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Performance Analysis for Producer Mobility in Named Data Networking

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ABSTRACT

The influence of producer mobility on Named Data Networking (NDN) networks in dynamic networking environments is amplified, hence necessitating an escalation in the demand for performance analysis. When producers transition between different sites or nodes relocation, there is a significant increase in packet loss. Consequently, the present work centres on conducting experiments and evaluating producer mobility by utilizing the Hybrid Indirection Method (HIM) to mitigate the effects of signalling cost on the handoff procedure. This study aims to analyse the effects of producer mobility, specifically focusing on two critical factors: handoff signalling cost and packet data ratio. The data gathered from the study provide significant insights into the benefits and challenges related to producer mobility. This research paper comprehensively investigates producer mobility within the network simulator ns3 framework. The findings demonstrate a notable enhancement achieved by the HIM technique, resulting in substantial improvements in handoff signalling cost and packet data ratio.

1. Introduction

The Named Data Networking (NDN) aims to revolutionize the traditional host-centric Internet by adopting a data-centric paradigm. Contemporary communication models are based on the fundamental principles of transmitting and receiving data through specifically assigned source and destination addresses associated with hosts or devices as mentioned by [1]. There exists a potential for eventual transformation towards a data-centric mode of operation. The NDN paradigm shifts the emphasis away from hosting activities and towards managing and processing data. Instead of making particular location-based data requests, users communicate their intention to acquire the data.

NDN routers can store and later transmit data packets based on their corresponding names. When consumers exhibit a requirement for particular information, NDN routers search within their caches or request said information from other routers or producers, then send it back to the users

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[2,3]. Afterward, intermediary routers can store this content in a cache to expedite future requests. The NDN framework presents a multitude of advantages. NDN architecture prioritizes data-centricity and facilitates efficient distribution and caching of data by strategically placing routers near consumers. These routers can store content that may be accessed and distributed among several users.

Moreover, the NDN architecture ensures security by implementing data integrity preservation and authentication mechanisms. The NDN architecture enables many data-centric functionalities such as synchronization, content routing, and multicast. The network's appropriateness encompasses several applications, such as content distribution, the Internet of Things (IoT) [4,5], and video streaming [6,7].

NDN is a novel Internet architecture that aims to overcome the constraints posed by conventional host-centric networking paradigms, including the prevalent Internet Protocol (IP) designs. The NDN architecture enables data retrieval using names rather than server addresses. Producer mobility has garnered significant Interest in networking research, with a specific emphasis on NDN. Within this paradigm, individuals express their Interest in data by explicitly defining its name. Subsequently, the network supplies the requested material, considering availability and proximity.

Producer mobility in NDN refers to the ability of data producers to change their locations or modify their positions while still meeting the data requirements of consumers. Significant differences exist between contemporary and classic intellectual property (IP) structures, as the latter conventionally rely on static servers and IP addresses. On the other hand, the generation of this specific data is frequently linked with server systems. The NDN framework facilitates the smooth transition of producers between different sites or the utilization of mobile devices to generate and deliver necessary information [8]. Producers' mobility offers many advantages for the NDN architecture. Utilizing alternative sources for data retrieval in network failures is a valuable practice that enhances resilience. This approach effectively reduces the adverse effects caused by the unavailability of the primary data generator.

Implementing several replicas distributed over a network facilitates the dissemination of content, hence improving its accessibility and minimizing latency. Producer mobility is a characteristic that demonstrates effective adaptability in dynamic environments, such as mobile devices or apps associated with the Internet of Things (IoT), when sources experience ongoing changes or frequent movement. The potential for producers to move freely can enhance the functioning of dynamic environments characterized by swift transformations, such as applications related to the Internet of Things (IoT). These applications facilitate dynamic situations where data is continuously in motion, especially in mobile scenarios. The mobility of producers enables the creation of dynamic environments in which data sources are situated.

2. Related Works

Current research on producer mobility in NDN involves enhancing the support provided to mobile producers operating in dynamic network environments. Research was done to allow a seamless transition for mobile producers within the NDN architecture [9]. The implementation of protocols that provide continuous connectivity during network transitions involves the formulation of suitable procedures. Academic scholars are currently examining proactive caching, efficient forwarding systems, and optimized routing protocols as potential strategies to address outages that may occur during producer relocations. The study's objective undertaken by the researcher [10] is to develop and deploy efficient mobility management algorithms tailored explicitly for NDN. These protocols tackle the difficulties of registering, discovering, and monitoring mobile producers as they move within the network.

The main goal is to enhance the efficiency of this process by simultaneously minimizing the signalling overhead while also developing a network infrastructure capable of scaling and maintaining resilience. Examining energy usage in mobile devices is noteworthy, as evidenced by the continuous research [11] dedicated to creating energy-efficient approaches for producer mobility in NDN. The study examines caching algorithms, forwarding mechanisms, and power-saving approaches that prioritize energy efficiency while preserving connectivity for mobile devices and ensuring data is accessible. Research by [12-14] explores the phenomenon of producer mobility inside Internet of Things (IoT) contexts, specifically focusing on its implementation utilizing NDN architecture. The primary objective of the research endeavour should be to address the unique challenges associated with managing mobility for IoT devices with restricted resources. The process involves the optimization of data distribution, as well as the addressing of security and privacy concerns.

The issue of trust continues to be a prominent concern within the realm of NDN research. The investigation of authentication systems and access control methods [14] about the policies of producer mobility research is being conducted by researchers. There is a current endeavour to develop and deploy secure communication protocols to protect the data generated by mobile producers, with the primary objective of restricting access to authorized consumers exclusively. Furthermore, trust management methodologies are designed to facilitate and nurture relationships among producers, consumers, and the network.

3. Network Simulation Tools

Table 1 shows the simulation tools that allow researchers and developers to explore the behaviour and performance of NDN networks under controlled environments. Such studies could include content retrieval, caching efficiency, forwarding strategies, and network scalability studies.

Table 1
Network simulation tools comparison

Tools	Benefits	Weakness
ndnSIM [15]	• Regular updates and contributions. • Integrates with ns3 network simulator, allowing for a more detailed network modelling.	Requires a steep learning curve due to its complexity.
CCNx/CBNSim [16]	• support for CCNx simulations • study some aspects of NDN insights into early content-centric networking research	Not fully reflect the latest developments and advancements in NDN
OMNeT++ [17]	mature simulation framework with a wide range of available models and components.	Does not have built-in support for NDN-specific features, protocols, or mechanisms
Mininet [18]	Integrate with actual NDN implementations, enabling more accurate simulations	• not offer the flexibility and control as dedicated simulation frameworks • scalability can be a challenge when simulating large-scale NDN networks.

4. ndnSIM Class Reference

ndnSIM is a simulator that enables researchers and developers to examine and assess NDN protocols and architectures built upon ns3. As a discrete event simulator, researchers and developers can study, test, evaluate, and experiment with NDN protocols and architectures using its class references feature. It gives researchers and developers an accessible means for precisely studying these elements. [19,20] represents detailed information regarding classes used for simulation or experimentation within NDN domain classes and methods and attributes provided in simulation tools available within NDN.

The ndnSIM class references typically include the following information:

Class name: The name of the class referenced, such as ndn::App or ndn::Face.
Class description: A brief overview of the purpose and functionality of the class.
Inheritance: Information about the parent classes from which the referenced class inherits its attributes and methods.
Public attributes: A list of the attributes (variables) that can be accessed and manipulated within the class.
Public methods: A list of the methods (functions) available for the class, along with their parameters, return types, and descriptions of their functionalities.
Usage examples: Code snippets or examples demonstrating how to use the class and its methods in simulation scenarios.
Related classes: References to other classes are closely related to the referenced class and can be used in conjunction.

Researchers and developers can fully use ndnSIM class reference to gain a comprehensive knowledge of all available classes and their functionalities, providing them with everything needed for designing simulations to support various NDN scenarios. Furthermore, this resource is an ideal means of exploring its capabilities while conducting experiments to assess protocols and algorithms in use by NDN.

5. Simulation Tool

ndnSIM, an extension of OMNeT++ network simulator specifically tailored for NDN networks, features an array of NDN-related modules and models, enabling researchers to simulate various aspects of networked digital radio communication between producers (and their subsequent IP addresses), such as forwarding strategies, caching policies and congestion control mechanisms. In this experiment, we focus on mobility performance [21] when producers move between locations, which changes the signalling cost and packet data ratio compared with multiproducer moving between stations.

Signalling cost effects refer to communication processes between mobile devices and networks when devices move from location to location. Mobility on IP-based networks is typically managed using Mobile IP or Proxy Mobile IP techniques, requiring extensive signalling between mobile devices, their home networks, and any new networks they connect to. NDN helps mitigate mobility's signalling effect by inherently disentangling data names from their physical locations or device identifiers, so when mobile devices move between locations, they continue to express Interest using similar names.

Packet data ratio measures the ratio between data packets exchanged between mobile devices and networks during mobility events and signalling packets sent back and forth - this serves to measure the efficiency of delivery as well as the impact of signalling overhead associated with mobility in NDN networks, with its aims to minimize its signalling overhead compared with traditional IP networks; however certain factors could impede that goal such as cache availability, frequency/distance of mobility events/cache hits rates, data popularity/distribution trends as well as network topologies/connectivities among others.

5.1 Simulation Environment

To set up the ns3 environment, we utilize; VMware® Workstation Pro version 17, a compatible 64-bit x86/AMD64 CPU, 4 GHz quad-core processor, and 8GB RAM. The ns3 lets users simultaneously run numerous virtual computers on a single physical machine and is also a ndnSIM emulator that is compatible with G++ programming. Since ns3 provides both a command-line interface (CLI) and a graphical user interface (GUI), the Linux-based operating system is recommended. Gnuplot must be installed to build the graphic from the delay trace file.

For this experiment, specific parameters with common values are set up to modify performance metrics for signalling cost and packet data ratio. The parameter set in this experiment is interest size, consumer node, producer node, number of access point, and state in Table 2 and Table 3. Refer to Table 2, the parameter is set up for single-stream mobility, consisting of a single producer moving from one location to another using constant velocity behaviour.

Table 2
Stream 1 for a single producer

Source Node	Destination Node	Interest Size	Bandwidth	Delay
Producer-1	AP 1	1024 bits	10 Mbps	10 ms
AP 1	Server Rendezvous	1024 bits	5 Mbps	10 ms
Server Rendezvous	AP 2	1024 bits	5 Mbps	10 ms
AP 2	Producer-2	1024 bits	10 Mbps	10 ms
Producer-2	Consumer	1024 bits	10 Mbps	10 ms

Refer to Table 3, the parameter is set up for multi-stream producer mobility, consisting of a multi-producer moving from one location to another using constant velocity behaviour.

Table 3
Stream 2 for multiple producers

Source Node	Destination Node	Interest Size	Bandwidth	Delay
Producer-1	AP 1	1024 bits	10 Mbps	10 ms
Producer-2	AP 1	1025 bits	11 Mbps	11 ms
AP 1	Server Rendezvous	1024 bits	5 Mbps	10 ms
Server Rendezvous	AP 2	1024 bits	5 Mbps	10 ms
AP 2	Producer-1'	1024 bits	10 Mbps	10 ms
AP 2	Producer-2'	1024 bits	10 Mbps	10 ms
Producer-1'	Consumer	1024 bits	10 Mbps	10 ms
Producer-2'	Consumer	1024 bits	10 Mbps	10 ms

5.2 Network Topologies

Figure 1 depicts the single-stream NDN producer mobility experimental setup using the Hybrid Indirection Method (HIM). Single-stream producer mobility moves continuously and connects to AP 1 for a single-stream experiment while all data is kept at server rendezvous (SR). After updating information at SR, Producer-1 will transfer to Producer-2. After Producer-2 processes the data packet, it is sent directly to the consumer for data retrieval.

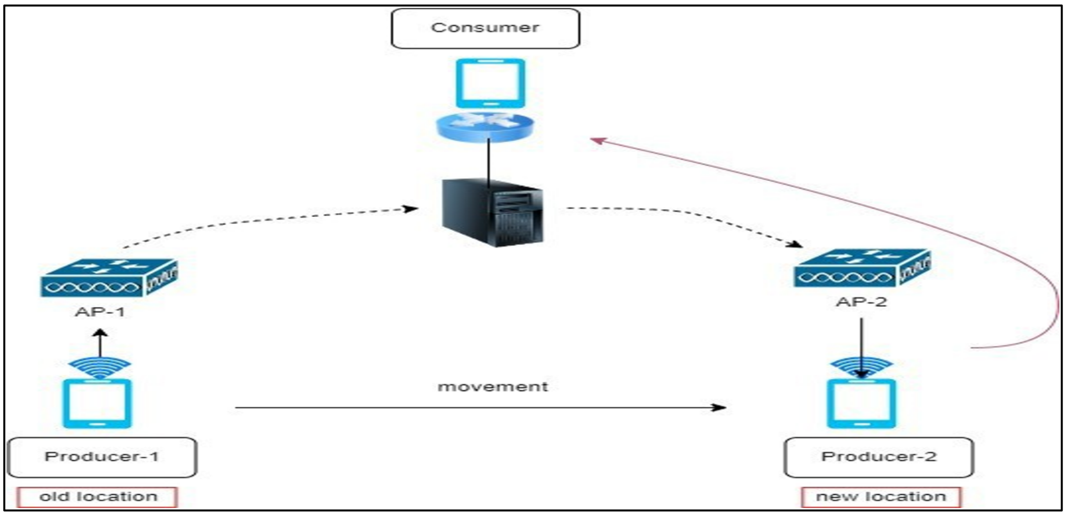

Fig. 1. HIM single-stream producer mobility

Figure 2 depicts the experimental setup for multi-stream producer mobility. Multiple-stream producer mobility consists of Producer-1 and Producer-2 connected to AP-1 to send Interest to be updated on SR before moving to a new location. After SR was updated, the producer moved to a new node while Interest was updated to AP-2. After the connection between AP-2, Producer-1' and Producer-2' is successful, the data packet will be processed and sent to the consumer.

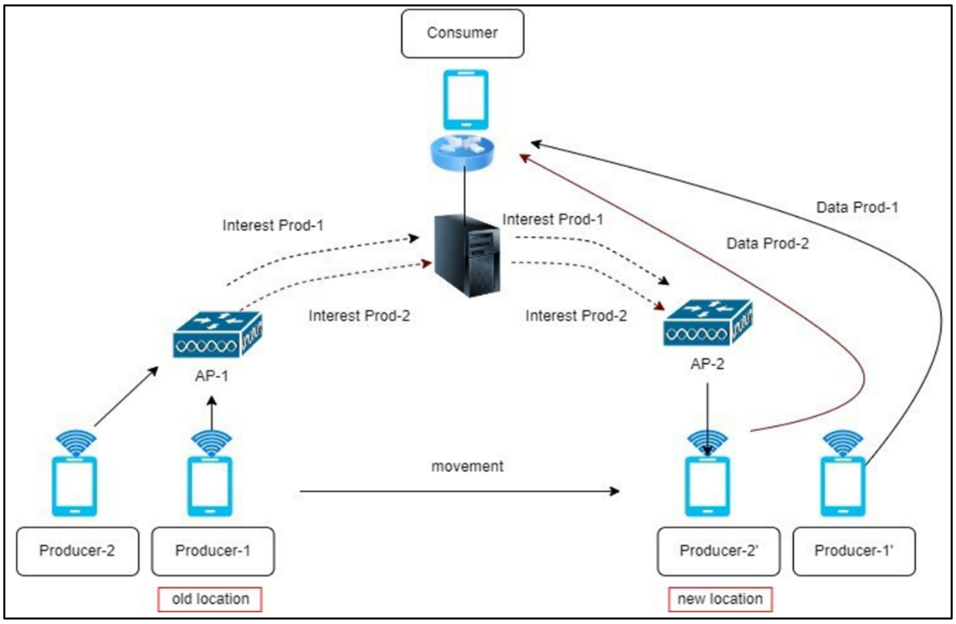

Fig. 2. HIM multi-stream producer mobility

5.3 Simulation Result

HIM signalling cost is the number of messages sent from the producer node to the consumer node over the network so that communication can reoccur after the handoff. Compared to other costs, a lower HIM signalling cost is seen as good and means the model or method works better. In Figure 3, handoff signalling costs remain constant as the transmission cost hop/packets between producer-1 and producer-2 change. There is a minimal route to sending Interest back to the producer-2. So, the gap between producer-1 and producer-2 remains the same, directly affecting how well HIM works.

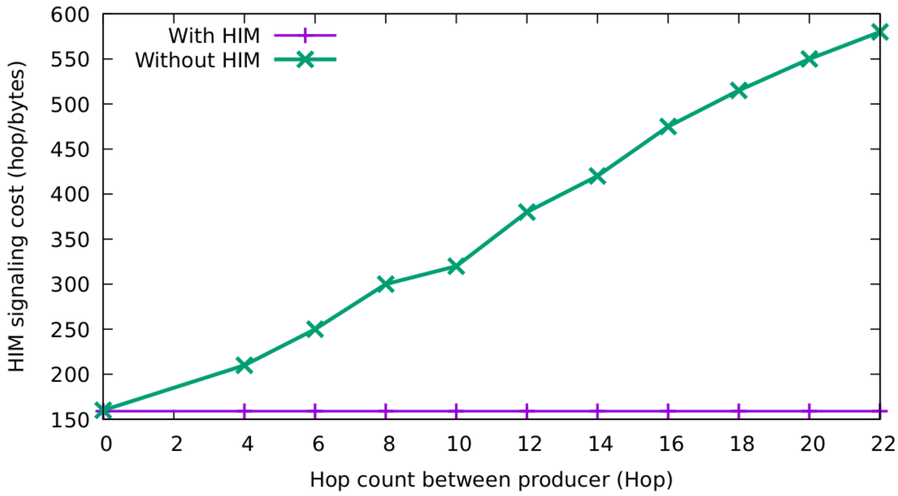

Fig. 3. HIM signalling cost producer single-stream producer mobility

In Figure 4, handoff signalling costs increase as the transmission cost hop/packets between Producer-1 and Producer-1' and Producer-2 to Producer-2' change. So, it makes the gap between Producer-1 and Producer-2 impact mobility performance. HIM technique has increased by almost 30% compared to traditional NDN mobility producers.

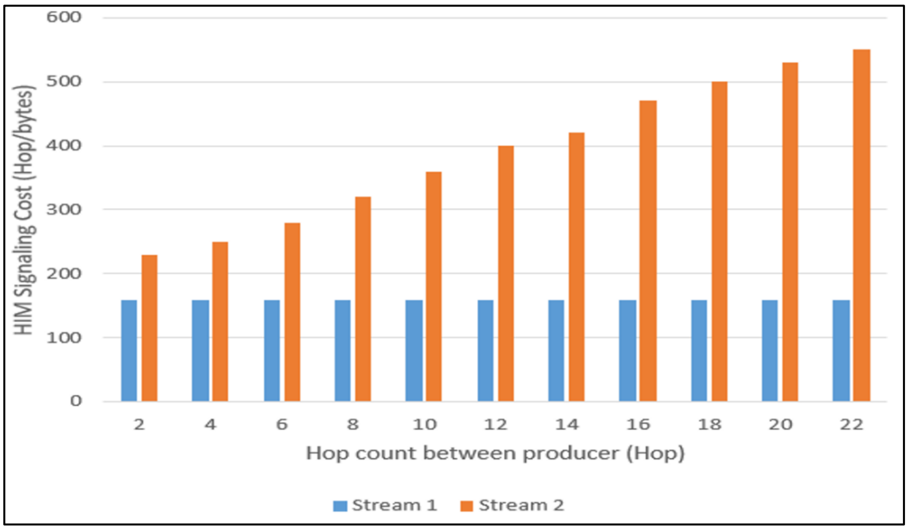

Fig. 4. HIM signalling cost multi-producer producer mobility

The packet data ratio measures how much data is delivered at a specific time without errors during mobility transmission. Figure 5 shows the result of the number of HIM packets sent. For a single stream of NDN traffic, at most 150kbps packets have been transferred to the consumer for time 20s.

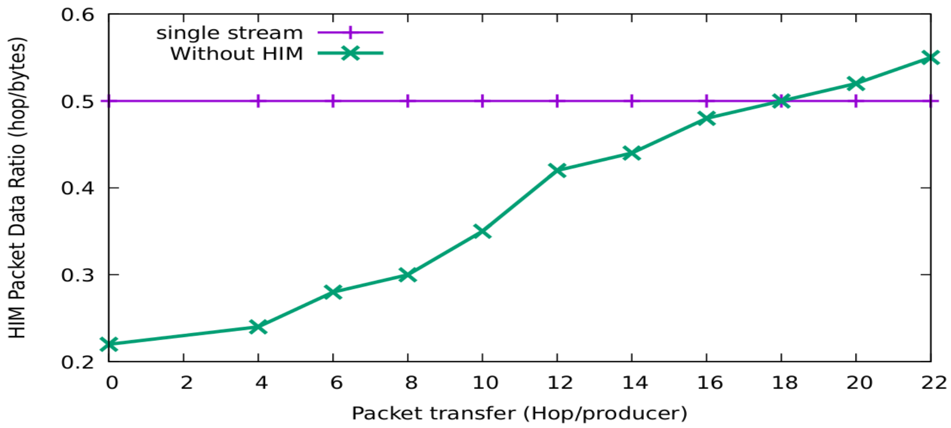

Fig. 5. HIM PDR single-stream producer mobility

In Figure 6, the HIM packet data ratio keeps going up for producers with more than one stream, but it stays the same for producers with only one stream. Data or interest files must go through several producers and a lot of rerouting when multiple streams exist.

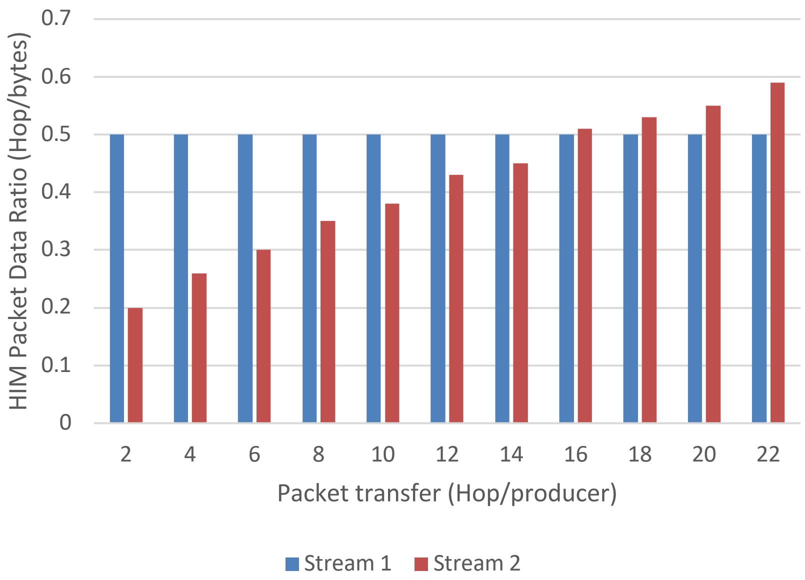

Fig. 6. HIM PDR multi-stream producer mobility

6. Conclusions

In conclusion, the analysis of producer mobility in NDN using ns3 has provided valuable insights into the behaviour and performance of NDN networks in dynamic environments. By evaluating the impact of producer mobility on signalling cost and packet data ratio between single and multi-producer, this study has highlighted both the advantages and challenges associated with producer mobility in NDN.

The findings have shown that producer mobility significantly affects the performance of NDN networks. The analysis has also identified areas for further improvement in handling producer mobility scenarios in NDN. Ultimately, this analysis contributes to the advancement of NDN as a promising networking paradigm and facilitates the design of robust and efficient NDN networks in dynamic environments. By considering the impact of producer mobility and addressing the challenges it introduces, NDN can be further optimized to accommodate the ever-changing nature of modern networks, ensuring reliable and scalable data delivery in various scenarios.

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