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A Handover Scheme for Subnet Mobility in Heterogeneous Networks

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***Abstract*— an increase number of wireless applications consist of a network of mobile nodes moving together in high velocity, existing protocols focused on roaming of single node, and there are no mature solutions to keeping uninterrupted high-speed mobile communications for roaming the entire subnet with a moving velocity as high as a vehicle. In this paper, firstly we propose the idea of the new handover scheme based on mobile IP, and then introduce the principle and key issues for subnet mobility in networks. The station (STA), a wireless communications equipments in mobile wireless subnet, taking the access point (AP) as the gateway, implements the multiple-hop subnet mobile IP by cooperation of the home agent, the foreign agent, interior network routing agent and reused tunneling, thus to overcome the limitation of one hop between the movement node (MN) to the exit of the tunnel. A dynamic next AP scanning and finding model and a handover trigger model named Well-time is designed to provide low latency. We implement the scheme on re-designed STA and AP, the experiment shows that the new scheme enables a mobile subnet to handover seamlessly across heterogeneous wireless networks and maintains all ongoing high-speed communications with the nodes in fixed networks, when moving at a high velocity up to 50km/h.**

***Index Terms*—Mobile Communication, Roaming, Mobile IP, Tunnel**

I. Introduction

With the popularization of mobile communication, more and more mobile devices, such as notebook computer, smart phone, PDA, etc., are demanding wireless access to heterogeneous networks and smooth handoff without disconnection, while they are moving with each other. Supposing your family members are enjoying online video or playing game with remote friends in a high velocity vehicle. In this scenario, the mobile devices are no longer independent. All the wireless devices around you in the car belong to a WLAN/WPAN, and they are moving with the car. The similar applications are rushing out, for example the wireless monitor and online schedule system in a subway, hot points on the train or plane etc. The mobile devices access the networks by the access points, and the corresponding requirement of these devices is to provide reliable service with high QOS, especially the high bandwidth, real-time and lower packet loss ratio. Many mobile applications in other fields such as industrial, agricultural, vehicular, medical sensors have more relaxed throughput and real-time requirements.

In the application requirements mentioned above, the mobile entity is a unit named subnet which includes many devices, not one device alone, linked by the networks, and is moving quickly as a whole. At the same time, the QOS of the wireless networks can not be affected even a little bit. Traditional communication technologies can not meet the requirement of fast-moving of the whole subnet and keeping high-speed communications at the same time.

Mobility management is one of the most important issues for seamless service, and its purpose is to maintain continuously communication when the terminals moving between networks while minimizing packet losses, latency etc. Many researchers have put forward some technologies in this area and the IP-based mobility, such as Mobile IP (MIP) [1] and Cellular IP（CIP）[2], is the most important one. As we know, Mobile IP is a network-layer solution which enables terminals to maintain all ongoing communications. A considerable amount of solutions based on MIP, for example Mobile Regional Registration (MIP-RR)[3], Hierarchical Mobile IP(HMIP) [4], Paging Mobile IP (PMIP) [5] etc., are proposed with different focuses. However, none of them is a satisfactory solution for roaming many terminals in a subnet as a whole. Because when all mobile nodes (MNs) roam together form current AP to the next one, these technologies would process all the handoffs of massive links at a very short time, that means the mobile status information of every MN should transmitted among the MN, FA and HA, and the correspond nodes should process them repeatedly. When we have much handovers, so called handover strength will happen.

The above constraints suggest the design of a new roaming scheme to roam all the devices as a subnet in heterogeneous networks. A new scheme is proposed to meet the special needs of the emerging new life. The key issues of our scheme are to ensure the mobile subnets serve continuous and high-speed data services regardless their movements among different access points (APs) with a high velocity. At the same time the QOS of ongoing full-duplex communication of

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every device in the subnet, for example, handoff latency, throughout, packet loss rate, delay etc., can be maintained at a perfect level to satisfy the needs of demanding low-latency, isochronous, and real-time applications.

The new scheme is a network layer (L3) scheme which can support the subnet roaming with a high speed (more than 50km/h). it is means the station (STA) and the access point (AP) work as network layer's gateways instead of as MAC devices. The traditional Mobile IP supports only one-hop between the MN and the exit of the tunnel, while in the new scheme can be multi-hops. We proposed a set of new models and algorithms on the STA, AP, foreign agent (FA), inner-network routing agent, tunnel and the home agent (HA), so the MNs in mobile subnet can connect with remote sites when they are roaming together.

The rest of the paper is organized as follows. After introduction, we describe the related works in section 2. Section 3 describes the proposed scheme, including the principle and some key issues. The performance analysis and results of proposed scheme is described in Section 4. Finally, Section 5 summarizes the paper and discusses the applicability and future works.

II. Related work

In the past few years, the roaming of mobile node is a prolific research field in wireless and mobile communications, and the most of the delivered proposal focused on data link layer or network layer. The typical representatives which realized roaming in data link layer include the cellular technology such as GPRS and 3G, Wireless LAN based on the IEEE802.11 and IEEE802.16 etc. GPRS and 3G require a dedicated band which needs to be applied from the government. In [6], the transfer rate at MAC layer of GPRS and 3G is less than 64kbps and 144Kbps respectively when moving at high speed. In [7], WiMAX, IEEE 802.16e, support roaming, which have the range of 5km and transfer rate of 15Mbps at physical layer. WLAN, IEEE802.11b/a/g, can achieve the speed of 11/54Mbps transfer rate at physical layer [8]. But WLAN can only support low-velocity moving, unable to support high-speed communication with a high roaming velocity. In 802.11f the devices can roam in the data link layer, but can not roam among different networks [9].

Roaming at the network layer is independent on the networking technologies[10], the primary solutions include changing the IP address of the mobile host , specific host roaming, Mobile IP(MIP) and cellular IP (CIP) [2]etc. The first two of them don't fit for large-scale network. HAWAII [11] and cellular IP (CIP) are some kinds of micro-mobility protocol based on IP routing. The region registered MIP (MIP-RR) [3], Hierarchy MIP (HMIP), and intra-domain Management Protocol (IDMP) are the tunneling-based micro-mobility protocols, which mainly focus on the register, management and smooth handoff intra-networks [10].

We can see that the main technology of roaming inter-networks is mobile IP (MIP) [10, 13-15]. MIP is a popular solution for mobility management, it enable the MN to maintain all ongoing communications while roaming between networks. It includes a mechanism which requires every MN to update its new care of address (CoA) to the home agent (HA) every time the MN moves from one subnet to another for routing packets to MN even the MN is not in home. However, MIP still suffers from some shortcomings, such as long handoff latency, triangle routing etc.

Recently, many research works are related to the handoff and performance issue based on MIP. [16] designed a client-based handoff management system as a common network interface at a client side and provided transparent services to IP/MIP layers without any modifications to the existing IP/MIP stack and core network. [17] introduced a distributed and dynamic mobility management strategy where the signaling burden was even and the regional network boundary was dynamical based on HMIP. In [18], a new handover scheme using the L2 information of user terminal at the AP (Access Point) or AR (Access Router) was introduced which reduced the handover latency time by means of L3 based fast handover and got rid of triangle problem through data tunneling between ERs (Edge Routers). In [19], the authors proposed MIP routing to eliminate triangle routing. In [12], HSIEH proposed so called S-MIP by predicting the information of mobile modes so as to reduce intra-domain handoff latency. TLMM, an approach of combing intra-domain care of address (CoA) with global CoA, implemented MIP-based three-tier mobile model [20]. Another method in [21] is a mathematical way, by which KAMAL etc. set the special proxy to obtain the minimal overall cost of updating the mobile register information and searching mobile nodes. DIP-MIP, constructed by introducing distributed independent paging extensions to mobile IP, can save energy consumption when the mobile nodes are inactive [22].

Nevertheless, there was no satisfactory solution for massive mobile users who moving with each other at a high velocity and demanding high-speed communication at the same time. Every MN should be processed separately when they moving together from one AP to another, huge amount of MNs would result in handover strength, even failure of the service. Furthermore, none of them supported a high moving velocity (more than 50km/h) covering a larger area and high-speed communication (more than 2M) at the same time.

III. Proposed subnet handover scheme

A. Principle of mobile IP and the motivation

Mobile IP enables MNs to maintain all ongoing communications while moving from one network to another. Fig. 1 illustrates the principle of mobile IP. MN can deliver packets to remote node (RN) by regular IP routing, however if RN send packets to NM, the home agent HA will capture the packets, and then create the tunnel from HA to foreign agent (FA), through which the packets will be transferred from FA to MNs [5, 7, 8]. When MN switches the link, it should detect the current subnet, and re-register to HA through FA to let HA know its current position, that is its care of address (CoA). When the MN is in foreign network, other RNs can access MN by its CoA. So it is CoA who makes mobile nodes keep their IP unchangeable and connect to any other links while moving.

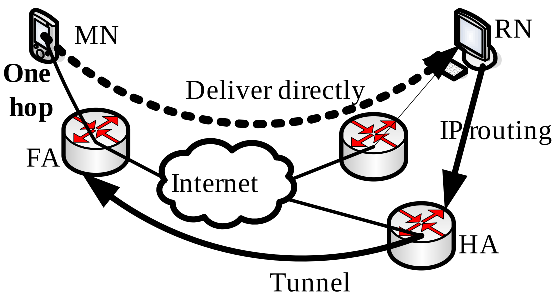

Fig. 1 Principle of mobile IP

However, the presumption of mobile IP protocol is that the distance between mobile node and gateway is one hop, which means there can be at most one hop between CoA and the MN. For this case, CoA is the IP address of the connecting of FA with MN, thus after the packets arriving at FA, they could be deliver directly to MN by using MAC layer address. So MN should be a single node, not a subnet. And we need multiple independent tunnels for multiple mobile nodes. This will lead to resources wastes. Further more, MIP is not a satisfied solution for high velocity mobile MNs. In summary, traditional mobile IP protocol cannot achieve roaming the entire subnets with a high velocity while maintaining a high-speed communication.

B. *Principle of subnet handover scheme*

According to the loosely coupled principle, we proposed and designed a subnet handover scheme that allows a set of MNs to roam across different types of wireless networks with high velocity while providing seamless connectivity and high-speed communication.

Fig. 2 shows the network configuration and the mobile subnets which includes several MNs and a STA. In the scenario the subnets move fast, keeping high-speed duplex communication with the fixed network F_net. In the Fig., M_net1 and M_net2, two mobile subnets with different topologies, are Ethernet and wireless ad-hoc respectively. That means the topologies of moving subnets are independent with our scheme. M_net1 and M_net2 establish wireless connections with AP through STA1 and STA2 respectively, and then communicate with nodes in F_net, which contains several subnets. Because M-net will connect to different AP of various subnets through STA when it is moving, we need manage the inter-network handover of it.

To meet the potential requirements of moving massive MNs together show in Fig. 2, we propose a self-adaptive subnet roaming scheme based on extended mobile IP for WLAN/WPAN. Fig. 3 illustrates how to roaming the mobile

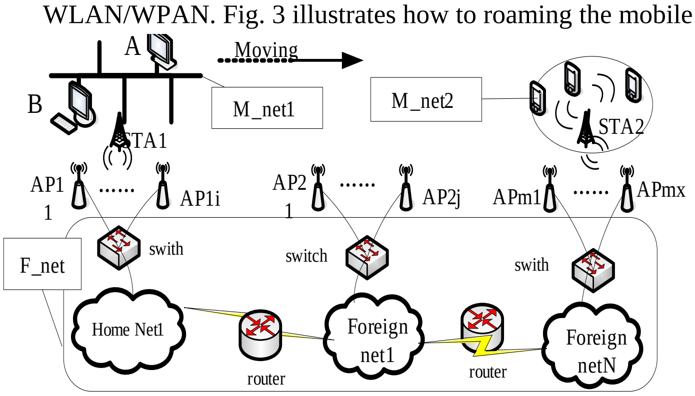

Fig. 2: Network configuration of proposed subnet roaming scheme

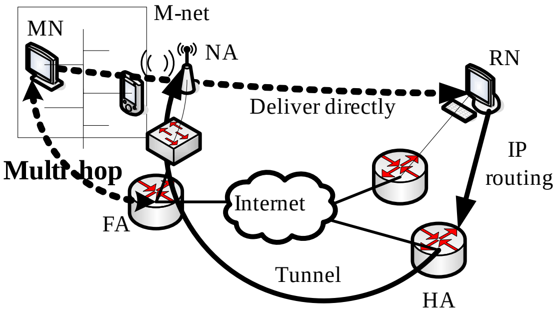

Fig. 3 Roaming the subnet in heterogeneous networks

network in heterogeneous networks. In the Fig., the node MN of subnet M-net connects the remote node RN in F_net by passing through STA, AP, foreign agent, and home agent, and the distance from outlet of the tunnel to MN is more than one hop. The main idea of the scheme is to implement multiple hops mobile IP based on home agent, foreign agent, intra-network routing agent, reused tunneling, and STA/AP gateway. By extending mobile IP protocol, we can breakthrough the limitation of roaming of single node, make all the nodes of a subnet move simultaneously while keeping duplex communications. The details are as follows:

1) Each MN in the M_net has a fixed IP address and the STA has two IP address, one is for the wireless and the other for Ethernet.

2) The STA and AP are promoted as network layer devices to provide the functionality of gateways. The data packets can be delivered from any node in M_net to any one in F_net and vice versa.

3) When the mobile subnet moving, a MAC algorithm named Well-time is adopted to choose the trigger time when STA and M_net moves in the same network, then the STA switching to next AP. A network layer handover occurs when M_net moves between different networks, the STA will get a its CoA and then the routing agent on AP will send registration information to foreign agent FA or home agent HA according to current position, so as to maintain the routing information from F_net to M-net.

4) A reused tunnel model for massive MNs is used to avoid establishing a tunnel for every MN separately. A references count is added to manage the reuse of the tunnel. When a MN connects to RN, the count will be added by one and reduced by one the other way round. Only if reference count decreases to zero, the tunnel will be deleted.

5) The HA decides how to deal with the packets according to the status of M_net. If M_net is not in the home network, HA will intercept all the packets send to M_net and forward them to the current FA of M_net.

6) The STA receives data packet from FA, whose MAC address of destination hardware is the same as itself or a broadcast address, and then removes the header of L2 to analyze the header of IP protocol. If the destination IP address is the IP address of one of the nodes in M_net (e.g., node MN), the IP data packets will be encapsulated into a Ethernet data packets and then deliver to MN. Conversely, the packets sent to F_net will be captured by STA through Ethernet port, and reassembled and delivered after analysis of the L3 header.

Fig. 4 describes the procedures of the proposed scheme for packets deliver. After the initialization of the system, the MN (M-node) of mobile subnet sets up a link connecting with

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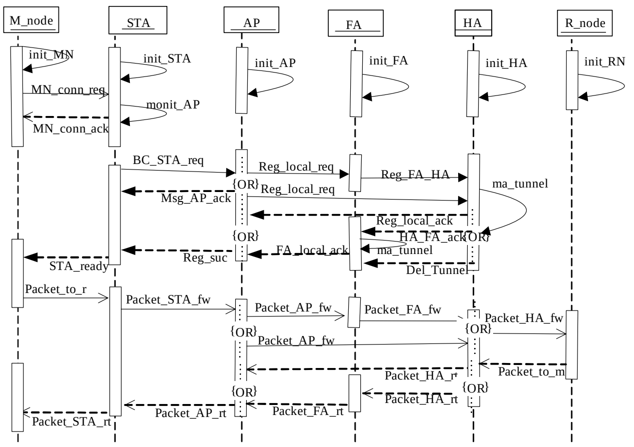

Fig.4 Packets deliver procedure in proposed scheme

STA. After STA finishing the registration to FA or HA through AP and notifying M_node that the link is ready, the data transmission can be started.

C. Gateway model on L3 STA

The STA of mobile subnet, a wireless communication device, and the MNs in M_net which connects with STA, are treated as a moving unit called STAPC. The nodes in F_net access MNs by STA. Fig. 5 shows the scenario that mobile subnet enters one region of F_net. The packets from PC2 to STAPC are received by the wireless port of STA, and then transmitted to its destination by Ethernet port. The data to PC2 are sent to STA, and then to wireless media by its wireless port, finally to PC2 by the routing of F_net. Therefore, STA should transmit packets between the wireless network and the Ethernet. For this purpose, STA, as a network layer device, should have the functionality of gateway to transfer packets between wireless network and wired network. The principles of L3 STA are as following.

1)STA as a L3 device is designed with at least two IP addresses (Ethernet *p*ort and wireless port), in this it can link two or more wireless and wired subnets; 2) To the STAPC, STA is the boundary entrance of fixed network, so its default gateway points to the Ethernet port of STA; 3)When M_net (includes the STA and a couple of STAPC) moves as a group, it register its current physical position to the home agent, providing the IP configurations of STA and M_net's wireless ports. 4) STA has the routing functionality, when some packets is received from one of its ports, it delivers them after routing according to the destination address, 5) The routing table in STA includes a routing to nodes of M_net, by which STA transmits the IP packets whose destination addresses are in M_net, and STA also contains a effective default routing, thus the IP packets from M_net can be send to their destination through the default gateway in the default routing, 6)When the physical location of STAPC changes, it registers to the home agent to notify current position and updates the settings of the default gateway. When some packets need to be transferred, the new address will be used.

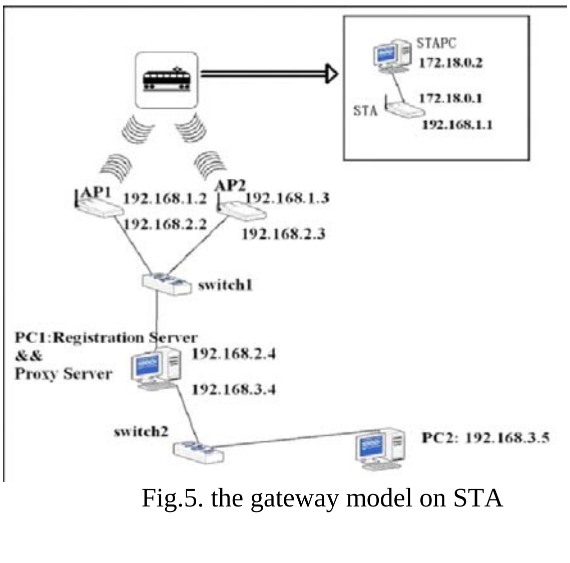

Fig.5. the gateway model on STA

D. Dynamic NAP scanning and finding model when subnet moving with a high velocity and trigger the handover

When the subnet is moving at a high velocity, one of the key issues of successful handover is find the neighbor APs and choose the right one as the next AP (NAP) with a shortest time. Usually, the STA scans neighbor APs in its region and put the result into the neighboring list, which is used to save ESSID and strength of the signals of neighboring APs, and sort them descending by their strength. After that, we can find the AP with the largest strength. If its strength is larger than that of current AP and the differences is more than a threshold, it will be the NAP, to which STA sends registration request information and waits for response. If the AP's response is received before the time threshold, the STA asserts that this AP can provide stable access services and we set ESSID of the STA as that of this AP; otherwise, it will discard it and choose the second highest AP as NAP. From that we can see that the time to choose the right NAP can be defined as:

$$T_{total} = N_{channels} * T_{each} + T_{Process} \tag{1}$$

Where $N_{channels}$ is the number of channels, T_{each} represents the maximum scan waiting time of single channel, and $T_{process}$ denotes other process time needed. If the scanning time is larger than T_{each}, we should stop scanning and deal with the next channel. We can adopt the following ways to reduce the scanning time: 1) Reduce the number of channels should be scanned; 2) Decrease the waiting time of single channel. If the possible APs of each channel are known, we stop scan it when all its APs are scanned; 3) If the next candidate AP can be determinate in advance, we need not to scan the channels. If the moving of subnet is regularity, or down a fixed path like a train, we can use switching queues to avoid channels scan.

In many scenarios the user always moving with some regular routing, for example an underground train in a city will run along the railway repeatedly, a family also has their favorite travel route. That means we can reduce the handover latency by find the appropriate NAP based on predicting and even historical information.

We adopt a dynamical AP queue to save all the candidate APs indexed by they ESSID based on predicting information as well as historical information. The APs are sorted by the handover order along the moving route of subnets. How to predict the NAP and use the historical information is depend on different scenario, and we present and test the framework based on an application of underground train of Nanjing, China. So the deployment of APs is easy to predict and the

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historical information is significant. According to the current AP connecting with STA, the neighboring AP of the current AP in the queue is NAP. When channel scan is triggered, it doesn't scan the possible channels, but find it from the AP queue. But there are still some disadvantages of NAP queue, it can't work when 1) ESSID of AP changes; 2) the position of AP in the moving route changes; 3) some AP fails. So the AP queue needs to update dynamically using the scanning result when needed.

The second key issue is handover trigger time, because inappropriate trigger will affect the efficiency of ongoing communications. The late handover will make it failure because current serving AP cannot provide stable services for MN before they switching to NAP, the packets will be lost. Contrary, the early one may lead to select a wrong NAP, so as lead to repeatedly scan NAP and increase handover latency.

Supposing the signal strength of AP is distributed in a hexagonal era, and AP can provide STA stable wireless service only in this area. Also assuming that the attenuation of the signals is linear, we propose a model named Well-Time to treat with the most appropriate handover time, which makes the decision by the strength of RSS of current AP received by STA and the velocity of mobile subnet. The attenuation path model is as follows.

$$L(d) = L(d_0) + 10n\lg(\frac{d}{d_0}) - G_r - G_t\,, \tag{2}$$

where d denotes the distance between MN and AP; $L(d)$ is the attenuation (dB) having the distance d; $L(d_0)$ is the path loss on a reference distance; n is path loss exponent; G_r and G_t are gains of receiving antenna and sending antenna respectively. Therefore, if the distance from MN to AP is d, the receiving signal is as follows.

$$P(d) = P_t - L(d)\,. \tag{3}$$

So, the S_{th} at the trigger time can be

$$S_{th} = P_t - L(d_0) - 10n\lg(\frac{d_{th}}{d_0}) + G_t + G_r\,. \tag{4}$$

Where S_{th} is RSS of current AP. That means when the RSS of current AP is attenuated to S_{th}, it's time to trigger the handover.

E. The reused tunnel model

The reused tunnel model avoids creating a tunnel for every MN in the Mobile subnet. With the moving of MNs, the reused tunnel model maintains the tunnels by:

1) Creation of the tunnels, which includes real creation and virtual creation. Considering the situation shown in Fig. 2, the mobile node A enters the foreign network. After the foreign agent obtains the information of A, it will send registration request to HA. Next, HA processes the registration request and creates a tunnel to the FA. For each tunnel a reference counter is defined also, which counts the number of the processed requests. When the registration is finished, the counter is set a value by one.

2) When mobile node B enters the foreign network. FA obtains B's information and registers to HA. HA will find that there exists a tunnel, therefore, the creation of real tunnel is no longer needed, and increasing of reference counter is enough. This is so called virtual creation. When multiple moving units come in, they can share the existing tunnels similarly.

3) Deletion of tunnels also includes real deletion and virtual deletion. When mobile node A moves to another foreign network, after the new FA registers it to HA, it decreases the reference counter related to A. This is a virtual deletion of tunnel because if the reference counter is not 0, we will not delete the tunnel really, therefore, the packets to B are still transmitted through it. When B is moving to another network, the reference is decreased similarly. If the reference is 0, the tunnel will be deleted because none of mobile nodes of the M_net will need it any longer.

IV. Performance Analysis

The subnet handover scheme is implemented on re-designed STA and AP based on IEEE802.11b and a test environment is also established. We test the scheme with the scenario which is shown in Fig. 2. The wireless subnet is in a car, and the STA connects with the M_net1 through Ethernet, and each AP connects to the fixed network through the switch. The test adopts IxChariot to analysis the experiment data, and the computer in M_net1 and F_net installs server and client of IxChariot respectively. The test settings are as follows: the UDP window size is 1200 bytes, retransmission timeout is 500 milliseconds, and number of retransmits before aborting is 50 and receives timeout is 10000 milliseconds. In the test script, parameters file size is set to 10000 and packet size is 10000.

The test is carried out in a moving car whose velocity is 10km/h, 30km/n and 50km/h respectively and continues for 2 hours. The data transmission result of the third experiment (moving with 50km/h) is shown in Fig. 6 and 7, and the former two tests are similar.

Fig. 6 shows the data transmission rate when M_net, moving between two subnets. It indicates that the real-time throughput can be high as 2.7M. Statistically, in 95% of the test time, the throughput is more than 2.2M. The highest throughput is 3.0M. Fig. 7 shows the averaged response time of handover when moving from one subnet of F_net to another, it is 40ms.

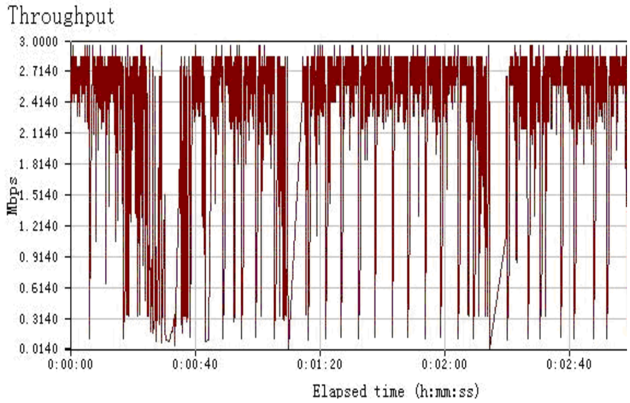

Fig.6. the data transfer rate when M_net1 moving in F_net

:tion Rate | Response Time | Raw Data Totals | Endpoint Configuration | Datagram

Timing Records Completed	95% Confidence Interval	Response Time Average	Response Time Minimum	Response Time Maximum	Measured Time (sec)
5,031		**0.040**	**0.027**	**5.137**	
5,031	0.003	0.040	0.027	5.137	202.285

Fig. 7 the averaged response time

Table Ⅰ is the statistics of packets when STA and M_net is moving with a velocity of 50km/h, N1 is a node in F_net and N2 is a move node of M_net.

Table Ⅰ statistics of packets delivered in the testing

	N1 to N2	N2 to N1
Number of sending packets	5246	5125
Number of re-sending packets	214	0
Rate of re-transmission (%)	4.07%	0
Number of lost packets	56	0
Lost rate (%)	1.06%	0
Number of transmitted packets	5190	5125
Success rate (%)	98.94％	100%

V. Conclusion

The subnet handover scheme is a new scheme based on the Mobile IP which can roam a wireless subnet as a whole when moving with a high velocity. The distance between MN and the exit of tunnel can be multi-hop. The scheme is applied to the light rail schedule and monitor system of Nanjing, China, and it is promising for many emerging wireless application, such as data transmission and video service for the passengers on the train or plane, a moving family etc. The future work will be focus on decreasing the handover latency and improving performance of the scheme. Double STA can be deployed to the mobile subnet as the gateways connecting M_net with AP, one for the data transmission and the other for scanning and finding the next AP. Some technologies in related researches in [12, 13, 20, 21, and 22] can be adopted to improve the performance and reliability of the new scheme.

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