Protocol and Evaluation of Network Mobility with Producer Nodes in Named Data Networking

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Abstract

The drawbacks of the current TCP/IP suits have been pointed out. However, Named Data Networking (NDN) has some limitations, the most notable of which is producer and network mobility. Mainly, producer mobility in moving networks receives scant attention. There are numerous issues that the NDN must address before it can be used by the public, one of which is mobility. In NDN, consumer mobility is naturally supported, but producer mobility is not. The latter is researched a lot, but few results have been reported regarding network mobility with producers. In this paper, two approaches will be focused on: the Hybrid Network Mobility (Hybrid NeMo) approach and the Network Mobility (NeMoI). These two approaches are being compared because they both employed similar techniques for managing network mobility. Furthermore, they will be compared using the same topology to allow more accurate comparisons of their signalling cost and data delivery cost.

Keywords: Named Data Networking, Producer mobility, Network mobility, NeMoI, HyNeMo

1 Introduction

Named Data Networking (NDN) is an emerging network infrastructure currently being researched and developed by many network engineers [1]. It is a relatively new concept, which needs much works to identify its strengths and weaknesses. NDN exceeds TCP/IP in some functions such as security, scalability and mobility, but it still requires much attention. NDN or Content-Centric Networking (CCN) is a network architecture proposed in 2009 [1], and since then, much research has been done. NDN was assumed to be the next-generation networking protocol that would replace TCP/IP and become the mainstream.

NDN is a network architecture that prioritizes data but not a location like IP protocol. Whenever data access is requested, an Interest packet with the requested data name is sent out. They send the data's name as an Interest packet over the Internet until it reaches that particular producer who can provide the data with the same name. The producer will then send back a Data packet and the user will receive the data packet with the same name as the interest packet they sent. Since the data producer will include their signatures and other information inside the data packet, data receivers can check that information and further prove its integrity. This security feature is naturally supported in NDN.

Consumer mobility refers to the consumers' constant movement within a network. NDN naturally supports this function, as its design enables users to receive data from any location. Producer mobility refers to the producer's ability to move within a network. This function is not supported by default in NDN, as the data packet will pass through multiple routers, each of which will record the producer's location. If the producer node changes positions, the request packet may not reach the producer, resulting in the user not receiving what they requested. In terms of network mobility, this refers to the fact that an entire network consists of several producers and users who move concurrently. NDN did not support network mobility as well, necessitating additional research to resolve this issue.

Although consumer mobility is naturally supported in NDN, producer mobility and network mobility are highly challenging issues for the NDN. A lot of researches about producer mobility have been carried out so far. Each of them has its strengths and weaknesses. However, there are only a few pieces of research about network mobility in NDN [5-7].

This paper compares the efficiency between 2 proposed network mobility support in NDN, which is the Hybrid Network Mobility Support (HyNeMo) [5] and the Network Mobility in ICN (NeMoI) [4].

The paper contains three sections. The following section will discuss related works, which will include research that is relevant to this paper. Following that, the evaluation metrics section will highlight the distinctions between HyNeMo and NeMoI in terms of the calculations in signalling and data delivery costs. In the following section, a comparison will be made using a fixed topology to demonstrate their performance efficiency. Finally, the comparison results will be discussed briefly in the final section.

2 Related Works

2.1 NDN Scheme

As mentioned above, NDN will be the next-generation networking. As proposed in [1-2], NDN router contains three data structures which are Pending Interest Table (PIT), Content Cache, and Forwarding Information Base (FIB). In

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NDN, there are only two types of packets: data packets and interest packets. The interest packet contains several fields such as data, the selector's name, and guiders. The data packet includes the data's name, meta information about the data, the data's content, and the sender's signature. Figure 1 shows the info of the data packet and the Interest packet.

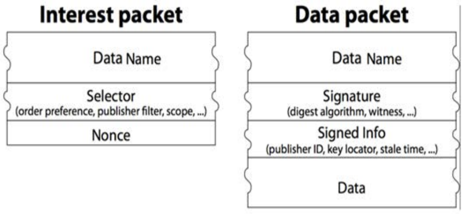

Figure 1. Interest packet and data packet of NDN [1]

NDN has two types of packets, where one is a request packet, called Interest packet, and the other is a reply packet, called Data packet. In an NDN router, there are three tables inside, which are Pending Interest Table (PIT) has information of a returning path, Content Store (CS) has data cache and Forward Information Table has information of forwarding interface.

When a user requests data, the user sends an Interest packet containing the data's name to a router, verifying the data's name against the CS. If the data name does not match, the Interest Packet is sent to PIT. At this time, if the PIT does not contain the same data entry, it adds the data name to an entry in the PIT and then uses the FIB to forward the Interest packet. When it reaches a producer, the producer sends out a Data packet in response. Then, it connects to the user node via PIT entries. Simultaneously, the data contained in the Data packet is stored in the CS of each router [7]. Figure 2 shows these operations of the Interest packet and Data packet in NDN.

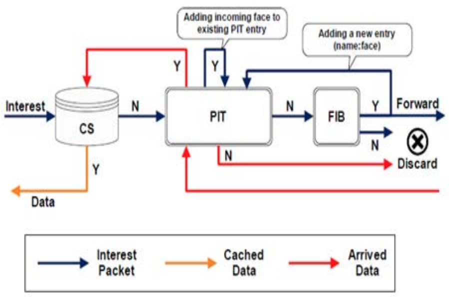

Figure 2. Operations in NDN [7]

2.2 Producer Mobility Approaches

When a producer node constantly moves, the Interest packet cannot use the FIB to communicate with the requestor. This is because the producer node's movement does not update the routers' FIBs. Therefore, unless and until the FIB notices each time the producer nodes move, the Interest packet cannot be forwarded to the producer. However, there are solutions for producer mobility that have been researched, and these solutions can be categorized as below:

2.2.1 Anchor-based Approach

This approach is currently used in TCP/IP. A special anchor node (Home Agent: HA) is used to record node movement. The user sends an Interest packet to HA, and HA redirects the Interest packet to the producer. There are several approaches to how the producer notifies its movement to HA. However, this solution is vulnerable as it only depends on one special node, HA. The transmission of all the packets via one specific node also causes the bottle-neck effect.

2.2.2 Anchorless Approach

In anchorless approach, the movement of the producer is notified to the old location of the producer and the other routers. The notified routers update their FIB to match the new location of the producer. By informing the movement to all routers in the network, the Interest packet can reach out to the producer. In this approach, no special routers are needed to record the movement. However, if the producers are moving very frequently, updating the FIB of all routers may also cause traffic.

2.3 Network Mobility Support in NDN

In TCP/ IP, Network Mobility (NEMO) supports node mobility in a moving network. It can connect to the Internet via specific gateways called Mobile Routers (MR) and contains other mobile networks to form a nested structure. We published the research about NDN in a moving network environment for the first time [3].

2.3.1 Network Mobility in ICN (NeMoI)

NeMoI was proposed in 2018 and is the first complete research paper about network mobility in ICN, especially NDN. They suggest Mobility Agents (MAs) to assist in both network-on-the-move and end-point mobility in ICN. Each MA is responsible for resolving a set of primary prefixes and secondary prefixes served by the producers.

The MAs maintain two tables, a primary table containing all the primary prefixes and their current location and a secondary table containing all the secondary prefixes and their current location. MA acts as a network service and will be maintained by the network administrators.

Each producer in the network is assigned at least one primary MA and many secondary MAs. When the producer moves to a new network, they connect to the new point-of-attachment (PoA), and can obtain the name of the PoA. Then, the producer will send a Binding Information (BI) which contains the prefix served by the producer and the name of the PoA. Those BI will be forwarded to any MA due to the shortest path. It will also be sent to the producer's old location. In this case, Non-NeMoI routers can also forward BI as an interest packet. The BI will then be sent to all the MAs until every MAs knows the new location. The first MA that the BI packet reaches will then send an interest packet to the producer to acknowledge the movement update.

The producer's old location will forward the BI packet back to its new location. The only difference between the packet sent and received is the Reverse Update (RU) and Reverse Update Received (RUR) fields included inside the BI packet. When the producer wants to notify its movement, the RU section will be set to true and RUR to false. After reaching the producer's old location, the RU section will be set to false and RUR will be set to true. Afterwards, the BI packet will be forwarded back to the producer. NeMoI uses a rendezvous node (RN) to control the traffic of the network. Figure 3 and

Figure 4 show the updating path that NEMOI uses the packet type information used in NEMOI respectively.

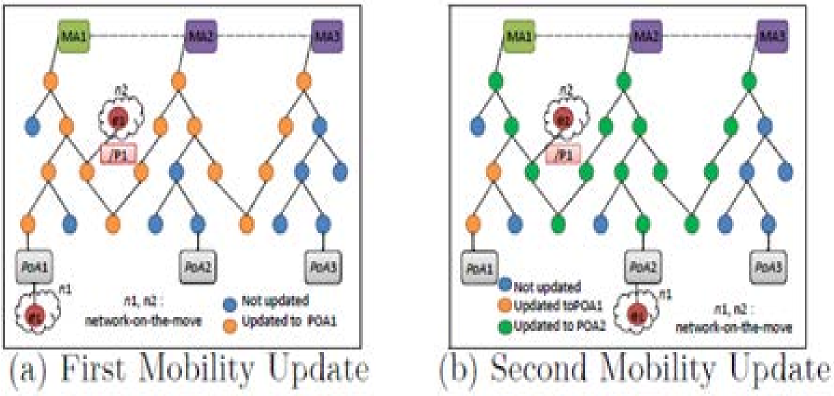

Figure 3. The network update in NemoI [1]

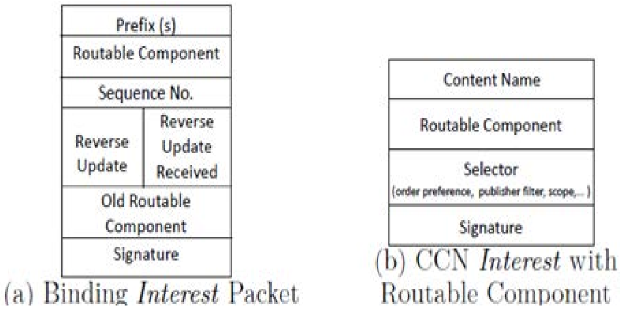

Figure 4. The Packet types in NemoI [2]

For the data retrieval process, the interest packet needs to reach any router or MA that contains the information of the producer. Therefore, the user will send an interest packet, which will travel through the network until it reaches any updated routers or MA. Then, the interest packet will be forwarded to the producer. The producer will then send the corresponding data packet via the PIT in the routers and reach the user.

2.3.2 Hybrid Network Mobility Support (HyNeMo)

Hybrid Network Mobility Support (HyNeMo) plays the same role as Network Mobility in NDN architecture. It is an approach of combining both anchor and anchor-less methods by considering producer mobility. By combining anchor and anchorless, we can get both of these methods' advantages without needing to overcome their weakness [5]. The anchor method is stable since there is only one place to update the information. Still, if an anchor is down as new location information is concentrated to the anchor, users in the network cannot get new location information. It may lead to a fatal situation. The anchorless method is more reliable because the failure of a node with new location information is restricted within small limits. On the other hand, the anchor method is simple and easily implemented, but the anchorless method is more complicated in implementation and management and gives more latency. By combining these two methods, we can get our proposed method which is reliable and provides less latency. HyNeMo consists of MR, Point of Attachment (PoA), Access Router (AR), Home Agent (HA) and some mobile network node (MNN). In this scheme, there are two types of movements: MR moving to another PoA under the same AR, which is called intra-NEMO, and another is MR moving to another PoA under another AR, which is called inter-NEMO. This paper focuses on inter-NEMO since inter-NEMO is more complicated than intra-NEMO. Figure 5 shows the difference between inter-NEMO and intra-NEMO.

When an MR moves to a new PoA, the MR will exchange location information with the new AR. The AR will forward a signalling packet to the home agent of MNN and the previous AR to inform the movement. Meanwhile, the AR and HA will make a Bind Information Table (BIT) entry. This entry consists of the mobile node, current PoA and the face number.

The mobile node is located directly or indirectly under the current PoA and the face number to forward a packet. The BIT act as a preliminary FIB, and an interest packet will refer to BIT before FIB. If there is a match in the BIT, the interest packet will be forwarded without looking up the FIB. Otherwise, the FIB will be used to deliver the interest packet.

When an MR moves under another AR, it gives its location and other information to the new AR. The information contains the new MR name, MNN name under it, and the old AR name. Then, the new AR gives its location information to the MR. After that, a BIT entry will be created in the new AR like {MNN;MR;Face} , which means MR can be reached through face, and MNN can be reached through MR.

After that, the new AR will send a PoA update (PU) packet to the old AR. The PU packet contains information like {MNN;New AR; Face}. A new BIT entry will be created in the old AR with the information given. Then, the PU packet will be forwarded to the MNN's Home Agent. All the intermediate routers will be updated with the BIT entry info. When the HA receives the PU packet, it will send an acknowledgement packet back to the new AR. This PoA update Acknowledgement (PUACK) packet will acknowledge that the HA has been informed of the movement of the MNN, and has the new location. The PUACK packet will be sent through the PIT in the intermediate routers to the new AR. If the new AR didn't receive the PUACK packet, it would retransmit the PU packet again. Figure 6 shows the movement of the packets during the signalling process while Figure 7 shows the information of PU and PUACK packet that is designed for HyNeMo.

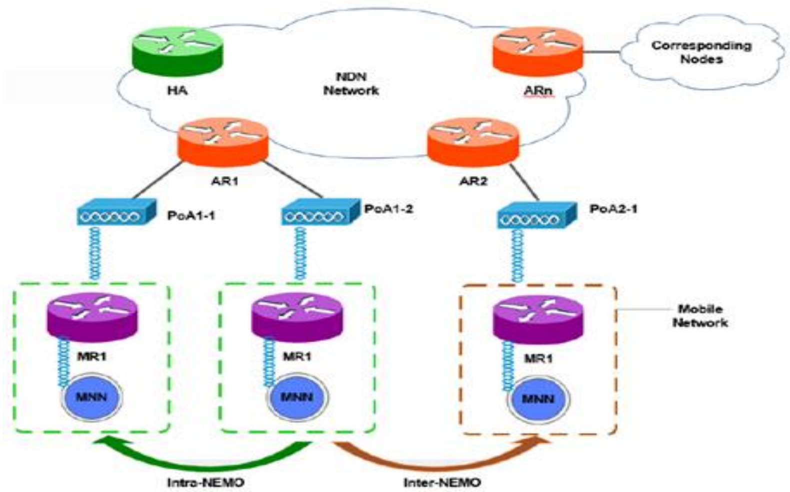

Figure 5. Network model of Hybrid NeMo [5]

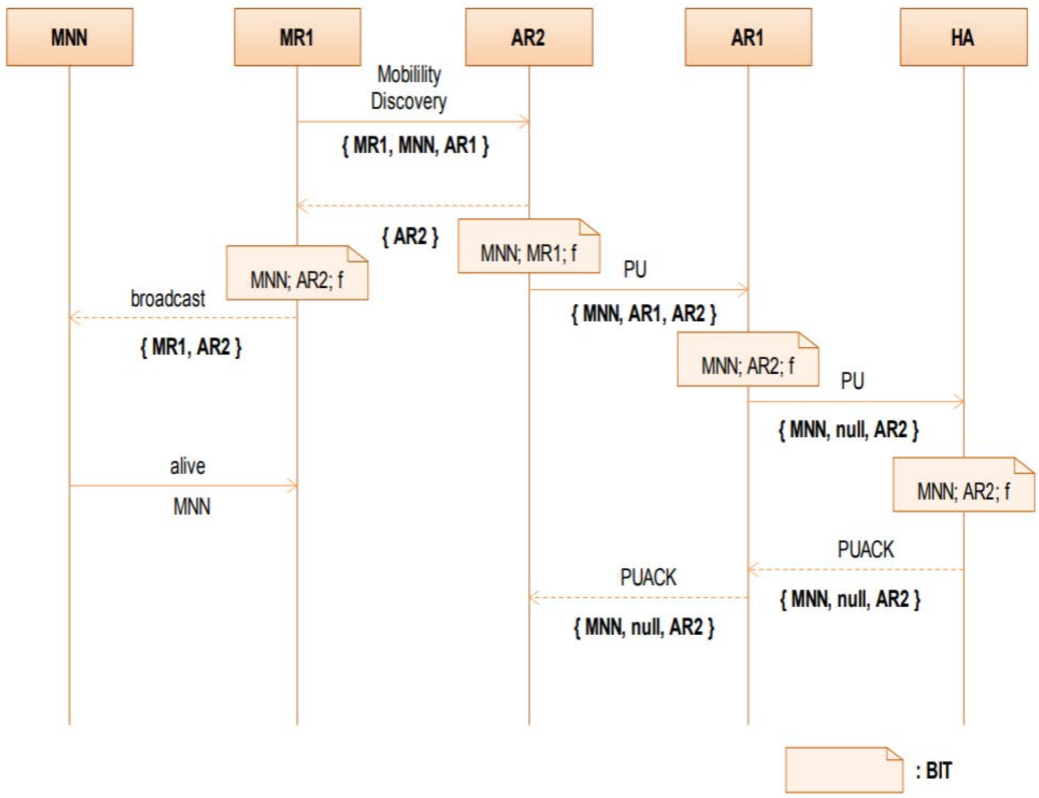

Figure 6. Process of signalling of Hybrid NeMo [5]

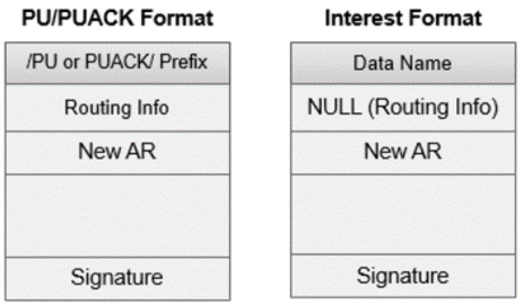

Figure 7. Format of the PU and PUACK packet [5]

Since Hybrid NeMo did not have any performance evaluation, there is no comparison between this approach and other approaches. Therefore, it is necessary to determine the performance of this approach before making any comparison with different methods.

In the next section, the differences between HyNeMo and NeMoI will be discussed and converted into equations for calculation purposes. The differences between these two approaches are mainly about the BIT part that HyNeMo implemented.

3 Evaluation Metrics

The key difference between these two approaches is the BIT table that uses the HyNeMo approach. With the BIT table, HyNeMo may provide less cost in processing time than NeMoI, which uses FIB for all the forwarding.

From the signalling cost, we can see the difference in the pathing between the two approaches. For HyNeMo, it only needs to send a PU packet to the HA and the old location of the producer. HA of the producer sends a PUACK packet back to the producer. All of these processes only involve the BIT in all of the routers. In NeMoI, the producer sends a BI packet to one of the MA and the producer's old AR. Once the BI packet reaches the MA, it is forwarded to all other MAs. The BI packet sent to the old AR is delivered back to the producer, with the RUR field marked true. In NeMoI, the signalling process involves PIT and FIB. It is because the BI packet and the acknowledgement packet are both forwarded as Interest packets. NeMoI needs to update the FIB frequently, and this may cause unnecessary network traffic by updating FIB entries when a routing protocol operates.

For the data retrieval cost, there is no difference between these two approaches during transferring data from a producer to the user, which only involves the lookup of PIT in the whole operation. However, each route of the two approaches may not be the same. The difference between these approaches is how Interest packets travel. In HyNeMo, the Interest packet needs to go through both BIT and FIB before reaching the BIT with the same data name as the Interest packet. After that, the rest of the route lookup only at BIT entries without going to FIB. On the other hand, NeMoI accesses FIB in their whole forwarding process from the user request to the producer. Thus, the difference between the two approaches comes mainly from the table lookup method by Interest packets.

3.1 Preliminaries

The network topology used here is as Figure 8.

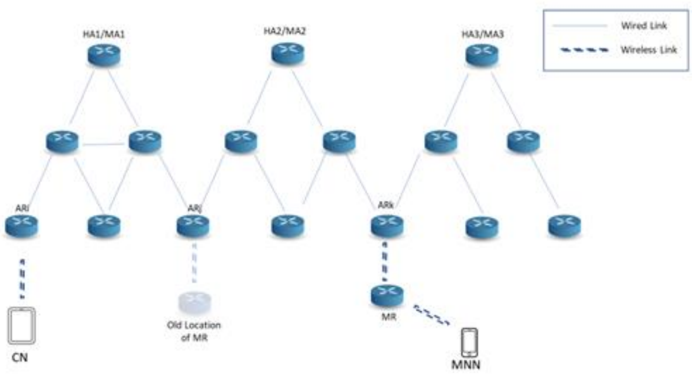

Figure 8. Network topology used

We use fluid flow mobility [6] due to its stability for a mobile terminal with static speed. A mobile producer moves in any direction with a uniform distribution probability. Table 1 contains the parameters and notations.

Cell crossing rate is the crossing rate for every mobile per second in each cell. Every AR in the network topology is assumed to manage a cell. When the producer or user moves from a cell to another, it may use up some cost. The cell crossing rate Rc is expressed by Equation (1).

$$Rc = \frac{\rho \cdot V \cdot L}{\pi} \quad \textbf{(1)}$$

L is the perimeter of the cell (m), V is the mobile node's average velocity, and ρ is the density of the Mobile Node.

Table 1. Parameters and values

Parameter	Values	Unit	Description
L	120	M	Cell's Perimeter
N	5-100		Number of Cells
ω	2		Transmission cost of wireless links
μ	1		Transmission cost of wired links
$D_{ARi,HAi}$	$\sqrt{N}$	Hops	Distance between ARi and HAi
$D_{ARm,ARn}$	5-100	Hops	Distance between ARm and ARn

3.2 Signalling Cost

The signalling means to update necessary tables. The signalling cost (time) denotes SH and SI for HyNeMo and NeMoI, respectively.

For HyNeMo,

$$S_H = [2(2\omega + (\mu \cdot D_{ARk,ARj})) + PC_{BIT} \cdot (D_{ARk,ARj}) + 2(\mu \cdot D_{ARj,HA1}) + PC_{BIT} \cdot (D_{ARj,HA1} + 1) + PC_{BIT} \cdot (D_{HA,MR} + 1)] \cdot RcN \quad (2)$$

The first and second terms of the equation are the transmission time and processing time during the PU packet transfer from MR to ARj, which is between the new location (ARk) and the old location (ARj). The third term is the PU packet's transmission time travels from ARj to the HA1, as the PU packet is forwarded from the old location to the HA. The fourth term is the acknowledgement, where the HA sends back the PUACK packet to the MNN's router (MR) as a Data packet.

For NeMoI,

$$S_1 = [2(2\omega + (\mu \cdot D_{ARk,MA2})) + 2 \cdot PC_{FIB} \cdot (D_{ARk,MA2} + 1) + 2(2\omega + (\mu \cdot D_{ARk,ARj})) + 2 \cdot PC_{FIB} \cdot (D_{ARk,ARj}) + (\mu \cdot (D_{MA2,MA3} + D_{MA2,MA1}) + PC_{FIB} \cdot (D_{MA2,MA3} + D_{MA2,MA1})] \cdot RcN \quad (3)$$

The first and second term of Equation (3) are the transmission time, FIB lookup time and acknowledgement time from the new location (AR_K) to the primary MA.

The third and fourth terms are the cost (time) from the new location (AR_K) to the old location (AR_I) as well as the acknowledgement.

The fifth and sixth terms update the movement from the primary MA to the secondary MAs.

Both BI (Binding Interest) packet's travel in NeMoI, which has the same role as PU in HyNeMo, and the acknowledgement uses the same route. Since the BI packets update FIB, it may need to update the FIB frequently by routing protocol operations.

As mentioned above, the two approaches make a big difference in terms of signalling cost. HyNeMo can reduce a lot of its signalling cost compared to NeMoI, which is based on FIB. HyNeMo accesses BIT first, and when there is no corresponding entry, it goes to FIB. The acknowledgement packet uses a Data packet to reduce the signalling cost.

3.3 Data Delivery Cost

The data delivery cost ($D0$) considers the following parameters:

(1) T_i: Processing time of an Interest packet in routers from CN to MNN,

(2) T_d: Processing time of a Data packet in routers from MNN to CN,

(3) T_t: Total transmission time from CN to MNN,

(4) λ_s and s: Arrival rate and session size.

Regarding HyNeMo,

$$Ti_H = [(PC_{BIT} + PC_{FIB}) \cdot (D_{ARi,HA1}) + PC_{BIT} \cdot (D_{HA1,MR} + 1)] \quad (4)$$

$$Td_H = [PC_{PIT} \cdot (D_{MR,ARi} + 1)] \quad (5)$$

$$Tt_H = 2[3\omega + (\mu \cdot D_{ARi,ARk})] \quad (6)$$

$$DO_H = \lambda_s \cdot s \cdot (Ti_H + Td_H + Tt_H) \quad (7)$$

WPC_{BIT} and PC_{FIB} are the lookup time of BIT and FIB, respectively. When an Interest packet arrives at a router, it looks up the BIT first, and if there is no matching entry, it will look up FIB.

For Ti_H, the Interest packet does not necessarily reach HA1. When the BIT in the intermediate router from CN to MMN via HA1 has the matching entry, the Interest packet can be forwarded to the MNN.

Another mentionable advantage of HyNeMo is that the data packet includes its location information inside during the first data transmission. Therefore, although the first Data packet transmission follows the path of the Interest packet, the second and subsequent transmission of the Interest and Data packets uses the direct path between the corresponding node and new AR. Therefore the further transmission cost is reduced a lot.

For NeMoI:

$$Ti_I = [PC_{FIB} \cdot (D_{ARi,MA1}) + PC_{FIB} \cdot (D_{MA1,MR} + 1)] \quad (8)$$

$$Td_I = [PC_{PIT} \cdot (D_{MR,ARi} + 1)] \quad \textbf{(9)}$$

$$Tt_I = 2[3\omega + (\mu \cdot D_{ARi,ARk})] \quad \textbf{(10)}$$

$$DO_I = \lambda_s \cdot s \cdot (Ti_I + Td_I + Tt_I) \quad \textbf{(11)}$$

Overall, the data transmission cost shows a difference between these two approaches. In HyNeMo, Interest packets are forwarded to the MNN by using BIT. On the other hand, NeMoI uses FIB all along the route. As the table size of FIB is much bigger than that of BIT, BIT takes much less in table lookup time.

In the next section, the comparisons between the performance and efficiency of these approaches will be carried out.

4 Performance Analysis

The parameters of some constants are shown in Table 1 and Table 2, referring to [5]. These values are an estimate of the router's processing cost. The numbers used here are merely to illustrate the differences in lookup costs between FIB and BIT. Due to the smaller size of BIT, it is assumed to be less expensive than processing in FIB. The remaining numbers are purely for calculation purposes and will have no effect on the results. The number of routers is included as a variable due to the variety of methods for updating the location of producer nodes (signalling).

Table 2. Constants

Parameter	Values	Description
PC_{FIB}	2	Lookup cost of the FIB
PC_{BIT}	1	Lookup cost of the BIT
PC_{PIT}	1	Lookup cost of the PIT
λ_S	1	Arrival rate
S	1	Average session size

The difference between the signalling cost can also be shown in Figure 9.

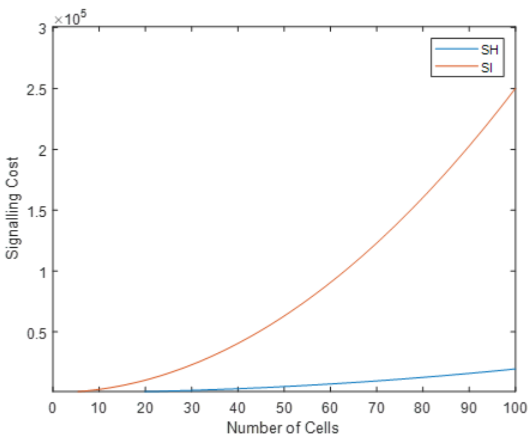

Figure 9. Difference of signalling cost between HyNeMo and NeMoI

The signalling cost of the HyNeMo is less than the NeMoI due to the smaller number of routers for an update. The main differences between these two approaches are the BIT table and the signalling process. HyNeMo will send the signalling packet (PU packet) to the HA by using BIT table, which is assumed to have a lower cost due to its smaller size. NeMoI will send the signalling packet (BI packet) to the MA by using FIB. Besides the forwarding method of the signalling packet, NeMoI also needs to send the signalling packet to all the MAs in the network, but HyNeMo does not. In HyNeMo, the signalling packet is only sent to the HA of the producer. These are the reasons why NeMoI has a higher signalling cost than HyNeMo.

The total cost will be a combination of both signalling cost and data delivery cost. For both approaches, the numbers of routers between the user and the router which knows the producer's location (routers that have the routing information of the producer, usually will be HA/MA) will affect the data delivery cost. Therefore, two assumptions will be made: assuming the number of routers between the user and the specific router is maximum or minimum.

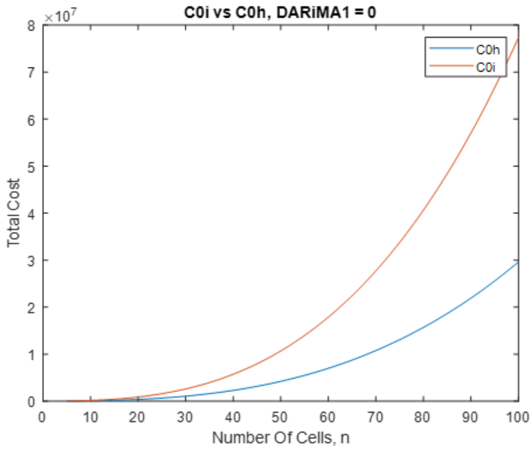

Figure 10. 1st Scenario when DARiMA = 0

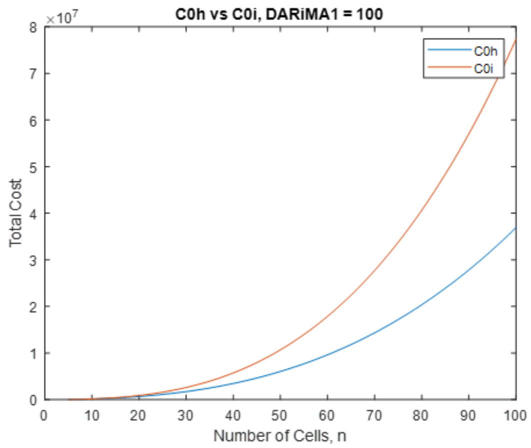

Figure 11. 2nd Scenario when DARiMA = 100

Figure 10 and Figure 11 show that in both of the scenarios, NeMoI still uses more cost than HyNeMo. In Figure 10, the distance between the user and the MA is minimal, and HyNeMo uses less cost. In Figure 11, the distance between user and MA is maximum. Thus HyNeMo will use more cost than NeMoI. However, due to the big difference in the signalling cost, the data delivery cost only slightly affects the total cost. The results clearly show that NeMoI uses more cost than HyNeMo in both situations.

5 Conclusion

This paper evaluates the performances of HyNeMo and NeMoI in terms of transmission and processing time and costs in their signalling and data delivery process. The mathematical equations are formulated, and the numerical results are obtained by using MATLAB. Although we assume one MMN in a moving network, it is easily expanded in the case of multiple MMNs.

HyNeMo uses BIT to transfer the Interest packet and signalling packet. The size of BIT is much smaller than that of FIB, which causes less table lookup time. While NeMoI uses FIB for all the forwarding processes. It also needs to forward the signalling packets to all the MAs. Therefore, it gives NeMoI much more time in the signalling process.

Both of these approaches have similar data delivery costs, but the cost depends on the network topology given. However, with multiple data transmissions within the movement, HyNeMo is still more time-efficient than NeMoI due to its ability to directly send the Interest packet from the user to the producer in its second and fourth deliveries because of the implementation of the routable component inside the Data packet. Thus, when a user receives the data packet with the routable part, it can send the further Interest packets to the producer by the shortest distance. Therefore, it will significantly reduce the time taken for the data delivery.

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Biographies

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