A New Scheme for Reducing Link and Signaling Costs in Mobile IP

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Abstract—IP mobility support is provided by the basic Mobile IP protocol. The main drawback of the protocol is that the packets must be routed along the paths longer than the optimal one. This is known as the triangle routing problem. Recently, the route optimization protocol was proposed to solve the triangle routing problem, which allows packets to be routed along an optimal path from a correspondent node to a mobile node. However, the route optimization protocol may cause high signaling and processing costs. In this paper, a new scheme for reducing costs in route optimization is introduced to solve the above problems. Link and signaling cost functions are introduced to capture the trade off between the network resources consumed by the routing, signaling, and processing load incurred by the route optimization. In this new scheme, route optimization is performed only when it minimizes the total cost function, which provides the optimal result from the point of view of link and signaling costs. The simulation results show that the proposed scheme provides the best performance.

Index Terms—Mobile IP, triangle routing, route optimization.

1 Introduction

IP mobility support is becoming very important as the Internet is growing fast, and the wireless communication technology is advancing. The basic Mobile IP protocol [1] was proposed to provide IP mobility support. It introduces three new functional entities: mobile node (MN), home agent (HA), and foreign agent (FA).

Although the basic Mobile IP protocol proposes a simple and elegant mechanism to provide IP mobility support, there is a major drawback, where each packet destined to the MN must be routed through the HA along an indirect path. This is known as the *triangle routing problem*.

The so-called *Route Optimization Protocol* (IETF RO) [2] was proposed by the IETF to solve the triangle routing problem. When packets are sent from a correspondent node (CN) to an MN, if the CN has a binding cache entry for the MN, they can be directly tunneled without the help of the HA to the care-of-address (COA) indicated in the binding cache. In this scheme, route optimization is achieved by sending binding update messages from the HA to the CN. In Mobile IPv6 [3], binding update messages are sent from the MN to the CN. Moreover, the FA smooth handoff scheme [2] allows packets in flight or sent based on the out-of-date binding cache to be forwarded directly to the MN's new COA.

The major drawback of the IETF RO [2] is that there are additional control messages such as binding warning and binding update, which cause communication overhead and introduce high signaling and processing load on the network and on certain nodes. Some mechanisms such as local anchoring scheme [8], regional registration [4], and hierarchical management scheme [5] have been proposed to reduce signaling costs and communication overhead recently.

Our work is motivated by the question: "Does route optimization need to be performed whenever an MN hands off, and a previous FA receives packets destined to the MN? What if we perform route optimization only when certain conditions are satisfied by doing that?" If the route optimization is not performed as often as it is in the IETF RO [2], signaling and processing load will be reduced. This question naturally leads to two issues:

1. how to guarantee that the packets destined to the MN are routed temporarily along a suboptimal path without performing route optimization, and
2. when to perform route optimization.

For the first issue, the FA smooth handoff scheme [2] gives an answer. By keeping the previous FAs serving as forwarding pointers until route optimization is performed, we can guarantee that IP datagrams are routed along a suboptimal path. We name this mechanism a *route extension* because it simply extends the routing path from the previous FAs to the current FA. For example, in Fig. 1, FA1 forwards packets to FA2, FA2 forwards them to FA3, and, finally, the packets are delivered to the MN through the FA3.

In this paper, we focus on the second issue. Although the route optimization increases the network utilization by allowing packets to be routed along an optimal path from the CN to the MN, it will also increase the signaling load of the network and the processing load of certain nodes. We know from this fact that there is a trade off between the network resources consumed by the routing path and the signaling and processing load incurred by the route optimization. The decision of when to perform route optimization needs to be considered based on the following:

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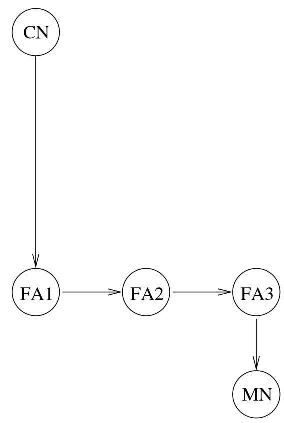

Fig. 1. Route extension.

1. the network resources consumed by the routing path,
2. the signaling and the processing load, and
3. the Quality-of-Service (QoS) requirements.

In IETF RO [2], when an FA receives a tunneled packet and, if it has the binding cache entry for the MN and does not have the visitor list entry for this MN at that point, the previous FA then sends a binding warning message to the MN's HA advising it to send a binding update message to the CN.

Regarding this FA-initiated route optimization, we propose that the previous FA should not send the binding warning message to the HA. In our scheme, we propose that route optimization should be initiated by the current FA.

We develop a mathematical model to determine when to perform route optimization. Link cost and signaling cost functions are introduced to capture the trade off. Our objective is to find a cost efficient scheme for route optimization, which minimizes the total cost function defined as the sum of the link and signaling cost functions. The simulation results show that the proposed scheme significantly reduces the signaling costs caused by IETF RO and provides the lowest total costs.

The rest of this paper is organized as follows: In Section 2, the mathematical model is described, and the decision model is provided. In Section 3, the performance evaluation is presented. Finally, we conclude the paper in Section 4.

2 The New Cost Efficient Scheme

2.1 The Mathematical Model

The decision must be made in the time interval $[t_i, t_{i+1})$ between the current handoff at t_i and the next handoff at t_{i+1} whether to perform route optimization or not.

As stated before, there is a trade off between the network resources utilized by the routing path and the signaling and processing load incurred by route optimization. We introduce two cost functions to capture the trade off: the link and signaling cost functions. The link cost function is denoted by $g(x_i(\alpha_i))$, where $x_i(\alpha_i)$ is the number of links in the routing path between the CN and the FA during the ith period and $\alpha_i \in \{RO, NRO\}$, where RO is the action which performs route optimization and NRO is the action without route optimization. The signaling cost function is denoted by $h(y_i, \alpha_i)$, where y_i is the number of links in the shortest path between the current FA and the previous FA during the ith period.

The total cost function is then defined as the sum of these two cost functions:

$$f(x_i(\alpha_i), y_i, \alpha_i) = g(x_i(\alpha_i)) + h(y_i, \alpha_i). \tag{1}$$

Let $\pi(i)$ denote a sequence of actions, $(\alpha_1, \alpha_2, \ldots, \alpha_i)$, which are taken sequentially during the occurrence of i handoffs. We call this sequence, $\pi(i)$, a *Route Optimization Sequence*. Let $G_i^{\pi(i)}$ denote the accumulative link cost, $H_i^{\pi(i)}$ the accumulative signaling cost, and $F_i^{\pi(i)}$ the total accumulative cost under the route optimization sequence $\pi(i)$, respectively. Then,

$$G_i^{\pi(i)} = \sum_{j=1}^{i} g(x_j(\alpha_j)). \tag{2}$$

$$H_i^{\pi(i)} = \sum_{j=1}^{i} h(y_j, \alpha_j). \tag{3}$$

$$\begin{aligned} F_i^{\pi(i)} &= \sum_{j=1}^{i} f(x_j(\alpha_j), y_j, \alpha_j) \\ &= \sum_{j=1}^{i} \{g(x_j(\alpha_j)) + h(y_j, \alpha_j)\}, \end{aligned} \tag{4}$$

where $\pi(i) = (\alpha_1, \ldots, \alpha_i)$. Here, $x_j(\alpha_j)$ and y_j are network parameters.

When a route optimization is performed under the sequence $\pi(i)$ during the ith period, a signaling cost, $h(y_i, \alpha_i)$, is incurred. In this case, the signaling cost, $h(y_i, \alpha_i)$, can be decomposed as follows:

$$h(y_i, \alpha_i) = v(y_i) + k_i(\alpha_i), \tag{5}$$

where $v(y_i)$ is a variable signaling cost function, which is independent of α_i, and $k_i(\alpha_i)$ is a portion of signaling cost, which depends on α_i, i.e.,

$$k_i(\alpha_i) = \begin{cases} w(x_i') & \text{if } \alpha_i = RO \\ 0 & \text{if } \alpha_i = NRO, \end{cases} \tag{6}$$

where $w(x_i')$ is a signaling cost function that depends on x_i'.

In (5), the two terms reflect the cost of sending a binding update message from the current FA to the previous FA, sending a binding warning message from the current FA to the HA, and sending a binding update message from the HA to the CN. Here, we assume every cost function to be linear. Then, the link cost function, $g(x_i(\alpha_i))$, during the ith period becomes

$$g(x_i(\alpha_i)) = A \cdot T_i \cdot x_i(\alpha_i), \tag{7}$$

where A represents the average link cost per link which captures the bandwidth consumed by the routing path of length $x_i(\alpha_i)$, and T_i represents the sojourn time of the MN from the ith handoff to the next handoff.

The variable signaling cost function v during the ith period becomes

$$v(y_i) = B \cdot y_i, \tag{8}$$

where B represents the average signaling cost per link in the path of length y_i.

Thus, we obtain (9) from (4), (5), (7), and (8).

$$F_i^{\pi(i)} = \sum_{j=1}^{i} (A \cdot T_j \cdot x_j(\alpha_j) + B \cdot y_j + k_j(\alpha_j)), \tag{9}$$

where $\pi(i) = (\alpha_1, \ldots, \alpha_i)$.

2.2 Optimal Solution

The objective of this section is to find the optimal sequence which we denote as $\pi_{opt}(i)$, which minimizes the expected value of total cost $F_i^{\pi(i)}$ in (9).

$$E[F_i^{\pi_{opt}(i)}] = \min_{\pi(i)\in\Pi} E[F_i^{\pi(i)}] = \min_{\pi(i)\in\Pi} \sum_{j=1}^{i} (A \cdot x_j(\alpha_j) \cdot E[T_j] + B \cdot y_j + k_j(\alpha_j)), \tag{10}$$

where $\pi(i) = (\alpha_1, \ldots, \alpha_i)$, and Π is the set of all possible sequences of $\pi(i)$.

If a route optimization is performed during the ith period, the shortest path between the CN and the current FA will be selected as the routing path. Thus, the length of the routing path will be x'_i in this case where x'_i is the number of links in the shortest path between the CN and the current FA during the ith period. If the route optimization is not performed during the ith period, then an extended path will be the routing path and, the length of the routing path during the period will be $x_{i-1}(\alpha_{i-1}) + z_i$, where

$$z_i = \begin{cases} y_i & \text{if MN visits a new FA} \\ -y'_i & \text{otherwise,} \end{cases} \tag{11}$$

where y'_i is the number of links which will be reduced after the ith handoff. For example, in Fig. 2, y'_{i+1} will be y_i if MN handoffs back to FA1 at time t_{i+1}.

This situation is detailed in Fig. 2, and can be summarized as follows:

$$x_i(\alpha_i) = \begin{cases} x_{i-1}(\alpha_{i-1}) + z_i & \text{if } \alpha_i = NRO \\ x'_i & \text{if } \alpha_i = RO, \end{cases} \tag{12}$$

where $x'_i \le x_{i-1}(\alpha_{i-1}) + z_i$.

In general, the source routing is not being adopted in the Internet. Even though it is being used, network parameters cannot be known completely as networks grow bigger and become more complex [6], [7]. Thus, $x_i(\alpha_i)$ and x'_i are not available in every node. Without knowledge of these parameters, (10) cannot be solved. However, it can be easily solved if we restrict our model within intradomain (intrasubnet) handoff, where $y_i = y_j$ for $i \neq j$ and make a reasonable assumption, i.e., *if handoffs occur in the same domain (subnet), the length of the shortest path between the CN and any FA is the same, i.e., $x'_i = x'_j$ for $i \neq j$*. This assumption is reasonable because the shortest path between the CN and any FA in the same domain will pass through the main router of the domain.

Let *i-stage* denote the decision stage when the decision whether to perform route optimization or not is made during the ith period. In the i-stage, we can think that the routing path has been extended n times without performing route optimization after the last one was performed, where n is an integer. Thus, in the i-stage,

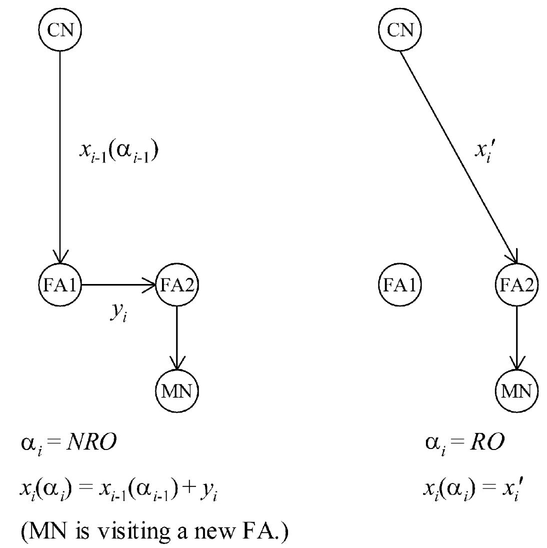

Fig. 2. Route extension and route optimization.

$$x_{i-1}(\alpha_{i-1}) = x'_{i-n-1} + \sum_{j=1}^{n} z_{i-j}. \tag{13}$$

But, $x'_{i-n-1} = x'_i$ by the above assumption. Hence, (13) becomes

$$x_{i-1}(\alpha_{i-1}) = x'_i + \sum_{j=1}^{n} z_{i-j}. \tag{14}$$

Finally, (12) becomes

$$x_i(\alpha_i) = \begin{cases} x'_i + Z_{i,n} & \text{if } \alpha_i = NRO \\ x'_i & \text{if } \alpha_i = RO, \end{cases} \tag{15}$$

where $Z_{i,n} = \sum_{j=0}^{n} z_{i-j}$.

Note that $Z_{i,n}$ is the length of the path between the COA and the current FA which is known within a domain.

Under this assumption, the signaling cost function $w(x_i)$ in (6) can be assumed to be constant. Thus, we can restate (6) as follows:

$$k_i(\alpha_i) = \begin{cases} K & \text{if } \alpha_i = RO \\ 0 & \text{if } \alpha_i = NRO, \end{cases} \tag{16}$$

where K is a constant portion of signaling cost.

We will sequentially minimize the expected value $E[F_i^{\pi(i)}]$ in (10) with fixed $\alpha_1, \alpha_2, \ldots, \alpha_{i-1}$ by solving

$$E[F_i^{\pi_{opt}(i)}] = \min_{\alpha_i \in \pi(i)} \sum_{j=1}^{i} (A \cdot x_j(\alpha_j) \cdot E[T_j] + B \cdot y_j + k_j(\alpha_j)). \tag{17}$$

Fig. 3 describes our decision model. To calculate the total accumulative cost $F_i^{\pi(i)}$ in (4) and make an appropriate decision in the i-stage, all we need to know are the current

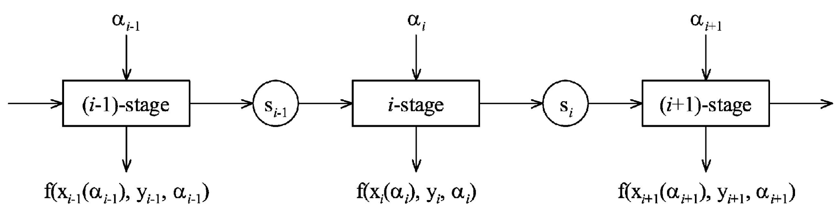

Fig. 3. Decision model.

length $x_{i-1}(\alpha_{i-1})$ of the routing path, the length y_i of the path between two adjacent FAs, and the length x'_i of the shortest path between the CN and the current FA. Let $s_{i-1} = (x_{i-1}(\alpha_{i-1}), x'_i, y_i)$ denote the current state vector in the i-stage. Our decision can be made only based on the current state vector s_{i-1}, and the next state vector s_i will be determined based on s_{i-1} and the action α_i taken in the i-stage. From this fact, we know that our decision model is Markovian, i.e., memoryless.

Our decision in each stage must constitute the optimal sequence $\pi_{opt}(i)$. $f(x_i(NRO), y_i, NRO)$ is the total cost which will be incurred during the ith period when the action NRO is taken, and $f(x_i(RO), y_i, RO)$ is the one which will be incurred during the ith period when the action RO is taken. Then, the expected value of total accumulative cost, $E[F_i^{\pi_{opt}(i)}]$, becomes

$$E[F_i^{\pi_{opt}(i)}] = E[F_{i-1}^{\pi_{opt}(i-1)}] + \min(f(x_i(NRO), y_i, NRO), f(x_i(RO), y_i, RO)). \quad (18)$$

From (18), a decision rule can be found.

Decision Rule:
if $E[f(x_i(NRO), y_i, NRO)] < E[f(x_i(RO), y_i, RO)]$
then
  $\alpha_i = NRO$;
else
  $\alpha_i = RO$;
end if

where

$$E[f(x_i(NRO), y_i, NRO)] = A \cdot E[T_i] \cdot x_i(NRO) + B \cdot y_i + 0 = A \cdot E[T_i] \cdot (x'_i + Z_{i,n}) + B \cdot y_i,$$

and

$$E[f(x_i(RO), y_i, RO)] = A \cdot E[T_i] \cdot x_i(RO) + B \cdot y_i + K = A \cdot E[T_i] \cdot x'_i + B \cdot y_i + K,$$

which can be derived from (15). The condition

$$E[f(x_i(NRO), y_i, NRO)] < E[f(x_i(RO), y_i, RO)]$$

means that $A \cdot E[T_i] \cdot Z_{i,n} < K$, i.e., $Z_{i,n} < \frac{K}{A \cdot E[T_i]}$.

Thus, the optimal sequence, $\pi_{opt}(i)$, can be obtained by following the above decision rule in each decision stage.

3 Performance Evaluation

In this Section, we evaluate the performance of the proposed scheme, $\pi_{opt}(\tilde{N})$, for route optimization and compare it with other schemes, which are explained below:

- Scheme 1: The proposed optimal sequence is $\pi_{opt}(\tilde{N})$.
- Scheme 2: Always perform route optimization.

$$\pi_{ARO}(\tilde{N}) = (\alpha_1, \ldots, \alpha_{\tilde{N}}),$$

  where $\alpha_i = RO$ for $i = 1, \ldots, \tilde{N}$.
- Scheme 3: Never perform route optimization.

$$\pi_{NRO}(\tilde{N}) = (\alpha_1, \ldots, \alpha_{\tilde{N}}),$$

  where $\alpha_i = NRO$ for $i = 1, \ldots, \tilde{N}$.

The sequence $\pi_{ARO}(\tilde{N})$ represents the IETF RO [2], while $\pi_{NRO}(\tilde{N})$ is a heuristic scheme. To obtain numerical results, we assume that $\tilde{N}$ intradomain handoffs occur during a session and that B is equal to A. The performance metrics are the total cost per session $F_{\tilde{N}}^{\pi(\tilde{N})}$ (9), the signaling cost per session $H_{\tilde{N}}^{\pi(\tilde{N})}$ (3), and the number of route optimizations per session. In our simulation model, the number of handoffs within a domain $\tilde{N}$ is assumed to be a uniform random variable whose average value N is assigned during a session, and the sojourn time of an MN within a subnet is assumed to be exponentially distributed.

3.1 The Total Cost

The total cost per session is the sum of link cost and signaling cost per session. We use (9) to compute the total cost per session for sequences $\pi_{opt}(\tilde{N})$, $\pi_{ARO}(\tilde{N})$, and $\pi_{NRO}(\tilde{N})$.

In (9) the first term reflects the network resources utilized by the routing path during a session, while the others explain the signaling load incurred by the route optimization. The sequence $\pi_{opt}(\tilde{N})$ is the one which we can find by following the decision rule of the previous section in each decision stage.

In Fig. 4, we show the total cost versus the average link cost per link A during a session. The sequence $\pi_{opt}(\tilde{N})$ shows the lowest total cost among the given sequences. The numerical result shows that the total cost under the sequence $\pi_{opt}(\tilde{N})$ is 20.0 percent lower than that under the sequence $\pi_{ARO}(\tilde{N})$, on the average. For each sequence, the total cost increases as A does. When the average link cost per link A is low, no difference can be observed between the results of $\pi_{opt}(\tilde{N})$ and $\pi_{NRO}(\tilde{N})$ because there is no advantage of performing route optimization. Under the sequence $\pi_{ARO}(\tilde{N})$, however, route optimization is performed regardless of A causing the additional signaling cost. As A increases the frequency of route optimization becomes higher, and thus, we can see that the results of $\pi_{opt}(\tilde{N})$ and $\pi_{ARO}(\tilde{N})$ converge.

In Fig. 5, we show the total cost versus the average number of intradomain handoffs N during a session. The sequence $\pi_{opt}(\tilde{N})$ shows the lowest total cost among the

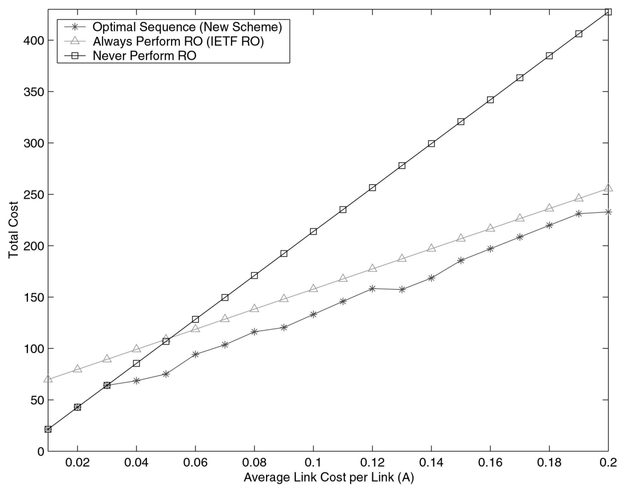

Fig. 4. Total cost versus average link cost per link A ($B = A$, $K = 3$, $N = 20$).

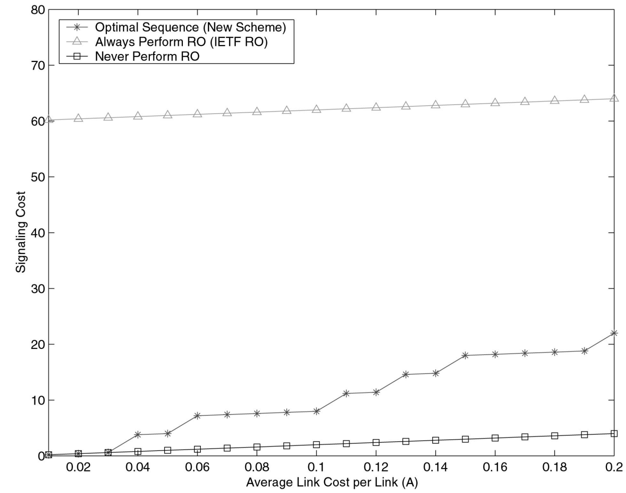

Fig. 6. Signaling cost versus average link cost per link A ($B = A$, $K = 3$, $N = 20$).

given sequences. When the frequency of intradomain handoff is low there is only a slight difference among the results of the given sequences. However the results of the sequences diverge and, thus, the gap between the results of $\pi_{opt}(\tilde{N})$ and $\pi_{ARO}(\tilde{N})$ becomes bigger as the frequency increases.

3.2 The Signaling Cost

The signaling cost per session is incurred by performing route optimizations during the session. We use (3) to compute the signaling cost per session for sequences $\pi_{opt}(\tilde{N})$, $\pi_{ARO}(\tilde{N})$, and $\pi_{NRO}(\tilde{N})$.

Whenever each handoff occurs, the decision must be made whether to perform route optimization or not. If route optimization is determined to be performed after a handoff, it causes the additional signaling cost and (3) captures it.

In Fig. 6, we show the signaling cost versus average link cost per link A during a session. As it can be seen in Fig. 6, the signaling cost of each sequence increases as A does. When A is low, no difference is seen between the results of the sequences $\pi_{opt}(\tilde{N})$ and $\pi_{NRO}(\tilde{N})$ because no route optimization is performed in that period. It is observed that the signaling cost of $\pi_{opt}(\tilde{N})$ is significantly reduced compared with that of $\pi_{ARO}(\tilde{N})$. The numerical result shows that the signaling cost under the sequence $\pi_{opt}(\tilde{N})$ is 83.0 percent lower than that under the sequence $\pi_{ARO}(\tilde{N})$ on the average.

In Fig. 7, we show the signaling cost versus the average number of intradomain handoffs N during a session. In this figure, it can also be observed that the signaling cost of $\pi_{opt}(\tilde{N})$ is significantly reduced compared with that of $\pi_{ARO}(\tilde{N})$.

Under the sequence $\pi_{ARO}(\tilde{N})$, the signaling cost grows linearly as N increases because the more frequently intradomain handoffs occur the more route optimization is performed. Under the sequence $\pi_{opt}(\tilde{N})$, however, the signaling cost grows slightly as A increases because route optimization is not always performed whenever intradomain handoff occurs, which reduces the signaling cost significantly.

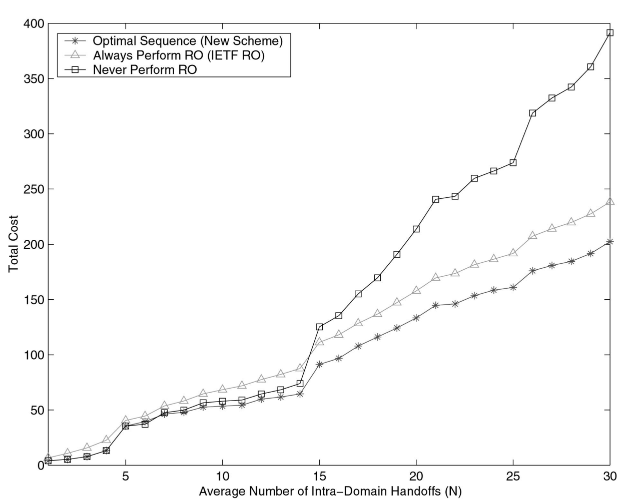

Fig. 5. Total cost versus average number of intradomain handoffs N ($A = B = 0.1$, $K = 3$).

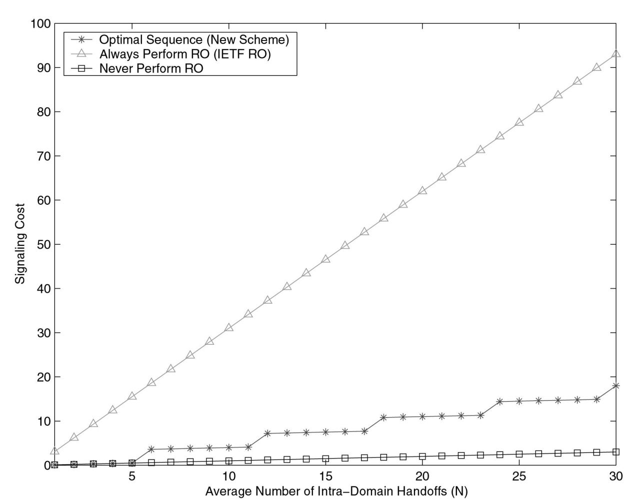

Fig. 7. Signaling cost versus average number of intradomain handoffs N ($A = B = 0.1$, $K = 3$).

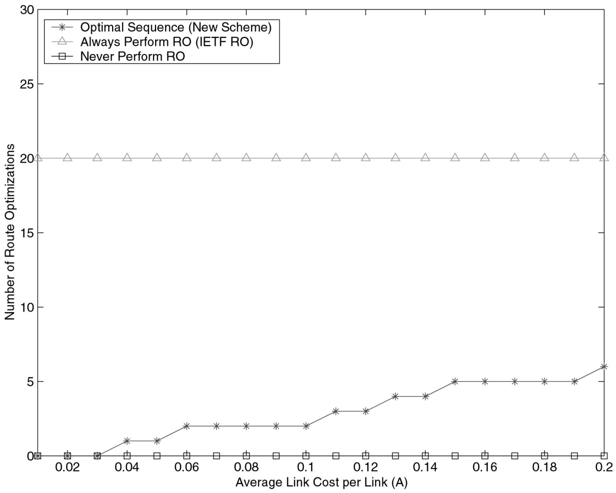

Fig. 8. Number of route optimizations versus average link cost per link A ($B = A,\ K = 3,\ N = 20$).

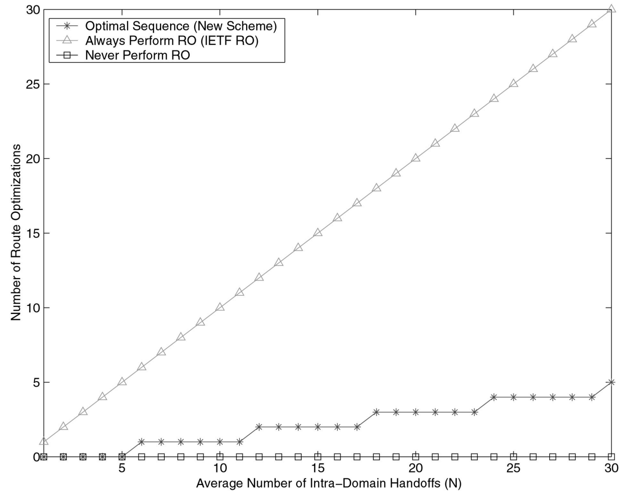

Fig. 9. Number of route optimizations versus average number of intradomain handoffs N ($A = B = 0.1,\ K = 3$).

3.3 The Number of Route Optimizations

In Fig. 8, we show the number of route optimizations versus the average link cost per link A.

As A increases, the number of route optimizations under $\pi_{opt}(\tilde{N})$ grows slowly. When A is low, no route optimization is performed under the sequence $\pi_{opt}(\tilde{N})$ because there is no advantage of performing route optimization. The number of route optimizations increases as A does because it is more profitable to perform route optimization from the point of view of cost.

In Fig. 9, we show the number of route optimizations versus the number of intradomain handoffs during a session. In this figure, it can be observed that the number of route optimizations under the sequence $\pi_{opt}(\tilde{N})$ increases slowly as the frequency of intradomain handoff increases, which results in the reduction of the signaling cost and the total cost.

In our simulation, the sequence $\pi_{opt}(\tilde{N})$ shows the best performance compared with other sequences. The optimal sequence $\pi_{opt}(\tilde{N})$ reduces the signaling cost caused by route optimization and provides the lowest total cost.

4 Conclusion

In this paper, we proposed a cost efficient scheme for route optimization to reduce the signaling cost caused by the route optimization. Link cost function represents the network resources utilized by the routing path, while signaling cost reflects the signaling and processing load incurred by route optimization. We presented a Markovian decision model to find an optimal sequence for route optimization. We restricted the model to intradomain handoff to simplify the decision process. A decision rule is derived from this model. The optimal sequence π_{opt} is obtained by following the decision rule in each decision stage.

The performance of the optimal sequence π_{opt} is compared with the other sequences π_{ARO} and π_{NRO}. The simulation results show that the optimal sequence π_{opt} provides the lowest total costs among the given sequences.

Acknowledgments

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References

[1] C. Perkins, "IP Mobility Support for IPv4," RFC 3344, Aug. 2002.
[2] C. Perkins and D. Johnson, "Route Optimization in Mobile IP," Internet Draft, Internet Eng. Task Force (IETF), Nov. 2000.
[3] D. Johnson, C. Perkins, and J. Arkko, "Mobility Support in IPv6," Internet Draft, Internet Eng. Task Force (IETF), June 2002.
[4] E. Gustafsson, A. Jonsson, and C. Perkins, "Mobile IP Regional Registration," Internet Draft, Internet Eng. Task Force (IETF), July 2000.
[5] H. Soliman, C. Castelluccia, K. El-Malki, and L. Bellier, "Hierarchical MIPv6 Mobility Management," Internet Draft, Internet Eng. Task Force (IETF), Oct. 2002.
[6] R. Guerin and A. Orda, "QoS Routing in Networks with Inaccurate Information: Theory and Algorithms," *IEEE/ACM Trans. Networking*, vol. 7, no. 3, pp. 350-364, June 1999.
[7] A. Orda, "Routing with End-to-End QoS Guarantees in Broadband Networks," *IEEE/ACM Trans. Networking*, vol. 7, no. 3, pp. 365-374, June 1999.
[8] J. Ho and I. Akyildiz, "Local Anchor Scheme for Reducing Signaling Costs in Personal Communications Networks," *IEEE/ACM Trans. Networking*, vol. 4, no. 5, pp. 709-725, Oct. 1996.

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