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E^2T: End-to-End Tunneling Extension To Mobile IPv6

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***Abstract*— In the standard Mobile IPv6, route optimization or bidirectional tunnelling through the home agent show inefficiency in per-packet forwarding, especially when both communicating endpoints are mobile. To be scalable and compatible, mobile devices' packets should be forwarded in a way with minimal changes to the network infrastructure. However, the current solutions do not provide any means for the end systems to perform optimized packet routing during the operation of mobile devices.**

In this paper, following a performance analysis of Mobile IPv6 routing mechanisms, we present the E^2T - an extension to Mobile IPv6 for routing packets. It reduces per-packet forwarding cost for the communications of mobile devices. With this approach, packets are routed thorough end-to-end tunnelling between communicating endpoints, which requires little change to Mobile IPv6, but allows more efficient forwarding behavior. The numerical analysis and simulation results show it requires less overhead than the standard route optimization and it helps to achieve a low end-to-end traffic delay.

***Index Terms*— Mobile IPv6, internetworking, mobility management, routing**

I. Introduction

With the fast evolution of mobile communication and Internet technology, there is a strong need to provide connectivity for moving devices to communicate with other devices on the Internet. Internet mobility support has been a hot topic in the last decade, and studies that address this issue have arisen, coming up with a number of protocol proposals and schemes [1]. Among them, Mobile IPv6 (MIPv6) [2] as the most mature solutions has been supported and adopted by mobile devices and network equipment vendors [3], and some of network providers are even starting to deploy the MIPv6 networks [4].

MIPv6 allows a Mobile Node (MN) to communicate with a Correspondent Node (CN) at any time and any place. Fundamentally MIPv6 can be regarded to comprise 4 functional blocks [2]: movement detection, Care of Address (CoA) configuration, (home or correspondent) registration, and packets routing. In [5], [6], [7], the former 3 aspects were addressed. However, to the best of our knowledge, there is little effort in improving the efficiency of routing for the MN's data packets. We believe efficient routing is necessary to fully realise the potential of mobility enabled on the future Internet. In the IP layer mobility solution, the traditional routing mechanism is realized by employing tunnelling technique [8], [9], [10], which is called as Bidirectional Tunnelling (BT) [2] in MIPv6. However, the BT forces all packets for a MN to be routed through its HA. Thus, packets to the MN are often routed along paths that are significantly longer than optimal [11]. Hence MIPv6 develops the Route Optimization (RO) mechanism [2] beside the traditional tunnelling mechanism. The RO enables routing packets directly to the MN's CoA, which allows the shortest communications path to be used. It also eliminates congestion at the MN's home link and Home Agent (HA). However, in the RO mechanism, the MN must not only register its CoA to the HA, but also update binding to the CN, which suffers from greater control traffic. In addition, it relies on the Routing and Destination Option extension headers for packets routing, which incurs the cost of overhead.

Besides, the prosperous development of mobile Internet together with the enormous growth in the number of mobile users of wireless technologies has resulted in a strong trend that there are more and more communicating endpoints, both of which are mobile on the Internet [12]. Therefore the scenario of communications between mobile users directly will be ubiquitous on the future mobile Internet.

Therefore, in this paper, we investigate the performance of mobility routing mechanisms in more common mobile environments where communicating endpoints are mobile, and point out their strengths and weaknesses. In terms of the perspective of routing performance in the mobile environment, we provide an alternative routing enhancement mechanism based on End-to-End Tunnelling Extension to MIPv6 (E^2T) for data packet routing. The scheme can utilize the advantage of smaller end-to-end traffic delay of RO, and at the same time avoid its disadvantages by means of reducing the overhead. The numerical analysis and simulation results show our scheme has better performance against the current routing mechanisms.

This paper is organized as follows. Following introduction, we present the related work in Section 2. And then Section 3 describes the routing mechanisms as specified in MIPv6. We also analyze the problems of the standard routing mechanisms and the potential goals for enhancement are discussed. In

Section 4, we present our approach, including the E^2T protocol architecture, routing mechanism and the changes to MIPv6. We conduct a detailed analysis of our approach against the packet routing mechanisms used in MIPv6, and compare it with the standard routing mechanisms by numerical analysis in Section 5. Section 6 also evaluates the proposed E^2T mechanism by providing simulation results, which demonstrate the performance of our proposal. Finally we draw our conclusions in Section 7.

II. Related Work

Some improvements have been suggested to the standard RO mechanism. C. Vogt et al. proposed proactive tests in [13], where the procedure of address tests in the standard RO mechanism can be done proactively.

C. Perkins presented a RO security enhancement mechanism between the MN and the CN by pre-configuring data useful for pre-computing a Binding Management Key that can subsequently be used for authorizing Binding Updates [14].

In [15], F. Bao et al. suggested that one of the HA's functions is to act as security proxy for its mobile nodes. The authentication is based on the HA's certificate and the secret session keys are generated by strong cryptosystems. This proposal avoids many security obstacles in the Return Routability mechanism and provides a security solution for mobile communication.

Since these proposals have been focused on the security enhancements to the return routability and correspondent registration procedures based on current RO mechanism, the issue of signaling optimization is not addressed. This will however be covered in our work.

III. The Standard MIPv6 Routing Mechanisms and Their Problems

As mentioned above, there are two common routing mechanisms for communications between the MN and the CN in MIPv6: the BT mechanism and the RO mechanism. In this Section, starting with a presentation of the standard MIPv6 routing mechanisms, we reveal their problems. And then we discuss the objectives for routing enhancement.

A. Bidirectional Tunnelling

The BT as the traditional mode is presented in the Mobile IPv4 (MIPv4) [8]. Because the tunnelling mechanism does not require mobile IP features support from the CN and is available even if the MN has not registered its current binding with the CN, it is simple to deployment. Therefore, it is still specified as part of MIPv6. Figure 1 illustrates the BT mechanism in MIPv6.

In the BT, packets from the CN are routed to the HA and then tunnelled to the MN. Packets to the CN are tunnelled from the MN to the HA called reverse tunnelling [9] and then routed normally from the home network to the CN (see step 4 in figure 1). In this mode, the HA uses proxy Neighbour Discovery [16] to intercept any IPv6 packets addressed to the MN's home address on the home link, and each intercepted

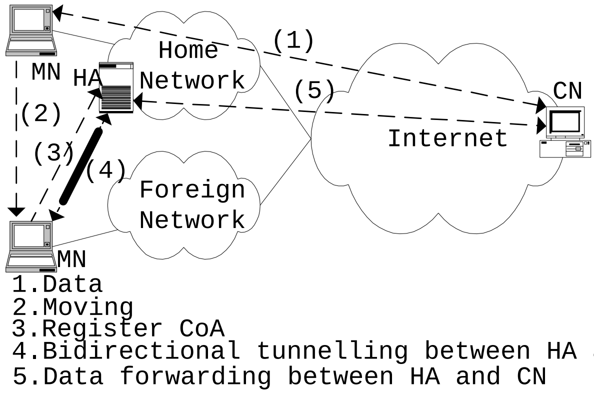

Fig. 1. Mobile IPv6 with bidirectional tunnelling

packet is tunnelled to the MN's CoA. This tunnelling is performed using IPv6 encapsulation [17].

However the BT has been criticized due to additional traffic delay. Moreover, the HA can become a single point of failure or a performance bottleneck with the increase of the number of mobile devices on the Internet. This gives the rise to the concept of RO mechanism.

B. Route Optimization

The RO addresses packets delivered directly between the MN and the CN. It requires signalling (e.g., the Binding Update messages (BUs) etc.) from the MN to its CN to map the MN's global identity (a home address) to its location (a CoA). This information is stored in a binding cache at the CN. The MN maintains a binding update list to control for which CN the route optimized communication is enabled. Figure 2 illustrates the RO mechanism in MIPv6.

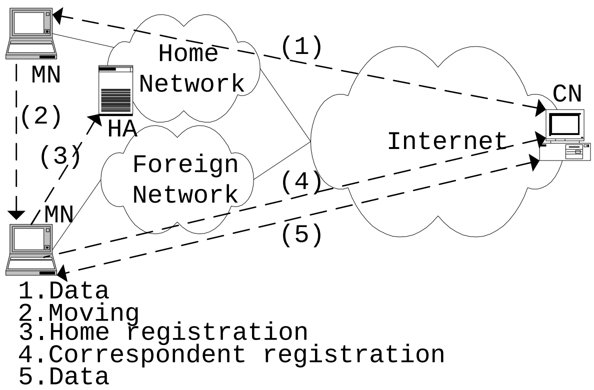

Fig. 2. Mobile IPv6 with route optimization

In the RO, the MN and the CN perform the following operations when routing packets directly to any IPv6 destination:

The MN checks its binding update list for the packet's destination address. If such an entry is found, the MN updates its home address in the packet header by replacing the source address field with its new CoA. It also adds a Home Address option in the packet header with its home address. This is in consideration of making the use of the CoA transparent above the network layer.

Similarly, The CN checks its cached bindings for an entry for the packet's destination address. If a cached binding for this destination address is found, the CN sets the destination address field in the IPv6 header to the CoA of MN. The CN also adds Type 2 Routing header to the packet for carrying the MN's home address.

MIPv6 supports simultaneous movement of both communicating endpoints [2]. When the CN is simultaneously moving, both communicating endpoints send packets using their own CoA as a source directly to the other's CoA. Hence, Type 2 Routing header carrying destination node's home address and a Home Address option carrying source node's home address are both present in the packet header.

C. Problems of Standard Routing Mechanisms

As described in previous subsections, RO as well as BT specifies messages and extensions to the basic protocol to route packets to the MN. In this subsection, we investigate the effect of the standard MIPv6 routing mechanisms on performance.

Overhead is a critical issue in the wireless environment. Spectrum is a scarce resource and must be used with care, and the radio link is typically constrained in bandwidth.

In the RO mechanism, when the MN wishes to let the CN to communicate directly with it in its visiting location, the CN sends packets with a Type 2 Routing header. Corresponding packets from the MN to the CN utilize a Home Address option in the Destination Option extension header. When both the MN and the CN are away from their home networks, packets delivered between the MN and the CN need additional messages of both the Type 2 Routing header and Destination Option extension header for correct routing. Therefore, the use of this direct data path incurs the cost of both Routing header and Home Address options in each direction, whereas the BT mechanism employs the tunnel header for packets forwarding between the MN and the HA, which suffers from the overhead of tunnel header.

The end-to-end traffic delay is also directly affected by the MIPv6 routing mechanisms. We assume that the two routing mechanisms are employed under the same Internet status including the same process time of routers and the same delay of link etc., so the traffic delay between two endpoints that are on the Internet are mainly depend on the delivery distance. Then from the figure 1 and figure 2, we can see it is obvious that the distance between MN and HA plus the distance between HA and CN is longer than the distance between MN and CN. Therefore the end-to-end traffic delay with the RO mechanism is reduced compared to the case using tunnelling mechanism.

D. Objectives for Routing Enhancement

From the above studies, the need for reducing the end-to-end traffic delay and routing overhead turns out to be increasing important.

The motivation on the enhancement to the routing delay is mainly in consideration of IP-based multimedia data delivery. In recent years, multimedia applications like VoIP, video conference, networked music are gaining momentum in the mobile Internet. Its traffic mix is subject to dramatic changes due to the ever-increasing proportion of packet-switch multimedia contents. Such applications are well recognized as delay sensitive and resource demanding. Therefore, any efforts that help to reduce the delay at any point from end to end will be much appreciated. Besides, a better routing approach with less overhead is obviously critical, in particular, with the increase of the traffic volume.

IV. E^2T: End-to-End Tunneling Extension To Mobile IPv6

Motivated by these objectives discussed in previous Section, we present an E^2T mechanism between the MN and the CN. We suggest to using tunnel header instead of Type 2 Routing header and Home Address option to carry both the MN and CN's home addresses.

A. Protocol Architecture for E^2T at Endpoints

To support the use of the E^2T communications, IPv6 encapsulation must be implemented at both endpoints - the MN and the CN. In addition, we extend the IPv6 tunnelling engine with binding cache. Figure 3 shows the architecture for E^2T at endpoints.

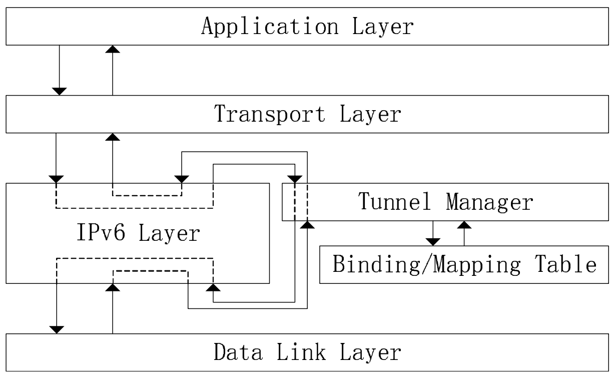

Fig. 3. The Architecture for E^2T at Endpoints

Here, the Tunnel Manager processes the data packets by performing encapsulation or decapsulation according to the Binding/Mapping table, and maintains and updates the Binding/Mapping table according to the received messages and data.

B. Data Packets Routing

When the MN sends a packet, which belongs to the connection established previously, to the CN, it will tunnel the packet to the CN using IPv6 encapsulation. When the MN encapsulates the packet for delivering to the CN, the MN sets the source address field in the new tunnel IPv6 header to the MN's CoA and sets the destination address field in the tunnel IPv6 header to the CN's CoA (see Figure 4). When the packet is received at the CN, the CN will bind the source address in the tunnel IPv6 header with the source address in the original packet IPv6 header of encapsulation in the binding cache, and then the encapsulation will be stripped away, yielding the original IP datagram, which is then delivered to the upper layer protocols of the CN, and finally processed by the upper layer protocols as if it had been routed to the CN's home address.

Tunnel Header	IPv6 Header	Payload
Src=MN's CoA	Src=MN's Home Addr.	
Dest=CN's CoA	Dest=CN's Home Addr.	

Fig. 4. The IPv6 Headers in E^2T Tunneled Packets

Similarly, in order to send the packet to the MN, the CN will tunnel the packet to the MN using IPv6 encapsulation. When the CN encapsulates the packet for delivering to the MN, the CN sets the source address field in the new tunnel IPv6 header to the CN's CoA and sets the destination address field in the tunnel IPv6 header to the MN's CoA. When the packet is received by the MN, the MN processes the received packet in the manner defined for IPv6 encapsulation, which will result in decapsulation and the decapsulated packet being processed normally by upper layer protocols within the MN as if it had been addressed only to the MN's home address.

By using the CoA as the source address in the tunnel header, with the MN's home address instead in the original packet header, the packet will be able to safely pass through any router implementing ingress filtering [18].

C. Changes to the Mobile IPv6

Because the proposed E^2T is an extension to MIPv6 and acts as an alternative beside the current routing mechanisms (i.e. the BT and the RO), especially for the scenario where the communicating endpoints are mobile, for compatibility and adaptability, the endpoints should distinguish standard routing mechanisms from the E^2T, so that it can decide whether to route packets to the CoA directly by the standard routing mechanisms, or to use the E^2T.

We modify the format of the Binding Update messages by the adding an E^2T flag to indicate that the endpoint that sends the Binding Update messages is using the E^2T.

Upon the receipt of such an extended binding update, the E^2T-aware CN should utilize the E^2T tunnel manager to process any incoming and outgoing data packets. Any E^2T-unaware CN simply ignores the bit and performs normal Mobile IPv6 operations.

V. Numerical Analysis

In this Section, we will analyze the performance of the proposed MIPv6 routing mechanism for its traffic delay and overhead. Because it is specified in the standard MIPv6 that the CN may be either mobile or stationary, we analyze the performance in the more general case where the CN is mobile.

A. BT vs. E^2T

Because the BT and the E^2T mechanisms all employ tunneling technique for packet routing, they have similar overhead. Therefore, we will analyze and compare the delay observed between the MN and the CN.

We build a general analytical network model, illustrated in Figure 5, for the measurement of traffic delay metric. In the model, We denote the packets delivery delay between the MN and HA_MN, the CN and the HA_CN, the HA_MN and the HA_CN, the MN and the CN are T_{MN-HA_MN}, T_{HA_CN-CN}, $T_{HA\_MN-HA\_CN}$, and T_{MN-CN} respectively.

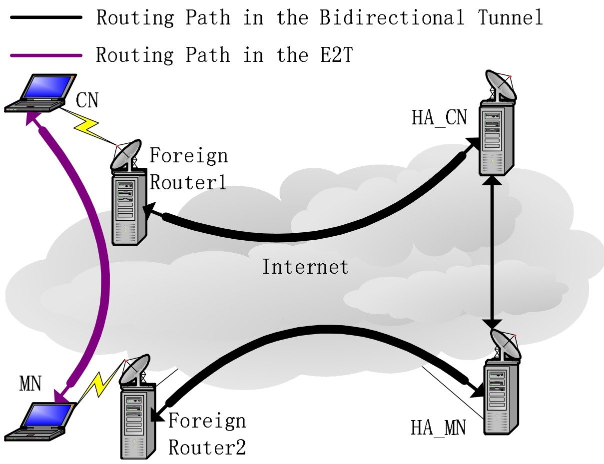

Fig. 5. The General Network Model of Bid-directional Tunneling and E^2T

In the BT, all the traffic between the MN and the CN must pass through the HA, so the end-to-end traffic delay can be expressed as:

$$T_{BT} = T_{MN-HA\_MN} + T_{HA\_MN-HA\_CN} + T_{HA\_CN-CN} \quad (1)$$

In the E^2T, the traffic is delivered directly between the CN and the MN. Therefore, the end-to-end transport delay can be expressed as:

$$T_{E^2T} = T_{MN-CN} \quad (2)$$

In the analytical network model, we assume the four paths, i.e. from the MN to the HA_MN, from the HA_MN to the HA_CN, from the HA_CN to the CN, and from the MN to the CN, are parts of the Internet. We denote the total delay in the Internet as $T_{Internet}$ [19], so in this case of BT, the end-to-end traffic delay will be mainly produced by three times of the delay that the data packet passes through the Internet, i.e. $T_{BT} = 3 * T_{Internet}$. In this case of E^2T, the end-to-end traffic delay will be mainly produced by only one time when the data packet passes through the Internet, i.e. $T_{E^2T} = T_{Internet}$. It can be easily understood that E^2T has lower end-to-end traffic delay compared to the BT approach.

This is true when both endpoints are away from their home networks, and are located in different foreign networks. In the case that both endpoints are located at the same foreign network, the data packets will just go through the same access point, further reducing the traffic delay.

B. RO vs. E^2T

In this subsection, we analysize and compare the traffic overhead of the standard RO mechanism against the proposed

E^2T mechanism. We define the performance metric of overhead ratio induced by mobility routing as follows:

$$Overhead\_ratio = \frac{Mobility\_Addition\_Size}{Ori\_Pkt\_Size} \quad (3)$$

In the standard RO mechanism, the CN sends packets using the Type 2 Routing header, and corresponding packets from the MN use a Home Address option in the Destination Option extension header. Therefore, the additional size for mobility routing includes the Type 2 Routing header and the Home Address option. And each extension header size is 24 bytes, so a total additional size of 48 bytes is essentially needed for the standard RO mechanism.

In order to utilize the link resource, the practical packets are delivered as large as possible by choosing the Maximum Transmission Unit (MTU). In Ethernet, the MTU is specified as 1500 bytes, so the overhead ratio in the RO is computed as follows:

$$Overhead\_ratio = \frac{Total\_Ext\_Hdr\_Size}{Ori\_Pkt\_Size} = \frac{48}{1452} = 3.3\% \quad (4)$$

In the proposed E^2T mechanism, the tunnel header is employed to take the place of Type 2 Routing header and Home Address option. Therefore, the additional size for mobility routing in the E^2T is the size of tunnel header. In IPv6 encapsulation, the tunnel header is the IPv6 header, which size is 40 bytes. Besides, the payload of packet in IPv6 encapsulation is the original packet. Therefore, the overhead ratio in the E^2T is computed as follows:

$$Overhead\_ratio = \frac{Tunnel\_Hdr\_Size}{Tunnel\_Payload\_Size} = \frac{40}{1460} = 2.74\% \quad (5)$$

It is noted that the proposed E^2T shows smaller traffic overhead as compared to the standard RO mechanism.

VI. Simulation Results and Evaluations

In this Section, we evaluate the effect of the proposed routing mechanism through simulation performed using OPNET simulator [20]. The simulation models are built by extending the proposed routing mechanism into the standard MIPv6 model. The simulation results demonstrate how the enhancement of routing performance can be achieved in our proposal.

A. Simulation Setup

Without loss of generality, we design the scenario where the communicating endpoints on the mobile Internet are point to point, that is to say, the connection may be originated at any one endpoint to another, and they may be mobile. The simulation network model, depicted in Figure 6, is composed by the IP cloud model, Access Routers (ARs), and communicating endpoints of the MN and the CN. The IP cloud model represents the Internet through which the IP traffic can be modelled. Each wired connection is modelled as 100Mbps duplex link with 0.1ms delay. In the network model, each of eight ARs consists of two interfaces, each supports IEEE802.11b, whereas the wired interface is connected to the Internet IP model through wired link. The AR of the HA (i.e. HA_MN and HA_CN) represents the wireless home network with home agent function while each of other ARs represents a different wireless IP subnet of foreign network. The ARs provide total coverage area with radius of approximately 300 meters. The MN and CN are mobile and they move within the coverage area of ARs.

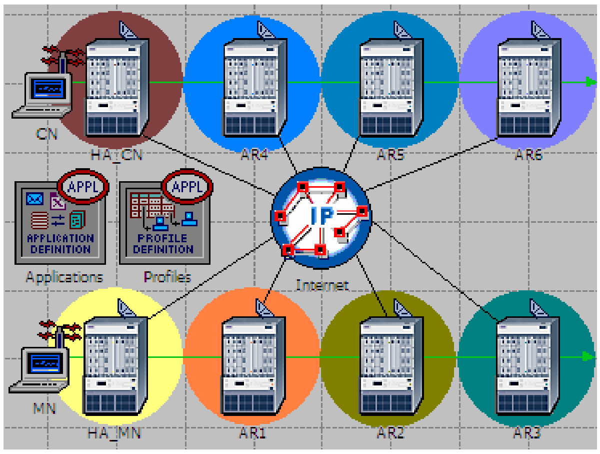

Fig. 6. The Simulation network model

B. Result for Overhead

In order to evaluate the induced overhead performance over different MIPv6 routing mechanisms, we measure the overhead metric by simulating a TCP application. In our simulation, we set the CN as the FTP server and the MN as the FTP client. The MN and the CN all roam in the range of ARs, the MN starts out at its home network (HA_MN), and switches to AR1, AR2 and AR3 in the deterministic path with rate of 100ms; the CN begins to move at its home network (HA_MN), and passes one by one through the AR4, AR5, AR6 in the deterministic direction with rate of 200ms (see Figure 6). This case allows for full control of the mobility and handover rate of the observed nodes. The FTP server of CN was sending a file of 16Mbytes to the MN while they were moving.

Figure 7 shows the overhead ratio for MIPv6 routing mechanisms, i.e. the RO, the BT and the E^2T. In this figure, the horizontal axis indicates the time in which the mobile devices are communicating with each other while they are roaming in terms of minute (m) and the vertical axis indicates the traffic overhead ratio in terms of percent (%). MIPv6_Testbed_Optimization represents the traffic overhead ratio due to the addition of the IPv6 extension headers when routing data traffic using the MIPv6 RO mechanism. The MIPv6_Testbed_Tunnel represents the traffic overhead ratio due to the additional tunnel header when routing data traffic through the MIPv6 BT mechanism. The MIPv6_Testbed_E^2T represents the traffic overhead ratio due to the tunnel header encapsulation when routing data traffic through the proposed E^2T mechanism.

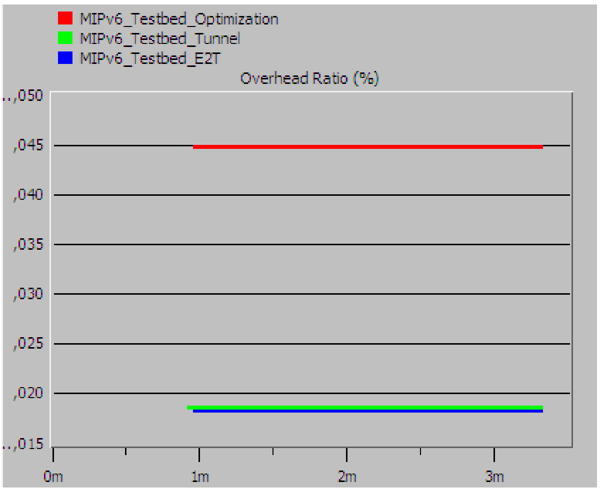

Fig. 7. The overhead ratio in MIPv6

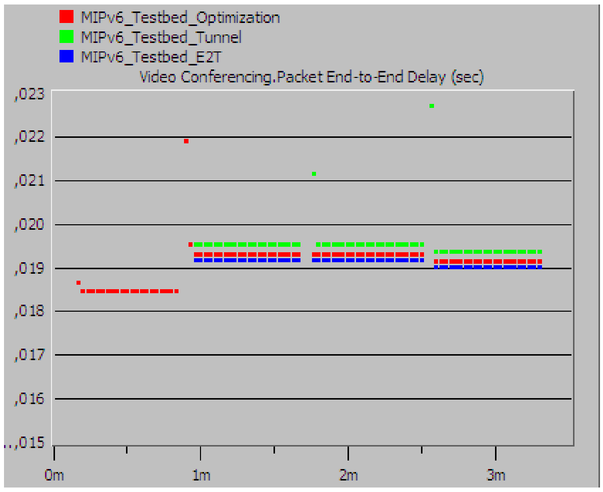

Fig. 8. The end-to-end delay of video conferencing traffic

It can be observed from the above figure that the RO mechanism presents significantly higher overhead than the BT and the E^2T. The BT and the E^2T introduce the same overhead since they all employ tunnelling technique for packet routing and have the same mobility addition messages of tunnel header.

C. Result for End-to-End Traffic Delay

We also study the differences in the end-to-end traffic delay metric over MIPv6 routing mechanisms. We measure the application traffic between the MN and the CN by running a video conferencing application. The real time application of video conferencing provides constant traffic over UDP for a constant bit rate. In our simulation, the incoming stream frame sizes and the outgoing stream frame size of the individual encoded video frames were configured with constant value of 1024 bytes as input for the real time video traffic application. The incoming stream interarrival time and the outgoing stream interarrival time were configured with constant 0.01s. The links and devices in the network model were all configured with background traffic. We set the same move mode as previous simulation scenario.

Figure 8 shows the end-to-end traffic delay with the RO, the BT and the E^2T, where the horizontal axis indicates the time in which the video conferencing traffic are being transmitted between mobile devices while they are moving in terms of minute (m) and the vertical axis indicates the packet end-to-end delay in terms of second (sec). As illustrated in the figure, the end-to-end traffic delay for the RO and the E^2T is less than that for the BT.

VII. Conclusions and Future Work

In this paper, we analyzed the standard routing mechanisms in MIPv6 on their pros and cons. Based on this, we proposed the E^2T, an alternative routing mechanism as an extension to MIPv6 routing mechanisms. Our numerical analysis and simulation results show that the direct routing path with tunnelling could reduce the traffic overhead and routing delay. The proposed E^2T mechanism extends the standard routing mechanisms by avoiding some of their drawbacks. We are currently working on a prototype implementation of this approach and evaluating its performance against the standard MIPv6. In the future, we will study its impact on other mobility optimization approaches, and consider the related security issues and the tradeoff between performance and complexity.

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