A Publish/Subscribe Communication Infrastructure for VANET Applications

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***Abstract*— Vehicular Ad-hoc Network (VANET) can be envisaged as the network of moving vehicles communicating in asynchronous and autonomous fashion. Efficient and scalable information dissemination is a major challenge due to the movement of vehicles which causes unpredictable changes in network topology. Publish/Subscribe communication paradigm provides decoupling in time, space and synchronization between communicating entities, making it most suitable for VANET like environments. In this paper, we propose our publish/subscribe framework for information dissemination in VANET. In our approach, we assumed a hybrid VANET consisting of stationary info-stations and moving vehicles where each vehicle can take the role of publisher, subscriber or broker. Every major crossing of city is equipped with stationary info-stations that act as ultimate place holders for publications and subscriptions. These info-stations are assumed to be connected to internet and form Distributed Hash Table (DHT) based broker overlay among themselves. They act as rendezvous point for publications and subscriptions and send matching publications to interested subscribers. Further, these info-stations also provide services for locating any vehicle in the network. Simulation results indicate that our approach performs well with increasing number of vehicles which suggests the applicability of our approach.**

Keywords-component; VANET, DHT, publish/subscribe

I. INTRODUCTION

VANET can be defined as a distributed, self- organizing communication network of moving vehicles and stationary road side info-stations. Vehicles in VANET move along roads and their movement trajectories are controlled unlike the mobile nodes in mobile ad-hoc network (MANET). However, forming a network of these moving vehicles is no less challenging than MANET as they move with different velocity which causes unpredictable changes in the network topology. VANET applications are either safety related or comfort related (commercial). Safety related applications are used by the drivers. Drivers can get information like post crash, obstacle or road condition, speed limit of the road, current traffic condition or weather condition. VANET can also be used to give comfort to passengers. Passengers can get information like the traffic condition or weather condition. Applications such as online games and instant messengers that run on the top of TCP/IP stack can be applied here.

Publish/subscribe [1] has been evolved as the most suitable communication paradigm for building applications where underlying interaction mechanisms are required to be flexible, asynchronous and highly dynamic in nature. The main strength of this paradigm lies in decoupling in time, space and flow between event producers, called publishers and event consumers, called subscribers. Another component, called broker, which acts as a mediator between publishers and subscribers, assists in creating a decoupled environment where publishers and subscribers are unaware about each other and can dynamically leave or join the system.

VANET is a delay tolerant network and asynchrony, anonymity and autonomy are its inherent characteristics. As publish/subscribe communication paradigm provides decoupling in time, space and flow between communicating entities, it is most suitable for VANET like environments. Decoupling in time means the event subscriber and event publisher need not be up at the same time. Decoupling in flow means sending and receiving does not block participants. Decoupling in space means the subscriber can move from one location to another without informing the publisher. Moreover, in VANET the vehicles are mobile and autonomous and it is not possible to establish any central administrative authority, which makes publish/subscribe approach most suitable for such environments.

Recently, some approaches [2][3][4] have been proposed which are using publish/subscribe paradigm for information dissemination in VANET like settings. These approaches have contributed significantly towards understanding the applicability of publish/subscribe over VANET. In these approaches, a hybrid setup is assumed where there are stationary info-stations and moving vehicles communicating in cooperative manner. These info-stations are assumed to be connected to internet for timely information spreading. Vehicles are assumed to be installed with navigation system and GPS (Global Positioning System) and they behave like mobile sensors that collect information about traffic condition, parking situation etc. Then with the help of GPS and navigation system a publish/subscribe middleware is used to disseminate information geographically.

In these approaches, the main goal is to design a P/S middleware for vehicular networks that considers location and time in its design objectives. This middleware enables the application developers to easily publish notification in

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specific location by treating location as context. It takes advantage of the information that can be extracted from the vehicle's navigation systems (location, map, destination of the driver etc) to generate subscriptions. Navigation system decides if a vehicle is interested on receiving a specific notification or not. Proposed system is an opportunistic Publish/Subscribe system.

These approaches treat vehicles as mobile sensors that collect information about traffic conditions, accidents etc. Mobile vehicles transfer this information to the info-station on its way. All the info-stations are directly connected. A centralized system combines the gathered information and generates traffic warnings. Traffic warnings are sent to the nearest info-station and from there they are routed towards the affected road segment by vehicle-to-vehicle communication. Every notification has the notification time and expiration time. After the notification time, notifications are continuously propagated in the network until the expiration time of the notification. Although these approaches are effective, they heavily depend upon GPS, navigation system, digital map of city etc. and they require highly sophisticated vehicles equipped with these devices.

In this paper, we present our publish/subscribe framework for VANET like environments. We also assume a hybrid environment of stationary info-stations and moving vehicles. Unlike previous approaches we do not utilize GPS or navigation systems in our proposal. In our approach, these info-stations connect themselves in a DHT fashion and act as rendezvous points for publications and subscriptions. Further, they also provide services to locate vehicles in network. Each vehicle can take the role of publisher, subscriber or broker and they communicate in cooperative manner to spread publications and subscriptions to info-stations. Notifications are also disseminated to targeted vehicle using vehicle to vehicle communication. We have simulated our approach for synthetic scenarios and initial results suggest the applicability of our approach.

The rest of the paper is organized as follows. Section II gives the system model of our approach. In Section III we define various data structures and procedures used in our approach. Simulation environment and results are provided in Section IV followed by conclusion in Section V.

II. System Model

In our approach, we have assumed a city based scenario where the info-stations are installed at every major positions (e.g important crossings) of the city. These info-stations are connected to internet and act as rendezvous points for publications and subscriptions by forming a DHT structure among them. Fig.1 depicts the DHT based overlay network of these info-stations. These info-stations are also equipped with IEEE 802.11 omni directional antenna and have fixed range. All the vehicles are also equipped with IEEE 802.11 omni directional antenna and they also have fixed range. We have assumed that the info-stations have a range of 100m and vehicles have a range of 50m. Vehicles can send publications/subscriptions to info-stations directly if they are in the range of info-stations. Otherwise, publications and subscriptions are forwarded hop by hop by utilizing other vehicles moving on road. If the network density is high then a vehicle can forward information to another vehicle in its range and information can be carried easily towards the broker. But if the network density is low which generally happens during night then forwarding information from one info-station to another becomes difficult. This variable network density makes VANET a delay tolerant network..

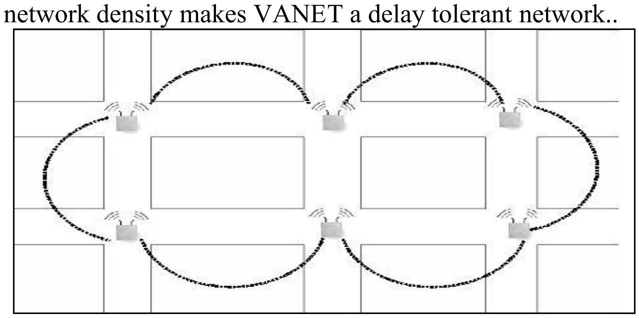

Figure 1. DHT based Overlay of Fixed Brokers.

Info-stations act as ultimate meeting points or brokers for publications and subscriptions and they forward matching publications to interested subscribers. In addition to this, some vehicles can also acquire the role of brokers. As the publications and subscriptions are forwarded to info-stations through moving vehicles on road, if any vehicle receives matching publication and subscription on the way then it can notify the publication to interested subscriber.

Each vehicle and info-station has its identification number. Info-stations form a Chord [5] like DHT structure. Chord technique is utilized to create hashed ids of info-stations to form their logical overlay ring. The published and subscribed messages are also hashed to get hashed content ids. These content ids are termed as keys. Both content and node ids are chosen from same identifier space which is taken big enough to avoid node and content ids mapping to same hash value. This overlay of info-stations is used to form rendezvous points for publication and subscriptions.

A. Chord DHT

In Chord, the identifier space can be viewed as an identifier circle where identifiers are represented from 0 to 2^m-1 where m is the number of bits in the identifier. This is called a chord ring. Each node in the Chord maintains a successor list and finger table. The successor list refers to some number of nodes that follows the node in ring. Finger table is a routing table having maximum of m entries. The i^{th} entry in the table at node n contains the identity of the first node, s, that succeeds n by at least 2^{i-1} on the identifier circle, i.e., $s = successor\ (n + 2^{i-1})$, where $0 < i \leq m$. When any node wants to publish or subscribe, the publication or subscription object is hashed to generate content id. The node uses its successor list and finger table to find the storage point of this publication or subscription in ring. A publication or subscription is stored at the successor node in identifier space, which is found by using the procedure *find_successor( )* of Chord.

III. DATA STRUCTURES AND PROCEDURES

In our approach, each vehicle and info-station can acquire the role of publisher, subscriber or broker dynamically. In this section we present algorithms for publication, subscription, location determination and notification used in our approach. Each vehicle has following data structures to manage publications and subscriptions and to provide location services:

- Subscription-Table: to store active subscriptions
- Publication Table: to store active publications
- Forwarding Table: to store others publication and subscriptions for further forwarding.
- Vehicle id: Identification number of vehicle.
- Last info-station crossed: Identifier of last info-station crossed and the occurrence time of this event.

A. *Information Publishing, Subscribing and Matching*

In our approach, publish primitive is defined as *Publish (publication specification, TTL)* where TTL is the time for which a publication is considered to be active. Subscribe primitive is defined as *Subscribe (subscription specification, subscriber_id, TTL)* where *subscriber_id* is the identification of the vehicle which subscribes and TTL is the time for which a subscription is valid. Fig.2 provides the procedures for publishing and subscribing.

```
Procedure Publish (publication, TTL)
1. Store publication in Publication Table
2. if (publication is active, Check TTL)
3.          if (any vehicle in 1-hop range)
4.           Send publication
5.           else
6.           keep on moving for some time
7.          goto Step2.
8. else (Discard the publication)
Procedure Subscribe (vehicle id, subscription, TTL)
1. Store subscription in Subscription Table
2. if (subscription is active, Check TTL)
3.          if (any vehicle in 1-hop range)
4.          Send subscription
5.          else
6.          keep on moving for some time
7.          goto Step2.
8. else (Discard the subscription)
```

Figure 2. Publication and Subscription

Vehicles willing to publish or subscribe send the publication/subscription to the nearest info station through other vehicles running between itself and the info station. Vehicles forward publication/subscription to its all one hop neighbor in its radio range. Vehicles which are running ahead of the vehicle that is publishing or subscribing in the same direction and the vehicle running in opposite direction carries the publication or subscription and broadcast it again to their one hop neighbor in their ranges. This process continues till the publication or subscription reaches at an info-station. If traffic is dense, then publication/subscription is transferred to info-station with less delay. On the other hand, if there are very few vehicles on road, a substantial delay is experienced in sending publication/subscription to info-station. In this process of hop by hop publication/subscription transfer towards info-stations, it may be possible that some of the vehicles (through which the publication/subscription is getting forwarded) receive matching publications or subscriptions. In this case, in addition to forwarding the publication/subscription they can also act as rendezvous point for publications and subscriptions. Once the publication/subscription reaches at info-station, it is sent to the rendezvous node by utilizing the DHT structure among the info-stations. Fig.3 provides algorithms which outline forwarding and matching processes at moving vehicles.

```
Procedure Forwarder (pub/sub/noti, vehicle id)
1. Store pub/sub/noti in Forwarding Table
2. Call Matcher (pub/sub/noti, vehicle id)
3. if (pub/sub/noti still active, Check TTL)
4.          if (any vehicle in 1-hop range)
5.           forward pub/sub/noti
6.           else
7.           keep on moving for some time
8.          goto Step3.
9. else (Discard pub/sub/noti)

Procedure Matcher (pub/sub/noti, vehicle id)
1. Case: (notification)
2. if (notification for itself)
3. accept
4. else return
5. Case: (subscription)
6. Match with publication table and forwarding table
7. if (match=True) then call Forwarder( ) to notify
8. else return
9. Case: (publication)
10. Match with publication table and forwarding table
11. if (match=True) then call Forwarder( ) to notify
12. else return
```

Figure 3. Publication and Subscription

Each vehicle, after receiving publication, subscription or notification from other vehicles first performs the matching operation with already stored publications and subscriptions in different tables of vehicles. At this instant, each vehicle acquires the role of broker. For example every received publication is first checked with the subscriptions in subscription table and forwarding table. If the received publication matches with any subscription of subscription table then it is accepted as notification by the vehicle receiving publication. If the publication matches with any subscription in forwarding table then the corresponding subscriber is notified by the vehicle itself. If none of the case mentioned above occurs, then the publication is forwarded to other vehicles in one hop range. This process is repeated until matching subscription is found at vehicles on the way or the publication reaches at the nearest info-station.

When a publication or subscription reaches at any info-station it is routed to a rendezvous info-station by utilizing the DHT routing substrate. These info-stations are connected with each other through virtual links provided by underlying transport layer. For ease of implementation we have categorized different publications and subscriptions in to topics or subject. Each publication and subscription specification has topic name associated with itself. This topic name is hashed to find the rendezvous info-station of publications and subscriptions. Consequently, it is guaranteed that publications and subscriptions related to same topics are routed towards one info-station. These publications and subscriptions are matched with each other at rendezvous info-station and corresponding subscribers are notified with the help of vehicles crossing through info-station.

B. *Tracking Vehicle Location*

As vehicles are moving and subscribing simultaneously, the location of vehicles, when the notification at info-station is ready for them and when they have subscribed is different. Vehicles might issue subscription in one region of city while at the time of notification they might be in any other region. In our approach, we have not assumed the GPS enable vehicles. Instead, vehicles and info-station work in cooperative manner for locating vehicles.

Location information of each vehicle is maintained at DHT of info-stations in distributed fashion. Every info-station is responsible for storing the location information for a set of vehicles. Vehicle id is hashed to find out the info-station which stores the location details of vehicle. Each vehicle broadcasts its id and direction at the time of crossing info-station. That info-station hashes the vehicle id to find out which info-station is responsible for location base of vehicle and updates the location information at that info-station. In this way, information of every vehicle is up to date at info-stations.

The info-stations are installed at major crossings of city in our approach. The roads emanating from info-station are marked with direction tags (North, South, East and West) as depicted in Fig.4.

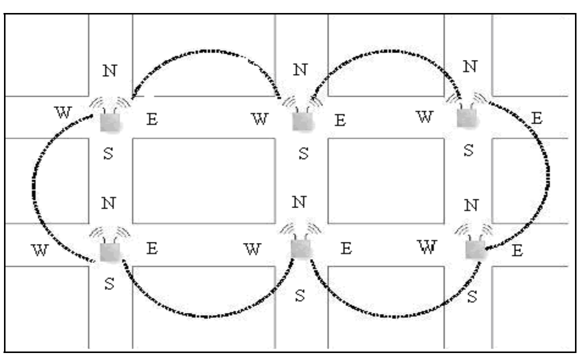

Figure 4. Location and Direction

Vehicles can inform the info-stations that they are coming from which direction of info-station and going to which direction. This information with timestamp is stored at info-station responsible for location base of vehicle. This last info-station crossed and direction information is also stored at vehicles. For example, suppose a notification is ready at an info-station regarding any vehicle. The info-station enquires about the location of vehicle by contacting the info-station maintaining the location base of vehicle. Location base informs about the last info-station crossed by that vehicle and the direction. The notification is forwarded to that last crossed info-stations using underlying DHT routing substrate which uses the direction information to forward the notification by using other vehicles as carriers that are crossing the info-station and moving towards that direction. If the notification is ready at any vehicle (matching publication and subscription meet at vehicles on the way), then the notification is first transferred to nearest info-station which forwards it to target info-station.

IV. SIMULATION ENVIRONMENT AND RESULTS

We have simulated our approach by using Oversim [6] over OMNeT++ [7] and Traffic control Interface (TraCI) client for OMNeT++/MiXiM [8,9] framework. OMNeT++ is an open-source, component-based, discrete event simulation environment coded in C++. OverSim is an open-source simulation framework for peer to peer overlay networks to be used over OMNeT++ simulation environment. The simulator contains several modules for structured p2p systems e.g. Chord, Kademlia and Pastry. We have used its Chord module for simulating DHT infrastructure of info-stations. MiXiM is a communication networks simulation package for OMNeT++ with a focus on wireless networks. TraCI client uses SUMO (Simulation of Urban Mobility)[10] with OMNET++ to simulate vehicle to vehicle communications.

We have simulated a model of a city. Info-stations are installed at fixed distance at every crossing. At an intersection, vehicle can go in three directions. Vehicle can go left, right or straight. We have simulated traffic condition of entire day. In morning and evening time, node density is high (number of vehicles on the road), but in night node density is low. We have calculated the delay in message delivery to interested subscriber in each condition. Each simulation was run for twenty four simulated hours and results are averaged over 10 runs of every simulation. Table.1 provides the simulation parameters used to simulate our idea.

TABLE I. SIMULATION PARAMETERS

Parameter used	**Value of Parameter**
Area	20km ×20km
Number of vehicles	100,500,1000,5000,10,000
Number of Inf0-stations	100
Transmission range of vehicles	100m
Transmission range of Info-stations	200m
Minimum speed of Vehicle	5 km/s
Maximum speed of vehicle	60 km/s

We have selected 25% of vehicles randomly that publish information from a set of predefined topics. Rest 75% of vehicles randomly subscribe for events from the same set of topics. Fig.5 and 6 provide our initial simulation results. In Fig.5 percentage of successful notification delivered is plotted against time elapsed. These results are gathered for 500 and 5000 vehicles in network. It may be noted that when number of vehicles are more (high node density) then delivery ratio is better. On the other hand delivery ratio decreases when the number of vehicles is less (low node density). Fig.5 provides the delay in notification delivery with respect to number of vehicles on network. It may be noted that delay reduces as the number of vehicles moving on roads increase.

These initial results are quite promising and expected. We are currently in process to gather simulation results in more realistic setting for e.g. taking road network of any urban area with actual density of vehicles at different times of day.

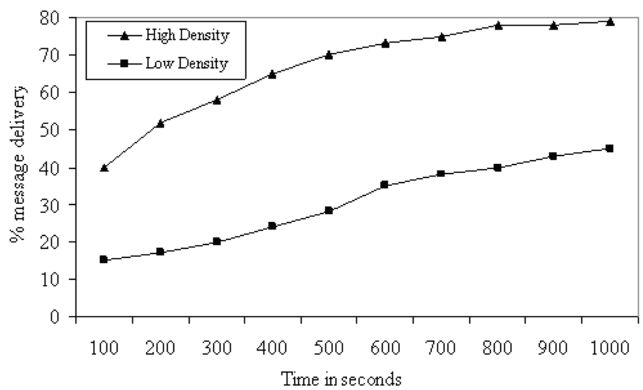

Figure 5. Percentage message delivery

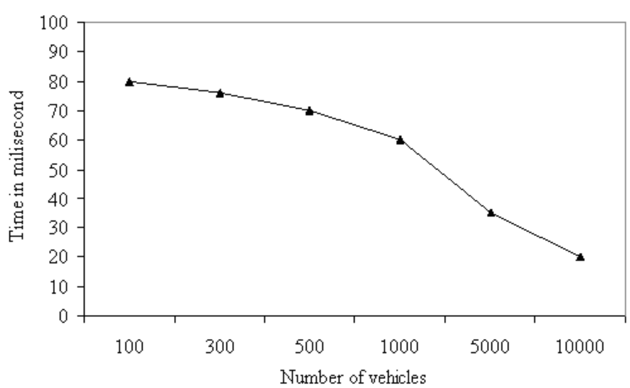

Figure 6. Delay in message delivery

V. CONCLUSION

We have proposed our approach of applying publish/subscribe communication framework for efficient information dissemination among fixed info-stations and moving vehicles. We utilized DHT routing substrate for information dissemination among stationary info-stations. In our approach GPS is not used to locate vehicles on road. Location of vehicles is figured out by info-stations in cooperative manner. Initial simulations results suggest the applicability of our approach.

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