simulates the running of the train, moving from the first node to the tail node in different speed. Other detailed parameters are shown in Table I.

TABLE I. PARAMETERS OF TEST

Parameters	Value
Payload size of Data packets	1200 bytes
Content Store size	1000 packets
Propagation loss model	Three Log Distance
NAP radio range	750 m
Technology	IEEE 802.11b
Number of NPP and NAP	10
Mobility model	Constant Velocity
Mobility speed	10-100 m/s
Consumer helper	ConsumerCbr
Interest frequency	40 packets/s

All of the simulation works are based on the multi-channel design and the direction-aware forwarding strategy so that we can avoid CCI problem and reduce the network load. In order to evaluate the performance of different handover mechanisms, we define the performance metrics as follows:

- **Handover latency**: The time between TAP disassociate with current NAP and associate with next-hop NAP.
- **Packet loss rate**: Numbers of Data packets lost / total number of Interest packets transmitted.
- **Delay**: The time between the Interest packet sent out and the Data packet returned.
- **Throughput**: (Numbers of Data packets received * payload size of Data packets) / simulation running time.
- **Hop count**: The number of network hops that the returned data packet traveled on the way.

B. Simulation Results

Average handover latency. To evaluate the proposed fast handover mechanism, we compare the average handover latency of different handover mechanisms. As shown in Fig. 6, with the speed increases, the handover latency has no significant change. And the FHM is better than the other two handover mechanisms. Compared to the traditional handover time of 0.1s [5], the FHM can reduce about 72% of the handover latency in high-speed movement environment. Compared to the SSHM, FHM can reduce about 35% of the handover latency in the highest speed. The reason is that the FHM can avoid the ping-pong handover with the help of BSSID.

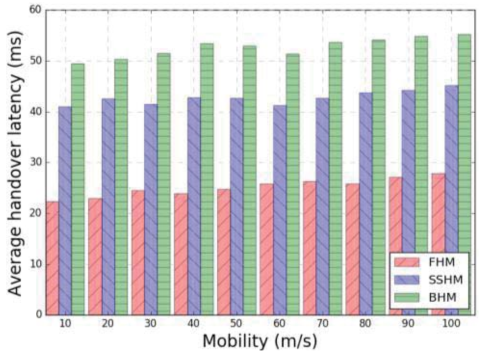

Fig. 6. Average handover latency.

Packet loss rate. Fig. 7 compares the packet loss rate of different handover mechanisms. We use the multi-channel design and DAF, the packet loss rate of different handover mechanisms is less than 9%. According to the result, the different handover mechanisms' packet loss rate increase as the speed increases. It can be seen that the packet loss rate of FHM is the lowest, the rate of BHM is the highest, and the rate of SSHM is between FHM and BHM. Compared to BHM, FHM can reduce packet loss rate by up to 8% . The packet loss rate of FHM is close to 1%, the reason is that the FHM can fast handover to the next-hop node. Combined with the DAF, FHM can provide the reliable communication service.

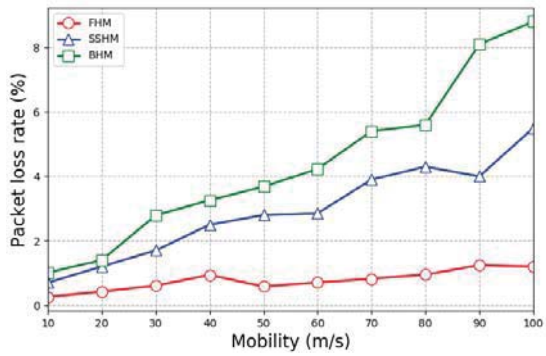

Fig. 7. Packet loss rate.

Average delay. Fig. 8 shows the average delay also increases as the speed increases. This is because the handover success rate will decrease with the increase of speed. In the high-speed movement environment, the handover occurs frequently. The more handover times will reduce the quality of communication service and increase the average delay. Therefore, reducing handover latency can effectively improve network performance. FHM can finish the handover quickly, it needs less handover time than the other mechanisms. Therefore, it can keep the highest handover success rate and the lowest average delay among these mechanisms. Compared to BHM, FHM can save about 14% average delay in the highest speed.

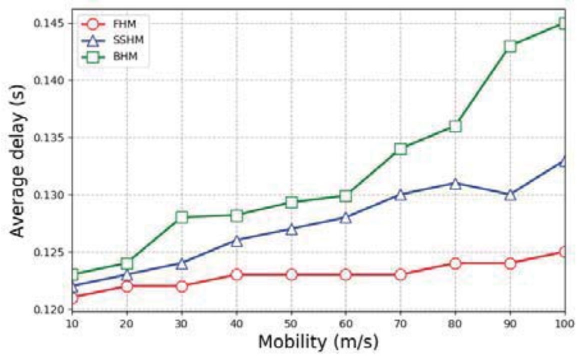

Fig. 8. Average delay.

Throughput. Fig. 9 compares the throughput among different handover mechanisms in DAF. The throughput will reduce as the speed increases. Result shows that the throughput of FHM has the best performance compares to other handover mechanisms'. FHM can increase the throughput by about 8% compared to BHM in the highest speed. This is because that the train moves keep forwardly, and the FHM ensures that the train connect with the next-hop node as soon as possible. It reduces the packet loss rate and the average delay, provides the reliable communication service. Surely, the throughput of FHM is better than the other mechanisms'.

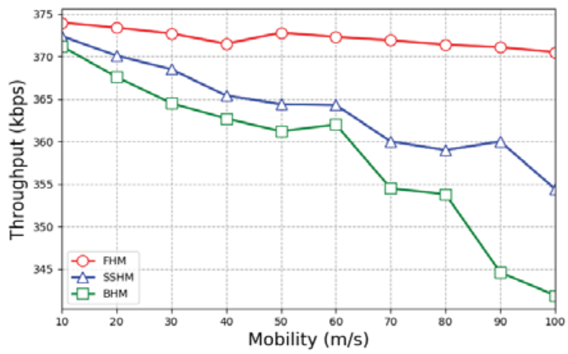

Fig. 9. Throughput.

Cache effect. In order to evaluate the effect of cache sufficiently, we added a train in the simulation. The first train is recorded as train1 and the second train is recorded as train2. Train2 will send the same Interest packets as train1 and it will start after the train1 has ran 2s. As shown in Fig. 10 and Fig. 11, with the help of cache, the average delay and the average hop count can be reduced significantly. In cache case, the Data packets can be obtained from the local NAP node or next-hop NAP node. While, in no cache case, the Data packets obtained must from the NPP node. Therefore, cache can reduce about 56% of the average delay compares to the no cache case. And the cache can reduce average hop count close to 1.

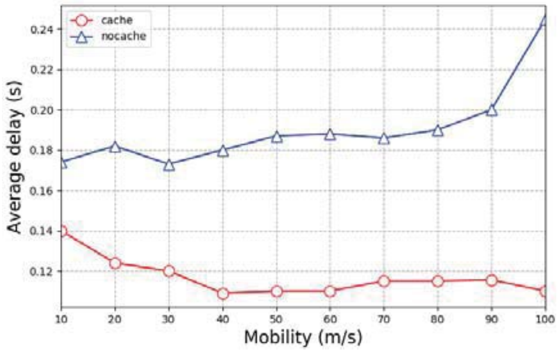

Fig. 10. Average delay of train2.

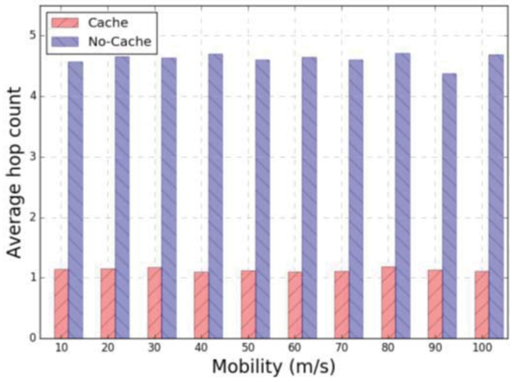

Fig. 11. Average hop count of train2.

VI. CONCLUSIONS

How to deal with the frequent handover problem in high-speed railway directly affects the quality of communication service. Due to the end-to-end communication model in TCP/IP architecture, the problem of frequent handover on the high-speed train cannot be solved effectively. In this paper, we take the advantages of NDN and propose the fast handover mechanism which can connect with the next-hop node as soon as possible. FHM uses the multi-channel design to avoid the co-channel interference problem in high-speed railway. As shown in the results, the FHM can reduce about 72% of the handover latency compared to the traditional handover mechanism. In addition, the packet loss rate, average delay can be reduced and the throughput can be improved. The fundamental reason is that the NDN is content oriented and does not need to establish the end-to-end connection after the handover occurs.

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REFERENCES

[1] Sniady A, Soler J. An overview of GSM-R technology and its shortcomings[C]// 2012 12th International Conference on ITS Telecommunications (ITST). IEEE, 2012: 626-629.

[2] Ai B, Cheng X, Kürner T, et al. Challenges toward wireless communications for high-speed railway[J]. IEEE transactions on intelligent transportation systems, 2014, 15(5): 2143-2158.

[3] Du P, Luo L, Ma Y, et al. A dual-antenna based handover scheme for GSM-R network[C]// 2012 International Conference on Wireless Communications & Signal Processing (WCSP). IEEE, 2012: 1-6.

[4] Li Z, Chen Y, Shi H, et al. NDN-GSM-R: a novel high-speed railway communication system via named data networking[J]. EURASIP Journal on Wireless Communications and Networking, 2016, 2016(1): 48.

[5] Zhou Y, Pan Z, Hu J, et al. Broadband wireless communications on high speed trains[C]// 2011 20th Annual Wireless and Optical Communications Conference (WOCC). IEEE, 2011: 1-6.

[6] Ming Z, Wang H, Xu M, et al. Efficient handover in railway networking via named data[J]. International Journal of Machine Learning and Cybernetics. 2015, 6(1): 167-173.

[7] Wang L, Guan J, You I, et al. Survey on distributed mobility management schemes for proxy mobile ipv6[C]// IEEE on Consumer Communications and Networking Conference (CCNC), 2014: 132-138.

[8] Xylomenos G, Ververidis C N, Siris V A, et al. A survey of information-centric networking research[J]. IEEE Communications Surveys & Tutorials, 2014, 16(2): 1024-1049.

[9] Augé J, Carofiglio G, Grassi G, et al. Anchor-less producer mobility in ICN[C]//Proceedings of the 2nd International Conference on Information-Centric Networking. ACM, 2015: 189-190.

[10] Zhang L, Afanasyev A, Burke J, et al. Named data networking[J]. ACM SIGCOMM Computer Communication Review, 2014, 44(3): 66-73.

[11] Fei M, Fan P. Position-assisted fast handover schemes for LTE-advanced network under high mobility scenarios[J]. Journal of Modern Transportation, 2012, 20(4): 268-273.

[12] Kim M S, Lee S K, Golmie N. Enhanced fast handover for proxy mobile IPv6 in vehicular networks[J]. Wireless Networks, 2012, 18(4): 401-411.

[13] Pan M S, Lin T M, Chen W T. An enhanced handover scheme for mobile relays in LTE-A high-speed rail networks[J]. IEEE Transactions on Vehicular Technology, 2015, 64(2): 743-756.

[14] Magnano A, Fei X, Boukerche A, et al. A novel predictive handover protocol for mobile IP in vehicular networks[J]. IEEE Transactions on Vehicular Technology, 2016, 65(10): 8476-8495.

[15] Yoo S J, Cypher D, Golmie N. Timely effective handover mechanism in heterogeneous wireless networks[J]. Wireless Personal Communications, 2010, 52(3): 449-475.

[16] Park J, Lim Y. A handover prediction model and its application to link layer triggers for fast handover[J]. Wireless personal communications, 2010, 52(3): 501-516.

[17] Alnas M, Awan I, Holton R D W. Performance evaluation of fast handover in mobile IPv6 based on link-layer information[J]. Journal of Systems and Software, 2010, 83(10): 1644-1650.

[18] Li C, Nguyen U T, Nguyen H L, et al. Efficient authentication for fast handover in wireless mesh networks[J]. computers & security, 2013, 37: 124-142.

[19] Choi J, Jung S. A handover authentication using credentials based on chameleon hashing[J]. IEEE communications letters, 2010, 14(1).

[20] Xu P, Fang X, He R, et al. An efficient handoff algorithm based on received signal strength and wireless transmission loss in hierarchical cell networks[J]. Telecommunication Systems, 2013, 52(1): 317-325.

[21] Wu F, Yang W, Chen R, et al. Broadband Communications for High-speed trains via NDN Wireless Mesh Network[C]//International Conference on Wireless Algorithms, Systems, and Applications. Springer, Cham, 2017: 791-803.

[22] Mastorakis S, Afanasyev A, Moiseenko I, et al. ndnSIM 2.0: A new version of the NDN simulator for NS-3[R]. NDN, Technical Report NDN-0028, 2015.