الجمهورية الجزائرية الديمقراطية الشعبية

People's Democratic Republic of Algeria

وزارة التعليم العالي والبحث العلمي

Ministry of Higher Education and Scientific Research

جامعة عمار ثليجي الأغواط

AMAR TELIDJI UNIVERSITY

كلية العلوم

FACULTY OF SCIENCES

قسم الاعلام الالي

Department of Computer Science

FORWARDING IN VEHICULAR NAMED DATA NETWORKING VNDN

By

Khadidja Fatima Zahra Laggoune

Khadidja Saihi

Jury

BENKOUIDER Sara	MCB	UATL	**President**
ABDELHAFIDI Zohra	MCA	UATL	**Supervisor**
CHAIB Noureddine	MCA	UATL	**Examiner**
BENARFA Abdelmadjid	MCB	UATL	**Examiner**

2023/2024

Acknowledgements

First of all we must thank Allah, for giving us the ability and perseverance necessary to complete this work ALHAMDULIALLAH.

We are very grateful to Dr. Zohra ABDELHAFIDI, who patiently taught us what we needed to know. Thank you we truly appreciate it.

We want to thank everyone that helped us during the project's development.

Dedicatory

As a token of love and appreciation for all of their support and effort during my academic career, I offer my sincere respect and devotion to my parents. I'm hoping that their affection has resulted in this work. I'm hoping you are proud of me.

To my sisters and Brothers Fatiha, Zohra, Fattoum, Mahfoud, Ziyan, Amer, and their Children you are the sunshine of my life, you provide brightness to the shadow moments.

To my supervisor Dr.Zohra ABDELHAFIDI Thank you for being there in difficult times and giving as all what we need to accomplish this work.
To my teachers Khadidja Guesmia and Massouda Guedime thank you for your support and encouragement.
To my friends Khadidja fatima, Hassina, and Aicha source of joy and happiness
To everyone who is important to me.

Khadidja SAIHI

Dedicatory

With great pride and gratitude, I present this humble work, which is the fruit of years of study and research. This achievement would not have been possible without the support and assistance of many special people who hold a significant place in my heart. Therefore, I dedicate this acknowledgment to express my deep appreciation and thanks to all those who stood by me and contributed to making this dream a reality.

To the one with an admirable legacy and enlightened mind, who played the foremost role in my pursuit of higher education, my beloved father. May God prolong his life and bless him for his constant support and prayers in the holy places.

To the one who set me on the path of life, made me steadfast, and cared for me until I grew up, my dear mother, who was always my motivator and encouraged me every step of the way.

To my dear friend Khadija Saihi, who has been my pillar of support throughout these five years, standing by me through everything we encountered, with unwavering support and solidarity.

To my esteemed supervisor, Dr. Zohra Abdelhafidi, who never hesitated to lend a helping hand and continuously supported me with her knowledge and guidance.

To my brothers and sisters Mohammed, Abdennour, Azzedin, Saber, Younes, Assil, and Sahar, and nieces, and my entire family who had a profound impact on overcoming many obstacles and challenges, and supported me with love and dedication.

To everyone who supported me, even if only with emotional encouragement, my dear sisters Nasira, Bouchra, Fatima and Khadidja Maicha, thank you from the bottom of my heart for your constant presence and support.
I thank God for His guidance and success, and I pray that He rewards them all with the best, and grants them happiness and prosperity.

Khadidja Fatima Zahra LAGGOUNE

ABSTARCT

Vehicular Named Data Networking (VANET-NDN) architecture prioritizes content names over content locations in vehicular ad hoc networks (VANETs). However, VANET-NDN forwarding strategies currently face broadcast storms and network fragmentation issues. To address these problems, our focus is on studying and improving existing protocols such as SAFT-VNDN. Our first step involves enhancing these protocols, followed by simulating SAFT-VNDN and its enhancement (referred to as new-SAFT) using the Ns2 simulator. The simulation results demonstrate that new-SAFT performs better than SAFT-VNDN in terms of end-to-end delay and packet delivery ratio.

Key-words: VANET, NDN, VANET-NDN, forwarding, broadcast storm.

RESUME

L'architecture named data networking pour less véhicules (VANET-NDN) donne la priorité aux noms de contenu par rapport aux emplacements de contenu. Cependant, dans VANET-NDN, les stratégies de dissimination des données sont actuellement confrontées à des problèmes liés aux innodations et à la fragmentation du réseau. Pour résoudre ces problèmes, nous nous concentrons sur l'étude et l'amélioration des protocoles existants tels que SAFT-VNDN. Notre première étape consiste à améliorer ces protocoles, suivie de la simulation de SAFT-VNDN et de son amélioration (appelée new-SAFT) à l'aide du simulateur Ns2. Les résultats de la simulation démontrent que le new-SAFT est plus performant que le SAFT-VNDN en termes de délai de bout en bout et de taux de livraison des paquets.

Mots-clés: VANET, NDN, VANET-NDN, Dissemination. Innodations

..

Contents

List of Figures

Introduction

Problem context and motivations

The Internet was originally designed to facilitate host-to-host communication but its increased use for information retrieval and distribution has resulted in several architectural issues. Information-Centric Networking (ICN) has emerged as the most promising idea for future Internet design. ICN enables efficient information dissemination by deploying in-network caching and multi-cast methods through naming information at the network layer. Named Data Networking (NDN) is one of the most promising ICN concepts [1].

NDN transmits packets based on named data, which have hierarchically organized names similar to URLs. This approach allows for traffic de-multiplexing and provides context for data consumption instead of forwarding packets based on IP destination addresses.

By leveraging NDN capabilities in VANET, known as Vehicular Named Data Networking (VANET-NDN), the challenges in VANET can be addressed. When a consumer vehicle needs specific data, it sends an Interest request containing the content name to other vehicles. In response, the vehicle with the requested data sends back a data packet [2].

However, due to the broadcast of Interest packets and the dynamic topology of VANETs, the flooding of unsatisfied Interest packets can lead to network overload. Hence,in this work,

1) we aim to study forwarding strategies and examine their solution to the aforementioned issues
2) we aim also to improve some existing works in VANET-NDN
3) we aim to study protocols performance using Ns2 simulator

Manuscript organisation

In chapter 1, we describe the TCP/IP and VANET basic concepts. In chapter 2, we give basic definitions of Named Data Networking(NDN) and VANET-NDN and we describe some forwarding strategies. In chapter3 we focus only on simulation. In addition, we analyze the performance of SAFT-VNDN and its improvement new-SAFT. Finally, the general conclusion is given at the end.

CHAPTER

1 Overview

1.1 Introduction

TCP/IP is, by definition, a set of protocols that enable connections between any two systems over any kind of network structure. TCP/IP provides unrestricted communication between computers with various systems and architectures. In Parallel, advances in intelligence transportation systems, and Internet of Things (IoT) platforms have given rise to a new and exciting area of study where VANETs are combined with wireless networks, GPS, and other sensors to improve the reliability of the infrastructure supporting vehicular interactions.

1.2 TCP/IP Protocol

1.2.1 What is the TCP/IP Protocol?

TCP is a connection-based protocol that connects devices or applications and keeps them connected until the data is exchanged. It decides how the original message should be divided into packets, and numbers. It reassembles the packets before sending them to switches, routers, security gateways, and other network devices before reaching their final destination. In addition, TCP controls flow control, transmits dropped packets, receives packets from the network layer, and ensures every packet reaches its destination[3].

Figure1.1 illustrates how data moves from the sender to the host through the TCP/IP protocol layers. A host receives frames that traverse the protocol levels in reverse order. The matching header information is removed in every layer.

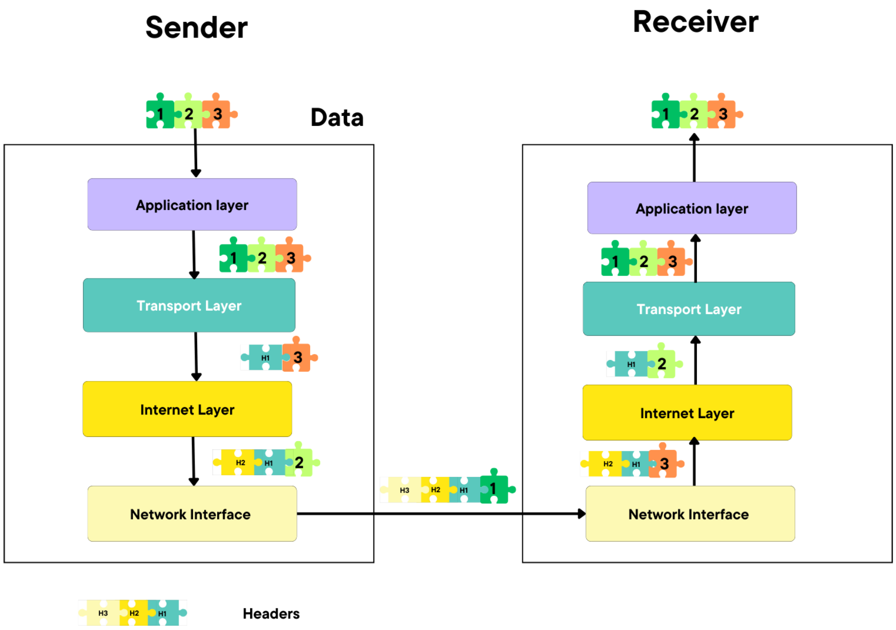

Figure 1.1: The TCP/IP Transmission.

To guarantee that multiple TCP socket connections can be transferred in both directions concurrently, TCP/IP employs a three-way handshake to establish a connection between a device and a server. Device and server synchronization is required[3].

Figure 1.2 explains that data caching is not implemented at the router level by the TCP/IP protocol. Rather than storing any data locally in the router, each request is forwarded straight to the server or provider.

1.2.2 The TCP/IP protocol layers :

The TCP/IP protocol suite is divided into 4 layers. They are :

- Application layer: This layer describes the protocols that apps use to exchange data and switches between layers. The protocols are: HTTP is used for document exchange, which creates the World Wide Web's Web pages. The intelligent record exchange is carried out using the FTP. SMTP is used to establish connections and exchange messages. Remote system logins are accomplished via Telnet[4].
- Transport layer: The Transport layer, also known as the Host-to-Host Transport layer, is responsible for providing the datagram and session to the Application layer. TCP and UDP are this layer's primary protocols. One-to-one, connection-oriented, dependable communications are offered by TCP. One-to-one or one-to-many, connectionless, and unstable communications are offered by UDP[4].

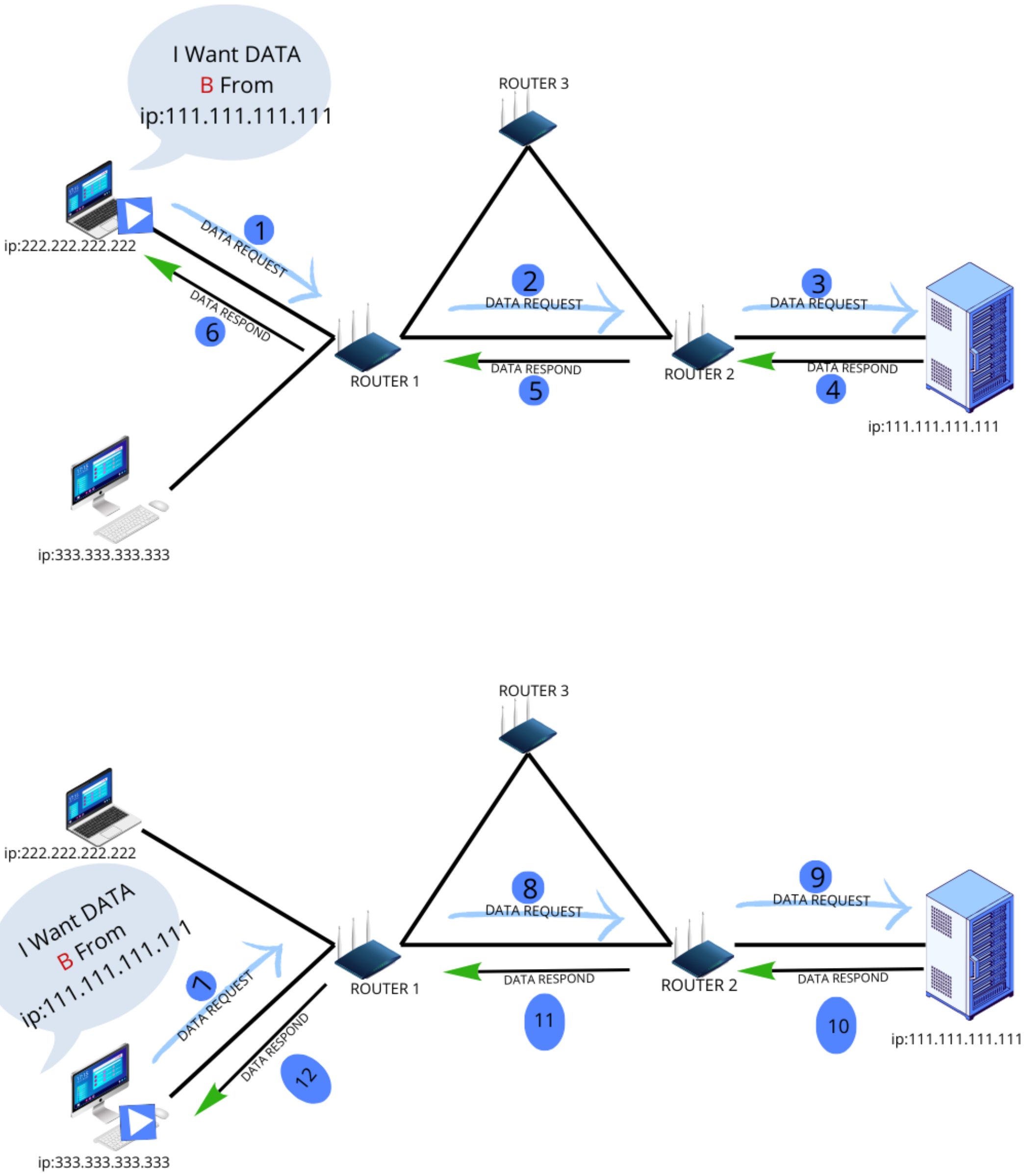

Figure 1.2: TCP/IP Mechanism

- Internet layer: The Internet layer controls directing capabilities and addresses. IP, ARP, ICMP, and IGMP are the Internet layer center conventions[4].
- Network layer: Also referred to as the network access layer, the network interface layer is responsible for sending TCP/IP packets across the system media and receiving them from it. The system access technique, casing organization, and media were not meant to be a part of TCP/IP[4].

1.2.3 Advantages of the TCP/IP model:

1) Interconnection of various computer kinds: TCP/IP makes it easier to link various computer types, which encourages interoperability.
2) Disconnection from the operating system: The operating system that is installed on linked PCs has no bearing on how the TCP/IP paradigm functions.
3) Several routing protocols supported: TCP/IP facilitates data sharing and communication across networks by supporting several routing protocols.
4) Exceptionally adaptable client-server design: Large-scale network infrastructures can benefit from the TCP/IP model's highly scalable client-server design.
5) Sleek and adaptable: TCP/IP is comparatively thin and doesn't put needless limitations on PCs or networks.

1.2.4 Disadvantages of the TCP/IP architecture:

1) Difficulty of setup and administration: Setting up and maintaining the TCP/IP paradigm can be difficult at times, necessitating significant technical knowledge.
2) Lack of packet delivery guarantee at the transport layer: In some circumstances, data loss may arise from the TCP/IP transport layer's inability to ensure packet delivery.
3) The challenge of substituting protocols: TCP/IP protocols are difficult to change, which makes it difficult to adjust to new technologies or guarantee security.
4) Lack of distinct division between services, interfaces, and protocols: It is challenging to characterize novel technologies or administer networks as the TCP/IP paradigm fails to distinguish between these components.
5) SYN attack vulnerability: TCP/IP is especially susceptible to SYN assaults.

1.3 Vehicular Ad Hoc Network (VANETs)

Different deployment architectures for automotive networks in highways, urban, and rural areas are made possible by the advancements in mobile communications and the current trends in ad hoc networks. These architectures serve a variety of applications with varying quality of service needs[5][6].
A VANET architecture's purpose is to enable communication between adjacent vehicles and between vehicles and stationary roadside units (RSU).
Due to developments in wireless technology, VANETs have become increasingly prominent in the Intelligent Transportation System (ITS), which includes a variety of applications targeted at enhancing infotainment, traffic efficiency, and passenger safety. Each vehicle in these networks can control, arrange, and make use of information shared by nearby vehicles or RSUs[7].
Even while a VANET is a special example of a MANET and shares certain similarities with it, it also has some unique properties, such as :

- High mobility: Moving vehicles and stationary RSUs make up the majority of VANETs. The vehicle's speed ranges from extremely slow to extremely fast, creating additional communication difficulties. Vehicles have plenty of opportunities to communicate when there is heavy traffic since they are either stopped or traveling slowly. However, because of the high vehicle density, they encounter significant difficulties such as message loss, channel fading, data collisions, and other interference issues. Vehicle speeds are extremely high in low-traffic regions (such as highways), which might cause connection failures, high end-to-end (ETE) delays, limited communication windows (few seconds), and other communication problems[8].
- Effectiveness: Node mobility in VANETs is not the same as in Mobile Ad-hoc Networks (MANETs). Mobile nodes in MANETs may go at any time and any place. On the other hand, with VANETs, vehicles adhere to the topology of the road networks in the regions they travel through. There are three broad types of situations: rural, urban, and highway. Compared to rural areas, urban areas have heavier traffic densities and more intricate road networks. In addition, it has more roadside units, traffic lights, and obstructions than a rural area or highway. In the latter, traffic travels in a single direction across many lanes. The efficacy and efficiency of communication are impacted by the geographical characteristics of the road network[8].
- Traffic density: varies from high to low based on the time factor (i.e., low traffic during off-peak hours and high traffic during rush hours) as well as the geographic location (i.e., high traffic density in urban areas and low traffic density in rural

areas and highways). Important issues concerning the development of effective VANET communication protocols are brought up by traffic density. For instance, data distribution methods need to handle the problem of network disconnection in rural locations with very low traffic density. Advanced data transmission systems, however, are necessary in situations of extremely high traffic density, particularly in urban areas during rush hour, in order to prevent the well-known broadcast storm problem[8].

- Heterogeneity: The features and capacities of VANET nodes vary. Vehicles, for example, are mobile nodes with varying sensing capacities, communication ranges, and classifications (e.g., private, authority, and maintenance vehicles). RSUs, on the other hand, are stationary nodes with full ad-hoc functionality that are positioned in strategic areas[8].

1.3.1 Types of communication in VANET networks

Three different kinds of network topologies are employed in data services: hybrid architecture, vehicle-to-infrastructure (V2I), and vehicle-to-vehicle (V2V) connectivity. V2I communication allows a vehicle to communicate with the RSU primarily for information and data-gathering applications. V2V communication allows direct vehicular communication and can be used primarily for safety, security, and dissemination applications; hybrid architecture combines both V2V and V2I(figure1.3)[9].

- Vehicle-to-vehicle :
  The purpose of V2V (Vehicle to Vehicle) technology is to enable communication between vehicles. The system will employ the 802.11p wireless protocol standard to operate in a 5.9GHz frequency for a range of public safety applications. This technology, which allows for dynamic wireless data interchange between neighboring vehicles, is intended to improve safety. It has the potential to significantly increase safety. The position, speed, steering angle, brake status, turn signal status, number of occupants in the vehicle, and other information about the vehicle may be communicated. A vehicle can detect risks and dangers by using vehicle-to-vehicle (V2V) communications to identify the position of other vehicles and the potential threat or hazard they pose. GPS and other non-vehicle-based technologies can be used to determine the message. Dedicated Short Range Communications (DSRC) is used in V2V communication technologies[10].
  - Advantages of V2V communication include:
    Enables communication over short and medium distances It delivers brief

messages and requires no roadside infrastructure, saving money. it is less expensive; it facilitates the transmission of brief messages. The communication link's latency is minimized. Real-time safety is ensured by its speed and dependability. Enhance road safety by shielding vehicles from possible dangers[10].

- The disadvantages of V2V communication :
  Frequently dividing topologies because to high mobility Difficulties with long-range communication Difficulties with using established protocols Issues with broadcasting messages under heavy traffic and environmental forces

- Applications of V2V:

  The three categories into which applications are divided.

  - Applications for road safety :
    preventing crashes, preventing obstructions (which might be stationary or movable), and disseminating information.
  - Driver assistance applications:
    Helps prevent straight or carved lanes from existing. Aids in vehicle passing.

  - Comfort applications:
    Mobile access to the Internet Electronic messaging Inter-vehicle chat, Network games, etc.

- Vehicle to Infrastructure Communication
  Vehicle to Infrastructure Communication (V2I) is a type of communication in vehicular ad hoc networks that provides long-range communication over cellular wireless networks. It uses roadside units and IEEE 802.11p standard communication protocols to create and support V2I protocols[11].
  - Functionality:
    - V2I communication provides a high-bandwidth link between vehicles and network infrastructures.
    - Managing relayed messages to control road traffic.
    - Reduce disruptions and accidents.
    - Improve road safety levels.
  - Components within V2I communication[11] .

- Cellular network stations.
- Traffic lights.
- Line signs.
- Road signs.
- Roadside units.

  Messages exchanged between the Roadside Unit (RSU) and the vehicle may contain items such as vehicle position, route history information, road condition and safety information, and variable information about the current route[11].

- Applications:
  - Warn vehicles about potential hazards or accidents ahead.
  - Receive real-time weather updates and warnings through V2I communication.
  - V2I systems help in managing traffic flow, providing alternative routes, and reducing congestion.
  - Vehicles receive information about speed limits, helping drivers to adhere to regulations and avoid speeding.
  - V2I systems can inform drivers about road conditions, such as construction zones, slippery roads, or deviations.
  - Enable entertainment services such as video presentation, internet search, emailing, and VoIP[11].

- Hybrid Communication:
  Incorporates both vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) exchanges. Depending on the distance, or whether it can access the roadside unit directly, a vehicle in this scenario can communicate with the roadside infrastructure in a single-hop or multi-hop method. It permits long-distance connections to distant vehicles or the Internet[12].

1.3.2 VANET Applications :

Applications on VANETs vary into three categories: infotainment, traffic efficiency, and safety Applications.

- Infotainment: by enabling users to communicate with the infrastructure and download files, access the internet, and use chat services, these applications aim to improve the trip experience[8].

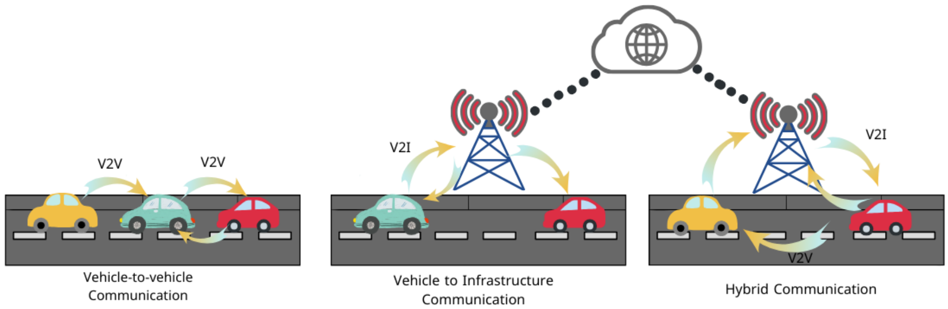

FIGURE 1.3: VANETS TYPES

- Safety applications: the purpose of safety applications is to improve driving safety by alerting drivers to potentially hazardous conditions on the road at the appropriate moment[8].
- Traffic efficiency applications: seek to improve the effectiveness of transportation networks by giving drivers and road operators access to traffic-related data. The VANET should be used to exchange traffic information in order to accomplish this purpose. Shorter travel times and lower road building and maintenance costs will therefore benefit both road users and road operators[8].

1.4 Conclusion

VANETs represent a specialized area of ad hoc networks designed for vehicular communication, harnessing advancements in wireless technologies and IoT platforms to enhance transportation systems. In contrast, While TCP/IP architecture offers unparalleled connectivity, it also presents challenges such as setup complexity, lack of guaranteed packet delivery, and difficulties in protocol substitution. As technology evolves, alternatives such as Vehicular Named Data Networking (VNDN) offer promising solutions to these challenges. By extending the principles of Named Data Networking (NDN) to vehicular environments, VNDN enables efficient data dissemination and retrieval among vehicles and infrastructure.

Chapter 2

Vehicular Named Data Networking (VNDN)

2.1 Introduction

Over Chapter1, we shed light on the disadvantages of TCP/IP architecture which is mainly based on the host Ip address to retrieve data. Hence, this chapter examines the new concept of Named Data Networking and Vehicular Named Data Networking (VNDN).

2.2 Named Data Networking Architecture

Named Data Networking (NDN) suggests a system based on named data to replace the conventional IP-based network layer, hence proposing a fundamental change in the design of the Internet. Instead of using the physical host's address to identify each data item, NDN uses a hierarchical name akin to a URL. Hence, resolving the IP architecture's address exhaustion issue [13].

2.2.1 NDN node

- Interest packet: The consumer generates an Interest packet that includes the name of the desired data chunk. Network routers forward such a packet to the producer using specified naming information.
- Data packet: A packet will be sent back once the producer (or intermediate forwarder) node receives the Interest packet with the desired data. The producer's signature, the name, and the content are all contained in the Data packet (figure2.1).

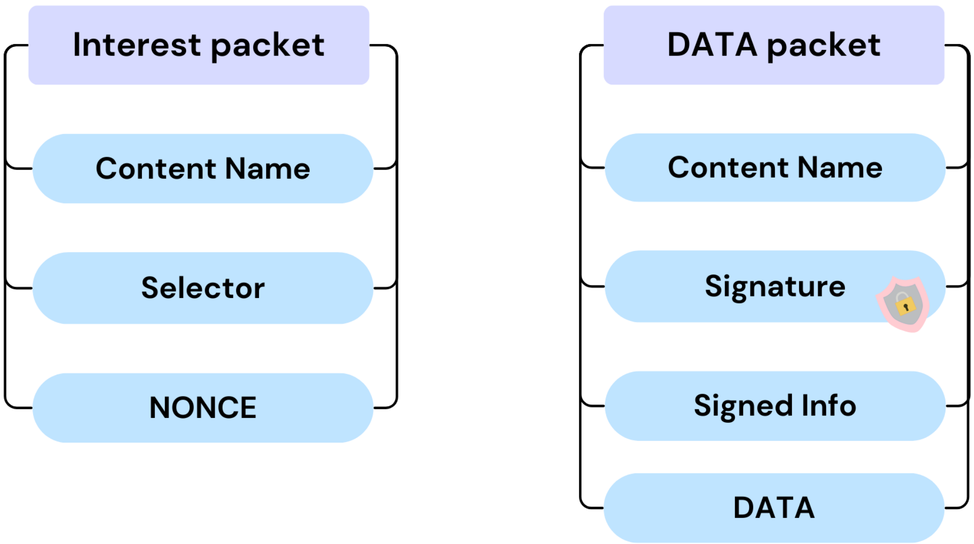

FIGURE 2.1: NDN INTEREST and DATA packets formats[13].

It is worth noting that the reverse path taken by Data packets and Interest packets is the same[14].

Each node maintains the following data structures [15][14].

Content Store (CS) CS is an essential component used for caching DATA Objects within the network. It is capable of satisfying INTEREST packets if it has previously cached DATA objects. The CS essentially functions as a temporary cache of received DATA objects. When a Consumer sends an INTEREST for a DATA object, routers steadfastly forward the INTEREST packet towards the content's Producer. Upon receiving the INTEREST packet, the Producer promptly responds by sending the requested DATA object, which is then efficiently forwarded to the Consumer by the routers.

Pending Interest Table (PIT) PIT plays a vital role in tracking the path of INTEREST packets. Each entry in the PIT table includes the INTEREST name, incoming faces. Additionally, the PIT table is utilized for various purposes such as INTEREST aggregation and Congestion Control.

Forwarding Information Base (FIB) FIB is a crucial table used by routers to route INTEREST packets to the data Producer efficiently. Each entry in the FIB table includes a name prefix and a set of faces that determine the next hop towards the Producer.

The three data structures are kept up to date by every NDN node(figure2.2).

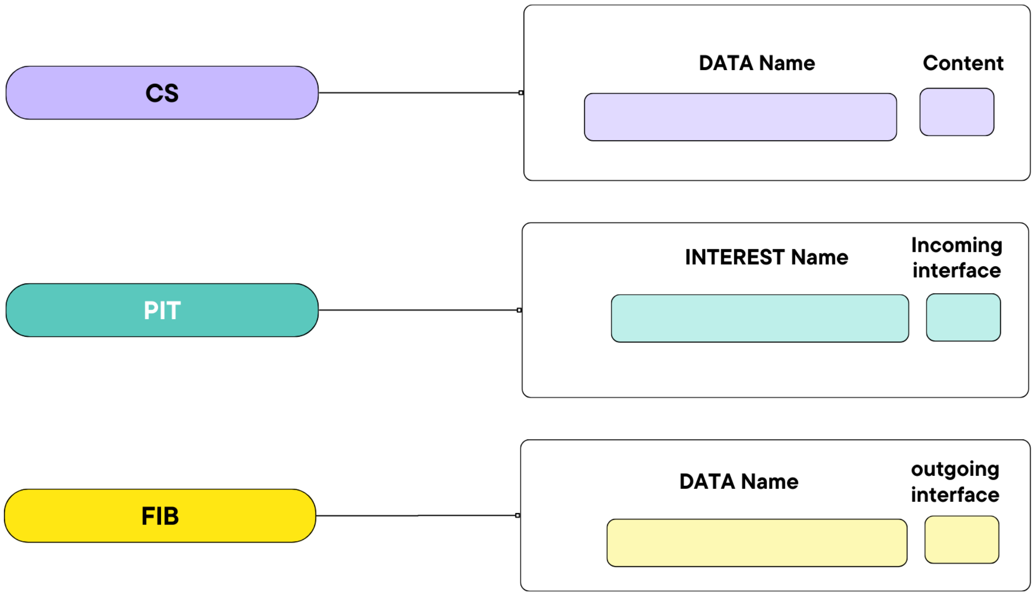

FIGURE 2.2: NDN Nodes.

2.3 Forwarding System in NDN

2.3.1 Interset forwarding

In NDN, forwarding is the act of taking packets, consulting the forwarding table,and delivering them in the direction decided by the table,whereas routing is the process of constructing the forwarding table. Names are used to route and forward NDN packets. As a result, unlike the IP design, NDN does not experienceaddress-related difficulties. First, unlike IP, there is no address exhaustion problem[2].

The received interest packet of a node can be satisfied, deleted, or forwarded further in the baseline NDN interest forwarding approach by successively checking CS, PIT, and FIB[16].

1) The node creates and sends back a data packet containing a copy of the cached data to fulfill the interest packet in the CS lookup if the received interest packet matches a data name in the node's local CS.

2) If there is no CS matching, a second verifying data-name matching between the interest and PIT is carried out to see if the interest is already present and just needs a data packet to satisfy it. In the event that a match is found, the interest's details, including its incoming face and nonce, are added to the matching PIT entry in order to aggregate the two, and the interest is then deleted.
3) if not, the node goes through the forwarding process for the received interest procedure. To locate an outgoing face capable of forwarding the interest via the one-hop forwarder, a lookup is performed in the FIB entries. A new PIT entry is made to track the forwarded interest if an FIB match is found; if not, the interest is either broadcast over all of the node's outgoing physical faces or discarded based on the forwarding strategy decision. The interest is forwarded further via the lookup-returned outgoing face(s). Every node keeps doing this until the desired data are found or the interest hop-limit is reached as shown in Figure2.3[16].

2.3.2 Data forwarding

The process of data forwarding establishes the same interest reverse path as the data packet forwarding path, and the intermediate nodes' data packet processing mechanism maintains the packet forwarding across that path.

The data packet is subsequently regarded as solicited data and downstream transmitted to the consumer over all incoming face(s) from where the pending interests are received after the node looks for a PIT match[15].

Once the data packet fulfills each of the various interests in the multiple-interest aggregate. Additionally, the relevant PIT entry is deleted and a copy of the requested data is cached in the CS according to the caching placement and replacement strategies in use. The data packet is regarded as uninvited in the PIT-matching absence case and is deleted without being cached or forwarded[16].

2.3.3 Caching

An essential component of NDN's data delivery system is caching. In order to fulfill upcoming requests without having to obtain data from the source, routers automatically store Data packets in their Content Store. This caching technique facilitates effective multicast and packet retransmission, lowers network congestion, and enhances data retrieval speed. NDN's architecture ensures data privacy at a fundamentally different level

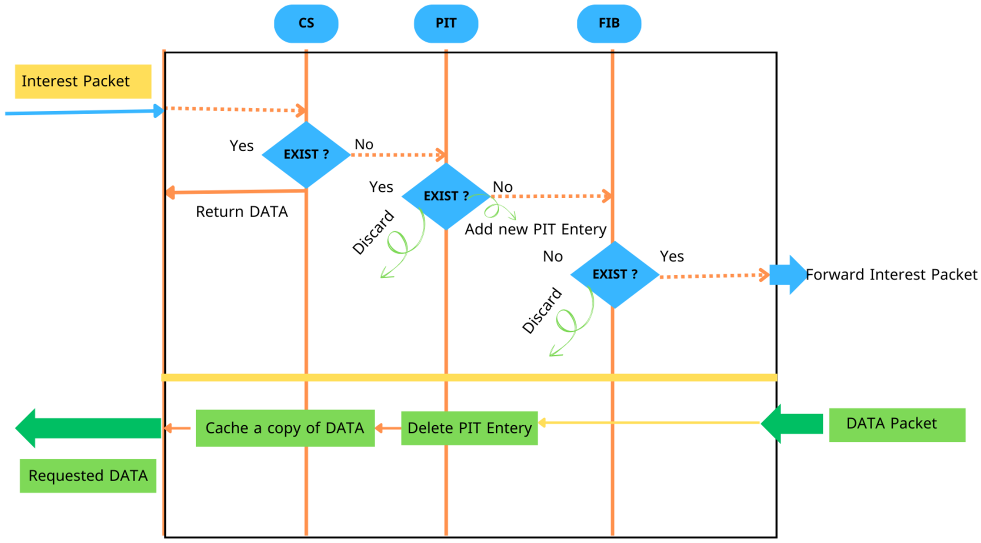

FIGURE 2.3: NDN Forwarding Process

than typical IP networks, not with standing privacy concerns, by eliminating information about data requesters from router [17].

2.3.4 Data-Centric Security

In NDN, data security is intrinsic to the data. To ensure data integrity and origin authenticity, each piece of data is signed with its name. Customers may trust data with this technique regardless of where or how it was collected. The data-centric security concept of NDN necessitates effective key management and trust formation procedures. NDN supports fine-grained trust models by securely binding names to data, empowering users to decide which sources to trust depending on the context and provenance of data. Strong security is ensured by this method in a variety of network environments and applications[15].

2.3.5 Limitations of IP vs NDN

This section examines the structural, functional, and performance limitations of the current IP Internet architecture[13].

- NDN packets utilize CN (content name), whereas packets use the destination IP address to identify the end host in TCP/IP [13].

- Because packets are not listed in the IP routing table, IP forwarding is stateless while NDN forwarding is state-full, the NDN router stores each passing packet of INTEREST for the duration of its existence [13].
- All features required for global interconnectivity are implemented via IP, while NDN is a completely new architecture that concentrates on the contents rather than the address needed to access them[13].
- IP is inefficient content distribution, While NDN content distribution handled efficiently[13].
- In IP, there are explicit mechanisms for controlling congestion; in NDN, routers manage congestion[13].
- Failures in NDN are managed locally via forwarding techniques that use recurrent packet probing from outgoing router interfaces. Congestion occurs on the Internet because IP packets travel random routes to get to their destinations[13].

2.4 Vehicular Named Data Networking (VNDN)

VNDN is an extension of NDN architecture to improve vehicle networking[16].

The use of Named Data Networking (NDN) in Vehicular Ad Hoc Networks (VANET) has seen significant growth in the past decade. Initially, only a few studies explored the feasibility and usefulness of the VNDN model, along with its potential advantages and performance compared to more established traditional VANET technologies. Vehicular Named Data Networking, with its decentralized communication model, offers increased convenience, better dependability, and enhanced resource-sharing capabilities [16].

As a result, VNDN is gaining traction as an improved communication method for Internet of Vehicles applications. NDN integration with the Internet of Vehicles is driving a revolutionary change. [18] [16].

In the VNDN The consumer forwards the interest to each possible producer who might have the desired data, one hop at a time. In the content detection analysis, relay nodes, also known as forwarders, are the intermediary nodes that receive and forward the interest packet. Additionally, depending on their caching strategy, the relay nodes may cache a copy of the content in the received data packet to fulfill incoming requests [15][16].

2.4.1 VNDN Architecture

The VNDN architecture is structured as a three-layered system, consisting of the application layer, the NDN layer, and V2X access technologies. This architecture enables NDN-enabled nodes to follow a three-layered communication model for named-based data distribution and delivery. This is depicted(Figure 2.4)[16].

Application layer Many VANET applications are created and executed at the application layer. Transferring data to and from local applications occurs via the logical/application face, which serves as an interface between the NDN layer and the application layer [8][16].

NDN Layer The NDN functionalities are achieved through three sublayers: security, NDN core layer, and strategy. The security sublayer is responsible for designing and implementing tasks and protocols for data-centric security. The NDN core sublayer implements primary NDN functionalities and manages operations to achieve named-based data dissemination. The strategy sublayer is where the strategies for packet forwarding and data caching are implemented to achieve efficient performance in resource utilization and named-based data dissemination.[16].

Physical layer The physical layer, which relates to the V2X access techniques, enables contact with neighboring vehicles, pedestrians, RSUs, and infrastructure networks[16].

2.4.2 VNDN naming scheme

The naming method in VNDN allows the data to be meaningfully defined through hierarchy, understandable by humans (e.g., /traffic-application/geolocation-info/timestamp/data-type), enabling the data to function as an independent communication object that may be requested, transmitted, saved, and secured whatever the structure of the network or the location or IP of the original data provider. Put differently, information identifying centers communication around the data, thus reducing the burden and constraints of TCP/IP-based end-to-end interaction while facilitating data-centric VANET application communication during node mobility. Therefore, the nodes and applications in VANET can connect by propagating a packet that provides the name of the requested data instead of forcing nodes to use the TCP/IP client-server-based communication model, which is difficult to deploy or seldom can ensure its scalability[15][16].

It may seem straightforward to align data names during data transfer. But creating a uniform, scalable naming strategy that can effectively identify, precisely characterize, and

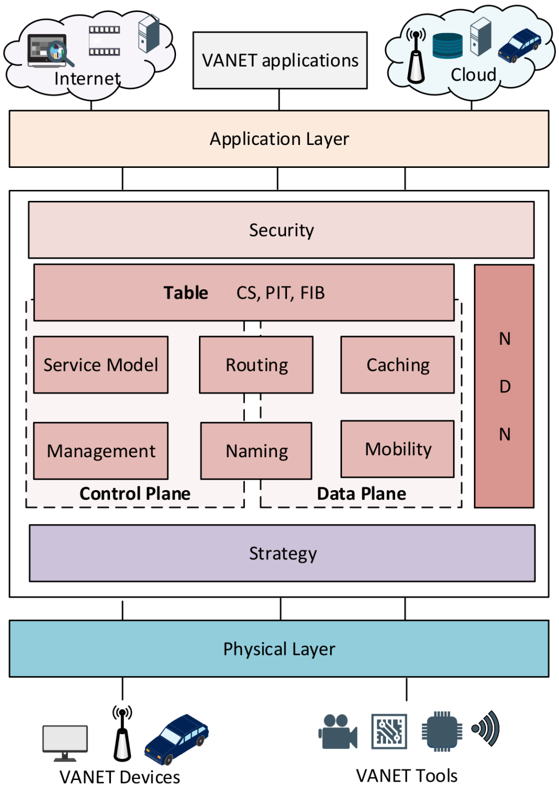

FIGURE 2.4: VNDN Architecture [15]

handle complex information while fully encapsulating the data features and their related semantic features[16].

2.4.3 VNDN forwarding strategy

VANET nodes can use single- or multi-network interfaces to broadcast an interest packet containing the requested data name. The interest packet is then routed hop by hop to intermediary nodes until a data provider is found, which can reply with a data packet containing the requested data name. NDN interest aggregation in PIT reduces the number of interest packets propagated and allows a single data packet to fulfill multiple interest packets. This contributes to lower bandwidth utilization and reduces the likelihood of broadcast difficulties in VANET. Enabling simultaneous multiple interface communication can improve Quality of Service (QoS) and Quality of Experience (QoE) by reducing latency, improving availability, and enabling data access from multiple sources.

However, VANET has to deal with the broadcast storm issue of interest packets which is a major network problem. Broadcast storms lead to unnecessary and redundant transmission of identical interest packets in the network. This means every vehicle has to broadcast the same interest packet across the network until it reaches the producer vehicle, causing additional delays and wasting network. VANETs are prone to disconnection due to the high mobility of nodes which means that VANETs can be partitioned frequently. In the case of network interruption, NDN suffers low-interest satisfaction ration [16].

2.5 VNDN forwarding strategy

Among many research studies in VNDN, we choose the following Forwarding strategies.

2.5.1 Request/Advertise-based Content Forwarding (RACF)

VNDN connections are prone to disconnection, leading to packet loss and lack of FIB direction for subsequent hops. RACF [19] has introduced procedures to establish effective forwarding paths to address this issue.

In addition to interest and data packets, RACF uses two lightweight messages (known as request and advertisement messages). The consumer uses a request message to inquire about available content, while the producer uses an advertisement message to promote the content that is available[19].

In RACF, each vehicle has a neighbor table (NT) that gathers data on nearby vehicles, such as vehicle ID, velocity, position, direction, link availability, and expiration time. This information is used to make forwarding decisions for request and advertisement messages, as well as for data packets. When a new vehicle joins the neighborhood, the NT is updated.

Content Advertisement The content provider sends out an advertisement message to let neighbors know what content is available. The goal is for the message to quickly reach a large number of vehicles. Each vehicle that receives an advertisement only transmits it to one other vehicle, based on mobility criteria, to determine the next hop.

So what is the process of forwarding an advertisement message [19]?

- case 1: If an interest entry exists in FIB, Drop the advertisement message.
- case 2: If the advertisement message is timed out, Drop the advertisement message.

- case 3: In other cases, simply add an advertisement message entry to FIB and then forward the advertisement message.

Content Request A node returns the associated data packet to the consumer node upon receiving an interest packet. However, RACF assists the interest in requesting a data packet through a content request if the node is unable to locate the relevant data packet. To find an available content producer.

So what is the process of forwarding a request message[19]?

- case 1: If a data packet is in the CS, add a consumer ID to the packet, then, forward it to the consumer.
- case 2: If matches the PIT, Drop the request message. Else matches an entry in the FIB then add a provider ID to the request message and forward the request message.
- case 3: In the other cases just forward the request message.

2.5.2 Interest Forwarding by Geolocations in Vehicular Named Data Networking (NAVIGO)

Navigo [20] is a Named Data Networking (NDN) system for vehicles that uses location-based packet forwarding. It tackles the issues of abrupt network modifications and frequent connection outages in vehicular networks. Navigo seeks to retrieve particular data segments from several possible data providers. It includes an adaptive discovery and selection mechanism to direct interests toward data producers via a customized shortest path across the road topology and a technique to bind NDN data names to the producers' geographic area(s).

Example (Navigo protocol)

In a city setting, numerous vehicles are constantly moving. Let's imagine a company that provides an online music streaming service. Subscribers to this service can access and listen to a vast music library that includes their favorite songs.

Now, imagine that a motorist is traveling through a city and wants to listen to a certain music. Here, the Navigo protocol makes it easier to retrieve the music by directing the driver's request to the location of the necessary information.

When the driver wants to listen to the song, they send a request (Interest) to get the data. Using the Navigo protocol, this request is directed towards the area where the desired song is expected to be found. This area could be a fixed location like the company's headquarters, or even the location of a car carrying the data in its cache (known as a Mule), or even an Internet access point on the street.

When the request is directed toward this area, the server or the vehicle, or the Internet access point can respond with the requested data, attaching its location (geographical area) to the sent data. This enables the driver to receive the data quickly without needing to specify the exact address of the sending device.

2.5.3 Density-Aware Delay-tolerant forwarding strategy (DADT)

To address intermittent connectivity and interest flooding issues in vehicular Named Data Networking. DADT [21] supposes that

- Each GPS-equipped vehicle periodically broadcasts its current location and vehicle ID through beacon signals.
- Each vehicle keeps track of its neighbors, including their vehicle IDs, current positions, and the timestamp of packet reception[21].

Figure2.5 represents the overall workflow for DADT interest forwarding strategy:

In DADT, each vehicle keeps the transmission queue (Tx) and Retransmission queue (Retx) for interest and data packets.

DADT follows the following steps to forward packets 2.3

1) When a vehicle overhears a packet:
   - i- updates the Tx and Retx queues.
   - ii- checks the Content Store (CS) and the Pending Interest Table (PIT).
2) A vehicle drops duplicate Interests If an interest packet has naming-matching data in the queues because it has already been satisfied.
3) A vehicle sets up rebroadcast deferring timers using the distance to the last hop.
   - i- At timer expiration, it will transmit the packet or
   - ii- If it overhears another vehicle sending the same interest/data packet with higher priority, it cancels its transmission.

It is worth noting that DADT uses a carry-and-forward strategy to deal with intermittent connections.

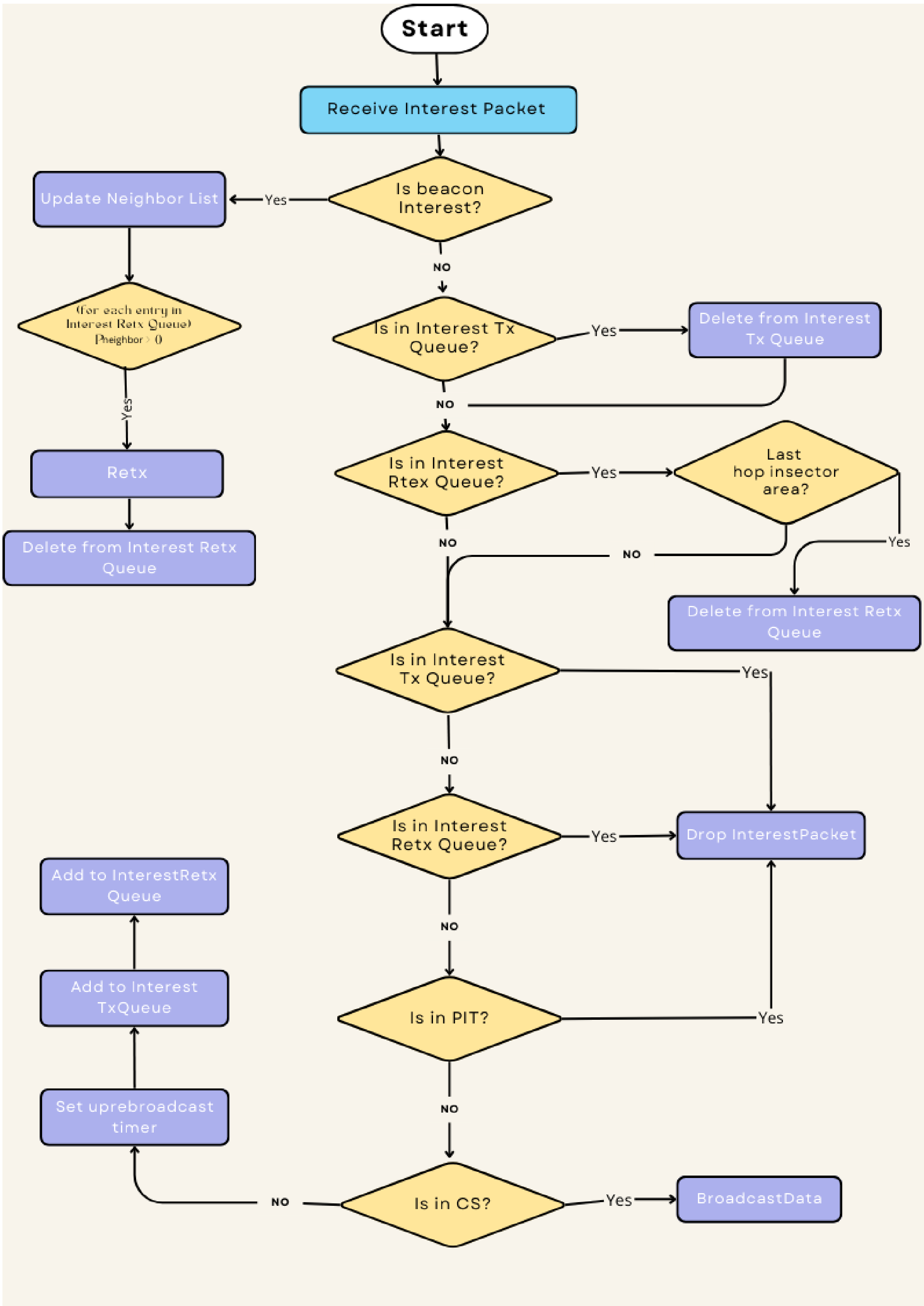

Figure 2.5: DADT interest forwarding strategy workflow[21]

2.5.4 SAFT-VNDN: A Socially Aware Forwarding Technique in Vehicular Named Data Networking VNDN

SAFT-VNDN is a novel hybrid VNDN-VSN forwarding protocol that integrates social concepts in VNDN. In addition, SAFT-VNDN offers a solution that enhances content delivery, and cache hit ratio while reducing transmission delay between end users and deals with aforementioned issues like broadcast storms and network partition.

2.5.4.1 Assumptions

SAFT-VNDN operates in a hybrid VNDN-VSN (Vehicular Named Data Networking - Vehicular Social Network) environment using IEEE 802.11p. The assumptions include

- Location Tracking: Each node can track the original data producer's location using the Grid Location Service (GLS).
- Pre-defined Communities: Social communities are predefined by a trusted authority (CA). Vehicles can join or leave these communities based on their interests extracted from VSN applications (user profiles like Facebook).

2.5.4.2 Node Design

The three primary data structures FIB, PIT, and CS are maintained by each vehicle according to the standard VNDN design. However, SAFT-VNDN splits the CS in half, with half storing community content and the other half storing public data as illustrated in Figure2.6. As a result, the community name is now a new field ("community") in the CS table.

Community construction involves several steps [6]

- Calculating the center value to identify core nodes.
- Selecting seed nodes with the highest center values.
- Expanding communities using a fitness function. Merging redundant communities to avoid overlap
- Iterating the process until all nodes are assigned to communities

Forwarding Technique

- The content naming scheme is extended to support VSN applications.

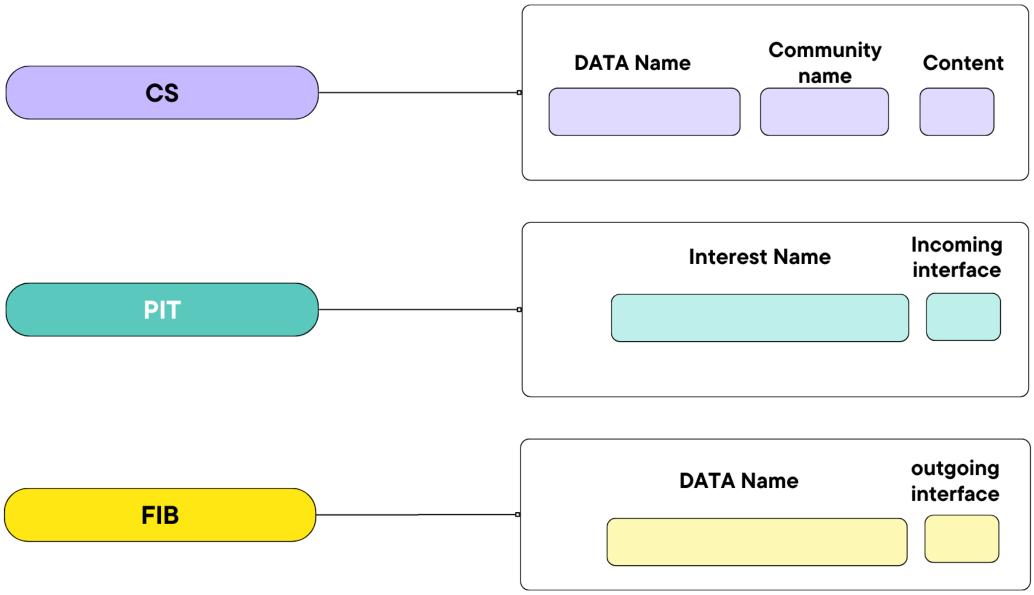

FIGURE 2.6: Node design[6]

- Cooperative Awareness Messages (CAM) is enhanced to include community information. These messages help vehicles identify nearby community members and their interests.
- The basic VNDN structure is retained with three main data structures:
  - FIB (Forwarding Information Base)
  - PIT (Pending Interest Table)
  - CS (Content Store): divided into two parts: one for community content and another for general content. This division improves data accessibility and storage efficiency[6].

2.5.4.3 *Retrieving VSN General Contents*

When a vehicle requests general VSN content, it performs the following steps[6]:

- The vehicle generates an interest packet and creates a PIT entry.
- Checks for a matching entry in the FIB. If a match is found the interest is forwarded accordingly; otherwise, it broadcasts the interest to all neighboring vehicles.
- Neighboring vehicles with the requested content respond with a Data packet. If no match is found, the interest is forwarded by other vehicles using a deferred timer to avoid collisions.
- Once a Data packet is received it is forwarded back to the requester, and the process stops(figure2.7).

2.5.4.4 Retrieving VSN Community Contents

For community-specific content, the following steps are taken[6]:

- The requesting vehicle checks its neighbor table for vehicles belonging to the desired community.
- If community members are found the interest is forwarded to the closest member. If multiple members are available, the one closest to the center of interest is selected.
- If no community members are nearby, the vehicle forwards the interest to a distant neighbor

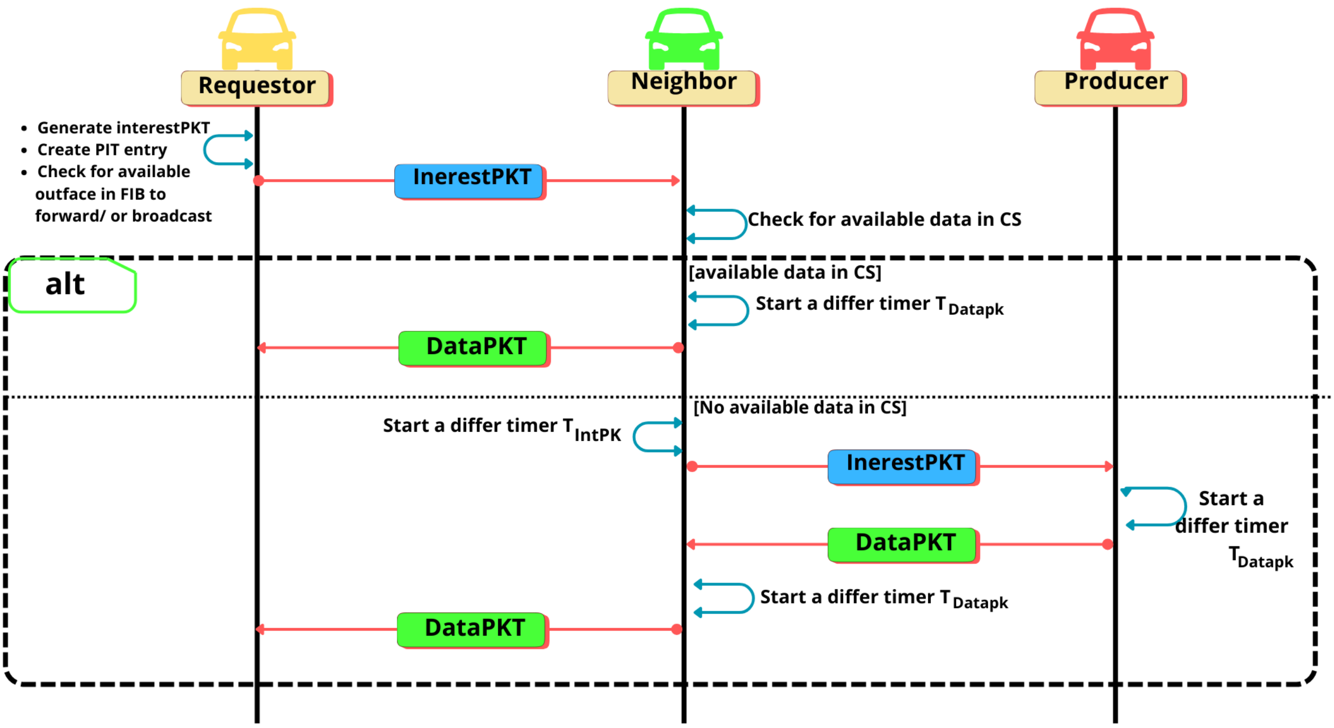

FIGURE 2.7: Retrieving general VSN contents [6]

Cache Management
The SAFT-VNDN approach involves innovative cache management and community construction techniques to enhance content delivery in vehicular networks. Cache management is optimized

- Dividing the Content Store (CS) into community and general content sections.
- Employing a priority-based replacement strategy when the community cache is full.

These methods collectively improve data delivery efficiency and cache hit ratios in vehicular named data networking.

2.6 Conclusion

This chapter discusses NDN and VNDN as modern designs created to overcome the constraints of conventional Internet Protocol (IP) networks. By introducing a novel forwarding technique, naming scheme, and other innovations, these architectures aim to improve communication effectiveness and resolve problems with vehicle networks.

Chapter 3 Simulation And Implementation

3.1 Introduction

Due to the high cost and lengthy turnaround times of real experiments, computer network engineering has made considerable use of simulation tools to evaluate the behavior of proposed protocols before deployment. Therefore, simulation is an essential step before realization. This chapter aims to examine and contrast SAFT-VNDN's functionality under various conditions. To accomplish this, our simulations were performed using a network simulator (Ns2.35).

3.2 Protcols to simulate

In the first step, a slight modification was made to SAFT-VNDN. Extra controls were added to mitigate broadcast storms in interest/data forwarding. In the new protocol, called new-SAFT, each forwarder will perform the following actions.

```
calculate distance1(last forwarder, destination)
calculate distance2(forwarder, destination)
if (distance2 < distance1) {
 Forward
}else{ do not forward}
```

In other words, the expected forwarder will calculate its distance to the destination(producer or consumer). If its distance is less than that of the last forwarder to the destination, it will perform forwarding else, it cancels forwarding

In the next step, we implemented SAFT-VNDN(SAFT for short) and SAFT in the Ns2 simulator.

Simulation Setup

To evaluate and compare the performance of SAFT and new-SAFT protocols in urban scenarios under different network densities. we conducted simulations using the Ns2.35 network simulator.

Based on the information provided in Table 3.1, we can analyze the performance of the SAFT-VNDN protocol in an urban environment, These settings provide a realistic simulation environment for testing the effectiveness of the protocol.

Parameter	**Default value**
Density of vehicles	[50, 300]
Simulation area	1×1 km
Vehicles maximum speed	30 (m/s)
Number of content requester	50
Number of community content producers	9
Communication technology	IEEE 802.11p
Transmission range	300 m

TABLE 3.1: Simulation Parameters

3.3 Results and discussion

The Simulation metrics are:

Average end-to-end delay: The average time between the times, an interest packet is issued, and a data packet is successfully delivered (including buffering, propagation, transmission, and re-transmission delays).

Packet delivery ratio: the ratio of successfully delivered data packets to the total number of originally issued interest packets in a given period.

3.3.1 Simulation Scenarios

General Scenario In this scenario, consumers retrieve only public content.

Mixed Scenario: In this scenario, consumers retrieve public and private content.

Private Scenario: In this scenario, consumers retrieve only private content.

3.4 Simulation results and analysis

End-To-End-delay (EED)

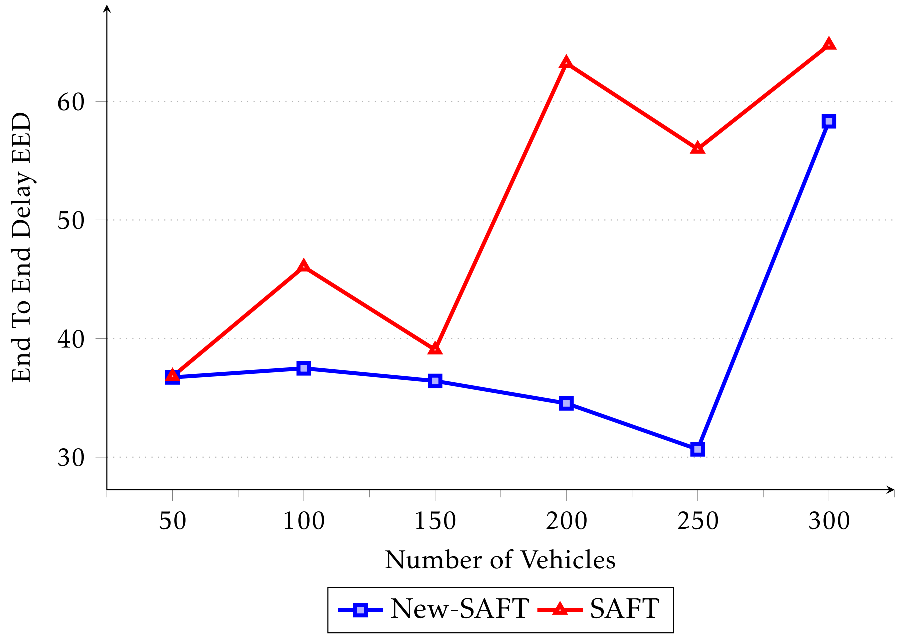

Figure 3.1: Average of End To End Delay vs Number of Vehicles (Scenario Mixed)

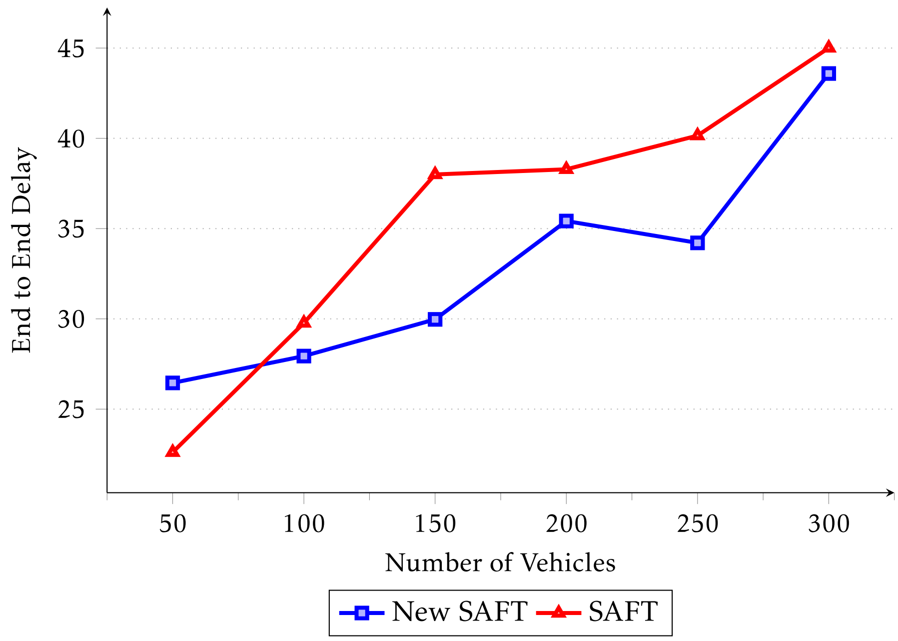

Figure 3.2: Average of End To End Delay per Number of Vehicles in general scenario

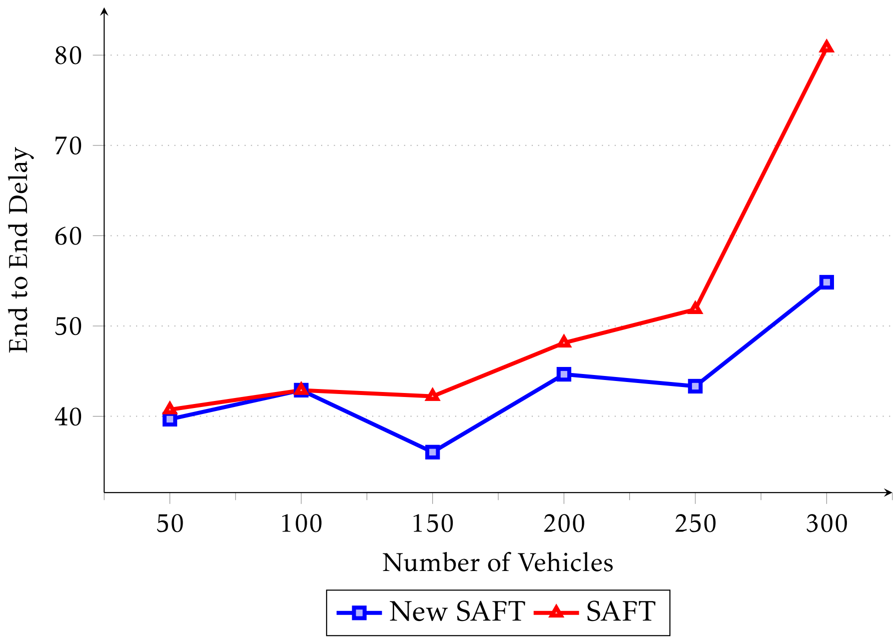

FIGURE 3.3: Average of End To End Delay per Number of Vehicles private scenario

Figures 3.1, 3.2 and 3.3 describe the average of end-to-end delay(EED) at different network densities in different scenarios.

For all scenarios, We can see that the end-to-end delay increases in parallel with the increase in vehicles' number.

In the **mixed** scenario case (Figure 3.1), the end-to-end delay increases from **35 ms** to **70 ms** for the SAFT protocol, while it increases from **35 ms** to **60 ms** for the new-SAFT protocol. When there are 200 vehicles, a significant difference in favor of the new-SAFT protocol becomes apparent.

However, in the **general** scenario, the EDD ranges from **25 ms** to **45 ms** for the two protocols, with a slight difference in favor of the new SAFT protocol.

In the private scenario, the EDD increases from **40 ms** to only **50 ms** for new-SAFT protocol while it increases from 40 ms to 80 ms for SAFT protocol.

As a result, the increase in End-to-End Delay (EED) is due to the growing number of vehicles, leading to a higher packet count and resulting in collisions and transmission problems that impact response time.

The distance control of New-SAFT significantly reduces EED across all vehicle counts compared to the SAFT protocol. This reduction indicates that the control mechanism effectively optimizes packet routing and controls flooding storms, thus decreasing broadcasts of interests and data packets. This leads to shorter transmission paths and reduced delays.

Packet Delivery Ratio

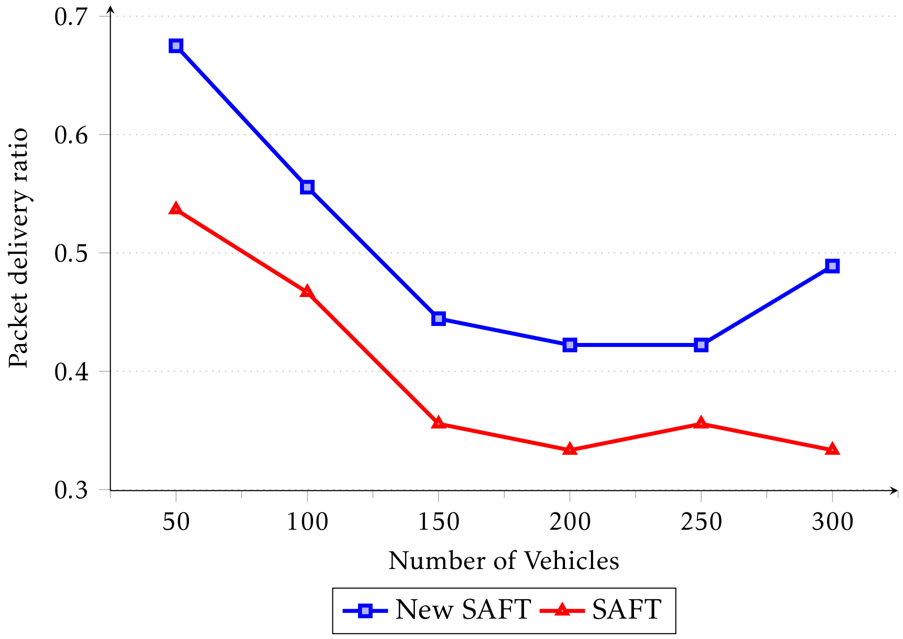

FIGURE 3.4: Average of Packet Delivery ratio per Number of Vehicles mixed scenario

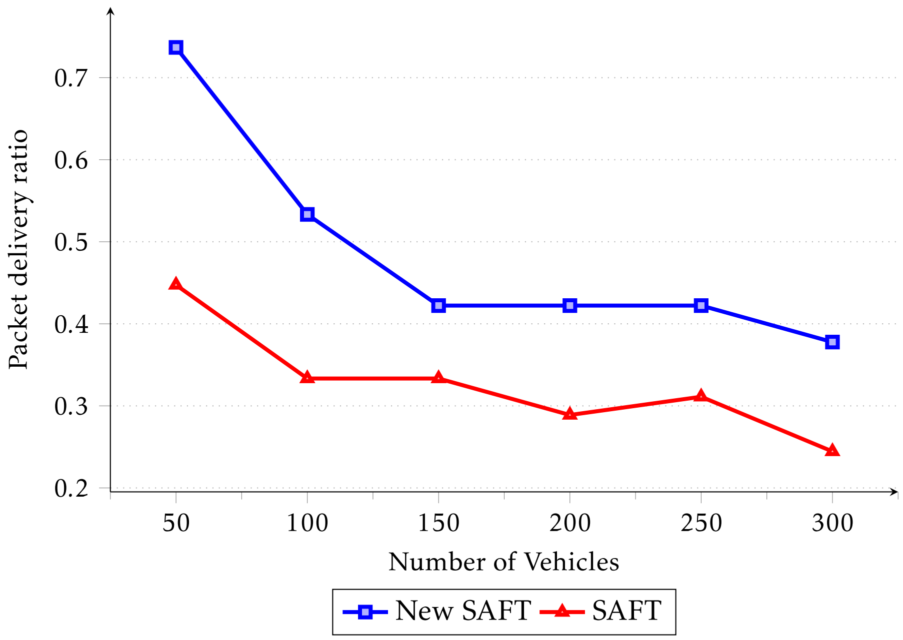

FIGURE 3.5: Average of Packet Delivery ratio per Number of Vehicles general scenario

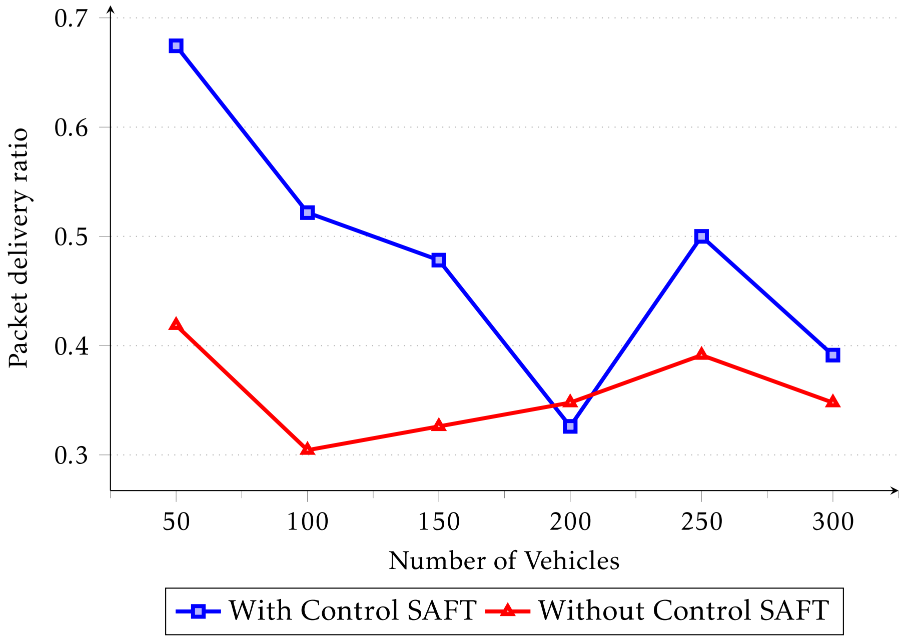

Figure 3.6: Average of Packet Delivery ratio per Number of Vehicles private scenario

Figures 3.4),3.5) and 3.6) show the packet delivery (PDR) in terms of vehicle densities.

In the mixed scenario(Figure3.4), PDR decreases from 70% downto 50% for new-SAFT protocol while it decreases from 50% to 10% for SAFT protocol. These observations are the same for general and private scenarios.

In all cases, we can see that the new-SAFT protocol outperforms the SAFT protocol that is due to its strategy of controlling the flooding problem

Overall, these results show that the extra control done by the new-SAFT protocol has an impact on its performance compared to the original one(SAFT protocol).

Cache Hit Ratio

We have calculated the cache hit ratio for only new-SAFT protocol in terms of vehicle density.

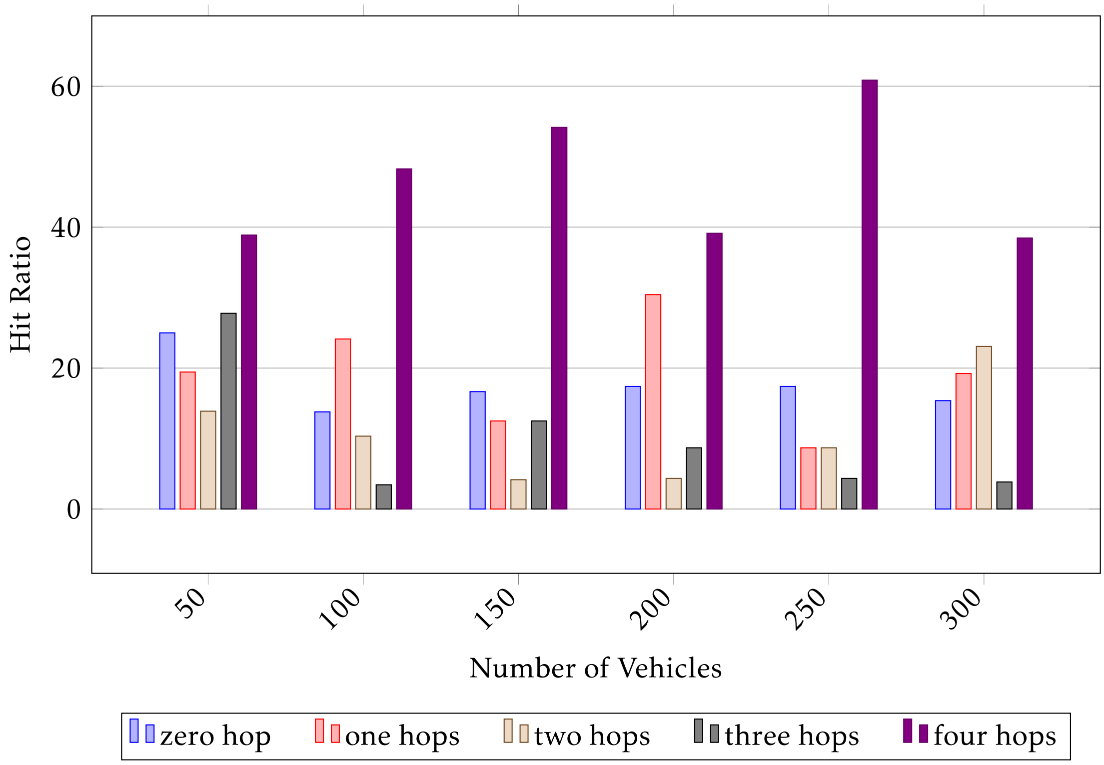

FIGURE 3.7: Average number of hops over network density mixed scenario

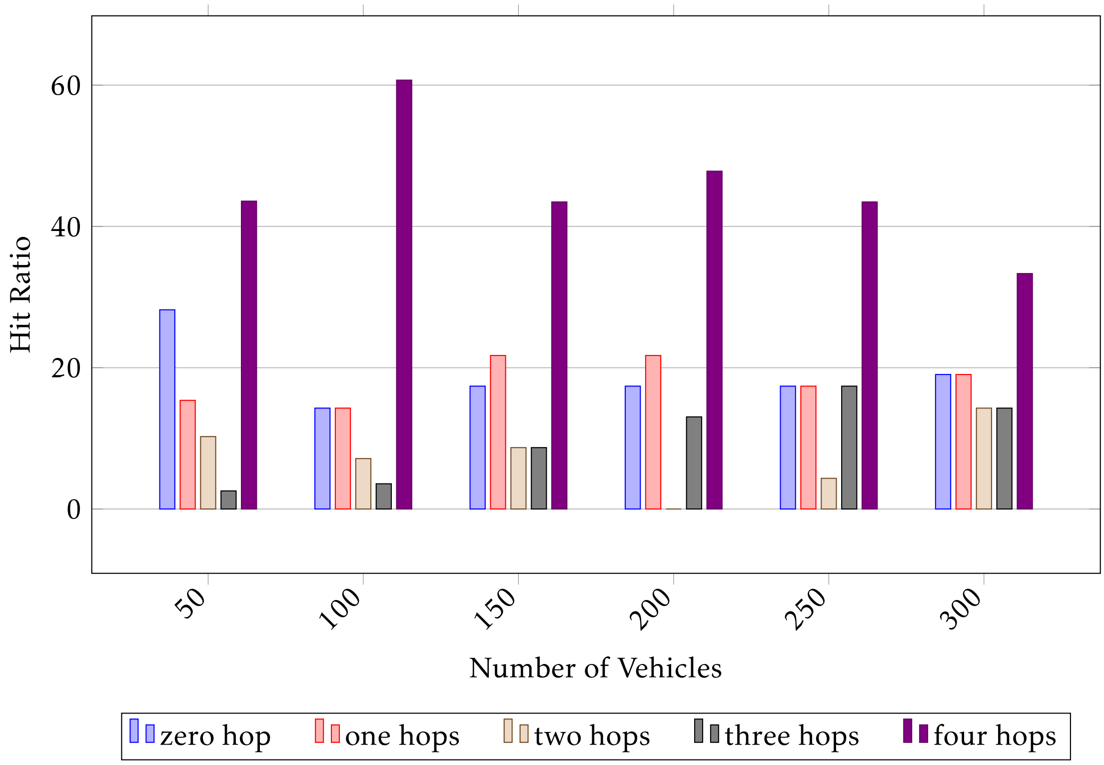

FIGURE 3.8: Average number of hops over network density general scenario

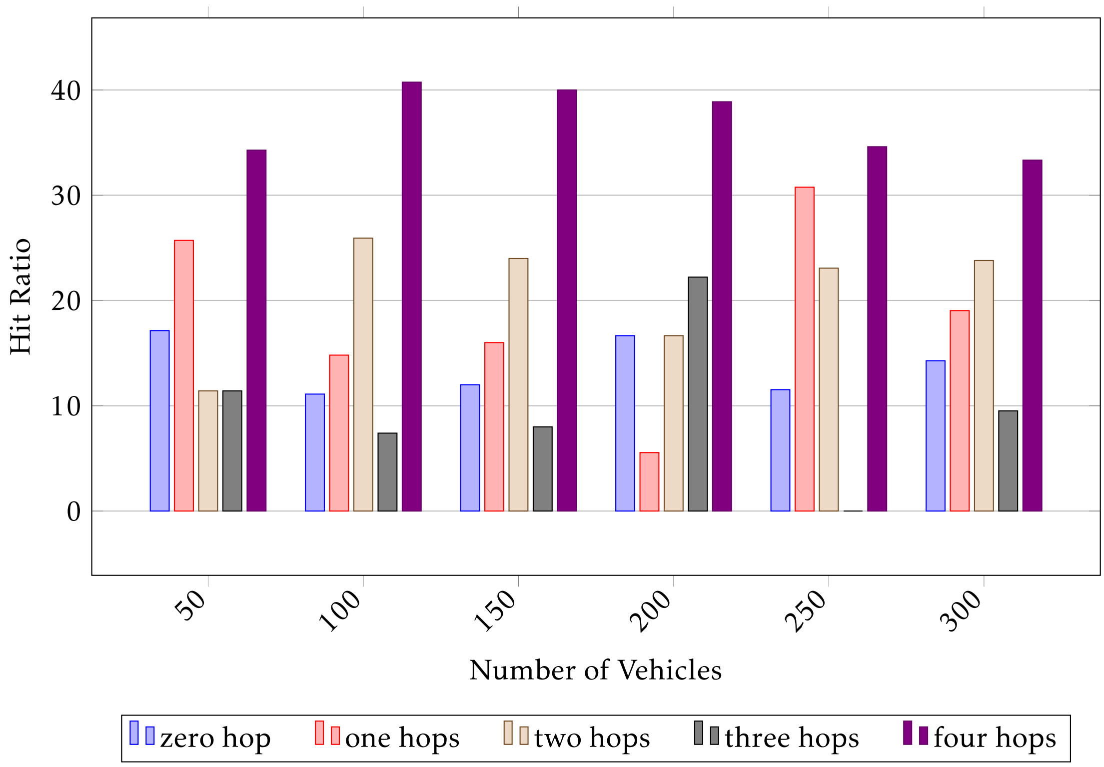

Figure 3.9: Hit Ratio vs Vehicles density private scenario

In the mixed scenario(Figure 3.7), the Hit Ratio ranged from 25% to 38.88% for zero hop, from 13.79% to 48.27% for one hop, from 4.16% to 54.16% for two hops, from 3.44% to 39.13% for three hops, and from 3.84% to 60.86% for more than four hops.

For the general scenario(Figure 3.8), the Hit Ratio ranged from about 28.2% to 43.58% for zero hop, from 10.2% to 60.71% for one hop, from 7.14% to 43.47% for two hops, from 0% to 47.82% for three hops, and from 14.28% to 33.33% for more than four hops.

In the Private scenario(Figure 3.9), the Hit Ratio ranged from about 17.14% to 34.28% for zero hop, from 11.11% to 40.74% for one hop, from 8% to 40% for two hops, from 0% to 38.88% for three hops, and from 9.52% to 23.80% for more than four hops.

Consumers have a 40% to 60% chance of retrieving data within three hops due to the caching strategy of the new-SAFT protocol. This probability increases, espetially in private cases, due to the utilization of community concepts.

3.5 Conclusion

In this chapter, we have studied the effects of the forwarding protocol SAFT and its improvement new-SAFT in three situations (mixed, private, and general) using distance control at varying densities.

Based on the simulation results of the suggested forwarding approach, which are shown in the three scenarios, the new-SAFT protocol outperforms the original one

Conclusion

In this master thesis, we explored advanced wireless network areas including VANETs, the new paradigm of named data networking (NDN), and its integration in vehicular named data networking (VANet-NDN).

Designing efficient forwarding strategies in VANET-NDN is still challenging, as these protocols encounter broadcast storms and network fragmentation. Some protocols mitigate such issues by using extra control messages like RACF, or by using deferring timers like DADT and SAFT-VNDN.

To further improve the forwarding process of SAFT-VNDN, we have added extra controls to ensure that an expected forwarder can only proceed with forwarding if it is closer to the destination than the previous forwarder. This improvement, called new-SAFT, has shown better performance than the original version in terms of end-to-end delay and packet delivery ratio as shown by simulation results.

For future work, we suggest:

- Taking social aspects deeper by integrating driver identification files from social networks over the Internet to predict their future interests and thus improving research and guidance processes.
- Improve the temporary storage technique to maximize the use of available resources and improve the efficiency of data dissemination.
- Develop strong security mechanisms and protocols specifically designed for the unique challenges posed by complex environments.
- VNDN merged with cloud computing to enhance capacity for expansion, resource allocation, and availability of services.

Bibliography

[1] Z. Li, Y. Xu, B. Zhang, L. Yan, and K. Liu, "Packet forwarding in named data networking requirements and survey of solutions," *IEEE Communications Surveys & Tutorials*, vol. 21, no. 2, pp. 1950–1987, 2018. 1

[2] G. Manisha, S. G. Emil, and M. Ramkumar, "Interest forwarding strategies in vehicular named data networks," in *2019 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC)*, pp. 053–057, IEEE, 2019. 1, 14

[3] G. R. Wright and W. R. Stevens, *TCP/IP illustrated, volume 2: The implementation*. Addison-Wesley Professional, 1995. 3, 4

[4] S. Mundra and T. El Taeib, "Tcp/ip protocol layering," *International Journal of Computer Science and Information Technology Research*, vol. 3, no. 1, pp. 415–417, 2015. 4, 6

[5] W. Liang, Z. Li, H. Zhang, S. Wang, and R. Bie, "Vehicular ad hoc networks: architectures, research issues, methodologies, challenges, and trends," *International Journal of Distributed Sensor Networks*, vol. 11, no. 8, p. 745303, 2015. 7

[6] A. Boudelaa, Z. Abdelhafidi, N. Lagraa, C. A. Kerrache, M. Bilal, D. Kwak, and M. B. Yagoubi, "Saft-vndn: A socially-aware forwarding technique in vehicular named data detworking," *CMC-COMPUTERS MATERIALS & CONTINUA*, vol. 73, no. 2, pp. 2495–2512, 2022. x, 7, 24, 25, 26

[7] S. K. Bhoi and P. M. Khilar, "Vehicular communication: a survey," *IET networks*, vol. 3, no. 3, pp. 204–217, 2014. 7

[8] T. Yeferny and S. Hamad, "Vehicular ad-hoc networks: architecture, applications and challenges," *arXiv preprint arXiv:2101.04539*, 2021. 7, 8, 10, 11, 18

[9] H. Shahwani, S. A. Shah, M. Ashraf, M. Akram, J. P. Jeong, and J. Shin, "A comprehensive survey on data dissemination in vehicular ad hoc networks," *Vehicular*

Communications, vol. 34, p. 100420, 2022. 8

[10] K. Tanuja, T. Sushma, M. Bharathi, and K. Arun, "A survey on vanet technologies," 2015. 8, 9

[11] S. Afshari, J. Akbari Torkestani, and M. Fartash, "Types of communication in vehicular ad-hoc networks: Various techniques and current challenges in this field," *Journal of Computer & Robotics*, vol. 15, no. 1, pp. 47–64, 2022. 9, 10

[12] F. Domingos, L. Villas, and A. Boukerche, "Data communication in vanets: Survey, applications and challenges," *Ad Hoc Networks*, vol. 44, no. C, pp. 90–103, 2016. 10

[13] A. Tariq, R. A. Rehman, and B.-S. Kim, "Forwarding strategies in ndn-based wireless networks: A survey," *IEEE Communications Surveys & Tutorials*, vol. 22, no. 1, pp. 68–95, 2019. x, 12, 13, 16, 17

[14] R. Hou, L. Fang, Y. Chang, L. Yang, and F. Wang, "Named data networking over wdm-based optical networks," *IEEE Network*, vol. 31, no. 3, pp. 70–79, 2017. 13

[15] H. Khelifi, S. Luo, B. Nour, H. Moungla, Y. Faheem, R. Hussain, and A. Ksentini, "Named data networking in vehicular ad hoc networks: State-of-the-art and challenges," *IEEE Communications Surveys & Tutorials*, vol. 22, no. 1, pp. 320–351, 2019. x, 13, 15, 16, 17, 18, 19

[16] H. Al-Omaisi, E. A. Sundararajan, R. Alsaqour, N. F. Abdullah, and M. Abdelhaq, "A survey of data dissemination schemes in vehicular named data networking," *Vehicular Communications*, vol. 30, p. 100353, 2021. 14, 15, 17, 18, 19, 20

[17] M. Amadeo, "A literature review on caching transient contents in vehicular named data networking," in *Telecom*, vol. 2, pp. 75–92, MDPI, 2021. 16

[18] E. T. da Silva, A. L. D. Costa, and J. M. H. de Macedo, "On the realization of vanet using named data networking: On improvement of vanet using ndn-based routing, caching, and security," *International Journal of Communication Systems*, vol. 35, no. 18, p. e5348, 2022. 17

[19] M. Al-Qutwani, X. Wang, and B. Yi, "Request/advertise-based content forwarding in vehicular named data networking," *IEEE Access*, vol. 9, pp. 226–236, 2020. 20, 21

[20] G. Grassi, D. Pesavento, G. Pau, L. Zhang, and S. Fdida, "Navigo: Interest forwarding by geolocations in vehicular named data networking," in *2015 IEEE 16th International Symposium on A World of Wireless, Mobile and Multimedia Networks (WoWMoM)*, pp. 1–10, IEEE, 2015. 21

[21] M. Kuai, X. Hong, and Q. Yu, "Delay-tolerant forwarding strategy for named data networking in vehicular environment," *International Journal of Ad Hoc and Ubiquitous Computing*, vol. 31, no. 1, pp. 1–12, 2019. x, 22, 23

[22] K. Ahed, M. Benamar, A. A. Lahcen, and R. El Ouazzani, "Forwarding strategies in vehicular named data networks: A survey," *Journal of King Saud University-Computer and Information Sciences*, vol. 34, no. 5, pp. 1819–1835, 2022.

[23] M. Aldaoud, D. Al-Abri, M. Awadalla, and F. Kausar, "Data structure and management protocol to enhance name resolving in named data networking," *Future Internet*, vol. 16, no. 4, p. 118, 2024.

[24] N. D. Networking, "Named data networking (ndn) project," 2010.

[25] W. Shang, A. Bannis, T. Liang, Z. Wang, Y. Yu, A. Afanasyev, J. Thompson, J. Burke, B. Zhang, and L. Zhang, "Named data networking of things," in *2016 IEEE first international conference on internet-of-things design and implementation (IoTDI)*, pp. 117–128, IEEE, 2016.

[26] L. Parziale, W. Liu, C. Matthews, N. Rosselot, C. Davis, J. Forrester, D. T. Britt, *et al.*, "Tcp/ip tutorial and technical overview," 2006.

[27] R. Hou, S. Zhou, M. Cui, L. Zhou, D. Zeng, J. Luo, and M. Ma, "Data forwarding scheme for vehicle tracking in named data networking," *IEEE Transactions on Vehicular Technology*, vol. 70, no. 7, pp. 6684–6695, 2021.