Routing Protocols for Vehicular Ad Hoc Networks in Rural Areas

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***Abstract*- Research on vehicular ad hoc networks (VANETs) has focused mainly on efficient routing protocol design under conditions where there are relatively large numbers of closely spaced vehicles. These routing protocols are designed principally for urban areas with high node density, fully connected networks, and are not suitable for packet delivery in a sparse, partially connected VANET. In this paper, we examine the challenges of VANETs in sparse network conditions, review alternatives including epidemic routing and propose a Border node Based Routing (BBR) protocol for partially connected VANETs. The BBR protocol can tolerate network partition due to low node density and high node mobility. The performance of epidemic routing and BBR are evaluated with a Geographic and Traffic Information (GTI) based mobility model that captures typical highway conditions. The simulation results show that under rural network conditions, a limited flooding protocol such as BBR performs well and offers the advantage of not relying on a location service required by other protocols proposed for VANETs.**

I. Introduction

Vehicle communication networks are designed to provide drivers with real-time information through vehicle to vehicle or vehicle to infrastructure communications. Vehicle communication methods often rely upon the creation of autonomous, self-organizing wireless communication networks, or vehicle ad hoc networks (VANETs) designed to connect vehicles with fixed infrastructure and with each other. Research projects such as COMCAR [1] and DRIVE [2] have examined how vehicles in a network communicate with each other or with the external networks, such as the Internet through the use of communication infrastructure such as wireless cellular networks. Other projects, including FleetNet [3] and NoW (Network on Wheels) [4] have explored ad hoc network techniques.

Recent improvements in mobile ad hoc network (MANET) technology and ever-increasing safety requirements as well as consumer interest in Internet access have made VANETs an important research topic. Vehicle to vehicle and vehicle to roadside communications have become important components of vehicle infrastructure integration. Most of the VANET research has focused on urban and suburban roadway conditions, where the numbers of vehicles are large, the inter-vehicle spacing is small, terrain is not a significant factor, and fixed communication infrastructure is available. In rural and sparse areas, the conditions and constraints are significantly different. Node densities are low, inter-vehicle spacing can be large, terrain effects may be significant, and there is very little or no fixed communication infrastructure available. The coverage provided by wireless carriers is predominantly in urban areas and along major highways, not in rural areas and minor roadways. Although position awareness, based on GPS and other techniques, has becoming widespread in portable and vehicular systems, lack of infrastructure and terrain effects limit its availability and utility in rural areas. While public safety and other applications rely or benefit from position awareness, making this a requirement for routing places an unnecessary constrain on system design.

VANETs have particularly important applications in sparse and rural areas because of the lack of fixed communication infrastructure. VANETs in sparse areas can be characterized as partially connected MANETs with low node density and high node mobility. Routing algorithms appropriate for these circumstances have been less explored and the design of such a routing protocol is challenging.

In this paper, we examine a range of VANET routing protocols and describe their main areas of application and the associated limitations. We also explore a simple epidemic routing approach that does not rely on end-to-end connectivity. We then propose a Border node Based Routing (BBR) protocol for partially connected VANETs that has some of the attributes of an epidemic protocol, but offers performance comparable to more conventional protocols under fully-connected network conditions. We apply a Geographic and Traffic Information based mobility model (GTI mobility model) [5] designed to model the movement of mobile nodes under typical highway constraints to explore the effectiveness of simplified epidemic routing in sparse conditions.

The remainder of the paper is organized as follows: Section II discusses related research work on routing protocol design as applied to VANETS and highlights work associated to rural areas and sparse networks. Section III presents the application of an idealized epidemic routing protocol to a rural area. In Section IV we present the BBR protocol and describe its key features. Section V provides simulation results of BBR and makes comparisons with epidemic routing under similar condtions. The conclusions are drawn in the final section.

II. ROUTING PROTOCOLS FOR VANETS

The design of efficient routing protocols for VANETs is challenging due to the high node mobility and the movement constraints of mobile modes. VANETs, as one category of Inter-Vehicle Communication (IVC) networks, are characterized by rapid topology changes and frequent fragmentation. Conventional topology-based routing schemes are not suitable for VANETs. Reactive routing schemes will fail to discover a complete path due to frequent network partition and proactive routing protocols will be overwhelmed by the rapid topology changes and even fail to converge during the routing information exchange stage.

Position-based routing schemes generally require additional node physical position information during the routing decision process. A location service is needed as well to provide the position information of nodes. Generally, location service is provided based on position information derived using GPS or other positioning systems. Broadcast and geocast protocols that make use of GPS information to improve the broadcast performance in IVC networks were proposed in [6], and [6] also makes explicit use of message caching under sparse network conditions where nodes are sometimes disconnected to improve the delivery success ratio.

Considerable work has been done using position–based routing for VANETs in the FleetNet and Network on Wheels projects. These efforts have included the development and evaluation of roadway mobility models and position-based routing techniques and comparisons with topology-based protocols including DSR and AODV [7]. The results generally show excellent performance for position-based routing (e.g., high packet delivery ratio and low latency) relative to other protocols, but have been applied primarily to high node density conditions. Some work has been reported that addresses non-ideal wireless propagation, but does not include specific terrain effects [7].

A multicast protocol for inter vehicle geocast by defining a restricted broadcast group using GPS information was studied in [8]. Other inter-vehicle communication schemes using GPS information include [9]-[10]. In [9], a zone-of-relevance is defined based on the distance from a receiving node to a source node. Intelligent opportunistic forwarding decisions using velocity information obtained through a GPS system are explored in [10].

In [11], optimal hop selection in VANETs on highway was analyzed to maximize the expected route lifetime. There are also other routing schemes exploit direction information of moving nodes or relative speed information among moving nodes to facilitate routing decision. These routing schemes and approaches are focused on the fully connected VANETs and not appropriate for sparse, partially connected networks.

From another point of view, the general rule for information delivery in partially connected MANETs is to relay messages hop by hop, not necessarily continuously, but at discrete time intervals as links become available. A partially connected ad hoc network that uses the generalized message relay approach is sometimes called a Delay Tolerant Mobile Network (DTMN). Examples of store-and-forward message relay approach include message ferrying approach and message relay approach. In these approaches, special mobile nodes called as “message ferries” or “data mules” are used as relayed nodes. The relayed nodes facilitate packet delivery by either repeatedly moving around a deployment area according to known routes or proactively modifying their trajectories to minimize the transmission delay. These approaches are mobility-assisted and proactive in nature. However, it is not always the case that non-randomness in the movement of nodes can be exploited to help data delivery. Sometimes no mobile nodes can serve as “message ferries” or “message mules”, and there is generally no repetition in the individual node’s trajectory.

Epidemic routing was introduced as an alternative approach for partially connected ad hoc networks [12]. In that routing algorithm, random pair-wise exchanges of messages occur among proximate mobile nodes. The movement inherent in the nodes themselves is exploited to help deliver the data when a network is partially connected. The epidemic algorithm is flooding-based, and it trades system bandwidth and node buffer space for the eventual delivery of a message.

To control flooding or save system bandwidth and node buffer space, different flooding control schemes have been proposed. However, these control schemes all assume that nodes have some prior knowledge or history information about other nodes. Probabilistic metrics such as “delivery predictability” and “utility function” were proposed to select the better next step candidates in a forwarding decision or for buffer space control. However, the above mentioned flooding control schemes are not readily applicable for partially connected VANETs. The low node density, combined with the difficulty of obtaining the information used in the routing determinations limits the effectiveness of these schemes. Furthermore, the assumption that nodes will have GPS-based location information is an additional constraint and there may not be repetition in node trajectories as needed in some of the approaches. Terrain effects in mountainous areas make GPS-based location awareness problematic.

III. EPIDEMIC ROUTING IN SPARSE NETWORKS

VANETS in sparse and rural areas can be characterized as partially connected with low node density and high mobility. With the motivation to design a routing protocol that is appropriate under these conditions, we carried out a simulation study to evaluate the performance of an ideal routing protocol, which is briefly described in the following paragraph. The ideal routing protocol is similar to the epidemic routing protocol, which was originally proposed in [12] for partially connected ad hoc networks. There are two reasons to choose the ideal routing protocol. First, using an ideal routing protocol we can better investigate the connectivity characteristics of the underlying mobile ad hoc network. Second, it provides some insights into the design of a practical routing protocol that might be more effective for a partially connected ad hoc network.

A. The ideal routing protocol

For purposes of simplification, the ideal routing protocol uses ideal message exchange rules:

1) Message hand offs occur when moving nodes are within radio range

2) Information exchange is instantaneous when two modes are within radio range

And we also make the following assumptions:

1) No message processing time in each individual node

2) Nodes keep the message when they move on

3) Number of vehicles in the network during the simulation period is constant

4) Simulation ends once the message reaches the destination

5) Nodes move in accordance with predefined trajectories

B. Simulation environment

We apply this routing protocol to a rural example based on the roadways of Yellowstone National Park (YNP) (see Figure 1) and use the geographic and traffic information-based (GTI) mobility model described in [5]. The simulation scenario is designed as follows: A source node or *Event node*, which represents a node that has an accident or has some local incident information, is located at the cross point of West Thumb of YNP. This node generates data traffic and sends this data to the destination node or *End node*, representing the Information Center located at the West Entrance of YNP. The ideal routing protocol is used for the information delivery. The explored questions are: Can the event information be transmitted from the *Event node* to the *End node* through the mobile ad hoc network? If the message can be successfully delivered, the *Transit time* (T_{trans}) that it takes to transmit a message from the *Event node* to the *End node* will be calculated. Based on the geographic and traffic data obtained from the park administration office, a scenario with an average traffic load (the total number of mobile nodes inside YNP is 1400) has been studied; Table 1 summarizes the general simulation parameters.

TABLE 1:SIMULATION PARAMETERS

Parameters	Value
Total simulation time	2 hours
Total number of nodes	1400
Approximate total physical road length after linearization	194.36 miles
Average distance between neighboring vehicles	223.4 meters
Transmission range	100~500 meters
Movement speed	12.1~14.7 m/s

C. Simulation Results

The GTI mobility model introduces randomness to the initial node distribution, node speed and direction chosen, and trajectories generated with each use of the model are different even with the same initial configuration parameters. With the parameters indicated in Table 1, trajectories for all mobiles nodes are generated for 15 trials and the transit times are calculated. Table 2 summarizes the simulation results.

TABLE 2: SIMULATION RESULTS

Radio range (R) (m)	Transit time (T_{trans})		
	Avg (s)	Max (s)	Standard deviation (s)
100	5463.0	7077.3	1103.7
200	4968.2	6692.0	847.3
300	0	0	0
>=400	0	0	0

The simulation results show that during average traffic load hours, when the radio range is less than 200 meters, the mobile ad hoc network is partially connected. At this radio range, which is less than the average distance between neighboring vehicles, the delivery of the message is mainly dependent upon the movement of the mobile nodes themselves, instead of forwarding by the intermediate nodes hop by hop. The average transit time of about 5000 seconds is close to the time for a vehicle to move from the position of the *Event node* to the position of the *End node*.

While epidemic routing and similar protocols are effective in achieving packet delivery under sparse conditions, there are numerous drawbacks. First, nodes must store messages requiring buffer space. Message exchange overhead can become significant as the network size increases. Several techniques have been developed to mitigate these effects, including coin-based, counter-based and blind message deletion schemes [13]. Methods that limit flooding and that use information about neighbors (e.g., lists or position) tend to be more efficient, as described below.

IV. BORDER NODE BASED ROUTING (BBR) PROTOCOL

We briefly describe a Border node Based Routing (BBR) protocol for partially connected VANETs that considers the characteristics of partially connected VANETs while at the same time takes into account the limitations of existing routing approaches for partially connected ad hoc networks [14]. The BBR protocol is mainly based on broadcast and applies the store-and-forward approach used in epidemic routing. Instead of simply flooding the network, a flooding control scheme is explored by using one-hop neighbor information only. The BBR protocol is specifically designed to accommodate for the effects of node mobility on data delivery.

The BBR protocol is designed for sending messages from any node to any other node (unicast) or from one node to all other nodes (broadcast). The general design goals are to optimize the broadcast behavior for low node density and high mobility networks and to deliver messages with high reliability while minimizing delivery delay.

The BBR protocol has two basic functional units: a neighbor discovery algorithm, and a border node selection algorithm. The neighbor discovery process is responsible for collection of current one-hop neighbor information. As in most proactive topology-based protocols, this step requires periodic beaconing of "hello" messages. The border node selection process is responsible for selection of the right candidate/candidates for packet forwarding based on the one-hop neighbor information collected in the neighbor discovery process.

The protocol design is based on the following assumptions. First, no node location information is available. Second, the only communication paths available are via the ad-hoc network itself. There is no other communication infrastructure. Third, node power is not a limiting factor for the design. Fourth, communications are message oriented. Real time communication traffic is not supported.

The BBR neighbor discovery algorithm is similar to the neighbor discovery protocol (NDP) proposed in the Zone Routing Protocol (ZRP) [15]. The NDP in the ZRP is MAC-level based and a periodic Hello beacon is sent out by the node MAC layer to advertise its existence. The BBR neighbor discovery algorithm is a network layer-level based NDP. The Hello message is sent out by network layer. The advantage of using a network layer based NDP is that all routing functions are accomplished in the network layer, without consideration of the specific MAC layer technology used.

In the BBR protocol, border nodes are selected per broadcast event. A border node is defined as a node which has the responsibility of saving received broadcast packet/packets and forwarding the packet/packets when appropriate. The BBR protocol uses a distributed border node selection algorithm. The decision whether a node is a border node or not for a particular broadcast event is made independently by an individual node based on its one-hop neighbor information and the received broadcast information.

For a specific broadcast, an ideal candidate to forward a packet would be node/nodes that is/are located at the edge of the radio transmission range of a source node. The border node is selected based only on one-hop neighbor information using a minimum common neighbor concept. The minimum common neighbor approach uses a protocol whereby nodes share nearest neighbor lists, and through a distributed procedure, determine which node/nodes share the least number of common neighbors. The node/nodes that satisfy this condition are typically furthest from the forwarding node. An alternative approach, most number of uncommon neighbors, was also examined and gave similar results. Position-based protocols, in contrast, use location information to select the neighbor node that is closest to the destination. The net effect is equivalent, but BBR does not require a location service.

V. Simulations And Results

The BBR protocol was implemented in OPNET™ Modeler and the results are averaged over 15 runs with different random number seeds. The results are illustrated in the figures by the mean and the error bars indicating the standard deviation. Protocol performance was measured using standard metrics including packet delivery ratio and delay.

Table 3 summarizes the basic parameter values used in the simulations. The nodes are initially uniformly placed within the simulation area. For the initial stationary distribution, the average distance among neighboring nodes which is noted as L_{av}, can be approximated by assuming these nodes are completely uniformly distributed in the simulation area. For this simulation area configuration, L_{av} = 171.4 meters.

A parameter α is defined as the ratio between the radio transmission range R and L_{av}, and characterizes the degree of network connectivity. For $\alpha < 1$, the nodes are on average separated by more than the radio range, and the network is disconnected. For $\alpha > 1$, the average node separation is less than the radio range, and the network becomes gradually connected.

Table 3. Simulation Parameters

Network simulator	OPNET™ Modeler	
Simulation area	$1000 \times 1000 m^2$	
Number of nodes	50	
Mobility model	Random waypoint	
Node speed	Uniform(0, 20) m/s	
MAC protocol	IEEE 802.11b	
Data rate	2Mbps	
Data traffic	Packet inter- arrival time	Uniform(1,3) s
	Packet size	Exponential Average:1024bits
BBR configurable parameters	HelloInterval	2 s
	MaxHelloLoss	2 times
	MaxRebroadcast	3 attempts
	TranDelaySlot	3 ms

B. Simulation Results

1) BBR performance as a function of radio transmission range. This set of simulations evaluates the routing protocol performance as a function of radio range. The radio range was varied from 8 meters to 800 meters. The vertical dotted line in Figures 2 and 3 indicate the point where the radio transmission range equals the average neighbor separation distance L_{av}.

Figure 2 shows that as the radio transmission range increases, the packet delivery ratio initially increases rapidly. After the radio transmission range reaches about 80 m, the packet delivery ratio remains constant at about 90% and then gradually reaches 99%. BBR can achieve a relatively high percentage delivery ratio even when the network is partially connected. The increased sizes of the error bars for radio range greater than 300m are due to fewer runs used in the simulations, and the apparent dip in delivery ratio between

300m and 600m is an artifact of the dimensions of the simulation area.

Figure 3 shows that average delay decreases rapidly when R increases. When R is larger than L_{av}, the delay is very short. The long delivery delay at small radio ranges is expected due to the fact that the network is highly partitioned at those radio ranges. Packet delivery under this condition is mainly dependent upon nodes carrying packets forward instead of using wireless communication among nodes. The network gradually becomes connected as R increases and exceeds L_{av}. In a more connected network, packets are delivered mainly through wireless communication among nodes, which significantly shortens the delay time. With BBR a relatively high and constant packet delivery ratio can be achieved for both fully connected and partially connected conditions. However, a high packet delivery ratio is achieved with a much longer packet delivery delay when the network is partially connected or highly partitioned.

VI. Conclusions

In this paper, routing protocols for VANETS have been reviewed with particular consideration of their application to sparse conditions as would occur in rural areas. Considerable research has shown that position-based protocols perform well in dense VANETs, little attention has been directed to rural VANETS, where low node densities and terrain effects are significant factors. Protocols that do not require a location service may be beneficial in these situations and a simple epidemic routing approach is shown to be effective, but suffers from the disadvantages of flooding as the node density increases. A BBR protocol was proposed for partially connected VANETs. Using OPNET™, the performance of the BBR protocol has been evaluated and the simulation results indicate that BBR performs well for networks with frequent partitioning and rapid topology changes. High packet delivery ratios can be achieved with long packet delivery delays when the network is highly partitioned. The BBR protocol yields a better performance when the network is partially connected and demonstrates comparable performance to reactive protocols when the network is fully connected. This new protocol is well suited for vehicle-to-vehicle communications along sparsely used highways, as would be the case in rural and remote areas.

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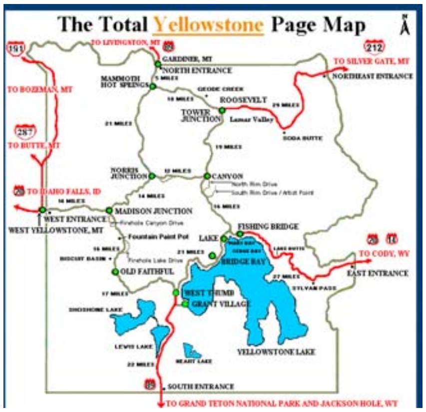

Figure 1. Geographic information of YNP

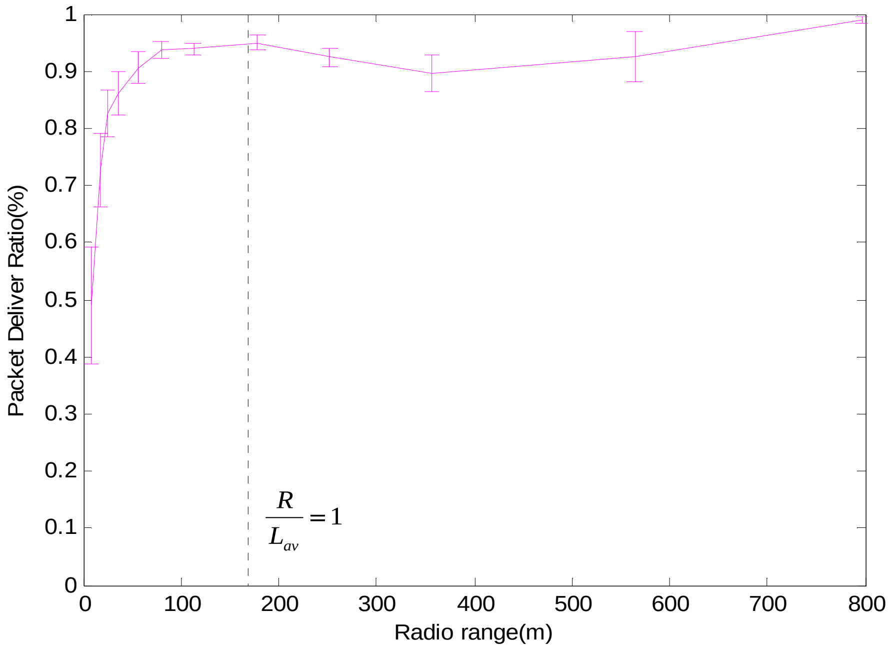

Figure 2. Packet delivery ratio vs. radio transmission range.

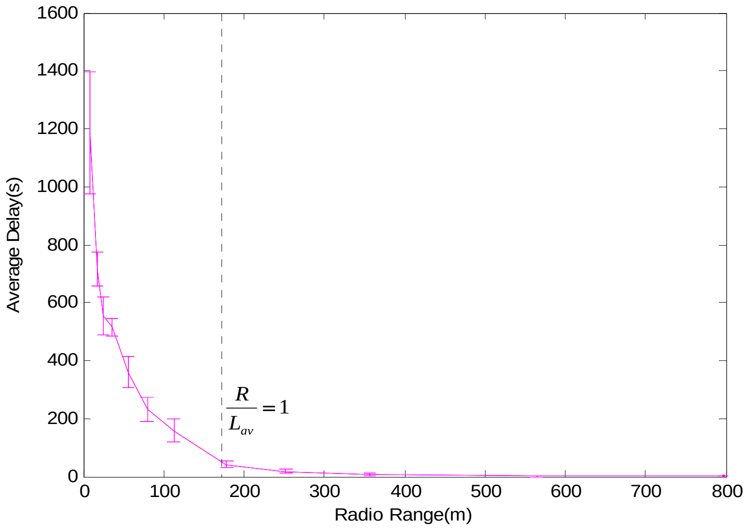

Figure 3. Average delay per delivered packet vs. *R*.