FFRDV: Fastest-Ferry Routing in DTN-enabled Vehicular Ad Hoc Networks

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***Abstract*— Non-real-time communication is the markedness of Vehicular ad hoc Networks (VANETs) because of the rapidly changing topology. A Delay/Disruption Tolerant Network (DTN) is defined as a dynamic network where the contacts among participants of the network are intermittent or link performances are highly unsteady. In such a periodic and disrupted network, Message Ferry (MF) is designed to collect and relay data between disconnected two ends. Our Fastest-Ferry Routing in DTN-enabled VANET (FFRDV) scheme extends MF to the disconnected VANET. Maximum velocity-based routing within the block benefits emergency services. Moreover the selection of single ferry design decreases recourses cost. The effectiveness of the proposed idea are attributed by Network Simulator 2 (ns-2).**

***Index Terms*—Message ferry (MF), vehicular ad hoc network, delay/disruption tolerant network (DTN)**

I. Introduction

Vehicular ad hoc networks (VANETs) are networks in which wireless mobile nodes establish temporarily network connectivity and perform routing functions under self-organization. The goal of VANET research is to develop a vehicular communication system, which enables quick and cost-efficient distribution of data for the benefit of passengers' safety and comfort [1]. However, in real life scenarios, the existence of physical barriers, limited radio range and so on, all prevent nodes from steadily communicating with others and result in network partitions. The fast changing topology results in periodic, intermittent, and disrupted network. Problems like: long disconnections, shifted delays, and high error rates cause barriers in implementation of common ad hoc routing protocols such as AODV [2] and DSR [3]. All these issues invite for vigorous research in Delay/Disruption Tolerant Network (DTN) and Bundle Protocols [4]. DTN plays an important role in the harsh communication environments, such as natural disaster, battlefields, or accidents areas. When connections are established opportunistically, it usually accompanies varied end to end delay. In such occasions, the ability to communicate, even at low transmit rates, is highly valuable for sharing emergent information.

In DTN-enabled wireless networks, nodes might be temporarily unreliable and disconnections may be long-standing. Several techniques in DTN enabled-MANETs have been developed, which contribute to the study of VANET. Aiming to successful transmission, epidemic routing was early recommended, in which the intermediate nodes forwarded data to all the potential neighbors without predicting the link or path forwarding probability. According the early epidemic protocol in [5], the periodic pair-wise connectivity is designed to distribute messages in ad hoc networks. Each host is equipped with a buffer to implement a store-and-forward strategy. Similarly, flooding routing [6] owns the brute force to propagate queries and hits across the network. After receiving queries and hits messages, every reachable node broadcasts them blindly. Although the above schemes can provide high message delivery ratio, the overall cost is high due to exponentially increasing buffer size. To decrease the cost, some conditional epidemic routings have been proposed in the literatures. For instance, Distance-Aware Epidemic Routing (DAER) in [7] offers a geographic routing, in which the maximum numbers of traveling hops and duplications of a bundle are restricted. The bundles are transmitted following greedy distance forwarding, which computes the distance between one node's current position and destination. That scheme is superior in lower average resource consumption to deliver a bundle, compared with the ordinary epidemic routing. However, in the realistic vehicular ad hoc network, the delay is simultaneously influenced by mobile node's route and velocity vector. Obviously, two locations' distance is not always equal to real route and the velocity also can't be ignored.

In this paper, our key contribution is to propose a novel unicast routing scheme for vehicular ad hoc network, where partitions usually occur due to dynamic topology. Our method inlets message ferrying technique to VANET and selects message ferries according to a velocity-based strategy. We call this scheme Fastest-Ferry Routing in DTN-enable VANET (FFRDV). In our scheme, the message has a limited number of destinations, such as traffic management bureau, rescue headquarter, etc. The roads are divided into logical blocks of certain units. Initially, the first vehicle which senses event becomes the initial ferry. Afterward, the initial ferry compares the velocities of neighbors' within one block, and chooses the fastest vehicle as the next ferry. The selection is performed, repeatedly block by block, until the bundles reach their destination. Simulation results show that our maximum velocity-based geographic routing achieve better in successful delivery rates in DTN-enabled VANETs.

The rest of this paper is organized as follows. Section II describes related work. In section III, we present the routing design of our fastest-ferry routing in DTN-enable VANET (FFRDV). In Section IV, evaluation results are revealed through simulation in ns-2. At last, we discuss the current conclusions and extend to explore the future work, section V.

II. Related Work

VANETs protocols are designed to enhance the transmission quality, reduce the amount of data drops, and decrease the overhead in ([8], [9], [10]). Distributed Vehicular Broadcast (DV-CAST) protocol in [8], uses 1-hop neighbor information to make routing decision, with the purpose of ensuring maximum reachability of broadcast message. The work in [10] extends clustering technique, which can enable one vehicle in opposite lane to perform data dissemination, aiming to cut the total cost of the dissemination time. In vehicle-heading based routing of [9], vehicles are classified into four different groups according to the velocity vectors. Route update messages exchange the destination address, next hop address, routing metric and sequence number among neighbor nodes. With those information, the system can predict a possible breakage of a route when the connection is set up between two vehicles from two different groups, resulting in reduction of the number of packet drops and achievement of higher throughput. Although it's not a Delay/Disruption Tolerant Network scheme, the velocity vector-oriented design motivates our work.

Existing routing protocols work powerlessly in VANETs when the disconnections and long delays often occur. Calling for delay/disruption tolerant schemes encourages the development of DTN. [11] provided a survey of latest development of delay/disruption tolerant mobile ad hoc networks, where message ferrying, multicast support, inter-region routing and transport layer issues are listed. Compared with reactive epidemic routings, Message Ferries (MFs) offer more proactive paradigms. In such schemes, network devices are labeled as message ferries or regular nodes based on their roles in communication in sparse mobile ad hoc networks. MFs go through the communication areas and carry data between regular nodes. The schemes can be classified into two types depending on the nodes trajectories which are designed for better communication. In [12], the Node-Initiated MF (NIMF) scheme, the ferry moves according the specific route and the nodes take proactively movement to meet up with the ferry. In Ferry-Initiated Message Ferrying (FIMF) scheme, the ferry takes proactive movement to chase nodes for communication purposes, where ferry is assumed moving faster than nodes.

For wireless ad hoc networks, MF provides an active strategy which assures good performance without requiring any online collaboration between the nodes and the ferry. Some recent work has been made in developing network protocols suitable for vehicular ad hoc networks. In DTN-enabled VANET, Kitani et al. [13] use the buses to collect traffic information from cars in their proximity and periodically disseminate the collected information to neighboring cars. They choose buses as message ferries mainly because the buses have regular routes. This scheme improves the efficiency up to 50%. Definitely, the performance is restricted heavily by the working periods and routines of the buses. Moreover, the intervals at each stop cannot be ignored, which also influences totally delay. In this paper, we try to overcome the above restrictions. In our scheme, the ferry can be any vehicle once it owns superiority in speed. The velocity-based geographic routing shows better performance (e.g. end-to-end delay) than others.

III. FFRDV Fastest-Ferry Routing

In this section, we first present the background of mobility model and then propose a novel DTN-enabled VANET routing protocol. We also analytical model and analyze our scheme for various performance matrices in message forwarding.

A. *Mobility Models and Assumptions*

The research evaluation mainly relies on simulation when a real world testbed is not available. As a result, mobility models are important for vehicular ad hoc network study. For velocity comparison scheme, we select the GIS-based Microscopic Mobility Model (Geographic Information System) [14]. Based on two behaviors, car-following and traffic light, the microscopic mobility models can be classified into three sub-mobility models: entity model, car-following model, car-following with traffic lights model.

In the first mobility model, entity model, there is no car following and no traffic lights are assumed [14]. Entity-based micro-mobility model, vehicle speed is imposed only by the speed limit of the current road ignoring any other vehicles in the proximity. If the current travel speed is below the speed limit, the vehicle smoothly accelerates until it reaches the maximal allowed speed. If it enters a road with a lower speed limit than its current speed, the vehicle smoothly decelerates. Such a model is easy to implement, but fails to reproduce realistic traffic effects like traffic congestion or long queues in front of traffic lights.

While car-following mobility model contains car following only and doesn't contain traffic lights. It is used to describe the traffic behavior on a single-lane under both free-flow and congested traffic condition in traffic management. The car-following mobility model assumes that each following vehicle keeps an inter-vehicle space from the leading vehicle. And each driver in a following vehicle is an active and predictable control element. The simulation of car-following depends on the current speed, the desired speed and on the distance to the front vehicle.

In the third place, the car-following model with traffic lights extends the behavior of vehicles at intersections. The foremost vehicle on each road checks if the intersection at the end of the road is free to pass. If the intersection is free, no additional action is performed and the vehicle acceleration is calculated. In the case the traffic light regulating access to the intersection is on red, the foremost vehicle decelerates and stops in front of the traffic light. A red traffic light is modeled as a vehicle with zero speed at the position of the traffic light. Other vehicles queue up behind the first vehicle until the traffic light switches to green and all vehicles start again to accelerate. Currently, no information is available from the GIS data to determine which traffic rules apply or if there is a traffic light.

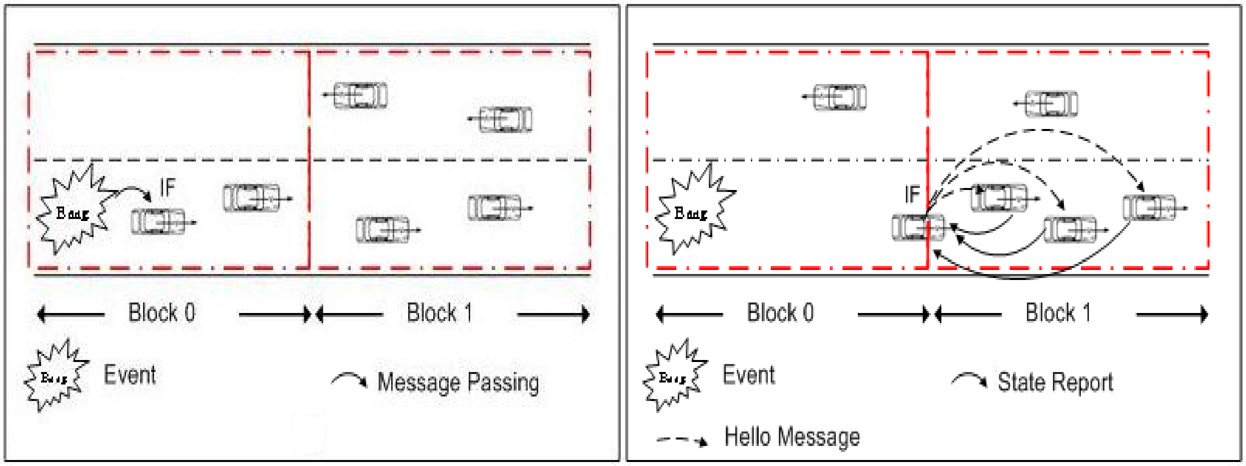

Fig. 1. (a) Mobile node sensing one urgent event becomes the initial ferry. (b) Ferry broadcasts hello messages upon entering into a new block.

In sparse ad hoc networks, such as Highway scenario, vehicles steadily keep running at high speeds with few traffic lights. When emergent events should be imminently reported to cop with unpleasant situations, our maximum velocity-based routing scheme has significant and obvious superiority over other counterparts. In the later simulation section, we select the GIS-based car-following mobility model.

B. The Proposed Scheme

In this section, we present the fastest-ferry scheme for DTN-enable vehicle ad hoc network. Our research is pertaining to highway road environment. We assume that each vehicle can get its current location information by Global Positioning System (GPS). Based on the geographic information, i.e. x-axis and y-axis coordinates, the road is divided into logical blocks, shown in Figure 1(a). The velocity of vehicles are compared within one block. At the initialization of the network communication, every vehicle create one state-report, which include the current position and velocity. And the state report is updated periodically. The node (vehicle) is called message ferry only when it's carrying data. Once the bundles are forwarded and acknowledged, the ferry will discard the data and change to be normal mobile node. Within one block, the priority of vehicle selection is decided by maximum velocity. In our scenario, each vehicle in the network is assumed to be equipped uniformly, therefore every vehicle has equal opportunity to become a ferry.

The following steps describe, in details, that how a ferry is selected and message is transferred in our proposed scheme. We divided our scheme into two phases: the Ferry Selection Phase and the Message Forwarding Phase.

1) *The Ferry Selection Phase*:
-When urgent event occurs, the event sources is sensed by nearby vehicles based upon request/response mechanism. The first responding vehicle becomes the initial ferry (IF) and is responsible for choosing next ferry, shown in Figure 1(a). Differently, IF chooses the next ferry basing on speed-priority.

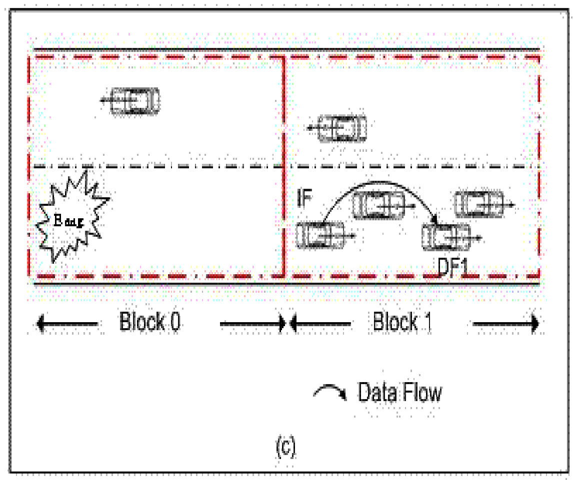

Fig. 2. The initial delivers data to the first dynamic ferry (DF_1).

- Once IF enters a new block, it broadcasts hello message and ask for state reports among neighbors within this block. Afterwards, any nodes that are able to accept new bundles send back current location S_i, a timer t_i, and its current speed v_i, as depicted in Figure 1(b). IF has a waiting period: time-to-live (TTL). Within TTL, IF compares the speed values, and choose the fastest vehicle k. If the $v_k > v_{IF}$, IF uses Eq. 1 to predict the node k's location and forward the bundles, as it's described in Figure2. S_{NF} is the location of new ferry. After receiving acknowledge from node k, IF discards the data. If there is no vehicle offers $v_k > v_{IF}$, IF holds the data until next block and repeats the same selection.

$$S_{NF} = S_i + v_i(t - t_i) \quad (1)$$

- The vehicle holding data is called ferry. In our proposed scheme, it is called dynamic ferry (DF), because the ferry varies with the changeable blocks. Figure 2 shows the generation of DF_1. Through the same procedure, DF_i selects DF_{i+1}. If DF_i can't get the faster vehicle or the faster ones are not available, it keeps data until it finds a new superior one in velocity vector.

- The message is forwarded on the current road until it reaches an intersection. When DF reaches crossing, the data transmission direction is varied for shortest path. Because our protocol is designed for unicast application, the distances between crossings and the destination can be calculated basing on the geographic information. If the next intersection along the same road is nearer to the destination than the current one, the data will be relayed along same direction. Otherwise, the data transmission direction is changed for shorter path. The current DF chooses the next DF in the new transmission direction.

2) *The Message Forwarding Phase*

High data delivery rate can be achieved through the careful selection procedure of ferry in the algorithm of our routing. The velocity-based scheme results in minimum number of ferries, which contributes to lower delay and high bundle transmission rate. The total end-to-end delay comes from the processing time (T_p) and transmission time (T_t), as shown in Eq. 2. DF is selected for the smallest sum of T_p and T_t among k mobile nodes within one block, as shown in Eq. 3. The total delay T_d equals to the sum of N_p packets' delay which are transferred through N times delay of each packet. Eq. 3 offers average packet loss rate.

$$T_d = \sum_{1}^{N} \sum_{1}^{N_p} min_{i=1}^{k} T_p^i, T_t^i \quad (2)$$

$$avgLR = \frac{1}{N} \sum_{p=1}^{N} \frac{N_{p_{arrived}}}{N_{p_{sent}}} \quad (3)$$

We are going to find out that what will be the minimum number of ferry required to route the data from source destination and the expected number of successful transmission of packets. It is considered that the ferry source $0,\ 1, 2, 3, \cdots, N-1,\ N$ can be regarded as source, intermediate ferries, and final destination, respectively. We want to find out the expected number of fastest ferry required for communicated with final destination. Our scheme is based on the minimum number of fastest ferries N to communicate from source do destination, as shown in Eq. 4:

$$N = Min\{l : \sum_{j=1}^{l} X_j = -1 \ or \ \sum_{j=1}^{l} X_j = n-i\} \quad (4)$$

Every fastest ferry is deemed to successfully receive and transmit the packet to the fastest ferry in the next block or final destination. The total expected number of successful transmission in the fastest ferry can be shown in Eq. 5.

$$E[\sum_{j=1}^{N} X_j] = (2p-1)E[N] \quad (5)$$

Here $E[N]$ denotes the expected number of fastest ferry and $E[\sum_{j=1}^{N} X_j]$ represents the expected number successful transmission from source to destination. The parameter p presents the successful receiving and forwarding rate of each packet or fragment, while q=1-p is the failure probability at each fastest ferry. The successful routed packets number depends upon the geometric probabilistic distribution at each fastest ferry.

$$E[N] = \frac{1}{(2p-1)} + \frac{n(1-(\frac{q}{p})^i)}{1-(\frac{q}{p})^n} \quad (6)$$

Finally, Eq. 6 represents the expected number of fastest ferries, from source to destination. Analysis result indicates selection among speed superior vehicles contributes to get minimum number of ferries, which reduces the possibility of data loss and transmission delay (T_d) . The above prove follows Wald's Equation [15].

IV. Performance Evaluation

In this section we will describe the performance evaluation of our proposed scheme. NS-2.31 [16] was used to evaluate our protocol. The simulation environment is set on a 1500×1500 meters area. The average velocity of vehicles in GIS-based car-following Model (Geographic Information System) [14] is set to 60km/h. The radio model is 2.4 GHz for IEEE 802.11b. Network traffic is generated as follows: for light load 100 packets are generated, and for heavy load 500 packets are generated. The packet size is 256KB and the transmission range is set to 250m for all cases. Simulation endures 1000 seconds. The simulation is compared with the Distance-Aware Epidemic Routing (DAER)[7],which is a DTN network protocol that is designed for vehicular ad hoc network. In the DAER scheme, the bundles are forwarded under greedy distance routing. The bundles are discarded following the antidiffusion replacement.

Fig. 3 shows the simulation results of delivery ratio both under light load and heavy load traffic conditions. In Figure 3(a), at the beginning, FFRDV performs slightly lower than the DAER. The reason is that IF is not chosen by velocity comparison. And it needs a period to show superiority after fastest vehicles are used. Results indicate the proposed routing shows better delivery ratio when the delay over 400sec. In the case of heavy load (Figure 3(b).), more messages are delivered to the destinations in our scheme as compared with DAER scheme. The main reason behind this is that, in DAER, the message is forwarded based on the epidemic routing where messages in buffer are replaced by new bundles. While in our scheme the bundles are kept with ferry until a better DF is selected. Above are the preliminary results showing the superiority of FFRDV over the previously scheme in terms of data delivery ratio.

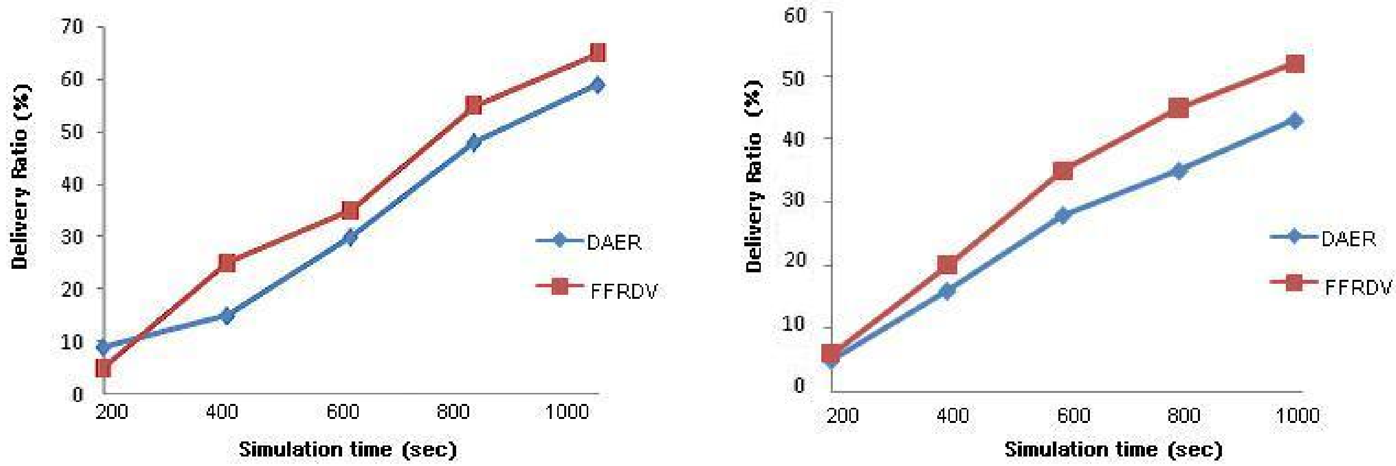

Fig. 3. (a) Delivery ratio under light load traffic.(b) Delivery ratio under heavy load traffic.

V. CONCLUSION AND FUTURE WORK

In this paper, a novel Delay/Disrupted Tolerant Network routing scheme using Message Ferry technique is proposed for vehicular ad hoc networks. We use geographic information to divide road into blocks, and control the block size to ensure 1-hop communication between vehicles. Speed selection is designed for minimum number of ferries and fast packet delivery.Simulation results from ns-2.31 show that the proposed scheme has advantages over contrast. However, more comprehensive simulation study needs to be conducted to confirm the superiorities of this protocol, such as end-to-end delay. Different comparisons with other DTN protocols are also needed, to promote the performance of the proposed scheme.

VI. ACKNOWLEDGMENT

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