

Time analysis of Route Optimization in MIPv6

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Abstract: - The Mobile IPv6 protocol allows mobile nodes in IPv6 networks to roam among subnets with various prefixes without the need to change its network address. This allows keeping the running TCP connections active even if the mobile node moves from subnet to subnet and keeps the mobile node reachable by its permanent home address all the time. The Mobile IPv6 protocol provides two ways of delivering data between the mobile node and its peer – bidirectional tunneling or route optimization. In bidirectional tunneling the data is tunneled through a central node in mobile node's home network – the home agent, whereas the other method routes the data directly between the two communicating nodes. The method of route optimization rapidly reduces the end-to-end delay, but requires implementation of Mobile IPv6 also at the mobile node's per. This article provides an analytical method for evaluating these two methods and investigates their efficiency based on various criteria.

Key-Words: - analysis, bidirectional tunneling, end-to-end delay, MIPv6, mobile node, roaming, route optimization

1 Introduction

The Mobile IPv6 protocol (MIPv6) is a layer 3 protocol that allows mobile services users (mobile nodes) to stay reachable independently on the mobile node's movement in the IP environment. Without the mobility support in IPv6 protocol, the traffic destined to the mobile node could not be delivered as far as the mobile node was situated out of its home network. For keeping its connectivity in such case the mobile node would need to acquire a new IP address every time it changed its location. However, this would lead to breaking all transport and higher layer connections.

The Mobile IP protocol allows the mobile node (MN) to move among various subnets without changing its home address (HoA). This protocol makes this movement absolutely transparent to higher layers and packets destined to this node can be routed through the network regardless its current location. The Mobile IP protocol is suitable for providing mobility among subnets of the same kind of access media as well as across various access media kinds (e.g. Wi-Fi, Bluetooth, UMTS, Ethernet, etc.)

2 Mobile IPv6

The principle of the MIPv6 protocol is the following [1], [2], [3]. There are 3 entities defined in MIPv6 (see Fig. 1) – Mobile Node (MN), Correspondent Node (CN) and Home Agent (HA). There are also two access routers (AR) – Previous Access Router (PAR) and Next Access Router (NAR). MN is a mobile workstation roaming among different subnets. CN is a node that

communicates with the MN. HA is usually a router in the home network of MN. When the MN leaves borders of its home subnet, it notifies its HA. The HA creates a mobile binding, which is an association between the home IP address and current Care of Address (CoA) – a temporary IP address topologically correct in the visited subnet. After that there are two ways of delivering the data between MN and CN – bidirectional tunneling or route optimization.

2.1 Bidirectional tunneling

In bidirectional tunneling there is no MIPv6 support required at the CN so the MN's movement is the CN transparent. The CN uses home address for communication with MN all the time. Packets sent by CN to MN are intercepted by the HA in MN's home network, equipped with an additional header and tunneled to actual location of MN (Fig. 1a)). In the opposite direction (packets sent from MN to CN) are tunneled back to HA and from there routed to CN. The additional overhead in CN → MN direction contains in the source address field the address of HA and in the destination address field the CoA of MN. In the opposite direction it is vice versa.

2.2 Route Optimization

Route optimization requires utilization of MIPv6 protocol in the CN. In case the MN roams to a foreign network, the mobile binding is updated not just in HA, but also in each CN that the MN has active connection with. Then the CN has information about CoA belonging to the MN and the data between MN and CN are routed

directly, without tunneling it through HA (Fig. 1b)). For this purpose a new routing header type is used that carries also the home address (HoA) of the MN in addition to source and destination addresses [1].

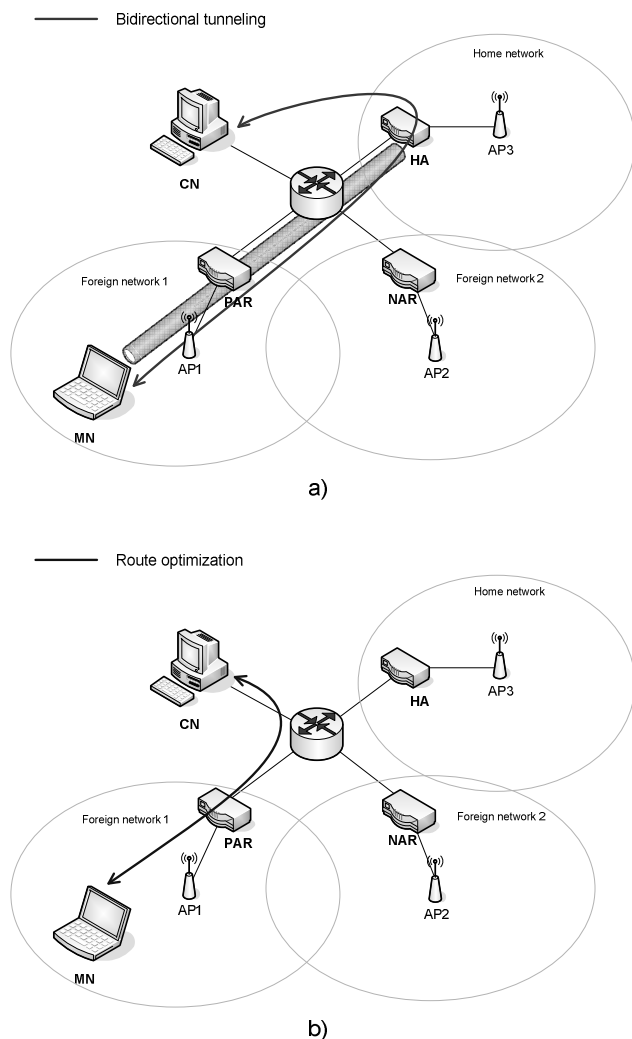


Fig. 1: Ways of data transfer between MN and CN: a) bidirectional tunneling, b) route optimization

When a CN intends to send data to any IPv6 address it first consults its binding cache if it contains an entry for this address. If so, it uses the new routing header type and sends the packet to appropriate CoA found in the entry. To the new routing header type it inserts to HoA of MN. After receiving the packet MN sets the destination address (currently set to CoA) to HoA it gets from the new routing header to make the route optimization transparent to higher layers. When a MN sends a packet to CN, it inserts its HoA to the new header. The CN that receives the packet replaces the source address (set to CoA) with the HoA. This assures that the application running at CN does not get any information about MN's movement and its location.

3 Performance evaluation

In this paper we present a method for comparing the performance of bidirectional tunneling and route optimization. The comparison is based on investigation of end-to-end delay between MN and CN. We introduce an analytical method for performance evaluation. The method is used for computing end-to-end delay based on various parameters like number of hops, bandwidth etc.

3.1 Assumptions

The analytical model has been designed to compute the end-to-end delay between MN and CN in an arbitrary network. For convenience of a derivation, a few basic assumptions have been set:

- The access point for wireless network is integrated in the access router – AR (PAR or NAR) and that PAR and NAR have no difference.
- Data rate of packets sent among MN, HA and CN is influenced by the slowest link along route and does not change. On the wired part of the route the bandwidth is constant.
- The delay caused by tunneling between HA and MN is neglectable.
- $T(A, B)$ is time required for a packet to pass from node A to B. It is assumed that $T(A, B) = T(B, A)$ [4].

3.2 Packet delay derivation

For the analysis we use a simple scenario of a basic network configuration which is shown in Fig. 2.

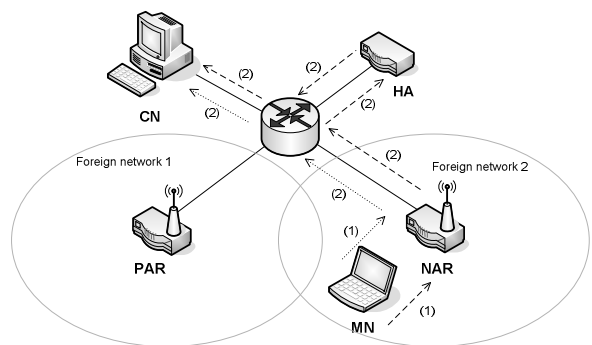


Fig. 2: Network topology for the end-to-end delay analysis

First we need to derive an equation for the time it takes the packet to get from MN to CN in bidirectional tunneling mode. The route of packets in bidirectional tunneling is marked with the dashed line in Fig. 2. The basic assumption is that:

$$T_{BT} = T(MN, HA) + T(HA, CN), \quad (1)$$

where T_{BT} is the end-to-end delay for bidirectional tunneling, $T(MN, HA)$ and $T(HA, CN)$ is time for the

packet to get from MN to HA and from HA to CN respectively. The entire route consists of two basic kinds segments – the route from MN to AR (in Fig. 2 denoted as (1)) and the route between two routers (in Fig. 2 denoted as (2)). Based on this we can write, that:

$$T(MN, HA) = T(MN, NAR) + m \times T(RT, RT), \quad (2)$$

$$T(HA, CN) = n \times T(RT, RT), \quad (3)$$

where $T(RT, RT)$ is a delay between two routers, m is number of hops between AR and HA and n is number of hops between HA and CN. Finally the end-to-end delay for bidirectional tunneling is given as:

$$T_{BT} = T(MN, NAR) + (m + n) \times T(RT, RT). \quad (4)$$

In the simple scenario in Fig. 2 the number of hops between MN and HA is 2 as well as between HA and CN, so $m = n = 2$.

In the same way we can evaluate the end-to-end delay for route optimization, which is marked with the dotted line in Fig. 2:

$$T_{RO} = T(MN, NAR) + l \times T(RT, RT), \quad (5)$$

where T_{RO} is the end-to-end delay for route optimization and l is number of hops between AR and CN.

We can see, that the end-to-end delay in both cases depends on the delay on the wireless link, delay on the network segment and number of hops between the communicating nodes.

Now we need to compute the delay on the wireless and wired part of the network. According to [5] we can get the delay of data fragment F on a link of bandwidth B from:

$$T = \frac{F}{B}. \quad (6)$$

In IPv6 It is required that every link in the Internet has a maximum transmission unit (MTU) of 1280 bytes or greater [enhanced FH]. Hence we can consider the F to be MTU , so use:

$$T = \frac{MTU}{B}. \quad (7)$$

Finally we can compute the delay of the bidirectional tunneling as:

$$T_{BT} = \frac{MTU}{B_{wl}} + (m + n) \times \frac{MTU}{B_w}, \quad (8)$$

where B_{wl} is bandwidth of the wireless link and B_w is bandwidth of the wired link. Analogically we can get the delay of route optimization:

$$T_{RO} = \frac{MTU}{B_{wl}} + l \times \frac{MTU}{B_w}. \quad (9)$$

Since we earlier assumed that the data is transferred with slowest data rate that is achieved along the entire route we can now rewrite (8) and (9) according to which link is slower – wireless or wired. Than (8) comes to:

$$T_{BT} = (m + n + 1) \times \frac{MTU}{\min(B_w, B_{wl})}, \quad (10)$$

and (9) results in :

$$T_{RO} = (l + 1) \times \frac{MTU}{\min(B_w, B_{wl})}, \quad (11)$$

where $\min(B_w, B_{wl})$ is a minimum of B_w and B_{wl} .

Knowing the end-to-end delays of bidirectional tunneling and route optimization T_{BT} and T_{RO} we can compute the difference delay of these two methods, which is given as:

$$\Delta T = T_{BT} - T_{RO} = (m + n - l) \times \frac{MTU}{\min(B_w, B_{wl})}. \quad (12)$$

3.3 Case study

Here we present the numerical results of the end-to-end delay analysis. First, as an example we compute the delay of bidirectional tunneling and route optimization of a scenario shown in Fig. 2, where the wireless link is 802.11b technology, the wired link is a 2 Mbps link and MTU is 1280 B. For the bidirectional tunneling we get:

$$\begin{aligned} T_{BT} &= (2 + 2 + 1) \times \frac{1280 \text{ B}}{\min(2 \text{ Mbps}, 11 \text{ Mbps})} = \\ &= 5 \times 4,9 \text{ ms} = \underline{24,5 \text{ ms}}, \end{aligned} \quad (13)$$

and for route optimization the result is:

$$\begin{aligned} T_{RO} &= (2 + 1) \times \frac{1280 \text{ B}}{\min(2 \text{ Mbps}, 11 \text{ Mbps})} = \\ &= 3 \times 4,9 \text{ ms} = \underline{14,7 \text{ ms}}. \end{aligned} \quad (14)$$

This gives us the difference in delay:

$$\Delta T = T_{BT} - T_{RO} = 24,5 - 14,7 = \underline{9,8 \text{ ms}}. \quad (15)$$

Second, we present the dependencies of the end-to-end delay (for bidirectional tunneling, route optimization

and their difference) on the size of MTU, bandwidth of the wired and wireless link and number of hops between the nodes.

The graph depicted in Fig. 3 shows the dependency on the MTU size. The other variables of the equations (10), (11) and (12) are constant, i.e. $m = n = l = 2$, $B_{w1} = 11 Mbps$, $B_w = 2 Mbps$. The MTU varies from the smallest size of 1280 B to 16384 B.

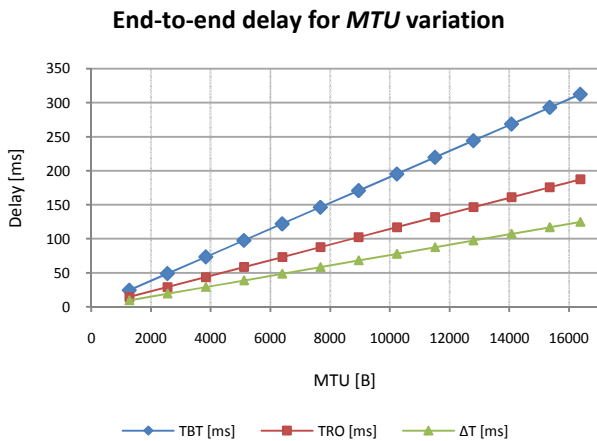


Fig. 3: The end-to-end delay dependency on MTU

From Fig. 3 we can see that with growing MTU the delay of both bidirectional tunneling and route optimization grows, which is quite obvious. But we can also notice, that the greater the MTU is, the bigger is the difference of delay ΔT . This means, that for bigger MTUs using the route optimization gives more performance compared to bidirectional tunneling.

Furthermore we investigate how the bandwidth of the wired link influences the communication and the performance of route optimization. For this purpose we set the MTU to its minimum value of 1280 B and we consider the wireless link to be 802.11b with bandwidth of 11 Mbps. The number of hops between the nodes remains unchanged. The dependency is shown in Fig. 4. We sweep the wired link bandwidth from 256 kbps to 100 Mbps. Because the value of the bandwidth varies from small values (10^{-1}) to rather high values (10^2) a logarithmic scale has been used on the horizontal axis for better orientation in the graph.

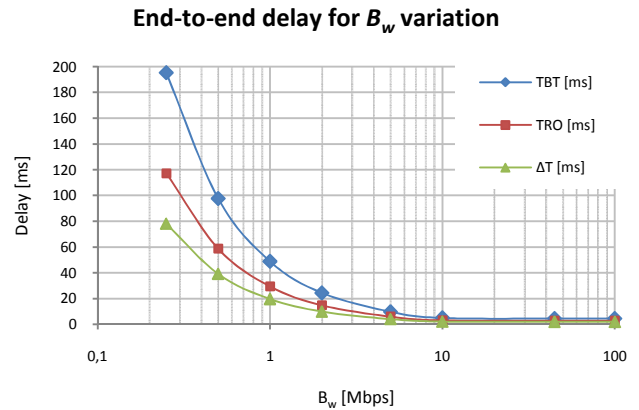


Fig. 4: The end-to-end delay dependency on B_w

The graph in Fig. 4 shows that route optimization gives us more benefits when used on slower links than on the faster ones. For example for a 256 kbps link the end-to-end delay is not suitable for VoIP anymore whereas we can still use with the route optimization. Here, the route optimization saves us almost 80 ms in delay, which is a lot. For bandwidth higher than 10 Mbps the difference is less than 2 ms. However, note that these are results for number 2 hops between MN – HA, HA – CN and MN – CN. In real networks, the number of hops is usually higher.

The final point of interest in this paper is the dependency of end-to-end delay on number of hops between MN (actually its AR) and CN. Fig. 5 shows the delay difference in dependence on the ratio of number of hops. The ratio r is computed as:

$$r = \frac{l}{m + n} \tag{16}$$

The rest of the parameters in the graph is constant – $B_{w1} = 11 Mbps$, $B_w = 2 Mbps$ and $MTU = 1280 B$.

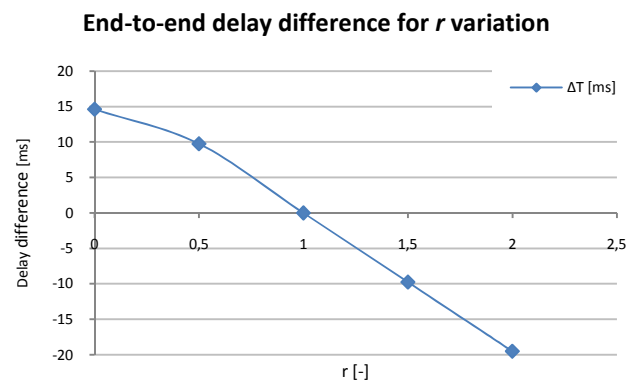


Fig. 5: The end-to-end delay dependency on ratio r

The graph in Fig. 5 shows that route optimization brings the desired results only if the ratio of number of hops is smaller than 1, that is when number of hops between MN and CN is smaller than number of hops among MN – HA – CN. It is quite obvious that number of hops on the optimized route should be smaller than on the non-optimized route, but it does not have to hold in all cases. An interesting result we get when the MN is situated in the same subnet as the CN. If we assume, that both nodes are wireless, the data in route optimization mode travel just to the serving access point (access router) so the delay is caused just by two passes through the wireless link (in this case $r = 0$ because number of hops between AR and CN is zero).

Furthermore, a similar result we can get when $r < 1$, but the bandwidth on the link of the optimized route is significantly smaller than the bandwidth on the non-optimized route. This can be noticed in Fig. 6.

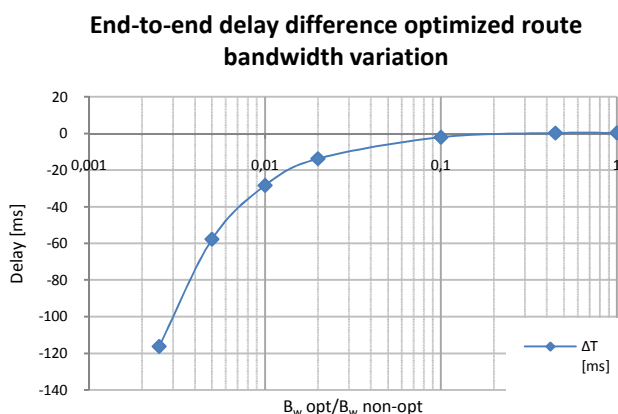


Fig. 6: The end-to-end delay dependency on optimized route bandwidth variation

Fig. 6 shows delay difference ΔT dependency on the ratio of bandwidth of the optimized route ($B_w \text{ opt}$) to bandwidth of the non-optimized route ($B_w \text{ non-opt}$) in the basic topology depicted in Fig. 2. For this calculation we assumed the $B_w \text{ non-opt}$ to be 100 Mbps and the $B_w \text{ opt}$ varied from 256 kbps to 100 Mbps. As we can see, for the ratio smaller than 1 the delay difference is in negative values, which means that the route optimization causes greater delay than bidirectional tunneling. This shows us that using route optimization is not always as convenient as it is supposed to be.

4 Conclusion

In this paper, we present an analytical method for performance evaluation of route optimization in Mobile IPv6 protocol. The route optimization has a great importance especially for real-time applications such as VoIP or videoconferencing since it significantly reduces

the end-to-end delay compared to bidirectional tunneling. The proposed analytical method allows evaluating the performance based on different criteria like number of hops or link bandwidth. In the paper we presented case studies for MTU variation, wired link bandwidth variation, number of hops ratio variation and optimized route bandwidth variation. The results of the analysis show in which cases using route optimization is convenient and in which it is not. It has been shown that in some cases using the route optimization degrades the communication more than bidirectional tunneling. Furthermore, the proposed method can be used also for evaluation of other methods and mechanisms in Mobile IPv6 like for example handover performance evaluation.

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