Chapter VII
Inter-Vehicular Communications Using Wireless Ad Hoc Networks

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ABSTRACT

This chapter proposes a new routing algorithm that allows communication in vehicular ad hoc networks. In vehicular ad hoc networks, the transmitter node cannot determine the immediate future position of the receiving node beforehand. Furthermore, rapid topological changes and limited bandwidth compound the difficulties nodes experience when attempting to exchange position information. The authors first validate our algorithm in a small-scale network with test bed results. Then, for large-scale networks, they compare our protocol with the models of two prominent reactive routing algorithms: Ad-Hoc On-Demand Distance Vector and Dynamic Source Routing on a multi-lane circular dual motorway, representative of motorway driving. Then the authors compare their algorithm with motorway vehicular mobility, a location-based routing algorithm, on a multi-lane circular motorway. This chapter then provides motorway vehicular mobility results of a microscopic traffic model developed in OPNET, which the authors use to evaluate the performance of each protocol in terms of: Route Discovery Time, End to End Delay, Routing Overhead, Overhead, Routing Load, and Delivery Ratio.

INTRODUCTION

How to best optimize traffic flow is one of the primary challenges of specialists studying congestion and safety on streets and motorways because of the economic, health, and safety issues related to inefficient traffic circulation. Proposals to mitigate traffic congestion, caused in part by inefficient traffic flow, have often included expensive construction projects. These projects, however, have had only limited success. In the United States, for highway travel congestion of personal vehicles, the Transportation Statistics Annual Report (2006) states that "highway travel times increased between 1993 and 2003 in all but 3 of the 85 urban areas (98 percent)", and "it took 37 percent longer, on average, in 2003 to make a peak period trip (from 6 to 9 a.m. and 4 to 7 p.m.)". Additionally, this same report reveals that "there were nearly 45,000 fatalities in transportation accidents in the United States in 2004, of which 95 percent involved highway motor vehicles". Furthermore, although the number of fatalities slightly decreased, "in 2005, 43,443 motorists and non-motorists were killed in crashes involving motor vehicles, up 1% compared with 2004, and about 2.7 million people were injured". Finally, the report mentions that "there were 1.47 fatalities per 100 million vehicle-miles of highway travel in 2005".

Although passive safety systems such as seat belts and air bags have been used to significantly reduce the total number of major injuries and deaths due to motor vehicle accidents, they do nothing to actually improve traffic flow or lower the actual number of automobile collisions. In order to reduce the number of vehicular accidents, computer and network experts propose active safety systems, including Intelligent Transportation Systems (ITS) that are based on Inter-vehicular Communication (IVC) and Vehicle-to-Roadside Communication (VRC). Presently, technologies related to these architectures and their related technologies may, in the future, more efficiently administer traffic flow, which, in turn, can have important safety, ecological, and economic ramifications.

Active vehicular systems employ wireless ad hoc networks and Global Positioning System (GPS) to determine and maintain inter-vehicular distances to insure the one-hop and multi-hop communications network needed to maintain vehicle spacing. Location-based routing algorithms may help in the development of Vehicular Ad Hoc Networks (VANETs) because their flexibility and efficiency provide the ad hoc architecture necessary for inter-vehicular communication. Although several location-based algorithms already exist, including Grid Location Service (GLS), Location Aided Routing (LAR), Greedy Perimeter Stateless Routing (GPSR), and Distance Routing Effect Algorithm for Mobility (DREAM), to name just a few, we propose a Location-Based Routing Algorithm with Cluster-Based Flooding (LORA-CBF) as an option for present and future automotive applications (Santos et al., 2005).

Ad Hoc routing protocols have the design goals of network optimality, simplicity, low overhead, robustness, stability, rapid convergence, and flexibility. However, since mobile nodes suffer from significantly less available power, processing speed, and memory, low overhead becomes even more important than in conventional fixed networks. The high mobility present in vehicle-to-vehicle communication also places great importance on rapid convergence. Therefore, it is imperative that ad hoc routing protocols effectively compensate for any inherent delays in the underlying technology, adapt to varying degrees of mobility, and be sufficiently robust to deal with potential transmission loss due to drop out. Additionally, such protocols must more effectively route packets than traditional network algorithms in order to effectively compensate for limited bandwidth resources.

Several routing algorithms for ad hoc networks have emerged recently to address difficulties related to unicast routing. Such algorithms can be categorized as either proactive or reactive, depending on their route discovery mechanism. This chapter presents a set of performance predications for ad hoc routing protocols used in highly mobile vehicle-to-vehicle multi-hop networks as part of the extensive research and development effort which will be undertaken in the next decade to incorporate wireless ad hoc networks in the automobile industry.

In proactive algorithms, each node continuously updates the routes to all other nodes in the network by periodically exchanging control messages. Consequently, the route is immediately available when a node needs to send a packet to any other node in the network. The main advantage of proactive algorithms is that they have a shorter delay. Examples of proactive algorithms include Optimized Link State Routing Protocol (OLSR) and Topology Dissemination Based on Reverse-Path Forwarding (TBRPF).

The disadvantage of the OLSR and TBRPF protocols, however, is their link state routing dissemination strategy. Recognized link changes cause nodes to flood control packets across the entire network, which taxes network resources (Zou, Ramamurthy, Magliveras, 2002). Vehicular ad hoc networks consist of many highly mobile nodes whose mobility is defined, in part, by the physical limitations of the motorway and the actual relative positions of the vehicles circulating on it, as well as the significant number of vehicles simultaneously entering and exiting the motorway. As a consequence of these factors, the dissemination of routing information increases the demand for often limited bandwidth resources and computation time.

Conversely, reactive algorithm nodes discover routes on demand and maintain smaller active route tables. Thus, a route is discovered whenever a source node needs to communicate with a destination node for which a route has not already been established. Discovery is based on flooding, which can be total, as in AODV and DSR, or limited, as in OLSR and TBRPF. In these scenarios, source nodes broadcast a route request message to all immediate neighbors, and these in turn, re-broadcast the route request to their neighbors. When the route request reaches either the destination or a node that has a valid route to the destination, a route reply message is generated and transmitted back to the source. Therefore, as soon as the source receives the route reply, a route is created from the source to the destination. The advantage of reactive algorithms is that there are no control messages for non-active routes. The major drawback is the latency in establishing transmission routes. Examples of reactive algorithms include AODV (Perkins, Belding-Royer & Das, 2003) and DSR (Johnson, Maltz, & Hu, 2007).

Previously, proactive algorithms were not considered suitable for highly mobile environments because they tend to have poor route convergence and low communication throughput (Royer & Toh, 1999).

Some Cluster-Based Flooding strategies for routing in wireless ad hoc networks have been reported in literature (Boris and Arkady, 1999; Krishna et al., 1997; Bevas et al., 1997; Raghupathy et al., 1998; Ching-Chuan et al., 1997). The main contribution of this work is the re-broadcast and gateway selection mechanisms. The cluster formation in Boris and Arkady (1999) is based on the Link Cluster Algorithm (LCA) (Baker et al., 1984) and the algorithm is based on Link State Routing protocol, where all nodes in the cluster are expected to acknowledge the Link State Update (LSU). If one of the nodes does not send an acknowledgement, the cluster head retransmits the LSU to that particular node. Flooding is transmitted from the source to a destination via cluster heads and gateways. In (Krishna et al., 1997) and (Bevas et al., 1997), the re-broadcast is handled by the boundary nodes. Nodes other than boundary nodes just listen and update their tables. In (Raghupathy et al., 1998), there are two types of routing strategies: Optimal Spine Routing (OSR) and Partial-knowledge Spine Routing (PSR). OSR uses full and up-to-date knowledge of the network topology, permitting the source to determine the route to the destination. On the other hand, PSR uses partial knowledge of the network topology and takes a greedy approach to compute the shortest path from the source to the destination. In (Ching-Chuan et al., 1997), the authors use a cluster head controlled token protocol (like polling) to allocate the channel among competing nodes. We have implemented a re-broadcast strategy where only gateways belonging to different cluster heads re-broadcast the location request packets, resulting in improved routing overhead.

Inter-Vehicular and Vehicle-to-Roadside Communications

The interest in inter-vehicular and vehicle-to-roadside communication has significantly increased over the last decade, in part, because of the proliferation of wireless networks. Most research in this area has concentrated on vehicle-to-roadside communication, also called beacon-vehicle communication (Rokitansky & Wietfeld, 1993), (Brasche, Rokitansky & Wietfeld, 1994), (Wietfeld & Rokitansky, 1994), (Rokitansky & Wietfeld, 1995), (Wietfeld & Rokitansky, 1995), in which vehicles share the medium by accessing different time slots (Time Division Multiple Access, TDMA), the beacon (down-link direction), and the vehicles (up-link direction). The beacon arranges up-link time slots (so called windows allocations) for the vehicles; the vehicles are not allowed to access the medium without a window allocation sent to them by the beacon. The beacon, as the primary station, offers two different types of windows to the vehicles: public and private windows. A public window is a time slot that can be accessed by any vehicle within the communication zone. A private window allocation reserves a time slot for one specific vehicle, thus protecting it against data collisions.

A typical communication process between a beacon and a vehicle can be divided into two phases: the connection establishment phase and the transaction phase. When a vehicle enters the beacon communication zone, the vehicle address is not known to the beacon, so the beacon periodically broadcasts a request for identification and offers a public up-link window before establishing the actual connection. When a specific vehicle responds to an identification request, it records the address in the transmitter node's table and individual addressing becomes possible. The beacon then opens a private uplink window to a specific vehicle for data exchange during the transaction phase.

Other mechanisms to communicate vehicles in vehicle-to-roadside communication have been proposed by (Kwak & Jae, 2004), (Dobias & Grabow, 1994), (Zandbergen & Van der Ree, 1992), (Abdulhamid, Abdel-Raheem & Tepe, 2007), (Matthaiou, Laurenson, & Cheng-Xiang, 2008), (Cottingham, Wassell & Harle, 2007), (Mussa & Upchurch, 2000), (Bantli, Ring & Goff, 1997), and (Dickey, Huang & Guan, 2007).

Some applications for vehicle-to-roadside communication, including Automatic Payment, Route Guidance, Cooperative Driving, and Parking Management have been developed to function in limited communication zones of less than 60 meters. However, the IEEE 802.11 Standard has led to increased research in the areas of wireless ad hoc networks and location-based routing algorithms, (Morris et. al., 2000), (Da Chen, Kung, & Vlah, 2001), (Füßler, et. al., 2003), (Lochert, et. al., 2003), (Kosh, Schwingenschlögl, & Ai, 2002). Applications for inter-vehicular communication include Intelligent Cruise Control, Intelligent Maneuvering Control, Lane Access, and Emergency Warning, among others. In (Morris et. al., 2000), the authors propose using Grid (Li, et. al., 2000), a geographic forwarding and scalable distributed location service, to route packets from car to car without flooding the network. The authors in (Da Chen, Kung, & Vlah, 2001) propose relaying messages in low traffic densities, based on a microscopic traffic simulator that produces accurate movement traces of vehicles traveling on a highway, and a network simulator to model the exchange of messages among the vehicles. Da Chen et. al., employ a straight bidirectional highway segment of one or more lanes. The messages are propagated greedily each time step by hopping to the neighbor closest to the destination. The authors in (Füßler, et. al., 2003), compare a topology-based approach and a location-based routing scheme. The authors chose GPSR (Karp & Kung, 2000) as the location-based routing scheme and DSR (Johnson, Maltz, & Hu, 2007) as the topology-based approach. The simulator used in (Füßler, et. al., 2003) is called FARSI, which is a macroscopic traffic model. In (Lochert, et. al., 2003), the authors compare two topology-based routing approaches, DSR and AODV (Perkins, Belding-Royer & Das, 2003), versus one position-based routing scheme, GPSR, in an urban environment. Finally, in (Kosh, Schwingenschlögl, & Ai, 2002), the authors employ a geocast routing protocol that is based on AODV.

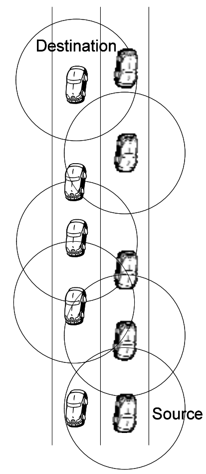
In inter-vehicular communication, vehicles are equipped with on-board computers that function as nodes in a wireless network, allowing them to contact other similarity equipped vehicles in their vicinity. By exchanging information, vehicles can obtain information about local traffic conditions, which improves traffic control and provides greater driver safety and comfort.

In this chapter, we will focus on inter-vehicular communication because vehicle-to-roadside communication has been already proposed for standardization in Europe (CEN TC 278 WG 9) and North America (IVHS).

Issues Concerning Inter-Vehicular Communication Using Wireless Ad Hoc Networks

Future developments in automobile manufacturing will also include new communication technologies. The major goals are to provide increased automotive safety, achieve smoother traffic flow, and improve passenger convenience by providing information and entertainment. In order to avoid communication costs and guarantee the low delays required to exchange safety-related data between cars, inter-vehicular communication (IVC) systems, based on wireless ad hoc networks, represent a promising solution for future road communication scenarios. IVC allows vehicles to organize themselves locally in ad hoc networks without any pre-installed infrastructure. Communication in future IVC systems will not be restricted to neighboring vehicles traveling within a specific radio transmission range. As in typical wireless scenarios, the IVC system will provide multi-hop communication capabilities by using “relay” vehicles that are traveling between the sender and receiver. Figure 1 illustrates this basic idea. In this particular example, the source vehicle is still able to communicate with the destination vehicle, although the destination vehicle is not in source vehicle’s immediate communication range. Vehicles between the source-destination act as intermediate vehicles, relaying data to the receiver. As a result, the multi-hop capability of the IVC system significantly increases the virtual communication range, as it enables communication with more distant vehicles.

Figure 1. Inter-vehicular communication system using wireless ad hoc networks



LOCATION ROUTING ALGORITHM WITH CLUSTER-BASED FLOODING (LORA-CBF)

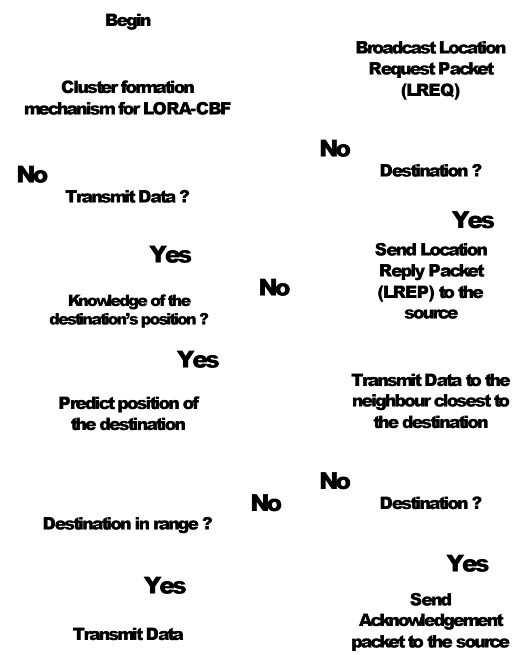
In this section, we present a Location Routing Algorithm with Cluster-Based Flooding (LORA-CBF), which is formed with one cluster head, zero or more members in every cluster, and one or more gateways to communicate with other cluster heads. Each cluster head maintains a "Cluster Table". A "Cluster Table" is defined as a table that contains the addresses and geographic position of the member and gateway nodes.

When a source attempts to send data to a destination, it first checks its routing table to determine if it knows the location of the destination. If it does, it sends the packet to the closest neighbor to the destination (Figure 2). Otherwise, the source stores the data packet in its buffer, starts a timer, and broadcasts Location Request (LREQ) packets. Only gateways and cluster heads can retransmit the LREQ packet. Gateways only retransmit a packet from one gateway to another in order to minimize unnecessary retransmissions, and only if the gateway belongs to a different cluster head.

Upon receiving a location request, each cluster head confirms that the destination is a member of its cluster. Success triggers a Location Reply (LREP) packet that is returned to the sender using geographic routing. This is possible because each node knows the position of the source and the closest neighbor, based on the information received from the LREQ and the Simple Location Service (SLS). Failure triggers retransmissions by the cluster head to adjacent cluster-heads (Reactive Location Service, RLS) and the destination address is recorded in the packet. Cluster heads and gateways, therefore, discard request packets they have previously seen.

Once the source receives the destination's location, it retrieves the data packet from its buffer and forwards it to the neighbor closest to the destination.

Figure 2. Flow diagram for LORA-CBF



Basically, the algorithm consists of five stages:

1. Cluster formation
2. Location discovery (LREQ and LREP)
3. Routing of data packets
4. Maintenance of location information
5. Short-term geographic positioning predictive algorithm

Cluster Formation

All nodes maintain neighbor information in their respective tables to enable cluster formation and maintenance.

Let t be the period of time between the Hello broadcasts. When a node first switches on, it first listens to Hello packets on the broadcast channel. If any other node on the broadcast channel is already advertising itself as a cluster head (status of node = cluster-head), the new node saves the heard cluster-head ID in its cluster-head ID field and changes its status to member. At any point in time, a node in the mobile network can associate itself with a cluster head. The cluster heads are identified by the cluster-head ID. Otherwise, the new node becomes a cluster head. Cluster heads are responsible for their clusters and periodically send Hello Messages.

When a member of a cluster receives a Hello message, it registers the cluster head and responds with a reply Hello message. The cluster head then updates the cluster table with the address and position (longitude and latitude) of every cluster member.

When a member receives a Hello packet from a different cluster head, it must first register it, but the member does not actually modify its cluster-head ID until the expiration time for the field has expired. Before the member rebroadcasts the new information, it must change its status to a gateway. After receiving the Hello packet, the cluster heads update their cluster tables with the new gateway information.

If the source broadcasts a message to the destination, it must first check its routing table to determine if it has a "fresh" route to the destination. If it does, it first seeks its cluster table to identify the closest neighbor to the destination. Otherwise, it starts the location discovery process.

Location Discovery Process

When the source of the data packet transmits to a destination that is not included in its routing table or if its route has expired, it first places the data packet in its buffer and broadcasts a Location Request (LREQ) packet (Reactive Location Service, RLS).

When a cluster head receives a LREQ packet, it checks the packet identification field to determine if it has previously seen the LREQ packet. Previously seen packets are discarded, but if the destination node is a member of the cluster head, it unicasts the Location Reply (LREP) packet to the source node.

If the destination node, however, is not a member of the cluster head, it first records the LREQ packet address in its routing table and rebroadcasts the LREQ packet to neighboring cluster heads.

Each cluster head node forwards the packet once. The packets are broadcasted only to the neighboring cluster head by means of an omni-directional antenna that routes them via the gateway nodes. Gateways only retransmit a packet from one gateway to another to minimize unnecessary retransmissions, and only if the gateway belongs to a different cluster head. When the cluster head destination receives the LREQ packet, it records the source address and location. From this, the destination cluster head locates the source node. The destination then sends a LREP message back to the source via its closest neighbor.

Finally, the packet reaches the source node that originated the request packet. If the source node does not receive a LREP after transmitting a LREQ for a set period of time, it goes into an exponential back off before re-transmitting the LREQ. Hence, only one packet is transmitted back to the source node. The reply packet does not have to maintain a source/destination routing path, and the path is determined from the location information given by the source node. Importantly, the path followed by the LREQ may be different from that traversed by the LREP.

Routing of Data Packets

The actual data packet routing is then based on source, destination, and neighbor location.

Since the protocol is not based on source routing, packets travel the path from the source to the destination, based on their relative locations. The packets find paths to their destinations individually each time they transmit data between the source and the destination. Packets are transmitted between nodes based on their knowledge of the position information in their tables. Moreover, since the transmission is in the direction of the destination node, the path found will be shorter than other routing mechanisms (non-positional-based). In non-positional-based routing strategies, the shortest path is measured in hops, meaning the path discovered may not be the shortest. However, the path found using location information will be significantly shorter. If the source of the data packet does not receive the acknowledgement packet before its timer expires, it will retransmit the data packet again. This might occur particularly during packet loss because of drop-out or network disconnection.

LORA-CBF uses the Most Forward within Radius (MFR) forwarding strategy. In MFR, the packet is routed via the neighbors that most reduce the distance to the destination. The advantage of this forwarding strategy is that it decreases the probability of collision and end-to-end delay between the source and the destination.

Maintenance of Location Information

The LORA-CBF algorithm is suitable for networks with very fast, mobile nodes because it maintains and updates the location information of the source and destination every time the pairs send or receive data and acknowledgment packets. The source updates its location information before sending each data packet. When the destination receives the data packet, its location information is updated and an acknowledgment packet is sent to the source.

Short-Term Geographic Positioning Predictive Algorithm

In highly mobile environments, precise knowledge of neighbor positions, to a great degree, determines the routing efficiency of any algorithm. LORA-CBF predicts the immediate future location of every neighbor node, based on its short-term geographic positioning predictive algorithm. After predicting the position of all neighbor nodes, LORA-CBF sends the packet to the neighbor node with shorter distance to the destination node (MFR).

Mobility and contention of wireless media may cause packet loss during transmission, which is a very important phenomenon to consider when developing predictive algorithms. Our algorithm also predicts the future probable location of a node, despite data stream time gaps caused by collisions.

Assuming the data follows a linear trend, our short-term geographic positioning predictive algorithm attempts to extrapolate the position of the next hop k ahead in time, according to the following equation:

$$Pj + k = Pj + \Delta P * e \tag{1}$$

Where:

$Pj + k$	future position of the next hop
Pj	current position of the next hop
ΔP	interval between current position and previous position of the next hop
e	factor indicating the gap between packets received

Short-term geographic positioning predictive algorithms are useful in highly mobile contention-based networks. LORA-CBF periodically broadcasts Hello messages to locate nodes entering or leaving the ad hoc network. Location information received from a Hello message helps neighbor nodes calculate the future nodal position of the sending node throughout the transmission range by calculating its immediate future position. When a node receives a packet, before forwarding it to a particular destination, it first checks its routing table to determine if it possesses the location information of the destination node. If it does, it triggers the short-term geographic positioning predictive algorithm to calculate the future position of the destination. If the sender node can directly reach the destination node, it forwards it directly. However, if the sender node cannot forward the packet itself, it must predict the locations of the receiving node's neighbors, and send the packet to the closest neighbor node to the predicted destination.

MICROSCOPIC TRAFFIC SIMULATION MODEL

Vehicular traffic models may be categorized into four classifications according to their level of detail: sub-microscopic, microscopic, mesoscopic and macroscopic (Hoogendoorn & Bovy, 2001). Sub-microscopic models describe the characteristics of individual vehicles in the traffic stream and the operation of specific parts (sub-units) of the vehicle. Microscopic models simulate individual driver behavior and the interaction among drivers. This type of model is very detailed and explicitly tracks the space-time trajectory of each vehicle (Festa et. al., 2001). Mesoscopic models represent transportation systems and analyze groups of drivers who display homogeneous behaviors. Finally, macroscopic models describe traffic at a high level of aggregation as a flow, without distinguishing its basic parts (Cvetkovski & Gavrilovska, 1998). Because we are interested in the space-time trajectory of each vehicle governed by the lead vehicle, our attention will focus on microscopic traffic models.

A large number of microscopic traffic simulation models have been developed. Basically, these models describe the time-space behavior of vehicles in the traffic system.

The microscopic traffic simulation model used in this work to evaluate the performance of the three algorithms is based on Simone 2000 (Minderhoud, 2002). The Simone 2000 model is a sophisticated microscopic traffic flow model that simulates a wide range of user-classes. The model distinguishes longitudinal (car-following) and lateral (lane-changing) driver behaviors. The longitudinal distance controller is one of the main elements of a microscopic simulation model for traffic flow. It describes how a vehicle progresses in a single lane, focusing on the car immediately in front of it. We have implemented this model in OPNET to simulate the mobility of the vehicles on a motorway.

Basically, the simulation model is divided into two functions:

Desired Gap Function

With this function, the longitudinal controller determines the acceleration (positive or negative) needed to obtain a desired minimum distance from the leader.

$$s_i(t) = l_i + \eta_i(t) \cdot (z0_i + z1_i \cdot v_i(t) + z2_i \cdot v_i(t)^2)$$

Where:

S (t) = desired gap distance (from rear follower I to rear leader) (m), i = index vehicle, l = length of vehicle i, η = congestion factor, z0 = margin parameter (m), z1 = linear headway parameter (s), z2 = quadratic headway parameter (s2), v (t) = speed at time t (m/s).

Longitudinal Controller

Once the position of a vehicle immediately in front of a following vehicle has been calculated, the longitudinal controller moves the following vehicle to its new position, using standard kinematics equations for vehicle speed and distance.

$$a_i(t+\tau) = \alpha_i \cdot \left(x_{i-1}(t) - x_i(t) - s_i(t)\right) + \beta_i^{\pm} \cdot \left(v_{i-1}(t) - v_i(t)\right)$$

With:

a(t + τ) = acceleration applied after delay time (m/s2), x(t) = x-coordinate vehicle rear bumper at time t (m), v(t) = speed at time t (m/s), i = index subject vehicle (follower), i-1 = index subjects' leader, α = distance error sensitivity (1/s), β+ = speed difference sensitivity (for positive difference) (1/s2), β- = speed difference sensitivity (for negative difference) (1/s2).

VALIDATION OF THE MODEL

Validating LORA-CBF with One, Two and Three Hops

Wireless ad hoc networks basically employ multi-hop communications, where packets are transmitted from source to destination. Therefore, the basic communication mechanism is peer-to-peer, with packets retransmitted several times.

The first task of our study is to validate our model at one, two, and three hops, comparing the results of the test bed with the results of the model we developed in OPNET. Finally, for more than 3 hops, we will validate our model comparing it with the AODV, DSR and GPSR algorithms.

Table 1 compares test-bed and OPNET simulation results, which validates LORA_CBF in a small-scale network.

Table 1. Results validating LORA_CBF for one, two and three hops

EED (ms)	One Hop	Two Hops	Three Hops
Test Bed (C-K Toh)	10.4	19.7	29.2
OPNET model	9.1	18.854	28.591
Throughput (Kbps)	One Hop	Two Hops	Three Hops
Test Bed (C-K Toh)	769.23	406.091	273.972
OPNET model	878.93	424.313	279.808

Validating LORA-CBF with More Than Three Hops

We have compared our model with the AODV, DSR, and GPSR algorithms. The comparison is reasonable because we have improved the data reception mechanism by using an acknowledgement packet in the AODV and DSR protocols. When the timer for an acknowledgement data packet expires, AODV and DSR start new Route Requests (RREQ). Additionally, we have improved GPSR with our short-term geographic positioning predictive algorithm.

SIMULATION METRICS

In comparing the performance of the algorithms, we chose to evaluate them according to the following five parameters:

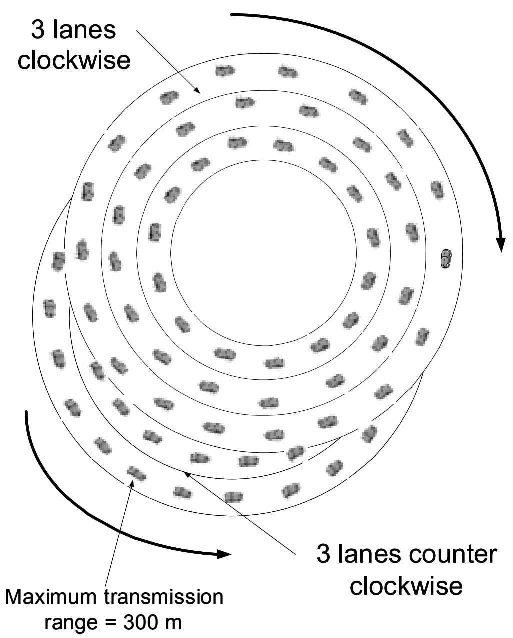
- Average end-to-end delay of data packets: all of the possible delays caused by buffering during route discovery, queuing at the interface queue, retransmission delays at the MAC, and propagation and transfer times.
- Routing load: the number of routing packets sent divided by the number of data packets transmitted. The latter includes only the data packets finally delivered at the destination and not the ones that are dropped. The transmission of each hop is counted once for both routing and data packets. This provides an estimation of network bandwidth consumed by routing packets with respect to "useful" data packets.
- Routing overhead: the total number of routing packets transmitted during the simulation. For packets sent over multiple hops, each packet transmission (each hop) counts as one transmission.
- Overhead (packets): the number of routing packets generated divided by the total number of data packets transmitted, plus the total number of routing packets.

- Packet delivery ratio: the ratio of data packets delivered to the number of data packets sent by the sender. Data packets, however, may be dropped if the link is broken when the data packet is ready to be transmitted.

The OPNET simulator was used to evaluate the three routing protocols. The simulation models a network of 250 mobile nodes traveling on a 6283m circular road (Figure 3).

This configuration is reasonable for motorway traffic in the United Kingdom because the low curvature rate of its roads permits vehicle circulation at a more constant velocity. The IEEE 802.11b Distributed Coordination Function (DCF) is used as the medium access control protocol. We also developed a microscopic traffic simulation model in OPNET to simulate vehicular mobility on a motorway. A 300m transmission range was chosen, which is consistent with current 802.11b Wireless LAN standards and 5 dBi gain car-mounted antennas. An experiment was carried out to validate the transmission range between two vehicles driving in opposite directions.

Figure 3. Simulated scenario



SIMULATION RESULTS

Figure 4.a shows routing overhead. In this simulation, DSR performs better because it lacks a neighbor sensing mechanism, and AODV increases its routing overhead according to the distance between nodes. LORA_CBF maintains its routing overhead at an almost constant level because routing overhead is proportional to the frequency of Hello messages, which is independent of the maximum distance between communication partners. AODV requires about 3 times the routing overhead of DSR (also reported in Broch et. al., 1998). Figure 4.b shows overhead, which is higher for AODV. Generally, highly mobile environments suffer from a greater frequency of broken links, resulting in the retransmission of RERR messages. In the case of AODV, overhead increases proportionally to the number of Hello messages. Figure 4.c represents the routing load. AODV shows a higher routing load than LORA_CBF and DSR. The routing load also increases with distance and depends on the amount of data delivered. End-to-End delay (EED), presented in Figure 4.d, shows that all of the algorithms have lower delays at a data rate of 1 Mbps. In general, AODV has the greatest delay because of its frequent retransmissions. DSR performs the best because of its packet control strategy. LORA_CBF has a slightly greater EED when compared with DSR. Figure 4.e compares the packet delivery ratio of all of the algorithms considered in this study. LORA_CBF shows good results at both data rates, and AODV has a slightly worse packet delivery ratio than DSR. Both AODV and DSR have their worst delivery ratios at a data rate of 11 Mbps.

We observe that the AODV and DSR algorithms suffer from sub-optimal routes and low delivery ratios. On the other hand, algorithms that employ GPS do not satisfy the requirements of multi-hop vehicular ad hoc networks. In this section, we will compare our Location-Based Routing Algorithm with Cluster-Based Flooding (LORA-CBF), with a very popular position-based

Figure 4.a. Routing overhead

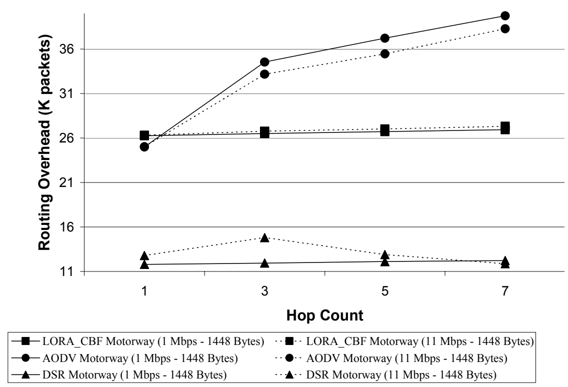


Figure 4.b. Overhead

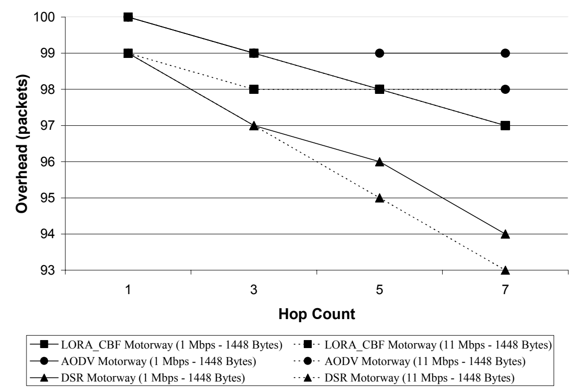


Figure 4.c. Routing load

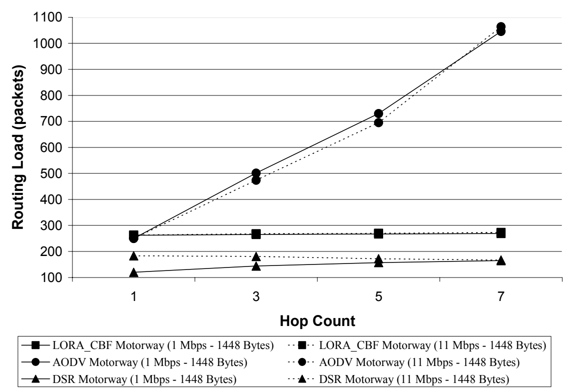


Figure 4.d. End-to-End delay (EED)

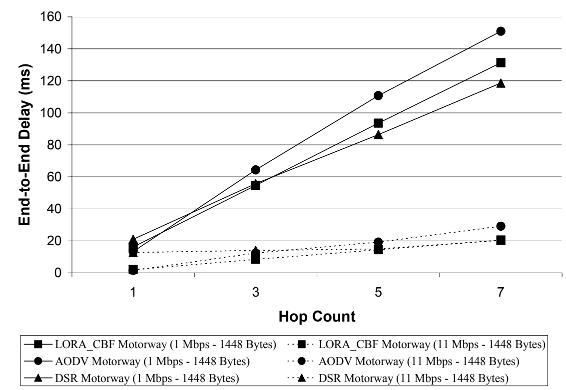
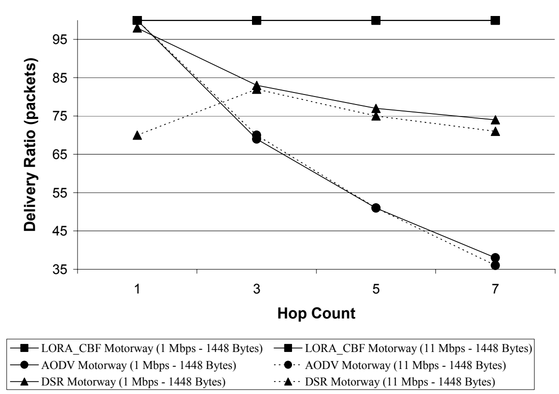


Figure 4.e. Delivery ratio



routing algorithm called GPSR, (Greedy Perimeter Stateless Routing) and demonstrate that at an average speed of 42 m/s (~150 km/h), the lack of a predictive algorithm in GPSR diminishes its performance.

We implemented the GPSR algorithm on the same circular dual carriageway scenario with the same number of vehicles and a relative speed of 84 m/s (~300 km/h). Results show that without a predictive algorithm, it is not possible to communicate a source-destination pair located further than two hops. Our intention here is to show that employing a predictive algorithm will improve communication on a motorway.

Using GPSR, we applied the same short-term geographic positioning predictive algorithm used in LORA-CBF and the same physical and MAC layer. In addition, the same metrics were previously employed to analyze the behavior of LORA-CBF, AODV, and DSR to compare the relative performance of LORA-CBF and GPSR.

Figure 5.a represents the delivery ratio of GPSR and LORA-CBF. The short-term geographic positioning predictive algorithm improved the communication of GPSR by 90 percent. Both algorithms perform similarly at data rates of 11 Mbps; however, GPSR has a slightly lower delivery ratio at data rates of 1 Mbps. In general, these two algorithms perform similarly because they both use the same forwarding mechanism (greedy forwarding).

Each hop is equivalent to approximately 300m and the delivery ratio is the percent of 100 packets sent at 100-second intervals. Importantly, the distance between the transmitter and the receiver is measured in hop counts. End-to-End Delay is shown in Figure 5.b. Because they employ the same forwarding mechanism, GPSR and LORA-CBF behave similarly in terms of EED. The End-to-End Delay represents the average time required to send one hundred packets at 100 second intervals. Also, the distance between the transmitter and the receiver is measured in hop counts.

Figure 5.c describes routing overhead. Here, LORA-CBF has a slightly higher routing overhead at a data rate of 11 Mbps compared with GPSR. On the other hand, at a data rate of 1 Mbps, LORA-CBF begins with a slightly higher routing overhead at a distance of less than 5 hops. Both algorithms have exactly the same routing overhead at a distance of 5 hops. At more than five hops, however, LORA-CBF has a lower routing overhead than GPSR. Routing overhead represents the total number of routing packets transmitted during the simulation. For packets sent over multiple hops, each packet transmission (at each hop) represents one transmission. Figure 5.d presents the route discovery time. Both algorithms show similar behavior at a data rate of 11 Mbps, however, at a data rate of 1 Mbps, GPSR's route discovery time is greater. Importantly, GPSR suffers from more packet collisions because the spatial separation of its packets is more limited. On the other hand, LORA-CBF reduces the route discovery time due to its cluster-based flooding mechanism. Route Discovery Time is the time required for the source to send the first data packet.

Figure 5.e shows the overhead. Here, GPSR has a slightly lower overhead compared to LORA-CBF at data rates of 1 Mbps. At data rates of 11 Mbps, however, both algorithms perform similarly. Overhead is the total number of routing packets generated divided by the total number of data packets transmitted, plus the total number of routing packets. Overhead represents the percent of 100 packets transmitted during 100 second intervals. The routing load is shown in Figure 5.f. again, at a data rate of 11 Mbps, LORA-CBF has a slightly higher routing load than GPSR, however, at a data rate of 1 Mbps, LORA-CBF has a slightly higher routing load when it initiates data transmission. However, at five hops (=1500m), both algorithms have the same routing load. At greater distances, LORA-CBF exhibits a lower routing load than GPSR. Again, due to its spatial separation, GPSR packet collisions are more frequent, resulting in an increased routing

Figure 5.a. Delivery ratio

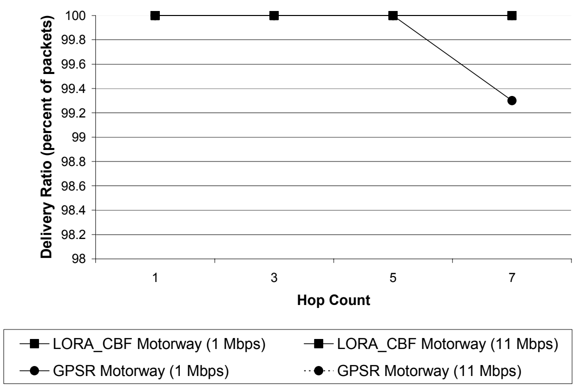


Figure 5.b. End-to-End delay

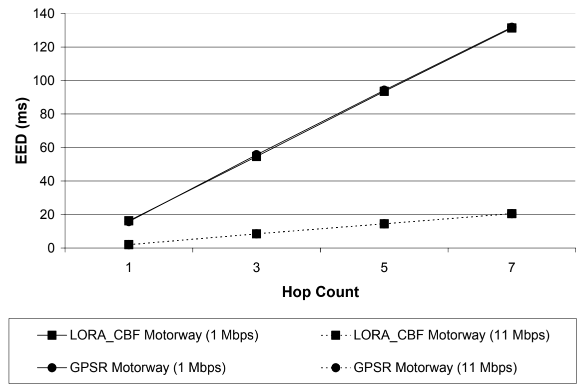


Figure 5.c. Routing overhead

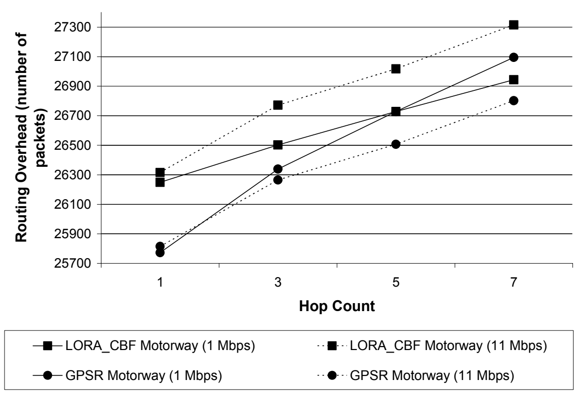


Figure 5.d. Route discovery time

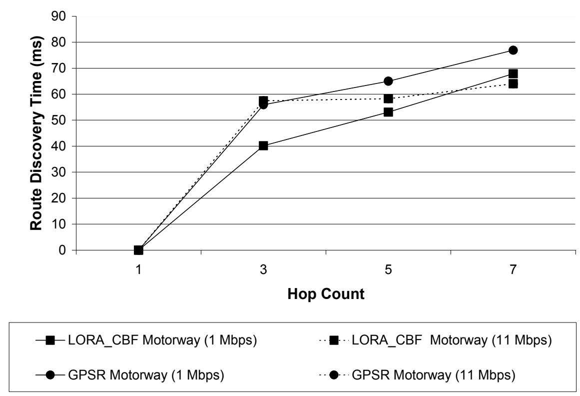


Figure 5.e. Overhead

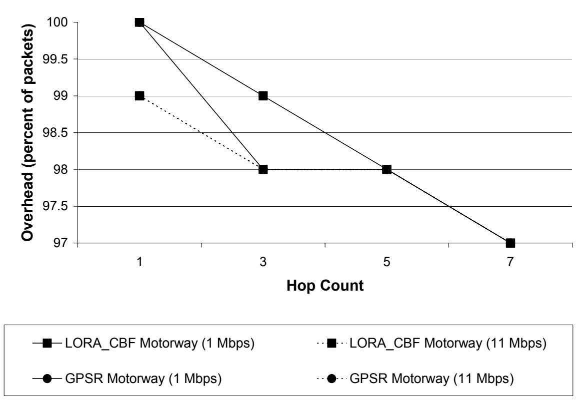
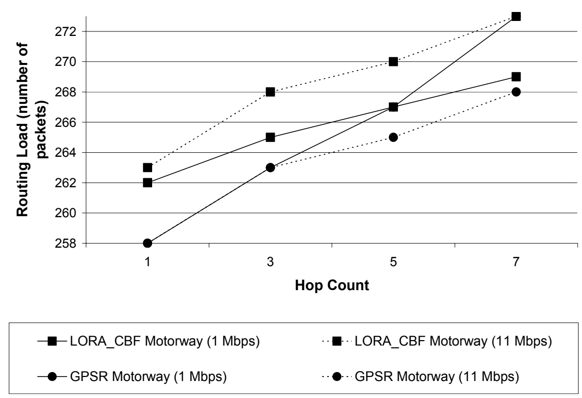


Figure 5.f. Routing load



load. Routing Load is measured in terms of the number of routing packets transmitted divided by the number of data packets transmitted.

IMPLEMENTATION OF THE LORA-CBF ALGORITHM ON A TESTBED

We deployed LORA-CBF on a test bed using Linux and equipped each node with an Enterasys wireless card, employing sockets to allow internodal communication. Five laptops with ad hoc routing capability were deployed in an outdoor environment representing a small-scale ad hoc network. To validate LORA-CBF statically, we compared LORA-CBF to the results of another wireless ad hoc network test bed (Toh, 2002). In (Toh, 2002), each node ran the Associativity-Based Routing (ABR) protocol. The ABR and LORA-CBF algorithms employ a periodic beaconing strategy to inform neighbor nodes of their presence, using both source-initiated on-demand ad hoc routing protocols to discover routes. The main difference between LORA_CBF and ABR is that the latter selects its route based on its longevity. On the other hand, LORA-CBF uses a predictive algorithm to select the single best route based on the geographic locations of neighbor nodes.

Figures 6.a and 6.b show 1, 2, and 3 hop results for LORA-CBF and ABR. Results show similar behavior for the different packet sizes selected for the study. Each value on the graphs represents results for 100 packets sent, and the margin of error is <15%. Discovery time for the first hop is 0 seconds due to the Hello mechanism. For 2 hops, the discovery time is 1.6 seconds and for three hops, discovery time increases to 1.74 seconds because of the route discovery mechanism of the two algorithms.

CONCLUSIONS AND FUTURE WORK

In the near future, automobile manufacturers may use wireless ad hoc networks to improve traffic flow and safety, in part, because it may be more cost effective than continually undertaking massive construction projects, which are proving to have only limited success. Consequently, future developments in automobile manufacturing will include new communication technologies that offer more effective spacing and collision avoidance systems, greater gas mileage (less braking), less pollution (cars are in movement), more information and entertainment, etc. In order to reduce communication costs and guarantee the

Figure 6.a. End-to-End Delay for one hop

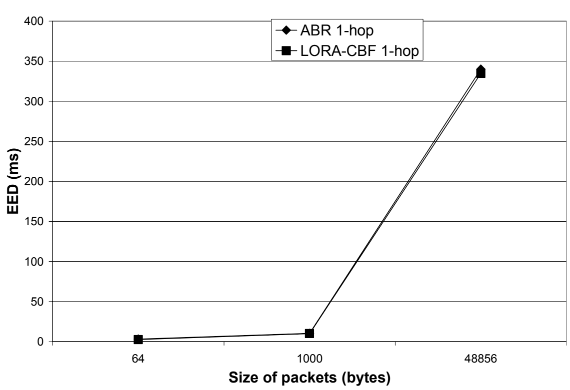
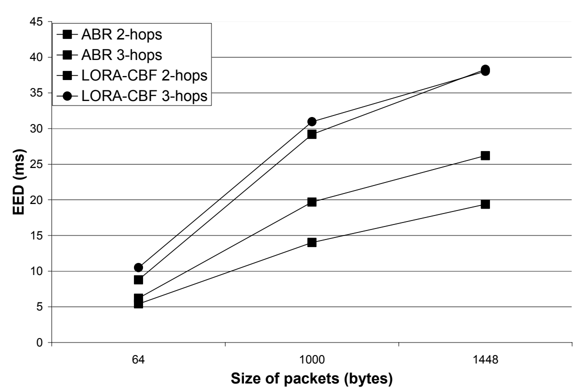


Figure 6.b. End-to-End Delay for two and three hops



low delays required to exchange data between cars, inter-vehicle communication (IVC) systems, based on wireless ad-hoc networks, represent a promising alternative for future road communication scenarios, as they permit vehicles to organize themselves locally in ad hoc networks without any pre-installed infrastructure.

LORA-CBF is an algorithm that can possibly be used in future wireless ad hoc networks because its reactive geographic routing algorithm employs GPS in tandem with its predictive algorithm, which is necessary for mobile networks to function optimally. Furthermore, LORA-CBF uses a gateway selection mechanism to reduce contention in dense networks, which is predictable in highly congested traffic conditions. Finally, the hierarchical structure of LORA-CBF facilitates its deployment as part of vehicular ad hoc networks because it requires minimal deployed infrastructure.

In this chapter, we have discussed the mobility involved in typical motorway traffic scenarios and have provided simulated results of a very large 250 node network. We validate our simulation, where possible, with measurements and analysis. We also consider six lanes of moving traffic (three in each direction) in all our simulations at theoretical data rates.

We have considered two non-positional-based routing algorithms (AODV and DSR) and two positional-based routing algorithms (LORA_CBF and GPSR). Results show that mobility and network size affects the performance of AODV and DSR more significantly than LORA_CBF and GPSR. Link failures are significantly more common in highly mobile, dynamic networks. Link failures trigger a new route discovery phase in all of the algorithms; however, in AODV and DSR, this occurs more frequently because of their routing mechanisms. Thus, the frequency of route discovery packets is directly proportional to the number of route breaks. We observe that positional-based routing protocols provide excellent performance in terms of end-to-end delay and packet delivery ratio. Their disadvantage, however, is that position-based protocols must transmit additional information, thus increasing network congestion. Non-positional-based routing algorithms suffer from sub-optimal routes and have a lower packet delivery ratio because of dropped packets. In addition, our Location Routing Algorithm with Cluster-Based Flooding (LORA_CBF) is robust in terms of delivery ratio, routing overhead, route discovery time, and routing load.

Future work related to the development of LORA-CBF will include integrating GPS, a predictive algorithm, and dynamic geographical maps into a sole architecture to be deployed in a test bed.

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