ROM-P: Route Optimization Management of Producer Mobility in Information-Centric Networking

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Abstract. In recent times, ICN (Information-Centric Networking) attracts interest as an auspicious future Internet architecture, which resolves problems of the current TCP/IP architecture. However, one of challenging problems is how to support producer mobility for explosively increasing mobile devices as well as vehicular communications. This paper proposes efficient producer mobility scheme with devices dynamically moving, considering route optimization. Our scheme, called ROM-P, uses auxiliary FIB (Forward Information Base), referred to BIT (Binding Information Table), which is located on top of FIB and contains producer mobility information. The features of the proposed scheme are: (i) distribute anchor points, which reduces system failure caused by anchor damage and (ii) enable caching using the same data name in comparison with our previous work [3].

Keywords: Information-Centric Networking (ICN) · Producer mobility · Route optimization

1 Introduction

The current TCP/IP Internet has severe challenges in aspects of security, scalability, and mobility. ICN (Information Centric Networking) attracts great interest as a promising future Internet architecture. The TCP/IP uses host-centric paradigm where IP protocol plays a central role and uses location-dependent address to establish communications. On the other hand, ICN takes data-centric paradigm and uses data names to access data instead of IP address as in TCP/IP [1], whereas NDN (Named Data Networking) [2] is the most typical implementation. This paradigm shift produces potentials to cope with the above- mentioned challenges in TCP/IP. However, ICN also has challenging problems to be solved. One of them is producer mobility [5] which is crucial particularly in explosively increasing mobile devices as well as coming connected cars, although consumer mobility is naturally supported in ICN based on its per-packet stateful data plane and caching mechanism. If a producer node moves, the corresponding node cannot continue to communicate with it. Some of routers should be informed about new network attachment information in some way.

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We published a paper [3], referred to as EPMS, which is the first paper realizing route optimization in NDN. It makes use of prepended data name method and supports producer mobility as well as the route optimization by creating and maintaining BIT (Binding Information Table) at Home Access Router (AR-H), Foreign Access Router (AR-F), and Consumer Access Router (AR-C), respectively. As these access routers play a role of anchors, EPMS belongs to anchor-based approach. However, it has downside because the failure of the anchor means dysfunction of BIT table and makes EPMS fatal. Furthermore, a different name is used for caching before and after prepending data name. This paper proposes ROM-P which improves these drawbacks by (i) distributing anchors and (ii) using the same data name in caching, which is anchor-less approach. Performance evaluation shows advantage of ROM-P.

2 Design Principle

2.1 Producer Mobility Management

The mobility operations begin after the Mobile Producer (MP) moves from the AR-H to the AR-F (Fig. 1). When the MP moves and attaches to AR-F, it transfers its previous prefix to the AR-F. When receiving the MP prefix, an entry is made in the AR-F's BIT, which shows the binding information of the AR-F prefix and MP prefix. Accordingly, the AR-F transfers to AR-H a Point-of-attachment Update (PU) message, where the PU message, using an Interest packet, is a control message which has the AR-H prefix of MP (/h.com) as the data name, and also includes the MP prefix (/h.com/alice) and AR-F's prefix (/f.com) in additional fields (which will be mentioned later in 2.4).

When the AR-H gets the PU message, it sends back a Point-of-attachment Update Acknowledgement (PUACK), using a Data packet with AR-F's prefix as its data name, to the AR-F in order to show that the redirecting path between the AR-H and AR-F was established. Then the AR-H gets the binding information of the AR-F prefix of the MP, MP's prefix, and incoming PU face number (f0) for its BIT.

When a consumer asks for the content of the MP, an Interest packet is transferred to the AR-H (Fig. 2). In this operation, FIB is referred at each router for forwarding. Then, the AR-H looks for its BIT entry first and gets the forwarding face (f0) if there is a positive match. The AR-H sends the Interest packet to the AR-F. When the Interest packet arrives at the AR-F, it is transferred to the MP. When the corresponding Data packet is transferred back from the MP, the AR-F forwards it to the AR-H by checking its PIT (Pending Interest Table). The AR-H forwards the Data packet to the consumer in the same way.

If there are several routers between AR-F and AR-H, the PU message updates the entry of each BIT on the intermediate routers in the same way like updating the BIT entry of AR-H (Fig. 3). As shown in Fig. 3, when an intermediate router *i* (IR-*i*) receives PU, a new entry is created and the incoming face number (fi) is also recorded. Upon PU's arrival at AR-H correctly, PUACK is sent back to AR-F along the reversed path. In this scheme, an Interest packet which is a data request from a consumer looks up BIT and can be forwarded between AR-F and AR-H. As the BIT entry gives forwarding information, looking up FIBs are omitted.

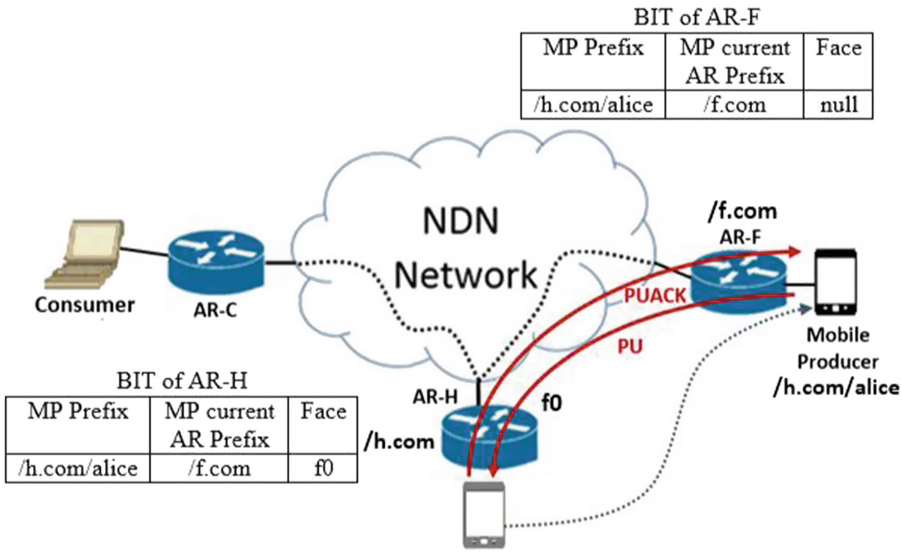

Fig. 1. Creation of BIT at the AR-H and the AR-F

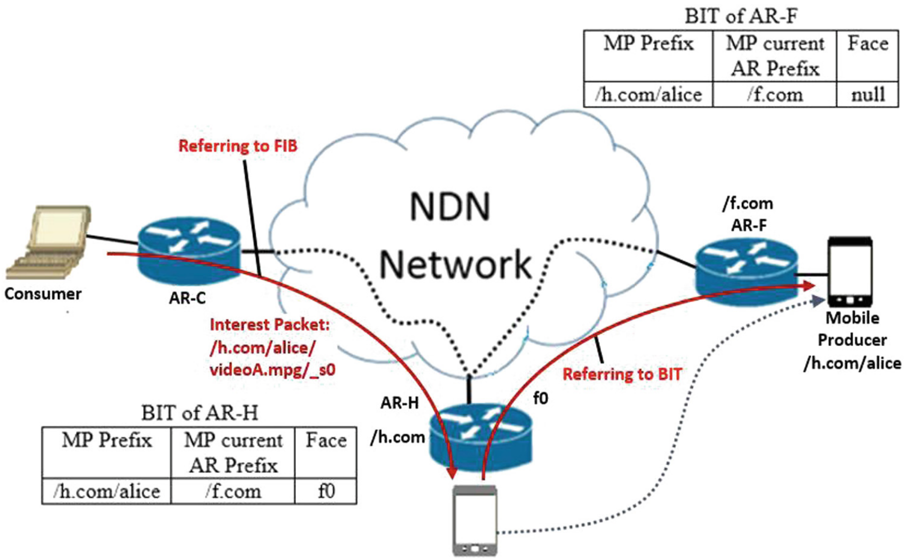

Fig. 2. Interest forwarding from consumer to AR-F via AR-H

2.2 Successive Handover Management

The MP is likely to move successively. Figure 4 shows that it moves into AR-F and then AR-G. PU message is transferred to the AR-F from AR-G and the AR-F's BIT entry is revised like Fig. 4 and PUACK is sent back. In ROM-P, the PU is not further sent to the AR-H. It is assumed that entries of BITs are soft-state. They will disappear after a certain period, if they are not refreshed. When the MP stays in AR-G over a pre-defined time threshold, PU is generated through AR-G toward AR-H to refresh the BIT entries on their path. PUACK is returned when the PU successfully arrives at AR-H.

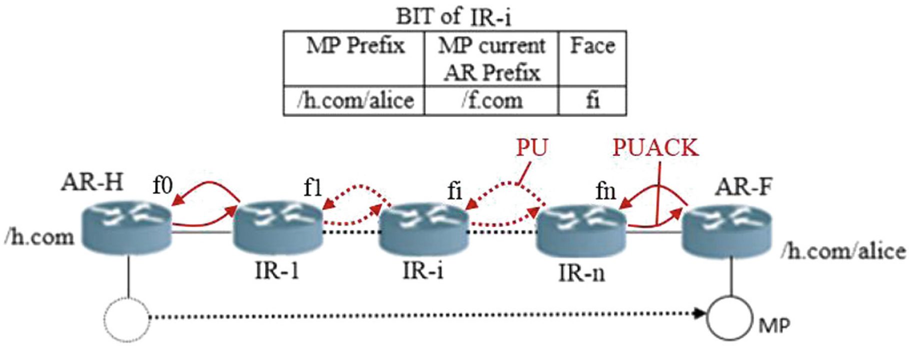

Fig. 3. **BIT** in intermediate routers between AR-F and AR-H

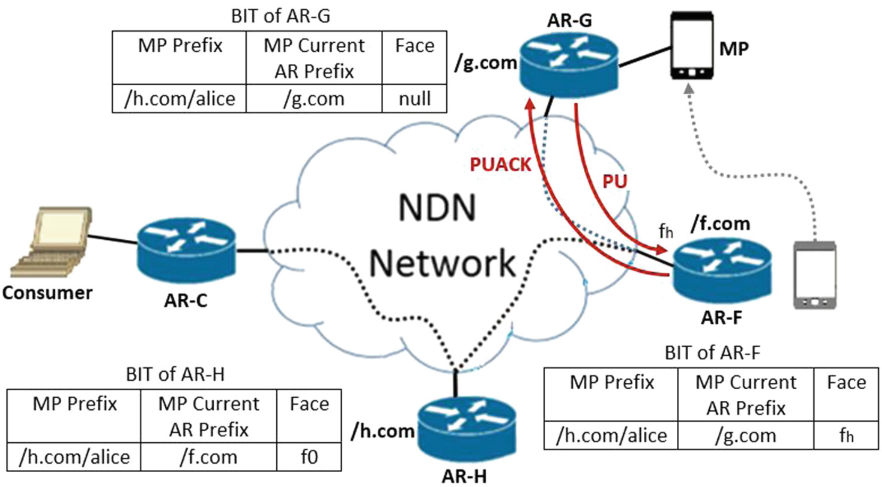

Fig. 4. Successive handover of MP

2.3 Route Optimization

The route optimization uses a piggybacked Data packet like EPMS. In the case of Fig. 2, when MP sends out the Data packet after movement, the binding information (/h.com/alice; /f.com) is placed in the additional header field of the Data packet. This Data packet is sent to the consumer through AR-H. When it reaches the AR-C, the AR-C's BIT makes a new entry for the biding information (Fig. 5).

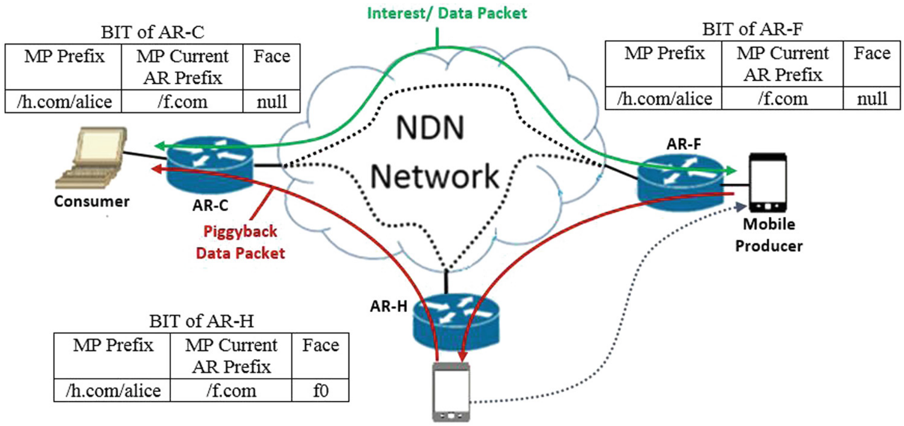

Fig. 5. Route optimization

Afterward when the consumer transfers the following Interest packets to the MP, the AR-C prepends the data name with the AR-F prefix, and the data name-prepended Interest packet (/f.com/h.com/alice) is directly sent to the MP. Then the Data packet is sent back to the AR-C and the consumer.

2.4 Control Message Format

When we refer to the NDN packet formats [2], the control messages in ROM-P are shown in Fig. 6. The "Guiders" field of the Interest packet and "MetaInfo" field of the Data packet have some additive information such as "message type", "AR-F prefix", and "MP prefix". The message type specifies normal Interest/Data packet or PU/PUACK packet. The PU packet contains "signature" for security. In this manner the control messages can make use of the original NDN packet formats.

3 Evaluation

Once PU and PUACK messages are exchanged, a new entry of BIT is created in AR-H, AR-F, and their intermediate routers. As the entry has the field of a forwarding face number, Interest packets which are data requests by a consumer don't need to look up FIB for forwarding in the intermediate routers between AR-H and AR-F. As the size of

FIB is usually much larger than that of BIT, the table look-up time is a lot reduced by ROM-P. Meanwhile, BIT is first checked in routers before looking up FIB. When a route optimization path is via AR-H or one of the by-pathed routers, the above-mentioned advantage is obtained. This is likely to happen, if MP moves in a limited area.

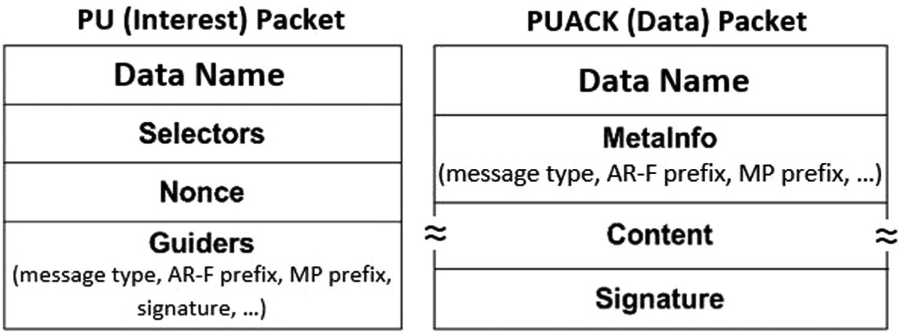

Fig. 6. Packet format

If new consumers connected to AR-H, AR-F and their intermediate routers want to the MP's data, they just need to generate Interest packets, where there are no need for PU and PUACK messages. Because there already exists the corresponding entry of BIT in their routers. When the original consumer moves to one of those routers like Fig. 7, the same is true. However, in EMPS these are not possible, since it has no face field in BIT entries. Therefore, PU/PUACK messages have to be used and the process about data name prepending is done in ARs.

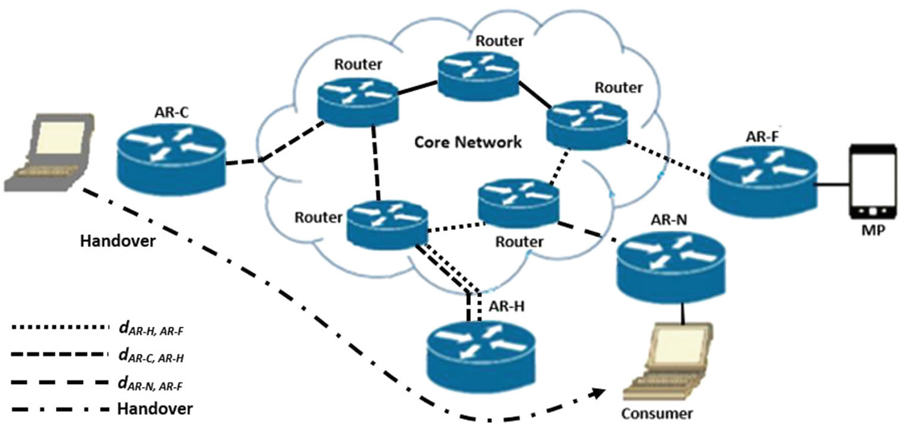

Fig. 7. Relocation of consumer between AR-H and AR-F

Performance evaluation is made about successive handovers in ROM-P in comparison with EPMS.

3.1 Network Mobility Model

As a network mobility model, the fluid-flow mobility [7] model is chosen, due to its suitability for a mobile terminal with a static speed and moving direction. MP moves in any direction within the range of (0, 2) with a uniform distribution probability. Table 1 contains the parameters and notation used, which is referred from [3] with slight modification. r_c (mobiles/s) is the cell crossing rate as shows below [8]:

$$r_c = (\rho * v * l)/\pi \tag{1}$$

in which l denotes the perimeter of a cell (m), and v (m/s) and ρ (mobiles/m^2) show the average velocity and density of the MP, respectively. The network model used here is shown in Fig. 8, where the wireless link is assumed to be one hop.

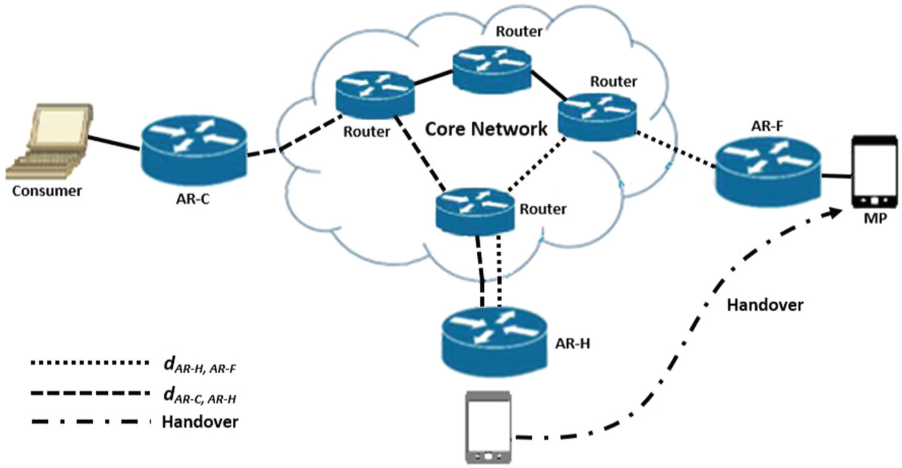

Fig. 8. Network model

Table 1. Parameters and notation

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

3.2 Signalling Cost

The signalling cost, represented by S, shows the cost of exchange of signalling messages, which are used for updating BIT and route optimization. It reflects the distance between two network nodes like the AR and MP, assuming that the distance indicates the number of hops. $d_{i,j}$ is the distance between network nodes i and j. μ and ω indicate the units of the transmitting cost of wired and wireless links, respectively. n is the number of cells within a domain. P_{bu} is the processing cost of binding update, which is the cost caused by making a BIT entry [3].

The signalling cost of EPMS, represented by S_o, can be calculated as the following equation:

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

The signalling cost of ROM-P, represented by S_n, is expressed as follows:

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

where PC_{BIT} is the update cost at each intermediate router between AR-H and AR-F to create a new entry of BIT. The first term of the square bracket in Eq. (3) represents the transmission cost from the AR-H to AR-F. The second term represents the update cost for all intermediate routers between the AR-F and AR-H.

3.3 Packet Delivering Cost

The packet delivering cost contains the transmitting cost of the Interest and Data packet after the handover process, which is transmitted between the consumer and MP. The packet delivering cost of EPMS and ROM-P, represented by Do and Dn respectively, are expressed as follows:

$$\begin{aligned} Do = {} & \lambda s \cdot \overline{S} \cdot [(PC_{BIT} + PC_{FIB}) \cdot (d_{AR\text{-}C,AR\text{-}H} + 1) + (PC_{BIT} + PC_{FIB}) \cdot (d_{AR\text{-}H,AR\text{-}F} + 1)] \\ & + \lambda s \cdot \overline{S} \cdot [PC_{PIT} \cdot (d_{AR\text{-}C,AR\text{-}F})] \\ & + 2 \cdot \lambda_s \cdot \overline{S} \cdot (2\omega + \mu \cdot d_{AR\text{-}C,AR\text{-}F}) \cdot r_c n \end{aligned} \tag{4}$$

$$\begin{aligned} Do = {} & \lambda s \cdot \overline{S} \cdot [(PC_{BIT} + PC_{FIB}) \cdot (d_{AR\text{-}C,AR\text{-}H} + 1) + PC_{BIT} \cdot (d_{AR\text{-}H,AR\text{-}F} + 1)] \\ & + \lambda s \cdot \overline{S} \cdot [PC_{PIT} \cdot (d_{AR\text{-}C,AR\text{-}F})] \\ & + 2 \cdot \lambda_s \cdot \overline{S} \cdot (2\omega + \mu \cdot d_{AR\text{-}C,AR\text{-}F}) \cdot r_c n \end{aligned} \tag{5}$$

in which λ_s is a session arrival rate, $\overline{S}$ is an average session size in the unit of packet, PC_{BIT} is the update or lookup cost at BIT, and PC_{PIT} and PC_{FIB} are the lookup cost at PIT and FIB, respectively. The first terms of Eqs. (4) and (5) represent the Interest packet processing time at all routers from AR-C to AR-F. The second term represents

Data packet processing time at all routers. The last term represents the transmission time from the consumer to the MP.

Using Eqs. (1) to (5) gives the total costs for the EPMS and ROM-P, represented by *Co* and *Cn* respectively, which are as follows:

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

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

3.4 Numerical Results

Numerical results are calculated for Eqs. (6) and (7). Our ROM-P indicates better performance than EPMS. Figure 9 shows the effect of the number of cells, where v = 1, $\rho = 0.005$ and $d_{AR\text{-}H,\,AR\text{-}F} = 10$. Figure 10 shows the effect of the velocity, where n is set to 25, $\rho = 0.005$ and $d_{AR\text{-}H,\,AR\text{-}F} = 10$. Figure 11 shows the effect of the distance between the AR-H and AR-F, where n is set to 25, v = 1 and $\rho = 0.005$.

From Fig. 9, we can see that the total costs for *Co* and *Cn* do not show significant difference at the beginning. However, as the number of cell increases, the total cost of *Cn* becomes much lower due to the signalling cost in each intermediate router. The same phenomena are shown in Figs. 10 and 11.

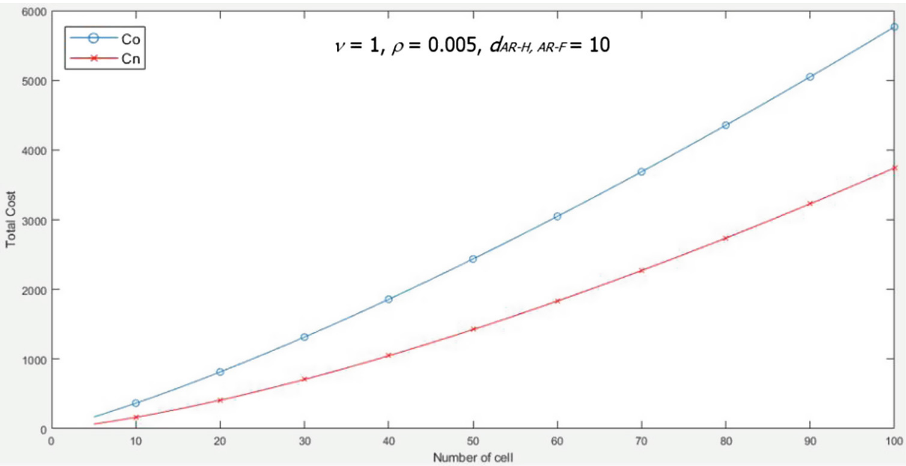

Fig. 9. Effect of the number of cells

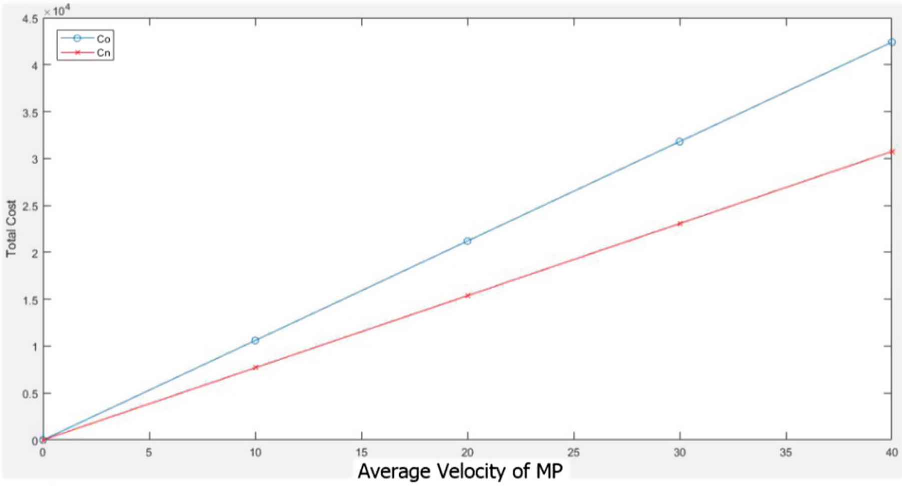

Fig. 10. Effect of MP's velocity

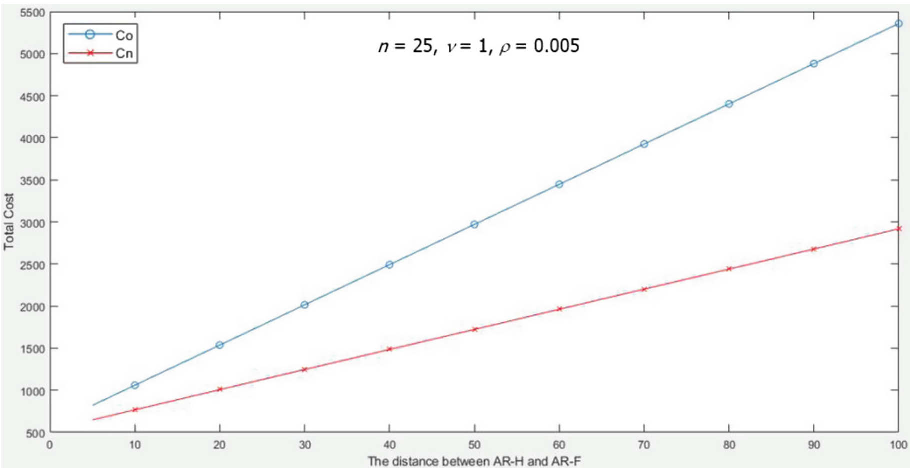

Fig. 11. Effect of the distance between AR-H and AR-F

4 Summary and Conclusion

Our scheme, ROM-P, creates a new entry on BIT in AR-H and AR-F, including their intermediate routers. In this way, BITs, namely anchors, are distributed on routers, and it reduces system failure caused by anchor damage. Caching can be made by the original data name on intermediate routers between AR-H and AR-F unlike EPMS.

An Interest packet should look up BIT first when there is no positive match in a PIT operation, and then if there is no positive match, it will look up FIB. The performance evaluation is made and shows that ROM-P is better that EPMS.

As BIT plays a role of auxiliary FIB by recording producer mobility information. In reference [4], producer movement updates FIBs of by-pathed routers but no other routers. Considering link-state routing protocols such as Named data Link State Routing protocol (NLSR) [6] like OSPF in IP protocol, all routers in the same domain have to keep the common routing database. MP movement should be immediately noticed to all the routers and the synchronization of the link-state database should be made, which means too much overhead.

Regarding the route optimization, caching is still made by prepended data name. Whether or not it should be used is dependent on sort of applications and network conditions. For example, when mobile devices are moving in high speed, the route optimization should be used. When not only is communication traffic volume or channel capacity small but redundancy of a route by route optimization is also low, the route optimization may not be used.

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