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An Efficient Multicast-based Binding Update Scheme for Network Mobility

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Abstract

Mobile IP (MIP) is the solution supporting the mobility of Mobile Nodes (MNs), however, it is known to lack the support for NEtwork MObility (NEMO). NEMO manages situations when an entire network, composed of one or more subnets, dynamically changes its point of attachment to the Internet. NEMO Basic Support (NBS) protocol ensures session continuity for all the nodes in a mobile network, however, there exists a serious pinball routing problem. To overcome this weakness, there are many Route Optimization (RO) solutions such as Bi-directional Tunneling (BT) mechanism, Aggregation and Surrogate (A&S) mechanism, Recursive Approach, etc. The A&S RO mechanism is known to outperform the other RO mechanisms, except for the Binding Update (BU) cost. Although Improved Prefix Delegation (IPD) reduces the cost problem of Prefix Delegation (PD), a well-known A&S protocol, the BU cost problem still presents, especially when a large number of Mobile Routers (MRs) and MNs exist in the environment such as train, bus, ship, or aircraft. In this paper, a solution to reduce the cost of delivering the BU messages is proposed using a multicast mechanism instead of unicasting such as the traditional BU of the RO. The performance of the proposed multicast-based BU scheme is examined with an analytical model which shows that the BU cost enhancement is up to 32.9% over IPD-based, hence, it is feasible to predict that the proposed scheme could benefit in other NEMO RO protocols.

***Keywords*:** Network Mobility (NEMO), Binding Update (BU), Prefix Delegation (PD), Improved PD (IPD), Multicasting

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1. Introduction

The Internet Engineering Task Force (IETF) Mobile IPv4 (MIPv4 [1]) and Mobile IPv6 (MIPv6 [2]) provide smooth communication whenever a Mobile Node (MN) moves out from its home network, where **NE**twork **MO**bility (NEMO) handles situations, when an entire network (composed of one or more subnets), dynamically changes its point of attachment to the Internet, as well as its accessibility in the topology [3]. **Fig. 1** describes a typical NEMO operation scenario with a moving vehicle, *i.e.*, a ship carrying passengers. The ship may be equipped with many types of devices, such as information panels in each cabin, fuel sensors in the engine, and embedded sensors that gather information such as wind velocity, water depth, and weather conditions, hence, these devices together constitute a Vehicular Area Network (VAN). Furthermore, the passengers may carry their personal wireless devices or even the entire Personal Area Network (PAN) devices which join and leave VAN as passengers embark and disembark.

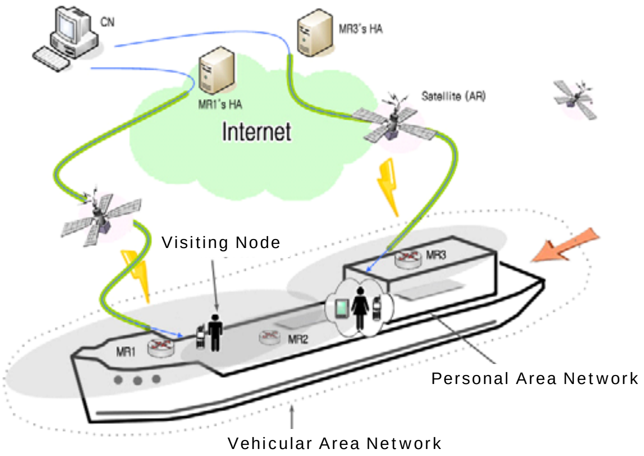


Fig. 1. NEMO Basic Architecture

Mobile IP (MIP) solutions support the mobility of MNs by performing a location registration to its Home Agent (HA) and Correspondent Nodes (CNs) with the Binding Update (BU) messages which inform them MN's current location after getting a Care-of-Address (CoA). Moreover, the MN also sends its renewal messages to the HA and the CNs through the BU messages before the expiration of lifetime of the BU message. In order to support the user's mobility, the MN regularly creates BU messages which in turn cause network overload due to the unnecessary consumption of frequency bandwidth from additional signaling. As a result, the BU messages increments have emerged as one of the serious barriers in efficient location management.

Furthermore, MIP is not capable of handling NEMO. In order to overcome the lack of capability, the NEMO Basic Support (NBS) [4], naturally originated in MIP, was introduced. The function of NBS ensures session continuity for all the nodes in a MObile NETwork (MONET), even when the Mobile Router (MR) changes its point of attachment to the Internet. In addition, the NBS also provides connectivity and accessibility to all the nodes in the MONET, as it moves.

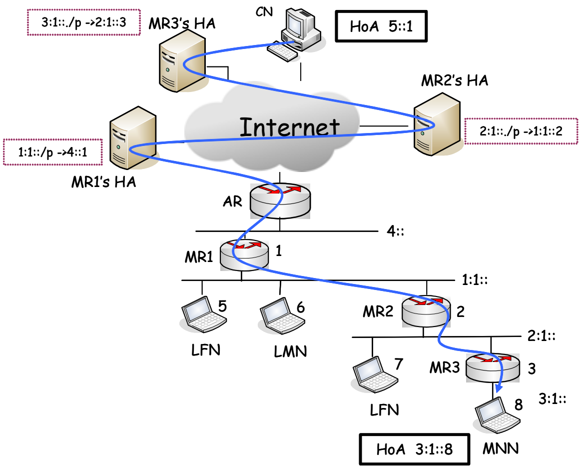


Fig. 2. Pinball routing problem in NBS

The NBS protocol relies on the establishment of a bi-directional tunnel between the MR and its Home Agent (HA). An MR forwards outgoing IPv6 packets through the tunnel, towards its home network. However, it suffers from the overhead due to the increased number of packets and transmission delay as the packets are repeatedly encapsulated by all the HAs of the MRs as the number of nested levels increases. This is called the pinball routing problem, as shown in **Fig. 2**. To avoid the problem, various types of Route Optimization (RO) schemes have been proposed through the NEMO Working Group (NEMO WG) and two of the well-known schemes will be briefly described in the latter section.

For example, consider the situation in which a large number of MNs are on the same train, bus, ship, or aircraft. As the vehicle may contain many MNs on board, each communicating with several other peers, the issues on location, optimal routing, and signaling overload are significantly important. Several of the introduced RO protocols yield efficient location management scheme, however, in a certain situation, some CNs and HAs may receive duplicate BU messages carrying the same address from several MNs in the subnet, hence, a solution to reduce the cost of delivering BU messages is under the consideration. In this paper, an efficient BU scheme is proposed. The concept of this new BU scheme is using a multicast mechanism. If each Mobile Network Node (MNN) has to perform BU for itself, with regard to unicasting such as the traditional BU of the RO, using a multicast mechanism should reduce the BU cost.

The remainder of the paper is organized as follows. Section 2 describes the previous research. Section 3 introduces the proposed scheme, and the analytical models to evaluate the proposed scheme with the counterpart scheme are shown in Section 4, followed by the conclusion in Section 5.

2. Preliminaries

2.1 Aggregation and Surrogate (A&S) RO Mechanisms in NEMO

In the NBS architecture [4], a bi-directional tunnel is used to enable an MR to communicate with its home network, however, this causes a serious pinball routing problem. To overcome this weakness, there are many RO solutions; Reverse Routing Header (RRH) [5], Path Control Header (PCH) [6], Prefix Delegation (PD) [7], Improved PD (IPD) [8], etc. In the reference paper [9], the authors give full detail of analysis for each RO scheme. The authors mathematically evaluate the many types of performances, and the Aggregation and Surrogate (A&S) RO scheme is generally better. Nonetheless, the BU cost of A&S is very high. Therefore, if the A&S RO scheme uses the proposed BU scheme presented in this paper, then the performance is significantly improved. Thus, two of the well-known A&S RO schemes, PD and IPD, are briefly described.

First, the PD approach achieves RO by having each MR act as a neighbor discovery proxy. An MR will configure a CoA from the network prefix advertised by its Access Router (AR), and it also relays this prefix to its subnets. Prior to the MR advertising, the prefix information, through the Router Advertisement (RA) message, must set the O (route optimization) flag, indicating that this prefix is used for the RO of the MNs. If an MN receives the new prefix information option through the RA message, the MN creates a new CoA with a network access prefix, and performs the binding procedure with its CN. In performing BU with the prefix of the access network, the MN can optimize the routes between its CNs and itself. However, a simple change in the point of attachment for the root MR will require every nested MR and MNN to change its CoAs and Delegated Prefixes (DPs). These will cause a significant burst of BUs to their HAs and CNs whenever the MR changes its point of attachment. In addition, this procedure requires a new protocol for performing extended MNN operations, since each MNN has 2 CoAs, based on its Mobile Network Prefix (MNP) and Delegated Prefix (DP).

Second, in the previous paper [8], the authors have proposed a RO scheme based on an Improved PD (IPD), in order to pass ingress filtering. In an effort to provide an RO based on the improved procedure, an address translation mechanism and registration procedure is performed to inform other nodes of an optimal path. IPD supports nested mobile networks without requiring additional tunneling, thus reducing packet overhead and latency, as compared to NBS. Using the PD method, the MR relays the DP advertised by the AR through the RA message. However, when the MR relays the DP to the entire mobile network, it multicasts the RA message only to routers on the link. That is, MRs configure their CoA using the DP and MNNs configure their CoA using the MNP advertised by the default MR. Therefore, the IPD protocol solves the problem of burst BU messages of MNN whenever a mobile network changes its point of attachment.

In this paper, we are considering the IPD protocol. As mentioned previously, the IPD protocol is a very well-known RO scheme. However, there is still the problem of a BU storm, even if the IPD can reduce the burdens more than PD. Therefore, the multicast mechanism is used to solve the BU storm problem. If another new RO protocol is introduced, the protocol similar to the proposed multicast-based scheme can easily be adopted.

2.2 Validity of Using A Multicast-based Mechanism

In order to solve the previously mentioned signaling overload problem, we present discussions of several multicast-based studies. In Helmy's paper (2000) [10], the author proposed a multicast-based protocol for supporting IP mobility on the Internet. The introduced architecture is multicast-based, in which an MN is assigned a multicast address, and the CNs send packets to the multicast group. When the MN moves to a new location, the

MN joins the multicast group from the new location and prunes from the old location. Dynamics of the multicast tree provide for smooth handoff, efficient routing, and conservation of network bandwidth. The author compared the proposed protocol to many types of other mobility support protocols, including basic MIP, MIPv4, and MIPv6 with RO. The simulation results show MIP consumes, on average, almost twice as much network bandwidth, and experiences more than double end-to-end delays and handoff latency of the proposed architecture. The proposed protocol incurred the least average handoff delay among all protocols.

In Chin's paper (2002) [11], the authors also proposed using the multicast tree for periodical BU, when an MN communicates with multiple CNs. The authors exploit IP multicast technologies to facilitate efficient BU delivery. The proposed main advantages of using IP multicast to deliver BUs are as follows: 1) utilization of IP multicasting technologies, 2) minimal state (*i.e.*, only multicast related states) maintained at the routers, and 3) and transparent to asymmetric routes. The authors have shown there are several advantages of using IP multicasting techniques and shared tree approaches over the traditional approach of delivering BUs, such as shorter time delays for delivering BU messages and efficient utilization of bandwidth.

In Helmy's paper (2004) [12], the authors proposed a scheme that translates the unicast address into the multicast address, when an MN sends its Mobile Anchor Point (MAP) the Regional CoA (RCoA) BU message, based on a Hierarchical MIP (HMIP [13]) environment. Thus, the authors improved on their previous research [10]. The authors presented a paradigm for multicast-based micromobility, where a visiting mobile is assigned a multicast address to use while moving within a domain. The multicast address is obtained using algorithmic mapping, and handover is achieved using multicast join/prune mechanisms.

In Chen's paper (2005) [14], the authors discussed the BU procedures of mobile network in a MIPv6 environment. The proposed multicast-based scheme improved the efficiency of the BU procedures of the MR. Based on the multicast approach, the MR only needs to inform its home agent when it moves to a new foreign network. All of the CNs can receive the new CoA through the multicast message sent by the HA. With this approach, the load on the MR is effectively reduced, and there is less dependency on the number of MNs within. However, the authors only considered MIPv6 while NBS and other RO schemes were not considered.

In H. Kim's paper (2005, 2007) [15] [16], the authors addressed the location management procedure that reduces the cost of location management. The authors applied the scheme to HMIPv6 and NEMO. Also, they proposed a scheme that combines multicast routing with MIPv6 to support a mobile network on the Internet. In other words, the authors only extended the previously mentioned Helmy's paper [12] based on NEMO-HMIP environments and HMIP is not a general MIP environment.

3. Proposed Multicast-based Binding Update Scheme

As mentioned above, A&S RO is a smart mechanism, but it has the burden of the BU problem. Although IPD of A&S protocols has reduced the cost problem of PD, the BU cost problem is still present. Therefore, the RO scheme used in this paper is assumed to be an IPD and the proposed scheme is unfolded and evaluated. Undoubtedly, if another new RO protocol is introduced, a protocol similar to the proposed scheme is appropriately adopted. The proposed scheme in this paper is a novel way to solve both the essential BU problem in network mobility and the BU storm caused by applying IPD. First, full details of the proposed protocol, with an example, will be given. To help the reader's understanding, the animation files has been created as examples of IPD and the proposed scheme, which is viewed at the websites [17] [18].

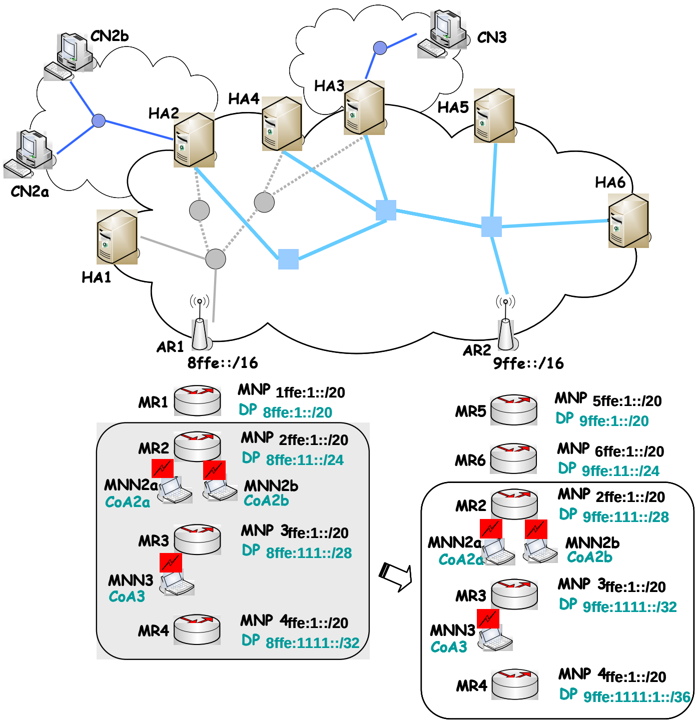


Fig. 3. Example of the proposed scheme

Fig. 3 depicts the proposed scheme in the form of a clear and simple example. Since our protocol is based on IPD, the DP for each MR is observed in Fig. 3. In addition, the root of a multicast tree is defined as an AR, because the multicast mechanism is used. First, in the introduced scenario, MR1 is attached under AR1 of the foreign network and performs its BU procedure. During this time, AR1 decides whether the received message is a BU message or not. If so, AR1 transmits the invite message for joining the multicast group member to HA1. After joining the multicast tree member, AR1 continuously performs the BU procedure to HA1. Second, MR2 is moved to the subnet of MR1, and its DP is generated by the IPD scheme. MR2 also performs its BU as the previously mentioned MR1, and AR1 continuously manages the group members for the multicast tree. Using the same procedure, MR3 and MR4 are sequentially performed.

One of the major concerns is the communication of MNNs under MR2. Each MNN communicates with each CN. That is, MNN2a, MNN2b, and MNN3 are connected to CN2a, CN2b, and CN3, respectively. The BU procedure of MNNs after handoff should also be considered. When CN2a takes the initiative in the communication with MNN2a, the data packets may be passed to the HA2 at least once, as shown in Fig. 3. At this time HA2 transmits the invite message for joining the multicast members and the multicast tree is constructed as the root HA2. If MNN2b takes the initiative in the communication with CN2b, CN2b looks at the Optimized Path Registration (OPR) of the received message, then, it requests a multicast group member to join HA2. Thus, the multicast tree is constructed as the root HA2 and HA2 is continuously managing the tree.

MR3 and MR4 are under MR2, MR2, which contains them, moves from MR1 to MR6, as described in **Fig. 3**. Since MR5 and MR6 are under the AR2 subnet from earlier, a multicast tree may be partially constructed and AR2 acts as the root of the existing multicast tree. Because MR2, MR3, and MR4 have migrated to the new foreign network, the DPs are generated by IPD. MR2, which is the top level of the moved subnet, performs BU by placing all multicast information into the message. At this time, MR2 only puts the longest address of all addresses, 9ffe:1111:1::/36, into the BU message. Each HA, receiving the message, can cut the longest address into /28, /32, /36 by using each MNP which is managed by itself. The reason is that if we use all the addresses of the MNNs, then, the multicast information load is very heavy. In order to overcome this, the address property of the IPD scheme has been applied. The data being transmitted is sent by using each MNP, AR2 has to continuously manage the multicast group members.

It is important to realize that the described BU procedure is not intended to be a step-by-step recipe. The goal of this paper is to reduce the cost of BU by using the multicast mechanism. If there is another smart RO scheme, then an appropriate scheme similar to this one should be adopted. The significant point is to find the means of applying the multicast mechanism, as the introduced example. In the next section, the proposed scheme is mathematically analyzed.

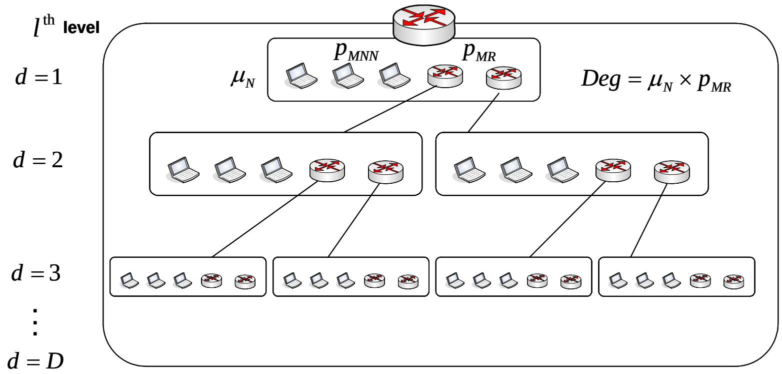
4. Performance Evaluation

In this section, the performance of the proposed scheme is analyzed by using an analytical model as shown in **Fig. 4**. Consider an arbitrary wireless subnet of an MR, as shown in **Fig. 4(a)**. p_{MR} is defined to be the probability that a child node under the parent MR is an MR. The probability that a node is an MNN is p_{MNN}. The average number of nodes, only one-level of depth, under the MR is μ_N. Then an MR has $\mu_N \cdot p_{MR}$ MRs and the value is defined as the subnet average degree, Deg. Therefore, the average number of nodes in the mobile network is defined by $Monet = 1 + \sum_{d=1}^{D} \mu_N \cdot Deg^{d-1}$ where, D is the depth from MR as the root of the subnet. Potentially, there could be several subnets in the network under AR. Hence, the assumed total number of nodes under AR is represented as $Net = \xi \sum_{i=1}^{l+D} \mu_N \cdot Deg^{i-1}$ where, ξ is a suitable constant and l is the nested level under AR. In addition, the average number of MNNs is $\mu_{MNN} = (Monet - 1) \cdot (1 - p_{MR})$ and the average number of MRs is $\mu_{MR} = 1 + (Monet - 1) \cdot p_{MR}$ in the mobile network.

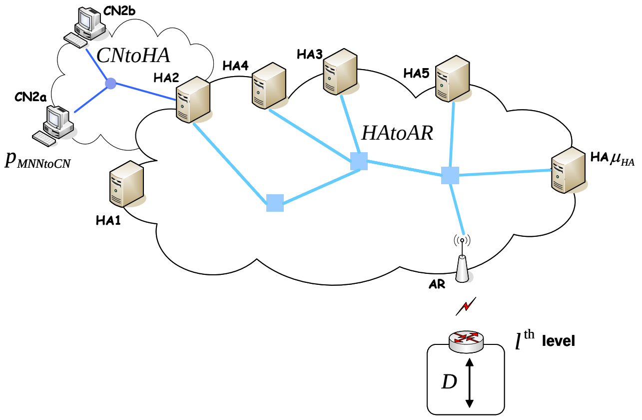
Furthermore, consider the wired network as shown in **Fig. 4(b)**. A random variable K is defined as the number of HAs connected to all multicast member MNNs for the BU procedure. That is, an HA of k HAs is connected to at least one MNN. By the Inclusion-Exclusion Principle [19], the number of every events that k HAs are connected to at least one node under AR connecting is ${}_{Net}C_k \cdot \sum_{i=0}^{k-1} (-1)^i {}_kC_i \cdot (k-i)^{Monet}$ [20]. Therefore, the expectation value that k HAs are connecting with at least one node under AR is as follows.

$$\mu_{HA} = \sum_{k=1}^{Monet} k \cdot \frac{1}{Net^{Monet}} \cdot {}_{Net}C_k \cdot \sum_{i=0}^{k-1} (-1)^i \cdot {}_kC_i \cdot (k-i)^{Monet} \tag{1}$$

The number of average hops between HA and AR is $HAtoAR$ in the wired network (outside of the AR's network). $CNtoHA$ indicates the number of average hops between CA and HA. Let $p_{MNNtoCN}$ be the probability that one of the MNNs is communicating with a CN.



(a) A subnet of MR under AR



(b) A given total network topology

Fig. 4. Topology model for analytical evaluation

Therefore, the BU cost, based on the multicast tree constructed by the proposed scheme, is obtained as follows.

$$\mu_{HA}\cdot HAtoAR\cdot\tau+\mu_{MNN}\cdot p_{MNNtoCN}\cdot CNtoHA\cdot\tau+\omega\cdot l \\ +\omega\cdot\sum_{d=1}^{D}\left(Deg^{d}+(\mu_N\cdot p_{MNN}\cdot p_{MNNtoCN})^{d}\right)\cdot d \tag{2}$$

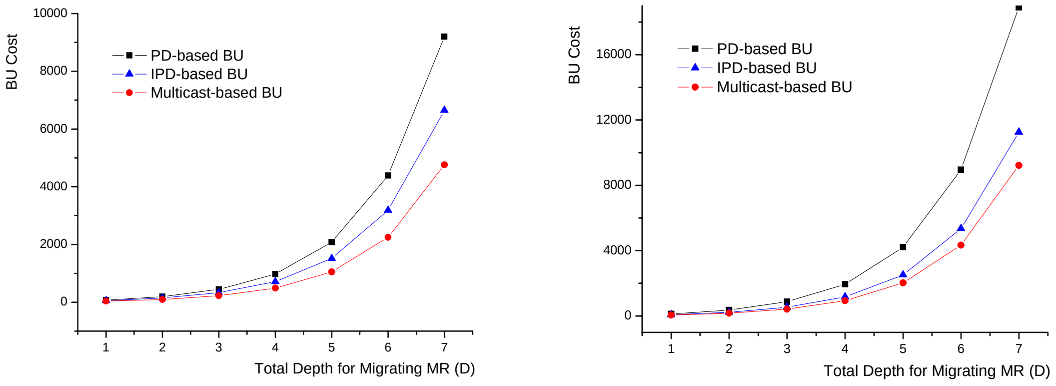
where, τ is the general benefit ratio from using a multicasting rather than an unicasting, ω is the number of average hops under the visited AR's wireless network, and l means the nesting level of an MR, counted from the AR.

In Eq. (2), the first term is the cost of the constructed multicast tree in the wired backbone network. The second term is also the cost of the other multicast tree, as shown in the left-up in **Fig. 4(b)**. The third term is the cost between AR and MR with nested level l. Finally, the last term is caused by IPD-based.

On the other hand, the BU cost, based on the IPD RO scheme, is as follows.

$$\begin{aligned}&\omega \cdot \sum_{d=1}^{D} Deg^{d} \cdot d + \mu_{MR} \cdot \omega \cdot l + \mu_{MR} \cdot HAtoAR + \omega \cdot \sum_{d=1}^{D} (\mu_N \cdot p_{MNN} \cdot p_{MNNtoCN})^{d} \cdot d \\ &+ \mu_{MNN} \cdot p_{MNNtoCN} \cdot \omega \cdot l + \mu_{MNN} \cdot p_{MNNtoCN} \cdot \sqrt{HAtoAR^{2} + CNtoHA^{2}}\end{aligned} \tag{3}$$

In Eq. (3), the last term is assumed to be the shortest path (*i.e.*, RO) between AR and CN. Furthermore, if we consider a PD-based scheme, then we have to modify the first and second terms to $\omega \cdot \sum_{d=1}^{D} (\mu_N \cdot Deg^{d-1}) \cdot d + Monet \cdot \omega \cdot l$ in In Eq. (3). Several parameters are set to calculate the numerical results of each scheme. We set $p_{MNNtoCN} = 2/3$, $\tau = 0.7$, $l = 4$, $\omega = 1$, $HAtoAR = 10$, and $CNtoHA = 10$. Conveniently, ξ is assumed to be 1.5 throughout.

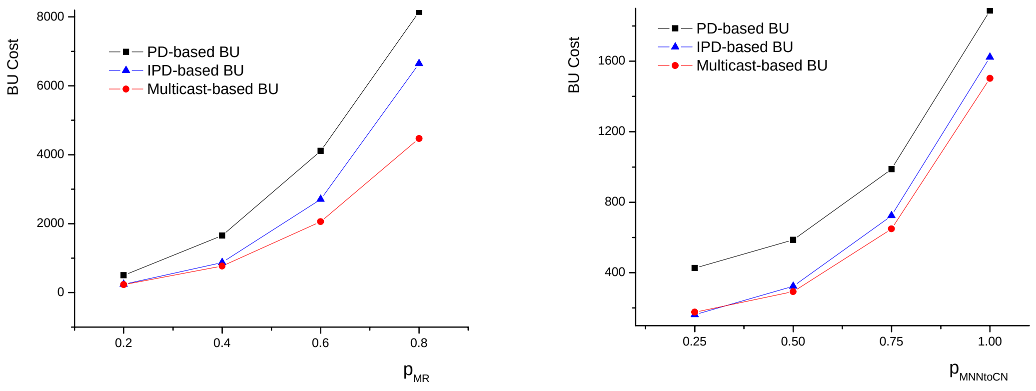


(a) $\mu_N = 3,\ p_{MR} = 2/3$ **(b)** $\mu_N = 5,\ p_{MR} = 2/5$

Fig. 5. Influence of total depth for migrating MR (D)

The depth from MR, as the root of subnet, d, ranges from 1 to 7. As described in **Fig. 5(a)** and **5(b)**, the enhancements increase up to approximately 32.4% and 22.8% in terms of the BU cost over IPD, which outperforms the PD scheme, respectively. The reason is that the proposed scheme may be better than others when the mobile network contains many nodes. Hence, we have adjusted the other factors, such as p_{MR} and $p_{MNNtoCN}$, related on the number of nodes.

As shown in **Fig. 6(a)**, the proposed scheme outperforms the IPD-based scheme by up to 5.1%-32.7%. And the performance enhancement of multicast-based BU over IPD-based BU is up to approximately 10.3%, as depicted in **Fig. 6(b)**. We also see the worst case of the proposed scheme when the numbers of MRs and communicated MNNs are small such as $p_{MR} = 1/5$ and $p_{MNNtoCN} = 0.25$. The reason is that the multicast tree managing cost is more high than unicasting in that time, however the difference is quite small.



(a) $\mu_N = 5,\ p_{MNNtoCN} = 2/5$ **(b)** $\mu_N = 5,\ p_{MR} = 1/5$

Fig. 6. Influences of p_{MR} and $p_{MNNtoCN}$

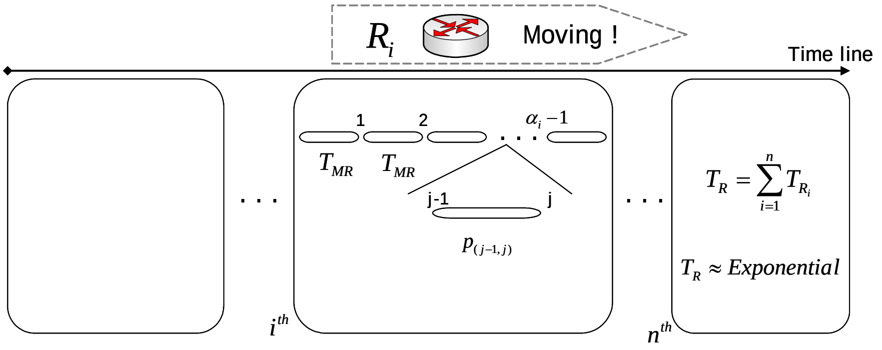


Fig. 7. Movement of MR and BU lifetime

Consider the movement of the MR containing MNNs, as depicted in **Fig. 7**. The number of migrations is assumed to be n. Each movement is defined to be R_i. In **Fig. 7**, the middle circle describes the i^{th} movement R_i. T_{R_i} depicts the staying time in R_i. T_{R_i} is assumed to have the exponential distribution with an average of $1/\lambda$. Thus, the probability of being within t in R_i is represented as follows.

$$Prob\left\{T_{R_i} \le t\right\} \quad = \quad \int_0^t \lambda e^{-\lambda x} dx \tag{4}$$

α_i is defined by the number of local BUs at the i^{th} movement R_i. Therefore, the average number of local BUs in R_i is as follows.

$$\sum_{j=1}^{\alpha_i - 1} j \cdot p_{(j-1,j)} \quad = \quad \sum_{j=1}^{\alpha_i - 1} j \cdot \int_{(j-1)\cdot T_{MR}}^{j \cdot T_{MR}} \lambda \cdot e^{-\lambda x} dx \tag{5}$$

where, $p_{(j-1,j)}$ is the probability such that j^{th} BU in R_i and T_{MR} means the local BU lifetime.

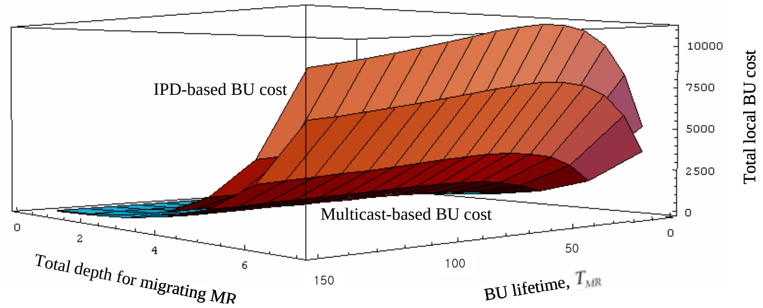


Fig. 8. Cost of BU tree for **Fig. 5(a)**, with $\alpha = 5$, $\lambda = 0.01$

We set $\lambda = 0.01$ and conveniently assume that α_i is 5, which is a constant α throughout. Therefore, Eq. (2) multiplied by Eq. (5) yields the average cost of the local BU for the proposed scheme. The result is shown in **Fig. 8**. Overall, the enhancement increases to between approximately 28.8%-32.9% over IPD-based BU, in terms of the local BU lifetime. That is, the result benefit is approximately 1.48 times.

5. Conclusion

Network mobility is concerned with situations when an entire network, composed of one or more subnets, dynamically changes its point of attachment to the Internet. In this environment, several avenues of research supporting the mobility have been investigated. The PD protocol is a well-known scheme from the literature. However, the scheme has a heavy binding update storm problem. Even though the IPD protocol solves both the RO problem and the BU problem of PD, the essential BU storm problem still exists.

In this paper, we are considering the IPD protocol and propose an efficient BU scheme to overcome this weakness. Several multicast-based studies are reviewed and thus they are in agreement with our work. A solution to reduce the cost of delivering the BU messages is proposed using a multicast mechanism instead of unicasting such as the traditional BU of the RO. The performance of the proposed multicast-based BU scheme is examined with an analytical model which shows that the BU cost enhancement is up to 32.9% over IPD-based, hence, it is feasible to predict that the proposed scheme could benefit in other NEMO RO protocols. In future studies, we will consider extending the performance evaluation of the proposed scheme to implementation using a simulator.

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Appendix

Terminology for IP mobility support is defined by IETF RFC 3753 [21] and RFC 4885 [22]. We introduce briefly the terminology used in this paper as follows in **Table 1**.

Table 1. Terminology

Abbreviation	Full form	Meaning
BU	Binding Update	A message indicating a mobile node's current mobility binding, and in particular its Care-of-Address.

CoA	Care-of-Address	An IP address associated with a mobile node while visiting a foreign link; the subnet prefix of this IP address is a foreign subnet prefix. A packet addressed to the mobile node which arrives at the mobile node's home network when the mobile node is away from home and has registered a Care-of-Address will be forwarded to that address by the Home Agent in the home network.
HoA	Home Address	An IP address assigned to a mobile node, used as the permanent address of the mobile node. This address is within the mobile node’s home link. Standard IP routing mechanisms will deliver packets destined for a mobile node’s home address to its home link.
MN	Mobile Node	A node that can change its point of attachment from one link to another, while still being reachable via its home address.
HA	Home Agent	A router on a mobile node’s home link with which the mobile node has registered its current CoA. While the mobile node is away from home, the home agent intercepts packets on the home link destined to the mobile node’s home address, encapsulates them, and tunnels them to the mobile node’s registered CoA.
CN	Correspondent Node	Any node that is communicating with one or more MNNs. A CN could be either located within a fixed network or within another mobile network, and could be either fixed or mobile.
MNN	Mobile Network Node	Any node (host or router) located within a mobile network, either permanently or temporarily. A Mobile Network Node may either be a mobile node or a fixed node.
LFN	Local Fixed Node	A fixed node, either a host or a router belongs to the mobile network and is unable to change its point of attachment while maintaining ongoing sessions.
LMN	Local Mobile Node	A mobile node or a mobile router that belongs to the mobile network (*i.e.*, its home link is within the mobile network). It can move topologically with respect to the MR.
MR	Mobile Router	A router capable of changing its point of attachment to the Internet, moving from one link to another link. An MR acts as a gateway between an entire mobile network and the rest of the Internet
MNP	Mobile Network Prefix	A bit string that consists of some number of initial bits of an IP address which identifies the entire mobile network within the Internet topology.

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