A Conceptual Model of Producer Mobility Support for Named Data Networking using Design Research Methodology

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***Abstract*—Named Data Networking is the clean-slate architecture and most recent designed approach under the umbrella of Information-Centric Networking architectures; that supports infrastructures less network structure, proposed to support content mobility and use hierarchical naming instead of IP addresses. Hierarchical naming structure of Named Data Networking architecture offers some benefits in supporting mobility. However, the architecture lacks sustainable producer mobility support as the entire network lacks the knowledge of content producer movement when moves to a new location, thus, causing a change of routing name prefix hierarchy. The hierarchical naming prefix changes cause significant challenge, such as high handoff latency, signaling overhead cost and unnecessary Interest packets losses. This paper proposed a conceptual model of producer mobility support using Design Research Methodology to address the problems. Two models' reference and the initial model was proposed to evaluate the success criteria and measurable success factors or metrics that influence the support of producer mobility. The result indicated that the provision of producer mobility knowledge using broadcast strategy and mobility update significantly reduces the handoff latency, signaling overhead cost and unnecessary Interest packets losses. Hence, improved the quality of data packets delivery.**

***Index Terms*—Mobility Support; Named Data Networking; Producer Mobility; Seamless Mobility.**

I. INTRODUCTION

AMONG the recent future Internet architectures generally known as Information-Centric Networking (ICN), Named Data Networking (NDN) is the clean-slate redesigned and most recent approach; that supports infrastructures less network architecture [1]. NDN was proposed to support mobility, provides network scalability and security due to the nature of its hierarchical naming architecture. Hierarchical naming structure of NDN architecture offers some benefits in supporting mobility, especially for the content consumer perspective, such as multicasting, route aggregation, in-network catching and improvement of scalability. NDN is a promising architecture that hopes to replace IP Internet architecture in the near future and is ready to be applied in different field such as, 5G network [2]–[5], IoT [6], [7], Wireless Sensor Networking [8]–[12], Space-Terrestrial Integrated Network [13], real-time application [14] and Vehicular Network [15], [16]. By default, NDN architecture as an approach of ICN was designed to support mobility, however, many issues arose for the support of source content mobility [17]–[20]. However, the architecture lacks sustainable producer mobility support, as the entire network lacks the knowledge of content producer movement when moves to a new location, thus, causing changes of routing name prefix hierarchy. Zhu et al. [21] discover that the mobility of content consumer is support in NDN, whereas mobility content producer faces many challenges as in IP architecture. Moreover, he suggested that the name needs to be decoupled between the content identifier and content locator and mapped between them after the change of location. Saxena et al. [22] surveyed general support of mobility in NDN, stated that mobile content consumer was inherently supported, while mobile content producer faces many challenges. The given assertion is the same as Feng et al. [23]. In addition, Feng et al. express that mobility is support in NDN for the content consumer by means of data leverage for in-network caching. Therefore, some researches were attempted to provide the solution to producer mobility and improved consumer mobility using mobility link service [24]. Hence, sustainable producer mobility is needed for NDN to be perfectly integrated into 5G, IoT as well as wireless sensor networking for seamless mobility.

Consequently, this paper used Design Research Methodology (DRM) [25], [26] to propose a conceptual model for the solution of producer mobility support. The goal of this paper using DRM as a method to design a conceptual model for the validation of founded support and theories about the designed phenomenon for the improvement of producer mobility support design practice in NDN. The solution may lead to the proposal of different analytical or mathematical models to verify and validate the different design of mobility support proposed ideas. Given the long introduction about NDN content consumer and producer mobility, some statement of the problem deduces

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from the literature and presented in Section two. Followed by a conceptual model design of producer mobility support scheme, using DRM graphical representation. Section four is the model analysis, result analysis and discussion, then the conclusion of the paper.

II. PROBLEM STATEMENT

Mobility support for ICN architectural perspectives was divided into consumer mobility and producer mobility [17], [18], [27]. By default Named Data Networking architecture support consumer mobility automatically by using stateful forwarding plane to send requested data to mobile consumers [28], [29] Saxena et al. [22] and Feng et al. [23] reported that mobility of content consumer is positively supported in NDN, when it relocates to another domain or point of attachment (PoA), the content consumer willingly resend unsatisfied Interest packets towards the content producer. However, the content producer mobility support was left unspecified [28], introduces significant scalability challenge [30], faces some problems similar to IP mobility, such problems are routing table size scaling [21], unnecessary Interest packet losses and long handoff delay or latency [31], [32]. In addition, influences high bandwidth utilization due to frequent routing update for a large network domain [30], [33].

In NDN, when mobile content producer relocates while transmitting data to the content consumer that requested it, the name prefix of mobile producer automatically change with a new prefix that not known by the network and consumers [34]. Hence, the communication would be interrupted as the entire network lacks knowledge about the movement of the content producer. On the other hand, the content consumer continuously sending unsatisfied Interest packet towards the previous location of the content producer. The interruption occurred as a result of changed the hierarchical location, which resulted to have a new name prefix and caused stale breadcrumbs inside FIBs [21].

For NDN to support the mobility of content producer, there is needs to address the following issues: decoupling of a name identifier and name locator from the name prefix, mapping of a name identifier and name locator once content producer attached to new Point of Attachment (PoA). After the completion of handoff process, a mobile content producer must provide a way for Interest packets request to reach content producer's new location and unsatisfied or pending Interest packets should be routed towards the location of content producer on mobile.

III. CONCEPTUAL MODEL ANALYSIS

The DRM proposed the use of networks of influencing factors for the model representation and explanation to describe the existing and desired situations of the conceptual model. The two different networks of influencing factors are first, the Reference Model that described the actually existing situation in the conceptual design and served as the reference model against the intended solution to benchmark and quantified the improvements. Secondly, the Impact Model that represents and described the desired situation in the conceptual design and shows the proposed impact of the desired solution support to be developed [25], [26].

A. *Graphical Representation*

Consider Figure 1 that shows the influencing factor which is mobility support serves as an attribute of an element producer. The three-factor or influencing factors depicted are handoff and signaling cost, producer mobility support and knowledge of producer movement. The influential factors are categorized into influential factors, key factors, success factors, measurable success factors in which were related to one another via a link. The links between factors are determined by the attribute of a given factor and it shows how the two or more factors influence one another or are anticipated to influences each other. In a nutshell, a single link represents explicit statements about the situation of the factors connected to the existing in the case of an initial reference model or desired situation for the impact model.

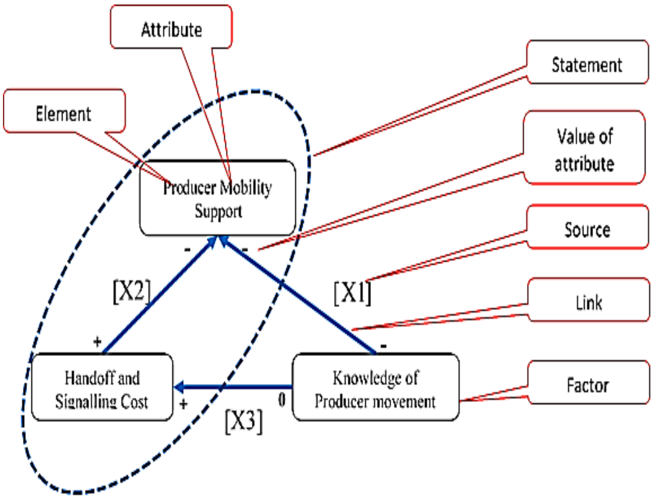


Fig. 1. Graphical representation of a statement and associated modeling terminology

B. *Initial Reference Model*

This section proposed graphical representations of the initial reference model for producer mobility support conceptual model. The initial reference model is presented to exhibit relationships between the influencing factors, attributes and values, and concepts in a visual diagram to represent the level of understanding about the research problem for the existing situation that needs to be addressed [35]. The influencing factor is the facet of the existing situation in the case of a reference model or facet of the desired situation in a case of impact model. A given situation is graphically represented by the factors available influencing the existing or desired situation and there exist some links between the factors, see Figure 2.

There is a direct relationship between knowledge of producer mobility movement and producer mobility support factor originated from the literature (Figure 2). Lack of knowledge on the whereabouts of the producer in the network domain resulted in poor mobility support that disrupted seamless mobility. On the other hand, causes high handoff latency and signaling overhead cost. Therefore, the link between knowledge of producer movement and handoff and signaling cost have a high impact for seamless mobility in NDN. The '+', '-' and '0' label indicates the value impact of an attribute attached to the link, which can be a quality or quantity such as, good, bad, high or low, etc depend on the research terminology or definition of a particular study.

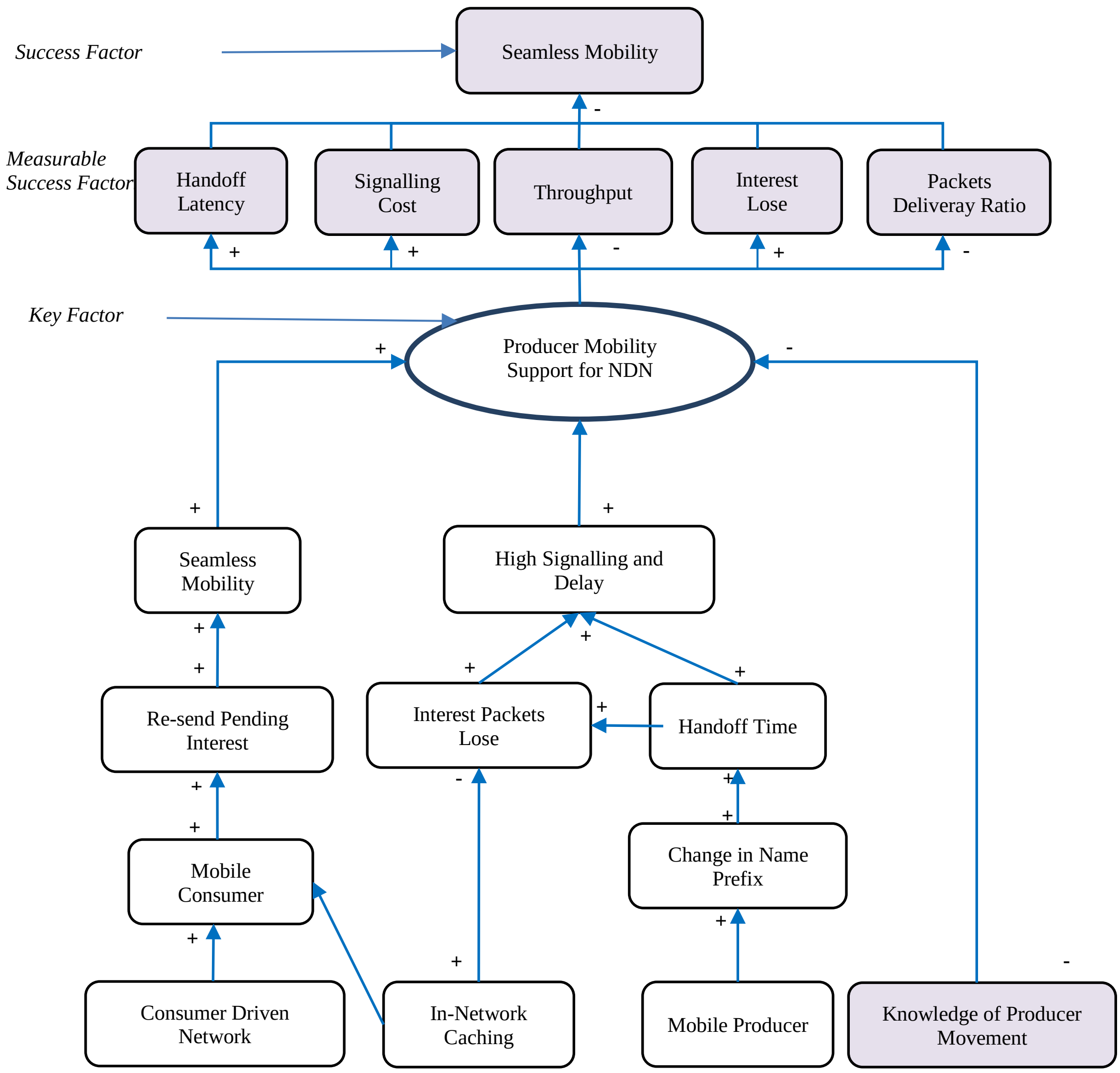


Fig. 2. Reference Model of Producer Mobility Support in NDN

TABLE I
MEASURABLE SUCCESS FACTORS OF REFERENCE MODEL

Factor Key Factor	Measurable Success Factors	Success Factor	Value	Elements	Link
PMS	1. Handoff latency	Seamless Mobility	High	Interest loss and High signaling cost	+
	2. Signaling cost		High	Producer Mobility support	-
	3. Throughput		Low	Packets delivery	-
	4. Interest loss		High	Change in name prefix	+
	5. Packets delivery		Low	Seamless mobility	-

The appearance of '+' and '0' on a link between handoff and signaling cost described the value of the two factors. For (0) it was found from the literature that lack of knowledge of the producer movement causes high handoff latency and high signaling overhead cost, the (+) shows that the handoff latency and signaling cost is high as a result of lacking producer movement information. The case (-) from the side of producer mobility support described that both handoff and signaling cost, knowledge of producer mobility degrades the producer mobility support.

C. *Factors*

The factors or influencing factors are nodes that represented a situation that influences other aspects of the existing or desired situation which can cover all facets of design. A factor can be formed from the literature, assumption, focus, question, hypothesis, experience or research goal. In addition, factors that are links together represent a particular situation that can be observed, assessed or measured. In this paper, the influential factors are divided into a key factor, success factor and measurable success factor. The key factor is the most useful factor that is considered as core or root factor needs to be addressed to improve seamless mobility, which will be addressed directly by providing Producer Mobility Support (PMS) through knowledge of content producer mobility. A success factor is always at the end of the cause-effect chain or top of the network named as seamless mobility (see Figure 2 and 3). The measurable success factors are linked directly with the success factors and can be applied to quantify or judge the outcome of this research. In this paper, five measurable success factors were provided such as Handoff Latency (HL) Signaling Cost (SC), Throughput (TH), Interest Packet loss (IL) and Packets Delivery (PD). Table I summarized the list of factors for the initial reference model, their values, elements, and link. The links between two or more influential factors show how the factors desired to directly influence or influences each other.

IV. CONCEPTUAL MODEL DESIGN

Based on initial reference model presented in Figure 2, the conceptual model of producer mobility support for named data networking can be designed as the impact model, that represents the desired situation to encounter the existing situation as presented in the reference model. The conceptual model is represented as a graphical representation of the desired situation or a solution of producer mobility support problem. Reference to initial reference model in Figure 2, Table II was presenting the influence between factors causing the problems of producer mobility support.

From initial reference model, we have discovered that NDN lacks the knowledge of producer movement, resulted in causing high handoff latency and signaling cost, the poor throughput of data, losses of unnecessary Interest packets and poor data delivery. However, two supporting influential factors were introduced to provide the network with adequate content producer's movement information to address the key factor in achieving seamless mobility. The supporting influential factors are producer mobility update Interest packet and broadcasting strategy to update the intermediate routers as presented in Figure 3. In addition, Table III summarized the list of factors for conceptual or impact model, their values, attributes, and link.

A newly mobility update packet is proposed as influencing factor similar to binding update [44], [45], mobility management packet [33], [46], [47],forwarding hint [31], [44], traced and tracing Interest [48], [49]. However, in this mobility update packet two attributes were added, namely, a mobility flag that indicates the status of producer that is either stable or on mobile and a filed for new name prefix that has the hierarchy of new location.

A broadcasting strategy is introduced as a supporting influential factor that carries the movement information of producer on mobile to the intermediate routers to be aware and tracked the new location of the content mobile producer. The two supporting influential factors are the basic factors proposed for the provision of a producer's mobility knowledge to the entire network to attain the desired goal of NDN seamless mobility.

TABLE II
STATEMENTS BETWEEN INFLUENCING FACTORS DERIVED FROM THE LITERATURE

S/N	Influencing Factor	Factor	Statement	References
S1	Consumer Driven Network & In-network catching	Mobile Consumer	The consumer-driven nature of NDN architecture influences the smooth movement of the mobile consumer.	[21], [23], [28], [36]–[38]
S2	Mobile Consumer	Re-send pending Interest	The mobile consumer can simply resent un-satisfied Interest towards the location of the producer.	[7], [21], [33], [38], [39]
S3	Re-send pending Interest	Seamless mobility	Re-sending of unsatisfied Interest leverage and support seamless mobility of mobile consumer.	[7], [21], [33], [38], [39]
S4	In-network caching	Interest packets loss	In-network caching reduces the number of unnecessary Interest packets losses.	[21]–[23]
S5	Producer Mobility	Change in name prefix	When the producer move to a new location, its name prefix would automatically change.	[1], [21], [28], [38], [40]–[42]
S6	Change in name prefix	Handoff time	Change in name prefix causes a lot of issues including the increase of handoff latency.	[21], [28], [38], [40], [41]
S7	Handoff time	Interest packets loss & High signaling and delay	High handoff latency causes Interest packets loss & high signaling cost and delay	[31]–[33]
S8	Interest packets loss	High signaling and delay	Interest packets loss influences high signaling cost and delay	[31]–[33], [43]
S9	Seamless mobility, High signaling and delay & Knowledge of producer movement	Producer mobility support for NDN	Seamless mobility and reduction of high signaling and delay & provision of Knowledge of producer movement formed a support for producer mobility in NDN	[14], [31]–[33], [43]
S10	Producer mobility support for NDN	Handoff latency, Signaling cost, Throughput, Interest loss, Packets delivery	Producer mobility support for NDN provides seamless mobility and reduction of high signaling and delay & provision of Knowledge of producer movement	[14], [31]–[33], [43]

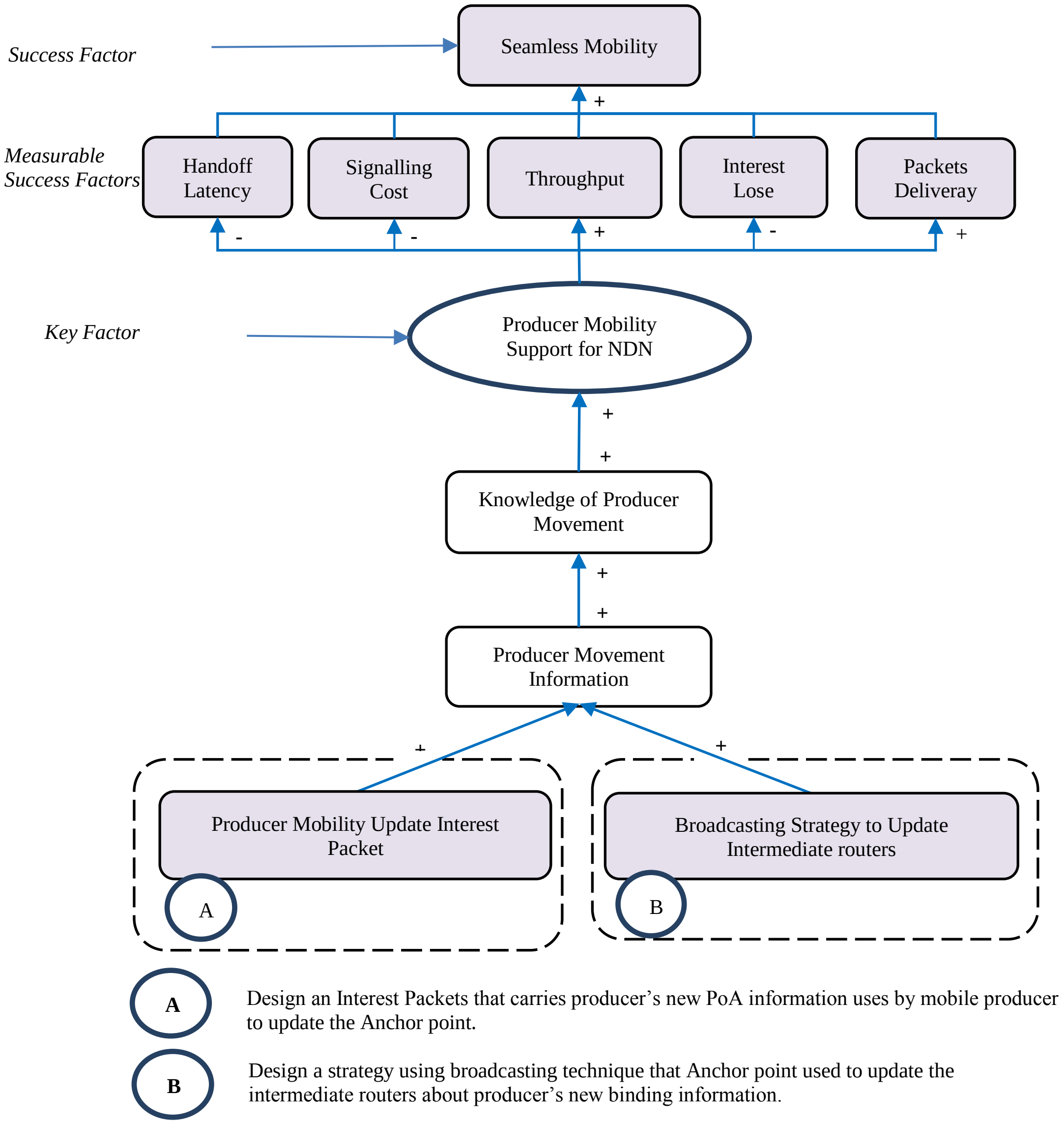
TABLE III
MEASURABLE SUCCESS FACTORS OF IMPACT MODEL

Key Factor	Factor Measurable Success Factors	Success Factor	Value	Attribute	Link
PMS	1. Handoff latency	Seamless Mobility	Low	Mobility support	+
	2. Signaling cost		Low	Mobility support	-
	3. Throughput		High	Packets delivery	-
	4. Interest loss		Low	Knowledge of producer movement	+
	5. Packets delivery		High	Mobility update and broadcast strategy	-

The conceptual model presented in Figure 3, which can be named or represented as an impact model according to DRM terminology is described in Table IV. The table expressed the influence of supportive factors proposed for the solution of content producer mobility in NDN. The two main supportive influential factors are producer's mobility update packet and broadcast strategy to update intermediate routers, works hand-in-hand to provide factor knowns as producer movement information (Update) that influence the availability of Knowledge of producer movement to provide seamless mobility. The factors, statements and their impact is highlighted in Table IV.

TABLE IV
SUPPORTIVE INFLUENCING FACTORS OF THE CONCEPTUAL OR IMPACT MODEL

S/N	Support Influencing Factor	Factor	Statement	Impact
S1	Producer's Mobility update packet	Producer movement information (Update)	Design Interest Packets that carry producer's new PoA information uses by the mobile producer to update the Anchor point.	Contains the mobility update information
S2	Broadcast strategy to update intermediate routers	Producer movement information (Update)	Design a strategy using a broadcasting technique that Anchor point used to update the intermediate routers about the producer's new binding information.	Update the intermediate routers
S3	Producer movement information (Update)	Knowledge of producer movement	Routers receive an update from producer's mobility update package.	Locate the new location of the producer
S4	Knowledge of producer movement	Producer mobility support for NDN	The whole network aware of the movement of producer, thus, support seamless mobility of producer in NDN	Provides optimal data delivery



Design an Interest Packets that carries producer's new PoA information uses by mobile producer to update the Anchor point.

Design a strategy using broadcasting technique that Anchor point used to update the intermediate routers about producer's new binding information.

Fig. 3. Conceptual Model (Impact Model) of Producer Mobility Support

V. CONCEPTUAL MODEL DISCUSSION

For the conceptual model design of producer mobility support in Named Data Networking, with the aims at providing seamless mobility, when content producer moves to a new location that causes changes to a new name prefix. Formulating a criterion for success is crucial, to determine whether the solution help to achieve the desired goal. Hence, criteria are needed for the evaluation of the research outcome against the research aim and goal. The result presented all the measurable success criteria and their influences on achieving the seamless mobility in NDN as a goal or success criteria of this research. However, each measurable success factor of existing and desired situation for the initial and impact model have been analyzed separately. Figure 3 and 4 describes the measurement of success factors as low or high.

Figure 4 shows that the five measurable success factors of the initial reference models, such as HL, SC, IL, TH, and PD are core indicating factors that influence the failure of NDN to provide seamless mobility for the content producer. The graph indicated that once HL and SC are high, the throughput of Interest and data packets will drop significantly to the lower level. Moreover, the IL will significantly increase which may result in poor data packet delivery.

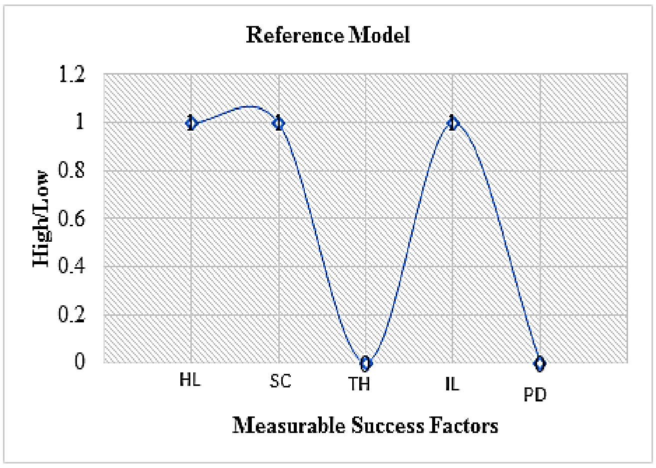


Fig. 4. Measurable Success Factors for Reference Model

However, Figure 5 counter affect the initial reference model once the solution is provided, that is, the five measurable success factor of impact model is core indicating factors that influence the success of the desired situation for NDN to support producer mobility. The result indicated that once HL and SC are low, the throughput of Interest and data packets will increase significantly to a higher level. Also, influence the reduction of unnecessary Interest packet losses which may result in good and optimal data packet delivery. The reason for lacking seamless mobility support is the knowledge of content producer whereabout in the network domain. Therefore, the result presented in Figure 5 shows that the producer's mobility update packet and broadcast strategy to update intermediate routers influence seamless mobility by providing movement knowledge to support producer mobility.

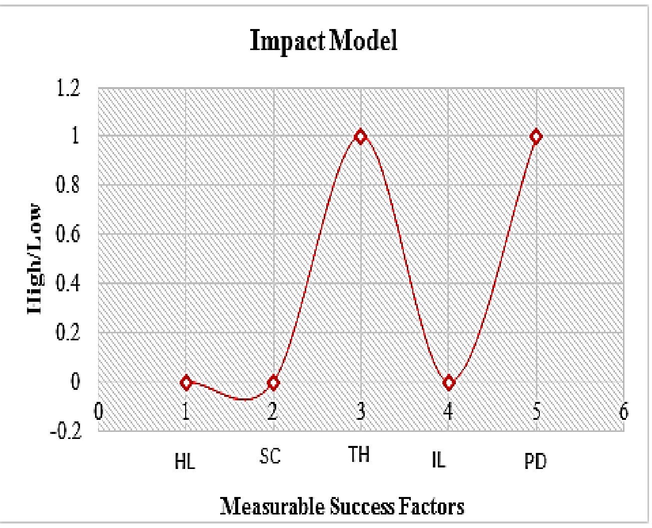


Fig. 5. Measurable Success Factors for Impact Model

Based on the detailed picture of the existing and desired situations (Figure 5 and 5), Figure 6 shows how reference and impact model oppose each other without correlation between them. Moreover, analysis of the current situation (initial reference model) that directly influence the result (impact model) reveal the supportive influential factors provides mobility knowledge to the network, hence, support NDN's producer mobility.

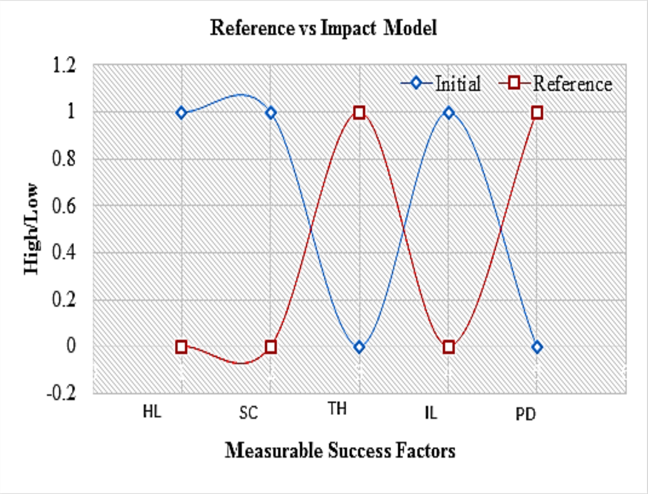


Fig. 6. Reference Model vs Impact Model

VI. MATHEMATICAL FORMULATION OF THE PMS CONCEPTUAL MODEL

The proposed conceptual model or Impact model designed of PMS using DRM graphical representation can be validated to determine whether the proposes PMS concept may attain the desired goal, a hop count tool or technique [50], [51] or method [52], [53], is used as in the previous researches [14], [32], [33]. The mathematical formulations of handoff signaling cost and latency are derived or formulated from the network analysis model presented in Figure 7 to measure the impact of handoff latency, handoff signaling, and packets delivery cost. The network analysis model was built and presented in previous researches as in [31], [33], [54] for the validation and evaluation of proposed producer mobility support schemes ideas, model, concepts, etc.

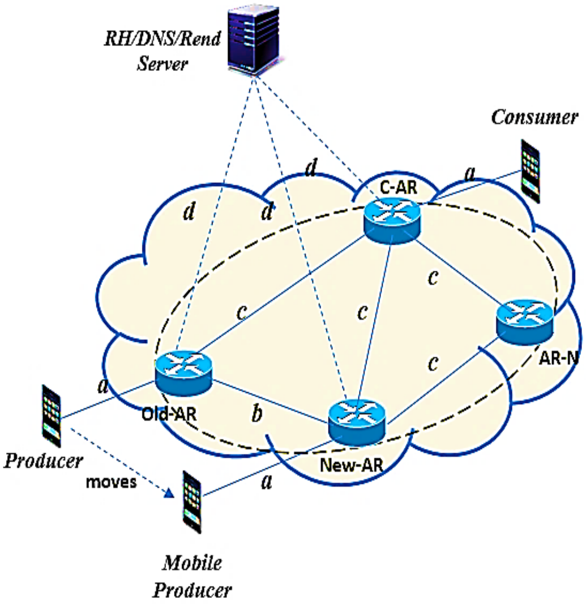


Fig. 7. Network Analysis Model

TABLE V
NETWORK ANALYSIS MODEL PARAMETERS

Category	Notation	Parameters	Value
Packets	S_{name}	Size of the signaling packet	+16 byte
	S_{data}	Size of data packets	2000 bytes
	S_{iint}	Size of Interest packet	40 bytes
Latency	L_{par}	Transmission latency between producer to AR	*a*
	L_{car}	Transmission latency between consumer to AR	*a*
	L_{sar}	Transmission latency between Server to new AR	*d*
	$L_{o\text{-}nar}$	Transmission latency between old AR to new AR	*b*
	L_{ars}	Transmission latency between new ARs/Anchors	*c*
	L_{pn}	Time interval btw producer disconnection and reconnection from old AR to new AR	I_{pn}
Signaling Cost	C_{par}	Transmission cost hop/packet producer to AR	*a*
	C_{car}	Transmission cost hop/packet consumer to AR	*a*
	$C_{o\text{-}nar}$	Transmission cost hop/packet old AR to new AR	*b*
	C_{ars}	Transmission cost hop/packet ARs/Anchors	*c*
	$C_{s\text{-}nar}$	Transmission cost hop/packet AR to Server	*d*

A. *The formulation for Handoff Latency*

Hope count is the number of intermediate nodes through which data and Interest must pass between content producer and consumer. In addition, hop count measure the distance between two nodes, that is consumers, producers, routers or servers with their queuing delay, link delay and bandwidth for the wired or wireless connection. Therefore, the total delay that a content producer spends for the disconnection, reconnection and the arrival of the first Interest packet through new PoA is called the handoff latency. The handoff latency of a mobile producer can be acquired when there is a disconnection from the current PoA and reconnection to new PoA as a result of the producer's movement. Equation (1) measured the delay for a wired link between two consecutive hops and Equation (2) for wireless link delay [33].

$$Lw_{name} = \left(\frac{S_{name}}{(Bw+Ldw+Qd)}\right) \qquad (1)$$

$$Lwl_{name} = \left(\frac{1+q}{1-q}\right) \times \left(\frac{S_{name}}{Bwl+Ldwl}\right) \qquad (2)$$

Where B_w and B_{wl} are bandwidth for the wired and wireless link, Ld_w and Ld_{wl} are linked delay wired and wireless, q is the probability of link failure and the queuing delay Q_d.
The hop count handoff latency formulation of PMS model can be express as Equation (3). When content producer disconnected form old-AR and reconnected to a new-AR and sends a mobility Interest to the new-AR, its completes the handoff over the transmission latency of the time interval *Ipn*. The new-AR add the mobility status and tag the MI packets, indicating that the content name is on mobile. Then broadcast the MI to update the intermediate routers within the domain, with transmission latency *Lpar*, and *Lars*. The content consumer sends normal pending Interest packets directly to the new location of content producer via an optimal path, with transmission latency *Lcar*, and *Lars*. The formulation is presented in Equation (3):

$$\begin{aligned} L_{pmss} &= L_{pn} + L_{par} + 2L_{ars} + L_{car} + L_{sar} \\ &= l_{pn} + a + 2c + a + c \\ &= l_{pn} + a \times Lwl_{nint} + 2c \times Lwl_{nint} + \\ & a\ Lwl_{int}\ c \times Lw_{int} \qquad (3) \end{aligned}$$

B. *Formulation Signaling Cost*

Handoff signaling cost is the total number of packets or messages sent over a consecutive hop, from producer to consumer and vice versa during the handoff period. The same as handoff latency hop count method or technique was used for the formulation of handoff signaling cost analysis. The signaling packets are S_{int}, S_{data}, and S_{name}, where their values are presented in Table V. Moreover, S_{name} can be any of the following S_{qryrep} for server query and reply, S_{upack} for server update and acknowledgment, S_{intLoc}, for Interest packet with location hint, S_{mobInt}, for mobility Interest packet, S_{qfibup}, for resolution handler query and FIBs update and S_{encInt} for encapsulated Interest. The values of S_{name} =+16 bytes over the S_{name}, which is 56 bytes [33]. Therefore, the formulation of handoff signaling and data delivery cost of the proposed PMS model is generated when a mobile producer update new-AR with MI packet, then the new-AR tag and broadcast the MI packet S_{mobInt} to the intermediate routers for FIBs update. The content consumer sends normal pending Interest packets S_{int} directly to the new location of content producer via an optimal path, then a mobile producer sent data packet S_{data} through the same route. The handoff signaling cost and data packets delivery cost is generated as in Equation (4) and (5).

$$
\begin{aligned}
C_{pmss} &= C_{par} + C_{sar} + C_{sar} + C_{car} + C_{sar} \\
&= a + 2c + a + c \\
&= S_{mobInt} \times (a + 2c) + S_{int} \times (a + c) \qquad (4)
\end{aligned}
$$

$$
\begin{aligned}
C_{pmss} &= C_{par} + C_{car} + C_{sar} + C_{par} + C_{car} + C_{sar} \\
&= 2a + c + 2a + c \\
&= S_{int} \times (2a + c) + S_{data} \times (2a + c) \qquad (5)
\end{aligned}
$$

VII. IMPLEMENTATION AND RESULT DISCUSSION

A. *Implementation of PMS and Existing Solutions*

The formulated handoff latency for PMS in Equation (3) and handoff signaling cost in Equation (4) and data packets delivery cost in Equation (5) were implemented in the Anaconda Python Spyder IDE environment. The Spyder IDE version 3.3.3 is a user-friendly and a powerful python programming development tool with an interactive prompt to execute programming codes. The mathematical model of PMS is validated using the values presented in Table V, where the values of a hop count parameters $a = 1$, $b = c = 5$ and $d = 9$, as in [14], [32], [33], [55], to validate the accuracy, evaluate and benchmark the handoff performance of the existing approach and proposed PMS model.

The validated result of PMS is benchmarked with prominent existing producer mobility support schemes. The existing schemes are DNS-like (DNS) and Rendezvous (RENDZV) that both used a stationary server for mapping process to support producer mobility. The PMS, DNS and RENDZV solution are implemented using the algorithm given below and obtained the results for handoff latency, signaling cost and packets delivery as shown in Figure 8 through Figure 13.

B. *Result Analysis*

Figure 8 shows the variation of transmission latency between the old Access Router (AR) and new AR, that is a parameter (*b*). The result proved that PMS reduced the handoff latency compared to DNS and RENDZV. In Figure 9 the latency of DNS and RENDZV schemes were increased significantly as parameter (*d*) increases, due to the number of messages sent for updating the server, while that of PMS remain constant, as there is no transmission delay of handoff messages via *d* routes in the absence of server. The server in DNS and RENDZV schemes are placed to provide a producer and consumer mean to update and query the server before the handoff became successful. Further, Figure 10 presents the handoff latency result by varying transmission latency between Ars with parameter (*c*). The result shows that all schemes are affected but PMS has the lowest and better latency. Therefore, the PMS has the lowest handoff latency compared to other solutions by varying *b*, *c*, and *d*.

ALGORITHM 1 ** Handoff Latency, Signaling and Data delivery Cost**

```
Get $B_w$, $B_{wl}$, $Ld_w$, $Ld_{wl}$, $Q_d$, $a, b, c, d$,
initiate $B_w = 100$, $B_{wl} = 11$, $Ld_w = 2$, $Ld_{wl} = 10$, $Q_d = 5$;
Let subscript $name \longrightarrow up, int, nint$
Compute the total delay for wired and wireless link delay
if wired link then
Compute wired link delay as $Lw_{name} \rightarrow \left(\frac{S_{name}}{(Bw + Ldw + Qd)}\right)$
  else wireless link
    Compute wireless link delay as $Lwl_{name} \rightarrow \left(\frac{1+q}{1-q}\right) \times \left(\frac{S_{name}}{Bwl + Ldwl}\right)$
end if
for all $b \in \{5, 6, \ldots, 23\}$ do
  for all $c \in \{5, 6, \ldots, 23\}$ do
    for all $d \in \{9, 10, \ldots, 27\}$ do
    Scheme_name → latency
    $latency \leftarrow l_{pn} + a \times Lwl_{up} + 2d \times Lw_{up} + a \times Lwl_{int} + c \times Lw_{int}$
    Scheme_name → Sig_cost → Data_delv
    Sig_cost ← $S_{upack} \times (a + d) + S_{qryrep}\ (d + a) + S_{int} \times (a + c)$
    $Data_{delv} \leftarrow S_{int} \times (2a + c) + S_{data} \times (2a + c)$
    Scheme_name → Sig_cost → Data_delv
    end for
  end for
end for
Compute Latency for dns, rendzvand pmss
Compute Signaling for dns, rendzvand pmss
return the value of ("  b, c, d: Scheme_name");
```

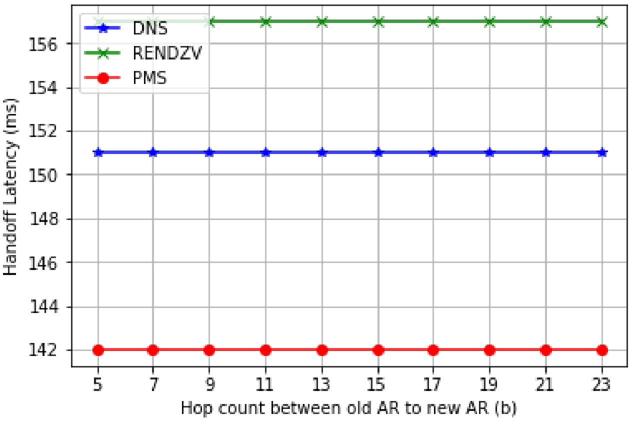


Fig. 8. Handoff Latency by varying Transmission Latency between Old-AR and New-AR

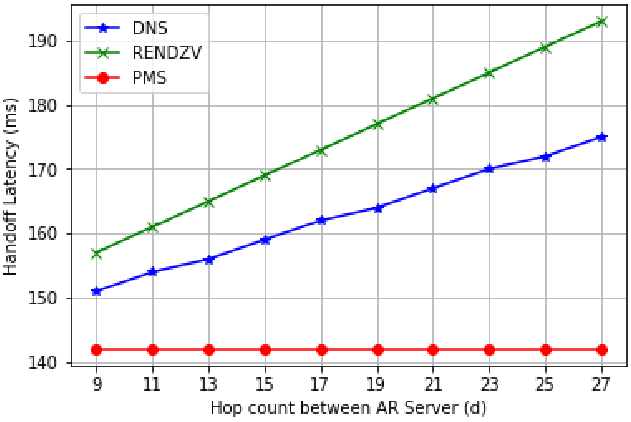


Fig. 9. Handoff Latency by varying Transmission Latency AR and Server

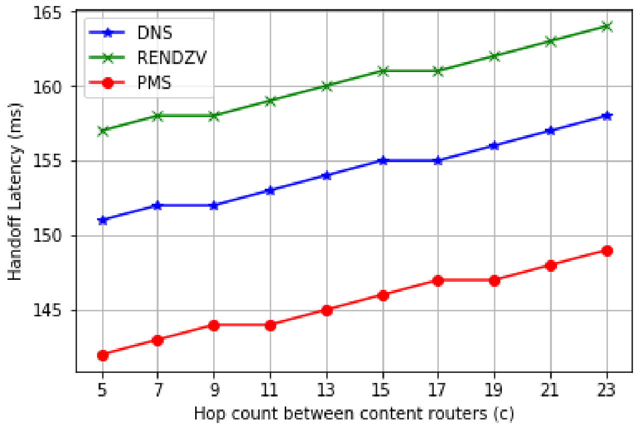


Fig. 10. Handoff Latency by varying Transmission Latency between Content Routers

The handoff signaling cost numerical result shown in Figure 11 and 12, proved our proposed PMS performed better compared to DNS and RENDZV. The handoff signaling cost output values of DNS and RENDZV keeps on increasing when transmission cost per packet between server and AR with parameter *d* increases, while for the PMS remain constant due to the facts that the PMS used a nearby router to broadcast IM packets to update the intermediate router's FIBs. Where in DNS and RENDZV solution the update is provided from the server, after receiving a query from consumer and update from the producer, as shown in Figure 11. Moreover, Figure 12 shows the handoff signaling cost performance result PMS, DNS and RENDZV for varying transmission cost hop per packets between ARs with parameter (*c*). The numerical result for proposed PMS and existing solution DNS and RENDZV were increasing significantly, due to the fact that both Interest and data packets must be passed through the intermediate routers, in general, the effect of parameter *c* plays a significant role on the performance of any producer mobility support solution. Therefore, in terms of signaling cost performance, an inference can be drawn that the PMS has the lowest handoff signaling cost compared to DNS and RENDZV solution. Because the lowest the signaling cost the better performance of producer mobility support.

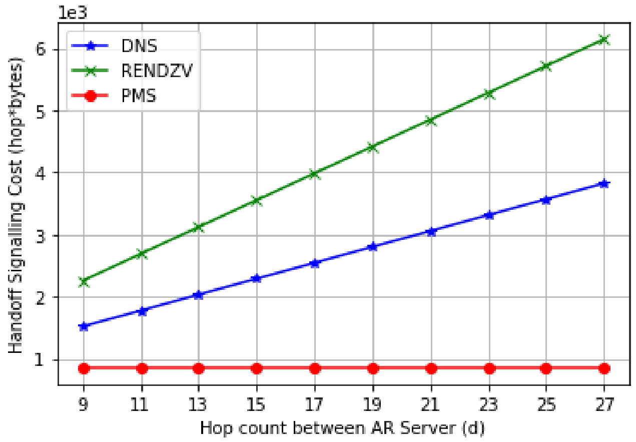


Fig. 11. Handoff Signaling Cost by varying Transmission Cost Hop-per-Packet between AR and Server

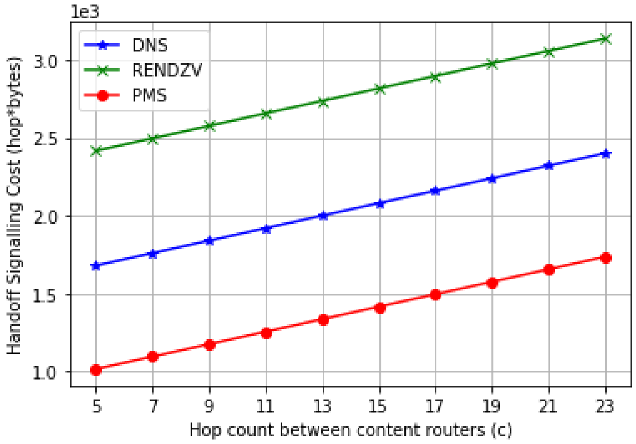


Fig. 12. Handoff Signaling Cost by varying Transmission Cost Hop-per-Packet between Content Access Routers

Figure 13 show that our proposed PMS possessed the data path optimality of DNS and RENDZV solution. By varying parameters, all solutions have the same result.

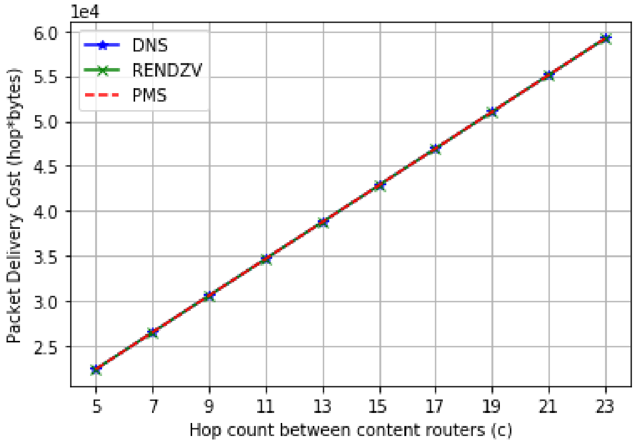


Fig. 13. Packets Delivery Cost by varying Transmission Cost Hop-per-Packet between Content AR

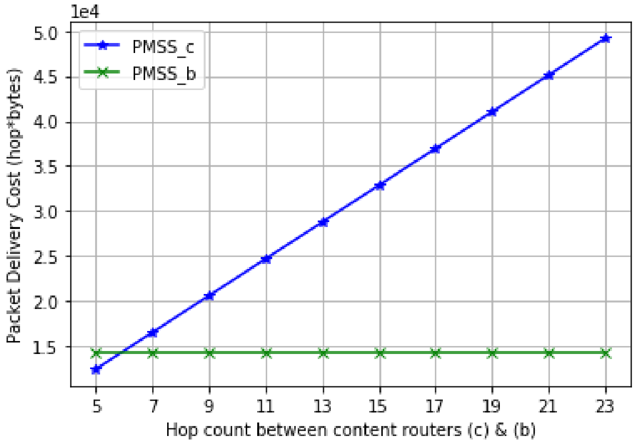


Fig. 14. Packets Delivery Cost by varying Transmission Cost Hop-per-Packet between Content AR, N-AR and P-AR

As shown in Figure 13 that all schemes have equal or similar result, this is happened due to the nature of routing path optimization for DNS and Rendezvous scheme. Both schemes used a dedicated server for mapping processes. In addition, the server helps for updating the FIBs for the entire network to provide a routing path optimization. Figure 14 shows the result for PMS scheme only while varying parameter *b* and *c*. By varying parameter *b* which is the packets delivery cost or the transmission cost hop per packet between old-AR and new-AR, shows that there is no change as the parameter does not affect the transmission processes. Unlike parameter *c*, by varying parameter b the result is significantly improving due to the increases of the distance between consumer and mobile producer.

C. Discussion

The overall result for handoff latency, handoff signaling overhead cost, and data packets delivery cost in respect to the average hop count variation are presented in Figure 15 and 16. The handoff latency described the accumulated delay for sending signaling messages to update the new trace inside the FIBs of intermediate routers. Between each consumer, routers, and producer, a kind of transmission latency was accumulated after the handoff process.

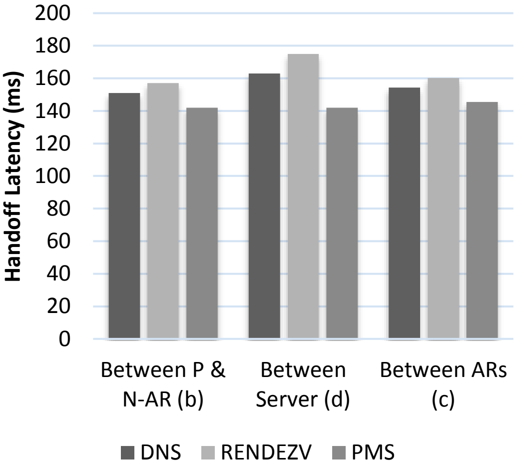


Fig. 14. The Average Handoff Latency

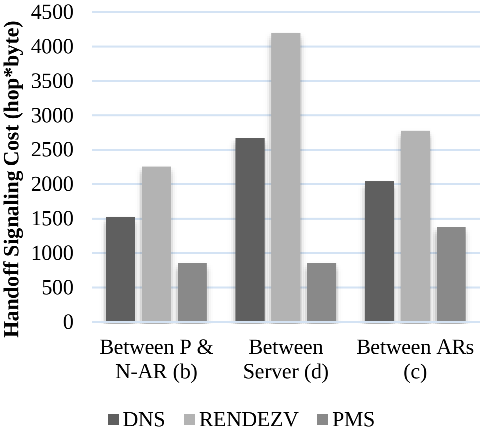


Fig. 15. The Average Handoff Signaling Cost

The accumulated handoff latency is used to measure the performance of any mobility support solution. From Figure 15 we can observe that our proposed PMS concept has the lowest average handoff latency with 142ms for both average hop count between old-AR and New-AR, also between AR and Sever. Moreover, the average handoff latency between access routers is 145ms a little bit higher than that between old-AR and New-AR, and between AR and Sever. This is because of the broadcasting of MI packets to update the intermediate router that does not require a query from rendezvous or DNS server.

The main important of NDN architecture is to provide a solution to the problem of existing Internet architecture, that covers from mobility support and efficient bandwidth utilization. The high level of bandwidth consumption deteriorates network performance and causes an excessive delay. The two solution DNS and RENDEZV concept performed well for optimal data delivery. However, their performance in terms of handoff signaling overhead cost is becoming worst. Figure 15 shows that averagely RENDEZV scheme causes very high signaling due to the timely update of the entire network, once consumer sent a query about producer new prefix. We can observe that the PMS concept has the lowest average handoff signaling cost. The average signaling cost accumulated for the average hop count between old-AR with New-AR, and between AR with a Sever are equal. This is because a server is out of the PMS network and there is no need to create a path between old and new AR. The average handoff signaling cost also between ARs is higher due to the MI packets broadcasting. In summary, the broadcasting nature of PMS concept, it has the lowest signaling coat. Figure 15 and 16 shows the overall performance of the PMS concept against server-based DNS and RENDEZV concepts. Moreover, Figure 13 shows the equal performance of data packets delivery cost, to prove that PMS concept possessed optimal packets delivery.

VIII. CONCLUSION

This paper designed a conceptual model of producer mobility support for NDN using DRM. The model can lead to the different proposal of analytical, mathematical and simulation models to verify and validate the different design of mobility support proposed ideas. The conceptual model is represented as a reference and impact model that revealed the influence of Handoff Latency, Signaling Cost, Throughput, Interest Packet loss and Packets Delivery. The result indicated that the provision of producer mobility knowledge using broadcast strategy and mobility update significantly reduces the handoff latency, signaling overhead cost and unnecessary Interest packets losses. Hence, improved the quality of data packets delivery.

Conclusively, Figure 6 depicts the two influencing factors producer mobility update Interest packet and broadcasting strategy to update intermediate routers that are added to influence the success factor by supporting producer mobility. Therefore, the most important influencing factors and their relations are captured, verify and validate this conceptual model, by proposing an analytical model. The overall result of PMS model that is implemented and benchmarked with DNS and RENDZV solution was assessed by varying *b*, *c*, and *d* parameters. The numerical result indicated that updating FIBs with the new prefix information of producer’s whereabouts, using the influential factors, mobility Interest packet and broadcast strategy significantly minimizes the handoff latency and signaling overhead cost of PMS. Our future work is to propose an analytical model that includes the movement behavior of content producer and the simulation model of the said analytical model using ndnSIM, which is a conducive environment for experimenting any NDN problems.

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