RESEARCH THESIS

Cluster-Based Device Mobility Management (CB-DMM) in Named Data Networking

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CERTIFICATE

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DECLARATION OF AUTHENTICATION

I state that the research work offered in this thesis is to the superlative of my knowledge. All causes used and any help established in the research of this study have been acknowledged. I hereby verify that I have not yielded this material, either in whole or in part, for any other degree at this or any other institution.

Signature…………………….

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May Allah bless them all with eternal happiness.

DEDICATION

To My Father, Mother, Family and friends.

Abstract

Named Data Network (NDN) was designed to eliminate or end the dependence of IP addresses in hourglass model. Named Data Network was a project started at 2007 by 12 campuses collaboration funded by US National Science Foundation. In Named Data Network routing is based on names instead of IP. When a user needs contents, it will send Interest packet to NDN router. Now it's up to the NDN router to find the contents and when contents found the router will use the reverse path to send contents through Data packets. NDN support consumer mobility by consumer re-request for data but Producer mobility still under research because locate Producer is tough sometimes. when an active session start between Consumer and Producer and suddenly Producer move from one NDN router to another. Different techniques are used to locate the Producer like Data Replication, Mobile IP, Trace-based and Mapping System, but these solutions have some cons which will be discussed later. We designed a new model to solve this issue and named it Cluster-Based Device Mobility Management in Named Data Network (CB-DMM). In CB-DMM a cluster head has all the information of its attached devices, and when a device move to another router, the router will send attachment information to cluster head and cluster head update the routes. Through CB-DMM model we will also decrease the numbers of interest packets in the network.

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Chapter 1

Introduction

1.1- Overview

Named Data Network is under developing phase. It is designed to overcome the IP address network. IP was designed for conversation between endpoints, but it used enormously for content distribution. Instead of IP addresses, NDN used data names. NDN remove the [1] restriction of IP datagram which can only use IP destination addresses and source addresses. NDN application is removing all the middleware which causes inefficiency. These middlewares used a map

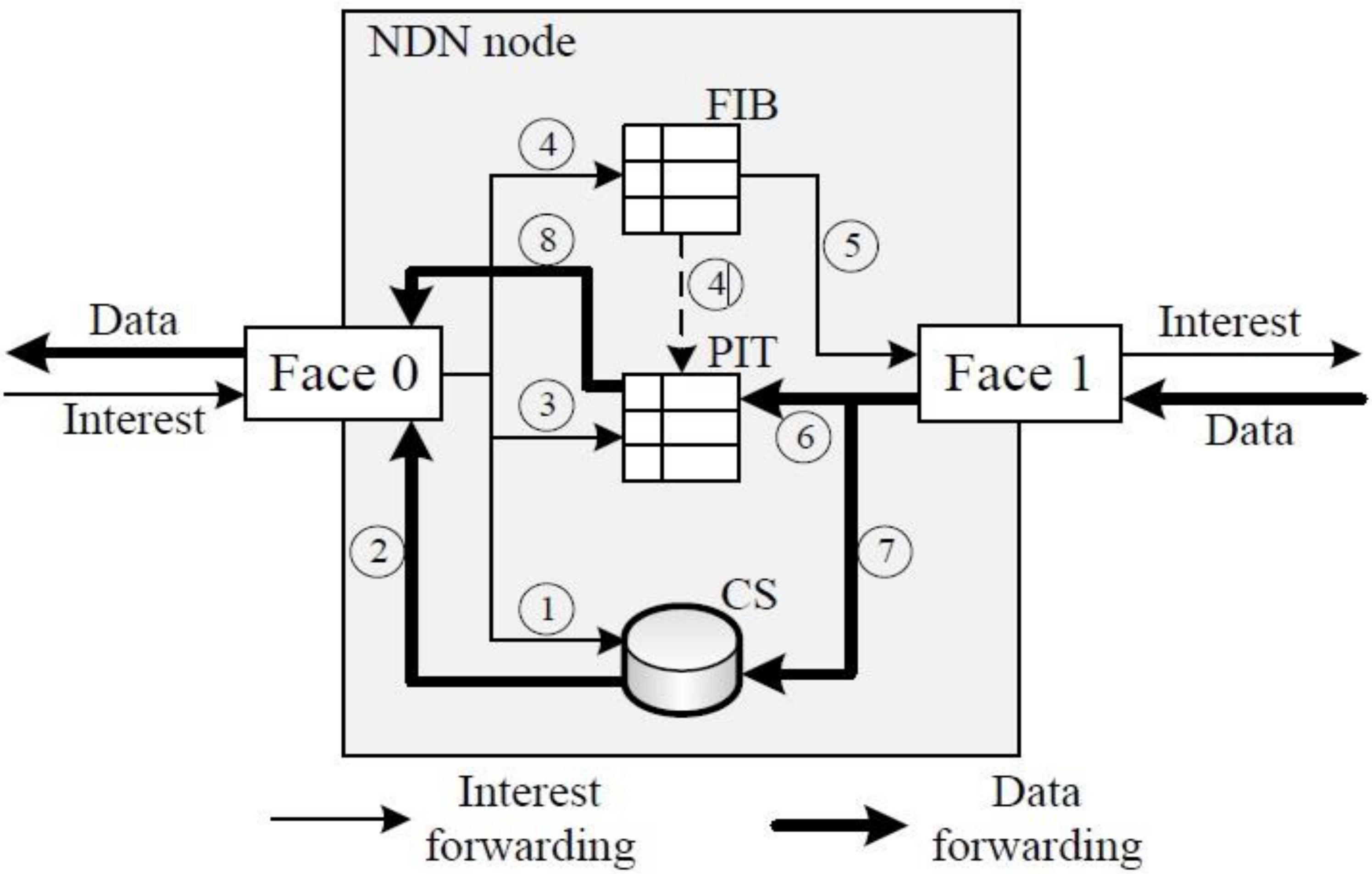

Figure 1: Working of Named Data Networking

application to interact. Data looping is prevent using memory because every chunk of data has a unique name while IP used single path forwarding.

NDN architecture used two types of packets. Interest packets and Data packets. Interest packet is used when a consumer makes a request for data. When interested data are found, it sends back to the consumer through the reverse path by using data packets. To entertains both interest packets and data packets each NDN router maintain three tables structure. Pending Interest Table (PIT), Content Store (CS) and Forwarding Information Base (FIB).

In Figure1, initially, when an interest packet reaches NDN router, the NDN router first check the interest contents in content store (CS) if contents found in CS it will send back to the consumer otherwise forward it to PIT. Where PIT check it and if PIT was waiting for the same contents from FIB it only marks an entry when contents reach the PIT, the PIT will forward it to the consumer. If PIT didn't send a request for interest packet to FIB, it would forward it to FIB and FIB will look for interest contents in other NDN routers when found the data. It sends it to the consumer by reverse path.

Named Data Networking by default support consumer mobility but Producer mobility still has an issue when from ongoing communication the Producer move from one network to another and the interest packets coming to the previous access router.

1.2- Motivation

Named Data Networking is introducing to eliminate the drawbacks of today Internet architecture. IP was designed in 1974, and it's too old to support the today internet architecture. For communication in IP network, data must be binding with IP addresses while in Named Data Networking data will be propagated by names.

Producer mobility is still an issue in Named Data Networking. As early mention Named Data Networking can support consumer mobility, but Producer mobility still has some issues, like from ongoing communication the Producer suddenly move or the interest coming to the previous access router while the Producer moves to another router.

In paper [1] the author proposed a scheme for Producer mobility and called it SMM model. In SMM model mapping system was introduce which was globally located in the network. Nowadays, usages of the internet increase and almost everyone used the internet for live streaming, file sharing and much more. Almost each and everyone used the internet through mobile devices and used these mobile for live streaming, social networking, and data sharing. For file sharing and live streaming, the mobility can be an issue for these mobile devices.

We introduce Cluster-Based Device Mobility in Named Data Network. These cluster heads have some responsibility like keep a record of the devices, update routes information and much more which will be discussed later in chapter 5.

1.3- Problem Statement

The main issue is how to locate the Producer when it is re-attached to the network or when it is unavailable. Figure 2 illustrate how Producer moves from R1 to R2 and the consumer from an R5 request for "contentSource/realtimeVideo1". When the request packets reach R1, the Producer move to R2 and the request is unsatisfied. In paper [1] the author used scalable mobility management for content sources in Named Data Network which used mapping system on a global scale which may cause the huge network latency and bring more complexity.

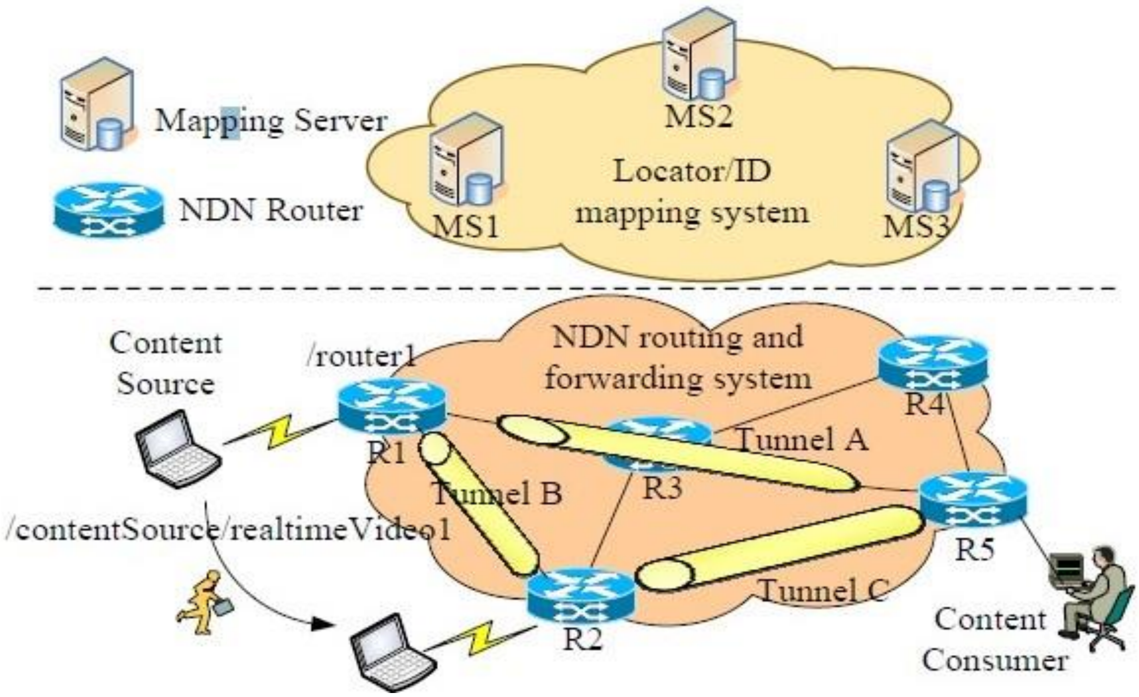

Figure 2: Network Model for SMM

1.4- Thesis Organization

The thesis organization as Chapter 2 the detailed overview of Named Data Networking will be discussed. In Chapter 3, we will be discussing the related work for mobility support in Named Data Networking. Chapter 4, the existing scheme is discussed in details. Chapter 5 will be based on our proposed solution and we will discuss the operation of our proposed model in detail. Chapter 6 have simulation results and we compare these results with the existing scheme. The last Chapter 7 will conclude this work and provide future direction.

Chapter 2

Overview of Named Data Networking

2.1- Introduction

Named Data Networking (NDN) is a new internet architecture which aims to eliminate the weakness of today host based architecture. There is no binding of data with addresses like in IP network. In NDN data is the first-class entity of network. NDN provide bandwidth optimization through a unique feature, data caching in NDN routers. In Named Data Networking, every node maintains three table. Content Store, Pending Interest Table, and Forwarding Information Base. In Content Store, previous data will be cached for future reused. When a router forward data packets to another router's or a consumer, it will keep a copy with itself for future, because of the NDN nature someone may later send Interest packet for same data and NDN routers have the capability that they can reuse forwarded data to another user. While IP router also buffers data but when it forwarded to the destination, then have no capability to reused them again. Pending Interest Table keep the record of Interest packet. When data reached for Interest packet, or timeout occurred the entry from PIT will be removed. Forwarding Information Base (FIB) used when data is not available in the router cache, so PIT sends Interest Packet to FIB and FIB send it to the web and waiting for data packets arrival. When data arrived, it will send to PIT. The PIT used face (where interest packet in) to send out data packet and caches the data in Content Store for future reuse purpose.

2.2-Motivation

Named Data Networking is a new architecture but from today internet architecture its principles are derived. Named Data Networking is designed to overcome the weakness of today Internet architecture. Before 1960 telephone was the only successful communication model but in the 1970s when TCP/IP was designed which give a unique solution for communication was groundbreaking. Which was dramatically change the world and provided ubiquitous interconnectivity of today internet architecture? Today almost anything available on the internet, from travel booking to hotel booking, from online shopping to online banking and from social networking sites to online videos streaming sites are on the internet.

On the advancing of the hardware, everything connects to the internet today. From supercomputer to personal computer, from factories to municipal infrastructure, from mobile phones to smartphone, from cars to appliances and even home appliances like light switches are connected to the internet today. The best examples of everything connected to the internet is IoT. Exabytes of new content are distributed yearly on today internet. Over 70 percent of today internet is used for the video stream.

IP was designed to provide end to end connectivity between two end users. I mention before that over 70 % of today internet is used for streaming purposes, so internet now a day are poorly matching of its primly use. Security is also a big issue for today internet. The malicious attack occurred on a daily routine which is increased concern of the users. Securing the data on the channels and in the system, are also a challenging factor for today internet. The conversational of IP was embodied in datagram format wherein IP datagram used the name for communication endpoints (source and destination addresses). Named Data Networked to eliminate the restriction of IP where a data embedded in a conversation between consumer and provider host. NDN makes data the first-class citizens of the internet architecture rather than containers.

Today applications are written in term of what they want rather than where it is located, then a middleware is used to locate the data on the internet and NDN all middleware is removing which cause the communication inefficiencies, and what model can be used directly in data delivery. In named data network, all data is signed by the Producer and verify by consumer and NDN will tell you that on the web page the data you are viewing was produced and signed by one's bank while IP cannot tell you that.

For future data used caching is another option which boosts the network efficiency in Named Data Network. In NDN every chunk of data is a unique named. Which can be a cache for future request. These unique names enable routers to maintain data plan which can be used to eliminate the looping of data between routers.

There may be some question regarding the namespace for NDN. NDN used unbounded namespace while IP has a finite namespace. But the NDN team believe that using hierarchical names like the URL's in today web content can control the namespace in global routing. IP used for routing and forwarding an exact state while NDN used approximate state which will reduce the burden on routing.

NDN can run over anything, including IP and everything can run over NDN including IP. NDN provide mobility support because when you move from one network to another, you don't have to change your name. NDN also provide robust security, application-friendly communication and content distribution and many more advantages over IP which will be discussed later.

2.3- NDN Architecture Principles

In figure 3, six architecture principle to design the NDN architecture. The first three was taken from internet success, and the last three from the lessons learned over the years. The hourglass model makes the Internet design more powerful. It used the IP in the thin waist which will provide the global interconnectivity. IP allow the lower and upper layer connectivity without any unnecessary constraints. The Named Data Network also used the same hourglass but a little bit modification.

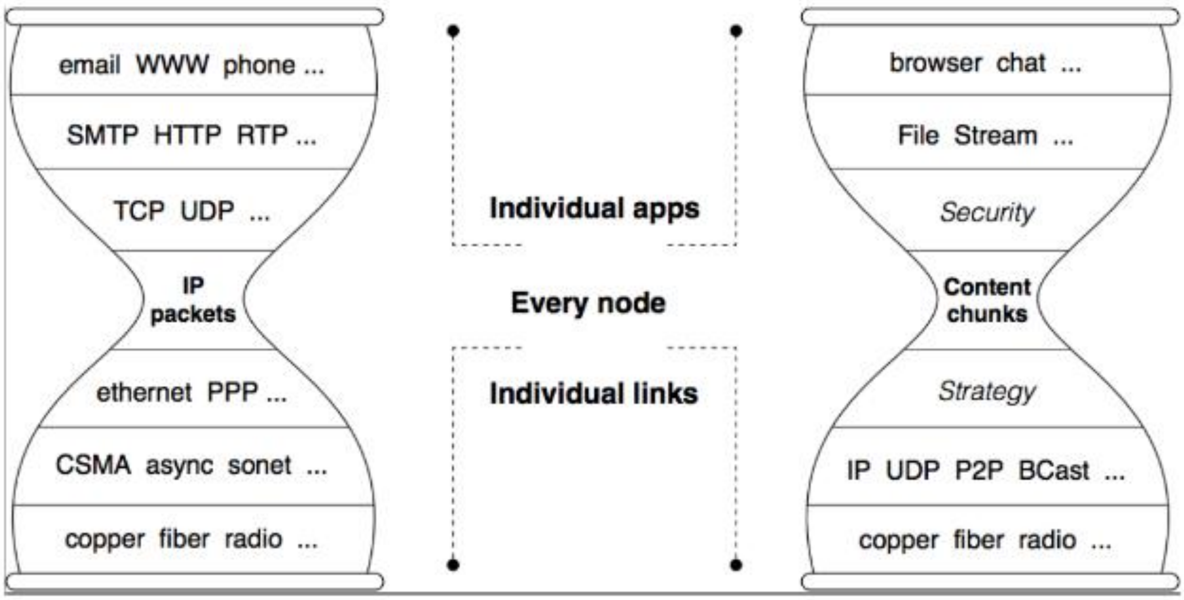

Figure 3: The IP Internet and NDN Hourglass Architecture

The separation of forwarding and routing plan necessary for Internet development. Security also built in the architecture. NDN provide a security mechanism in the thin waist where all named data signed by the Producer. NDN provide flow balancing in thin waist model which stable the network from congestion.

2.4- NDN Architecture

NDN used names instead of IP addresses in thin waist model architecture for delivery. In this section, we will be briefly explaining the basic concept of NDN data delivery and overall architecture of NDN.

In NDN the communication starts from the consumer end where a consumer sends Interest Packet for data to NDN network. In figure 4 show the content of Interest Packet. Where content names used for object identifier, Selector used is an optional field for order preference, publisher filter, and Nonce is a random number assigned by the PIT.

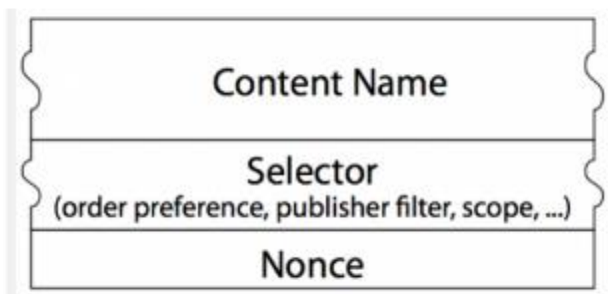

Figure 4: NDN Interest Packet Format

When NDN router finds the desired data, it will have used reverse path for Data Packet to the consumer. Figure 5 illustrate Data packet where Content Name is desired data information or object identifier, the Signature mean Producer is available for review inconsistencies. Signed Info has information about the publisher key which required by the responding node. In Data section have the data portion contains the information requested.

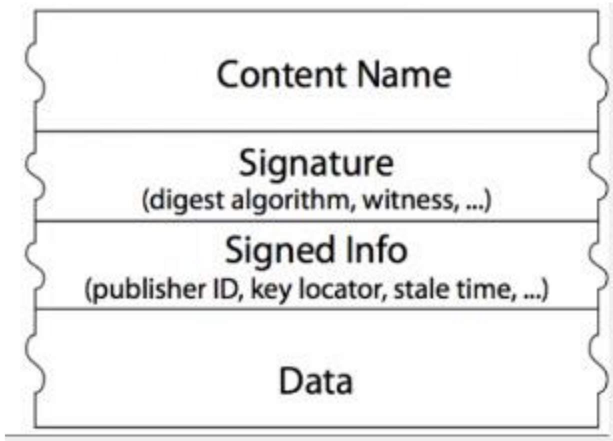

Figure 5: NDN Data Packet Format

Figure 6 show how Interest Packet and Data Packet will be satisfied in the network. NDN node maintains three tables. Content Store, Pending Interest Table, and Forwarding Information Base which will be briefly explained later. When Consumer needs the desired data, it will send Interest packet to NDN node or router. Now it's up to the NDN network to find the desired data for the consumer. When an NDN node receive Interest packet for desired content it will first check Content Store (CS) for data, if the data not available in CS it will forward the Interest Packet to PIT where PIT check if it already sends request for the same data to FIB it will only remember the face from which Interest in otherwise send the Interest Packet to FIB and remember the face for later data delivery. FIB remember the face and send the Interest Packet to the web. When desired data found the NDN router used the reverse path for data delivery.

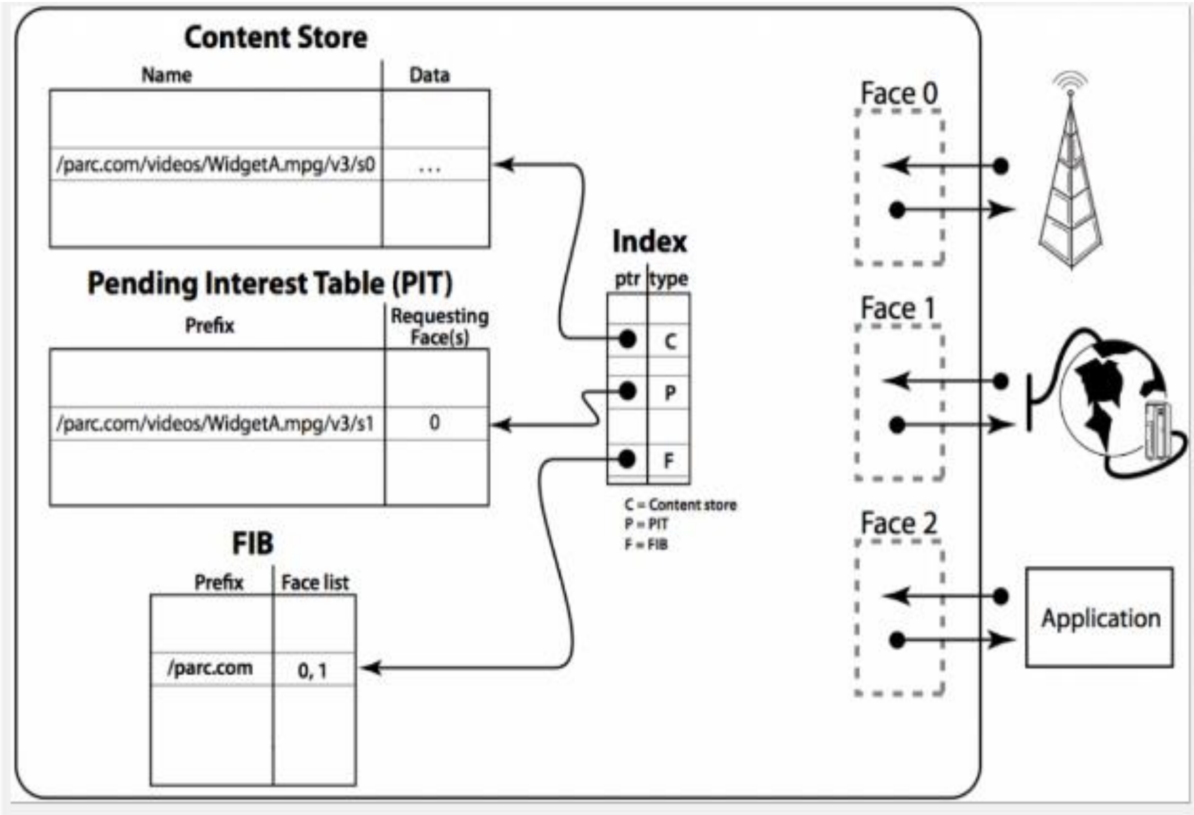

Figure 6: NDN Router Structure

2.4.1- Names

Hierarchically structured names are assuming to use in Named Data Networking. For example, video from YouTube may have name /YouTube/videos/part1.mp4, where "/" is used for the boundary between name. The Hierarchically structure for names is used because of it helpful for an application which epitomizes relationship between data pieces, e.g., version 2 segment 5 of the upper mention video may have like this /YouTube/videos/part1.mp4/2/5. There is another advantage of using hierarchically name it will help to enable routing scale. The naming convention only specific for applications but opaque to the network. For example, router, do not know the meaning of the name but they see the boundaries of naming components. NDN allow the application to use the names which best fit for its need.

For naming, may not be globally unique but only those are required to be globally unique which retrieve data globally. For local communication name, may be based on local context and required only local routing. The namespace is not the part of NDN architecture, Just like the IP address space management not part of the IP architecture. But naming is an important aspect of NDN design because its support different functionality includes multicast, mobility, content distribution and DTN.

2.4.2- Data-Centric Security

In Named Data Network, each piece of data is signed by the Publisher and verify by Consumer. In NDN each piece of data must be signed, and it is mandatory in Named Data Networking. It will allow the Consumer to trust the data which they are gone be access. It will also be determined that the publisher for a specific piece of data is the rightful owner. But security through public cryptography is now inefficient, and difficult to deploy. In Named Data Networking key, can be communicated as Named Data Networking data and key distribution can be simplified. For example, if a part of data is a public key, a binding is a public key certificate. Which offers to the consumer, Producer, and application to choose their customizing trust model.

The Named Data Networking data-centric security can be extending to infrastructure and content access control. The Named Data Networking is under research, so they are working on efficiency security, network security, trust management and privacy.

2.4.3- Routing and Forwarding

Named Data Networking used names for routing which eliminate four problems which are associated with IP addresses. NAT traversal, address management, mobility and address space exhaustion. The namespace is unbound so no need for address space exhaustion. In Named Data Networking host, do not need to expose its address, so NAT traversal is also useless in NDN. NDN by default support mobility because the node does not need to change its address to offer contents. Address management is no longer required in local networking. In Named Data Networking the router announces name prefix while IP is announcing IP prefix. NDN support routing security by default, first signed by publisher and then no one knows where the data are coming and going.

2.4.4- Intelligent Data Plane

Named Data Networking to have stateful data plan while IP has stateless because NDN used PIT table for pending Interest and their interfaces. When data received PIT, the entry will be removed. In PIT table the entry will also be removed if the timeout occurred. The state-full mechanism of Named Data Networked utilities of the network resources and handle during a network failure. Looping can be discarded in Named Data Network through Nonce used in Interest packet. Through Nonce NDN node can identify that packet come back to the same node twice and the same goes for Data packets.

2.4.5- Caching

When data packet reached NDN router, the NDN router sends the data packet to the consumer through the reverse path and store the information in Content Store for future reused. Both NDN and IP buffer the data packets but in IP network, once the data forward it cannot reuse it while NDN can reuse the data packets because NDN identifies them by data names. The caching techniques raise a question regarding privacy, but in Named Data Networking the router does not know who are originating the data request while in IP network anyone can easily identify who request for data. In Named Data Network the router may know about originator if both connect through point to point link.

2.4.6- Transport

Named Data Networked used the same transport layer of today Internet architecture. Multiplexing and demultiplexing done between application directly through names. NDN router has the functionality of load balancing which enables congestion control in the network while also eliminate dependence on end host to control congestion in the network.

Chapter 3

Related Work

3.1- Introduction

Mobility is a major issue in Named Data Network (NDN). Consumer mobility is automatically solved by NDN architecture. The consumer can re-request for desire contents while Producer mobility is still an issue in NDN. The consumer is those who send interests packets for data and Producer are those who provide data packets to the consumer.

We will introduce Cluster-Based Mobility Management to counter-Producer mobility handover from one NDN router to another.

Table 1: Review of existing work

Paper Reference & Publish Year	Objective	Proposed Solution	Network
[1], 2016	Mobility issue of MIP techniques	Scalable Mobility Management for content source in NDN	NDN
[2],2012	Introduce DNS type mapping system for mobility	A content provider Mobility solution of NDN	NDN
[3], 2014	Testing NDN for Mobility support in Wireless network for different scenarios	Mobility study for NDN in Wireless access network	NDN
[4], 2016	Mobility solutions which were previously discuss divided into three categories	A survey of Mobility support in NDN	NDN

[5], 2014	Trace-based solution for mobility	Kite: A mobility support scheme for NDN	NDN
[6], 2016	Solve the mobility issue through Data replications	Providing Producer Mobility support in NDN through Proactive Data Replication	NDN
[7], 2012	Minimizes the data loss of real-time application because of mobility	Supporting Seamless mobility in NDN	NDN
[8], 2016	Cache techniques has been used to counter the mobility	Optimal caching for producer mobility support in NDN	NDN
[9], 2014	Forwarding hint is used for mobility	What benefits does NDN have in supporting mobility	NDN

Mostly Producer mobility issue solves by using Mobile IP techniques which suffer from different problems like single point failure and non-optimal routing etc. In [1] a distributed scalable mobility management mechanism SMM introduce to solve the issues of MIP based solution for NDN mobility without changing the original NDN paradigm. SMM protocol separate content locator and identifier. A threefold separation model used like separate locator and ID, Separation of routing and management, separation of access and core. To achieve the handover in intra and inter-domain an HMIP is used. But used mapping system on a global scale which may cause the huge network latency and bring more complexity.

The [2] author encounters the content provider mobility by providing locator and mapping system. The locator is used because mostly we do not know, where the information is locating, and mapping system used to map identifier to the locator. The matching in CS and PIT the author used identifier while for forwarding in FIB they used locator. Every provider join network initially will give locator. Locator describes address of the provider in the access point. Mapping system like a DNS which resolve the query, map name to the locator. The author used locator in interest packet and called it a secondary label for NDN. Through this locator, the author finds the content provider in the network with the help of mapping system. No simulation is present nor a comparison of the proposed model in the given paper. Extra-label causes the network more complexity and burden.

In [3] the author tested the named data network mobility support in the wireless access network and gave a simulation based result in ndnSIM. The focus of the author is in delay sensitive and delay tolerant traffic by using different network topologies like the single autonomous system and multiple AS's. The author gives four scenarios. The first scenario single mobile host with single static host and assigned to a different AS. The second scenario based on the first scenario with modification which allowed both hosts to be mobile. The third scenario has a single mobile host with single static host and each host assigned to different AS. In the last scenario, scenario third is modified which allowed both hosts to be mobile. In these scenarios and its application like delay tolerant and delay sensitive traffic the performance is degraded in message overhead and throughput. NDN also not satisfy for the small sized network. The author wants to introduce location routing policies in NDN to satisfy the requirement of the different application and reduce the burden on the network infrastructure.

The author [4] divided the existing solution for Producer mobility in NDN into three categories. Routing, mapping, and tracking. A mobile node can keep its IP address while moving to another network but MN must update another router in routing based approach. Mapping based solution whenever MN change network it must tell it a current IP address. Hop by hop reverse path has been used to reach current Producer in tracing-based approach. The author main concentration on Producer mobility and give a detailed overview of already available proposed solution. For Producer mobility, 2 chase mechanism of the moving Producer and two data-centric ways to find interest data.

In [5] a trace based scheme is proposed in Kite for NDN mobility a new forwarding mechanism are introducing in Kite. A traceName field is used to find out which trace interest to traced. And tracing flag are used to, how to forward these tracking interest. Kite are locator free and based on application. The developer makes changes in their application to achieve batter performance. But the author not provided any simulation or any other way that the idea is worked and trace based solution causes the huge network traffic and time-consuming.

In [6] the Producer mobility problem solves through data replication. The proposed solution may require more memory and cause network overhead. The author solves two main issue handling of Producer mobility and on which condition Producer mobility support can increase in NDN. The Producer mobility issue divided into two categories. 1)unavailability period 2) re-attachment to the network. In the unavailability period, the author suggested replicating the content when Producer unavailable. Through different parameter, the author evaluates the network but the replication techniques can cause the network more storage and what about real-time contents?

In paper [7] the author minimizes data loss in real time application because of mobility in NDN network. Three solutions are providing for this purpose. i) PoA based where an MN register himself with nearby PoA. Then PoA sends any interest packet or data packet to specific MN. ii) The rendezvous point is used for seamless mobility. Rendezvous is strategically located routes. iii) the third method are based on multicast seamless mobility where multipath interest and multipoint content used.

In [8] Producer mobility solves by using caches techniques. Before handover happens, the data of Producer can be a cache to provide seamless operation in NDN. In this paper handover, can be predicate when it happens. But it is very difficult when Producer handover and data may not replicate.

Paper [9] built a prototype of NDN in NS3. A forwarding hint is used to counter-Producer mobility. Forwarding hint was previous IP mobility solution which may cause a single point of failure.

Chapter 4

Existing Scheme SMM

4.1- Introduction

SMM "Scalable Mobility Management for Content Source in Named Data Networking" was proposed by [1]. It was a solution which counters the Producer mobility in Named Data Networking. The author used the mapping system on a global scale which may sometimes cause the huge network latency and bring more complexity to the network. As the nature of Named Data Networking, it can store information of ongoing communication for some time and reuse it when someone else requests for it. The problem that causes the NDN network through SMM model will be discussed later?

4.2- SMM Network Model

The problem occurs during the communication in Named Data Network when the Producer handover to another network. The figure 7 show when a consumer sends interest packets toward Producer for data "contentSource/realtimeVideo1". When interest packet reached the access router through which the Producer previously connected will handover to another access router. In this case, the previous access router is R1, and the new access router is R2 in figure 7. Now locate the Producer is a very difficult job. The SMM model was proposed to solve this issue. The author of SMM model bound the Producer and new access router to send its current location information to the previous access router. In the SMM model, they used mapping system on a global scale which causes the huge network delay, increased overhead, consuming network resources and bring complexity into the network.

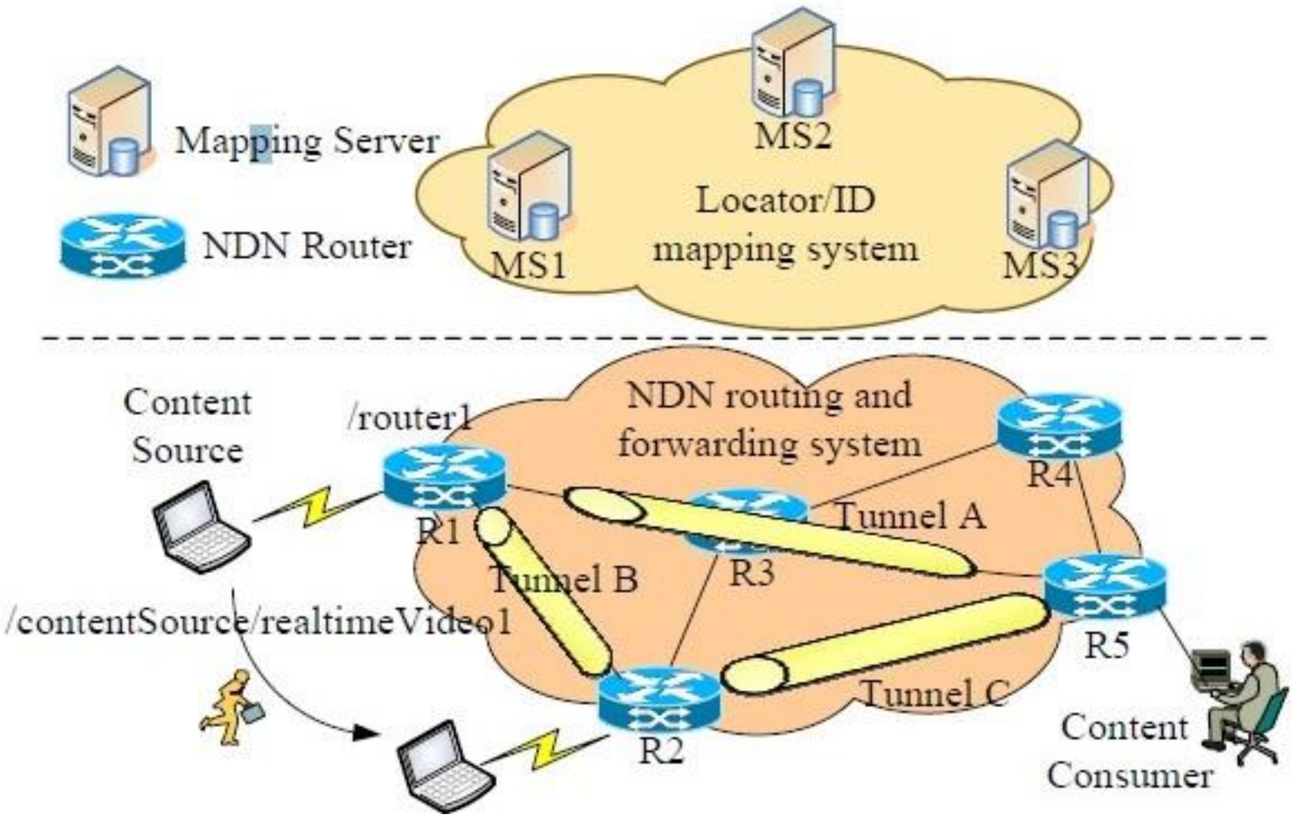

Figure 7: SMM Network Model

4.3- SMM Handover Procedure

In SMM Network model the author used the mapping system to locate the Producer. The mapping system place in the network on a global scale to locate the Producer. When Producer change, the location mean from previous access router to the new access router the Producer send binding updates to a mapping system, and the mapping system sends these binding updates information to the previous access router, and the interest packets from previous access router divert to the new access router.

In figure 8 illustrate handover procedure of SMM model. When Producer connected with new access router, it will send attachment packet to the new access router (NAR) and another interest with Binding update packet will be sent toward the mapping system which may place far away from NAR and PAR in the network. The mapping system sends data with BU and another request sends toward the previous access router about the Producer new location. The previous access router (PAR) update the Producer information and divert the interest packets towards the new access router (NAR).

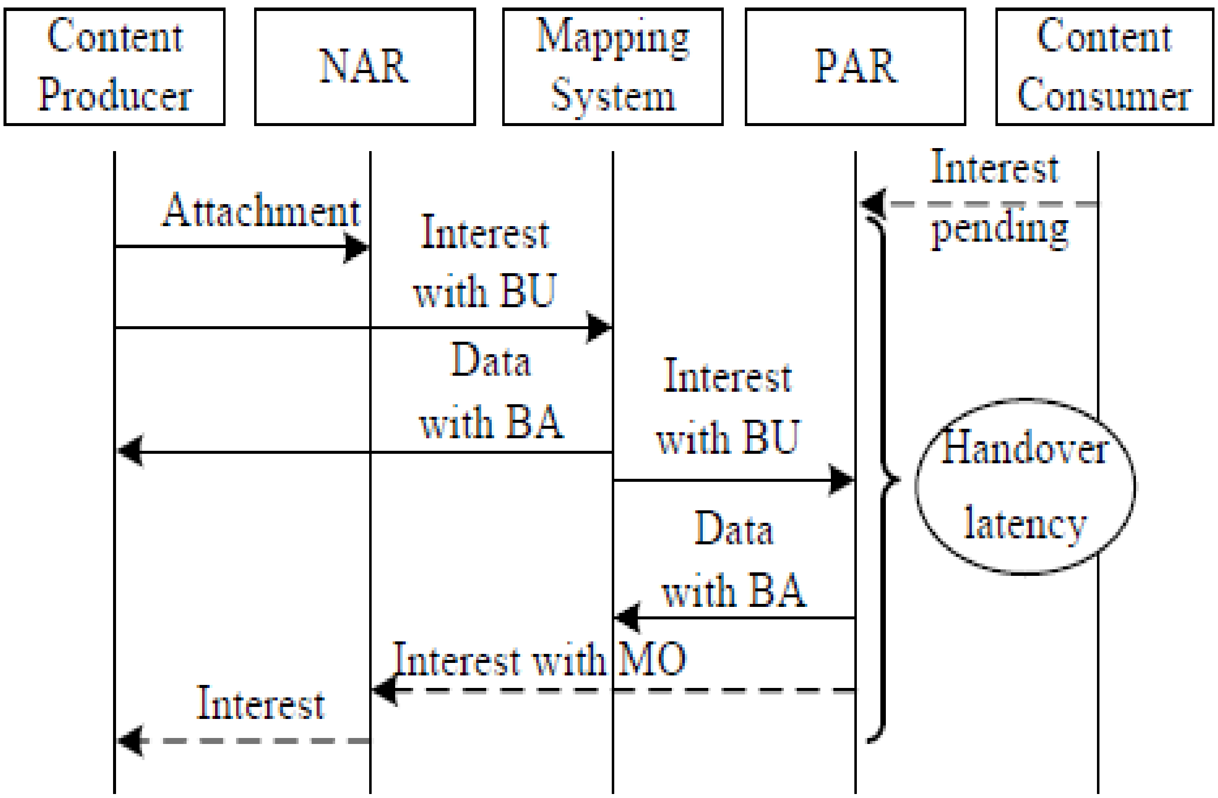

Figure 8: Handover Procedure in SMM Model

Chapter 5

Proposed CB-DMM Model

5.1- Introduction

The proposed scheme is proposing to mitigate the mobility in Named Data Networking. When from the active communication the Producer move to another network while the interest packets reached the previous access router and didn't get data and interest packets wasted. Because of didn't get data, there are a lot of resources wasted of the network. To mitigate the wastage of resources we proposed the Cluster-Based Device Mobility in Named Data Networking. Different solutions have been proposed to counter-Producer mobility in Named Data Network which suffers from different problems like overhead in cache, replication, and trace based techniques and single point of failure or non-optimal routing in Mobile IP techniques. We designed a model and named it Cluster-Based Device Mobility Management (CB- DMM) to counter-Producer Mobility in Named Data Network.

5.2- CB-DMM Network Model

In figure 9 showed a detailed overview of our model. In [1] used mapping system to locates Producer in Named Data Network which gives extra burden on the network. We design new model based on CB-DMM. When a consumer makes a request for desired contents and the Producer handover to another network. The request reached the old location of a Producer and unsatisfied because Producer move to another network which is very difficult to locate the Producer new location and it took time and lot of resource to locate Producer in Named Data Network. In figure 9 the consumer makes a request and send interest packet toward Producer, but Producer move from NDN R-3.1 to NDN R-3.2 and the request reached NDN R-3.1. The cluster head not aware of the

Producer current location and the interest packets reached the previous access router waste. To counter this issue, we design a handover procedure in figure 10.

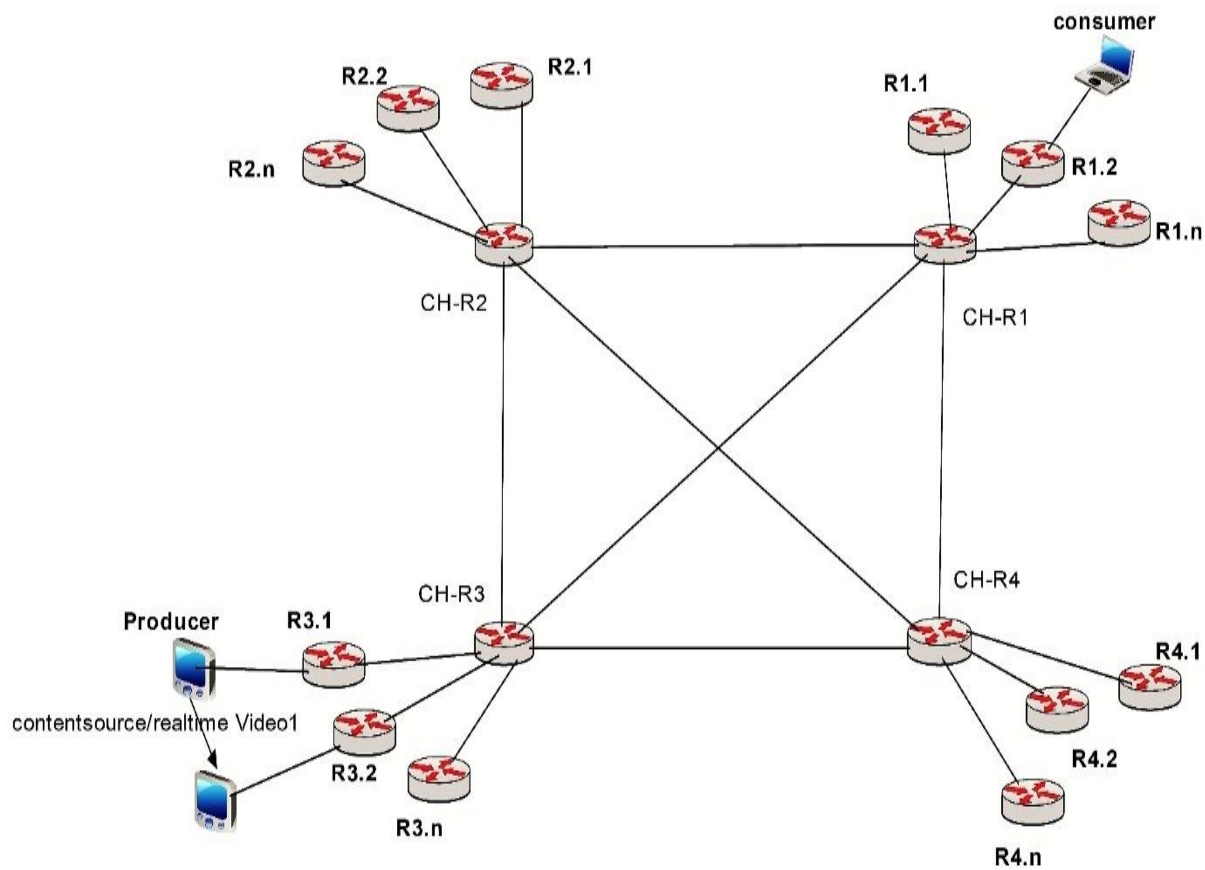

Figure 9: CB-DMM Network Model

5.3- Selection of Clusters Head

Different approaches can be taken to select the clusters head. Depend upon the networks like in wired network the situation is different from the wireless network. Selection of clusters heads in the wired network a little bit easy while selection in wireless is difficult. Our scenario is based on both wired and wireless network. In our scenario, the consumer connected through wired and the Producer is wirelessly connected to the network. The AP points connected to a cluster head which is weirdly connected. Based on our approach we selected the cluster head on the following approaches. First, we used the algorithm 1 to select cluster head based on memory. Second, the cluster head must provide easy connectivity to other cluster heads. Third, the cluster heads know each other addresses. Fourth, the cluster heads connected with each other directly. In [12] the author proposed an algorithm for selection of cluster heads which is shown in Algorithm 1.

Algorithm 1: Selection of Cluster Heads

For each router, send to its one-hop neighbors "***inform***"
Wait for reply
Mem [i] ← Probe (inform)
Mem_{self} ← *Check self-memory*
Mem_{max} ← Highest (Mem[i])
IF Mem_{self} = Mem_{max} **Then**
    CH ← self
    *Wait for the "**name**" Interest*
    Reply "***name***" *Interest* declaring it is CH
ELSE
    Request CH for "***name***" *Interest*
    Wait for *name Interest* from CH
ENDIF

5.4- Operation of Routers

Each router will maintain three tables. i) CS ii) PIT iii) FIB. All the end user's terminals which are connected directly or indirectly to these routers whenever requested for contents goes through these above tables. User A wants contents "Bahria/live streaming/video/part1" and make a request for it to the router. If the router has the contents in the CS table it will forward to the user an otherwise forward to PIT, if PIT have already requested for the same contents, it only record the user A request and when data reached it will forward to user A. if the PIT did not send request for contents it would forward to FIB, and the FIB send it to the web and when contents found it will forward to the user A. Now another user B also request for the same data and when the interest reached the router, the router have already forward the same contents to user A and it store the contents in has caches table CS. Now the router will forward the contents to user B. through this process the repeated transmission is discarded.

5.5- Operation of Cluster Heads

In our scenario, there are different operation can be possible of the cluster heads. The different router has been connected to the same cluster head. Now User A connected to router R1 and User B connected to R2 and both R1, R2 connected to cluster head R. same situation which was previously discussed in 5.4, but routers are different. When user A, interest packets send through R1 toward cluster head R, and the data packets come back through cluster head R. Cluster head R also store the contents in CS table. Now User B sends interest packets for the same data through different router R2 when the interest reached the cluster head. The cluster head simply sends data packets to user B from it CS table. Through this process, a lot of network resources can be saved and decreased overhead from the network. The cluster heads in our scenario also send a periodic update to each other about connected devices through this process the contents can be easily found in the network. The mobility problem can also be solved through periodic updates which cluster heads share with each other.

5.6- CB-DMM Handover Procedure

When Producer handover from PAR (Previous Access Router) to NAR (New Access Router) in figure 10. The moving device sends the attachment information to NAR about the current location. The NAR send the attachment information to the cluster head and inform it about the Producer. The cluster head updates it cache table and saves the current location of the Producer. The cluster head sends the binding acknowledgment about the binding update to the Producer. The cluster heads exchange periodic update to each other. When a request reached cluster head for the Producer, it simply checks its cache and sends a request to the current location of the Producer. The Producer sends the contents through reverse path to the consumer.

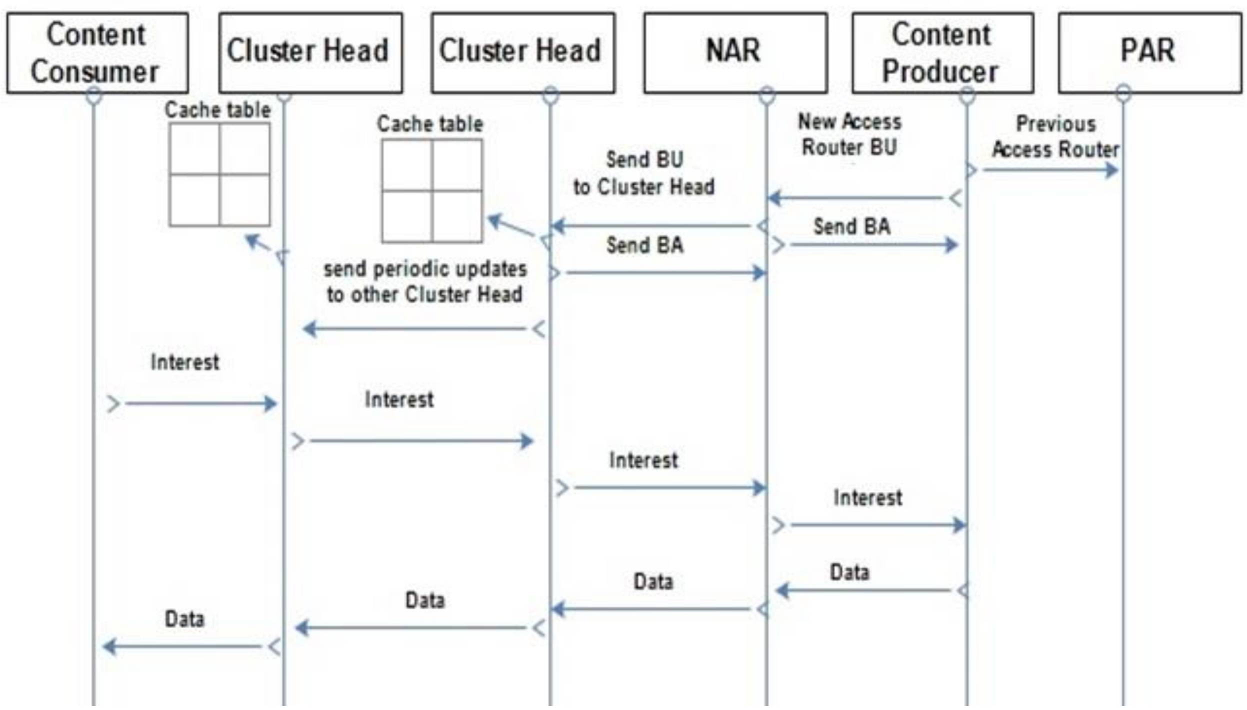

Figure 10: CB-DMM Handover

Chapter 6

CB-DMM and SMM Results

6.1- Introduction

We simulate both CB-DMM and SMM network model in ndnSIM. Following are some network parameters for both network. We will need more nodes in SMM model for a different scenario like when Mapping System is placed 6 hops away from Producer node. For MS place three hops away we used the same network parameters which will be used in CB-DMM model. Figure 11 and figure 12 are used for CB-DMM and SMM (we used two scenarios for SMM model wherein the first scenario the mapping system is 3 hops away and the second scenario the mapping system is 6 hops away) simulation scenario models.

6.2- CB-DMM and SMM Network Topologies

We used two different scenarios for SMM model because in SMM model the Mapping system can be globally located in the network.

6.2.1- Scenario 1

Figure 11 shown the basic network topology for CB-DMM and SMM models. For CB-DMM scenario model, the Producer initial connected with AP1. Both the AP's connected with cluster head and the cluster heads connected with each other. The consumer connected to NDN router and that NDN router connected with cluster head. For SMM model the mapping system is placed 3 hops away from the Producer node. In figure 12 for SMM model, the routers are default NDN routers which are discussed in [1].

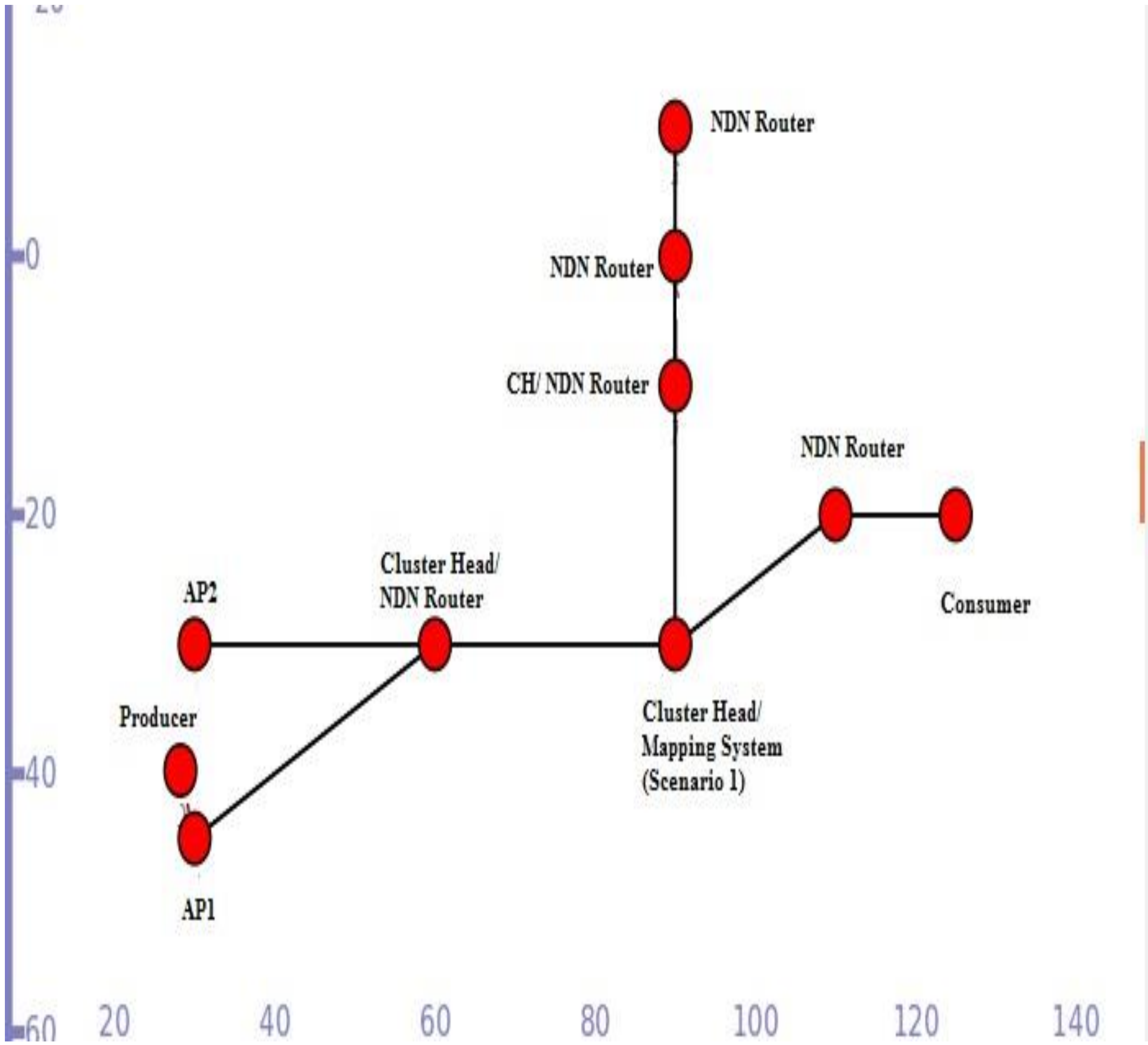

Figure 11: CB-DMM and SMM Network Simulation Scenario 1 Model

6.2.2 Scenario 2

In figure 12 CB-DMM and SMM (Mapping System is 6 hops away) scenario models are shown. For CB-DMM model some routers have the functionality of cluster heads while for SMM model one router have the functionality of mapping system which can be used to locate the contents in the NDN network. For SMM model we placed the mapping system 6 hops away. According [1], the mapping system can be placed globally in the NDN Network.

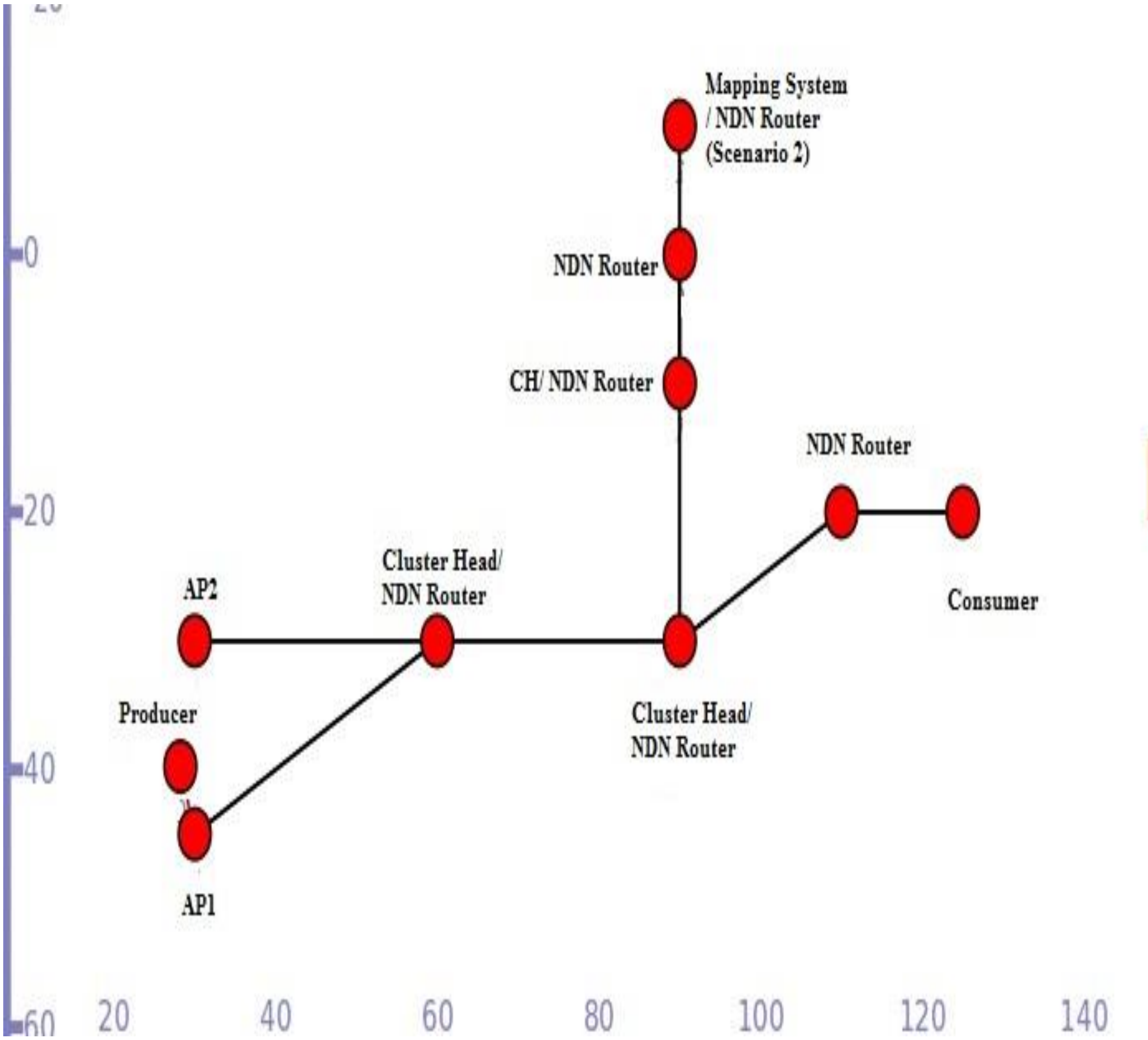

Figure 12: CB-DMM and SMM Network Simulation Scenario 2 Model

6.3- Network Parameters for 10 Mbps Link and 5ms Delay

6.3.1- CB-DMM and SMM (MS placed 3 hops away) Models parameters

Table 2: CB-DMM Network Parameter for 10 Mbps and 5ms Delay

Parameters	Values
Number of Nodes	11
Link Capacity	10 Mbps
Link Delay	5ms
Wi-Fi AP bandwidth	24 Mbps
Simulation Time	10s

Table 2 showed basic parameters for CB-DMM and SMM model. For SMM model we used two parameters table like Table 2 and Table 3. In Table 2 we used same parameters for both networks but SMM mapping system place at 3 hops away while in Table 3 the mapping system place at 6 hops away from the Producer node and the rest of the parameters are the same. The number of nodes in Table 3 is 11. The link capacity is 10 Mbps, and the link delay is 5ms. The Wi-Fi AP bandwidth is 24 Mbps and the simulation time is 10 seconds.

6.3.2- SMM Model parameter where MS placed 6 hops away

Table 3: SMM Network Parameter 10 Mbps and 5ms Delay with MS place at 6 hops away

Parameters	Values
Number of Nodes	11
Link Capacity	10 Mbps
Link Delay	5ms
Wi-Fi AP bandwidth	24 Mbps
Simulation Time	10s

Table 3 have parameters for SMM network topology where mapping system is placed 6 hops away from the Producer. Other parameters are the same which are used in Table 2.

6.3.3- Interest satisfied ratio for CB-DMM and SMM (where MS placed 3 hops away)

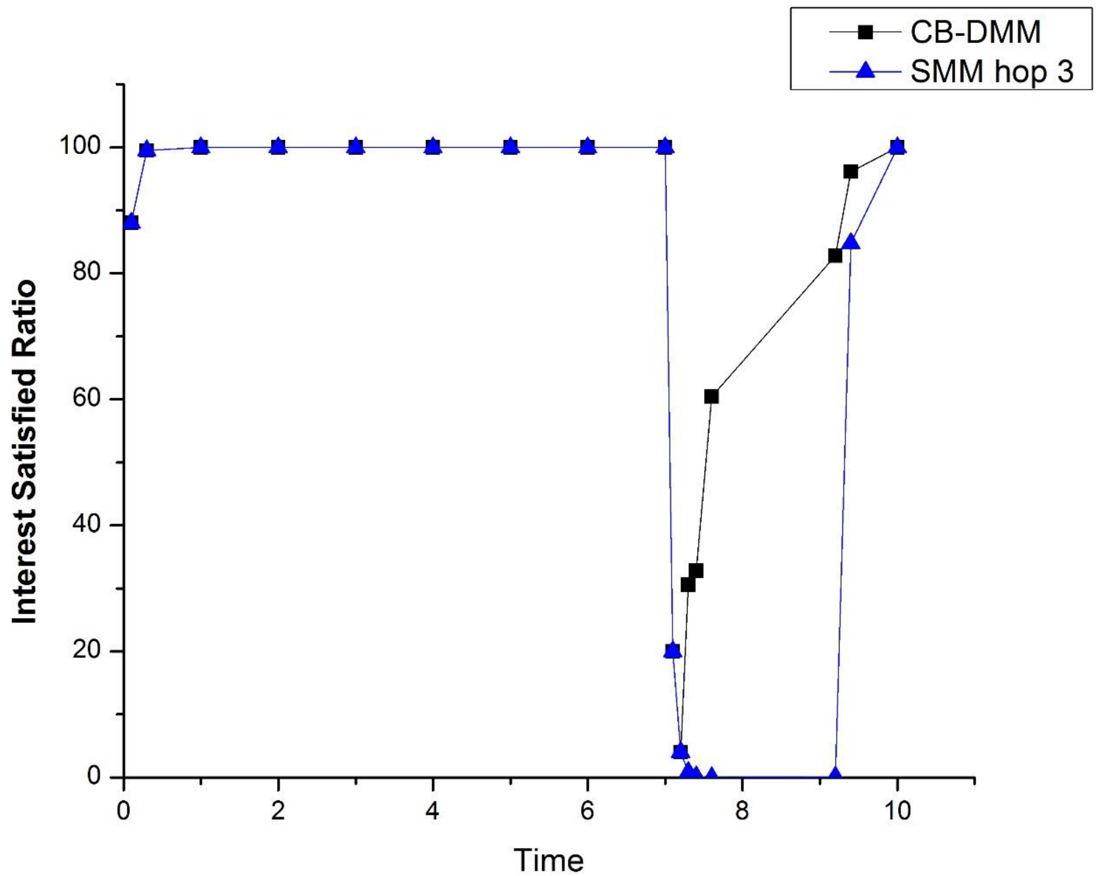

Figure 13: 10Mbps link delay 5ms and SMM Mapping System is 3 hops away

Figure 13 illustrate the result of CB-DMM and SMM model. For SMM model the mapping system is placed 3 hops away from the Producer. In the start of the simulation both model satisfied 88 percent interest in the first 0.1 second while both reached around 100 at 0.2 seconds. The handover happened after 7 seconds of the simulation. Around 7.1 both models satisfied 20 percent interests. At 7.2 both model, down to 0 because of no connectivity with the previous access router. The CB-DMM model started communication at 7.3 seconds, and satisfied interest's ratio is 30 percent and reached to 100 percent again in 10 seconds while SMM model starts communication at 9.1 and reached to 100 percent at 10 seconds.

6.3.4- Interest satisfied ratio for CB-DMM and SMM (where MS placed 6 hops away)

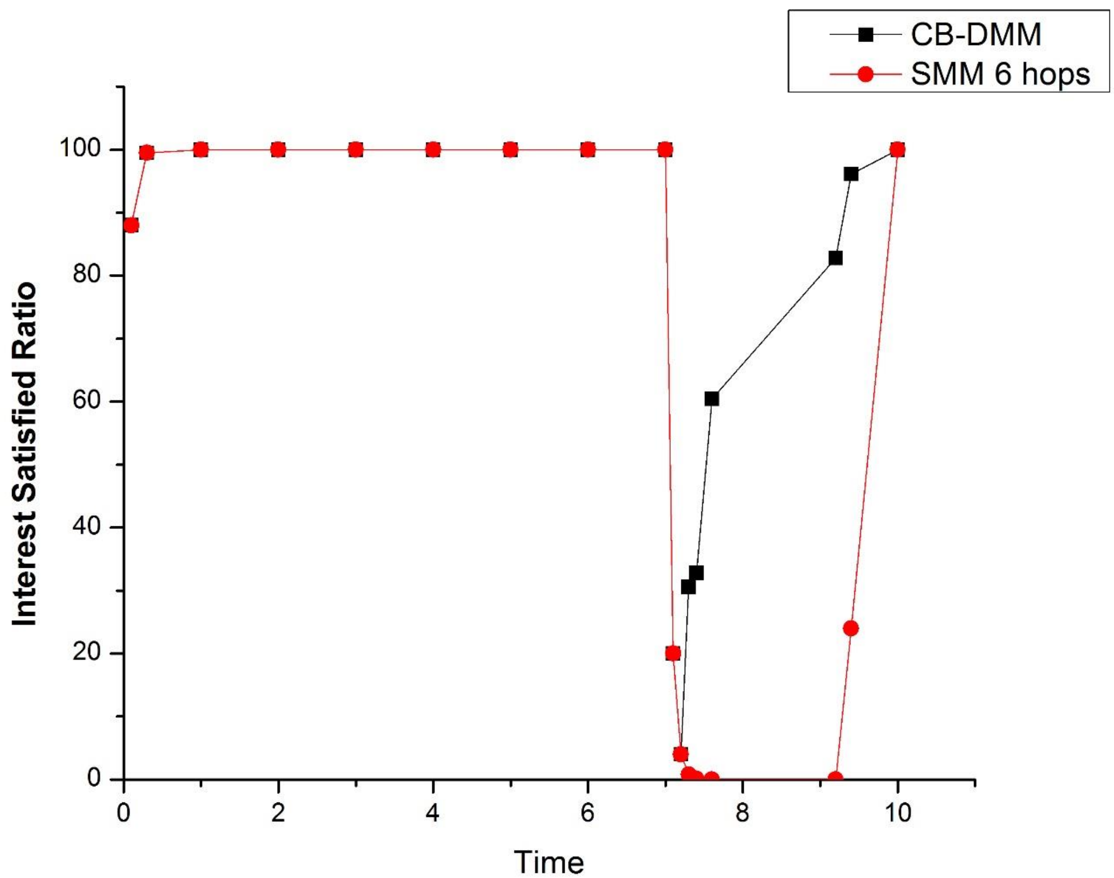

Figure 14: 10Mbps link delay 5ms and SMM Mapping System is 6 hops away

Figure 14 illustrated the result of both models. In both model the interest satisfied ratio around 88 percent at the start of the communication. As shown in figure 15 that CB-DMM model communication starts again very soon compare to SMM model. The mapping system is placed 6 hops away from Producer node in SMM model. Both network model handover to AP2 after 7 seconds. At 7.2 both network, down to 0 while at 7.3 second the CB-DMM model start communication and satisfied interest ratio was around 30 percent. The SMM model resumed communication at 9.2 seconds and reached to around 100 in 10 seconds. Figure 16, as a result of Table 2 and Table 3 parameters.

6.3.5- Interest satisfied ratio for CB-DMM and SMM (where MS placed 3 and 6 hops away)

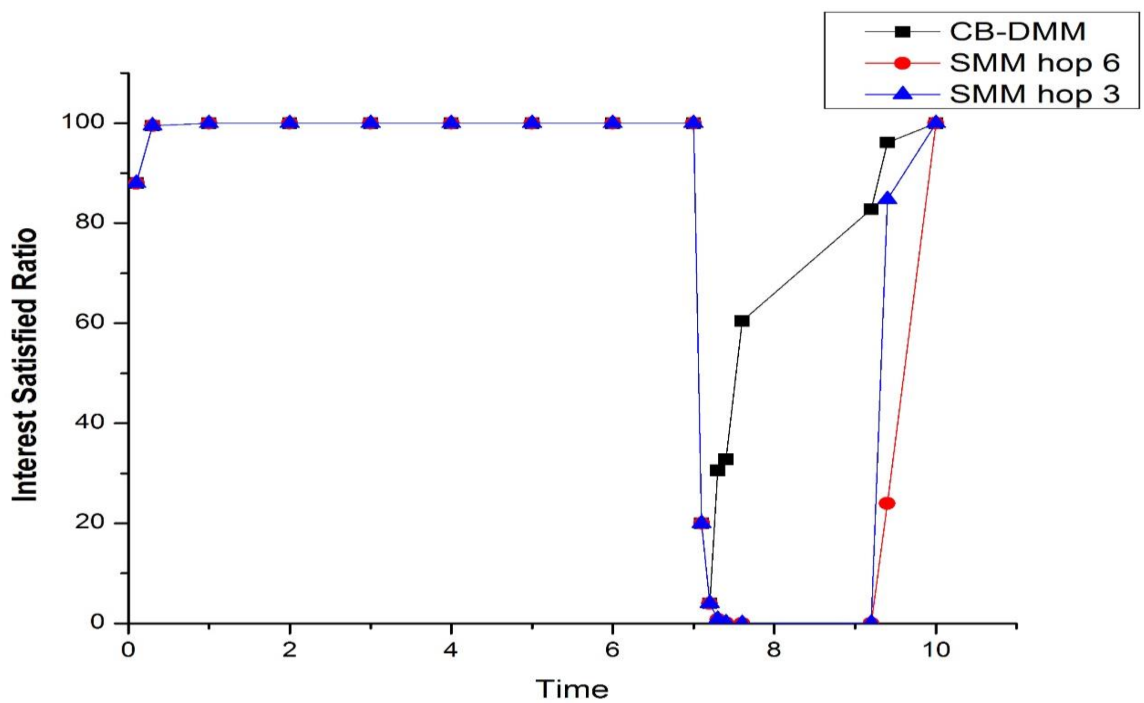

Figure 15: 10Mbps and 5ms delay

In figure 15 for SMM, the MS has placed 6 hops and 3 hops away and then compare with CB-DMM model. As a result showed that both networks satisfied 84 percent interest at the start of the simulation. When handover happened after 7 seconds, the CB-DMM model resume communication and 30 percent interest were satisfied around 7.3 seconds. While for SMM model when MS place it 3 hops away from the communication start again at 9.1 and interest satisfied ratio was 78 percent. For MS place at 6 hops away the communication resume at 9.3 and interest satisfied ratio was 22 percent. All of three scenarios reached 100 percent at 10 seconds.

6.4- Network Parameters for 10 Mbps Link and 10ms Delay

6.4.1- CB-DMM and SMM (MS placed 3 hops away) Models parameters

Table 4: CB-DMM and SMM Network Parameters for 10 Mbps and 10ms Delay

Parameters	Values
Number of Nodes	11
Link Capacity	10 Mbps
Link delay	10ms
Wi-Fi AP bandwidth	24 Mbps
Simulation Time	10s

Table 4 illustrate the parameters for both CB-DMM and SMM (MS place 3 hops away) model. The link capacity is 10 Mbps, and link delay is 10ms. The Wi-Fi bandwidth for Access Point used 24 Mbps. Simulation time is 10 seconds.

6.4.2- SMM (MS placed 6 hops away) Models parameters

Table 5: SMM Network Parameter for 10 Mbps and 10ms Delay with MS place 6 hops away

Parameters	Values
Number of Nodes	11
Link Capacity	10 Mbps
Link Delay	10ms
Wi-Fi AP bandwidth	24 Mbps
Simulation Time	10s

Table 5 same parameters which used in Table 4 but Table 5 parameters are for SMM model where MS placed 6 hops away. Here the nodes size increased for SMM model. The resets parameters are the same.

6.4.3- Interest satisfied ratio for CB-DMM and SMM (where MS placed 3 hops away)

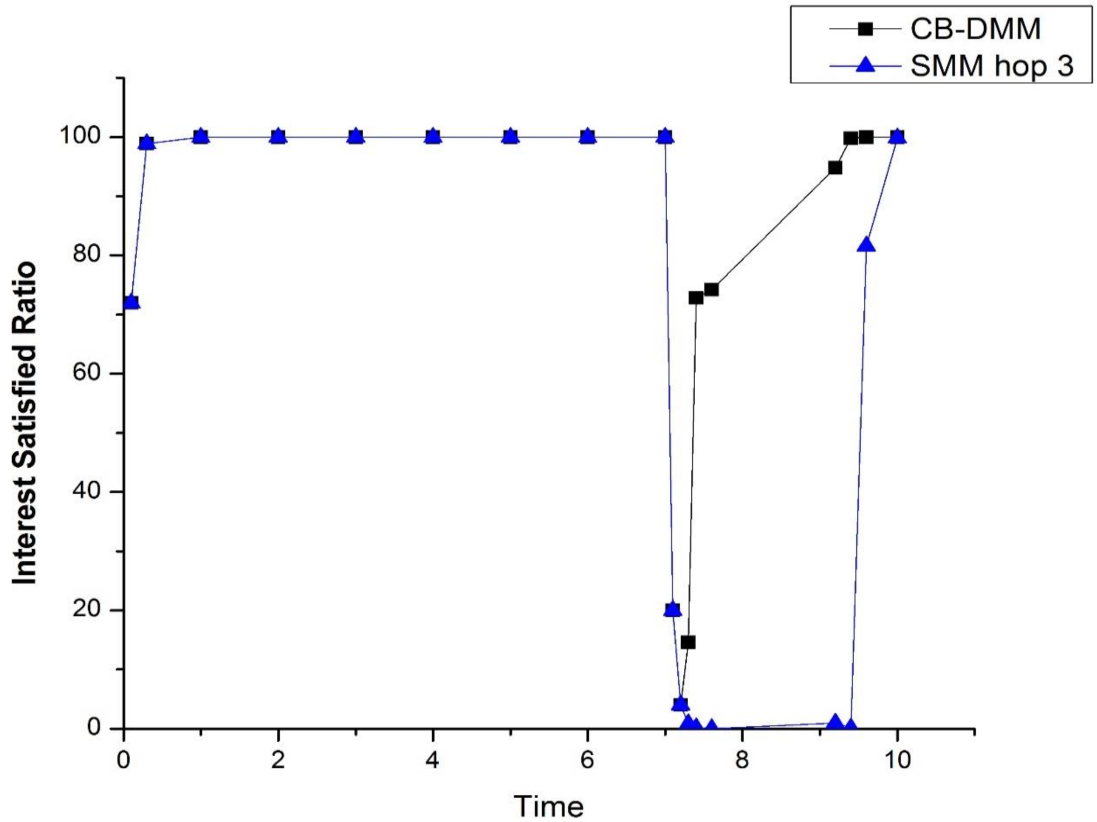

Figure 16: 10 Mbps and link delay 10ms SMM MS 3 hops away

Figure 16 showed the result of CB-DMM and SMM (MS placed 3 hops away) model. The link delay impact on the interests satisfied ratio. At the start of the communication, the interest satisfaction ratio for both models are 72 percent and reached to 100 percent at 0.2 seconds. After 7 seconds in both models the handover happened and 7.1 seconds both model down to 0 percent. The CB-DMM model starts the communication again at 7.2 in that seconds the interest satisfaction ratio was 18 percent and reached to 100 percent interest satisfactions ratio at 9 seconds. While the

SMM model start communication 9.3 and the interest satisfactions ratio at 9.3 seconds are 80 percent and reached to 100 percent around 10 seconds.

6.4.4- Interest satisfied ratio for CB-DMM and SMM (where MS placed 6 hops away)

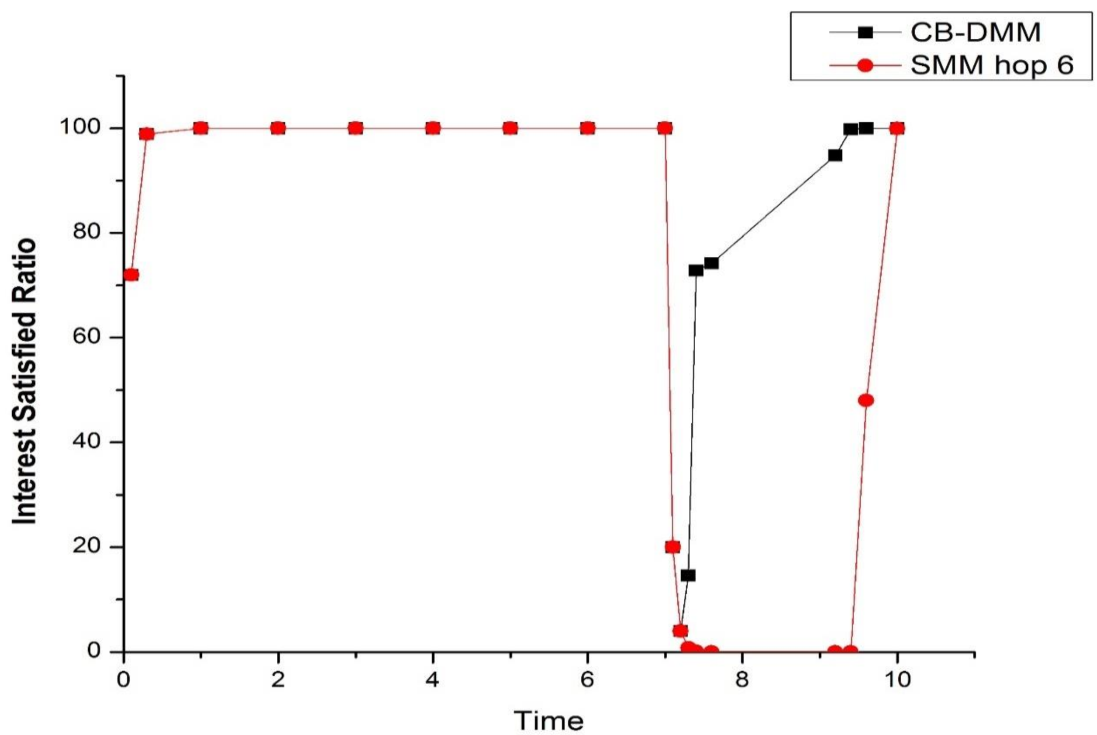

Figure 17: 10 Mbps link delay 10ms and SMM MS 6 hops away

In figure 17 compare the result of CB-DMM and SMM model where the mapping system placed at 6 hops away from the Producer node. At the start of the simulation, both models interests satisfied ratio was 72 percent. At 7.1 the handover from AP1 to AP2 happened and the interest satisfied ratio at 7.1 seconds are 20 percent. Both model down to 0 percent at 7.2. CB-DMM model starts communication again at 7.3, and the interest satisfied ratio was 18 percent and reached to

100 percent 9 seconds while SMM model start communication again at 9.3 seconds and interest satisfied ratio is 50 percent. The interest satisfaction ratio reached 100 at 10 seconds.

6.4.5- Interest satisfied ratio for CB-DMM and SMM (where MS placed 3 and 6 hops away)

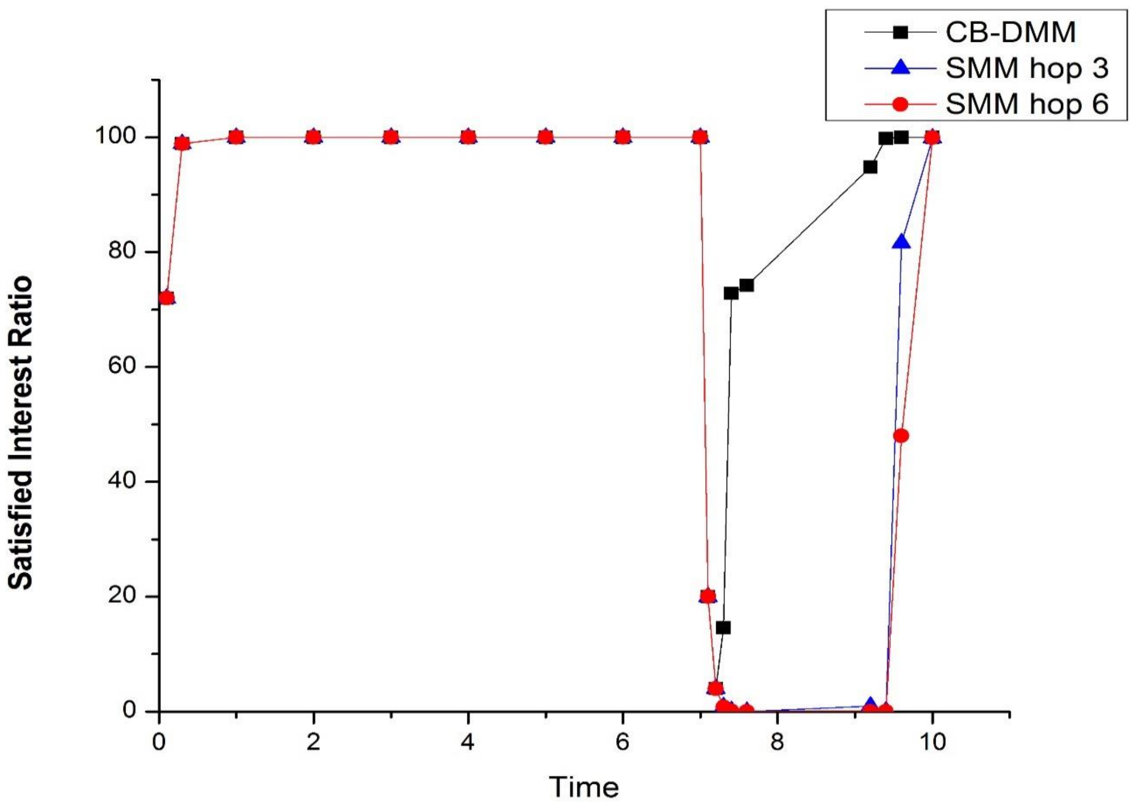

Figure 18: 10Mbps and 10ms delay

Figure 18 is the comparison of CB-DMM and SMM (MS placed 3 hops and 6 hops away) models. The CB-DMM model satisfied ratio at 0.1 seconds are 72 percent and goes to 0 percent at 7.1 seconds. The communication starts again at 7.2 seconds, and satisfied interest ratio is 18 percent and reached the satisfied interest ratio to 100 percent at 9 seconds. The SMM model where MS place 3 hops away are the same behavior, but the difference occurs when handover happened. At 7.1 the SMM (MS 3 hops away) model down to 0 percent and the communication start at 9.3 and interest satisfaction ratio was 80 percent and reached to 100 percent at 10 seconds. The SMM model where MS placed 6 hops away from the communication down to 0 percent in 7.1 seconds and the communication start at 9.4, and the interest satisfied ratio was 50 percent and reached to 100 percent at 10 seconds.

6.5- Network Parameters for 100 Mbps Link and 2ms

6.5.1- CB-DMM and SMM (MS placed 3 hops away) Models parameters

Table 6: CB-DMM and SMM Network Parameters for 100 Mbps and 2ms Delay

Parameters	Values
Number of Nodes	11
Link Capacity	100 Mbps
Link Delay	2ms
Wi-Fi AP bandwidth	24 Mbps
Simulation Time	10s

Table 6 showed the parameters for CB-DMM and SMM (MS 3 hops away). The number of nodes used is 11 for both CB-DMM and SMM models. The link capacity is 100 Mbps and link delay 2ms. The Wi-Fi AP bandwidth is 24 Mbps and simulation duration 10 seconds.

6.5.2- SMM Model Parameters where MS placed 6 hops away

Table 7: SMM Network Parameters for 100 Mbps and 2ms with MS place 6 hops away

Parameters	Values
Number of Nodes	11
Link Capacity	100 Mbps
Link Delay	2ms
Wi-Fi AP bandwidth	24 Mbps
Simulation Time	10s

Table 7 illustrate the parameters for SMM models where the MS placed 6 hops away from the Producer node in our scenario. The number of nodes increased for SMM model. We used 11 nodes here for our scenario and the rest of parameters are the same which are used in Table 6.

6.5.3- Interest satisfied ratio for CB-DMM and SMM (where MS placed 3 hops away)

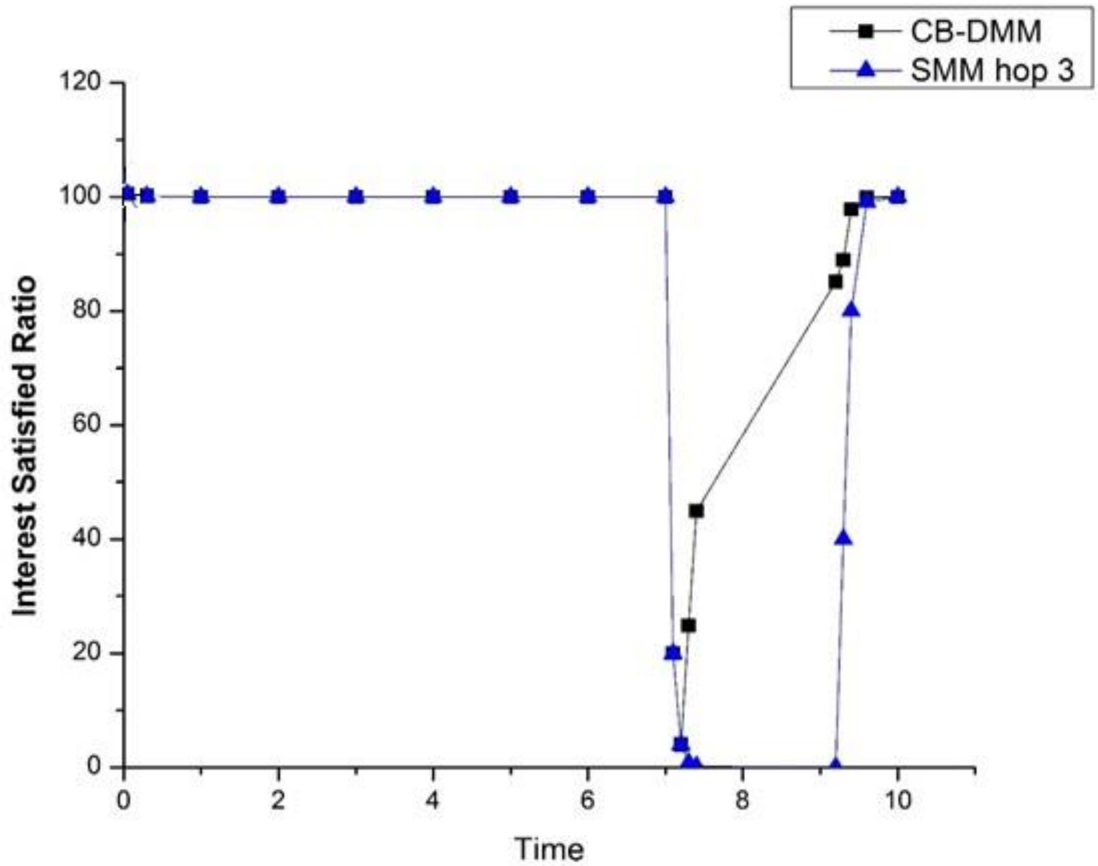

Figure 19: 100 Mbps, Link Delay 2ms and SMM MS 3 hops away

Figure 19 illustrate the results of CB-DMM and SMM (MS 3 hops away) models. Compare to the SMM model CB-DMM communication start early after handover happened. Both at 0.1 seconds satisfied interest ratio was 100 percent. After 7.1 second the handover procedure start and 7.3 the CB-DMM started communication again and reached to 100 at 9.5 seconds while the SMM model resume communication at 9.2 and reached to 100 percent around 9.5 seconds.

6.5.4- Interest satisfied ratio for CB-DMM and SMM (where MS placed 6 hops away)

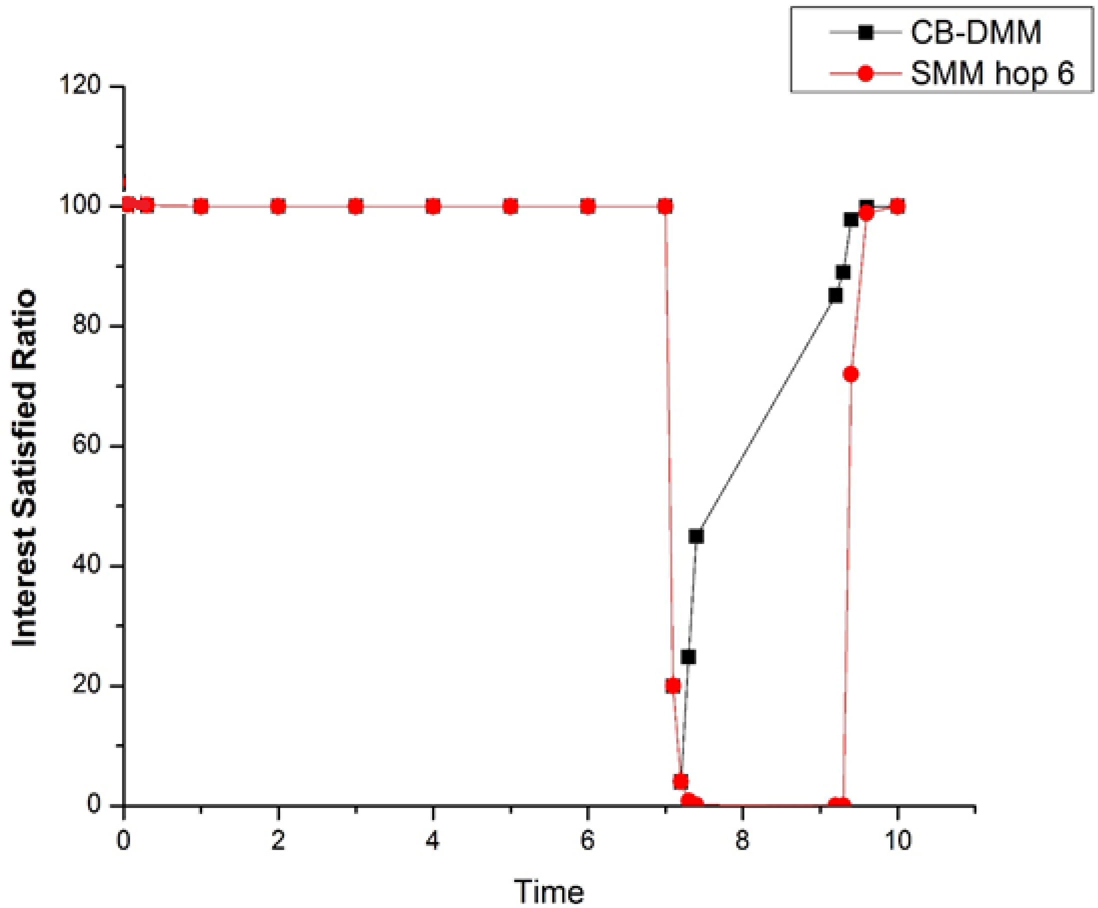

Figure 20: 100 Mbps, Link Delay 2ms and SMM MS 6 hops away

Figure 20 illustrate the result for CB-DMM and SMM (MS place 6 hops away) model. Both scenarios satisfied 100 percent interest at 0.1 seconds. After handover happened at 7.2 both model goes to 0 percent and the CB-DMM model resume communication at 7.3 seconds, and the interest satisfied ratio was 24 percent. CB-DMM model reached to 100 percent at 9.5 seconds. The SMM model resuming communication at 9.4 and satisfied interest ratio was around 78 percent. And reached to 100 percent at 9.5 seconds.

6.6.5- Interest satisfied ratio for CB-DMM and SMM (where MS placed 3 and 6 hops away)

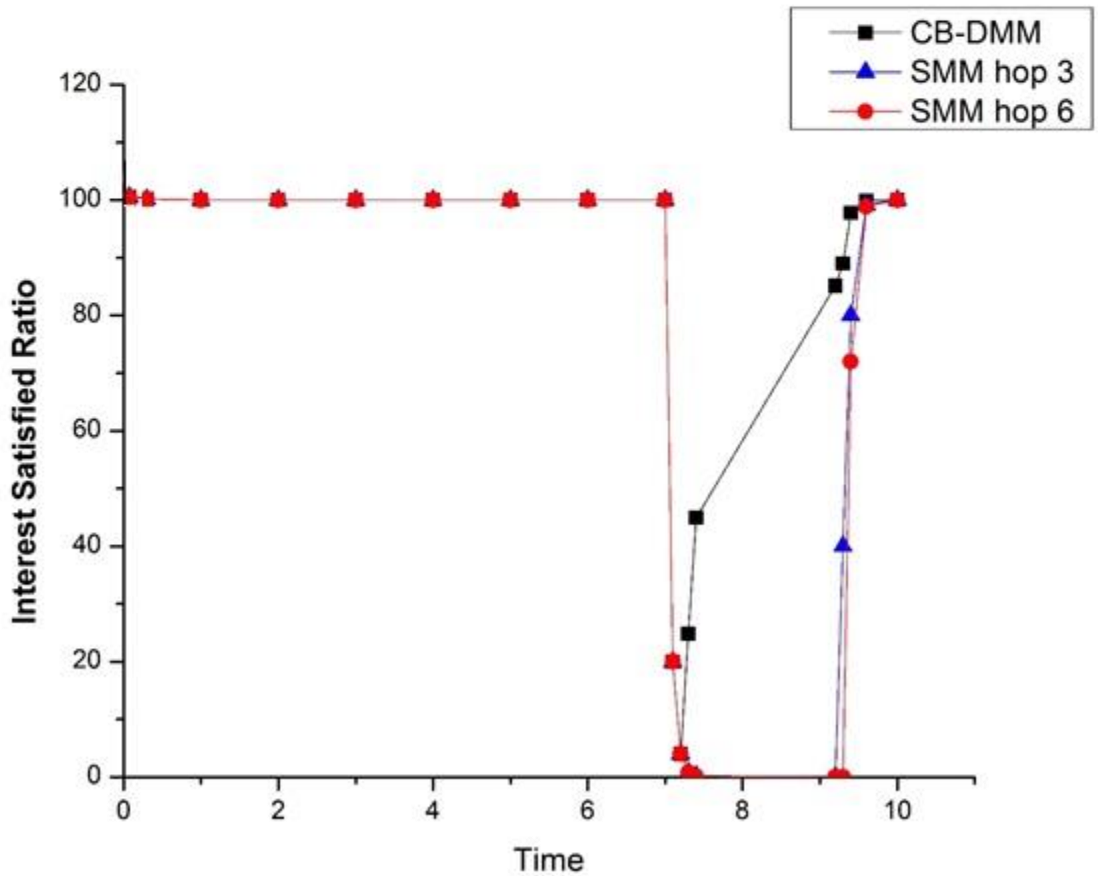

Figure 21: 100Mbps and 2ms Delay

In figure 21 comparison are given for CB-DMM and SMM (MS 3 and 6 hops away) models. As early explain in figure 10 and 11 the same data are here but compare both SMM models with the CB-DMM model. as we can see that after handover from AP1 to AP2 the CB-DMM model resume the communication from both models of SMM. CB-DMM model starts communication again at 7.2 while the SMM (MS placed 3 hops away) start communication again at 9.2 and SMM model where MS placed 6 hops away resume communication at 9.3 seconds. All three models reached to 100 percent at 9.5 seconds.

6.6- Network Parameters for 100 Mbps Link and 5ms Delay

6.6.1- CB-DMM and SMM (MS placed 3 hops away) Models parameters

Table 8: CB-DMM and SMM Network Parameters for 100 Mbps and 5ms Delay

Parameters	Values
Number of Nodes	11
Link Capacity	100 Mbps
Link Delay	5ms
Wi-Fi AP bandwidth	24 Mbps
Simulation Time	10s

Table 8 showed parameters for CB-DMM and SMM (MS 3 hops away) models. The number of nodes used for both scenario is 11 The link capacity is 100 Mbps and the link delay 5ms. The Wi-Fi AP bandwidth is 24 Mbps and the simulation duration is 10 seconds.

6.6.2- SMM (MS placed 6 hops away) Models parameters

Table 9: SMM Network Parameter for 100 Mbps and 5ms with MS place 6 hops away

Parameters	Values
Number of Nodes	11
Link Capacity	100 Mbps
Link Delay	5ms
Wi-Fi AP bandwidth	24 Mbps
Simulation Time	10s

Table 9 illustrate the parameters for SMM model where the MS placed at 6 hops away. The number of nodes increased for this scenario because the mapping system placed 6 hops away. The rest of parameters is the same which are used in Table 8.

6.6.3- Interest satisfied ratio for CB-DM and SMM (where MS placed 3 hops away)

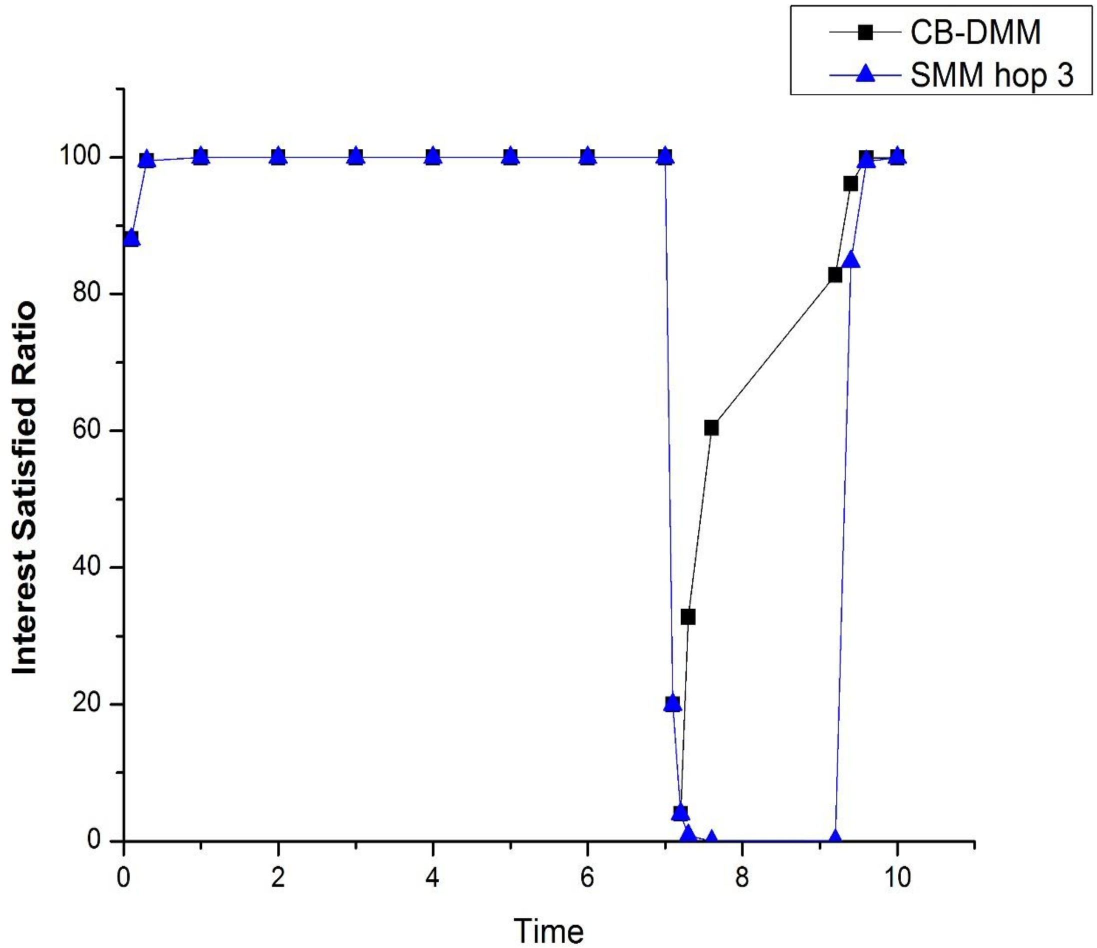

Figure 22: 100 Mbps, Link Delay 5ms and SMM MS 3 hops away

Figure 22 compare the result of CB-DMM and SMM (MS 3 hops away) models. We can see the effect of link delay increased in the graph. Compare to figure 11 and 12, here both model initial interest satisfaction ratio at 0.1 seconds are 88 percent. Both CB-DMM and SMM model goes to 0 percent at 7.1 but CB-DMM resumes the communication at 7.2 seconds while the SMM model starts communication again at 9.2 seconds. Both models reached to 100 percent at 9.3 seconds.

6.6.4- Interest satisfied ratio for CB-DMM and SMM (where MS placed 6 hops away)

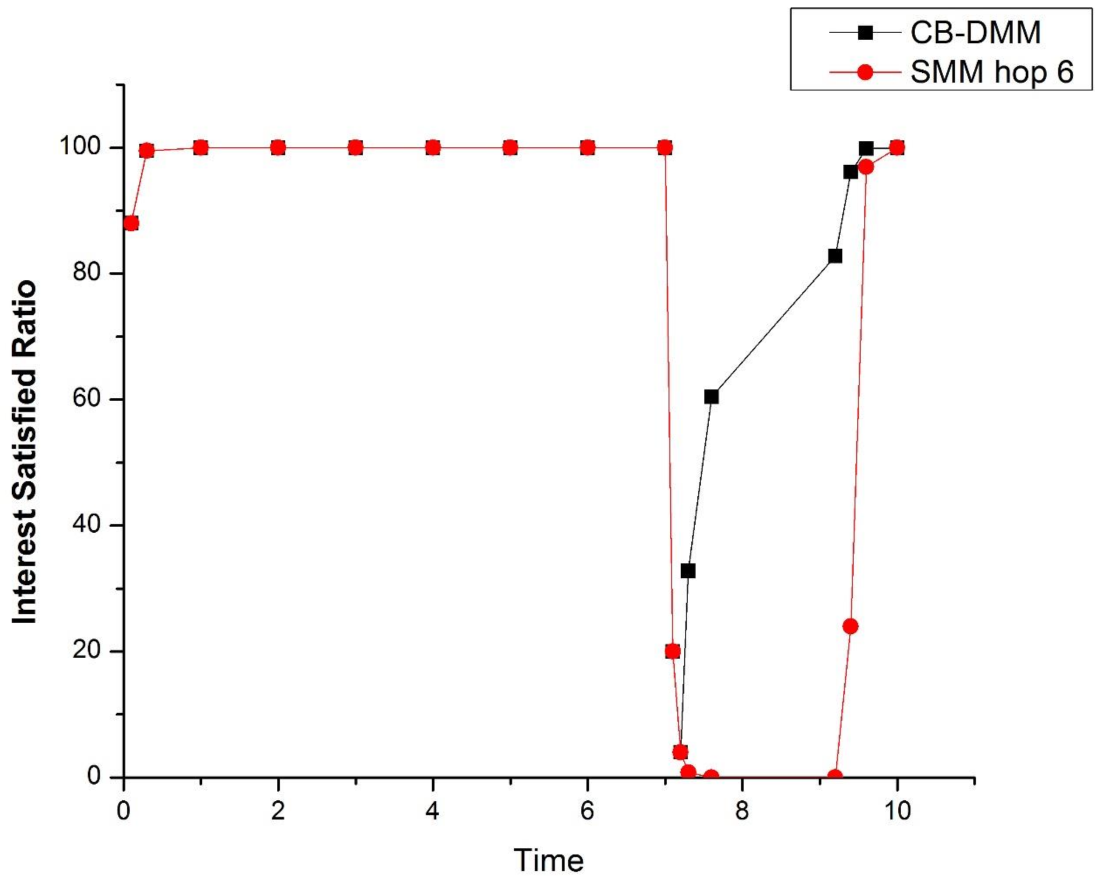

Figure 23: 100 Mbps, Link Delay 5ms and SMM 6 hops away

Figure 23 illustrate the result of SMM model where MS place at 6 hops away with CB-DMM model. At 0.1 seconds the interest satisfied ratio was 88 percent for both models. After handover at 7.2 the CB-DMM model resume the communication at 7.3 seconds and satisfied interest ratio was 32 percent. The SMM model resumes the communication at 9.2 seconds and satisfied 28 percent interest at 9.2 seconds. CB-DMM reached to 100 percent at 9.3 seconds while SMM model reached to 100 percent at 9.4 seconds.

6.6.5- Interest satisfied ratio for CB-DMM and SMM (where MS placed 3 and 6 hops away)

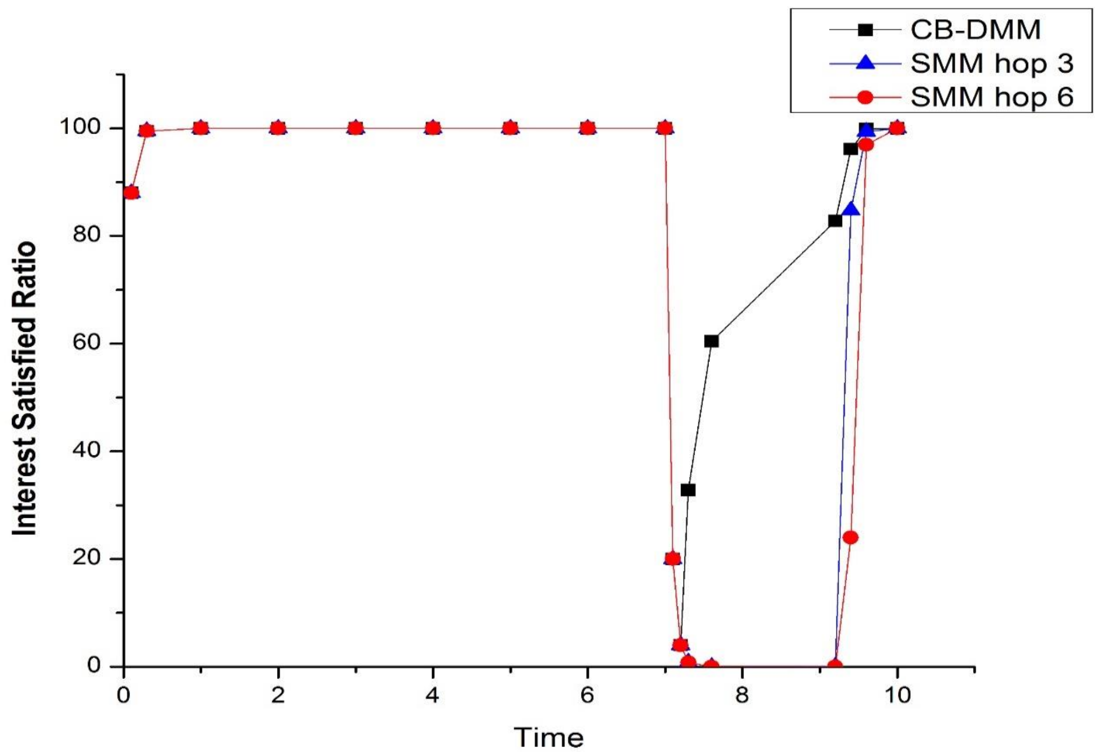

Figure 24: 100Mbps and 5ms Delay

In figure 24 showed the comparison of both SMM models and CB-DMM model. all of three satisfied 88 percent interest at 0.1 seconds. When handover happened at 7.1 all of three models goes to 0 and the CB-DMM model resumes the communication again at 7.3 seconds while the SMM model where the MS place 3 hops away resume the communication at 9.2 and SMM model where the MS place 6 hops away start communication at 9.3 seconds. CB-DMM and SMM (MS 3 hops away) reached to 100 percent at 9.3 seconds while SMM model where the MS placed at 6 hops away reached to 100 percent at 9.4 seconds.

Chapter 7

Conclusions and Future Work

In NDN network to locate Producer, different solutions have been proposed and still need some improvement. Our proposed solution called CB-DMM where devices send their information to cluster head after the handover. The cluster head keeps that information for future used. we compare our result with SMM model which was proposed for Producer mobility. In SMM model the Producer send has new location information to the mapping system. Then the mapping system sends the information to the previous access router to divert the interest packets toward the new access router. In our solution, we send the device information to the cluster head now the cluster head responsible for diverting the interest packets towards new access router. No need to tell the previous access router to divert the interest packets. As shown in chapter 6, the results of our model are very good compared to SMM model. For both models, we did not count the timing where the device not connected to the network.

We used two different scenarios for CB-DMM and SMM model. in the first scenario, both CB-DMM and SMM model have the same number of nodes and other network parameters are also the same. In the second scenario, we increased the number of nodes for SMM model because placing the mapping system at a specific point which is mention in chapter 6.

The proposed scheme compare to SMM model have good results in term of diversion of interest packets toward Producer and interest satisfied ratio. The diversion of interest packets toward Producer is quickly in our proposed model. The interest packet satisfied ratio are also good in our proposed scheme.

The future work will be to reduce the overhead of cluster head in the network and used the cluster head for other purposes which can solve the network query very quickly. We also planning to move the producer into different cluster heads in the network and then compare our results with the SMM model.

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