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# A Novel Routing Algorithm for Vehicular Ad Hoc Networks

# Un Nuevo Algoritmo de Enrutamiento para Redes Ad Hoc Vehiculares

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## Abstract

This article examines the importance of wireless ad hoc networks and the Location Routing Algorithm with Cluster-Based Flooding (LORA-CBF) for inter-vehicular communication in the context of optimizing traffic flow and increasing motorway safety. The LORA-CBF routing algorithm is discussed and simulated in detail, considering a motorway environment with its associated high mobility. First, for small-scale networks, our proposed simulation model is validated with the results of a test bed. Then, for large-scale networks we use simulations to compare our model with both the Ad Hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR) algorithms. We use a microscopic traffic model, developed in OPNET, to ascertain the mobility of 250 vehicles on a motorway. Finally, we apply LORA-CBF in a vehicular test bed.

--------- *Keywords:* vehicular ad hoc networks, mobile ad hoc networks, wireless ad hoc networks.

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## Resumen

Este trabajo examina la importancia de las redes inalámbricas ad hoc y el algoritmo de enrutamiento con inundación basada en grupos (LORA-CBF) para la comunicación inter-vehicular con la finalidad de optimizar el flujo de tráfico e incrementar la seguridad en las autopistas. Se discute el algoritmo de enrutamiento LORA-CBF y se presentan los resultados de simulaciones realizadas en OPNET de una autopista con alta movilidad vehicular. Primero, el modelo de simulación propuesto se valida a pequeña escala con resultados experimentales. Posteriormente, se emplean simulaciones de nuestro modelo comparándolos con Ad Hoc On-Demand Distance Vector (AODV) y Dynamic Source Routing (DSR). Finalmente, se emplea un modelo de tráfico microscópico desarrollado en OPNET para simular la movilidad de 250 vehículos en una autopista y se aplica el algoritmo de enrutamiento LORA-CBF en un escenario vehicular.

--------- *Palabras clave:* redes ad hoc vehiculares, redes móviles ad hoc, redes ad hoc inalámbricas.

## Introduction

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-vehicle Communication (IVC) and Vehicle-to-Roadside Communication (VRC). Presently, technologies related to these architectures and their related technologies may, in the future, have significant applications in the area of efficiently administering traffic flow, which, in turn, can have important economic and safety ramifications.

Active vehicular systems employ wireless ad hoc networks and Geographic Positioning System (GPS) to determine and maintain the inter-vehicular distancing necessary to insure both the one hop and multi hop communications needed to maintain spacing between vehicles. Location based routing algorithms form the basis of any Vehicular Ad hoc Network (VANET) because of the flexibility and efficiency they provide with regards 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 a few, we propose a Location-Based Routing Algorithm with Cluster-Based Flooding (LORA-CBF) as an option for present and future automotive applications [1].

Generic routing protocols have the design goals of optimality, simplicity and low overhead, robustness and stability, rapid convergence, and flexibility. However, since mobile nodes have less available power, processing speed, and memory, low overhead becomes more important than in 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 protocols deal with any inherent delays in the underlying technology, be able to deal with varying degrees of mobility, and be sufficiently robust in the face of potential transmission loss due to drop out. In addition, such protocols should also require minimal bandwidth and efficiently route packets.

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 paper 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 networking in the automobile industry.

In order to assess this proposed algorithm, the performance of Dynamic Source Routing (DSR) and Ad hoc On-demand Distance Vector Routing (AODV) for non-positional and Location Routing algorithm with Cluster-Based Flooding (LORA_CBF) for positional algorithms are compared. Our model applies to vehicles on a motorway, uses a microscopic traffic model based on Simone 2000 [2] and uses proto-c code in OPNET. Our simulation evaluates average End-to-End Delay (EED), Routing Load, Routing Overhead, Overhead, and Delivery Ratio for the above protocols.

Then, a brief introduction to inter-vehicle and vehicle to roadside communication is presented. Our proposed optimal protocol, the reactive Location Routing Algorithm with Cluster-Based Flooding (LORA_CBF), is also discussed, as well as details of a microscopic traffic simulation model representing vehicular movement on a motorway. Next, the simulation of the scenario and results are discussed. Controls for validation of the OPNET model, description of the implementation of the LORA-CBF test bed, conclusions and suggestions for future research are finally presented.

### *Inter-Vehicle and Vehicle to Roadside Communications*

The last decade has witnessed an increased interest in inter-vehicle and vehicle to roadside communication, in part, because of the proliferation of wireless networks. Most research in this area has focused on vehicle-roadside communication, also called beacon-vehicle communication [3, 4] in which vehicles share the medium by accessing different time slots (Time Division Multiple Access, TDMA), beacons (down-link direction) and vehicles (up-link direction).

Some common applications for vehicle to roadside communications with limited communication zones of less than 60 meters include: Automatic Payment, Route Guidance, Cooperative Driving, Parking Management, etc. However, with the introduction of the IEEE 802.11 standard, wireless ad hoc networks and location-based routing algorithms have made vehicle-to-vehicle communication possible [5, 6].

The authors in [5] compare a topology-based approach and a location-based routing scheme. The authors chose Greedy Perimeter Stateless Routing (GPSR) as the location-based routing scheme and Dynamic Source Routing (DSR) as the topology-based approach. In [6], the authors compare two topology-based routing approaches, DSR and Ad hoc On-Demand Distance Vector (AODV), versus one position-based routing scheme, GPSR, in an urban environment.

In inter-vehicle communication, vehicles are equipped with on-board computers and wireless networks, allowing them to contact other similarly equipped vehicles in their vicinity. By exchanging information, in the near future, vehicles will be able to obtain knowledge about local traffic conditions, which may improve comfort, traffic flow and safety.

The focus of this work is inter-vehicle communication because vehicle-roadside communication has already been proposed for standardization in Europe (CEN TC 278 WG 9) and North America (IVHS).

### *Location Routing Algorithm with Cluster-Based Flooding (LORA-CBF)*

LORA-CBF 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 locations 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 1). 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 returns to the sender using geographic routing because each node knows the position of the source and the closest neighbor, based on the information from the LREQ received 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 location of the destination, it retrieves the data packet from its buffer and sends it to the closest neighbor to the destination.

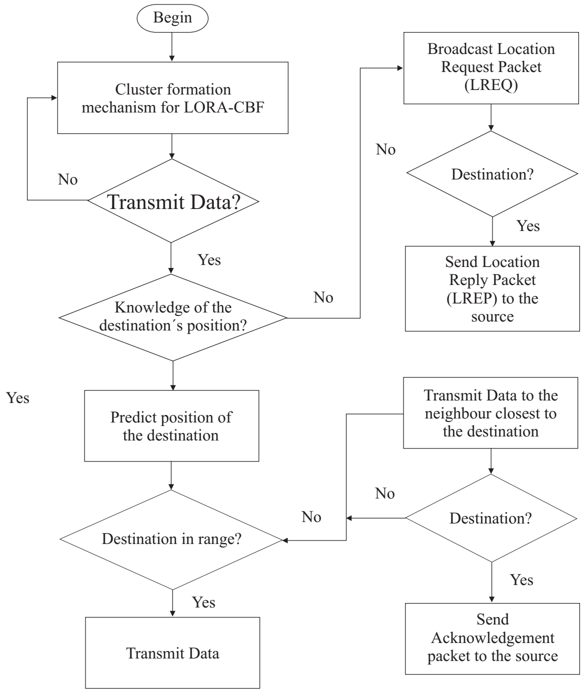

**Figure 1** Flow diagram for LORA-CBF

Basically, the algorithm consists of four stages:

1. Cluster formation
2. Location discovery (LREQ and LREP)
3. Routing of data packets
4. Maintenance of location information

### Cluster formation

To enable cluster formation and maintenance, all nodes maintain neighbor information in their respective tables.

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 member in the cluster.

When a member receives a Hello packet from a different cluster head, it first registers the cluster head, but the member does not modify its cluster head ID until the expiration time for the field has expired. Before the member rebroadcasts the new information, it changes its status to a gateway. After receiving the Hello packet, the cluster-heads update the Cluster Table with the information about the new gateway.

If the source wants to broadcast a message to the destination, it first checks its routing table to determine if it has a "fresh" route to the destination. If it does, it first seeks its Cluster Table to determine the closest neighbor to the destination. Otherwise, it starts the location discovery process.

### Location discovery process

When the source of the data packet wants to transmit 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 identification field of the packet 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 address of the LREQ packet in its routing table and rebroadcasts the LREQ packet to its neighboring cluster heads.

Each cluster head node forwards the packet once. The packets are broadcast 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 in order 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 cluster head of the destination knows the location of 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 any LREP after sending out 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 routing path from the source to the destination, and the path is determined from the location information given by the source node. The path followed by the LREQ may be different from that traversed by the LREP.

### *Routing of data packets*

The actual routing of data packets is then based on the location of source, destination, and their neighbors.

Since the protocol is not based on source routing, packets travel the path from source to a destination based on 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 their relative position. 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 found 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 situation might occur during loss of packets due to drop out or network disconnection.

LORA-CBF uses MFR (most forward within radius) as its forwarding strategy. In MFR, the packet is sent to the neighbors that most reduce the distance to the destination. The advantage of this method 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 predictive algorithm*

In highly mobile environments, having the correct knowledge of neighbor positions is fundamental in the routing efficiency of any algorithm. LORA-CBF predicts the next position (geographical location) of every neighbor node, based on its short-term predictive algorithm. After predicting the position of all neighbor nodes, LORA-CBF sends the packet to the neighbor node with the optimal position (MFR), meaning that it can reach the node that is closest to the destination.

Mobility and contention of the wireless media may cause the loss of packets being transferred, and this is a very important aspect to consider in the development of predictive algorithms. We address this problem, including the gap between packets being received.

The short-term predictive algorithm tries to extrapolate the position of the next hop *k* ahead in time. For example, a simple technique is to assume the data follows a linear trend.

$$P_{j+k} = P_j + \Delta P * e \qquad (1)$$

Where:

| | |
|---|---|
| $P_{j+k}$ | future position of the next hop |
| $P_j$ | current position of the next hop |
| $\Delta P$ | interval between current position and previous position of the next hop |
| $e$ | factor indicating the gap between packets received |

The predictive algorithm is useful for contention-based networks with very high mobility. In LORA-CBF, a Hello message is broadcast periodically. Every node maintains the location information of every neighbor from which it has received a Hello message. When a node receives a packet for transmission to a particular destination, it first checks its routing table to determine if it knows the location of the destination node. If it does, it triggers the short-term predictive algorithm to calculate the future position of the destination. If the node can reach the destination, it sends the packet directly. Otherwise, before retransmitting it, the node predicts the locations of the neighbor nodes, based on previous positions, and sends the packet to the closest neighboring node to the predicted destination.

## Microscopic traffic simulation model

Vehicular traffic models may be categorized according to the level-of-detail into four classifications: sub-microscopic, microscopic, mesoscopic and macroscopic [7]. The 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 each driver's behavior and the interaction among drivers; the implemented algorithms are very detailed and allow tracking explicitly the space-time trajectory of each vehicle [8]. Mesoscopic models represent the transportation systems analyzing groups of drivers having homogeneous behaviours. Finally, macroscopic models describe traffic at a high level of aggregation as a flow without distinguishing its basic parts [9]. Because we are interested in the space-time trajectory of each vehicle governed by the vehicle in front, 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 the vehicles in the traffic system.

The microscopic traffic simulation model used in this work for evaluating the performance of the three algorithms is based on Simone 2000. [2] The model is a sophisticated microscopic traffic flow model that represents a wide range of user-classes. The model distinguishes longitudinal (car-following) and lateral (lane-changing) driver behavior. The longitudinal distance controller is one of the main elements of a microscopic simulation model for traffic flows. It describes how a vehicle progress along a 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, $\eta$ = 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 the vehicle immediately in front of the 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

### The communication mechanism

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

The first task of our study is to validate our model in 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 and DSR algorithms. We validate LORA-CBF against a topological algorithm due to that ABR (Associativity Based Routing protocol) was the first algorithm showing results in a test bed.

Table 1 shows the results of the comparison between the test bed and the simulation's results in OPNET, which validate LORA_CBF.

**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 and DSR algorithms. The comparison is reasonable because we have improved the data reception mechanism by using an acknowledgement packet in AODV and DSR protocols. When the timer for an acknowledgement data packet expires, AODV and DSR start a new Route Request (RREQ) packet.

### Metrics of Simulations

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

- Average end-to-end delay of data packets: are 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: is measured in terms of 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 on each hop is counted once for both routing and data packets. This provides an

idea of network bandwidth consumed by routing packets with respect to "useful" data packets.

- Routing overhead: is 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): is 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: is the ratio of data packets delivered to the number of data packets sent by the sender. Data packets, however, may be dropped en if 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 mobiles nodes traveling on a 6283m circular road (Figure 2).

This configuration is reasonable for UK motorway traffic 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 and 5 dBi gain car-mounted antennas. An experiment was carried out to validate the transmission range between two vehicles driving in opposite directions.

## *Simulation results*

Figure 3 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 overheard 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 5). Figure 4 shows overhead, which is higher for AODV. Generally, highly mobile environments suffer from broken links more frequently, resulting in the retransmission of RERR messages. In the case of AODV, overhead increases proportionally to the number of Hello messages. Figure 5 represents the routing load. AODV shows a higher routing load than for 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 6, illustrates that that all of the algorithms have lower delays at a data rate of 1 Mbps. In general, AODV has greatest delay because of its frequent retransmissions. DSR has been shown to have the best performance because of its packet control strategy. LORA_CBF has slightly greater EED compared with DSR.

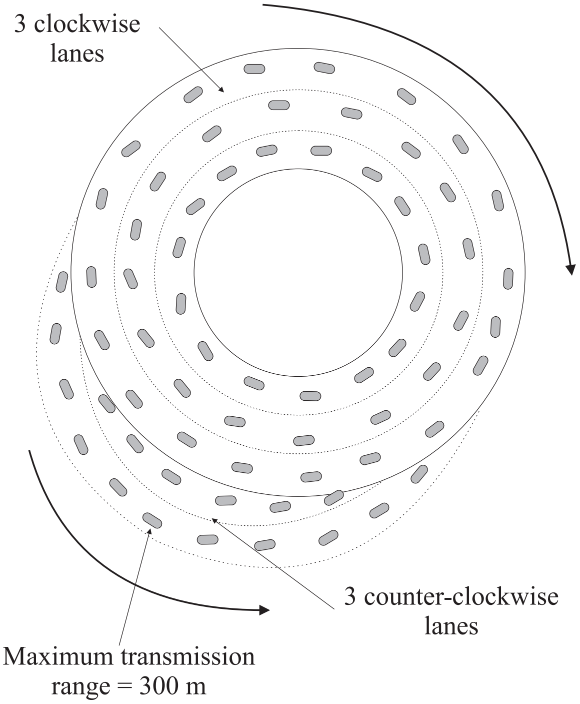

**Figure 2** Scenario simulated

Figure 7 compares the packet delivery ratio of all of the algorithms considered. LORA_CBF shows good results at both data rates, and AODV has a slightly worse packet delivery ratio than DSR. Both AODV and DSR perform the worst at delivery ratios at a data rate of 11 Mbps.

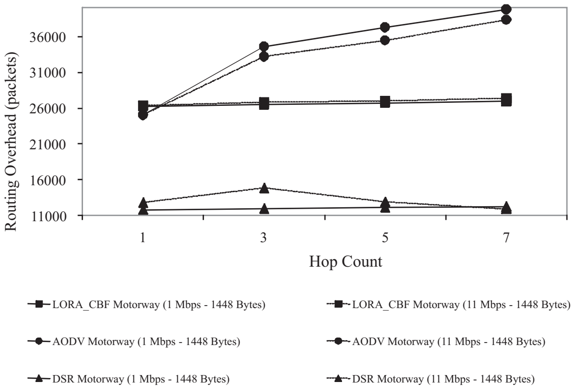

**Figure 3** Routing Overhead

### *Implementation of the LORA-CBF Algorithm Test Bed*

We deployed LORA-CBF on a test bed using *Linux* and equipped each node with an Enterasys wireless card, employing sockets to allow the communication between neighbor nodes. Five laptops with ad hoc routing capability were deployed in an outdoor environment to represent 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 [11]. In [11], each node ran the Associativity-based routing (ABR) protocol. The ABR and LORA-CBF algorithms a employed periodic beaconing strategy to inform neighbor nodes about their presence, using both source-initiated on-demand ad hoc routing protocols to discover routes. The main difference is that ABR selects the route based on its longevity. On the other hand, LORA-CBF uses a predictive algorithm to select the best route based on the geographic locations of neighbor nodes.

Results show that LORA-CBF and ABR have similar behavior for the different packet sizes selected for the study.

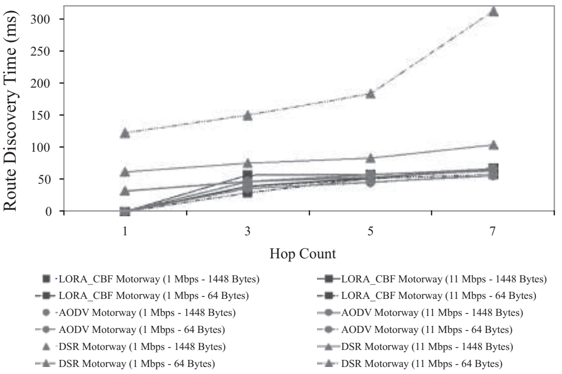

**Figure 4** Overhead

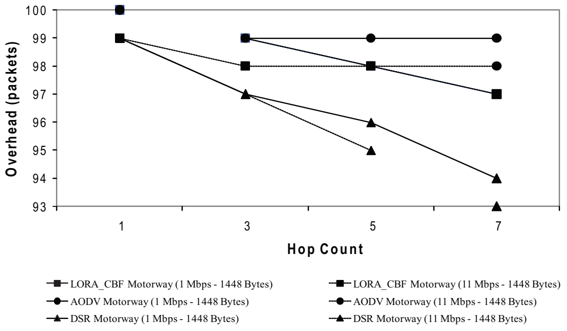

**Figure 5** Routing Load

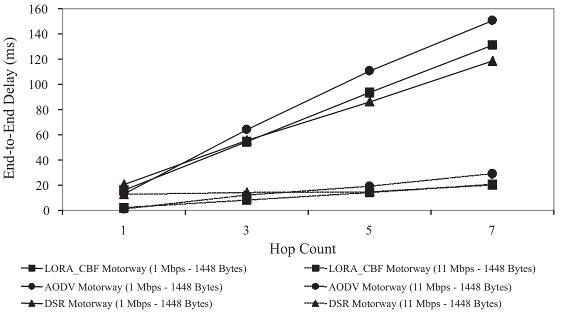

**Figure 6** End-to-End Delay (EED)

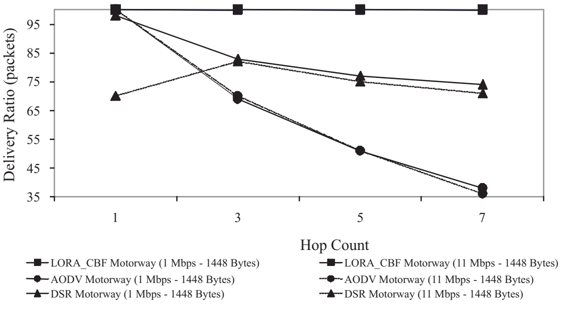

**Figure 7** Delivery Packet Ratio

## Conclusions and future work

In order to reduce communication costs and guarantee the low delays required for the exchange of safety-related 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 of its reactive geographic routing algorithm, which employs GPS in conjunction with its predictive algorithm, both of which are necessary in mobile networks. Furthermore, LORA-CBF uses a gateway selection mechanism to reduce contention in dense networks, which is a predictable scenario 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 work, we have taken into account the mobility involved in typical motorway traffic scenarios and have simulated a very large network of two hundreds and fifty nodes. 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 one positional-based routing algorithm (LORA_CBF). Results show that mobility and network size affects the performance of AODV and DSR more significantly than LORA_CBF. In the presence of high mobility, link failures are more common. Link failures trigger new routes discoveries in all of the algorithms, but in AODV and DSR, this happens more frequently due to their routing mechanism. Thus, the frequency of route discovery 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, at the cost of using additional information. Non-positional-based routing algorithms suffer from sub-optimal routes and have a worse packet delivery ratio because of dropped packets. In addition, our Location Routing Algorithm with Cluster-Based Flooding (LORA_CBF) is robust in terms of Routing Overhead, Overhead, Routing Load and Delivery Ratio.

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

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