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Evaluation of Route Optimization Method in Mobile IPv6 Networks

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Abstract

With Mobile IPv6 (MIPv6) protocol support, mobile hosts can move from their home networks or one network to another without interrupting ongoing session. In MIPv6 network, packets from CN to MN undergo rectangular routing owing to long delay and tunneling overhead that affect the performance of mobile network. Furthermore, during handover process packet loss due to MN mobility is high which eventually hinder the performance of real application such as video conference, VoIP. Route optimization methods are applied in mobile network to avoid rectangular routing thus reducing delay, tunneling overhead and improving packet delivery. This paper investigated Return Routability Procedure (RRP) as a route optimization method for MIPv6 networks in terms of packets received, tunneling overhead, route optimization overhead and traffic control received. The result showed that video conference received is the same as if no route optimization was applied. However, comparing tunneled control traffics reduced with route optimization control traffic introduced is negligible. Instead, 0.02% of the tunnel and route optimization overheads were more introduced compared to tunneled and route optimization overheads introduced when no route optimization was applied.

Keywords: MIPv6, RRP, CN, MN, Tunneling, MIPv6 Routing Optimization

1. INTRODUCTION

Due to a rapid increase in the use of mobile devices, the need for mobility support has inevitably increased. This led the Internet Engineering Task Force (IETF) to introduce a MIPv6 protocol [1-2] to support the single node mobility when roaming. However, with time sensitive nature of real applications such as video conferencing, Voice over IP (VoIP), music's, online film, movies, gaming and other new applications introduced in recent years, researchers are compelled to pay attention to the Route Optimization methods in mobile networks. Many Route Optimization methods such as Return Routability Procedure (RRP), Enhanced Return Routability Procedure (ERRP), Timely One-Time Procedure (TOTP) etc., have been introduced in the literature.

RRP is a standard route optimization mechanism adopted by IETF in [1-2]. This mechanism was proposed to reduce end-to-end delay, tunneling

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overhead, increase packet delivery and to some extent adding security features to the mobile network. Because of its necessity, it is used as the reference by researchers in the field of mobile network when suggesting a new routing optimization method.

According to [3], the best route optimization scheme is expected to improve packets delivery, to optimize a route between MN and CN, reduce latency owing to MN mobility and tunneling overhead. In addition, when proposing a route optimization method, it is recommend that control signal and route optimization overhead should be reduced as much as possible [4]. The motivation behind this study is to evaluate the RRP route optimization method performance improvement such as end-to-end delay, reduced tunneling overhead with respect to control signal and route optimization overhead introduced.

Route Optimization method is an important phenomenon in the mobile network because bandwidth is typically limited in the wireless medium. Therefore, resources in the wireless network should be used in an economical way to avoid unnecessary overheads and delays. When managing MN mobility in mobile networks, route optimization methods introduce an amount of signaling messages when any mobility management protocol is used. For example, RRP method in MIPv6 exchanges periodic signaling messages even in the absence of MN movement. The signaling overhead is estimated to be 7.16bps when MN communicates with a stationary CN [5]. However, the delay due RRP handover process in the network is undesirable because it can impact performance of real-time applications or interactive applications such as VoIP, video conferencing, and so forth.

The remainder of this paper is organized as follows. In section 2, we discusses the MIPv6 route optimization method as a related works. Section 3 presents the standard MIPv6 network operations while section 4 the focus is given in Return Routability Procedure (RRP) method operations. The definition of network model for this study is depicted in section 5. Performance evaluation including simulation results and discussion are presented in Section 6. Finally, conclusion of the paper is provided in Section 7.

2. RELATED WORKS

Unlike cable network, mobile network suffers sub optimal routing due to the mobility of MNs. MIPv6 was designed for mobile network, hence it suffers from the problem of sub optimal routing. Several methods have been introduced in the literature to optimize a route in the mobile network. However, packet loss may happen in the mobile network because of frequently exchanging access points in the network. Without quantitative measurement of the extent of tunneling reduced, route optimization, level of security added and loss of packet and handover latency in the mobile network, the proposed method would be worthless. The following are literatures that discuss the MIPv6 network route optimization methods that are deemed relevant for this work.

RRP as one of the route optimization method in MIPv6 has an undesirable impact on handover delay, increases overhead and signaling control traffic as it involves signaling among all three nodes (MN, HA, and CN) in the mobile network [5]. With undesirable cost, the result is not what one would expect. This route optimization procedure is the subject of serious discussions concerning its network performance and security implications.

In the literature, several methods tries to improve RRP method by quantifying the weak point as few of the methods based on security messages that authenticate MN and CN such as HoTI, CoTI, HoT and CoT to overcome this weakness. Others try to focus on reducing interaction of messages during handover process and overheads in the network. Although these methods seek to improve RRP method, the majority have not specified the number of features they seek to improve. As this would be important avoiding introducing a route optimization method with a similar effect as RRP or more worse.

In [5, 6, 7, 8] proposes a method based on the security features in the mobile network. Shah, P. A at al., in [5] proposes an enhance route optimization on RRP process which is Time-based; One-Time Password Route Optimization (TOTP-RO). This method uses stateful shared token and maintains original state to use one password to avoid HoTI, CoTI, HoT and CoT messages. Kong, R., and Zhou, H. in [6] Proposes an improvement on the HoTI message to NPT to avoid packet loss if MN is attached or MR. However, [7, 8] focuses on reducing the number of messages to Return Routability Test. For example, in [7] together with IPsec reduces Return Routability Test messages from 6 to 5.

In [9, 10] focuses on the messages exchanged during handover process to reduce latency. Gupta, S., and Gambhir, S. in [9] proposed an architectural structure to minimize the handover latency by removing DAD (one of the most time-consuming processes during handover) and allow the router to configure CoA instead of MN itself. The router maintains two pools of addresses, the used ones and yet to be assigned ones that are free to be given to new connected nodes. Khan, M. Q., & Andresen, S. H. in [10] proposed a MN mobility prediction at CN which is a buffering mechanism. The CN is responsible for calculating the probability movement of MN from one location to another. This solution may suffer from resource problem if mobile CN is communicating with MN. CN buffer memory may be too short to maintain all those computed data and this cause delays.

Cabellos-Aparicio, A., and Domingo-Pascual, J. [11] in their solution introduced a Mobility Agents solution to perform RRP instead of it being done by each mobile client. This solution optimizes a route between MN and CN during handover and reduces the load on CN. The centralized solution (Mobility Agents) that performs Route Optimization on behalf of CN may suffer security threats whenever the Mobility agent is attacked. This will collapse the whole system as all RRP issues are centrally performed. Le, D., & Chang, J., in [12] proposed a tunneling-based route optimization mechanism to reduce per packet overhead compared to standard RRP mechanisms by optimizing packet routing between the MN and CN. It uses tunnel header instead of Type 2 routing header and Home Address option were suggested to carry the MN and CN HoA.

Barbudhe, A. K., et al in [3] stated that Route Optimizations' main problem is handover latency due to signaling control message exchange, which results in severe packet loss. To develop a better route optimization mechanism, they suggested key features to be considered such as minimizing handover latency, CoA Registration time, context establishment time, Binding Registration time, providing security and improve signaling latency. In [13, 14] simulated the MIPv6 network using RRP as a route optimization method. While Al-Saedi, F. A. T., & Asem, M. M., in [14] analyzed the results based on throughput and delay. Le, D., Fu, X., and Hogrefe, D., in [13] outlined and evaluated the results in signaling traffic control and overhead in the mobile network based on the network structure developed by the Institute of Informatics of Goettingen University.

R. Meng, et al in [15] proposed two enhanced schemes for MIPv6 and PMIPv6 so as to achieve low-latency handoff and route optimization method for future mobility oriented applications. In MIPv6, the trustworthiness is merely maintained between MN and HA. In this proposal, once MN attaches to a new Gateway, the MN establishes a trust linkage with the gateway. This route optimization method improves handover delay especially when MN is far away from HA, the handover delay is a half of legacy MIPv6. In other case, the proposed method expected to reduce overhead compared to standard MIPv6 in networks with large amount of short-lifetime connections. This route optimization method is similar to RRP except that the HoTI and HoT messages are exchanged via active gateway instead of HA.

M. Hata, et al. in [16] focused on MIPv6 routing optimization problems and proposed an SDN based end-to-end routing mechanism specified for mobility management instead of RR procedure.

The proposed method optimize an end-to-end delay based on various parameters such as bandwidth, number of domains, and flow operations for mobility after an MN has moved across SDN domains. The nodes in this method communicate with low-delay after inter-domain handovers and avoid disconnection that might occur when switching the route frequently. This method focuses on standard MIPv6 protocol instead of RR method.

Performance evaluation of route optimization in MIPv6 are presented in [17-20]. K. K. Ofosu, et al. evaluated the MIPv6 routing performance by combining MIPv6 and MANET protocols to route packets between the internet and the MANET through gateway agents. The simulation suggested that MANET On-demand routing improved the performance of MIPv6 on MANET regarding the average end-to-end delay, throughput, packet delivery ratio and normalized packet ratio. In the other hand, A. O, Alwer focuses in evaluating MIPv6 route optimization in pure IPv6 and mixed (6to4) network. The result shows that working in pure IPv6 networks was better than working in mixed networks. S. K. Hussein evaluates route optimization security and Quality of service (QoS) requirements of packet streams between MN and CN. These studies did not addresses the main requirement for the better route optimization in MIPv6.

3. MOBILE IPV6 (MIPV6)

MIPv6 was designed for MN to maintain an ongoing connection with CN while changing its location within a topology. While in the home network, a MN is configured with Home Address (HoA) and Care of Address (CoA) when it is in a foreign network. The HoA is assigned to nodes when they are at home subnets and is used for two reason: first, to allow a mobile node to be reachable by having a stable session through the communication and second, to hide the IP layer mobility from the upper layers. The advantage of keeping the HoA permanently to mobile node is that all the Correspondent Nodes (CN) tries to reach the mobile node using HoA without knowing the actual location of the mobile node, the packet will be forwarded to mobile node whether the mobile node is physically attached to a home subnet or not. If the mobile node is not attached to its home subnet, it is the responsibility of home agent to tunnel the packets to the mobile node’s CoA.

The CoA is used when the mobile node moves from its home subnet to a foreign subnet, the mobile node acquire a CoA based on the prefix of the foreign subnet. The CoA can be formed based on stateless or stateful mechanisms. Due to the change in position and new address configuration while away from home network, MN must inform Home Agent (HA) of such changes by sending Binding Update (BU) message. In order for the HA to forward packets addressed to MN, it needs to store BU from MN. In this case, HA maintains a Binding Cache (BC) lists which contain all the BU for the MNs it serves. The HA then sends a Binding Acknowledgement (BA) to MN and from this point onward HA acts as a proxy for MN and tunnel all packets destined to MN.

4. RETURN ROUTABILITY PROCEDURE (RRP)

RRP is a Route Optimization method acquired by IETF in [1-2]. It gives CN assurance of the claimed MN CoA to accept a BU from MN. As shown in Figure 1, CN can accept a BU from MN after exchanging Tokens with MN by first MN sending two separate messages; Home Test Init (HoTI) and Care-of Test Init (CoTI), each with its own token encrypted by secret key Kmn (which known only by MN) and then CN uses both tokens to create a secret key Kcn and also sends back two separate messages; Home Test (HoT) and Care-of Test (CoT) to MN each with its own token.

The two messages (HoTI and CoTI) are sent to CN by MN to request HoT and CoT from CN. The HoTI is tunneled to the HA using HoA as a source address while CoTI is transmitted directly to CN with a CoA as a source address. The HA decapsulates the HoTI from MN and forwards it to CN. The CN replies these two messages with HoT and CoT in the same path. All of these messages are transported inside a mobility header type 1. After this process, the MN can now send a BU using the token shared by CN. On the other side, CN can accept BU from MN with a claimed CoA. From here onward, CN can send all packets directly to MN CoA network.

Before the RR Test process begins, MN uses Router Discovery process to discover that is on a home network or has moved to a new router by acquiring FA CoA. MN sends a Router Solicitation message and in response receives an Agent or Router Advertisement from the router. In some cases, routers are configured to send Agent Advertisement on regular basis or required to respond to any Router Solicitation message received by sending the advertisement. After Router Discovery process, MN performs CoA Registration together with new router Duplicate Address Detection (DAD) to avoid any duplicate address with any host in the foreign network. These three processes (Router Discovery, CoA Registration, and DAD) add some reasonable delay during handover of MN to a new network. To reduce packet drops for all the packets that are directed to the HA, MN sends BU to HA before performing RR Test. Here, the total time required to complete RRP method is shown in the equation 1.

$$T_{rrp} = t_{rd} + t_{cr} + t_{dad} + t_{bha} + t_{rrt} + t_{bcn} \qquad (1)$$

Where T_{rrp} = Total latency for RRP

t_{rd} = Router Discovery latency

t_{cr} = CoA Registration latency

t_{bha} = BU with HA latency

t_{rrt} = Return Routability Test latency

t_{bcn} = BU with CN latency

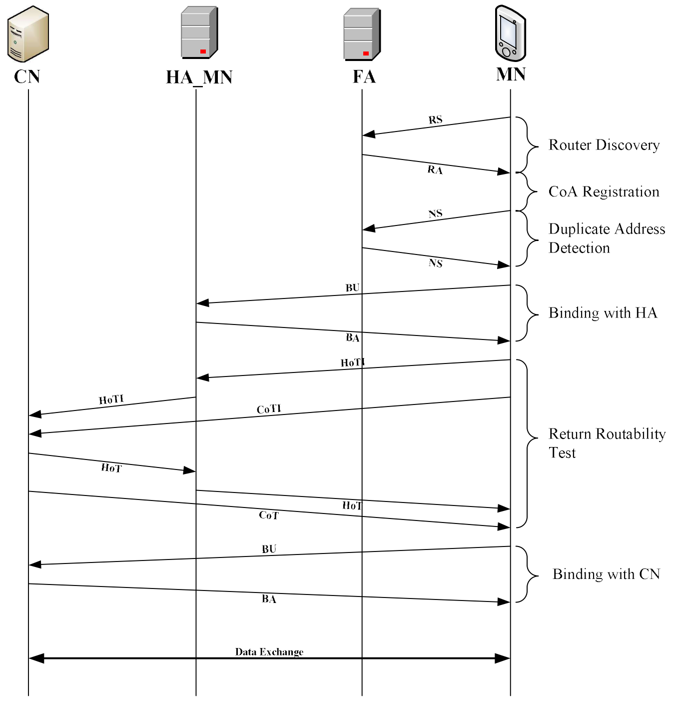

Figure 1. MIPv6 Routing Optimization Using RRP Operational Flows

One objective of MIPv6's RRP was to optimize a route from CN to MN and provide a certainty in the security level of MIPv6 network as opposed to the non-mobile network. RRP-based Route Optimization (RRP-RO) has an advantage that, it is a lightweight mechanism and has no requirements of pre-shared authentication keys. In addition, it does not maintain status at the CN [5]. This is because the home address test and the care-of address test involves message exchange between the MN and the CN, the MN and HA and HA and the CN. The delay during the handover process is high because MN cannot resume a direct communication with CN until both tests are completed.

5. NETWORK MODEL

MIPv6 protocol enables mobile devices to switch between networks and maintain ongoing sessions regardless of the physical location on the internet infrastructure. Figure 2 depicts the simulated network topology for this study. The network topology composed of four routers, CN and MN.

One Router acts as HA for MN while the three Routers act as Foreign Agent (FA) and one of them (FA_2) act as a default gateway for CN. In the network topology, each of the four routers comprises two interfaces; wireless interface which supports IEEE802.11b for roaming connection of MN and wired interface directly connected to the IPv6 internet cloud. FA_2 has one more wired interface to connect to CN. A MN is roaming from its HA passes through FA_1, FA_2, and FA_3 on the way back to its HA in an anti-clockwise direction. Other simulation parameters are shown in Table 1.

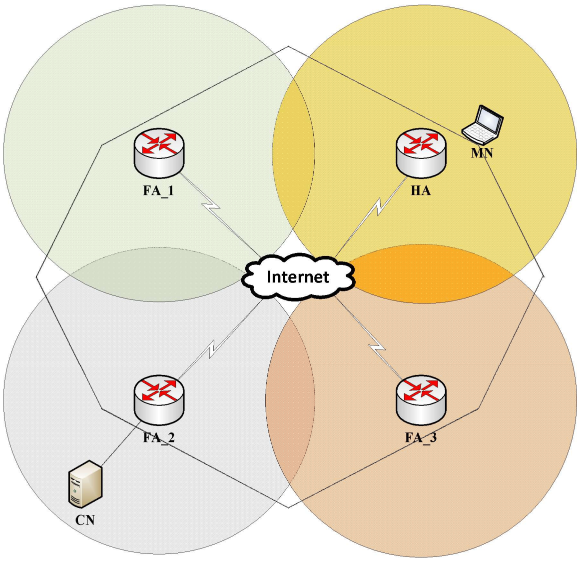

Figure 2 Network Topology

The MN assumes that it has moved to a foreign network if it does not receive agent advertisement from the current agent for a specific period. Once a MN moves to a foreign network, must configures new CoA. The MN movement detection and agent discovery is performed by FA to make itself available to MN by periodically sending Router Advertisement (RA) advertising the FA network prefix. From the advertised network prefix, a new CoA is generated by means of Ipv6 stateless or stateful address autoconfiguration.

On the other hand, if MN needs to configure a new CoA in foreign network but does not need to wait for the periodic RA, it broadcast an Agent Solicitation (AS) message to any available FA. The FA responds to an agent advertisement message with the FA network prefix. To verify the uniqueness of the configured new CoA, MN performs the Dublicate Address Detection (DAD) process before using the CoA. During all this time, MN cannot receive packet directly from CN or in a tunneled via HA.

Table 1. Simulation Parameters

Parameter	**Value**
Topology size	Campus (10km×10km)
Trajectory	Vector
Ground Speed	28mps
Application	Video Conference (light)
Route Optimization Method	RRP
Simulation Time	720 sec

6. EVALUATION OF SIMULATION RESULTS

This section analyses and evaluates the results obtained after the simulated network topology in OPNET Modeler 14.0. Two scenario results were taken from the topology; Route Optimization Enabled and Route Optimization disabled. This paper, analyses and evaluates RRP Route Optimization method in MIPv6 with standard MIPv6 protocol. Video conference packets received, signaling traffic control received and signaling overhead performance results were collected in this study.

6.1. Video Conference Packets Received

Figure 3 shows a video conference received in packets/sec. The results show that the video conference packets received for both cases are the same. In addition, there was a low video conference received around 129.6 to 151.2 sec, 295.2 to 316.8 sec, 460.8 to 482.4 sec and 626.4 to

640.8 sec during the simulation time because of handoff process.

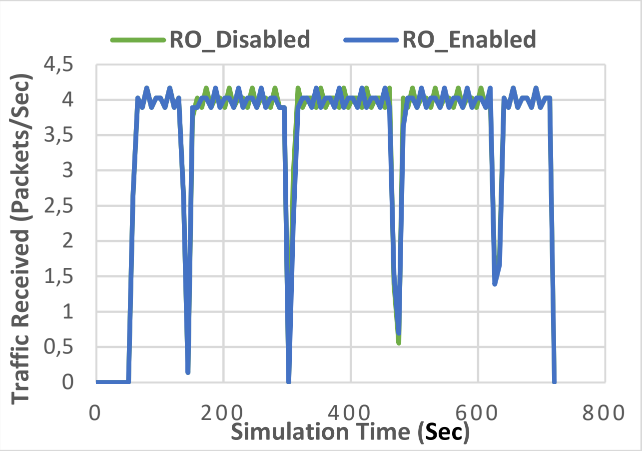

Figure 3. Video Conference Traffic Received

During Router Discovery, CoA Registration, DAD and BU with HA process, MN was not receiving any packet from a CN until the Binding with HA process was completed. The latency values caused by these four process $(t_{rd} + t_{cr} + t_{dad} + t_{bha})$ during handover are shown in Table 2 (i, ii and iii).

Table 2 Latency during Handover Process

No.	Handover	Time Range	Latency
i	HA to FA_1	129.6 to 151.2	21.6 sec
ii	FA_1 to FA_2	295.2 to 316.8	21.6 sec
iii	FA_2 to FA_3	460.8 to 482.4	21.6 sec
iv	FA_3 to HA	626.4 to 640.8	14.4 sec

The latency value during handover for these four process is the same with a value of 21.6 sec. This latency accounted for both scenarios because this was before performing a Return Routability Test. The latency value from FA_3 to HA has a different value of 14.4 sec because MN was returning to its home network. Therefore, no BU with HA process was performed. This is shown in Table 2 (iv). From these latency values, it shows that BU with HA process has a latency value of 21.6 – 14.4 = 7.2 sec. This means the RRP has an undesirable impact on the handover delays which resulted in an undesirable video conference received during this process. This further makes the same results appear as if no route optimization was enabled.

6.2. Signaling Control Traffic Received

Control traffic represents a signaling messages exchanged between MN and HA or MN and CN. It can be a BU or Routability Test messages. Figure 4 shows a control traffic received in packets/sec. It shows that RRP method removes tunneling overhead completely when MN is away from home network and has bonded with CN (from 165.5 to 302.4 sec, 324 to 475.2 sec, 489.6 sec. to the end of simulation time). But this method shows that still there is tunneling exists as shown in Figure 4 with a small interval from 138.8 to 165.5 sec, 302.4 to 324 sec and 475.2 to 489.6 sec of simulation time. This happens when a MN has bound with HA and a Return Routability Test is performed.

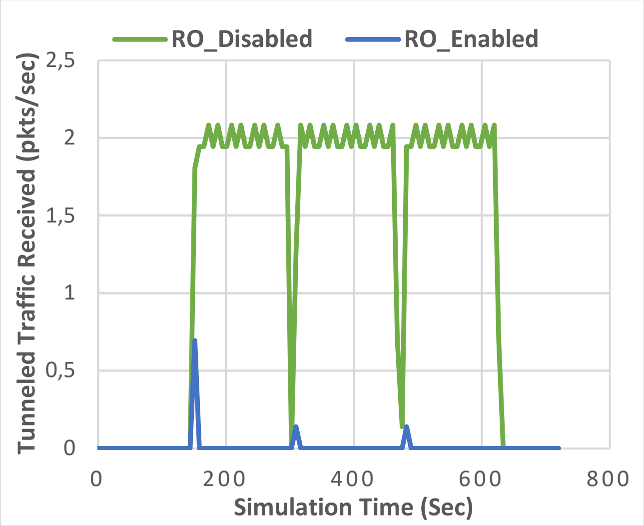

Figure 4. Tunneled Traffic Received

Figure 5 shows Route Optimization Traffic Received in packets/sec. No route optimization overhead was accounted when Route Optimization was disabled. However, during 302.4 sec and 475.2 sec of simulation time, the route optimization overheads were reduced to zero because of the handover process. During this time MN could not receive any traffic except traffic for registration from a new Foreign Router.

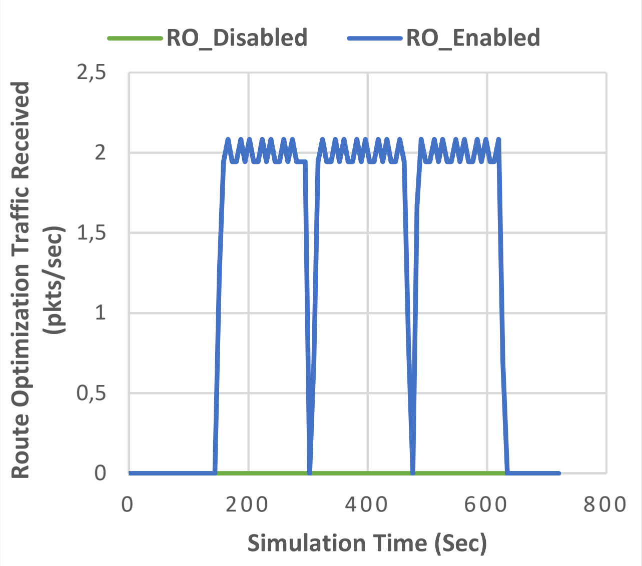

Figure 5. Route Optimization Traffic Received

In Figure 6, Tunneling plus Route Optimization control traffic received in packets/sec were compared for both scenarios. In this figure, it is shown that the Tunneling control traffics and Route Optimization control traffics are the same for both scenarios. This is obvious because RRP reduces tunneling control traffic in the network but introduces an equivalent amount of Route Optimization control traffics in the network.

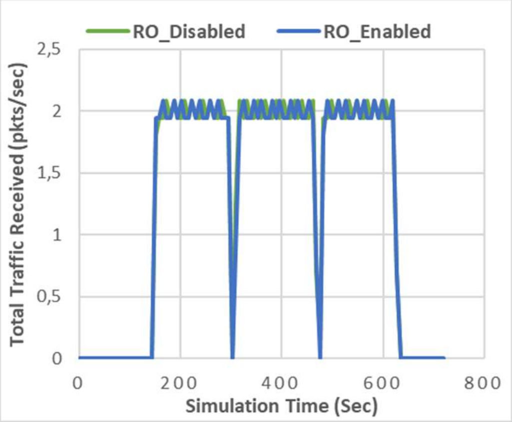

Figure 6. Tunneled and RO Traffic Received

6.3. Signaling Overhead

One objective of Route Optimization is to reduce tunneling traffic overhead as much as possible in the network because it increases the chance of packet fragmentation. Figure 7 shows a tunneling traffic overhead in percentage wise. Tunneling overhead represents an overhead ratio of IPv6 header encapsulation when MN is away from home network and packets for MN are sent to the home network. Upon receiving them HA encapsulates and tunnel them to MN foreign network. Tunnel overheads can be represented by the formula as given in Equation 2.

$$TO = \frac{Outer\ Packet\ IPv6\ hea\quad size}{Inner\ packet\ total\ size} \times 100 \qquad (2)$$

Where, TO is Tunneling Overhead.

From Figure 7 it is shown that, while a MN is away from the HA, if no Route Optimization is enabled, all traffics are tunneled to the MN and this happens at around 150 to 640 sec of simulation time with a value of 0.09%. Where Route Optimization was enabled, tunnel traffic existed for few seconds (around 138.8 to 165.5 sec, 302.4 to 324 sec and 475.2 to 489.6 sec of simulation time) with a value up to 0.36% before MN bound with CN and remove tunneling completely. This is because at these time intervals, the MN bound with HA, finish Return Routability and completing binding with CN.

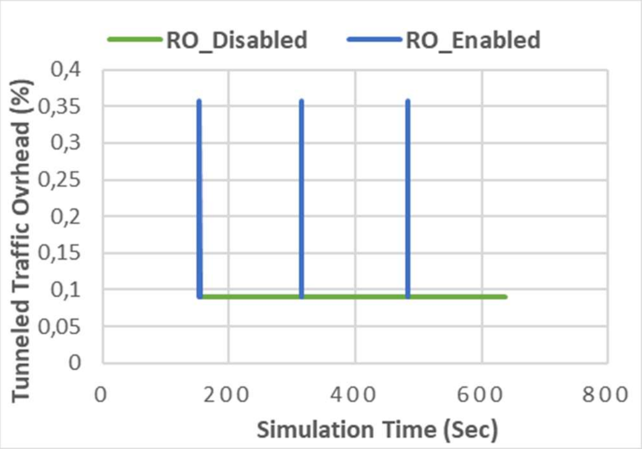

Figure 7. Tunneled Traffic Overhead

In other cases, route optimization overhead represents the overhead ratio of more IPv6 extension header when sending data packets using RRP or any other Route Optimization method. IPv6 packets may have more than one extension headers and there is no limitation of the number of extension headers in the IPv6 protocol. Route optimization overhead can be represented by the formula as given in Equation 3.

$$ROO = \frac{Total\ extension\ hea\quad size}{Original\ packet\ size} \times 100 \qquad (3)$$

Where, ROO is Route Optimization Overhead.

Figure 8 shows route optimization overhead in percentages wise. It shows that no route optimization overhead took place for a case when no Route Optimization was enabled. A route optimization overhead was around 0.11% when MN was away from the HA.

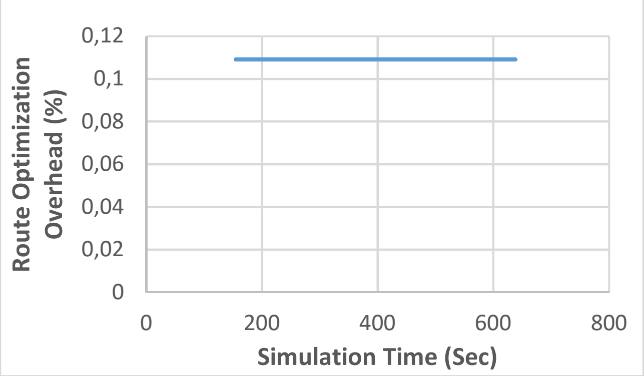

Figure 8. Route Optimization Overhead

Figure 9 shows the sum of Tunnel and route optimization overhead in percentage wise for both scenarios.

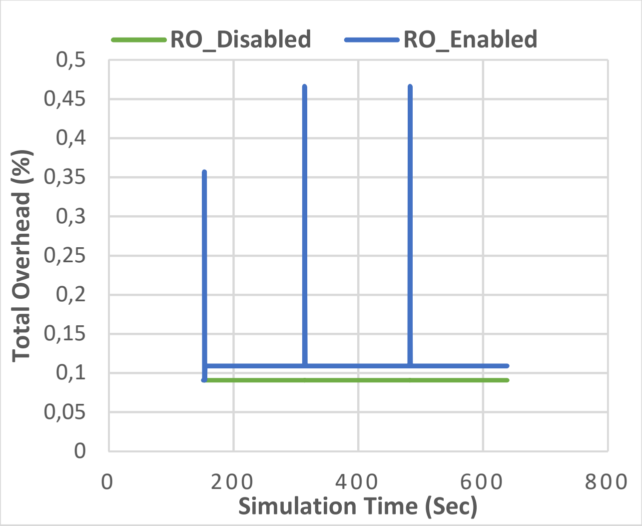

Figure 9. Tunneled and RO Overhead

The total overhead can be calculated as shown in the equation in equation 4.

$$Total\ Overhead = ROO + TO$$

$$Total\ Overhead = \left(\frac{Total\ extension\ heade\quad size}{Original\ packet\ size} + \frac{Outer\ Packet\ IPv6\ header\ size}{Inner\ packet\ total\ size}\right) \times 100 \qquad (4)$$

It is shown that RRP has a higher overhead value of 0.11% compared to normal MIPv6 protocol with no Route Optimization enabled and overhead value of 0.09%. This is because, when no route optimization is enabled, packets are encapsulated with a header length size of 40 Bytes only and forwarded to MN foreign network and for this case, zero route optimization overhead was encountered. Whereas, route optimization enabled using RRP, CN send packets using Type 2 Routing Header and Home Address option with Destination Extension headers, which incurs the overhead cost of both Routing Header and Home Address options. Each extension header has a size of 24 Bytes, which means, two extension headers have a total of 48 Bytes. This makes a difference of 8 Bytes for the data packets from a scenario where no route optimization enabled.

7. CONCLUSION

In this paper, evaluation of RRP Route Optimization method in MIPv6 networks was conducted. Packets received, tunneled traffic received, route optimization control traffic received, tunneled overhead and route optimization overhead performance results for video conference application were collected. Video conference packets received for RRP method were the same as standard MIPv6 protocol. However, results show that packets dropped dramatically during handover process. Compared to tunneling overhead and control traffic received, RRP method adds an equivalent amount of Route Optimization control traffics in the network. The RRP method introduces more overhead to the network compared to legacy MIPv6. Though this method improves End-to-End delay and security in MIPv6 networks, more research is needed for route optimization method in MIPv6 networks. This study serves as a benchmark for proposing route optimization method in MIPv6 networks so that the suggested route optimization method can enhance end-to-end delay, packets delivery, throughput while reducing tunneling, signaling and route optimization overhead.

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