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SMART FORWARDING IN NAMED-DATA NETWORKING VANET (VEHICULAR
AD-HOC NETWORK)

by

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A Thesis

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Master of Science

Major: Computer Science

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Abstract

Intelligent Transport System (ITS) applications rely on efficient forwarding or routing of the packet. However, routing or forwarding packet in Connected Vehicles is a challenging task and data retrieval rate can be very low due to highly dynamic topology and intermittent connectivity. Most of the routing solutions in the literature are location-based accompanied with limited flooding when location information is not available. For efficient communication and data retrieval in the vehicular network, we propose a hybrid forwarding solution, called CCLF. CCLF takes into account content-based connectivity information, i.e., Interest satisfaction ratio for each name prefix, in its forwarding decisions. To overcome the shortcomings of IP in mobile environment, CCLF is based on a data-centric network called Named Data Network (NDN). By keeping track of content connectivity and giving higher priority to vehicles with better content connectivity to forward Interests, CCLF not only reduces Interest flooding when location information is unknown or inaccurate, but also increases data fetching rate.

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Chapter 1

Introduction

1.1 Motivation

With the increasing support from academia as well as automobile industry, a large array of Intelligent Transport System (ITS) applications have been developed and installed in recent years. The applications can be of various types (Figure 1.), such as road safety, driver assistance, and various others infotainment applications.

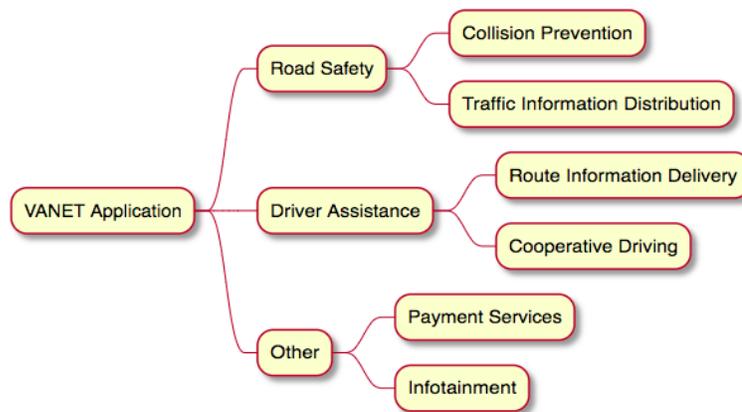


Figure 1. VANET Applications

Currently, most of these applications rely on various sensors, e.g. camera, radar, or lidar. But sensors have some limitations: they have limited range, and can be blocked (Figure 2.). If the vehicles can communicate with each other, then it will enable them to acquire information which would not have been possible with sensors. Many of the ITS applications also require the vehicles to either have V2V (vehicle to vehicle) or V2I (vehicle to infrastructure) connectivity. For example, a road safety application that prevents collision might need to retrieve the speed of the preceding vehicles to determine traffic speed and predict a probable crash. Similarly, a driver assistance application can employ the speed and direction information of other vehicles to accomplish cooperative driving. Vehicles might also need to share the traffic information with RSUs (Road-side Unit) which then can analyze and control traffic effectively.

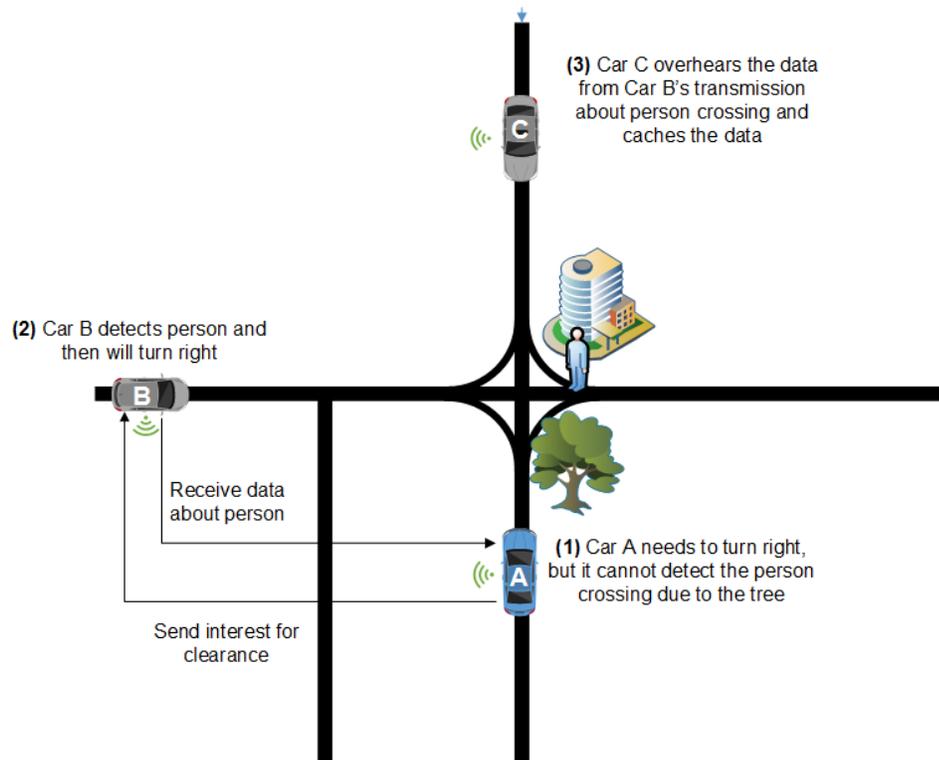


Figure 2. Benefit of V2V Communication [1]

Figure 2. Source: M. Chowdhury, A. Gawande, and L. Wang, "Secure information sharing among autonomous vehicles in ndn," in 2017 IEEE/ACM Second International Conference on Internet-of-Things Design and Implementation (IoTDI). IEEE, 2017, pp. 15–26.

Effective V2V communication depends on efficient routing of packet that may be difficult in highly-mobile environment. In short, routing and forwarding in VANET(Vehicular Ad-hoc NETwork) poses a unique set of challenges:

1. Frequent change of routing table
2. High network latency
3. Mobile consumer and producer
4. Broadcast storm.

We have discussed various routing protocol proposed in the literature in 3. Many of these routing-protocols are topology based, which means they keep a list of their neighbors. And due to high mobility, the neighbors of a node keeps changing. As a result, the node needs to find new neighbors by issuing control messages to rebuild the table, and this leads to high protocol overhead. Moreover, finding the producer of a data in mobile environment is challenging and time-consuming. Another common approach to forwarding is to use the location of the vehicle. But this approach often resort to broadcasting when there is no location information available. Excessive broadcasting will flood the network with redundant packets and cause broadcast storm that might render the network useless [5].

1.2 Contribution

In this paper, we propose a new forwarding strategy for VANETs called *Content Connectivity and Location-aware Forwarding (CCLF)*. We designed and built the forwarding strategy on top of NDN (Named-Data Network), which is a data-centric network layer protocol. The proposed strategy aims at (1) discarding frequent change of routing table, (2) lower network latency, (3) cope with mobile consumer and producer and (4) reduce broadcast storm by forwarding packets based on both location of the data and vehicle's connectivity. The organization of the thesis is as follows. In Chapter 2, we briefly introduce the Named-Data Network, and how VANET can benefit from this.

Chapter 3 introduces the previous routing or forwarding strategies in the literature. Chapter 4 describes the design and theoretical concepts of the forwarding strategy. In Chapter 5, we discuss the implementation detail of the proposed algorithm. The evaluation and experimentation of the strategy is detailed in Chapter 6. We have also discussed different experiment scenario and result in the chapter. Finally, Chapter 7 summarizes the key point of the thesis.

Chapter 2

Background

2.1 Named Data Networking

Most of the applications in today’s world are data-centric in nature, where a huge amounts of data is produced and consumed by people. Apart from the usual internet applications, there are various IoT devices that produce great amount of data. Named Data Networking (NDN) [2] is a network-layer protocol that is developed to keep up with the recent time’s Internet applications. NDN is one of the most dominant data-centric networks under the umbrella of Information-centric network. NDN aims at retrieving data, in this data-centric Internet, easier by making “data“ the essential element of the network.

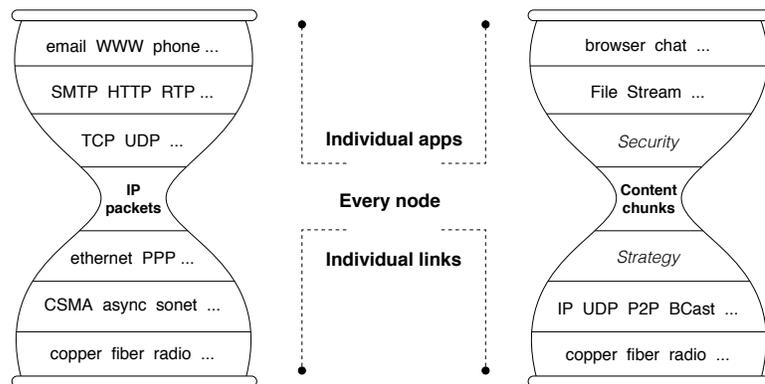


Figure 3. Internet vs. NDN [2]

Figure 3. Source: L. Zhang, A. Afanasyev, J. Burke, V. Jacobson, k. claffy, P. Crowley, C. Papadopoulos,L. Wang, and B. Zhang, “Named Data Networking,”ACM SIGCOMM ComputerCommunication Review (CCR), vol. 44, no. 3, pp. 66–73, Jul 2014.

In IP network, applications have to know the address of the producer to retrieve a content. On the other hand, in NDN, an application does not have to know anything about the producer of the data. Figure 3. shows the differences between NDN and IP network. Application can merely send a request, containing the name of the data, to the network, and the request will be routed to the producer. NDN network introduces two kinds of packets (Figure 4. shows the packet format): Interest and Data packet. The request that is sent by the consumer is called Interest packet, and the returning packet, containing data, is

called Data packet. Interest packet leaves a footprint in every hop; Data packet follows the footprint to find it's way back to the requester. It should be noted that NDN has in-network cache, so if an Interest packet hits a cache on its way to the producer, data will be served from the cache.

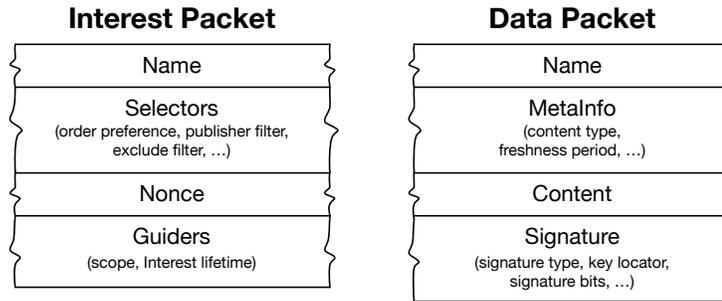


Figure 4. Interest and Data Packet Format [2]

Figure 4. Source: L. Zhang, A. Afanasyev, J. Burke, V. Jacobson, k. claffy, P. Crowley, C. Papadopoulos, L. Wang, and B. Zhang, "Named Data Networking," ACM SIGCOMM Computer Communication Review (CCR), vol. 44, no. 3, pp. 66–73, Jul 2014.

2.2 VANET over NDN

High-mobility makes it very difficult to deploy VANET in IP because of it's host-centric model.

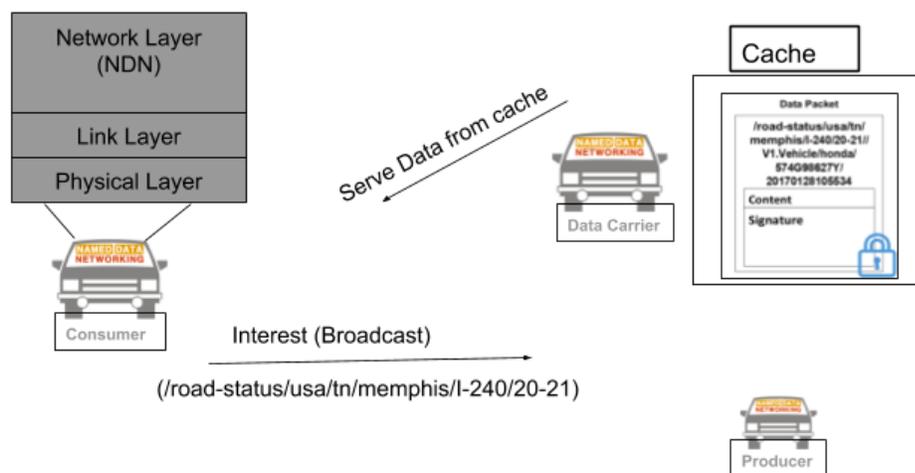


Figure 5. VANET over NDN

A vehicle has to constantly keep track of its ever-changing neighbors. On the other hand, NDN is data-centric, i.e. the consumer does not have to keep track of its neighbors, it can just broadcast the request and network will give it back the data. As long as the name of the data is known, a vehicle can ask for the data. This data-centric approach to communication suits vehicular networking where it is very inefficient and sometimes impossible to keep track of all neighboring nodes. A node in NDN-VANET (Figure 5.) can benefit from NDN's (1) data-centric model, (2) hierarchical naming, (3) pervasive caching, and (4) security.

[6] has shown how NDN facilitates the communication of mobile nodes. The integration of VANET and NDN is explored in [7] and [8]. They have done so by making NDN forwarder [9] aware of geographical information. NDN's hierarchical data naming scheme is also aligned with traffic data. Using NDN name it is very convenient to ask for traffic data. For example, a vehicle can ask for traffic information for interstate I-240 of Memphis, TN, USA using NDN name (Figure 5.). Moreover, hierarchical naming can be used to request data for different granularity, e.g. a particular segment of a road. NDN's built-in security (Figure 3.) makes it very easy to establish trust among vehicular nodes in VANET. Different security benefits of NDN have been discussed in details in [1, 10].

Chapter 3

Related Works

Despite the inherent benefits of NDN in ad-hoc networks, there has been relatively fewer research towards the direction of the design of routing protocol for VANET in the NDN paradigm. Conversely in the traditional TCP/ IP network, a plethora of routing protocols have made its way to VANET from different ad hoc networks, such as MANET (Mobile Ad-hoc NETWORK).

Most VANET-based routing protocols proposed in the literature are table-driven, where tables contain information about neighbors. Some routing protocols, such as OLSR [11], DSDV [12], WRP [13], FSR [14], STAR [15], proactively build and update the table by periodically requesting information from neighbors. While others, such as LAR [16], ZRP [17] do it reactively, i.e. find the route on-demand by sending route probing messages. Reactive protocols are more appropriate for VANET environment because topology is unstable. However, in terms of how fast the the topology changes, VANET is much different than other ad hoc networks. Consequently routing protocols for traditional ad hoc networks might not be applicable for VANET. The design of VANET routing protocols can not solely rely on the status of the link to find a route. It should also take other information, such as speed, location, or direction of the vehicle, into consideration. GPSR (Greedy Perimeter Stateless Routing Protocol) [18] is the first routing protocol that has accommodated the position of a mobile node to routing decision. In this scheme, a vehicle greedily chooses next hop if the latter is closer to the destination than the former. If the forwarding vehicle itself is the closest to destination (local maximum), then GPSR switches to face routing, where it forwards packet using the right hand rule. Later on, many other VANET routing protocols were proposed which, in addition to vehicle-position, utilizes various vehicular and traffic information to route packets. Directional Greedy Routing (DGR) [19] by Gong et al. considers the moving direction of vehicles.

VNDN [8] and NAVIGO [7] are the earliest works that propose routing/ forwarding solutions for VANET over NDN. Both of the work forwards packets based on the geographic location. VNDN [8] calculates a timer based on previous hop, whereas Navigo [7] takes forwarding decision based on the destination location of the data producer. Lin et al. [20] employed vehicular density, vehicular transmission range and velocity variance information in forwarding decision. Another approach is to make forwarding decision based on the number of hops and TTL ([21], [22]). In vehicular network environment often broadcasting is the most efficient way of disseminating information. But broadcasting blindly can cause broadcast storm, which can result to packet loss due to channel saturation. There has been many works that try to mitigate the effect of broadcast by controlled broadcasting. In [23], authors tried to curb the broadcast storm problem by limiting the number of re-transmissions.

Chapter 4

CCLF Design Overview

One of the challenges in designing a forwarding strategy in VANET environment is to cope with mobility of the Data producer. An Interest packet needs to be forwarded toward the geographical location of the Data producer. However, purely location-based forwarding might not be effective in some cases, as it does not consider the connectivity of the forwarding node. For example, Interest forwarded by a poorly-connected node has less probability of reaching the producer. Moreover, it just contributes to increase the overhead of the network. CCLF strategy allows a vehicle to consider both connectivity and location information while making forwarding decisions. Location information is used to direct an Interest toward the location of the data producer, while connectivity information is used to give priority to the well-connected nodes. To quantify the connectivity of a node, we propose a centrality scheme, called Content-Connectivity centrality. A node in a neighborhood is elected as central node and selected, according to the scheme, for forwarding. The details of centrality score and location score are given below.

4.1 Centrality-Location Tree

We use a data structure called Centrality-Location (C-L) Tree (Figure 6.), which is an augmentation of the NameTree structure of NFD [4], to store the centrality score and location information of each name-prefix. The tree structure enables us to store information for each prefix. Each node of the tree holds a name prefix along with the corresponding centrality score (CS) (discussed in 4.2) and location information (discussed in 4.3). CCLF strategy looks up the tree to make forwarding decision of an Interest packet.

4.2 Centrality Score

In Content-Connectivity centrality scheme, the centrality score (CS) of a node is calculated using the Interest satisfaction ratio of the node. Higher the ratio, higher the centrality score, and higher the probability of that node to forward. There is a similar

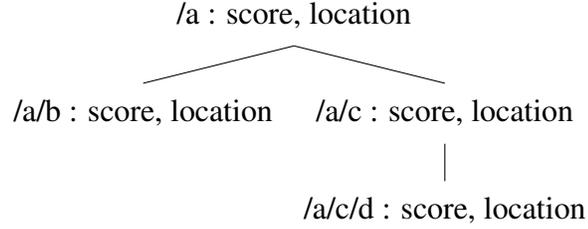


Figure 6. An example C-L Tree [3]

Figure 6. Source: M. Chowdhury, J. A. Khan, and L. Wang, “Smart forwarding in ndn vanet,” in Proceedings of the 6th ACM Conference on Information-Centric Networking. ACM, 2019, pp. 153–154.

work [24] that also proposes a centrality scheme based on the Interest satisfaction ratio. However, the work calculates centrality score of a node based on the total satisfied Interest of the node. On the other hand, our proposed Content-Centrality calculates score of a node for each name-prefixes. It means a node can have different score for different prefix. A node having higher score for a name-prefix indicates that the node is well-connected to the producer serving data under that prefix. So, a node can have different scores for different prefixes depending on their connectivity to various data producers.

The CS of a name prefix is calculated using the total Interests and Data packets forwarded for this prefix and its descendent (see Equation (4.1)). Figure 6. shows an example C-L tree where the CS of the prefix /a is calculated using the accumulated Interest and Data count of its descendants: /a/b, /a/c, and /a/c/d. CS quantifies the connectivity of a vehicle for the name prefix - the more data it can fetch for that name prefix, the higher the score, and our algorithm will give a higher priority for this vehicle to forward Interests under the name prefix.

$$CS_{prefix_j} = \frac{D_{prefix_j} + \sum_{i \in Descendent_T(j)} D_{prefix_i}}{I_{prefix_j} + \sum_{i \in Descendent_T(j)} I_{prefix_i}}, \quad (4.1)$$

where

D_{prefix_j}	Data count for prefix j
I_{prefix_j}	Interest count for prefix j
$Descendent_T(j)$	Descendent of prefix j

We discussed earlier(2) that each piece of Data in NDN has hierarchical name prefix, and a producer produces data under a certain name prefix. When responding with a data packet, producer attaches the name prefix under which it is producing the data to the packet. Upon receiving the packet, a node in the C-L tree is created if the name prefix is not already there, and the corresponding CS is updated. We use the weighted average instead of the instantaneous value of the CS (Equation (4.2)) in forwarding.

$$\widehat{CS}_{N+1} = \alpha \cdot \widehat{CS}_N + \beta \cdot CS_{N+1} \quad (4.2)$$

$$\alpha + \beta = 1$$

When a vehicle receives a data packet, it updates the Interest and Data count for the corresponding name prefix and its ancestor prefixes. It also recalculates the CS values periodically based on Equation 4.1 and 4.2.

4.3 Location Score

Considering geo-location information for forwarding packet in mobile ad-hoc network, particularly in vehicular ad-hoc network, is very popular due to its efficacy. Consequently, we are also including the geo-location information to make forwarding decision. Similar to many other routing protocols, we are adopting an approach similar to GPSR [18]: nodes geologically closer to the destination node is given priority in forwarding. Like CS , location information is also per-name-prefix, and NameTree is used to hold it. Producer attaches its own location in the Data packet before sending. All the nodes receiving the packet update the location of the C-L tree node corresponding to the name prefix of the Data.

The location information is used to calculate the location score (LS)

(Equation (4.3)).

$$LS_{prefix_j} = 1 - \frac{Dist_{me}}{\max(Dist_{me}, Dist_{prev})}, \quad (4.3)$$

where:

LS_{prefix_j}	Location Score of $prefix_j$
$Dist_{me}$	Distance from this vehicle to the destination
$Dist_{prev}$	Distance from the previous vehicle to the destination

4.4 Timer Calculation

The CS and LS is used to calculate $weight$ using Equation 4.4. A $timer$ is calculated from the $weight$ using Equation 4.5.

$$weight_{prefix_j} = \alpha \cdot LS_{prefix_j} + \beta \cdot \widehat{CS}_{prefix_j} \quad (4.4)$$

The vehicle will suspend the forwarding of the Interest till a Waiting Timer expires (Equation (4.5)). If it receives the same Interest during this time period, it cancels the forwarding of the interest.

$$timer = \begin{cases} \frac{1}{weight}, & \text{if } weight > 0 \\ 0, & \text{otherwise} \end{cases} \quad (4.5)$$

If the vehicle does not have any information (i.e., $CS = 0$ and $LS = 0$), the $timer$ will be zero and the vehicle will broadcast the Interest immediately.

4.5 CCLF Strategy Algorithm

CCLF Strategy employs packet suppression to encounter broadcast storm. The workflow of the strategy is shown in Algorithm 1. When a vehicle receives an Interest, the forwarding strategy extracts the location information from the packet. It also retrieves the CS from the C-L tree for the interest name prefix. The Interest packet contains the

location of the previous vehicle and location of the producer Vehicle. The location information is used to calculate LS . The CS and LS of the prefix are then used to calculate the *weight* of the vehicle (Algorithm 2) that in turn is used in Equation 4.5 to calculate the timer. The vehicle will wait *timer* amount of time before forwarding the Interest. If it receives the same Interest before its *timer* expires, it will not forward the scheduled interest and drop the current one.

Algorithm 1: Interest Forwarding Algorithm

Algorithm ForwardInterest (*Interest I*)

```

if  $I$  already scheduled to forward then
    Drop  $I$ ;
    return;
end
 $I_{name} \leftarrow$  GetName ( $I$ );
 $L_{dest}, L_{prev} \leftarrow$  ExtractLocation ( $I$ );
 $CS \leftarrow$  LookUpCS ( $I$ );
if  $L_{dest} \neq null$  then
     $timer =$  CalculateTimer ( $CS, L_{dest}, L_{prev}$ );
else
     $L_{dest} \leftarrow$  LookUpLocation ( $I_{name}$ );
    if  $L_{dest} \neq null$  then
         $timer =$  CalculateTimer ( $CS, L_{dest}, L_{prev}$ );
    else
         $timer =$  CalculateTimer ( $CS, null, null$ );
    end
end
Schedule Forwarding of  $I$  after  $timer$  unit

```

Algorithm 2: Timer Calculation Algorithm

Procedure CalculateTimer (CS, L_{dest}, L_{prev})

```

 $Dist_{prev} \leftarrow$  CalculateDist ( $L_{dest}, L_{prev}$ );
 $Dist_{me} \leftarrow$  CalculateDist ( $L_{dest}, L_{me}$ );
 $Weight \leftarrow \alpha(1 - \frac{Dist_{me}}{Dist_{prev}}) + \beta CS$ ;
Calculate  $timer$  using Equation 4.5;
 $timer \leftarrow$  Randomly choose a value from  $timer/2$  and  $(3 * timer)/2$ ;
return  $timer$ ;

```

Higher LS and CS will make the *weight* larger, consequently the *timer* smaller.

Vehicles closer to the data producer (higher LS) and more successful in fetching data under the name prefix (higher CS) are given priority in forwarding the Interest. To make sure no vehicles having same LS and CS send simultaneously, we choose a random value between $timer/2$ and $(timer * 3)/2$.

4.6 CCLF with Data Suppression

In our preliminary experiment and result, we observed that in some cases protocol overhead is too high for CCLF, due to high number of Data packet. Some of these Data packets can be suppressed without hurting the satisfaction ratio. Therefore, we added a simple data suppression algorithm to the forwarding strategy. The algorithm will simply wait for some time before forwarding a received Data packet. If it receives the same Data packet again, it will cancel the forwarding of the previous Data packet as well as drop the current one.

Chapter 5

Implementation

5.1 ndn-cxx

ndn-cxx is the C++ library that implements the fundamental functionalities of NDN: constructing and signing a packet, scheduler, management support, data structures, security support etc. The format of NDN packets are also defined and implemented in the library.

5.2 NDN Forwarding Daemon (NFD)

NFD is the forwarding daemon of NDN, whose main job is to forward Interest and Data packets. Different modules (Figure 7.) of NFD are Management module, RIB manager module, Tables, Forwarding, Strategies, Faces.

5.2.1 Face

Interest and Data packets come at and go out of Faces in NFD. Face is a generalization of network interface which can run on top of various communication channels. For example, NFD communicates with a local application using local Face that uses inter-process communication channel in the background. The job of NFD is to move packets from one Face to another Face.

Face has two submodules: LinkService and Transport (Figure 8.). Transport is the lower part of the face and responsible for abstracting the underlying communication functionalities. LinkService gets the packet as TLV block from Transport and converts them into Network Layer packet (Interest, Data, or Nack). Afterwards, LinkService passes the network-layer packet to Forwarding module.

5.2.2 Forwarding Module

Forwarding module implements the basic packet processing with aid of Faces, Tables and Strategies. Most important submodule of Forwarding module is Strategy that provides a framework to support various forwarding strategies for various applications. Strategy submodule in the Forwarding module makes decision about forwarding of an

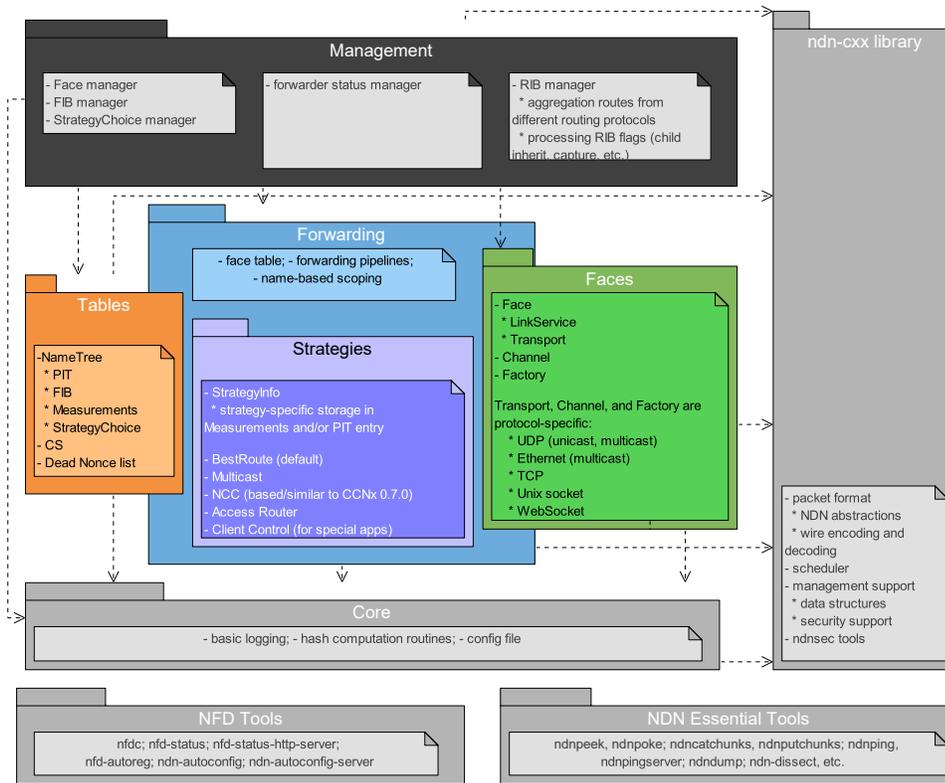


Figure 7. Overview of NFD modules [4]

Figure 7. Source: A. Afanasyev, J. Shi, B. Zhang, L. Zhang, I. Moiseenko, Y. Yu, W. Shang, Y. Huang, J. P. Abraham, S. DiBenedetto, et al., "Nfd developer's guide," Dept. Comput. Sci., Univ. California, Los Angeles, Los Angeles, CA, USA, Tech. Rep. NDN-0021, 2014

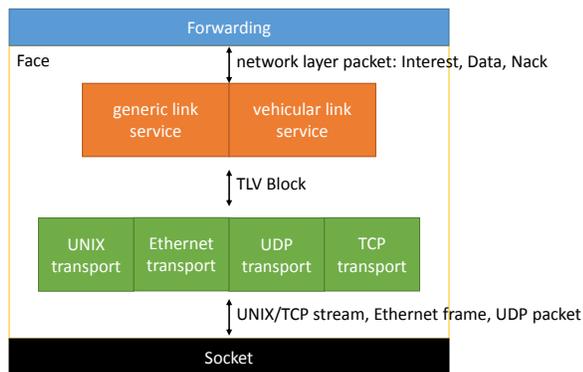


Figure 8. NFD Face [4]

Figure 8. Source: A. Afanasyev, J. Shi, B. Zhang, L. Zhang, I. Moiseenko, Y. Yu, W. Shang, Y. Huang, J. P. Abraham, S. DiBenedetto, et al., "Nfd developer's guide," Dept. Comput. Sci., Univ. California, Los Angeles, Los Angeles, CA, USA, Tech. Rep. NDN-0021, 2014

Interest packet, e.g. when to forward, which face to forward etc. When Forwarding module receives an Interest (9.), if the interest does not violate */localhost*, is not looped, and does not hit a Data in CS, then it will be dispatched to Strategy.

5.3 CCLF Implementation

We have introduced a Vehicular Link Service sub-system in NFD by extending Generic Link Service, the default link service in NFD. Like Generic Link Service, Vehicular Link Service uses NDN Link Protocol (NDNLP) [25]. NDNLP packet, known as LpPacket, is encoded to and decoded from the network layer packets, Interest, Data, and Nack.

We have added a header in LpPacket; the header consists of two fields: Previous Hop Location and Data Destination Location. Each moving node will attach its current location as Previous hop location before sending Interest. On the other hand, the producer of a piece of data will attach its location as Data Destination Location while sending data. These two fields will aid the forwarder take forwarding decision. The headers will be encoded and decoded by the Vehicular Link Service. Vehicular Link Service provides a uniform interface between forwarding and underlying location services by encoding and decoding the Location header.

The Strategy is implemented as a new Strategy module in NFD. We also modified the Interest and Data forwarding pipeline (Figure 12.) to make it comply with the logic of our CCLF strategy.

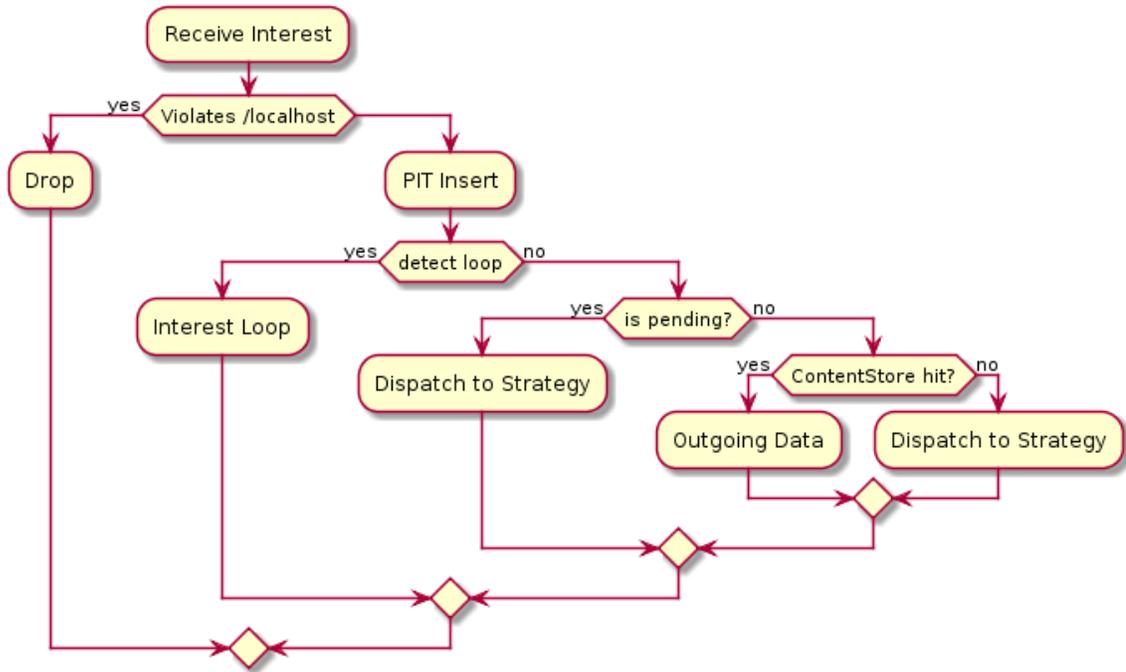


Figure 9. Interest Forwarding Pipeline

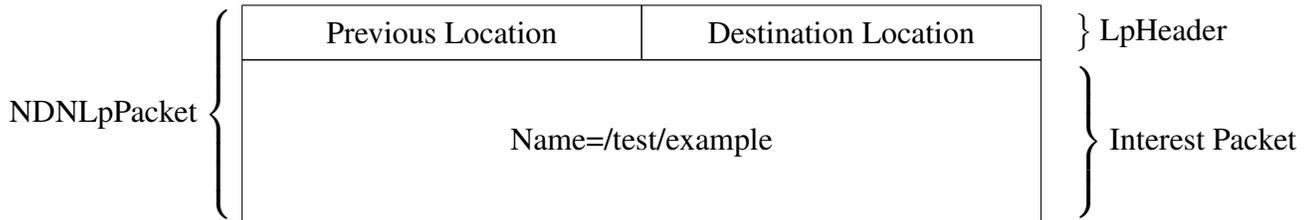


Figure 10. Interest Packet Format

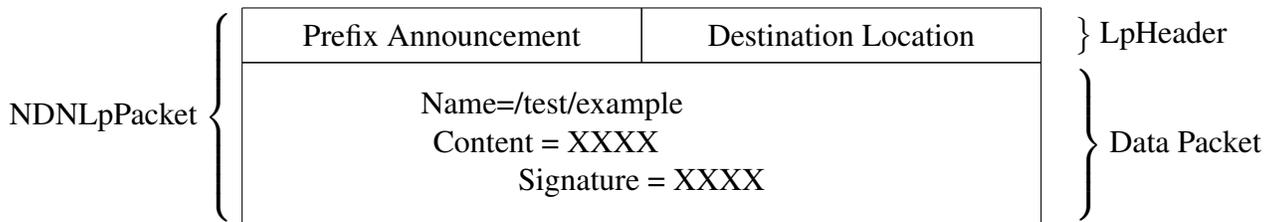


Figure 11. Data Packet Format

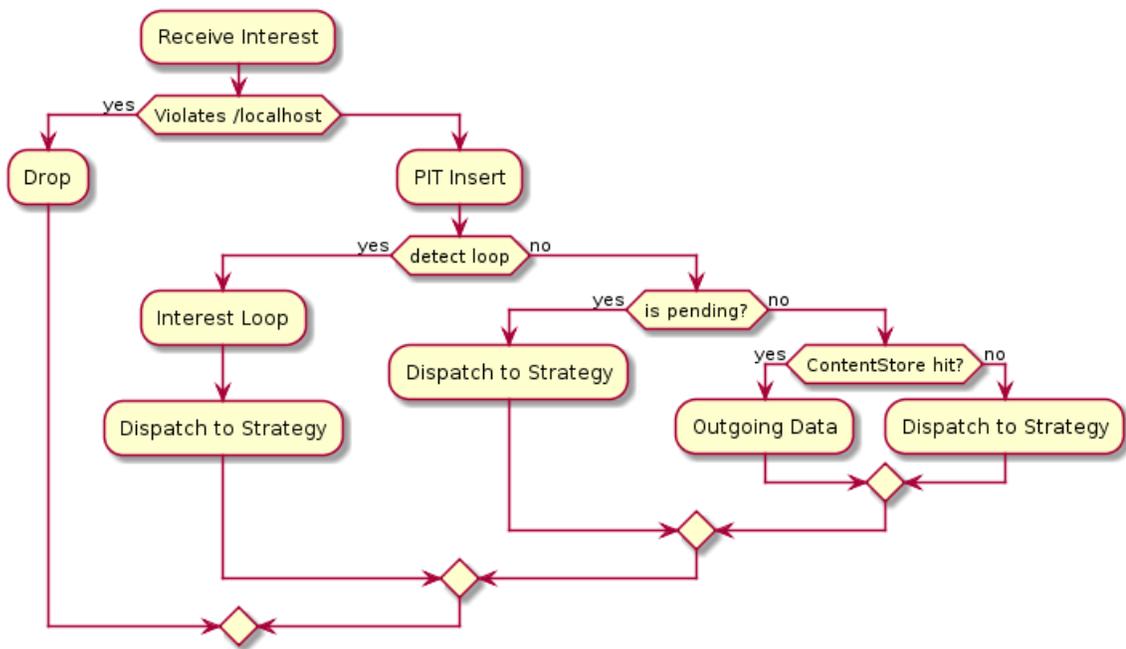


Figure 12. Modified Interest Forwarding Pipeline

Chapter 6

Evaluation

This section will illustrate a comparison between our proposed forwarding strategy and two other commonly used strategy found in the literature, namely broadcasting and VNDN ([8]). Broadcast scheme is devoid of any suppression mechanism and floods the network with packet. We have used the performance of the Broadcast as a benchmark. We have already introduced VNDN in Chapter 3.

To simulate network traffic and to experiment our proposed strategy we used ndnSIM [26]. It is a widely used and open-source NDN simulator that is publicly available for research. It is based on ns-3 [27], which is an open source network simulator. ndnSIM has been implemented as a module of ns-3. The ndnSIM module of ns-3 contains all the necessary components of NDN: NDN Forwarding Daemon (NFD [4]), NDN C++ library (ndn-cxx). Moreover, it also provides several NDN applications, e.g. consumer and producer application, which can be installed on simulated nodes.

6.1 Metrics

The aim of our forwarding strategy is to ensure the successful and timely delivery of data packet by reducing transmission overhead. Therefore we have chosen the following metrics to evaluate our forwarding strategy: transmission overhead, satisfaction ratio, and delay. The definition of the metrics are given below.

Protocol Overhead is the total number of packets send by all the nodes in the network during the experiment time period. If we denote the number of nodes in the experiment as N , then protocol overhead can be expressed by Equation 6.1.

$$\sum_{n=1}^N (I_n + D_n) \quad (6.1)$$

where

D_n Outgoing Data count of node n

I_n Outgoing Interest count of node n

However, we used normalized protocol overhead, which is expressed by Equation 6.2, to present the result of vehicular topology experiment (in Section 6.3.1 and 6.3.2). In the equation, T is the experiment time period in seconds, and IF is the Interest Frequency, i.e Interest packets generated by consumer per second.

$$\frac{\sum_{n=1}^N (I_n + D_n)}{T * N * IF} \quad (6.2)$$

Satisfaction Ratio is the ratio of total Interest packet sent by the consumer and total received Data packet. It measures the strategy's efficiency to fetch a Data packet.

Delay is the difference between the timepoint an Interest packet is sent by the application and the timepoint the corresponding Data packet is received. Delay quantifies the timely Data packet delivery of the strategy.

6.2 Experiment: Static Topology

We believe that our proposed strategy is not limited to only Vehicular ad-hoc network, but rather can be used in any ad-hoc network. Therefore, we have evaluated our forwarding scheme in both static and mobile topology. Before moving to mobile topology, we have run the experiment in 3x3 Grid topology. The distance between the nodes is 30 unit, and the transmission range is 46 unit, so the diagonal nodes are in range. We have used 802.11b WiFi standard with 1Mbps speed. Details of the setting are given in Table 1.

We can see from the results (Figure 13.) that, in static topology CCLF performs better in terms of Protocol Overhead. CCLF almost achieves similar Satisfaction Ratio as the other two strategies, but has less protocol overhead. It should be noted that we have not normalized protocol overhead in this result. The main purpose of the running experiment on static topology is to ensure that our implementation is working as expected.

6.3 Experiment: Mobile(Vehicular) Topology

Since our proposed strategy is for Vehicular Ad-hoc network, we run our strategy in such networking environment. Communication parameter settings are given in Table 2. We have used 802.11p when experimenting with vehicular topology, as this standard is

Table 1. Simulation Parameter Settings for Static Topology

Parameters	Value
Topology	Grid
No. of nodes	9
Experiment duration (secs)	60
Wireless Connectivity	WiFi
Wireless Operating Mode	Adhoc Wifi Mac
Propagation Loss Model	Range Propagation Loss Model
WiFi Transmission Range(m)	46
WiFi Model	802.11b
Propagation Delay Mode	Constant Speed Propagation Delay Model
Bandwidth	1Mbps
No. of Consumer/Producer	1
Data Packet Payload Size (Byte)	1200
Interest frequency	1, 2, 3

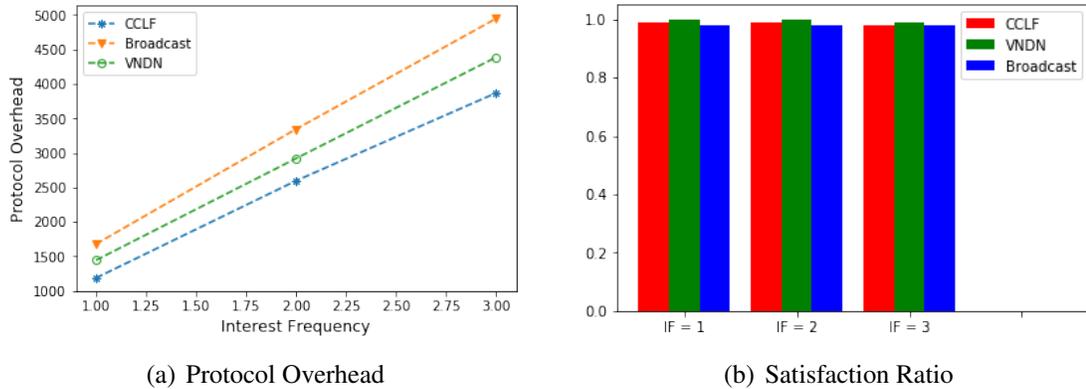


Figure 13. Comparative Analysis of CCLF, VNDN, and Broadcast in Static topology

specifically designed for vehicular communications. Among the vehicles in the network, there will be one consumer and one producer. That is only one vehicle will request for a piece of data, and only another one vehicle will produce that data. Other vehicles in the network will act as a forwarder or data mule.

To generate the road topology and vehicular movement, we used Bonnmotion [28]. Unlike Mobile Ad-hoc Network, where the nodes move randomly, the mobility pattern of nodes in VANET is defined by the road network. For this work, we evaluated the strategy in urban area setting, where the roads are two-lane and vehicles move in a slower speed.

Therefore, we consider a two-lane, straight path as the road network, where vehicles will move from one end of the path to another end. Each lane is 4 meter wide and 1600 meter long, which are representative of a urban area road. The details of the traffic parameters are given in Table 2. Each data point shown in the results is the median of ten runs, and in each run we selected a different consumer-producer pair.

We have evaluated the strategy in two different scenario: (1) vary the number of vehicle in the simulation area, i.e. vary vehicle density, (2) vary the number of requests sent by the consumer every second, i.e. vary interest frequency.

Table 2. Communication Parameter Settings for Vehicular Topology

Parameters	Value
Wireless Connectivity	WiFi
Wireless Operating Mode	Adhoc Wifi Mac
Propagation Loss Model	Range Propagation Loss Model
WiFi Transmission Range	250
WiFi Model	802.11p
Propagation Delay Mode	Constant Speed Propagation Delay Model
Bandwidth	6Mbps
No. of Consumer/Producer	1
Data Packet Payload Size (Byte)	1200

Table 3. Traffic Parameter Settings for Vehicular Topology

Parameters	Value
Mean Speed (m/s)	12
No. of Lane	2
Lane Width	4 meter
Lane Length	1600 meter

6.3.1 Results: Vehicle Density

We have run this set of experiments for 600 seconds and collected result. The goal of this experiment scenario is to evaluate the strategy's performance in various vehicle density that is defined as the number of vehicles per mile per lane. We have chosen

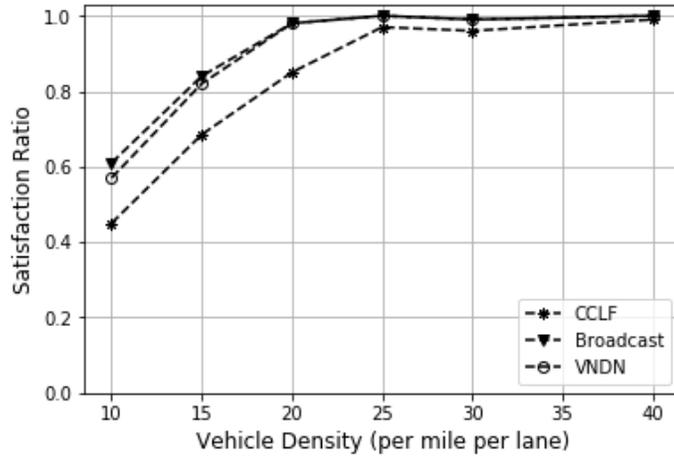
different number of vehicles per mile per lane (Table 4.) based on the traffic flow theory found in the transportation literature.

Table 4. Vehicle Density

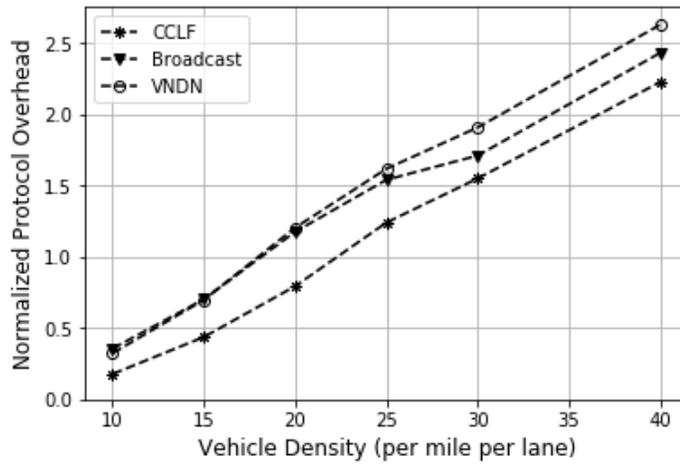
Density	No. of Vehicle/ Mile/ Lane
Sparse	12
Medium	12 - 30
Dense	above 30

We can see from the result (Figure 14.) that in different vehicle densities CCLF performs better in terms of protocol overhead. However, CCLF has smaller satisfaction ratio for the sparse density. It is due to fact that CCLF suppresses Interest and Data packet in order to remedy broadcast storm. As a result, less number of Interest packet reaches the producer, and/or less number of Data packet reaches the consumer. But as the density of the vehicles increases, CCLF can achieve similar satisfaction ratio, but with lower protocol overhead. We do not use RTS/CTS channel access mechanism in the simulation. So, if two vehicles try to send simultaneously, there will be collision. The situation gets aggravated in the dense environment, as the number of vehicles trying to access the WiFi channel increases. This results in the Broadcast strategy to have comparatively lower protocol overhead in the dense environment, because a lot of packets are getting lost due to collision. However, the situation does not lead to lower satisfaction ratio, as there are still enough packets to reach consumer or producer.

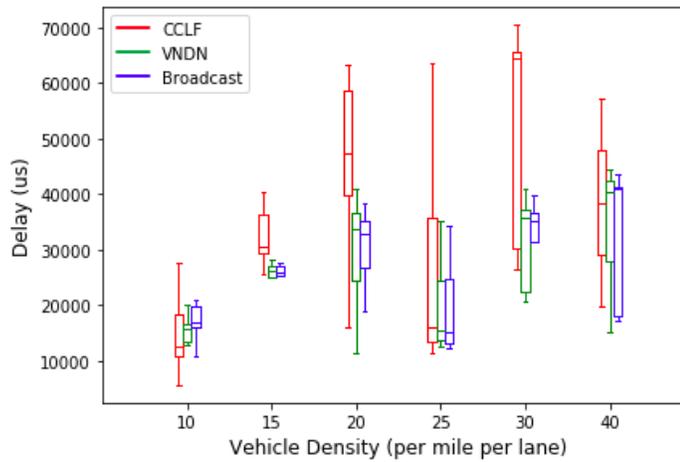
The results also show the end-to-end delay of the strategies. In almost every density, CCLF has high delay. It is because it waits for some time, which is calculated based on distance and centrality of the vehicle, before forwarding. On the other hand, Broadcast has the lowest delay, because it does not wait before forwarding a packet; whenever it receives a packet it will immediately forward it. VNDN also has lower delay, because it also broadcasts a packet when location information is not available. For CCLF,



(a) Satisfaction Ratio



(b) Protocol Overhead



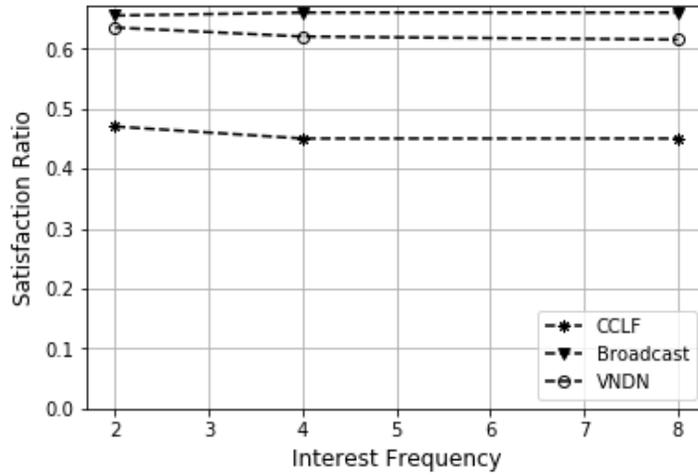
(c) End-to-End Delay

Figure 14. Vary Vehicle Density: Comparative Analysis of CCLF, VNDN, and Broadcast

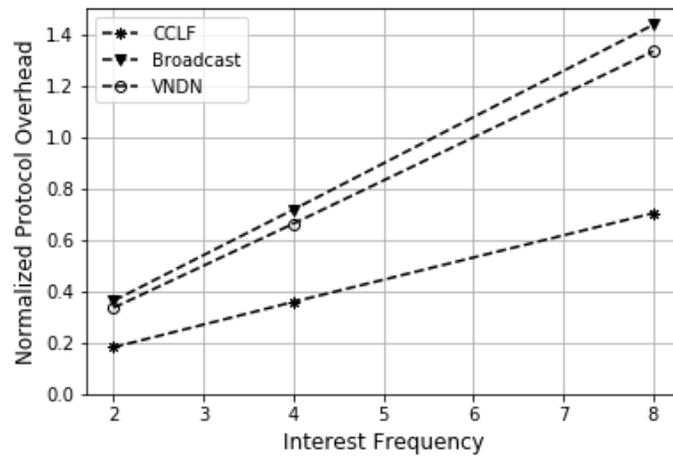
even if the delay is higher, but it is in the range of 20 to 60 milliseconds for various densities that is good for time-sensitive data[29].

6.3.2 Results: Interest Frequency

From the previous (in Section 6.3.2) results, we observe that CCLF does not perform well in the sparse density environment. We want to see the performance of the strategy in sparse density and congested-network scenario. So we increase the number of requests send by the consumer per second, i.e. interest frequency (IF). This experiment scenario was run for 200 seconds and the number of vehicle is 10 per mile per lane.



(a) Satisfaction Ratio



(b) Protocol Overhead

Figure 15. Vary Interest Frequency: Comparative Analysis of CCLF, VNDN, and Broadcast

Even though, with the increasing IF, CCLF has substantially low protocol over, but we don't observe any improvement on the satisfaction ratio. We believe that this situation can be improved by keeping a track of number of neighbors around you. And regulating the intensity of packet suppression based on vehicle density.

Chapter 7

Conclusion

Forwarding strategies in NDN VANET use content location information resulting in high network overhead due to large number of interest flooding. We present a new forwarding strategy, CCLF, where vehicles not only consider location information but also the content connectivity to decide when and where to forward interest, thus reducing interest flooding and overhead in the network. Through experimentation, we have identified some limitations of the strategy, such as, lower satisfaction ratio in the sparse traffic environment. We are currently working on including the vehicle density information in the packet suppression decision. With this change, the strategy will dynamically be able to adjust suppression according to surrounding vehicle density. Our current evaluation is limited to urban area, where vehicles move comparatively slower. Our future works include running experiment in highway scenario: vehicles moving in high-speed and more than two lane road. Eventually, we want to run our experiment in larger topology with real traffic trace.

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