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Article

A Hierarchal Clustered Based Proactive Caching in NDN-Based Vehicular Network

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Abstract: An Information-Centric Network (ICN) provides a promising paradigm for the upcoming internet architecture, which will struggle with steady growth in data and changes in access models. Various ICN architectures have been designed, including Named Data Networking (NDN), which is designed around content delivery instead of hosts. As data is the central part of the network. Therefore, NDN was developed to get rid of the dependency on IP addresses and provide content effectively. Mobility is one of the major research dimensions for this upcoming internet architecture. Some research has been carried out to solve the mobility issues, but it still has problems like handover delay and packet loss ratio during real-time video streaming in the case of consumer and producer mobility. To solve this issue, an efficient hierarchical Cluster Base Proactive Caching for Device Mobility Management (CB-PC-DMM) in NDN Vehicular Networks (NDN-VN) is proposed, through which the consumer receives the contents proactively after handover during the mobility of the consumer. When a consumer moves to the next destination, a handover interest is sent to the connected router, then the router multicasts the consumer's desired data packet to the next hop of neighboring routers. Thus, once the handover process is completed, consumers can easily get the content to the newly connected router. A CB-PC-DMM in NDN-VN is proposed that improves the packet delivery ratio and reduces the handover delay as well as cluster overhead. Moreover, the intra and inter-domain handover handling procedures in CB-PC-DMM for NDN-VN have been described. For the validation of our proposed scheme, MATLAB simulations are conducted. The simulation results show that our proposed scheme reduces the handover delay and increases the consumer's interest satisfaction ratio. The proposed scheme is compared with the existing state-of-the-art schemes, and the total percentage of handover delays is decreased by up to 0.1632%, 0.3267%, 2.3437%, 2.3255%, and 3.7313% at the mobility speeds of 5 m/s, 10 m/s, 15 m/s, 20 m/s, and 25 m/s, and the efficiency of the packet delivery ratio is improved by up to 1.2048%, 5.0632%, 6.4935%, 6.943%, and 8.4507%. Furthermore, the simulation results of our proposed scheme show better efficiency in terms of Packet Delivery Ratio (PDR) from 0.071 to 0.077 and a decrease in the handover delay from 0.1334 to 0.129.

Keywords: Vehicular network; named data networking; caching; hierarchical architecture

1 Introduction

The newest breakthroughs in artificial intelligence, mobile edge computing, and embedded systems have aided in the fast development and implementation of self-driving vehicles and vehicular networking for increased driving safety, traffic management, and energy savings. V2X data communications, such as Vehicle-to-Vehicle (V2V), Infrastructure-to-Vehicle (I2V), and Vehicle-to-Infrastructure (V2I), require high mobility and efficient content-oriented properties. Because of its effectiveness in content delivery, NDN has been regarded as one of the most feasible network architectures for vehicular networks. What is the content rather than the hosts and where is the data transferred and shared between content consumers and providers [1]? The data transferred between content consumers and providers in NDN is based on the content's name, not its location. Consumers send interest packets requesting data by name, and routers use these interests to find the data and send it back to the consumer in data packets. This eliminates the need for the consumer to know the location of the content and for the content provider to know the location of the consumer. The data transfer occurs between the consumer and the first router that receives the interest packet. The router checks its content store to see if it has the requested data, and if not, it forwards the interest packet to the next router in the path toward the content provider. However, when the data is found it is returned in data packets back to the consumer along the same path as the interest packets. Overall, in NDN content is retrieved based on its name and the location of the content and the consumer is not relevant. This is in contrast to traditional host-centric networks, where content is retrieved based on its location.

The following describes the NDN architecture, which defines the interest and data forwarding mechanisms.

1.1 NDN Architecture

In NDN, data is obtained by name, and there is no requirement for information like address or destination as required in the IP-based architecture. To get the data, the consumer issues an interest packet, the name of which is used for the desired data. Fig. 1 shows the structure of the interest packet and data packet. For instance, the user sends in an interest packet with the name gar/videos/youtube.mpg. The router remembers the interface from which the data packet came and forwards the interesting packet by looking at the name in its FIB, as in [2], which was developed by the name-based routing protocol. At the point when the interest packet reaches the desired destination, the data packet is sent by a reversed path to the desired consumer. In reality, a router in NDN can reserve data packets in its content store and use them to fulfill future demand. NDN Packet Types: Interest and Data Packet. For communication, NDN uses two types of packets: the interest packet and the data packet described in [2,3], as shown in Fig. 1. An interest packet is used in NDN to request data from the content producer or provider to access content that the consumer wants. The interest packet consists of the content name that the consumer wants to access, the selector, and the nonce, as shown in Fig. 1. The naming scheme of the NDN is hierarchical and unique. The data packet was used by the producer to deliver data to the consumer. The packet contains the name of the content, the signature, signature information, and the requested data of the consumer, as shown in Fig. 1.

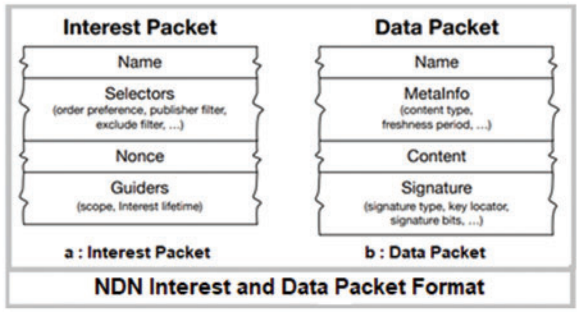

Figure 1: NDN data and interest packets format [2]

The following section describes the mobility management mechanism of NDN nodes and describes the procedures for NDN consumer mobility and producer mobility.

1.1.1 NDN Node Mobility

The NDN has a centric environment that reduces the mobility problem of retrieving and sending data by the consumer [4]. In the NDN mobility scenario, two packets are used to access data; one is an interest packet, and the other is a data packet. The issues in NDN have been divided into two sub-issues: how the consumer's requested data can come back to the desired consumer and how the consumer's interest is formed by data generated by a moving producer. ICN is designed to address IP's weaknesses and mobility but faces significant challenges in NDN regarding mobility support. In NDN, mobility enables mobile devices to switch locations between access points without interruptions or delays in content availability, or with minimal handoffs [5].

In a host-centric communication environment, every network device requires an IP address at every access point to exchange data with other devices. However, ongoing connections are not guaranteed, and mobile devices need a new IP address after relocating to continue communication. Although some researchers have proposed solutions such as mobile IP and Host Identification Protocol (HIP), these mobility approaches do not directly address present mobility issues. These solutions rely on indirection points and topological information for traffic redirection. On the other hand, NDN supports data access by content names rather than IP addresses as shown in Fig. 2. This allows mobile devices to access content seamlessly without repeatedly acquiring new IP addresses to continue communication. In NDN, consumers access contents by its name, which supports multiple network interfaces by sending an "interest", rather than a host-centric network that requires individual application connections, such as Bluetooth. Consumers can communicate and establish TCP connections through different IP addresses without any notice of application, making consumer requests freely multiplexed over several interfaces in NDN [5].

In the NDN environment, mobile devices do not need to establish a connection again with the data source for communication when they move. Unlike the current Internet architecture, which supports connection-oriented sessions that require mobile devices to re-establish a TCP connection for communication, NDN allows for seamless mobility. Mobile nodes can change their location freely between different access points without interruption in content availability and with minimal handoff delays. Consequently, NDN mobility is classified into two categories: consumer mobility and producer mobility [5].

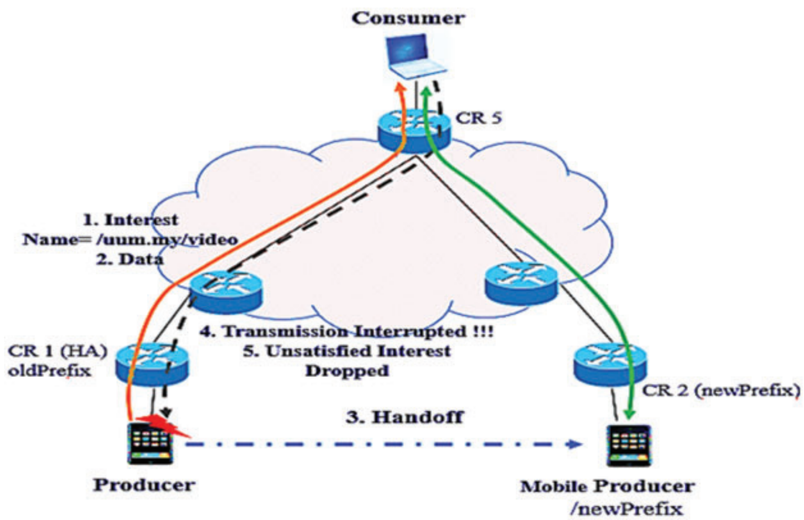

Figure 2: Mobility management mechanism in NDN [5]

1.1.2 Consumer Mobility

Consumer mobility is the process by which the user (consumer) changes their existing state and moves to another state or position. On consumer mobility, if the consumer wants to change their existing router and connect to the next router, this type of consumer mobility creates a lot of problems like handover delays and packet losses [6].

Fig. 3 explains the overall process of consumer mobility that contains three routers (R1, R2, and R3), all of which are connected to the server. If a consumer wants to access some data from the network, it issues an interest packet to the network. After that, when the router receives the interest packet, the NDN routers check the desired content into the Content Store (CS), and if the desired interest matches the CS, the content is sent back to the consumer. If not found, then routers record the interest into the Pending Interest Table (PIT), and then on the bases of the forwarding strategy, the router forwards the interest, and then the consumer's desired content sends them back to the consumer on the reverse path. The router that provides the desired content is known as the producer. In this situation, the user (consumer) wants to change its position (from the existing router R2) and move to the next location (connect to the next router R3). This type of movement is called consumer mobility.

1.1.3 Producer Mobility

Producer mobility is the process by which the producer changes its existing state and moves to another node. Producer mobility has a special effect on real-time transmission [6]. For example, if a producer provides real-time data transmission to the user, it means the producer wants to change its position and move to the next node. In this scenario, many problems are created for the consumer in establishing a new connection with the producer. The main issues with producer mobility are the handover delay and packet loss ratio. Fig. 4 shows the producer mobility in NDN when a consumer wants to change its position and is connected from R2 to R3.

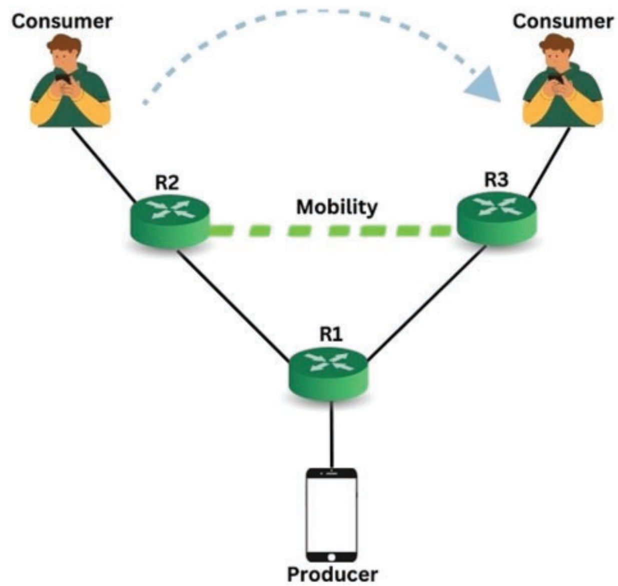

Figure 3: Data accessing procedure of consumer mobility

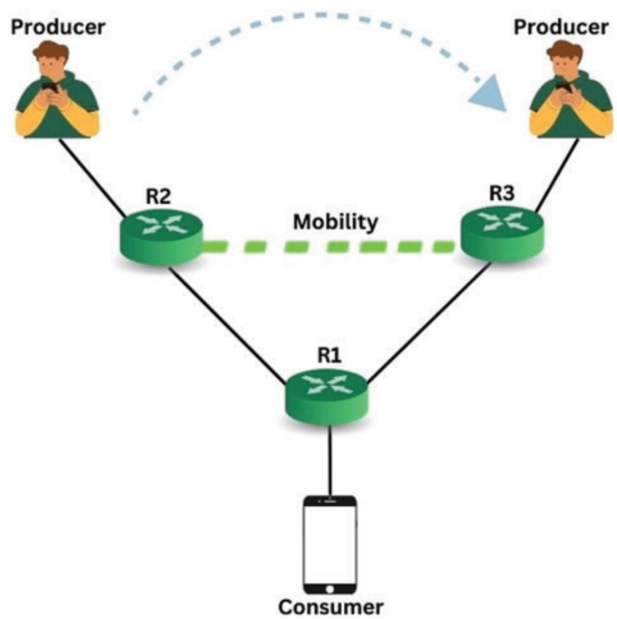

Figure 4: Data accessing procedure of producer mobility

1.2 Motivation

ICN is the future Internet architecture that moves from host-centric end-to-end communication to retrieve this content from a request. It is a new architecture of ICN that supports consumer and producer mobility and provides a means of reissuing the interest packets if the consumer still needs the preferred content data after shifting to the new point of attachment. However, there are various issues that NDN consumer mobility faces, such as maintaining the connection establishment by frequently changing the position of users and sending interest packet transmission and retransmission without any correspondence delay, which ultimately disrupts the Quality of Service (QoS) in real-time streaming. The problem is further compounded by the fact that consumer mobility significantly impacts QoS during handover, leading to service disruptions.

The proposed work aims to address these challenges by proposing a CB-PC-DMM that can minimize handover delay, improve the packet delivery ratio, and reduce CH overhead. Proposing the proactive caching concept in NDN-VN, where the consumer-connected router sends a multicast message to the one-hop neighbor proactively. This ensures that after handover, the consumer can easily access content from the newly attached router, which improves QoS during mobility.

1.2.1 Problem Formulation

Gohar et al. present [7] a Cluster-Based Device Mobility Management (CB-DMM) Model for NDN that is responsible for handover procedures, cluster head selection, and other cluster head responsibilities in the router. In this paper, the main focus is given to mobility in order to reduce the device mobility issue in NDN-based vehicular networks by proposing a clustering scheme. In the CB-DMM model, when the consumer or producer changes its position from its attachment point, which is the Previous Access Router (PAR), and moves towards the new attachment point, which is the New Access Router (NAR), after handover, when the consumer is connected to the NAR, the producer sends the current location information to the NAR, and this information is sent by the NAR to the Cluster Head (CH). CH updates the cache table and keeps this information for future use. So, the CH is responsible for connecting both the consumer and the producer. In short, when a device switches from one access point, i.e., a router, to another router in CB-DMM, it sends the CH information about its present location, and the CH directs any pending interest packets to the new device. In this overall procedure, time is consumed to connect both the consumer and the producer, and cluster overhead occurs. Fig. 5 shows the formulation of the problem for the proposed scheme.

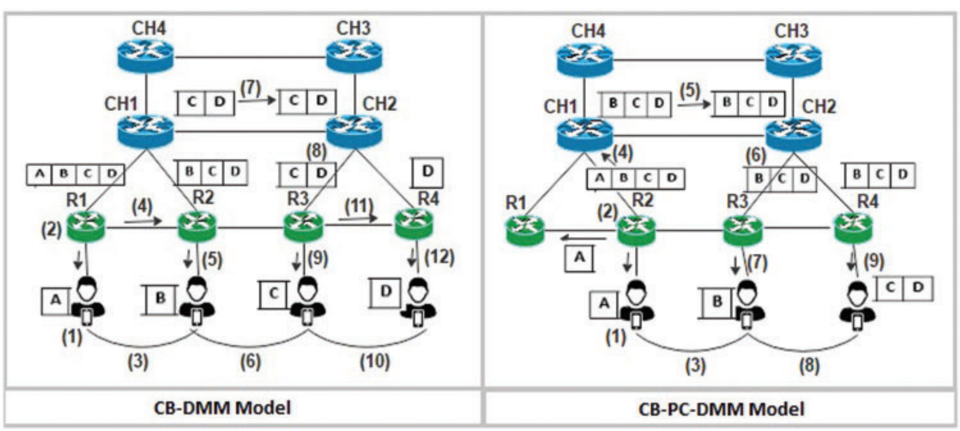

Figure 5: Problem formulation for the proposed method

In the proposed strategy, we enhanced this CB-DMM by proposing a proactive caching mechanism known as CB-PC-DMM, in which PAR proactively multicasts the desired content of the consumer to the next neighboring one-hop routers, accepting CH to access the content before the given threshold time has expired. This improves the QoS of the network in terms of reducing the handover delay, increases the consumer's interest satisfaction ratio, and reduces the CH overhead, especially in real-time videos.

1.2.2 Our Contribution

The following are the main contributions of the paper:

- The design of Cluster Base Proactive Caching for Device Mobility Management (CB-PC-DMM) for NDN-VN addresses mobility issues by proposing the proactive caching mechanism in which the Previous Access Router (PAR) proactively multicasts the desired content of the consumer to the next neighboring one-hop routers, accept CH to access the content before the given threshold time has expired. This improves the QoS of the network.
- In this paper, the CB-PC-DMM for NDN-VN describes the intra-domain and inter-domain handover handling scenarios to preserve routing stability and effectively determine consumer mobility to reduce the handover delay, increase the consumer's interest satisfaction ratio, and reduce the CH overhead.
- The suggested approach CB-PC-DMM for NDN-VN was simulated in MATLAB, and the simulation results show that our proposed scheme reduces the handover delay from 0.1334 to 0.129 and increases the consumer's interest satisfaction ratio from 0.071 to 0.077.

1.2.3 Paper Organization

An overview of NDN architecture, its packet types (i.e., interest and data packet formats), NDN node mobility, and the overall procedure of consumer and producer mobility is given in Section 1. Moreover, the motivation, formulation of the problem, and contribution of the research are also described in Section 1. Section 2 presented the literature review covering the following topics: Related work on the mobility of NDN, NDN-based vehicular networks, proactive caching, and hierarchical clusters Section 3 describes the proposed CB-PC-DMM model and its algorithm, its intra- and inter-domain handover procedures, and the selection procedures for CH and neighbor routers. In Section 4, the performance and evaluation of the proposed scheme are described. Finally, Section 5 concludes the paper.

2 Literature Review

An NDN allows users to float a data request without knowing anything about the hosting entity. NDN can handle user mobility and security issues more efficiently than the current Internet. Mobility management in NDN is one of the main challenges of seamless operation on the future Internet. For this purpose, a literature review is presented, covering the following topics:

- Related work on the mobility of NDN
- Related work on NDN-based vehicular network
- Related work on proactive caching
- Related work on hierarchical clusters

This is followed by reviewing and analyzing proposed solutions in the literature.

2.1 Related Work on Mobility of NDN

Cha et al. [8] present an NDN communication model for user mobility in which interest and data packets are communicated through a single transaction unit. The author proposed a Mobility Link Service (MLS) working in NDN to establish the connection for transactions. The main advantage of using the MLS is that it reuses the current connection for a transaction instead of creating a new connection due to the frequently changing positions of users. If a consumer changes its position, which is apart from the neighbor node, the existing connection is corrupted, and the data cannot be received completely due to handover. So, in this case, the connection is restored instead of creating a new connection and a new interest is requested for content to the New Access Router (NAR). So, the previous NAR sent the data to the NDN producer, and the NDN producer sent data to the new NAR that the user requested for the remaining content. So, in this scenario, when data is sent to the NDN producer and the NDN producer sends data back to the new NAR, there will be a burden on the NDN producer and a delay will occur in the transmission of packets, which is the drawback of the system. To solve the mobility handover problem, The authors [9] proposed a scheme called "Proactive Cache" for Named Data Networking (PCNDN) to be used to enhance the support in NDN. The main idea of PCNDN is to proactively request and cache the content which is not received during a disconnection period. The author uses a random waypoint model to find the mobility of the user. After simulation, the results show that compared to the existing NDN router, the PCNDN is suitable for NDN mobility with the basis of minimum handover delay, high delivery ratio, and reduced handover latency. The scheme also reduces unnecessary packet loss during handover. In [6], the authors present three seamless mobility schemes: Point of Attachment (PoA), Rendezvous Point Based (RP), and multicast-based. In NDN, the main aim of the scheme is to decrease the pending interests and data between two parties concerned in a real-time conversational session. The RP-based and PoA schemes use attached points in the network to perform seamless mobility. In the first scheme, a Mobile Node (MN) registers with the near PoA and then the PoA connects to the MN, which sends interest and data packets to the MN. In the second scheme, RP is used, which corresponds to strategically located routers. And the third scheme takes the benefits of basic network property to get seamless mobility in NDN. In [10], the motivation and vision behind the NDN and its essential architecture and mechanism are also discussed, along with the main challenges, development status, and current design. and also provides a lot of information about the project and others that are available on the name data network. In [11], the authors show some of the capable payback of ICN before discussing significant future research questions that must be answered. Also included is a survey on mobility in ICN, with a special emphasis on challenges and research methods in mobility such as producer mobility, pair-wise path routing, security, and privacy. Device mobility management is one of the main issues in NDN. So, in [12], the authors try to manage the mobility of a device in NDN and propose a mobility management system for CCN to give better service access latency and lower routing overhead. To handle the performance of mobility in NDN, the authors [10] present the performance of mobility based on NDN in wireless access network simulation results, showing that the existing NDN architecture is not capable of handling mobility and architectural enhancements need to be made to fully support the mobility of producers and consumers. In [13], the authors show the mobility problem for real-time applications in CCN and suggest three solutions to follow the handover procedures of the different proposals and analyze the Quality of Experience (QoE) score during handover. A test has been established. To eliminate or shorten the delay time for handover and decrease the unnecessary traffic in the area of the broadcast domain in CCN, three proposals are suggested. In [14], to support seamless mobility for the producer, the authors present the hop-count-based forwarding scheme, the main aim of which is to enable the router to take a decision on the basis of how many hops to travel the interest and whether to forward the interest through the entries of FIB. The perception behind the scheme is two-fold; the first one is the producer spatial region, and the other is the flow of data packets through the reverse path to the consumer in NDN. Through the spatial region of the producer, the author predicted the possible position that the producer could move to. The simulation result of the existing scheme gives better results in delivery ratio and also reduces the number of generated packets. Video traffic shares a large portion of the current Internet bandwidth. One of the objectives of designing NDN is to reduce the burden of large content delivery. Since mobile devices are the prime means of content access for many users, NDN is also required to support mobility. The On-Path Resolver Architecture (OPRA) [15] is the scheme that is presented to maintain the mobility of producers and consumers. The authors proposed this mechanism to also maintain the scalability of the producer and consumer during a mobility scenario. In this mechanism, hierarchical name-based routing and placing route resolvers in different positions on a pathway to content are supported. To forward packets of interest to the device provider that has left the original network, and a sequence of resolvers are placed on the way to the original position. To enhance the producer mobility problem, especially in real-time communication for this purpose, the authors in [16] proposed an anchor-less mobility management technique to maintain the upcoming location prediction of the mobile node. For maintaining seamless handover of the provider during real-time multimedia, the author used location-based prediction to present the anchor-less mobility management solution. This scheme reduces handover delays for the producer. In [17], the author presents a scheme for multi-level that is very efficient to reduce handover problems in order to overcome the consumer's handover process and improve their performance. The approach is sufficient for the two-level structure of the router and also for multi-level router structures. If the user wants to change its position and disconnect from the existing router to prefetch the content, the scheme is designed for this purpose. After the simulation of the proposed scheme, the result gives better performance in handover situations. The authors propose a scheme to reduce producer mobility issues of the NDN architecture as explained in [18]. They designed the KITE method. In this approach, they create a way between hop-by-hop authenticated interest data exchange and the available rendezvous server. This method is locator-free and works best for transferring data retrieval and routing which show how the existing scheme supports the communication of mobile scenarios and other name-based environments.

2.2 Related Work on NDN-Based Vehicular Network

Vehicle systems are getting connected with other cars, infrastructure components, or cloud servers. This raises the question of whether the current host-centric communication model of today's networks is ready for networking billions of new devices. Proactive caching is the best approach to reduce the mobility problem. In their research paper [19], the authors proposed a scheme PeRCeIVe. The basic goal of the paper is to cache data proactively before consumers request it, demonstrating that directly placing the data improves network performance. Through the PeRCeIVe approach, the scheme wants to place that in the network at the right time and without changing the architecture of NDN and improve the determined interest ratio and one-hop ratio.

A Markov chain model is used in this paper to predict the next location. The authors [20] use the Markov chain model to predict the next location. Prediction of the next location of a consumer or producer is an important area of research. A lot of research has been examined to predict the next location and departure arrival time. The author used a Markov chain model for the prediction of the next location, and for arrival and departure, they used the probability density function. The results show that the Markov model gives the best result in predicting the next location, especially in mobility scenarios.

The Markov decision process is the best and easiest way to handle content location and other network problems. In their paper [21], the authors proposed a forwarding strategy based on a Markov Decision Process (MDP) that reflects the location of content and network issues. The whole scheme consists of three parts. First, a Markov Decision Model is developed for the entire forwarding process in a single node, and for solving the forwarding decision problem, the MDP is utilized. In the second part, they created the content-based request output queue and used queue theory to guess the state of the network. Finally, a rate control mechanism is provided to resolve the rate problem caused by the fast forwarding of request packets and is used to create a steady queue. The proposed scheme is simulated in ndnSIM and shows better performance in the delay scenario.

2.3 Related Work on Proactive Caching

Mobility management in NDN is one of the main challenges of seamless operation on the future Internet. Techniques used in existing proposals for consumer mobility are either reactive or semi-proactive, which try to reduce data access time, but retransmissions are required. In their research [22], the author proposed a scheme called "Proactive Optimal Scheme (OpCCMob)" which is a proactive optimal cache that forecasts data pattern forecasts to support consumer mobility in the network proactively and adopts location. On the other hand, data that is closely cached with the consumer so that it can be retrieved before handover and then not dropped is the main theme of the OpCCMob. The scheme minimizes the delay in fetching the data and binds the overhead of the network. In [23], they present a proactive caching technique that uses ICN adaptability to reserve information anyplace in the system, instead of exactly at the edge, as in an ordinary content delivery network. The principal commitment of the paper is to utilize entropy to gauge versatility expectations vulnerability and find the best per-fetching node, consequently taking out repetition. The author uses a method called Markov predictor to locate a mobile entity's upcoming location. In [24], the authors propose a Proactive Caching for Mobility (ProcCacheMob) scheme for NDN in order to support producer mobility through the utilization of location prediction and for caching data requests for data before handover occurs. This scheme provides a prediction for interest during mobility and will be forwarded to the mobile producer who caches the content data by leading the handover. So, in this way, interest retransmission is avoided, which can cause an increase in the consumer's delay and decrease the network efficiency during the producer's mobility.

2.4 Related Work on Hierarchical Clustered

In [25] the authors present a Hierarchal Cluster-Based Caching (HCC) scheme based on a two-layer core layer and edge layer, the focus of the core layer is to be routing and forwarding and the core layer is not allowed for cache content. In order to give a faster response to the user for the purpose of cache contents the routers are designed the in edge layer. In the edge cluster, importance is given to the content based on node popularity. If the node popularity is less, then less importance is given to the node cache and if the node popularity is greater, the most importance is given to the node cache. The importance of nodes is collected by the cluster head which also calculates the probability matrix. A cluster-based method is used to solve the mobility problem in CCN. There are two main phases in this scheme: one is cluster formation, and the other is node moment. In a clustered building, every node shares its available memory weight, and then the basis of their available memory cluster head will be formed. This cluster-based scheme supports both inter-domain and intra-domain environments. The main advantage of clustering is that it does not require any physical tools. In [26], the authors have proposed a novel algorithm for designing clusters to resolve the scalability and energy issues in an efficient manner in wireless sensor networks. The proposed RSC clustering algorithm distributed the deployment of the sensor nodes in various concentric rings virtually. Besides, each virtual call is further distributed into sectors. The sector is also referred to as a cluster, in which the cluster head is selected near the midpoint of the set. However, the data of each cluster is aggregated and transmitted toward the base station using angular inclination routing to enhance the sensor network's lifetime with minimal cost. In [27] the authors proposed a secure and intelligent approach to integrating the concept of an IoT-based medical healthcare system with a cyber-physical system for managing resources in an effective way at cloud and fog levels. However, the suggested methodology utilized minimal processing cost to enhance the lifetime of the sensors deployed in the resource-constrained environment of IoT during the task scheduling method. Furthermore, data were collected from social websites along with dug reviews for further analysis using sentiment analysis and text mining approaches. Besides, features are extracted using the k-means clustering method. In [28] the authors proposed a novel and efficient approach for continuous monitoring of real-time patient vital signs from remote areas using IoT-based computing devices. Furthermore, for efficient patient data analysis and prediction, the concept of deep learning is utilized. Moreover, the load is balancing, and tasks are prioritized among sensor nodes in an effective way to minimize the energy consumption of sensor nodes during the processing, transmission, and storage process. However, this proposed methodology is used in sustainable smart cities to execute real-time patient information for better diagnoses and treatment. In [29] the authors analyzed the performance of various clustering approaches based on routing protocols in the resource-contained environment of wireless sensor networks. Moreover, the current research challenges in wireless networks are discussed in detail. Additionally, the energy consumption, QoS, and throughput are evaluated and compared with the novel schemes.

2.5 Summary of Literature Review

This literature review covers a brief overview of NDN and how it differs from traditional network architecture, i.e., IP-based networks. In the NDN architecture, an overview of several functions is provided such as mobility, security caching, naming, routing, forwarding, etc. Several issues occur in the NDN architecture. One of them is mobility issues, which have been discussed. In the case of consumer and producer mobility, the problems of communication delay and handover will occur. To cope with these issues, this scheme uses a proactive cache mechanism in NDN-based vehicular networks in order to reduce handover delays for the consumer and clustered overhead as well.

3 Proposed Scheme

In our proposed scheme a Clustered Based Device Mobility Management (CB-DMM) Model is utilized for NDN as proposed in [7] which used the proactive caching mechanism to reduce the handover delay and minimize the packet loss ratio during transmission. For this purpose, first provides an overview of the CB-DMM Network Topology Model, and their handover procedure. Then a discussion is provided for the proposed CB-PC-DMM model. The following Table 1 lists the notations that were used throughout the article.

Table 1: Notations and description

Notation	Description
ICN	Information-centric networking
NDN	Named data networking
NDN-VN	NDN vehicular networks
CCN	Content-centric networking
HCC	Cluster-based caching
CB-DMM	Cluster-based device mobility management
CB-PC-DMM	Cluster base proactive caching for device mobility management
PCNDN	Proactive caching for named data networking
NDO	Name data object

(Continued)

Table 1: Continued

Notation	Description
NAR	New access router
PAR	Previous access router
CH	Cluster head
CNs	Content nodes
PIT	Pending interest table
FIB	Forwarding information based
V2V	Vehicle-to-vehicle
I2V	Infrastructure-to-vehicle
V2I	Vehicle-to-infrastructure
QoS	Quality of service
MLS	Mobility link service
PoA	Point of attachment
RP	Rendezvous point based
MN	Mobile node
QoE	Quality of experience
OPRA	On-path resolver architecture
MDP	Markov decision process
OpCCMob	Proactive optimal cache content scheme
PDR	Packet delivery ratio
HO	Handover delay

3.1 Existing CB-DMM Model

This section describes an overview of CB-DMM model, its network topological structure, and the handover procedure.

3.1.1 Network Topology Model

To facilitate device mobility in NDN, the authors in [7] created the CB-DMM model. Assume that a consumer requests the contents "content source/real-time/video1." as shown in Fig. 6. When the interest packet reaches the Prior Access Router (PAR) and the producer switches to the New Access Router (NAR), the interest packet is unable to be sent to the producer. The CB-DMM technique is utilized to overcome this challenge. This methodology is capable of addressing various mobility challenges, such as consumer mobility. When a device switches from one access router to another in CB-DMM, it sends its current location information to the CH, and the CH redirects pending interest packets to the correct device.

3.1.2 Handover Procedure

When a producer switches from PAR to NAR, the moving device (producer) provides attachment information to NAR. The NAR transmits attachment information to CH and notifies it about the producer. The CH refreshes its cached table and stores the current position of the producer. The CH sends the binding acknowledgement to the NAR. Then, the NAR delivers it to the producer content. The CHs exchange frequent updates. When a request reaches the CH for a producer, it simply verifies its cache and makes a request to the producer's current location. The producer provides the data to the consumer through the reverse path.

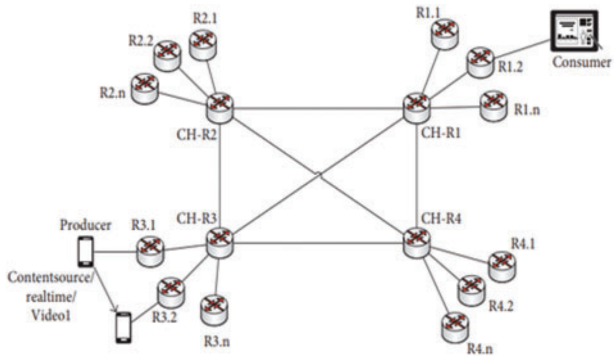

Figure 6: CB-DMM network topology model [7]

3.2 Proposed CB-PC-DMM Model

By enhancing CB-DMM model, the network efficiency is improved by reducing cluster overhead, handover delay, and low packet loss ratio during the transmission of packets by proposing a proactive caching mechanism known as Cluster Base Proactive Caching for Device Mobility Management (CB-PC-DMM) in NDN. According to this connection, first, an overview of the CB-PC-DMM network topology model is illustrated, the proactive caching mechanism and algorithm in CB-PC-DMM, the CH formation mechanism in CB-PC-DMM, and the handover procedure of intradomain and interdomain.

3.2.1 CB-PC-DMM Network Topology Model

This paper proposed a proactive caching mechanism in the CB-DMM model. Proactive caching is a term describing a class of strategies to take an action before a consumer issue an interest packet during mobility or a prouder change their existing location. This concept of proactive caching reduces the cluster overhead, minimizes the handover delay, and low packet loss ratio during transmission. In our proposed scheme, a proactive caching mechanism for clustered-based consumer mobility in real-time multimedia is used, to access the content after handover directly from the newly connected router.

3.2.2 Proactive Caching Mechanism

As a device switches from one access point, i.e., a router, to another router in CB-DMM, it sends the CH information about its present location, and the CH directs any pending interest packets to the new device. In our proposed proactive caching mechanism, when a consumer wants to change its position and connect to the next available router, the PAR multicasts the desired content of the consumer to the next neighboring one-hop routers, accepting CH (because the CH already has all the data that the consumer accesses through the connected router), and gives them some threshold value of 13.9 s to access the content before the threshold time has expired. When the consumer is connected to the new router during the threshold time, he or she easily receives the content as well as any data packets that were lost during transmission. The following algorithm describes the entire process of our proposed proactive caching mechanism and its algorithm.

Algorithm 1: Proactive Caching Algorithm

Inputs:

- *R:* Router
- *HANDOVER_IP:* Handover Interest Packet
- *Multicast-DP:* Multicast Data Packet
- *CS:* Content Store
- *PIT:* Pending Interest Table
- *THt:* Threshold Time
- *THS* **:** Threshold Signal Strength
- *DP:* Data Packet

1. ***If*** a consumer requests data from the *PAR*
2. a. *PAR* checks the *CS* for the interest
3. b. *If* found, then *PAR* sends the *DP* to the consumer
4. c. ***End if***
5. ***If*** the signal strength of the consumer is less than the *THS*
6. a. Construct a *HANDOVER_IP* and send it to *PAR*
7. b. *PAR* stops the *DP* and caches it in the *CS*
8. c. ***End if***
9. *PAR* generates the *DP* and sends it to the neighbor routers connected to the *CH*
10. a. Routers store copies of the *DP* for *THt*
11. *If* the consumer does not receive the *DP* within *THt*
12. a. Discard the stored *DP* after *THt*
13. b. *Else*, receive *DP*.
14. c. ***End if***

This algorithm aims to optimize the proactive caching process in NDN-VN by using the HANDOVER_IP and Multicast-DP techniques. The algorithm takes input parameters including the router, handover interest packet, multicast data packet, content store, pending interest table, threshold time, and threshold signal strength. It first checks if the consumer has requested data from the PAR and if it exists in the CS, then the PAR sends the data packet to the consumer. If the signal strength is lower than the threshold value, a HANDOVER_IP is constructed and sent to PAR. The PAR then stops the data packet transmission and caches it in the CS. PAR generates the DP and sends it to neighbor routers connected to the CH. The routers store copies of the DP for the specified threshold time. If the consumer does not receive the DP within the threshold time, the stored DP is discarded. Otherwise, the DP is received. Through this proactive caching algorithm, the process of NDN VANETs can be optimized, reducing the handover delay, and improving the packet delivery ratio.

3.2.3 Selection of CH and Neighbor Routers Connection

Apart from the CB-DMM model [7], the CH basic formation method and native NDN rule that every router has a specific hop-by-hop connectivity requirement. The authors suggest an approach for choosing CH as illustrated in [30]. The choice of our CH will likewise be made using that technique. The authors in [30] introduce the concept of clusters, where each cluster has a CH and several neighbor routers. The CH is responsible for forwarding Interests and Data packets between the Content Nodes (CNs) and the neighbor routers in its cluster. They developed a cluster formation algorithm to form the clusters and select the CH based on available memory. They also propose Hello Interest to detect the movement of CNs and the formation of new paths. When a CN moves to a new location, the scheme uses a series of Interests and messages to update the path and forward the packets to the new location. The approach for choosing the CH is, the three interests, such as (1) *inform*, (2) *name*, and (3) the *CH name*, were freshly specified for the cluster creation. Uses for them include each router starting the cluster-building process by utilizing the function "probe (inform)" to send information of interest to its neighbors within a one-hop distance. When routers get an inform interest request, they respond with a mem[i], an entry containing details about the memory they have available. The originating router examines each of the incoming replies against the largest amount of memory, i.e., Mm_{Max}. The router then checks its internal memory, or Mem_{self}. Moreover, it compares this to the largest amount of memory that is currently accessible. The router announces itself as CH if the amount of memory space it has available is equal to the highest. Router then waits for the cluster member routers to express an interest in a *name* before responding with its original name, CH. If not, it sends a *name* of interest to the CH and awaits a response. Because the CH must keep track of data about its cluster members as well as the CN connected to the cluster, it is chosen as the CH based on the router with the most memory. Fig. 7 shows that prior to the formation of the CH, each CH has a direct connection from the CH to the router as well as an intradomain or interdomain router-to-router connection as shown in Fig. 7. After the handover, consumers have some probably connected routers, which are at least 3 or 4 because of the topological structure of the clustered-based NDN. Neighbor routers mean the distance from the router in one hop is a neighbor router. The below Fig. 7 shows the direct connection between router to router and then all routers are connected to a specific CH.

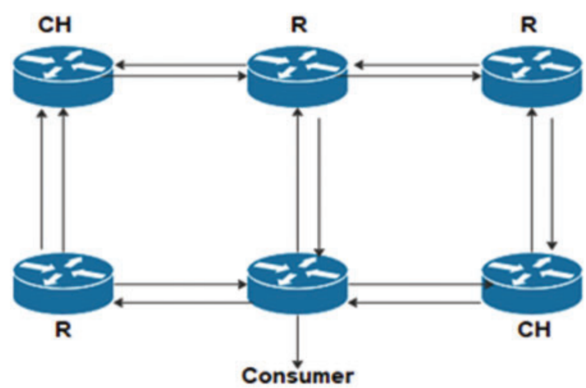

Figure 7: Selection of cluster head and neighbor routers connection

3.2.4 Intra-Domain Handover Procedure

It refers to the management of intra-domain handovers when a consumer switches from one router to another inside the domain of a single CH or when the content provider and the consumer are members of the same CH. Fig. 8 shows the intradomain handover-handling handover procedure for this scheme. An NDN, the motion of a consumer, detects from their signal strength that the handover has happened [1,2,3]. The scheme judges the handover of the consumer from the threshold signal THS = (−77dbm) [3]. If the signal strength of the consumer drops below that of the THs, then the below proposed proactive caching strategy is applied.

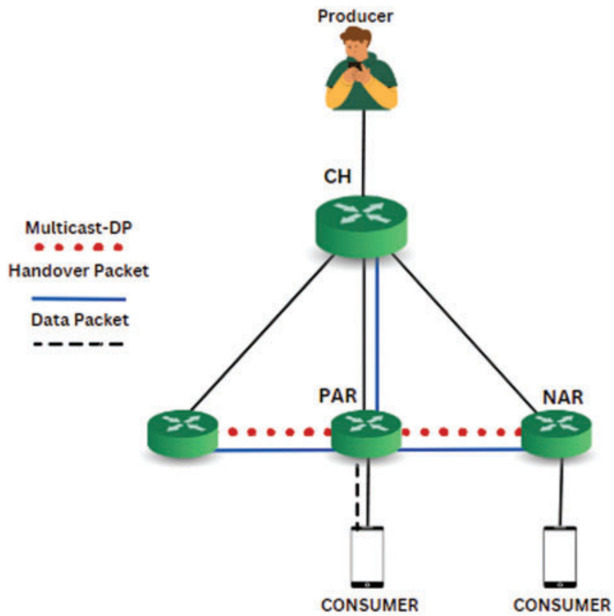

Figure 8: Intra domain handover procedure

If a consumer wants to change their position and move from PAR to NAR when the handover is pending, they should send a handover control interest packet to PAR to notify them about the handover. When PAR receives the handover interest packet from the consumer, they stop the arriving data packet, store it in CS, and generate the multicast data packet that contains the consumer's desired data, which is sent by the producer to the consumer. Subsequently, PAR sends a multicast data packet to the selected one-hop neighbor routers and accepts the connected CH because the CH already has the desired content for the connected consumer. When routers receive data packets from the PAR, they store the packets in the CS for a threshold of 13.9 s (the threshold time is the total handover and some extra time for other consumers). In the meantime, the consumer handover is pending. Once the consumer is again connected to the new router, which is NAR, the consumer sends a control interest packet to the new router, which is NAR. When NAR receives the interest packet, it starts caching and prefetching data packets that match the request of the consumer and then sends the desired data packet to the consumer and also sends those data packets that they will not receive during handover. As a result, proactively sending data packets to the next routers reduces handover delay, increases packet delivery ratio, and lowers cluster overhead.

3.2.5 Inter-Domain Handover Procedure

The various CHs are involved in system setup and handover handling if a consumer switches between CHs or if the content source and consumer are members of different CHs. This mechanism is known as the interdomain handover-handling scenario. This section presents the overall handover procedure of a consumer through proactive caching in cluster head based NDN. Fig. 9 shows that if a consumer is watching a real-time video and connected to the producer, R1, R2, and R3 are connected to the CH, and then all the CH are connected with each other, the consumer is connected to the R1, and the producer is connected to the PAR, and both are connected to the CH. Now consumers want to watch a real-time video and issue an interest packet for content "content/real-time/video2" and send it to the connected router R1, and R1 sends this interest packet to the CH and provides the video from the producer.

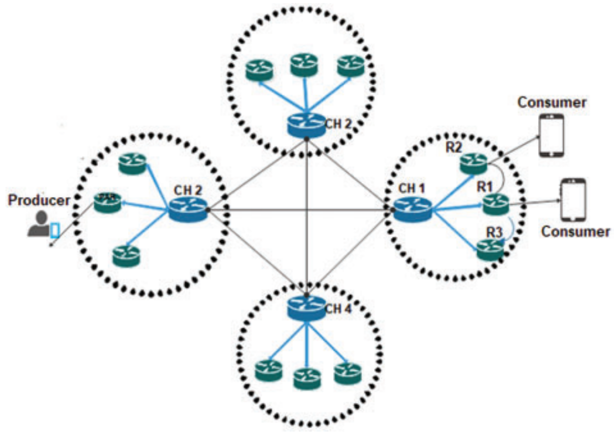

Figure 9: Inter domain handover procedure

If a consumer wants to move from R1 to R2, then a handover interest packet is sent toward the R1, and then the R1 will receive the interest packet from the consumer. The R1 redirects arriving data to the consumer side and caches it in the content store before generating the data packet (as in Fig. 10) and multicast these data packets to the neighboring connected routers, accepting CH because the CH already has the desired content for the consumer in their CS. Multicasting data packets to the connected node, the router gives them some threshold time (THt). When neighbor's routers receive the multicast packet, they update the PIT entry and cache it to the content store. When handover time is completed and the consumer is again connected to the new router, an interest packet is sent to the newly connected routers. The routers check the interest packets in the content store and send data packets to the consumer and also send those data packets that were lost during handover. This proactively cached mechanism reduces the handover delay, and clustered overhead, and also provides an advantage for the consumer to get the content from the connected router.

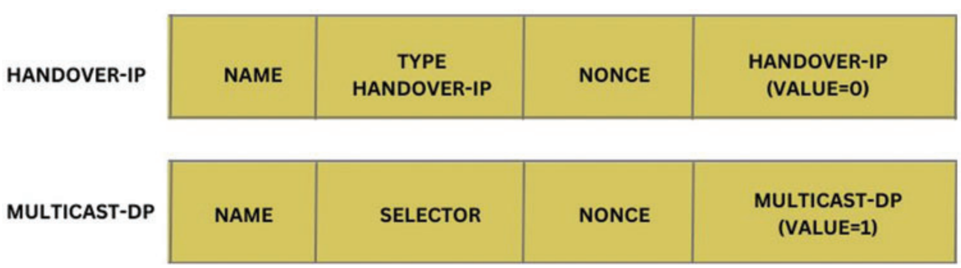

Figure 10: Packets format

In this procedure of proactively caching mechanism, two types of packets are used, as shown below in Fig. 10.

- **Handover Interest Packet (HANDOVER_IP):** A consumer sends a handover interest packet to its PAR to notify it of his handover and mobility.
- **Multicast Data Packet (MULTICAST_DP):** From the PAR, multicast data packets are forwarded to all neighbor's routers that accept the attached CH.

3.2.6 Inter-Domain Handover Steps

Herein, all the steps are elaborated and an algorithm for these steps is explained. The below steps are for Fig. 11.

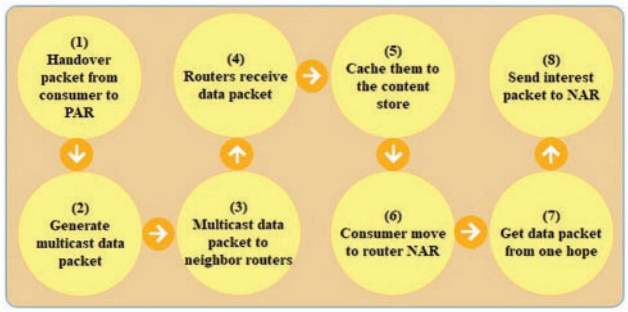

Figure 11: Packet flow of cluster base proactive caching

- Sending a control interest packet from the consumer to the PAR: After detecting the better signal strength from the AP. A control interest packet is sent from the consumer side with the type of handover interest to the PAR.
- The PAR receives data packets and stops them before caching them in the content store: It stops the data packets from the consumer, caches them in the content store, and updates the PIT entry.
- Multicast message to the router: The PAR generates the data packets and sends them proactively to selected routers. The multicast packet contains the remaining content which the consumer cannot access during handover time.
- Attachment of the consumer to the NAR and fetch of content: When the handover is completed and the consumer is attached to the NAR, they send the interest packet to the NAR and easily pick the data packets of the desired content in one hop.

3.2.7 Signaling Flow of the Proposed Handover Model

The signaling flow is depicted in Fig. 12 below, the consumer sends a message to the router R1, then, R1 transfers a data packet to the CH, and then to the producer, so the CH is responsible for connecting both the consumer and the producer. In handover, the consumer sends a handover interest packet to the connected router, and then the connected router multicasts the desired data packet to the neighbor router. After performing handover, consumer gets the packet from the producer proactively without any delay.

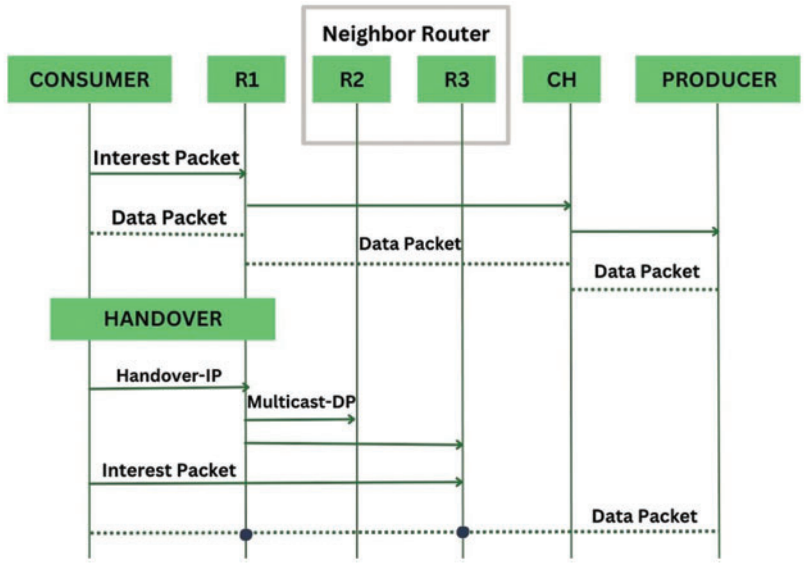

Figure 12: Signaling flow of proposed scheme

4 Performance and Evaluation

Our proposed scheme maintains consumer mobility and clusters overhead of the existing CB-DMM model. The main issues with the existing scheme are that if the consumer moves to another router, they send an interest packet to the newly connected router and the router sends it to the CH. In this process, a lot of handover delays will occur, which will also increase the clustered overhead. In our proposed CB-PC-DMM, the proactive caching mechanism for consumers to reduce the handover latency is utilized, packet loss ratio, and clustered overhead of the existing scheme.

4.1 Simulation Background

To evaluate the performance of the proposed scheme, MATLAB simulation is performed to construct the overall performance evaluation model. First, the NDN-based cluster topology is created, and each cluster has three nodes connected to it, and the link between each router from the CH and router-to-router is only one hop. The simulation time is 15 s, the link delay between nodes is 10 ms, and the Wi-Fi bandwidth is 25 Mbps. The mobile speed of the consumer is 5 to 30 m/s. The total size of the sending interest packet per 80 packets is 55 Mb, and the total size of the data packet from the provider is 55 Mb.

Handover Delay

Fig. 13 shows that handover delays increase with the speed of the consumer. This is because of the reason that at high speeds, the handover will be more frequent. This frequent handover delay during high speed affects the performance of communication, especially in real-time multimedia. Fig. 13 shows that our scheme has fewer handover delays than the existing benchmark strategies.

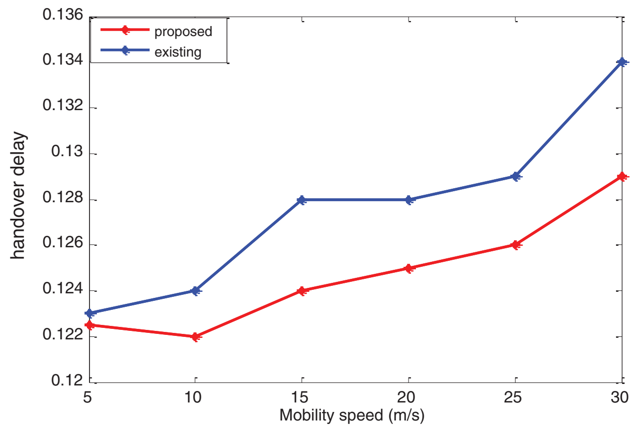

Figure 13: Handover delay

Percentage Improvement in Handover Delay

At the mobility speed of the consumer of 5 m/s, the efficiency of delay during handover decreased by 0.1632. At the mobility speed increased to 10 m/s, the efficiency was 0.3267. Moreover, with a mobility speed of 15 m/s, the efficiency was 0.3267. 3.125, with a mobility speed of 20 m/s and efficiency in comparison, mobility speed 25 m/s efficiency 2.3437, Mobility Speed 30 m/s and an efficiency of 2.3255. With the existing scheme [7] by using the below formula, it can be clearly seen from Table 2 that our scheme is efficient and gives better results.

Table 2: Handover delay efficiency result

S. No	Mobility speed m/s	Existing scheme HD ratio	Proposed scheme HD ratio	Efficiency in terms of HD ratio
1	5	0.1225	0.1223	0.1632
2	10	0.1224	0.1220	0.3267
3	15	0.128	0.124	3.125
4	20	0.128	0.125	2.3437
5	25	0.129	0.126	2.3255
6	30	0.1334	0.129	3.7313

$$\frac{Handover\ delay\ of\ the\ existing\ scheme - Handover\ delay\ of\ proposed\ scheme}{Handover\ delay\ of\ the\ existing\ scheme} \times 100$$

$$\text{Mobility speed m/s} = \frac{0.1225 - 0.1223}{0.1225} \times 100 = 0.1632\%$$

4.2 Packets Delivery Ratio

Fig. 14 shows that the packet delivery ratio of the consumer is better than the existing schemes with the same mobility speed. Because the proposed scheme has the advantage of data packets that are cached in neighbor routers proactively, Percentage Improvement in Packet Delivery Ratio

$$\frac{PDR\ of\ proposed\ scheme - PDR\ of\ existing\ scheme}{PDR\ of\ existing\ scheme} \times 100$$

$$\text{Mobility speed m/s} = \frac{0.084 - 0.083}{0.083} \times 100 = 1.2048\%$$

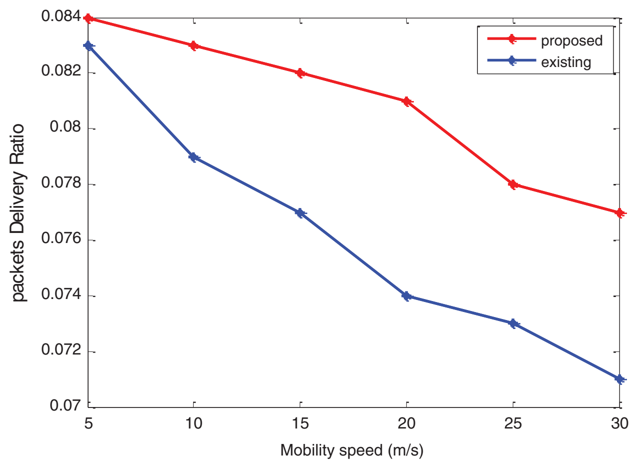

Figure 14: Packets delivery ratio

Simulation Result

In our simulation, two parameters are obtained. The packet delivery ratio and the handover delay. The first is the packet delivery ratio (the total ratio of the number of packets received by the consumer over the total number of packets transmitted in the network). The second is handover delay (the time required for the consumer to receive pending data after moving). The main focus of our experiments is on the clustered mobility of consumers moving in a vehicular network. These two parameters are essential for the mobility of the consumer in a vehicular network. The simulation result of the packet delivery ratio in the proposed scheme and the existing scheme is shown in Tables 2 and 3. The mobility speed of the consumer is the same in both schemes. But the proposed scheme has a better result in terms of packet delivery ratio than the existing one. By increasing the mobility speed of the vehicle, the delivery ratio will decrease.

Table 3: Packet delivery ratio efficiency result

S. No	Mobility speed m/s	Existing scheme [7] PDR ratio	Proposed scheme PDR ratio	Efficiency in terms of PDR ratio
1	5	0.083	0.084	1.2048
2	10	0.079	0.083	5.0632
3	15	0.077	0.082	6.4935
4	20	0.074	0.081	9.4594
5	25	0.073	0.078	6.9493
6	30	0.071	0.077	8.4507

5 Conclusion

NDN faced different types of issues during mobility, like maintaining the connection establishment by frequently changing the position of the consumer and packet transmission and retransmission without any correspondence delay. Consumer mobility affects QoS during handover in real-time streaming, which disrupts these services during mobility. To cope with the above issues, the design of the CB-PC-DMM for NDN Vehicular Networks addressed the mobility issues and proposed the proactive caching mechanism, in which the PAR proactively multicasts the desired content of the consumer to the next neighboring one-hop routers and accepts CH to access the content before the given threshold time has expired. So, after handover, the consumer easily accesses the content from the newly attached router. Moreover, the CB-PC-DMM for NDN-VN described the intra-domain and inter-domain handover handling scenarios in order to preserve routing stability and effectively determine consumer mobility to reduce the handover delay, increase the consumer's interest satisfaction ratio, and reduce the CH overhead. Moreover, the proposed CB-PC-DMM for NDN-VN has been simulated in MATLAB, and the simulation results show that the percentage of the proposed scheme's handover delay efficiency is improved to 0.1632%, 0.3267%, 3.125%, 2.3437%, 2.3255%, 3.7313% at the mobility speed of 5, 10, 15, 15, 20, 25 m/s and efficiency of packet delivery ratio improved to 1.2048%, 5.0632%, 6.4935%, 9.4594%, 6.9493%, 8.4507% at the mobility speed of 5, 10, 15, 15, 20, 25 m/s. Thus, this improves the QoS of the network in terms of reducing the handover delay, improving the packet delivery ratio, and reducing clustered overhead.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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