A Pipe-Assisted Mobility Management in Named Data Networking Networks

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***Abstract*—A new non-IP networking technology, called as named data networking (NDN), is an emerging research topic for the future Internet. In this paper, we propose a pipe-assisted mobility protocol in NDN networks. The proposed mobility protocol is constructed based on a new proposed name-based routing scheme by utilizing a pipe technique. A new name-based routing protocol is developed by constructing a pipe from a consumer to a producer in NDN networks. With the assistance of the constructed pipe, a pipe-assisted producer mobility protocol is proposed. When a mobile producer enters a new domain, a pipe-based pre-route with the maximum popular levels is built to increase the successful probability of discovering a new path from the producer to the consumer. Extensive simulations illustrate that the proposed pipe-assisted mobility protocol significantly reduces the packet loss rate.**

I. Introduction

A new non-IP networking technology, called named data networking (NDN) with explicitly hierarchical names, is an emerging research topic to replace the current host-centric IP-networks to overcome the massive content diffusion problem. NDN is one of the implementation of information-centric networking (ICN) [1]. The current internet infrastructure is for host-to-host communication [2], which inherits the telephony technique. In contrast, NDN architecture aims to overcome the problem caused by the current host-centric IP-based Internet. The goal of NDN is to provide a newly efficient Internet architecture to satisfy the ever-growing demands in terms of traffic and emerging future applications.

This paper specially focuses on the mobility management in Named Data Networking (NDN) [3] networks. NDN networks are based on Content-Centric Networking (CCN) [4] proposal. NDN is designed for efficient, secure and reliable dissemination of information. In NDN networks, the content name is based on explicitly hierarchical names, and data consists in a sequence of chunks. The network layer in NDN uses unique content name to identify content data objects, and there are two packet types in NDN protocol [2], namely Interest packet (IntP) and Data packet (DatP). IntP is similar to a content request, which is expressed by the information consumer (also called requesters and subscribers), and the DatP is responded by the producer (also called publishers).

NDN communications is built on the explicit and hierarchical named data and request/response model. NDN supports in-network and on-path caching and is optimized for the content sharing. Data is cached on each router on the transmission path and when IntPs match a named data on Content Store, the router can transmit the named data to the consumer directly. The NDN communication is driven by the requests sent from consumers. The normal operation of NDN may cause the mobility problem, which is caused by the consumer mobility and producer mobility. The consumer mobility in NDN is slight. The consumer just simply resends the IntP whose corresponding content has not received yet at the worst. The producer mobility is difficult due to the location of the named data might be relocated, such that the consumer should search the content data again and obtain the new name prefix of the producer and the consumer must re-issue a new IntP.

The remainder of this paper is organized as follows. Section II describes system model. Section III describes the proposed mobility protocol. Simulation evaluations are presented in sections IV. Finally, conclusions are presented in section V.

II. System Model

The system model is based on Named Data Networking (NDN) project [3] and CCNx proposal [4], as shown in Fig. 1. NDN node implements the forwarding and buffering operations. A mobile producer will be re-assigned a new domain name if the producer attaches to a new domain. It is observed that the consumer suffers problems of the long handover latency and the high packet loss ratio if the data objects are still supplied from the mobile producer located at the different domain. Let T_{HL} denote the handover latency between the consumer and the mobile producer, when the producer moves from the previous domain to the next domain. To achieve the objective, some notations are defined. Let $N_{i,j}$ denote an i-th row and j-th column NDN node in an NDN network, where $1 \leq i \leq h_{max}$, $1 \leq j \leq k_{max}$, h_{max} and k_{max} denote the maximum number of rows and columns of the NDN network respectively. Each $N_{i,j}$ can communicate with $N_{i,j-1}$ and $N_{i,j+1}$ to perform the pipe-assisted mobility protocol. Before defining the pipe structure, a chain is firstly defined, and a pipe is constructed by a number of chains.

Definition 1: **Chain** $C_{i,k,\alpha}$. Let $C_{i,k,\alpha}$ represent the i-th chain with k numbers of NDN nodes, $C_{i,k,\alpha}$ contains $N_{i,1+\alpha}$, $N_{i,2+\alpha}$,, $N_{i,k+\alpha}$, where $1 \leq i \leq h_{max}$ and $\alpha \geq 0$.

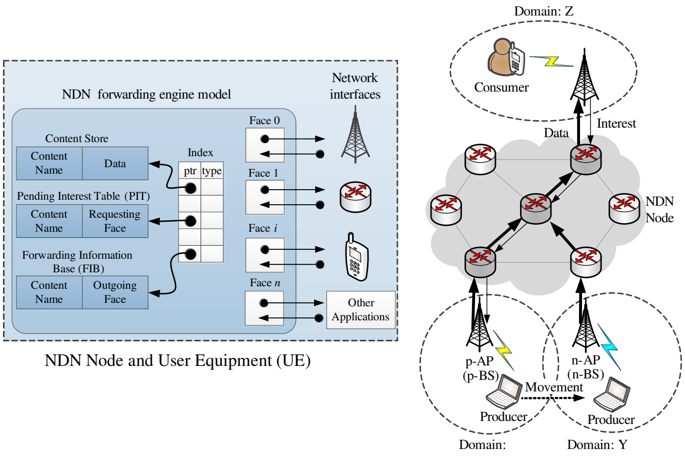

Fig. 1. Named data networking networks and NDN forwarding model.

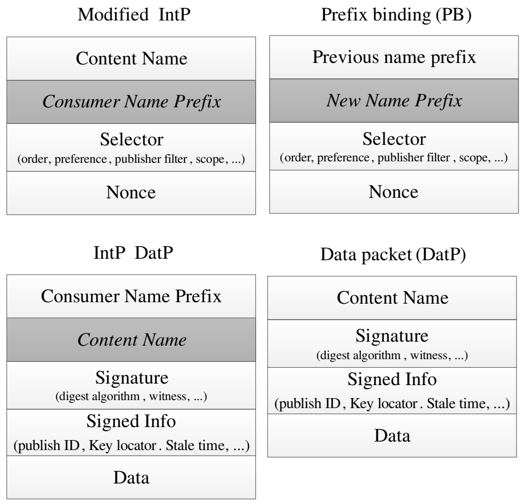

Fig. 2. The new packet format.

Definition 2: **Maximum Popularity Value of Chain $C_{i,k,\alpha}$.** Let $p_{i,j+\alpha}$ denote the popularity value of a NDN node $N_{i,j+\alpha}$, where $1 \leq i \leq h_{max}$, $1 \leq j \leq k_{max}$, and $\alpha \geq 0$. The popularity value is calculated by the longest prefix match from all packets against the FIB. The high popularity value indicates that the high path searching probability. The maximum popularity value of Chain $C_{i,k,\alpha}$ is obtained as follows.

$$Max(\sum_{j=1}^{k} p_{i,j+\alpha}), \text{for } \alpha \geq 0 \qquad (1)$$

Definition 3: **Pipe Structure $P(h,k)$.** Let $P(h,k)$ denote a pipe structure which is constructed by h chains, and each chain $C_{i,k,\alpha}$ has k NDN nodes with the maximum popularity value, where $\alpha \geq 0$, $1 \leq i \leq h$, $h \leq h_{max}$, and $k \leq k_{max}$.

To minimize the handover latency and re-build a fast route for solving the producer mobility when the mobile producer moves to a new domain, a $P(h,k)$ will be utilized to provide a fast mobility solution. With a $P(h,k)$, a pipe-based name routing scheme can be developed. Thus, the main purpose of the new mobility protocol is developed to minimize T_{HL} as follows.

$$Min(T_{HL}) \qquad (2)$$

III. Pipe-Assisted Mobility Protocol

The main objective of the pipe-assisted mobility protocol is to reduce the handover latency and the packets loss ratio. Without loss of generality, let $\widehat{P}$ denote as a content producer, and $\widehat{C}$ denote as a content consumer. In the following, we describe the mobility condition when $\widehat{P}$ moves from the current domain to the next domain, a producer mobility problem is occurred to keep the connection with $\widehat{C}$. Then, a pipe-structure is constructed from $\widehat{C}$, since $\widehat{C}$ acquires the new domain name of $\widehat{P}$ from $\widehat{P}$ by a location prefix binding operation along the original path through the previous domain. Our protocol is divided into three phase, described as follows.

A. Content Prefix Binding Phase

Before describing the content prefix binding operation, the location/ID split implementation is introduced. To achieve our purpose, the modified packet format of IntP and DatP are shown in Fig. 2. Our protocol only adds *New Location Name* field into both of IntP and DatP, all other fields are the same with the original IntP and DatP packets in NDN [3].

To perform the content prefix binding operation, a prefix binding message is defined, let PB(*previous_name_prefix*, *new_name_prefix*) or PB denote a prefix binding message, where *previous_name_prefix* is a previous domain name prefix and *new_name_prefix* is a new domain name prefix of $\widehat{P}$, as shown in Fig. 2. To easily explain our producer mobility protocol in NDN networks, some notations are defined. Let p-AP denote as an attachment point of the previous domain of $\widehat{P}$, and n-AP denote as an attachment point of the new domain of $\widehat{P}$. In our design, p-AP can be seen as a base station, which is denoted as p-BS to represent as a base station of a previous domain of $\widehat{P}$, and also let n-BS denote as the base station of a new domain of $\widehat{P}$. PB message will be sent out from $\widehat{P}$ to $\widehat{C}$ through n-AP (n-BS) and p-AP (p-BS). The main purpose of PB packet is to inform $\widehat{C}$ the new domain name prefix of $\widehat{P}$. In addition, $\widehat{P}$ proactively sends a next data packet, which is denoted as IntP_DatP message, due to this packet contains control and data planes. IntP_DatP message contains a consumer location name field which is used to directly send the next DatP to $\widehat{C}$. The main purpose is to reduce the handover latency. In the location/ID split implementation, it is noted that the location/ID split implementation does not require to change the existing routing table. It makes our protocol easily to implement.

The content prefix binding operation aims to perform a content prefix binding operation initiated from $\widehat{P}$ after $\widehat{P}$ is moving to a new domain and acquiring a new domain name prefix. In content prefix binding operation, $\widehat{P}$ sends out the prefix binding message, PB, through n-AP and p-AP toward

$\widehat{C}$, the reversed path from original p-AP to $\widehat{C}$ is used. After $\widehat{C}$ receiving PB message, $\widehat{C}$ may replace the content name field of IntP of $\widehat{C}$ with the new domain name. The procedure of content prefix binding phase is given.

When $\widehat{P}$ leaves the previous domain and attaches to a new domain, $\widehat{P}$ is configured with a new domain name prefix. This new name prefix needs to replace with the content names of all name objects of $\widehat{P}$.

To inform $\widehat{C}$ for the new name prefix, $\widehat{P}$ generates a prefix binding message, PB(*previous_name_prefix*, *new_name_prefix*), where *previous_name_prefix* is a domain name prefix of a previous domain and *new_name_prefix* is a domain name prefix of the new domain of $\widehat{P}$. PB message is sent out from n-AP through p-AP, and along the revered path from p-AP to $\widehat{C}$. The content prefix binding operation is done by the location/ID split implementation as follows. When p-AP receives PB message with two name prefixes, p-AP checks the reversed path based on the *previous_name_prefix* and domain name prefix of $\widehat{C}$.

Upon $\widehat{C}$ receiving PB(*previous_name_prefix*, *new_name_prefix*) from a reversed path between p-AP, it learns the new domain name prefix of $\widehat{P}$. With the new domain name prefix, $\widehat{C}$ updates the content name filed of all other data objects of all other IntPs messages, due to the fact of $\widehat{P}$ moving to a new domain.

B. High Popularity Pipe-Based Routing Phase

After $\widehat{C}$ obtaining a new domain name prefix of $\widehat{P}$, $\widehat{C}$ must re-perform the name-based routing operation from $\widehat{C}$ toward the new domain of $\widehat{P}$ along a new path. To reduce the handover latency, $\widehat{P}$ will send out the next DatP toward $\widehat{C}$ along a new path. To improve the hit rate of these two paths, a new routing scheme, called as pipe-based name routing operation, is develop to achieve the above purpose.

A popularity estimation operation is needed to estimate a popularity value based on the longest prefix match level of a given content name or the destination domain name. This popularity value is very similar with the pheromone value [5]. The higher popularity value of a pipe-based route will be selected. This part describes how a node calculates a popularity value. Assumed that an IntP or DatP messages reaches an NDN node $N_{i,j}$, while the content name prefix of IntP or DatP is n, a popularity value $p_{i,j}(n)$ for $N_{i,j}$ is calculated as follows. Assumed that there are number of records of FIB, let c_i, for $1 \le i \le f$, denote as the accumulated counter of the same content stored in FIB. Let $M_i(n)$ denote as the longest match level of the content name n with the stored content name of the i-th record of FIB, where $1 \le i \le f$. The popularity value $p_{i,j}(n)$ of $N_{i,j}$ is defined as follows.

$$p_{i,j}(n) = \sum_{i=1}^{f}((\frac{M_i^{\beta}(n)-1}{M_i^{\beta}(n)}) \times (\frac{c_i^{\gamma}(n)-1}{c_i^{\gamma}(n)}))/f \qquad (3)$$

where β and γ represent the scaling factors for the i-th content name of FIB, β and γ effect match level and accumulate the counter of the i-th content name in FIB respectively.

The main purpose of our work is to identify a $C_{i,k,\alpha}$, which is the i-th chain with k numbers of NDN nodes, $N_{i,1+\alpha}$, $N_{i,2+\alpha}$,, $N_{i,k+\alpha}$, where $1 \le i \le h_{max}$ and $\alpha \ge 0$, such that $C_{i,k,\alpha}$ satisfies $Max(\frac{\sum_{j=1}^{k} p_{i,j+\alpha}(n)}{k})$, for $\alpha \ge 0$.

Before describing the construction of the pipe structure, $P(h,k)$, for pipe-based name routing, we first introduce the construction of a chain, $C_{i,k,\alpha}$ which is an i-th chain with k number of NDN nodes, $N_{i,1+\alpha}$, $N_{i,2+\alpha}$, ..., $N_{i,k+\alpha}$, where $1 \le i \le h_{max}$ and $\alpha \ge 0$. The main procedure of the construction of a chain, $C_{i,k,\alpha}$, is to determine the value of α.

Two procedures of constructing a $P(h,k)$ are given; the initial procedure and the main pipe discovery procedure. The initial procedure is stated as follows. The initial procedure is to construct the first chain $C_{1,k,\alpha}$ from a $\widehat{C}$. It is noted that the construction of $C_{1,k,\alpha}$ must satisfies $Max(\frac{\sum_{j=1}^{k} p_{i,j+\alpha}(n)}{k})$, for $\alpha \ge 0$. Let $CP_i(n, r)$ denote as the *chain probe message*, where i is the i-chain level, n is a content name from IntP, and r represents the remaining forwarding step, where $r \le k$. A *chain probe reply*, R_{cp}, message, is used, and R_{cp} contains node ID, popularity value, and face information.

Initially, $i = 1$, $N_{1,0}$ is assumed to be the first NDN node which receives an IntP message from a $\widehat{C}$. The first step is to construct a $C_{1,k,\alpha}$ from $N_{1,0}$ to satisfy $Max(\frac{\sum_{j=1}^{k} p_{i,j+\alpha}(n)}{k})$, for $\alpha \ge 0$. This work is done by sending a chain probe message $CP_1(n,k)$, along left and right neighboring NDN nodes; there are ($N_{1,1}$, $N_{1,2}$, ..., $N_{1,k}$) and ($N_{1,-1}$, $N_{1,-2}$,..., $N_{1,-k}$) by k hops, respectively. There are $2k$ hops totally to centrally determine a $C_{1,k,\alpha}$ by $N_{1,0}$ under the satisfaction of $Max(\frac{\sum_{j=1}^{k} p_{i,j+\alpha}(n)}{k})$, for $\alpha \ge 0$.

This chain probe message $CP_1(n,k)$ is sent out for k hops along the left and right direction, and collect enough information and carry these information back to $N_{1,0}$ by chain probe reply message, R_{cp}, to determine the $C_{1,k,\alpha}$ with $Max(\frac{\sum_{j=1}^{k} p_{1,j+\alpha}(n)}{k})$, for $\alpha \ge 0$. After determining a chain $C_{1,k,\alpha}$, there are k NDN nodes; i.e., $N_{i,1+\alpha}$,$N_{i,2+\alpha}$, ..., $N_{i,k+\alpha}$.

The main pipe discovery operation is executed by recursively building a $C_{i+1,k,\alpha'}$ with the satisfaction of $Max(\frac{\sum_{j=1}^{k} p_{i+1,j+\alpha'}(n)}{k})$, for $\alpha' \ge 0$, from a $C_{i,k,\alpha}$ with the satisfaction of $Max(\frac{\sum_{j=1}^{k} p_{i,j+\alpha}(n)}{k})$, for $\alpha \ge 0$, where $i \ge 1$. The above operation is repeatedly performed and stops until $C_{i+1,k,\alpha'}$ meets with an IntP_DatP message which is sent from a $\widehat{P}$, or reaches the domain of $\widehat{P}$.

Initially, chain $C_{i,k,\alpha}$ is appended into $P(h,k)$. Let $\widehat{N}$ be an NDN node in $C_{i,k,\alpha}$. If there is an $\widehat{N}$ in $C_{i,k,\alpha}$ meets with IntP_DatP message or a $C_{i,k,\alpha}$ attaches to the domain of $\widehat{P}$, then the pipe discovery operation is terminated. More specially, $P(h,k)$ becomes $P(h,1)$, and the data object of the IntP_DatP packet is sent back to $\widehat{C}$ along the reversed path of $P(h,1)$.

Each $\widehat{N}$ of $C_{i,k,\alpha}$ sends a CP_{i+1} message to its (i+1)-th level neighboring NDN node, denoted as $\widehat{N}'$. If $\widehat{N}$ is the first or the last node of $C_{i,k,\alpha}$, let $\widehat{N}'$ send out the chain probe message, $CP_{i+1}(n,k)$, by at most k hops along the left or right direction, respectively. If $\widehat{N}$ is not above node, then $\widehat{N}$ just needs to send out two $CP_{i+1}(n,1)$ along the left and right neighboring NDN nodes of $\widehat{N}'$.

One $\widehat{N}'$ is selected such that $\widehat{N}'$ can collect h, $h \geq k$, different chain probe reply messages, R_{cp}, for $CP_{i+1}(n,k)$ message. Thus, $\widehat{N}'$ determines a $C_{i+1,k,\alpha'}$ which satisfies $Max(\frac{\sum_{j=1}^{k} p_{i+1,j+\alpha'}(n)}{k})$, for $\alpha' \geq 0$. Let $C_{i,k,\alpha}$= $C_{i+1,k,\alpha'}$ and $i = i+1$, and repeatedly executes the above operations.

C. Fast Content Retrieving Phase

The fast content retrieving phase is to proactively send the next data object to $\widehat{C}$ so as to reduce the handover latency. After the high popularity pipe-based routing phase, a $P(h,k)$ is constructed from $\widehat{C}$ to $\widehat{P}$ and two cases occurs. Either $P(h,k)$ is attached to the domain of $\widehat{P}$ or $P(h,k)$ meets with an IntP_DatP message in the NDN networks. Both of the above conditions, $P(h,k)$ becomes $P(h,1)$, and the data object from the IntP_DatP message or $\widehat{P}$ is sent back to $\widehat{C}$ along the reversed path of $P(h,1)$.

Consequently, a path from $\widehat{P}$ to $\widehat{C}$ is constructed by a combination of the path of the IntP_DatP message and $P(h,1)$ if the IntP_DatP message meets with $P(h,k)$ in the NDN networks, or a $P(h,1)$ if IntP_DatP message does not meet with $P(h,k)$ in the NDN networks. All the remaining data objects can be accessed through the $P(h,1)$. This result avoids the unnecessary packet overhead cost. After executing this operation, $\widehat{C}$ knows the new name prefix of $\widehat{P}$, then $\widehat{C}$ can directly sent the next IntP to $\widehat{P}$ for the next data objects.

IV. Simulation Results

A. Simulation Setup

This paper presents a pipe-assisted mobility protocol with low handover latency and packet loss ratio in NDN networks. To the evaluate pipe-assisted mobility protocol, the proposed scheme mainly compared with the global source mobility protocol and the tunnel-based redirection protocol. To simulate these protocols, network simulator-3 (NS-3) and NS-3 NDN simulator model ndnSIM are used. To discuss the effect of simulation results, 20∼180 nodes are distributed. The data rate is assumed to be 1Mbps, the initial link delay is set as 10ms, the interest sending frequency is 10 interests per second, and the drop tail queue is 10. In the simulation, the chain length is assumed to be k = 1, 3, and 5.

B. Packet loss ratio (PLR)

The simulation results of PLR under the various numbers of nodes and the various link delay are illustrated in Fig. 3. Fig. 3 provides the observed performance of the PLR vs. the various numbers of nodes, where $20 \leq$ nodes ≤ 180 with the link delay fixed at 10ms. In general, the PLR of the proposed protocol becomes high as the number of nodes increases. The PLR of our protocol is lower than that of the global source mobility protocol and the tunnel-based redirection protocol. We observed that the average PLR of the pipe-assisted mobility protocol $<$ that of the tunnel-based redirection protocol $<$ that of the global source mobility protocol. This is because that the proposed protocol provides a fast content retrieving during the handover. We observed that the PLR of the proposed protocol becomes low as k increases. The simulation result shows that the average link delay becomes high as PLR increases.

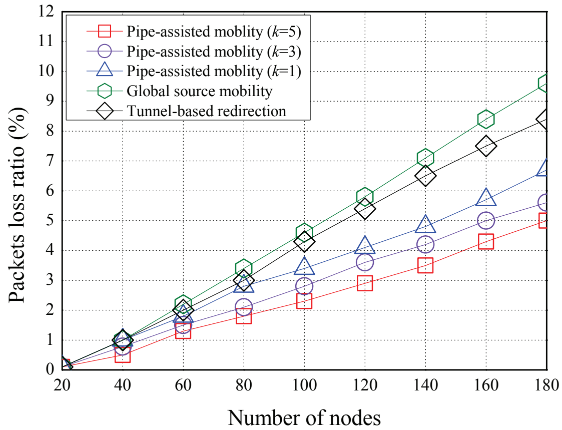

Fig. 3. Packet loss ratio vs. number of nodes.

V. Conclusions

In this paper, we have developed a new mobility protocol for named data networking (NDN) networks. To improve the producer mobility problem, a pipe-assisted mobility protocol with a new designed pipe-based name routing protocol is developed. Extensive simulations has been conducted to illustrate that the proposed pipe-assisted mobility protocol can significantly reduce the packet loss rate.

Acknowledgement

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