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Performance evaluation of route optimization management of producer mobility in information-centric networking

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ABSTRACT

Named data networking (NDN) is a network service evolving the Internet's host-based packet delivery model. The idea of NDN is to use named data for routing, which specifies what they are looking for, instead of using location addresses that determine where they expect it to be provided. This architecture is expected to solve many issues that are currently faced by transmission control protocol/internet protocol (TCP/IP) architecture, such as scalability, robustness, mobility, security, and etcetera. One of the problems is about handling producer mobility. Considering the explosion growth rate of Internet connection in public transport vehicles, this is a challenge that needs to be overcome. Therefore, we have proposed a new scheme called route optimization management of producer mobility (ROM-P) with new features such as distributing anchor points and caching by using the same data name and com-paring our previous scheme, efficient producer mobility support (EPMS). This paper shows the analysis result between the ROM-P and EPMS by using simulation. All simulations were conducted using ndnSIM 2.4 NS-3 based. Throughout the simulation ROM-P shows a promising development in better performing compares to EPMS.

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1. INTRODUCTION

Nowadays, internet connections are increasing significantly due to business globalization and studying online. Furthermore, public transportation such as buses, trains, and airplanes also allow users to remain connected to the Internet to continue their progress. This is achievable thanks to a build-in cellular network that consists of a mobile router (MR) [1], wireless local area network (LAN), and wireless link to the internet. All mobile networks in transmission control protocol/internet protocol (TCP/IP) architecture were standardized by network mobility (NEMO) [2].

Within all information-centric networking (ICN) architectures, many researchers suggested using named data networking (NDN) as backbone [3]. The idea of NDN is focusing on naming data rather than location addresses that use by TCP/IP. This architecture offers NDN several advantages such as security, caching, and etcetera. However, it also comes with some serious challenges: consumer mobility, producer mobility, and network mobility [4]. One of the most concerning issues is producer mobility [5], which is critical because mobile devices connected to mobile vehicles are increasing exponentially. When the producer node begins to move, the corresponding node cannot reach it, and the routers will need to renew to find out the latest producer node position. This progress will cause network congestion and affect network stability. Hence, some optimization mechanisms such as [6], [7] was introduced to overcome these problems.

In the past, we have published two papers. The first paper [8], referred to as efficient producer mobility support (EPMS), proposed a route optimization in NDN by creating and maintaining the binding information table (BIT) in all access routers for route optimization. These access routers are now acting as anchors, while EPMS is assorted as the anchor-based approach. However, EPMS comes with a critical downside; if it anchors breakdown or malfunctions, this will lead to the BIT table's dysfunction and unable to function correctly. After that, we have created another module called route optimization management of producer mobility (ROM-P) [9]. The main contribution of this work is to show that ROM-P is capable of producer mobility management with distributing anchors that does not need any specific router act as anchor node and apply data-name caching for intermediary routers.

This paper will be organized as the following. Relevant study such as architecture and mobility support of NDN is given in section 2. Section 3 talks about the idea of ROM-P, which includes design basis, route optimization, and others. In section 4, the evaluation for both ROM-P and EPMS is performed to determine an improvement in mobility support. Finally, section 5 is the conclusion and future work.

2. RELATED STUDY

2.1. NDN architecture

Figure 1 depicts basic principles in NDN [3]. First, the consumer node will send an interest packet to the data producer node. Next, intermediary routers will begin to look into their content store (CS) to confirm whether the same named data exist. If positive, a data packet will return to the consumer node. If negative, pending interest table (PIT) will confirm whether a forwarded request with same data name exists. If there is a match in the entry, it will record incoming interface (Face) of this interest into PIT entry and discard request packet. If none, forward information base (FIB) will send interest toward the next router until it reaches the producer node. Producer node will confirm interest and return data packet. With the usage of PIT in access routers, reply packet will now reach consumer node with back tracing the request packet travelled.

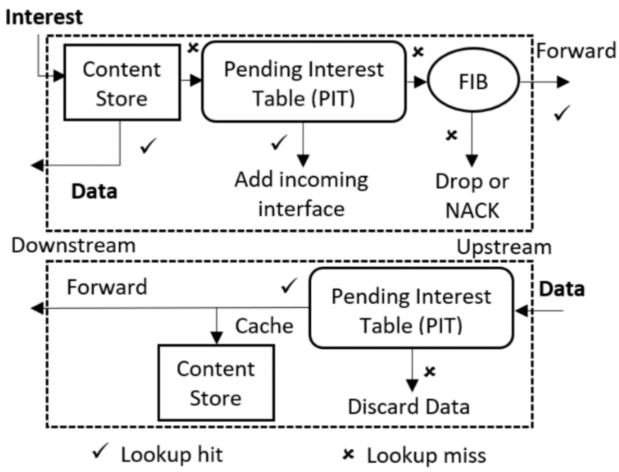

Figure 1. Basic architecture of NDN

2.2. Producer mobility in NDN

Once the producer node starts to move or relocate, the interest packet will not reach since it is still using the outdated FIBs. Furthermore, if FIBs in the involved routers are move, the regular operation will be carried out and time-consuming. Some propositions for mobility support in NDN were suggested such as [5]. There are three approaches for mobility support which was:

2.2.1. Rendezvous approach

Rendezvous proposed a fixed rendezvous node (RN) acting as a finishing role and gives all mobile nodes mobility information [10]. In the beginning, consumer node will send interest packet to RN. Next, it will find producer node's latest position and send packet to it. Whenever producer node wants to relocate, its latest position will be sent to RN and updated. In this approach, the network domain might contain several numbers of RNs [11].

2.2.2. Anchor-based approach

Anchor-based was operated by mobile IP [12] in TCP/IP. This approach is almost similar to Rendezvous approach except that one of the NDN routers will be chosen as an anchor node, also known as home agent (HA), to trace all the new producer mobile nodes' location. First, the consumer node will send an interest packet to HA. Since HA have all the information, including the producer mobile node's new location, the packet will send to the producer node. A tracing-based producer mobility support which analogous to flying a kite (KITE) [13]. It is a tracing-based solution that operates in the forwarding plane by setting up a forwarding path from an immobile rendezvous server (RV) that acts as an anchor node to a mobile producer (MP). Whenever MP moves to a new location, it will send a signed trace interest (TI) to the RV. RV will send signed trace data (TD) back to MP via the path traversed by TI to complete the verification. Upon receiving the TD, all intermediary routers create or update FIB entries for MP’s data prefix. This approach has a fatal disadvantage as it only depends on a single node, the home agent. Furthermore, all packets will need to be relayed through the anchor node, resulting in congestion.

2.2.3. Anchorless approach

Anchorless enables the mobile node to deliver its latest location information back to the former router and passed through routers. This can be achieved when mobile producer goes to another location; it will transmit prefix update message back to the last node. The last node will now act as a home-agent and redirects all approaching interest packet to the new node. Simultaneously, all intermediary routers that received the messages will begin to update the backward path in their FIB, allowing interest packets to go to the new node [14] directly. Another example is managing anchor-less producer mobility (MAP-Me) [15]; it also applies this approach and updates FIBs of related routers to forward to the mobile node. However, this approach can lead to router efficiency problems such as the "triangle routing problem" due to the long distance between the old and new node.

2.2.4. Hop-count based forwarding

Another forwarding strategy for producer mobility was proposed, which is the Hop-count based forwarding [16]. This strategy suggests two additional fields: hop-count threshold (θ) and hop-count (α). In the beginning, the consumer will set value of α to 0 and increment with the following router. First interest is broadcasted since the location of the producer is not known. Next, the value of θ was set to find the producer’s access point. When the producer is unreachable, the value of θ will be reduced, thus increase the number of nodes where interest is forwarded. In the end, the forwarding decision is decided by using values of α and θ. The router will drop the interest when α exceeds the time to live value. Data packet also has the hop-count field as the consumer requires it to estimate θ [17]. However, this approach has a disadvantage that required consumers to check all the routers to find the producer's location and time-consuming.

2.2.5. Anchor-chain approach

Anchor-chain inherits from anchor-based that comes with connectionless characteristic in NDN [18]. It requires to set up anchor-chain, which is a multi-level anchor nodes that transfer interest to producer. Interest can now enter anchor-chain, which is now act as producer, from any anchor then be forwarded to producer. Due to locality of producer’s mobility, the new generated anchor-chain after producer moved will inherit the previous anchor-chain to a large extent and only need to reset the anchor nodes that are close to producer. For interest packets which have entered the old anchor-chain before producer moves, they could now reach the producer along the new anchor-chain after producer moved and do not have to be reissued, which improved the interest response ratio [19]. However, this is not suitable because due to its complexity of creating many anchor-chain and rely on stronger access point signal to define latest location of producer.

2.3. Producer mobility in NDN

Network mobility (NEMO) is a network segment that can move and connect to any point in the internet infrastructure [20]. The mobile network can be accessed via specific gateways called mobile routers (MR), capable of managing its movement. In NDN, Yan *et al.* [21] discusses NEMO. It discusses consumer mobility also proposes how to deliver PIT of MR to access router efficiently. Next, Adhatarao *et al.* [22] offers mobility agents (MAs) that update producer nodes' location information.

3. ROM-P DESIGN BASIS

3.1. Producer mobility

The process will initiate when MP relocates from one location to another. For instance, MP is moving from home access router (AR-H) to foreign access router (AR-F), which display in Figure 2. After MP is transferred to a new place and connects to AR-F, the previous prefix is now sent back to AR-F to update its latest position. An extra entry is now formed inside BIT of AR-F when receiving MP prefix and continuing with MP prefix and AR-F binding information. Next, AR-F will send point-of-attachment update (PU) note back to AR-H. PU is a control message containing AR-H prefix of MP that acts as data-name, MP prefix, and AR-F's prefix in additional fields that returned as interest packet (more details in 3.4).

After AR-H receives PU note, point-of-attachment update acknowledgement (PUACK) note will be sent back to AR-F by using a data packet containing AR-F's prefix data name. This ensures passage among AR-H and AR-F is connected. Next, AR-H will begin with retrieving AR-F prefix's binding information of MP and its current prefix. Furthermore, the incoming PU face number is marked as f0 and recorded inside the BIT to differentiate it with the others. If a consumer begins to ask for the MP's content, interest packet is forwarded to AR-H, as display in Figure 3. Throughout this process, FIB in the related routers will be referred. BIT of AR-H will be check and retrieve forwarding face (f0) as recorded before. Next, AR-H will send interest packet to MP's latest access router, which is AR-F. To return data packet that retrieves from MP, AR-F will forward the data packet back to consumer.

Suppose that intermediary routers exist among AR-F with AR-H. In that case, PU note will update each BIT's entry on the intermediary routers. As display in Figure 4, after the intermediary router (IR-i) obtains PU, fresh entry formed, and incoming face number (fi) will be documented. After AR-H receiving PU, PUACK will begin to forward to AR-F through the predetermined passage. Since BIT entry already has the sending information, FIBs were skipped.

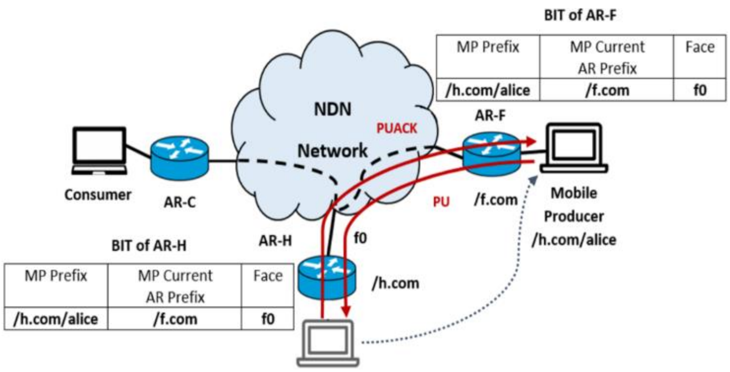

Figure 2. BIT in AR-H and AR-F with updated MP location

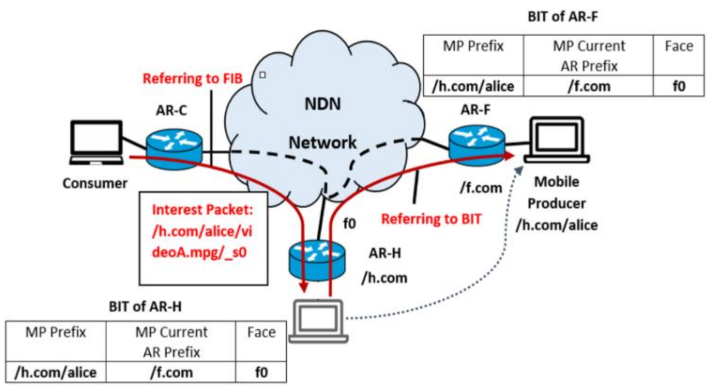

Figure 3. Interest dispatch from consumer to AR-F through AR-H

3.2. Continuous handover

Figure 5 displays that MP is now relocating from AR-F to a new location and then connect to guest access router (AR-G). Like the previous, MP will send a PU from AR-G back to AR-F to update its current location. Then, a PUACK will send to AR-G from AR-F after checking its BIT entry. For ROM-P, AR-H will not receive any PU. This is because the entries inside BITs were assumed to be temporary, which mean it will relinquish after some time if they are not continuously updated. However, if MP remains to connect to AR-G after the determined period, a PU will now send from AR-G back to AR-H to renew BIT entries among the passage. When PU has successfully arrived at AR-H, PUACK will send back to AR-G to complete the process.

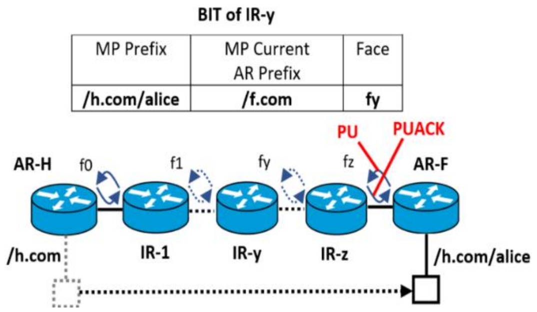

Figure 4. BIT of intermediary routers among AR-F with AR-H

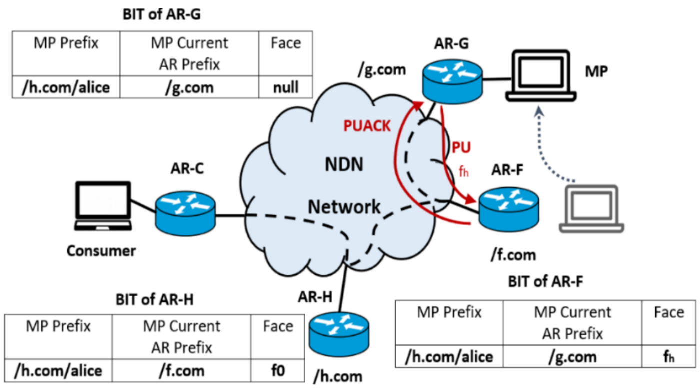

Figure 5. Successive handover of MP

3.3. ROM-P route optimization

Like EPMS, this scheme also requires a piggybacked data packet for the optimization. As display in Figure 3, MP begins to send data packet back to the consumer when it moves to another location. Binding information is now attached to the additional header field of data packet. After data packet arrived in consumer access router (AR-C), its BIT will create a new entry in the binding information as shown in Figure 6. When consumer sends interest packets to MP, it will prepend data name with AR-F prefix and send prepended interest packet directly to MP. After that, data packet will then forward back to consumer through AR-C.

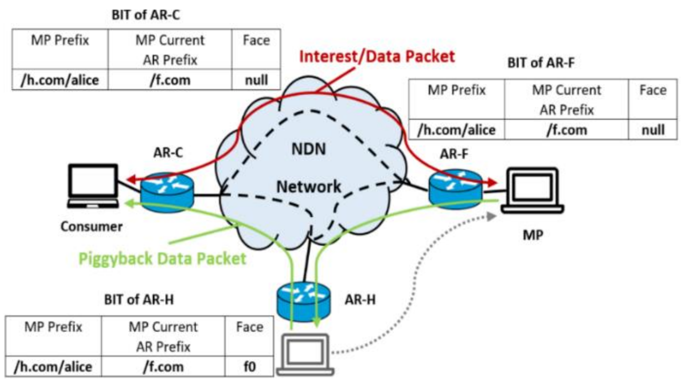

Figure 6. Optimization of ROM-P

3.4. Control message

Control messages of ROM-P display in Figure 7. Guider's domain of interest packet and MetaInfo field of data packet contains additional data, for instance, message type, AR-F prefix, and MP prefix. Message type can be further classified as regular interest/data packet or PU/PUACK packet. Additionally, PU packet consists of "signature" work for protection purposes [23]. Therefore, control message can also apply the original NDN packet formats.

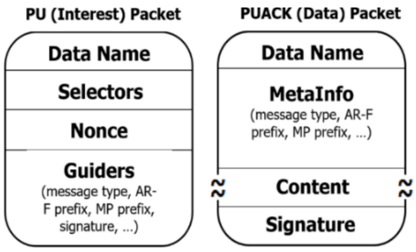

Figure 7. Packet format

4. EVALUATION

To evaluate both mentioned schemes, the performance evaluation is conducted to record the successive handovers between EPMS and ROM-P. The determining factors for their performance are the delivery cost, D, and the signaling cost, S. The proposed scheme will be represented as n. At the same time, the other is designated as o for this section.

4.1. Network mobility ideal

Fluid-flow mobility model [24] was preferred as network mobility model. It was chosen because of its compatibility with a mobile node that travels frequently. MP usually travels in all directions in-between range of (0, 2π) with uniform distribution probability. All apply symbols and parameters were shown in Table 1, stated in Zhang *et al.* [8]. The cell crossing rate is designated with r_c (mobiles/s), and its formula are shown in (1) [25]:

$$r_c = (\rho * v * l)/\pi \quad (1)$$

where: ρ is the density of the MP, mobile/m^2; ν is the average velocity of MP, m/s; and l is the perimeter of a cell, m. Figure 8 shows the network model used. In this case, the distance for the wireless link is specified to be one hop only.

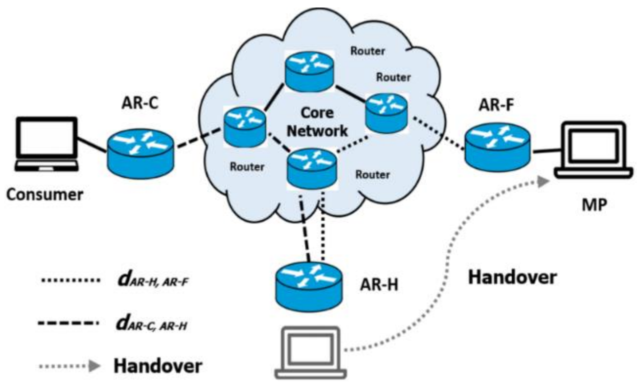

Figure 8. Network model

4.2. Signaling cost

Signaling cost, denoted with S, indicates cost for exchanging signaling messages to update BIT and route optimization. This shows the gap among designated network nodes such as AR-F and AR-C, with several hops' assumptions. dx, y is the distance between x and y. The symbol μ represents units transmitting the wired link cost while ω represents as unit transmitting cost for wireless links. Symbol n defined as number of cells inside the region. P_{bu} indicates binding update cost that occurred when creating a BIT entry. Signaling cost for EPMS will be represented as S_O, and the equation for it will be as (2).

$$S_O = (2\omega + 2 \cdot \mu \cdot d_{AR-H,AR-F} + 3P_{bu}) \cdot r_c n \quad (2)$$

Signaling cost of ROM-P will be represented as S_n, and the equation for it is (3):

$$S_n = \left[2\omega + 2 \cdot \mu \cdot d_{AR-H,AR-F} + PC_{BIT} \cdot \left(d_{AR-H,AR-F} + 1\right)\right] \cdot r_c n \quad (3)$$

where PC_{BIT} is update cost in all intermediary routers among AR-H and AR-F that form extra BIT entries. As shown in (2), 2ω represents the unit transmitting cost of the wireless link between a consumer with AR-C and producer with AR-F. $2\,.\,\mu\,.\,d_{AR-H,\,AR-F}$ represents unit transmitting cost of wired link from AR-H and AR-F back and forth. $3P_{bu}$ is binding update cost in PC_{BIT}, PC_{PIT}, and PC_{FIB}. For (3), the front part is the same except with $PC_{BIT}\,.\,(d_{AR-H,\,AR-F} + 1)$. It represented the update cost at BIT for all intermediary routers and needs to include itself. The whole equation needs to multiply with r_c and n to obtain the actual processing time for the packet to travel.

4.3. Delivering cost

Delivering cost, denoted by D, indicates the transmitting cost of interest and data packet after the handover procedure, which is transferred among consumers and MP. Delivering cost for EPMS, that denoted as D_o, and ROM-P, that denoted as D_n, with their equation are shown as (4) and (5):

$$D_o = \underbrace{\lambda_s \cdot \bar{S} \cdot [(PC_{BIT} + PC_{FIB}) \cdot (d_{AR-C \cdot AR-H} + 1) + (PC_{BIT} + PC_{FIB}) \cdot (d_{AR-C \cdot AR-H} + 1)]}_{FIRST\ PART} + \underbrace{\lambda_s \cdot \bar{S} \cdot [PC_{PIT} \cdot (d_{AR-C.AR-F})]}_{SECOND\ PART} + \underbrace{2.\lambda_s \cdot \bar{S}}_{} \cdot \underbrace{(2\omega + \mu.d_{AR-C.AR-F})}_{THIRD\ PART} \quad (4)$$

$$D_n = \underbrace{\lambda_s \cdot \bar{S} \cdot [(PC_{BIT} + PC_{FIB}) \cdot (d_{AR-C \cdot AR-H} + 1) + PC_{BIT} \cdot (d_{AR-C \cdot AR-H} + 1)]}_{FIRST\ PART} + \underbrace{\lambda_s \cdot \bar{S} \cdot [PC_{PIT} \cdot (d_{AR-C.AR-F})]}_{SECOND\ PART} + \underbrace{2.\lambda_s \cdot \bar{S} \cdot (2\omega + \mu.d_{AR-C.AR-F}) \cdot r_c n}_{THIRD\ PART} \quad (5)$$

where λ_s is session arrival rate; PC_{BIT} is update cost at BIT; PC_{PIT} is lookup cost at PIT; PC_{FIB} is lookup cost at FIB; $\bar{S}$ is average session size of packet unit

Same as the signaling cost equation, the first part of (4) and (5) shows the interest packet processing time in all routers, which consists of $\lambda_s \cdot \bar{S} \cdot [(PC_{BIT} + PC_{FIB}) \cdot (d_{AR-C \cdot AR-H} + 1) + (PC_{BIT} + PC_{FIB}) \cdot (d_{AR-C \cdot AR-H} + 1)]$ and $\lambda_s \cdot \bar{S} \cdot [(PC_{BIT} + PC_{FIB}) \cdot (d_{AR-C \cdot AR-H} + 1) + PC_{BIT} \cdot (d_{AR-C \cdot AR-H} + 1)]$. $PC_{BIT} + PC_{FIB}$ is the total lookup cost at BIT and FIB. Every time an interest packet was sent to a router, it will check its BIT and FIB table whether such interest exists. $d_{AR-C \cdot AR-H}$ is the distance of routers between AR-C and AR-H and needs to include AR-C, which adds 1 more router. $d_{AR-H,\,AR-F} + 1$ is the distance of routers between AR-H and AR-F and needs to include AR-H itself and add 1 more router. The second part shows the processing time for data packet at all routers, consisting of $\lambda_s.\bar{S}.[PC_{PIT}\,.\,(d_{AR-C,\,AR-F})]$. PC_{PIT} is the lookup cost at the PIT while $d_{AR-C,\,AR-F}$ is the distance of routers between AR-C and AR-F. The final part shows transmission time from consumer to MP, $2.\lambda_s.\bar{S}.(2\omega + \mu.d_{AR-C,\,AR-F})$. ω and μ represent unit transmitting of a wireless and a wired link, respectively. 2ω represent the wireless for consumer connect to AR-C and producer connect to AR-F. μ multiply with $d_{AR-C,\,AR-F}$ is representing the routers that connect between AR-C and AR-F with wired cable. The whole part multiply with 2 because we need to calculate time required for sending the interest and getting the data. All parts need to multiply λ_s, the session arrival rate, and the average session size of packet unit to know the actual packet processing time. The significant difference between the old and new is the processing time for interest packet in all routers. The new one, ROM-P, is referred directly to BIT because it already obtained the latest location of AR-F during the signaling process while EPMS still needs to refer to FIB and BIT to send the interest. By utilizing (1) to (5), total costs for EMPS and ROM-P, denoted with C_o and C_n, can be written as in (6) and (7).

$$C_o = S_o + D_o \cdot r_c n \quad (6)$$

$$C_n = S_n + D_n \cdot r_c n \quad (7)$$

4.4. Testbed setup

For the testbed, we prepare a detailed and realistic simulation environment in Ubuntu Linux 16.04.3 LTS, where we compare the time required for both EPMS and ROM-P to complete the process. The simulation is conducted by creating routers AR-C, AR-H, AR-F, and intermediary routers starting from 5 to 100. It is to get the data from different parameters shown in Table 1.

4.5. Test results

As shown in (1) to (7) from section 4.3 were implemented to retrieve all test results for the old and new scheme. The scheme's performance was influenced by the parameters such as the velocity or density of MP. Through the test with variable parameters, both schemes appear to be linearly proportional to the numerical results. This indicates that parameters only have a minor effect on the number of test results. Therefore, parameter settings listed in Table 1 are used to see different results. The tests include the effect of number of cells, effect of velocity of the MNs, effect of session arrival rate, effect of average session size in the packet unit, and the effect of the AR-H and AR-F distance. The test results for both total cost change is shown in Figures 9 to 13.

From Figures 9 to 12, the test result shows that ROM-P's total cost is lesser than EPMS but not very much because they have the same route optimization. In signaling cost, EPMS has a lesser cost compared to ROM-P. EPMS only needs to process the binding update in consumer, home, and foreign access router while ROM-P performs the binding update process in all intermediary routers. Signaling cost for ROM-P is lesser than EPMS because it can directly refer to BIT while EPMS needs to refer to PIT and FIB. However, as the distance between the AR-F and AR-H increases further, the result differs significantly, as shown in Figure 13.

By referring to Figure 13, the total cost for ROM-P has significantly reduced compared to EPMS as the distance between AR-H and AR-F becomes larger. ROM-P only needs to look into BIT due to all routers' continuous handover management between AR-H and AR-F. This allows AR-C to find the location of AR-F easier and faster. On the other hand, EPMS still has to look up at both BIT and FIB of all routers. This process increases the packet delivering cost for EPMS and hence results in a significant difference.

Table 1. Symbols and parameters

Parameter	Value	Unit	Description
n	5 to 100		Number of cells
l	120	M	Cell's perimeter
μ	1		Unit transmitting cost of a wired link
ω	2		Unit transmitting of a wireless link
P_{bu}	2		Process cost of binding update
$d_{AR\text{-}C,\ AR\text{-}H}$	$\sqrt{n}$	Hops	Distance between AR-C and AR-H
$d_{AR\text{-}H,\ AR\text{-}F}$	5 to 100	Hops	Distance between AR-H and AR-F

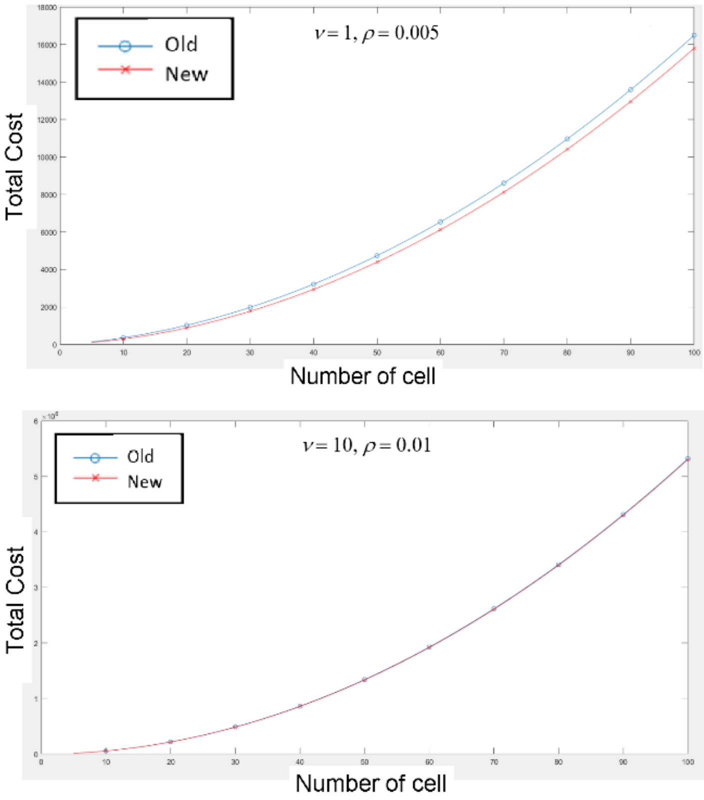

Figure 9. Effect of the number of cells

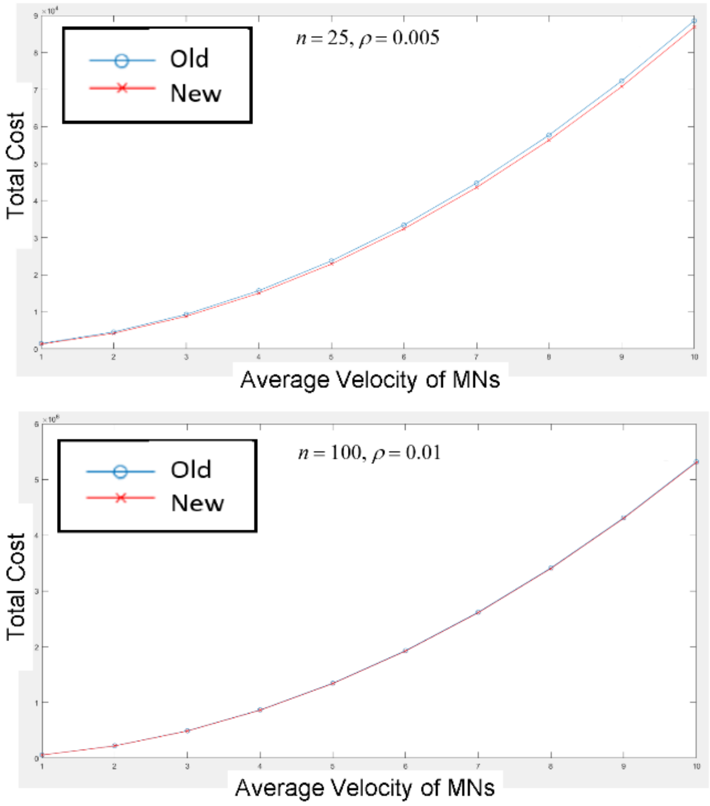

Figure 10. Effect of the velocity of MNs

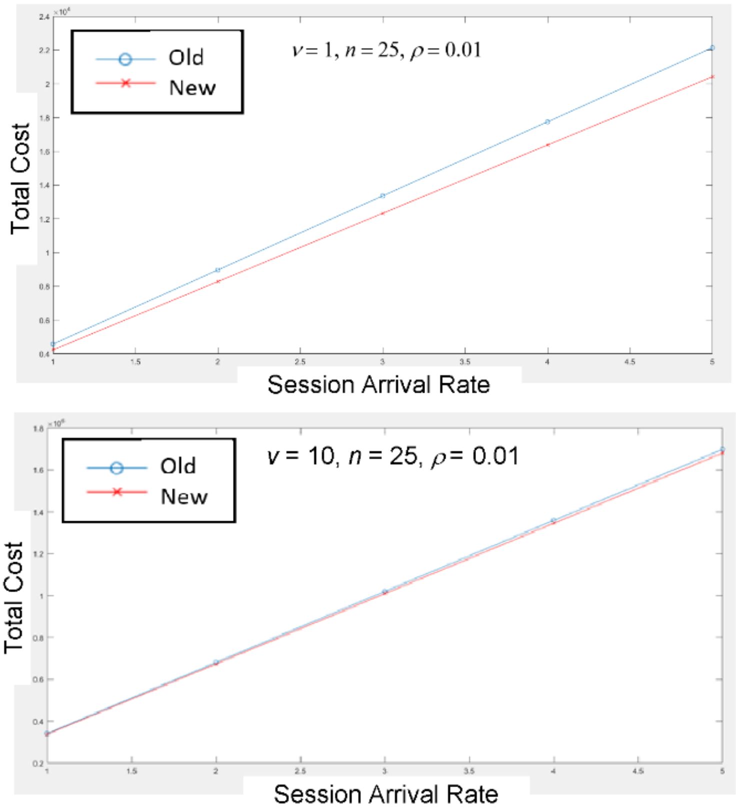

Figure 11. Effect of the session arrival rate

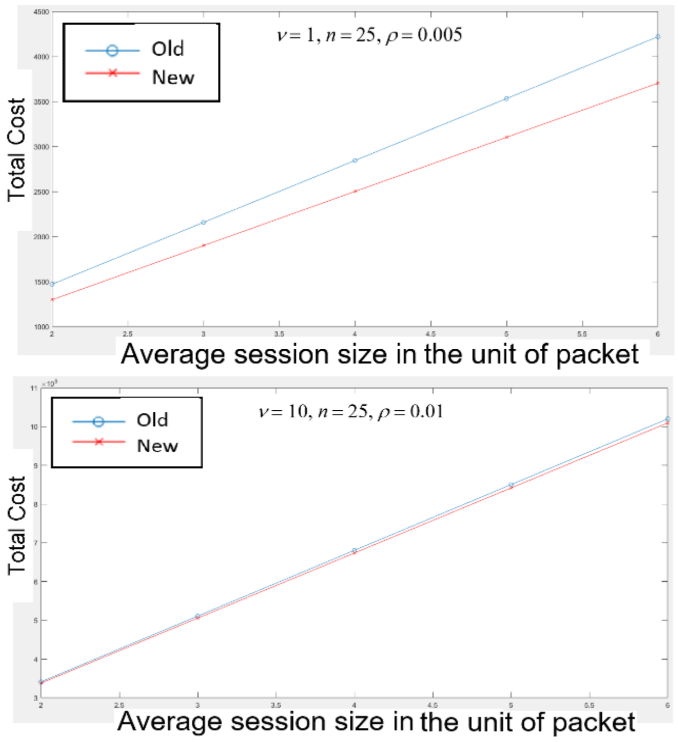

Figure 12. Effect of the average session size in the unit of packet

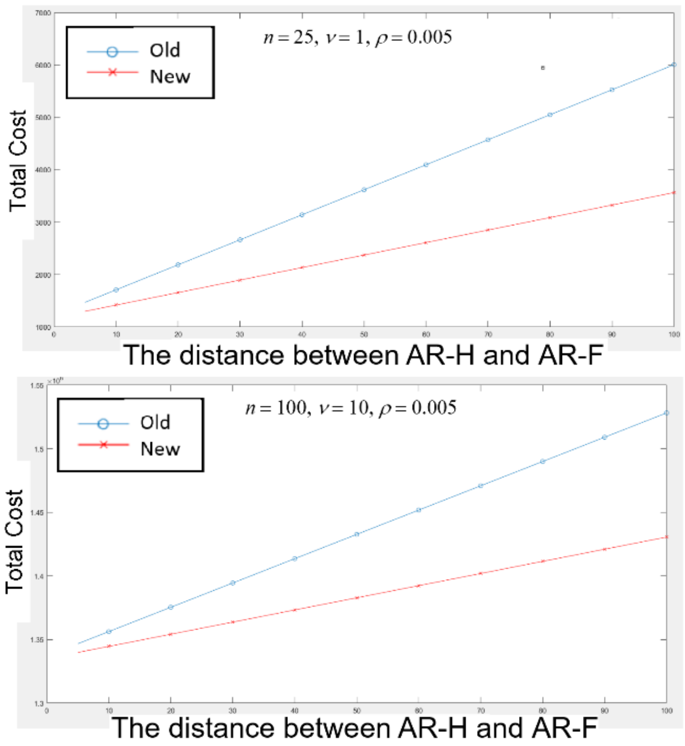

Figure 13. Effect of distance among AR-H and AR-F

5. CONCLUSION

Mobility management, especially producer mobility, is a critical issue in NDN. An optimization ROM-P protocol is suggested to help maintain stability and reduce the packet delivery cost for producer mobility. This proposal forms a new entry called BIT in all access routers. This method with BITs now acts as anchors can help reduce system failure, which is usually caused by anchor damage. The test results show that the proposed ROM-P scheme does succeed in reducing packet delivery costs. Its feature with distributing anchor that allows any intermediary router to act as anchor help to prevent network breakdown and congestion due to constant updating in all routers. Furthermore, the interest packet will always look into BIT first to ensure a matching PIT operation. If none, it will proceed with looking into FIB and continue to the next router until it reaches the routers contain the information. This significantly reduces the time required for the consumer to get the data packet.

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