BSMM: A Broadcast Storm Mitigation Model Based On Distributed Data Clusters and Hybrid Network Architecture in Vehicular Named Data Network

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Abstract. Vehicle networks play a key role in intelligent traffic field. Named Data Networks (NDN) which has characteristics of interest packet driving and content caching is suitable for Vehicle networks. After the technology of NDN is used in vehicle networks, Vehicular Named-data Network (VNDN) is constructed. However, the efficiency of communication is affected by the high-speed movement of vehicles and the changing topology of VNDN. In VNDN, vehicles broadcast interest packets to retrieve required data. It is easier to rise broadcast storm because of the broadcast behaviour. In order to deal with this problem, we firstly propose a hierarchical hybrid network architecture which is consisting of vehicle network and infrastructure network. Secondly, we propose a concept of distributed data named cluster based on the hybrid network architecture. Based on the above, a novel broadcast storm mitigation strategy (BSMS) which includes a real-time route update algorithm and a hierarchical routing request algorithm is proposed to relieve the broadcast storm. At the same time, the proposed model based on distributed data named clusters provides a real-time update data request interface for vehicles. The simulation results show that the proposed model BSMM is able to resist the broadcast storm and improve the efficiency of communication among vehicles in VNDN.

1. Introduction
In recent years, with the development of communication technology, Vehicle ad hoc network (VANET) has developed rapidly. As one of wireless mobile ad hoc networks, VANET aims to provide safe and comfortable experience for drivers, and it is also able to improve the efficiency of road-networks. It has the characteristics of distribution, self-organization and decentralization. Therefore, VANET is considered to be the key technology of smart transportation. There are two common communication models in VANET. Vehicle to Vehicle(V2V) and Vehicle to Infrastructure(V2I). In V2V, Vehicles do not rely on any infrastructure for communication. In addition, sometimes vehicles need infrastructure assistance for information exchange or decision-making, which is called V2I.

Named data network (NDN) is a future network architecture, which discards the idea of using IP address to retrieve data in TCP/IP architecture. As a kind of content center network (CCN), NDN routes and forwards packets by the name of the required data. In NDN, there are three communication entities; the communication entity that generates the interest packet is called a consumer. Producer is the entity who satisfies the data of the specific interest packet naming prefix. In addition, interest packets are forwarded by intermediate node according to its naming prefix. In the process of interest packet delivery, each NDN node has three main modules:
• FIB table is used to guide the forwarding of interest packets in combination with forwarding strategy.

• PIT table is used to record the forwarding interface of interest packets. Whenever there is a data packet returned, it returns according to the pit table records.

• Content Store (CS) is used to cache packets that may meet potential needs.

In VNDN, Consumer vehicle node initiates communication by generating interest packets. Because of the high-speed movement of vehicles, it is difficult to establish a stable forwarding path between vehicles. Therefore, in order to retrieve the data back as much as possible, in most cases, vehicles will forward the interest packet to every vehicle in the communication range. When a vehicle receiving a interest packet, it will forward the interest packet to other vehicles within its communication range. When the density of local vehicles is very high, it is very easy to cause a broadcast storm. In addition, due to the rapid change of vehicle topology, some vehicles may not find other vehicle for communication, which makes the satisfaction rate of low vehicle density decreasing rapidly.

By considering the characteristics of NDN paradigm over vehicular networks, Broadcast Storm Mitigation Model (BSMM) model is proposed to reduce the broadcast storm and improve satisfaction. BSMM consists of two parts: hierarchical hybrid network and broadcast storm mitigation strategy (BSMS) based on data named clusters. Hierarchical hybrid network has two layers: hierarchical inter domain infrastructure network and intra domain network. We divide the whole area into domains and each domain has its own infrastructure node which is called local interface node (LIN).

These infrastructure nodes form a network which is called inter domain hierarchical network. In addition, these LINs provide management and services for vehicles running in the domain. The network composed of vehicle and LIN is called intra domain network. Each LIN will periodically collect name of the exchangeable data of each vehicle in the domain and update its local data named cluster. And then, based on these distributed data named clusters, we can build a hierarchical routing network on a hierarchical hybrid network. Finally, BSMS consists of two algorithms: real-time route update algorithm and data request algorithm. A communication interface is provided for each vehicle in each domain. (BSMM) model not only provides stable communication services for the vehicles, but also effectively resist broadcasting behavior.

The rest of the paper is organized as follow: the main contribution regarding the broadcast storm and communication services in VNDN is described in section 2. The causes of the problems in VNDN are shown in Section 3. In section 4, we introduce the architecture and algorithm of BSMM in detail. In addition, section 5 is used to show the simulation results of BSMM and comparative analysis with the control group. Finally, in Section 6, we summarize our research work.

2. RELATED WORK

In recent years, there are several researches on VNDN [1-4]. In this section, we discuss some of the studies which presented in order to tackle the problem of broadcast storm regarding the Interest packets in VNDN.

The method of CUIF is proposed to avoid flooding storm within two fields named GPS and Moving Direction (MD) in interest packet and one field named Location in data packet [6]. In this paper, the receiver of the interest package will decide whether to accept the interest package according to whether the MD field matches their own direction. However, it is meaningless to set the MD field of the interest package unless you know where the data is.

In [9], a method which is called CODIE proposed to controls data and interest forwarding by using one field named hop-count in interest packet and another field named DDL in data packet and PIT table. The hop-count value indicates number of hops. However, the DDL is used to bound the unnecessary data packets, which reduces the number of packets and reduces the satisfaction rate.

In [10], a scheme named CONET is proposed to control the propagation of data packets in VNDN. In this scheme, two fields named hop-counter and time-to-live (TTL) is used to ensure data packets
could not go further than consumer in network. While this scheme only considered the broadcast storm of data packets. It did not consider the broadcast storm of interest packets.

Ahmad Arsalan et al. [12] proposed a method named NSDVN. In this method, intermediate vehicles will calculate the distance using its and sender coordinates. After calculating the distance, it schedules packet according to the threshold of value. That makes the vehicle which is closer to the boundary of transmission range of the forwarder will have smaller counter value. However, the proposed scheme did not consider the scenario, when local vehicle density is very high, broadcast storm is still easy to be triggered.

Muhammad Burhan et al. [13] proposed a scheme in order to tackle the problem of broadcast storm in VNDN. In this scheme, a field of Receiver Timer Counter is used to receive and select interest packets. Those vehicle nodes far away from the sender are considered to be closer to the producer, and their interest packet time count value will be lower than those nodes in the consumer's communication range. In this way, the receiver can accept some interest packets selectively, which reduces the number of interest packets. However, this scheme is not able to deal with the broad storm.

In this paper, we propose the scheme of BSMM provides a clear and stable path for interest packet forwarding to resist the broad storm and improve the efficiency of communication in VNDN.

3. PROBLEM STATEMENT
Due to the high-speed movement of vehicle nodes, there are two main problems in VNDN. First of all, VNDN has a low satisfaction rate of interest packet even when using broadcast. Because the vehicles often move at high speed, it is difficult to construct a stable communication among vehicles. As shown in Figure 1, a vehicle cannot get data back or produce and broadcast new interest packets to other vehicles. There are no other vehicles within the communication range of the gray vehicle node that can establish a connection, which results in that other vehicles cannot receive the interest packets of the gray vehicle and the gray vehicle cannot get the data packets back. Furthermore, VNDN is based on broadcast communication approach where broadcast storm of interest packets is considered as a critical problem in the network. Large number of interest packets with the same naming prefix are repeatedly forwarded, which greatly consumes the network resources, causing network congestion and reducing network performance.

![Fig.1 Low satisfaction rate of interest packets in VNDN](image)

The broadcast storm is illustrated in Figure 2. The gray vehicle broadcasts its own interest packets to all vehicles in its communication range, and then all green vehicles send interest packets with the same name prefix to each other, which lays big burden on the whole network.
4. BROADCAST STORM MITIGATION MODEL

BSMM proposed consists of broadcast storm mitigation strategy (BSMS) and hierarchical hybrid network.

Hierarchical hybrid network is composed of hierarchical inter domain infrastructure network and intra domain network. The intra domain network is shown in Figure 3. When a vehicle drives into or out of a domain, it needs to establish a temporary connection with the local interface node (LIN) to submit a named set of exchangeable data. LIN will update the local data named cluster after receiving the data named set. In addition, LIN also provides communication services. All vehicles driving in the domain can submit interest packets to LIN for data request.

LIN will broadcast HELLO packet regularly to announce data request status. Hello packet will also be used for route information update. The fields of Hello packet are described in Table 1. When a vehicle detects its own vehicle ID in the Hello packet, it needs to establish a temporary connection with LIN. Then the vehicle will upload or download according to the operate field. The status field indicates whether the data request was successful.
TABLE I. THE FIELDS OF HELLO PACKET

| Field    | Description                                      |
|----------|--------------------------------------------------|
| vehicle ID | A string of integers that identify vehicles   |
| Interest ID | A string of integers that identify interest packets |
| operate    | Add, delete, upload or download                 |
| status     | Success, failure, or not ready                  |

The hierarchical inter domain infrastructure network is a tree network as shown in Figure 4. LIN is at the leaf node of the network. All data exchange nodes have parent nodes and child nodes, where N₀ represents the most advanced node. In Figure 4, N₂, parent node of LIN and directly connected to LIN. All these infrastructures provide communication services for the whole driving area.

```
1: ROUTE UPDATE PROCESS
2: Each LIN has its ID number
3: Each infrastructure has its child nodes and parent node ID
4: When LIN receives a data named set or infrastructure receives a 5: Hello packet from child node.
6:   if(LIN receives a data named set)
7:     {
8:        Update local data named cluster and FIB
9:        Generate a hello packet and send it to the parent node
10:    }
11:   if(The packet is not empty)
12:     for(Item in packet)
13:      if(Item->oprate==add)
14:          add Item->prefix, vehicleID in FIB
15:      if(Item->oprate==delete)
16:          delete entry which prefix == Item->prefix in FIB
17:      if(FIB table changed)
18:          if(Current infrastructure has parent node ID)
19:            Send the Hello packet to the interface of parent
20: END PROCEDURE
```

In our model, the forwarding of interest packets with the same named prefix is reduced and the effect of the broadcast storm is mitigated. Based on the distributed data named clusters stored in LINs, we can build a named prefix routing network on the hierarchical inter domain infrastructure network. The route update process is shown in algorithm 1.
When a node receives a non-empty Hello packet, the current node checks all entries in the Hello packet. If the operation field of the current entry is “delete”, the current node queries its FIB table and deletes the prefix of the corresponding entry. If the operate field of the current entry is “add”, the current node adds the named prefix to the FIB and stores the ID of the source interface of the Hello packet. Then, if the current node has a parent node and the FIB table changes, the current node forwards the Hello packet to the parent node. Therefore, whenever any data naming cluster changes, it will update the routing information of the hierarchical inter domain infrastructure network.

Finally, based on the distributed data named cluster, we construct a real-time updated routing network on the hierarchical inter domain infrastructure network and LIN will provide communication service for it. When a vehicle need communicates with others, the vehicle can send an interest packet to LIN and LIN requests data between domains. LIN will regularly broadcast the communication results to inform the vehicle to upload or download data. The details of the communication process are shown in algorithm 2.

When LIN receives an interest packet from the parent node, LIN queries the local data named cluster and informs the vehicle with the corresponding data to upload data. If the interest package comes from a vehicle in the domain, LIN first queries whether the cache hits. If hits the corresponding data is returned. Otherwise, query FIB to whether the corresponding path exists. If there is a corresponding FIB entry, the interest packet will be forwarded to the child node interface; otherwise the interest packet will be forwarded to the parent node interface. If the current node does not have a parent node, no data information will be returned. When the data packet is returned to the LIN, the LIN will inform the vehicle to download the data according to the vehicle ID and interest packet name. In the above process, all the unsatisfied interest packets are forwarded to the parent node, and the parent node has more routing information than the child node. Therefore, each interest packet can be forwarded through a clear path to avoid broadcast behaviour. In addition, any vehicle can find a stable communication interface to request data, which improves the satisfaction rate of interest packets.

```
1:PROCEDURE Routing strategy
2:Each infrastructure has a parent and child interface
3:Each infrastructure will have NDN data cache
4:When LIN receives an interest packet with vehicle ID
5:    if(interest packet comes from the parent node)
6:        Inform the vehicle with corresponding data to upload data
7:    if(Cache Hit)
8:        return data
9:    else
10:       if(FIB table has no data corresponding to prefix)
11:          if(This node has no parent)
12:              return No data
13:          else
14:             Send interest packet to parent node interface
15:          else
16:             Send the interest packet to the child node interface
17:     if(Data request and return results)
18:        Inform vehicle to download data according to vehicle ID
19:END PROCEDUER
```
5. PERFORMANCE EVALUATIONS AND ANALYSIS

In this section, the performance of BSMM proposed model BSMM is evaluated. BSMM is compared with the traditional VNDN implementation [19]. Network Simulator NS-3 along ndnSIM [20, 21] is used to simulate the proposed model as well as comparative scheme in a vehicular network scenario. We used two experimental parameters to verify the performance of BSMM. One is to compare the satisfaction rate in the low vehicle density scenario; the other is to compare the proportion of useless interest packets in the high vehicle density scenario. Furthermore, the hierarchical inter domain infrastructure network topology used in the experiment is shown in Figure 5.

![Fig.5 The hierarchical inter domain infrastructure network topology](image)

We consider common network topology models, such as star network, ring network, tree network. In the simulation experiment, we randomly select 10% of vehicles as consumers and 10% of vehicles as producers. In order to simulate different vehicle densities, we set different numbers of vehicles to move randomly in the driving area. Table 2 shows the remaining simulation parameters.

| Parameters     | Values                          |
|----------------|---------------------------------|
| Vehicle speed  | 0-30m/s                         |
| Mobility Model | Random                          |
| Mac layer      | IEEE 802.11a                    |
| Transmission range | 220m               |
| Communication type | V2V                      |
| Area(m*m)      | 500*500,1000*1000               |
| Number of vehicles | 320,340,360,380,400, 100,150,200,250,300 |
| Simulation time | 30s * 10 each group             |
| Number of LIN  | 31                              |
| Mac layer      | IEEE 802.11a                    |
| Transmission range | 220m               |
| Communication type | V2I                      |
| Replacement Policy | LRU                      |
In order to increase the vehicle density as much as possible, we set the number of vehicles from 320 to 400 in the driving area of 500m * 500m. In this scenario, we calculate the proportion of useless interest packets. In the area of 1000m * 1000m, we set the number of vehicles from 100 to 300 to get the result of satisfaction rate of interest packets. The experimental results are shown in Fig.6 and Fig.7.

![Fig.6 Proportion of useless interest packets](image)

Fig.6 Proportion of useless interest packets

Fig.6 shows the proportion of useless interest packets in the simulation of high vehicle density. It can be realized through simulation results that, proposed BSMM decreases the proportion of useless interest packets in the network. Because BSMM has a real-time updated interest packet forwarding network based on the distributed data naming cluster, which avoids the broadcast behaviour of the vehicle. However, broadcasting is widely used in traditional VNDN. Therefore, BSMM outperforms the traditional VNDN.

![Fig.7 Comparison of satisfaction rate](image)

Fig.7 Comparison of satisfaction rate
Fig. 7 presents the simulation results of satisfaction rate in sparse scenario. It can be realized through simulation results that, although the satisfaction rate of traditional VNDN increases slowly with the increase of the number of vehicles, the satisfaction rate is still very low. However, BSMM can increase the satisfaction rate to about 60%. LINs in BSMM can provide communication service for each vehicle driving in the domain through the local interface instead of broadcasting in the traditional VNDN to improve the satisfaction rate.

6. CONCLUSION

In this work, firstly, we propose a hybrid network structure, which divides the network into intra domain network and hierarchical inter domain network, and LIN provides communication interface for vehicles in the domain. Then, we propose the concept of data named cluster. Based on the data naming clusters, we construct a real-time updated routing network on the infrastructure network and provide communication services for vehicles. Whenever the vehicle enters or leaves the domain, it is necessary to submit the named set of data that it is willing to exchange to LIN. Then LIN will update the local data named cluster and FIB and submit the update information to the parent node. Whenever the parent node receives the update information of a child node, the parent node updates the routing information of the child node and submits the information to the parent node again until the routing information of the whole network is updated. In this way, we provide a clear forwarding path for each interest packet in the network to obtain data packets. LIN provides a communication interface for each vehicle to avoid the broadcast of interest packets and thus alleviate the broadcast storm. In addition, LIN also provides communication support for vehicles in sparse scenarios and improves the satisfaction rate.

In future, we will improve the update strategy of data named cluster to reduce the size of FIB table. In addition, we will try to use LIN to detect and resist early flooding attacks. We hope to find a balance between infrastructure network and vehicle network to reduce costs while improving VNDN performance as much as possible.

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