Proxy Mobile IPv6 における経路最適化のためのパス切替効率化手法の提案

野一色裕人[†]　北辻佳憲[†]　横田英俊[†]

Proxy Mobile IPv6 (PMIPv6) では，Local Mobility Anchor (LMA)，ならびに，Mobile Access Gateway (MAG)と呼ばれるエンティティにより，モバイルノードがモビリティのためのシグナリングに関わることなく，モバイルノードへの IP モビリティを提供する．PMIPv6 ドメインでは，モバイルノード間の通信トラヒックは必ず LMA を経由してしまうが，経路最適化処理により LMA を迂回し，MAG のみを通る経路とすることができる．しかし，LMA 経由の非最適な経路から，最適化経路へと切り替える際，それらの経路の伝送遅延差により，パケットの順序逆転や通信中断の発生などの通信性能劣化を起こす可能性がある．本論文では，このような PMIPv6 での経路最適化において，適切なタイミングでのパス切り替えを実現する手法を提案する，本手法では，経路最適化処理において，最適化経路が構築された後，シグナリングメッセージにより，MAG において適切なタイミングで経路の切り替えを実行し，その結果，通信中断を最小化しながらパケットの順序逆転防止を実現する．実機によるテストベッドでの性能評価により，提案手法がシームレスなパス切り替えを実現することを示す．

Right-time Path Switching Method for Proxy Mobile IPv6 Route Optimization

Yujin Noishiki[†], Yoshinori Kitatsuji[†], Hidetoshi Yokota[†]

Proxy Mobile IPv6 provides IP mobility to a mobile node by the proxy mobility agent called a Local Mobility Anchor and a Mobile Access Gateway without requiring mobile node’s participation in any mobility-related signaling. Increased demand for content-rich mobile data communications is prompting mobile network operators to deploy efficient mobility management including Proxy Mobile IPv6. The route optimization technique is applied to the data path between mobile nodes in the same Proxy Mobile IPv6 domain by bypassing the Local Mobility Anchor(s). However, when switching the data path from the default (non-optimized) route to an optimized one, the delay gap between these paths leads to performance degradation due to out-of-sequence packets, or unnecessary communication disruption. We propose a right-time path switching method for Proxy Mobile IPv6 route optimization. This method enables the Mobile Access Gateway to switch these paths with the accurate timing provided by the designated signaling messages, which prevents out-of-sequence packets as well as minimizing communication disruption during the route optimization procedure. The proposed method is evaluated in an actual testbed to show that the proposed method achieves the seamless path switch.

[†](株)KDDI 研究所
KDDI R&D Laboratories, Inc.

1. Introduction

Mobility management is an important function for mobile communication. The Internet Engineering Task Force (IETF) has standardized Mobile IP [1][2] to provide mobile nodes (MNs) with IP mobility. However, Mobile IP is a client-based mobility management scheme that requires MNs to implement protocol stacks and exchange mobility-related signaling. Therefore, the IETF has standardized Proxy Mobile IPv6 (PMIPv6) [3] as a network-based mobility management protocol. PMIPv6 brings the IP mobility to the MN without requiring its participation in any mobility-related signaling.

PMIPv6 operations are performed by two network entities, Local Mobility Anchors (LMAs) and Mobile Access Gateways (MAGs). An LMA is a home agent for the MNs and a topological anchor point for the home network prefix of MNs. An MAG is an access router that exchanges the mobility-related signaling with an LMA instead of an MN attached to the MAG via the wireless accesses.

In PMIPv6, all data traffic originating from or destined for the MNs is transferred through an LMA even if the MNs communicate with each other. Such a redundant routing increases transfer delay, which leads to performance degradation of MN’s communications. In addition, data traffic transferred via the redundant route concentrates traffic on LMAs. To overcome this situation, route optimization for PMIPv6 is an attractive solution for minimizing delay and realizing traffic offload.

The route optimization for PMIPv6 is realized by using the direct tunnel established between the MAGs, to which mobile nodes are attached, with bypassing the LMA [4]. However, when switching the data path from the redundant (non-optimized) one to the direct tunnel (the optimized path), the delay gap between these paths causes performance degradation of MN’s communication. If the data path is switched before finishing receipt of data packets via the non-optimized path, out-of-sequence packets occur, which decreases TCP performance of MN’s communication. On the other hand, if the data path is switched too late, MNs experience communication disruption. This unnecessary disruption degrades the service (e.g., voice and video) quality of real-time applications.

In this paper, we propose a right-time path switching method for PMIPv6 route optimization. After the optimized path is ready, our proposed method initiates the path switch using signaling messages. This feature prevents out-of-sequence packets as well as minimizing communication disruption duration in the route optimization procedure.

The proposed procedure is evaluated in an experimental testbed using actual PCs. The results reveal that our proposed method prevents out-of-sequence packets while the baseline route optimization procedure causes them. In addition, performance evaluation shows our proposed method decreases communication disruption duration in the route optimization procedure.

This paper is organized as follows. Section 2 shows related work. Section 3 proposes a right-time path switching method for PMIPv6 route optimization. Section 4 evaluates the performance of the proposed method using the experimental testbed. Section 5 concludes this paper.

2. Related Work

Mobile IPv6 (MIPv6) [2] supports a route optimization scheme, which allows an MN to register its binding information with a corresponding node (CN). The CN directly sends or receives data packets using the MN's care-of address after route optimization. Similarly to the route optimization for PMIPv6, when MN and CN switch the data path from the non-optimized path to the optimized path, out-of-sequence packets are caused. However, unlike PMIPv6, the route optimization procedure for MIPv6 is performed by MN and CN themselves, thus they are involved in preventing out-of-sequence packets. On the other hand, in PMIPv6, MNs cannot handle out-of-sequence packets because they do not detect the timing of the path switch to the optimized path.

Lee, et al. [5] have proposed a route optimization scheme for PMIPv6 to prevent out-of-sequence packets. In the proposed scheme, an MAG buffers data packets originating from MN until the optimized path has been created. However, this scheme may increase communication disruption duration because the buffering MAGs cannot know the end of data forwarding through the non-optimized path. Our paper proposes a route optimization procedure that avoids out-of-sequence packets while minimizing the communication disruption duration.

In order to indicate the end of data forwarding at path switching, an end-marker approach is applied in the 3GPP standard [6]. During handover procedures, this end-marker is transferred to indicate the end of the data stream in a forwarding tunnel. The indication is included in GPRS Tunneling Protocol User Plane (GTP-U) [7], which is the transport protocol for user data packets. While this indication is deployed only for GTP-U and requires packet inspection on the user plane, our approach using PMIPv6 signaling messages is separate from user plane transport protocol.

3. Proposal of Right Time Path Switching Method

In this section, we introduce the basic PMIPv6 operation and the required functions for PMIPv6 route optimization. Then, the right-time path switch method for PMIPv6 route optimization is proposed.

3.1 PMIPv6 Operation

The PMIPv6 domain is shown in Fig. 1. In the PMIPv6 domain where mobility management is performed using PMIPv6, LMAs and MAGs are located.

Basic PMIPv6 operation is as follows. When an MAG detects the attachment of an MN, it sends a proxy binding update (PBU) message. When an LMA receives the PBU message, it registers the MN in a binding cache entry (BCE), and replies to the MAG by sending a proxy binding acknowledge (PBA) message. The PBA message includes the Home Network Prefix (HNP) of the MN. Then, the MAG notifies the HNP of the MN. After exchanging PBU and PBA messages, MAG and LMA hold the binding cache entries of MNs including the HNPs.

Once the MN is registered in the PMIPv6 domain, all data packets of the MN are transferred through the MAG and the LMA. This characteristic causes a redundant routing when MNs communicate with each other. For example, when MN1 is registered in LMA1 via MAG1 and MN2 is registered in LMA2 via MAG2, data packets from MN1 to MN2 are forwarded via MAG1, LMA1, LMA2, and MAG2. This redundant routing leads to transfer delay in communication of MNs, such as performance of real-time applications.

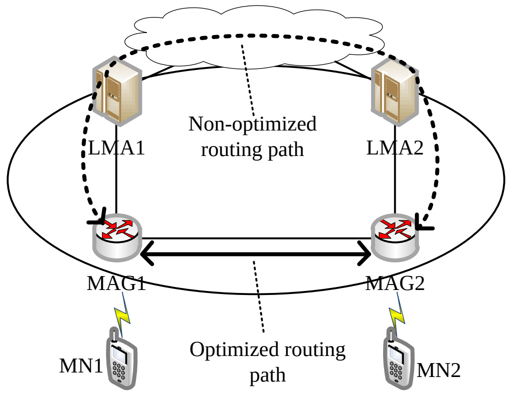

Fig. 1 PMIPv6 domain with non-optimized and optimized routing paths

3.2 Required Functions for Route Optimization

To overcome the redundant routing in PMIPv6, route optimization is a promising approach. Route optimization transfers data packets between two MNs attached to the same PMIPv6 domain, through an optimized routing path between MAGs bypassing the LMAs as shown in Fig. 1.

The functions required to realize route optimization are as follows.

- Detection of the target communication for route optimization: to trigger the route optimization procedures, data packets exchanged between MNs in the PMIPv6 domain must be detected. When MNs are attached to different MAGs and registered at different LMAs, this packet detection is complicated because the binding cache entries of each MN are distributed in LMAs and MAGs.
- Discovery of network entities (LMA and MAG) relating to the target MNs: to exchange signaling messages, the LMAs that register the MNs' BCEs and the MAGs that attach the MNs must be discovered. When MNs are registered at different LMAs, discovery of the LMA from another LMA is difficult since each LMA does not know the MNs in the other LMAs.
- Establishment of the optimized routing path: the optimized routing path is established between MAGs that attach MNs.

3.3 Baseline Route Optimization Procedure

We first explain the baseline route optimization procedure, which meets all requirements mentioned in the previous subsection.

In the case where either or both proxy mobility agent(s) (MAG/LMA) is/are shared by the MNs, the requirements of detection of the target communication and discovery of the involved mobility agents are fulfilled in a straightforward way because the shared mobility agent manages the binding caches of both MNs. However, since each MN is registered with separate MAG and LMA, none of these agents satisfy the requirements because the binding cache entries of MNs are distributed over different LMAs and MAGs. In order to cover this most generalized case, we discuss the situation where MN1 is attached to MAG1 and registered at LMA1, and MN2 is attached to MAG2 and registered at LMA2 in the PMIPv6 domain shown in Fig. 1.

To fulfill the requirements for the route optimization in the above situation, the Policy Store (PS) defined in [8] is leveraged. As shown in Fig. 2, the PS is deployed in the same PMIPv6 domain and stores binding caches of MNs including the HNPs and the IP addresses of LMAs. LMAs register the binding cache with the PS when their BCEs are updated, for example, at the time of the reception of PBU by the LMA. Each LMA obtains the information of MNs registered at other LMAs by referring to this PS. In the 3GPP standard, the AAA server plays a role of the PS in the PMIPv6-based mobile core networks [9], where the LMA registers binding caches with the AAA server when the binding caches are updated.

The baseline route optimization procedure is shown in Steps 1 to 9 of Fig. 3 except Steps E1a-d and E2a-d enclosed in boxes. In this procedure, we show that the data packets of the target of route optimization are transferred from MN1 to MN2. To detect the target data packets, LMAs monitor the source IP addresses. In this procedure, LMA2 checks the data packets in Step 1a. If the source IP address is not registered at LMA2, LMA2 refers to the source IP address from the PS in Step 1b. When the source IP address is found, LMA2 begins the route optimization. In this step, LMA2 recognizes LMA1, which has the BCE of the source IP address (MN1) from the PS. To prevent a route optimization triggered by the data packets in the other direction (from MN2 to MN1), LMA notifies the beginning of route optimization for pairs of MNs to the PS. After this notification, the PS does not allow other LMAs to begin the route optimization for the same pair of MNs.

To meet the requirement of establishment of the optimized path, Steps 2 to 9 are performed. While PMIPv6 has no interface between LMAs in the IETF standardization, this paper introduces a new signaling interface between LMAs as shown in Fig. 2 to handle the situation where MNs are registered at different LMAs.

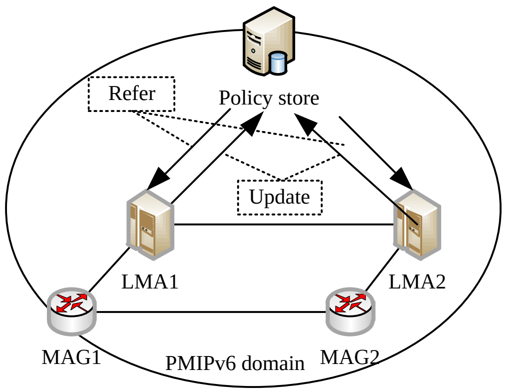

Fig. 2 Proposed architecture with a policy store.

In Steps 2 and 3, LMA2 sends a Route Optimize (RO) Trigger message to LMA1, and then LMA1 sends an RO Initiate message to MAG1, respectively. The RO Trigger and RO Initiate messages include the HNPs of MN1 and MN2, and the IP address of MAG2. In Step 4, MAG1 offers MAG2 establishment of the direct tunnel by sending an RO Request message including the HNPs of MNs. When receiving this message, MAG2 creates the forwarding tunnel to MAG1 and replies with an RO Request Acknowledge message to MAG2 in Step 5. This message requests MAG1 to establish the direct tunnel from MAG1 to MAG2. After the direct tunnel is ready, MAG1 responds an RO Request Complete message to MAG2 and an RO Initiate Acknowledge message to LMA1 in Steps 6 and 7, respectively. LMA1 responds an RO Trigger Acknowledge message to LMA2 in Step 8. Finally, LMA2 updates the binding caches of MN1 and MN2 by notifying the end of the procedure to the PS in Step 9.

Steps E1a-d and E2a-d enclosed in boxes in Fig. 3 are described in the next subsection.

3.4 Right-time Path Switching Method

When the optimized path is established, the path switch from the non-optimized path to the optimized path should be performed in an appropriate timing. In this subsection, we propose the optimized path switching method for route optimization in PMIPv6.

In [5], to prevent out-of-sequence packets at the path switch, MAGs buffer the packets originating from MNs until the optimized routing tunnel is established. In this method, the sender for data packets from MN1 to MN2 on the optimized path, e.g., MAG1, buffers the data packets and decides to begin data forwarding through the optimized path. Therefore, we call this method the sender-buffering method. If this sender-buffering method is employed for the procedure shown in Fig. 3, after Step 3, MAG1 begins to buffer the packets from MN1, and then releases the buffered packets just after Step 5. Similarly, MAG2 begins to buffer the packets from MN2 after Step 4, and then releases the packets in Step 6.

However, this sender-buffering method may cause one of two drawbacks: out-of-sequence packets and relatively large communication disruption, because the sender of the optimized tunnel cannot detect when the buffered packets should be released by itself (the sender cannot know when the receiver at the tunnel receives the last data packets transferred via non-optimized tunnel). Therefore, if the data packets buffered are released too early, out-of-sequence packets will be caused at the receiver at the tunnel. On the other hand, if the buffered data packets are released too late, disruption duration for data packets occurs from the last packets through the non-optimized path to the first packets through the optimized path. Such communication disruption duration degrades MN’s communication.

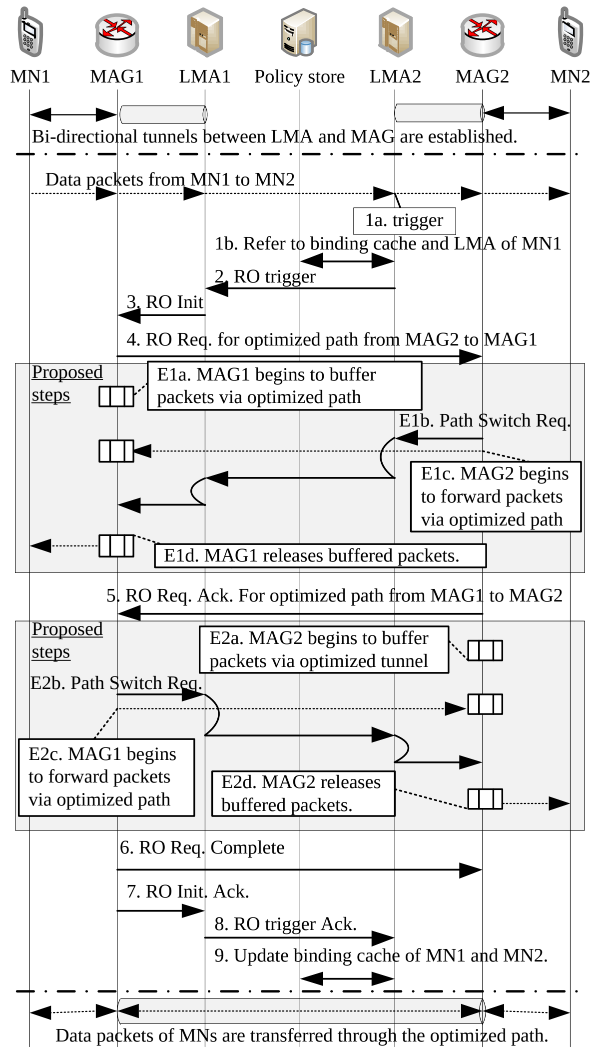

Fig. 3 Route optimization procedure with optimized path switching. Signaling messages are indicated by a solid line while data packets are indicated by a dotted line. The procedure regarding the optimized path switching is enclosed by boxes.

To switch the data path from a non-optimized path to an optimized path with accurate timing, we propose a new method shown in Steps E1a-d and E2a-d in Fig. 3. In this method, after the optimized path is established, the receiver at the tunnel buffers the data packets through the optimized path as opposed to the sender-buffering method. Then, the sender at the tunnel notifies the end of data forwarding through the non-optimized path by sending signaling messages after the sender forwards the last packets through the non-optimized path. This signaling message is transferred via the non-optimized path. The receiver that buffers the data packets recognizes the receipt of the last packets transferred through the non-optimized path, preventing out-of-sequence packets and communication disruption.

The proposed method is implemented as follows: After MAG1 sends MAG2 the RO Request message in Step 4, MAG1 begins to buffer the packets that arrive through the optimized tunnel in Step E1a. When it receives the RO request message in Step 4, MAG2 sends a Path Switch Request message to MAG1 via LMA2 and LMA1 in Step E1b. This message includes the HNPs of MN1 and MN2, and the IP addresses of LMA1 and LMA2. Just after sending the message, MAG2 begins to forward data packets from MN2 to MN1 through the optimized routing tunnel in Step E1c. While MAG1 receives the data packets from LMAs (through the non-optimized path), MAG1 buffers all the data packets forwarded through the optimized tunnel. Thus these data packets are not forwarded to MN1. In Step E1d, when MAG1 receives the Path Switch Request message, MAG1 begins to release the buffered data packets, which are transferred through the optimized tunnel. Finally, MN1 receives all the data packets in the correct order.

Similarly to Steps E1a-d, the proposed approach in Steps E2a-d is performed in the opposite direction. Thus, the proposed path switch method is applied in both directions.

4. Performance Evaluation

4.1 Evaluation Environment

To investigate the effect of the path switching method for the route optimization procedure on the quality of service, we focus on two metrics, the total number of out-of-sequence packets in both directions and the duration of the communication disruption. These values are measured during the path switch from the non-optimized path to the optimized one. In this paper, we define the duration of the communication disruption as the time at the MN from the receipt of the last packet through the non-optimized path to the arrival of the first packet through the optimized path. All results were obtained 10 times and the average is presented.

To evaluate the number of out-of-sequence packets, the proposed procedure with the optimized timing of path switch is compared with the baseline route optimization procedure. In addition, to investigate the performance with respect to the communication disruption duration during the route optimization procedure, the sender-buffering method as described in Section III is implemented for comparison.

The performance of the proposed procedure is evaluated in an experimental testbed where actual PCs implement the proposed functions of network entities. Table 1 shows the hardware specifications of the network entities. The network topology of the experimental testbed is shown in Fig. 4. An MN is attached to an MAG via an IEEE 802.11g access point. LMAs and MAGs are connected to each other via gigabit Ethernet link. The expected one-way link delay between the network entities illustrated in Fig. 4 is added by a network emulator Dummynet [10]. UDP packets are transferred from MN1 to MN2 and vice versa by using an Iperf traffic generator [11]. The data rate in each direction is 500 Kbps and the packet size is 1250 bytes, that is, 50 packets per second.

Let G denote the delay gap of one-way delays between the optimized path and the non-optimized path in Fig. 4, that is, $G = d_2 + d_3 + d_4 - d_1$. This delay gap G affects the number of out-of-sequence packets because a large delay gap will cause out-of-sequence packets at path switching. Moreover, d_1, which is the link delay from MAG1 to MAG2, is a key parameter when focusing on the duration of the communication disruption. This is because the waiting time for path creation in the sender-buffering method depends on this link delay. Therefore, this paper evaluates the performance by varying the two key parameters, delay gap G and link delay d_1. Table 2 shows the parameter sets used in this paper.

Table 1 Hardware specification of network entities

	MN	LMA, MAG, and policy store
Model	Panasonic CF-R9JWACDR	Dell PowerEdge R300
CPU	Intel Core 7 820UM 1.06 GHz	Intel Xeon L5410 2.3 GHz
OS	Fedor core 10	Cent OS 5.3
Network interface	IEEE 802.11g	Gigabit NIC

Table 2 One-way delay used in this paper

Notation	Description	Values
d_1	Link delay between MAG1 and MAG2	10~50 msec
d_2	Link delay between MAG1 and LMA1	10~50 msec
d_3	Link delay between LMA1 and LMA2	10~50 msec
d_4	Link delay between MAG2 and LMA2	10~50 msec
G	Delay gap (= $d_2 + d_3 + d_4 - d_1$)	20~100 msec

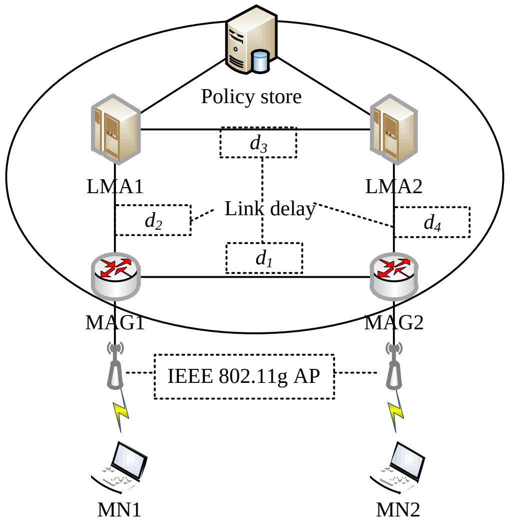

Fig. 4 Network topology of experimental testbed.

4.2 Evaluation of Path Switching Methods

Fig. 5 plots the total number of out-of-sequence packets versus the delay gap between the non-optimized path and the optimized path, where the link delay between MAG1 and MAG2, d_1, is fixed at 10 msec. As the delay gap increases, the number of out-of-sequence packets also increases in the baseline method and the sender-buffering method. When comparing the baseline method with the sender-buffering method, the sender-buffering method decreases the number of out-of-sequence packets. This is because the sender-buffering method prevents out-of-sequence packets by buffering the data packets originating from MNs until the optimized path is ready. However, the sender-buffering method does not eliminate out-of-sequence packets when the delay gap is large. On the other hand, the proposed path switching method does not have out-of-sequence packets at any values of delay gap.

The total number of out-of-sequence packets is also shown in Fig. 6 and Fig. 7 where d_1 is 30 msec and 50 msec, respectively. In both results, the baseline method increases the number of out-of-sequence packets when the delay gap increases. The sender-buffering method prevents out-of-sequence packets, while several out-of-sequence packets occur by the large delay gap at d_1 = 50 msec (Fig. 6). When d_1 is 50 msec (Fig. 7), the sender-buffering method eliminates the out-of-sequence packets. From these results shown in Figs. 5 to 7, the sender-buffering method improves the performance when the link delay between MAGs is large. Similarly to the results in Fig. 5, the proposed method does not have any out-of-sequence packets. This means that the proposed method achieves route optimization while avoiding out-of-sequence packets by optimized path switch.

5. Conclusion

This paper proposed a route optimization procedure in PMIPv6 with the optimized timing of path switch. The proposed procedure notifies the end of data forwarding through the non-optimized path accurately after the optimized path is established. The performance results showed that the proposed method prevented out-of-sequence packets and minimized the communication disruption time for the various values of delay parameters between network entities. With this feature, the proposed method contributes to performance improvement in TCP throughput or seamless continuity of real-time applications during the route optimization procedure.

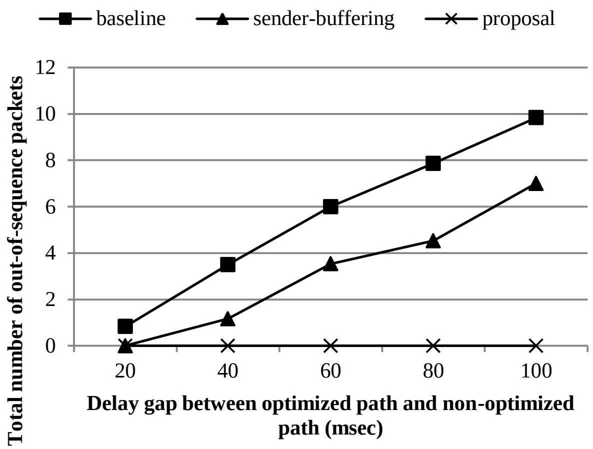

Fig. 5 Number of out-of-sequence packets vs. delay gap between optimized path and non-optimized path (d_1 = 10 msec).

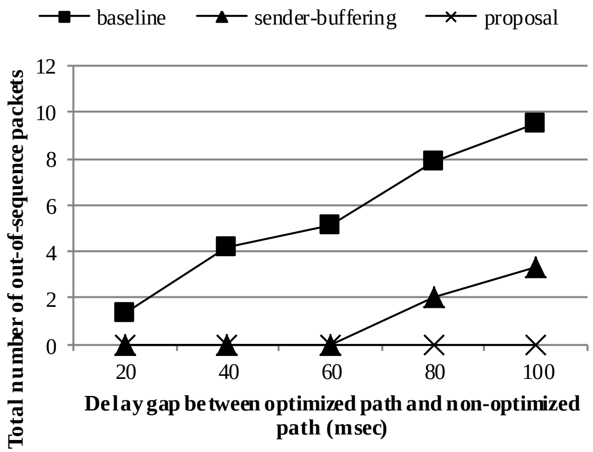

Fig. 6 Number of out-of-sequence packets vs. delay gap between optimized path and non-optimized path (d_1 = 30 msec).

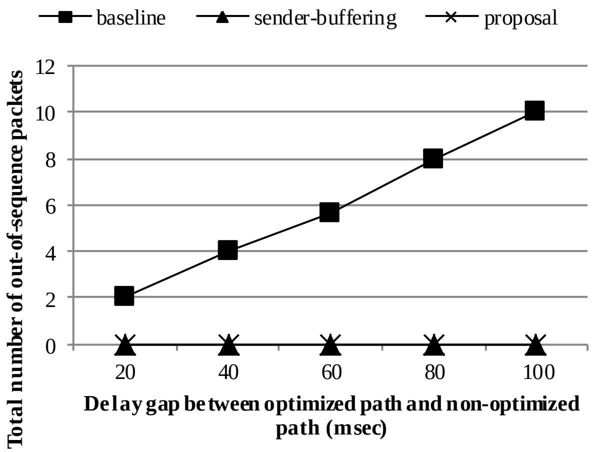

Fig. 7 Number of out-of-sequence packets vs. delay gap between optimized path and non-optimized path (d_1 = 50 msec).

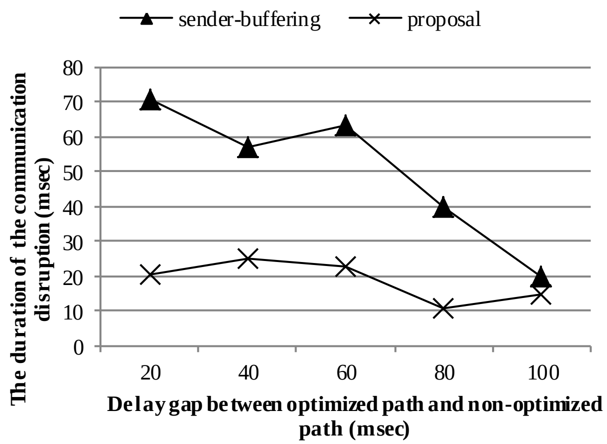

Fig. 8 Duration of communication disruption during route optimization (d_1 = 50 msec).

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