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A Reactive Location Routing Algorithm with Cluster-Based Flooding for Inter-Vehicle Communication

Un Algoritmo de Enrutamiento de localización Reactivo con Diseminación Basada en Grupos para Comunicación Inter-Vehicular

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Abstract

In this paper, we present a reactive location routing algorithm with cluster-based flooding for inter-vehicle communication. We consider a motorway environment with associated high mobility and compare position-based and non-position-based routing strategies, along with a limiting function for flooding mechanisms in reactive ad-hoc protocols. 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 is considered. First, for small-scale networks, our research validates our proposed simulation model with the results of a test bed and the results of mathematical analysis. Then, for large-scale networks, we use simulations to compare our model with both the AODV and DSR reactive routing algorithms. Finally, we use a microscopic traffic model, developed in OPNET, to ascertain the mobility of 250 vehicles on a motorway with regards to average Route Discovery (RD) time, End-to-End Delay (EED), Routing Load, Routing Overhead, Overhead, and Delivery Ratio.
Keywords: Unicast routing, multi-hop wireless networks, inter-vehicular data exchange, ad-hoc networks, location routing algorithm with cluster-based flooding.

Resumen

En este trabajo, presentamos un algoritmo de enrutamiento reactivo por posición basado en grupos para comunicación Inter.-vehicular. También se ha estimado un escenario automovilístico de alta velocidad (autopista), y se ha comparado estrategias de enrutamiento reactivas basadas en posición y no-posición, además de un mecanismo de reducción de diseminación de información en protocolos ad-hoc reactivos. El rendimiento de los algoritmos basados en no-posición: Dynamic Source Routing (DSR) y Ad-Hoc On-Demand Distance Vector (AODV) y del algoritmo basado en posición: Location Routing Algorithm with Cluster-Based Flooding (LORA_CBF), han sido considerados. Como primer paso, hemos validado nuestro modelo de simulación propuesto en redes de pequeña escala, con los resultados de un experimento y los resultados de análisis matemático. Después, hemos usado simulaciones para comparar y validar nuestro modelo en redes de gran escala, con dos prominentes algoritmos reactivos: AODV y DSR. Finalmente, hemos desarrollado en OPNET, un modelo de trafico microscópico, que nos permite evaluar el rendimiento de 250 vehículos en términos del tiempo de descubrimiento de ruta, retardo punto a punto, carga de enrutamiento, sobre encabezado de enrutamiento, el sobre encabezado general y la razón de entrega de información.
Palabras Claves: Enrutamiento de difusión única, redes inalámbricas multisaltos, intercambio de datos inter-vehicular, redes ad-hoc, algoritmo de enrutamiento de localización con diseminación basada en grupos.

1 Introduction

Good examples of ad-hoc routing protocols can be found in [1, 2], where they are applied both in static networks (i.e. Rooftop networks, sensor networks) [3, 4] and highly dynamic networks (i.e. vehicular networks) [5, 6].

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.

The past few years have witnessed the growth of wireless technologies that have gained increased relevance and acceptance in the form of laptops, PDAs, and personal area networks, all of which require ad-hoc connectivity. The areas of personal computing and communications are converging and evolving to create new patterns of technological deployment and human behaviour because of communication-enabled technology. Our hypothesis is that a vehicular point-to-multipoint deployment is likely to become the first properly mature ad-hoc implementation of these emerging technologies.

Economically, we believe this is the case because there is already a great demand and a potentially enormous market for vehicular services, particularly in the areas of real-time automobile diagnostics, communication, entertainment and safety. Technologically speaking, point-to-multipoint deployment best parallels real-life, real-time vehicular behaviour and needs. Furthermore, power consumption does not represent a significant limitation as automobiles generate power continually when the motor is in operation and can store it in a battery. Therefore, we believe systems requiring point-to-multipoint deployment of ad hoc mobile networks will become standard factory installed equipment within the next decade.

Several routing algorithms for ad-hoc networks have emerged recently to address the problem of unicast routing. Such algorithms can be categorized as either proactive or reactive, depending on the route discovery mechanism that is used. 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.

With 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 introduce a shorter delay before sending data. Examples of proactive algorithms include Optimized Link State Routing Protocol (OLSR) and Topology Dissemination Based on Reverse-Path Forwarding (TBRPF).

The disadvantage of OLSR and TBRPF protocols is their link state routing dissemination strategy. Recognized link changes will cause nodes to flood control packets across the entire network [9]. It is often common for nodes to have high mobility in wireless ad-hoc networks, as is the case for cars driving on a motorway. As a consequence of this mobility, 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 tables of active routes. Thus, a route is discovered whenever a source node needs to communicate with a destination node for which a route is not already available. 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 neighbours, and these, in turn, re-broadcast the route request to their neighbours. 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 drawback is the latency when establishing a route. Examples of reactive algorithms include AODV [10] and DSR [11].

Previously, proactive algorithms were not considered suitable for highly mobile environments because they tend to have poor route convergence and low communication throughput [12].

This applies, of course, to our proposed scenario for inter-vehicular communication on a motorway. To overcome these limitations, several new types of routing algorithms that use Geographic Positioning System (GPS) have been developed, including Location-Aided Routing (LAR) [13], Distance Routing Effect Algorithm for Mobility (DREAM) [14] and Grid Location Service (GLS) [15]. We now consider each of these protocols for suitability in our proposed network of highly mobile vehicles.

Trends suggest that a broad variety of location dependent services will become feasible in the near future because of Global Positioning System, and while GPS power consumption is a problem for hand held devices, automobile devices may be quick to benefit.

To continue discussion of the new protocols, LAR does not, in fact, define a location-based routing protocol. Instead, it uses position information to enhance its route discovery phase and is actually a directional flooding-based routing protocol [16]. DREAM is proactive in nature and may have issues relating to its scalability and may not, therefore, be appropriate for large-scale networks [17]. Lastly, GLS although hierarchical, is also proactive and thought to be inefficient in highly dynamic environments [17]. This discussion, therefore, provides a reasoned set of arguments and published work that offer support for not using proactive protocols in our highly mobile scenario.

Justification exists for the creation of a new protocol that is optimised for highly dynamic environments of dense inter-vehicular networks. Consequently, we propose a reactive location routing algorithm with cluster-based flooding (LORA_CBF).

In order to assess the value of 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. This comparison is reasonable because we have improved the data reception mechanism by employing the packet acknowledgement mechanism used in DSR and AODV. When the timer for an acknowledgment data packet expires, DSR, AODV and LORA_CBF start a new Route Request (RREQ) packet.

Our model applies to vehicles on a motorway and uses a microscopic traffic model based on Simone 2000 [18] and is applied using proto-c code in OPNET. Our simulation is used to evaluate average Route Discovery (RD) time, End-to-End Delay (EED), Routing Load, Routing Overhead, Overhead, and Delivery Ratio for the above protocols.

In this paper, a representative non-causal circular topology is used to represent a system of 250 automobiles circulating in a large diameter circle.

The rest of the paper is organised as follows: Our proposed optimal protocol, the reactive Location Routing Algorithm with Cluster-Based Flooding (LORA_CBF), is discussed in Section 2; Section 3 details a microscopic traffic simulation model that represents vehicular movement on a motorway; Section 4 provides discussion of the simulation of the scenario and provides results. This section also discusses controls for validation of the OPNET model; lastly, section 5 discusses our conclusions and provides suggestions for future investigation.

2 Reactive Location Routing Algorithm with Cluster-Based Flooding (LORA_CBF)

We propose a reactive algorithm for mobile wireless ad-hoc networks, which we have called *Location Routing Algorithm with Cluster-Based Flooding (LORA_CBF)*. The algorithm inherits the properties of reactive routing algorithms and has the advantage of acquiring routing information only when a route is needed. LORA_CBF has the following features: Firstly, this protocol improves the traditional routing algorithms, based on non-positional algorithms, by making use of location information provided by GPS. Secondly, it minimizes flooding of its Location Request (LREQ) packets. Flooding, therefore, is directive for control traffic as it uses only the selected nodes, called gateways, to diffuse LREQ messages. The function of gateway nodes is to minimize the flooding of broadcast messages in the network by reducing duplicate retransmissions in the same region. Member nodes are converted into gateways when they receive messages from more than one cluster head. All the members in the cluster read and process the packet, but do not retransmit the broadcast message**.** This technique significantly reduces the number of retransmissions in a flooding or broadcast procedure in dense networks. Therefore, only gateway nodes retransmit packets between clusters (hierarchical organization). Moreover, 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.

Apart from normal Hello messages, the protocol does not generate extra control traffic in response to link failures and additions. Thus, it is suitable for networks with high rates of geographical changes. As the protocol keeps only the location information of the [source, destination] pairs in the network, the protocol is particularly suitable for large and dense networks with very high mobility.

The protocol is also designed to work in a completely distributed manner and does not depend upon any central entity. The protocol does not require reliable transmission for its control messages, because each node sends its control messages periodically and can, therefore, sustain some packet loss. This is, of course, important in radio networks like the one being considered here, where deep fades are possible.

The algorithm we propose in this work does not operate in a source routing manner [11]. Instead, it performs hop-by-hop routing as each node uses its most recent location information of its neighbour nodes to route a packet. Hence, when a node is moving, its position is registered in a routing table so that the movements can be predicted, which is necessary to correctly route the packets to the next hop to the destination.

2.1 Protocol functions of LORA_CBF

Location Routing Algorithm with Cluster-Based Flooding (LORA_CBF) carries out different functions that are needed to perform the task of routing. This section will present some of the functions of the protocol.

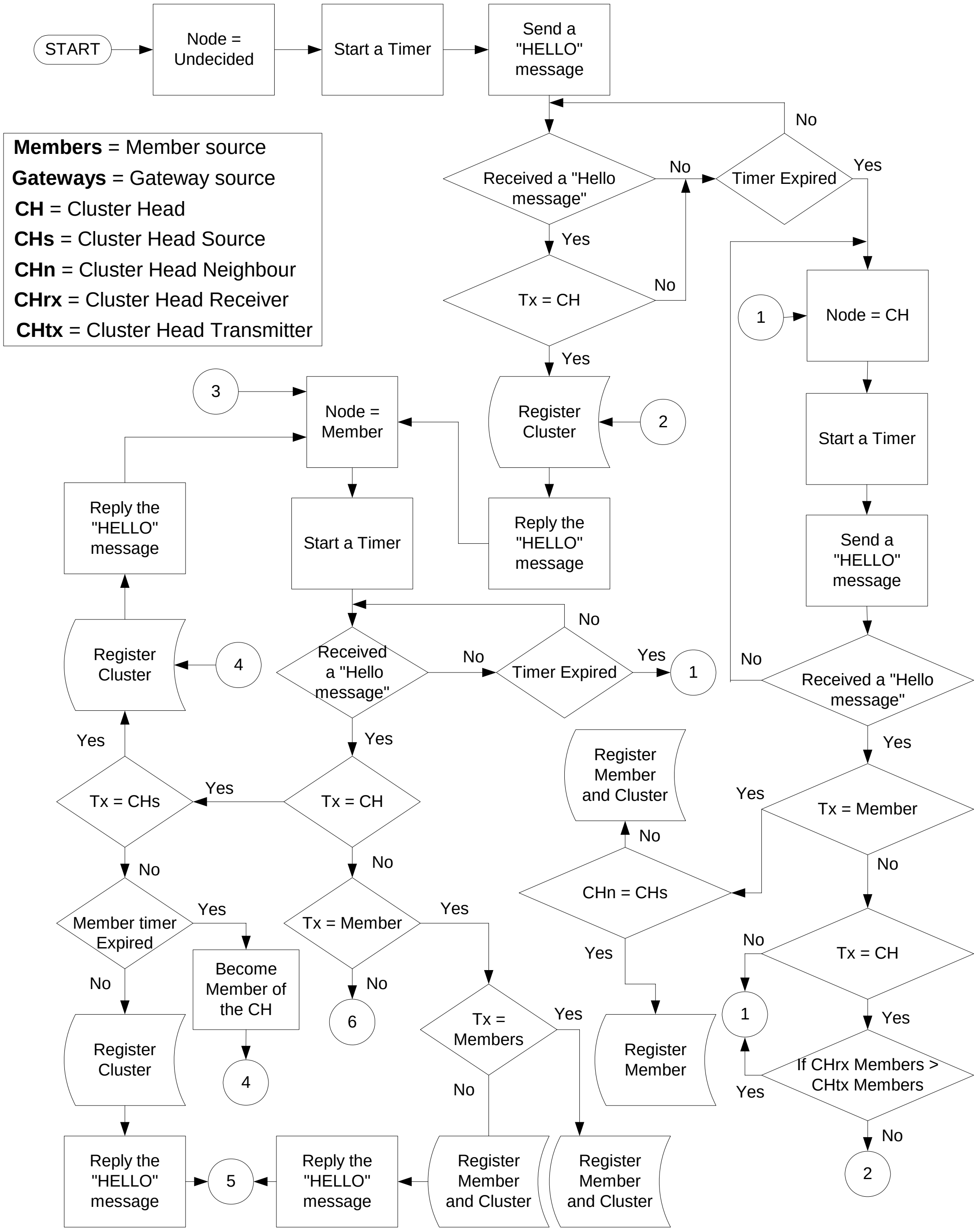
2.1.1 Neighbour sensing

Each node must detect the neighbour nodes with which it has a direct link. To accomplish this, each node periodically broadcasts a Hello message, containing its location information, address and status. These control messages are transmitted in broadcast mode and received by all one-hop neighbours, but they are not relayed to any further nodes. A Hello message contains the following information:

- Node Address.
- Type of node (Undecided, Member, Gateway or Cluster head).
- Location (Latitude and Longitude).

2.1.2 Operation of Location Routing Algorithm with Cluster-Based Flooding (LORA_CBF)

LORA_CBF must have one cluster head, zero or more members in every cluster, and one or more gateways, in order to communicate with other cluster heads (Figure 1). Each cluster head maintains a “Cluster Table,” which is defined as a table that contains the addresses and geographic locations of the member and gateways nodes. We have assumed that all nodes can ascertain their positions via GPS or some local coordinate system.


START
Node = Undecided
Start a Timer
Send a "HELLO" message
Members = Member source
Gateways = Gateway source
CH = Cluster Head
CHs = Cluster Head Source
CHn = Cluster Head Neighbour
CHrx = Cluster Head Receiver
CHtx = Cluster Head Transmitter
Received a "Hello message"
No
Timer Expired
No
Yes
Yes
Tx = CH
No
Yes
Register Cluster
2
Reply the "HELLO" message
3
Node = Member
Start a Timer
Reply the "HELLO" message
Register Cluster
4
Received a "Hello message"
No
Timer Expired
No
Yes
1
Yes
Tx = CH
Yes
Tx = CHs
Yes
No
No
Member timer Expired
Yes
No
Become Member of the CH
4
Register Cluster
Reply the "HELLO" message
5
Reply the "HELLO" message
Tx = Member
Yes
No
6
Tx = Members
Yes
No
Register Member and Cluster
Register Member and Cluster
1
Node = CH
Start a Timer
Send a "HELLO" message
No
Received a "Hello message"
Yes
Tx = Member
Yes
No
Register Member and Cluster
No
CHn = CHs
Yes
Register Member
Tx = CH
No
1
Yes
If CHrx Members > CHtx Members
Yes
No
2

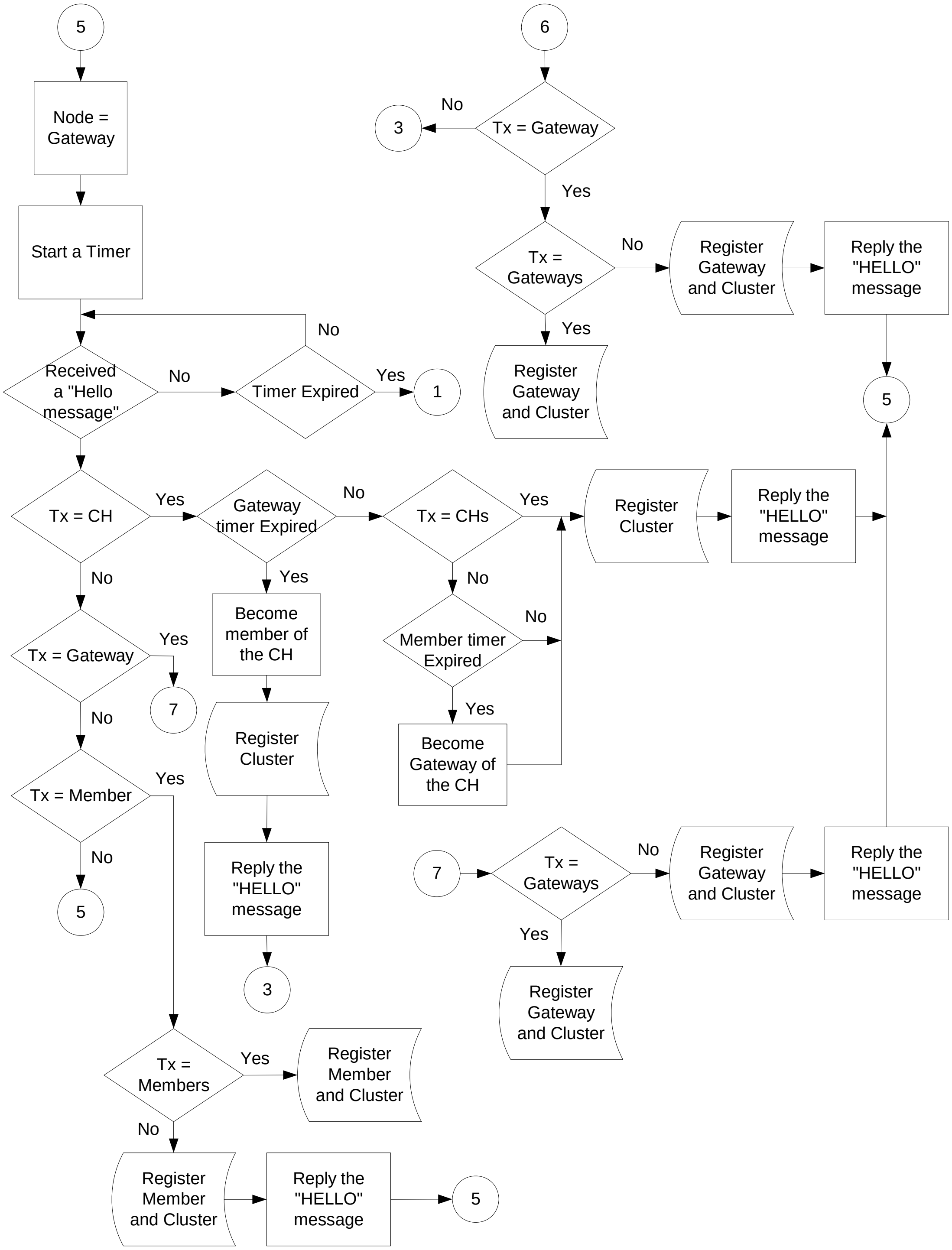


Fig. 1. Cluster formation mechanism for LORA_CBF

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 neighbour to the destination. 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 LREQ packets. 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 checks to see if 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 neighbour, based on the information received from the LREQ and the neighbour sensing mechanism. Failure triggers retransmissions by the cluster head to adjacent cluster heads, where the destination address is recorded in the packet. Cluster heads and gateways, therefore, discard location request packets they have already seen.

Once the source receives the location of the destination, it acquires the data packet from its buffer and sends it to the closest neighbour to the destination.

Essentially, the algorithm consists of four stages:

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

2.1.2.1 Formation of clusters

The LORA_CBF algorithm initializes by first forming clusters. When the communications start, every node begins as undecided, starts a timer, and broadcasts a Hello message. If the undecided node receives a Hello message from a cluster head before the timer expires, it becomes a member. Otherwise, it becomes a cluster head.

Cluster heads are responsible for their clusters and have to send a Hello Message periodically. When a member 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 and changes its status to a gateway and broadcasts the new information to the cluster heads. After receiving the Hello packet, the cluster head updates the Cluster Table with the new information.

In the case where the source wants to send 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 searches its Cluster Table to determine the closest neighbour to the destination. Otherwise, it starts the location discovery process.

2.1.2.2 Location discovery

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 puts the data packet in its buffer and broadcasts a Location Request (LREQ) packet.

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. If it has, it discards the packet. Otherwise, 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 is not a member of the cluster head, it first records the address of the LREQ packet in its list and rebroadcasts the LREQ packet to its neighbouring cluster heads.

Each cluster head node forwards the packet only once. The packets are broadcast only to the neighbouring 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 destination’s cluster head can determine the location of the source node. The destination then sends a LREP message back to the source via its closest neighbour.

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. It is important to note that the path traversed by the LREQ may be different from that travelled by the LREP.

2.1.2.3 Routing of Data Packets

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

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 the destinations individually each time they transmit between the source and the destination. Packets are transmitted based on the knowledge of their relative position. Moreover, since the transmission is in the direction of the destination node, the path found will be shorter than in other routing mechanisms. In non-positional-based Routing strategies, the shortest path is measured in hops. Therefore, the path found may not be the shortest, but 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 packet loss due to drop out or network disconnection.

2.1.2.4 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 the 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.

2.1.2.5 Forwarding strategy

LORA_CBF uses MFR (most forward within radius) as its forwarding strategy. In MFR the packet is sent to the neighbour with the greatest progress 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 [16].

3 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 [19]. The sub-microscopic models describe the characteristics of individual vehicles in the traffic flow and the operation of specific parts (sub-units) of the vehicle. Microscopic models simulate each driver's behaviour and the interaction with other drivers. Mesoscopic models represent the movement of groups of drivers with homogeneous behaviours, and finally, macroscopic models describe traffic in great detail as a flow without distinguishing its basic parts [21, 22]. Note that since the speed of each vehicle is governed by the vehicle immediately in front of it, our attention will focus on microscopic traffic models.

Several microscopic traffic simulation models have been developed [23]. Basically, these models describe vehicular behaviour within 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 [18], which effectively models longitudinal (car-following) and lateral (lane-changing) driver behaviour. The longitudinal distance controller is one of the main elements of a microscopic simulation model for traffic flows. It describes how vehicles progress along a lane. 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:

A. Desired gap function

With this function, the longitudinal controller determines the acceleration (positive or negative) needed to obtain a desired minimum distance to the vehicle immediately in front of it.

$$s_i(t) = l_i + \eta_i(t) \cdot (z0_i + z1_i \cdot v_i(t) + z2_i \cdot v_i(t)^2) \tag{1}$$

Where:

S(t) = desired gap distance (from rear follower ί to rear leader) (m), ί = index vehicle, l = length of vehicle ί, η = congestion factor, z0 = margin parameter (m), z1 = linear headway parameter (s), z2 = quadratic headway parameter (s^2), v(t) = speed at time t (m/s).

B. Longitudinal controller

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

$$\alpha_{\iota}(t+\tau) = \alpha_{i} \cdot (x_{i-1}(t) - x_{i}(t) - s_{i}(t)) + \beta_{\iota}^{\pm} \cdot (v_{i-1}(t) - v_{i}(t)) \tag{2}$$

With:

$\alpha(t+\tau)$ = acceleration applied after delay time (m/s^2), *x(t)* = x-coordinate vehicle rear bumper at time t (m), *v(t)* = speed at time t (m/s), ί = index subject vehicle (follower), ί -1 = index subjects' leader, α= distance error sensitivity (1/s), β^{+} = speed difference sensitivity (for positive difference) (1/s^2), β^{-} = speed difference sensitivity (for negative difference) (1/s^2).

4 Validation of the Model

4.1 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 hop, considering the results of an experimental test bed [24] and the mathematical analysis for IEEE 802.11 wireless radios. For two and three hops we will compare 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 with the comparison of the models of the AODV and DSR algorithms.

4.1.1 One hop Validation

Two metrics were considered for validation: Throughput and End-to-End Delay (EED). Equation (3) can be used to determine the EED:

$$EED = DIFS + Overhead + \frac{Data(bits)}{Transmission\_Rate(bits/\mathrm{sec})} + SIFS + ACK \tag{3}$$

Where:

DIFS= Distribute Inter-frame Space, SIFS= Short Inter-frame Space and ACK= Acknowledgement Frame

For Throughput, we consider the same modulation technique used in [24].

$$\text{Throughput (bits/sec)} = \frac{Data}{EED} \cdot (1 - PER) \tag{4}$$

Equation (4) expresses throughput, taking into account the time required to transmit a data packet (EED) and the probability of a packet being received in error (PER).

$$PER = 1 - (1 - P_e)^{number\_of\_bits\_in\_the\_packet} \tag{5}$$

Equation (5) depends on the packet size; the greater the packet size, the greater is PER. Finally, the probability of error for DBPSK in IEEE 802.11 radios can be determined using the following equation.

$$P_e = \frac{1}{2 \cdot \left(1 + \frac{E_b}{N_0}\right)} \tag{6}$$

$$\text{Where } E_b = P_{out} - 20\log_{10}\frac{(4 \cdot \pi \cdot D)}{\lambda} \tag{7}$$

Equation (7) represents the energy of the bit at the receiver side.

Table 1 shows the results for one-hop transmissions of 1000-Byte data packets at a distance of 300 m between the transmitter and receiver, with a data rate of 11 Mbps. The three values are similar for experimental, analytical and OPNET simulation results.

Table 1. Results validating LORA_CBF in one hop.

	EED	**Throughput**
Test Bed (C-K Toh)	10.4 ms	769.23 Kbps
Numerical Analysis	8.4 ms	956 Kbps
OPNET model	9.1 ms	878.93 Kbps

4.1.2 Two and Three Hops Validation

Table 2. Results validating LORA_CBF for two and three hops

EED (ms)	**Two Hops**	**Three Hops**
Test Bed (C-K Toh)	19.7	29.2
OPNET model	18.854	28.591
Throughput (Kbps)	**Two Hops**	**Three Hops**
Test Bed (C-K Toh)	406.091	273.972
OPNET model	424.313	279.808

Table 2 shows the results of the comparison between the test bed and the simulation's results in OPNET, which validate LORA_CBF for the transfer of data packets of 1000 Bytes. We employ a packet size of 1000 Bytes to better compare LORA_CBF with Associativity-based routing, proposed by C-K Toh, who uses a packet size of 1000 Bytes [24], and writes that the maximum packet size permissible for two and three-hop route experiments is 1448 Bytes.

4.1.3 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.

4.2 Metrics of Simulations

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

- ***Route discovery time (Latency)***: *is the amount of time the source has to wait to send the first data packet.*

- ***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 routing packets transmitted per 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 transmission of the packet (each hop) counts as one transmission.*
- ***Overhead (packets):*** *is the total number of routing packets generated divided by the total number of data packets transmitted, plus the number total routing packets.*
- ***Packet delivery ratio:*** *is measured as a ratio of the number of data packets delivered to the destination and the number of data packets sent by the sender. Data packets may be dropped en route for one reason: the next hop link is broken when the data packet is ready to be transmitted.*

The simulator for evaluating three routing protocols is implemented in OPNET. The simulation models a network of 250 mobiles nodes, moving around a 6283 m length circular road of (Figure 2).

This configuration is reasonable for UK motorway traffic because of the low rate curvature rate of its roads, which allows vehicles to circulate at a more constant velocity. We have considered a non-causal model, where vehicles cannot enter or exit the system. The IEEE 802.11b Distributed Coordination Function (DCF) is used as the medium access control protocol. In order to enable direct, fair comparison between the protocols, they are all simulated with identical loads and conditions. We also developed a microscopic traffic simulation model in OPNET to simulate vehicular mobility on a motorway. A transmission range of 300 m. was chosen, which is consistent with current 802.11b Wireless LAN and 5 dBi gain car-mounted antennas. An experiment was realized to validate transmission range between two vehicles driving in opposite directions. The sideway rate of direction change is small when compared to the forward rate of direction change.

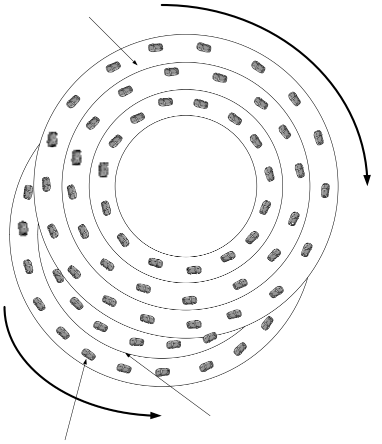


Fig. 2. Scenario simulated.

4.3 Simulation results

We select a packet size of 1448 Bytes because this is the maximum size permissible in two and three hop transmissions using the ping application, and the 1000 Byte-packet size is employed only to validate the model with a test bed published by [24]. We consider two data transmission rates for our simulations: a theoretical maximum of 11 Mbps and the worst case with 1 Mbps. The model is valid in upper and lower boundary situations as each value represents the results of 12 simulations with a margin of error of <20%. Figure 3 shows the route discovery time for all the algorithms evaluated. DSR has been shown to fare worst at 1 Mbps and its performance is worst at a data rate of 11 Mbps. AODV and LORA_CBF perform similarly at both data rates. Figure 4 shows routing overhead. Here, DSR performs better because it lacks a neighbour sensing mechanism and AODV increases its routing overhead according to distance between nodes. LORA_CBF maintains its routing overhead at an almost constant level, because the level depends on the frequency of Hello messages. This is constant and independent of the maximum distance between communication partners. AODV requires about 3 times the routing overhead of DSR (also reported in [25]). Overhead is shown in the Figure 5; again, AODV has the lowest performance. Generally, highly mobile environments cause link breaks more frequently, resulting in the retransmission of RERR messages. In the case of AODV, overhead increases according to the number of Hello messages. Figure 6 represents the routing load. AODV shows more routing load than both LORA_CBF and DSR. This also increases with distance and depends on the data delivered. End-to-End delay (EED), which is presented in Figure 7, shows that all of the algorithms have a lower performance at a data rate of 1 Mbps. In general, AODV has the worse delay due to its frequent retransmissions. DSR has been shown to have higher performance because of its economy of control packets. LORA_CBF has slightly greater EED compared with DSR.

Figure 8 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.

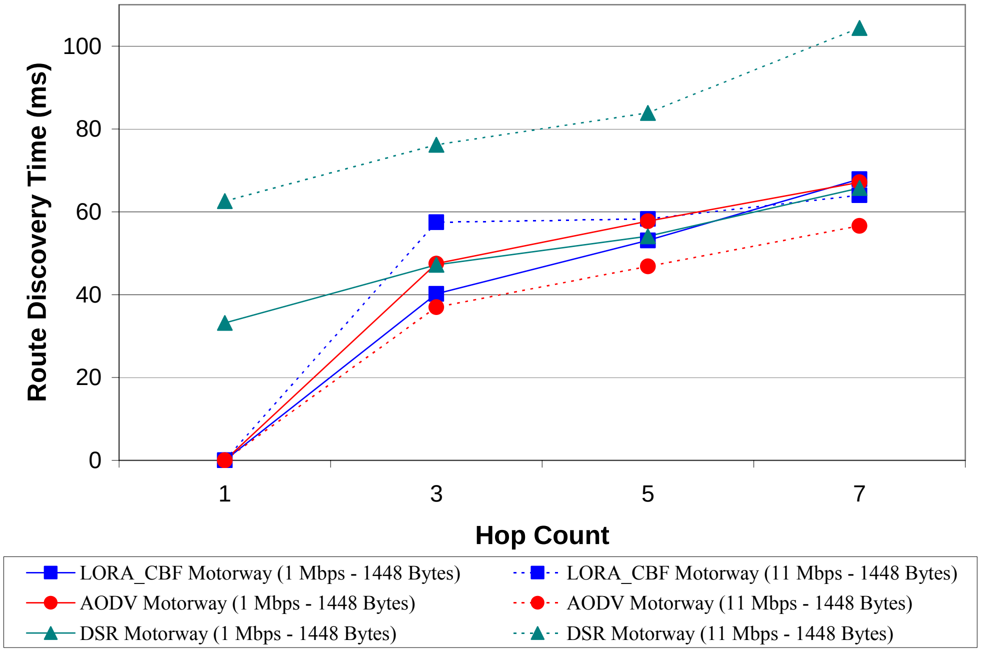


Fig. 3. Route Discovery Time

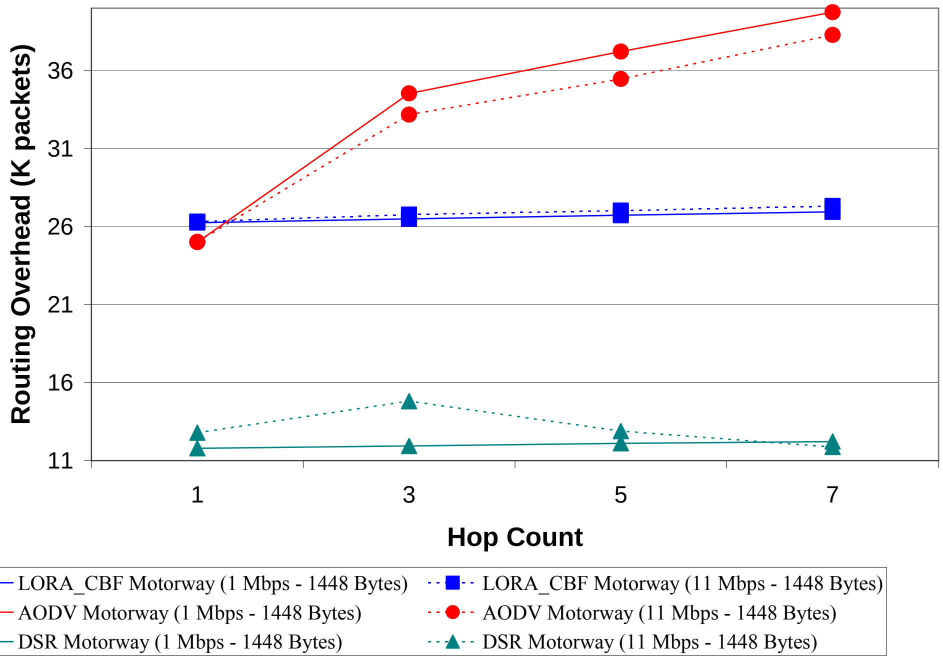


Fig. 4. Routing Overhead

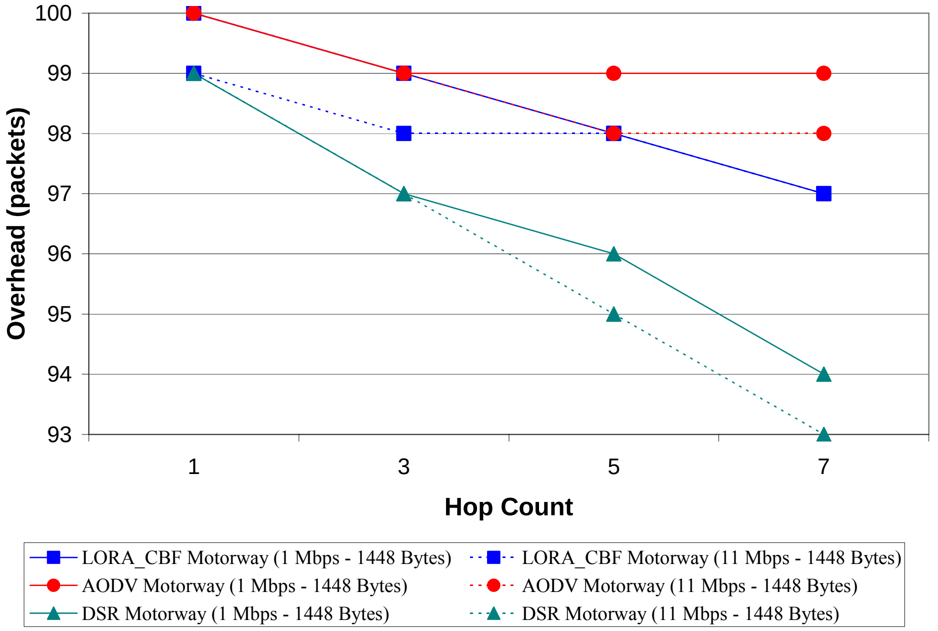


Fig. 5. Overhead

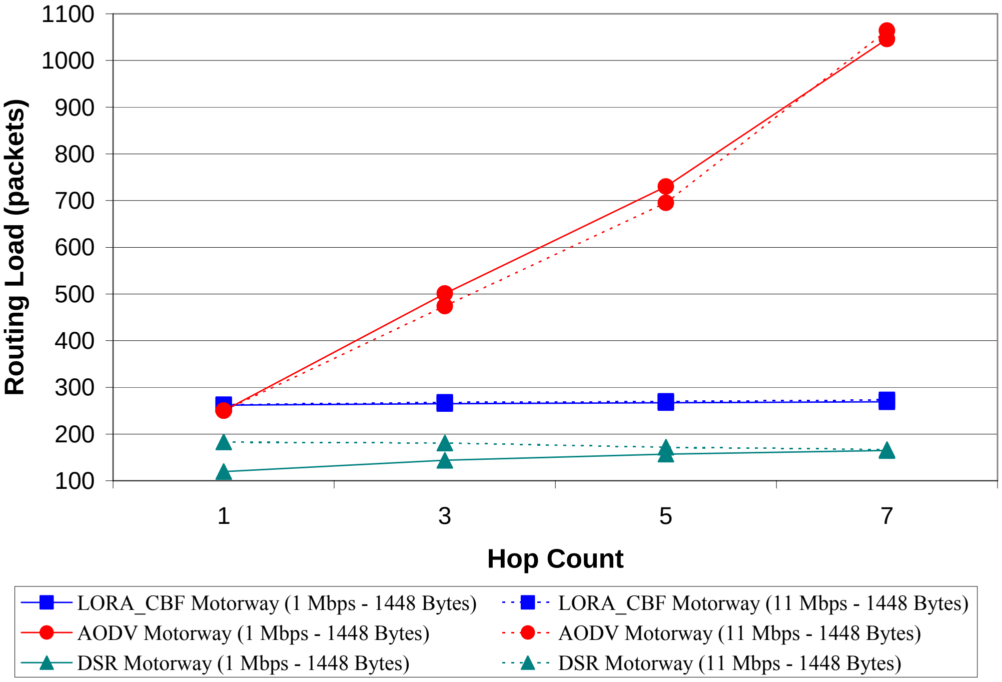


Fig. 6. Routing Load

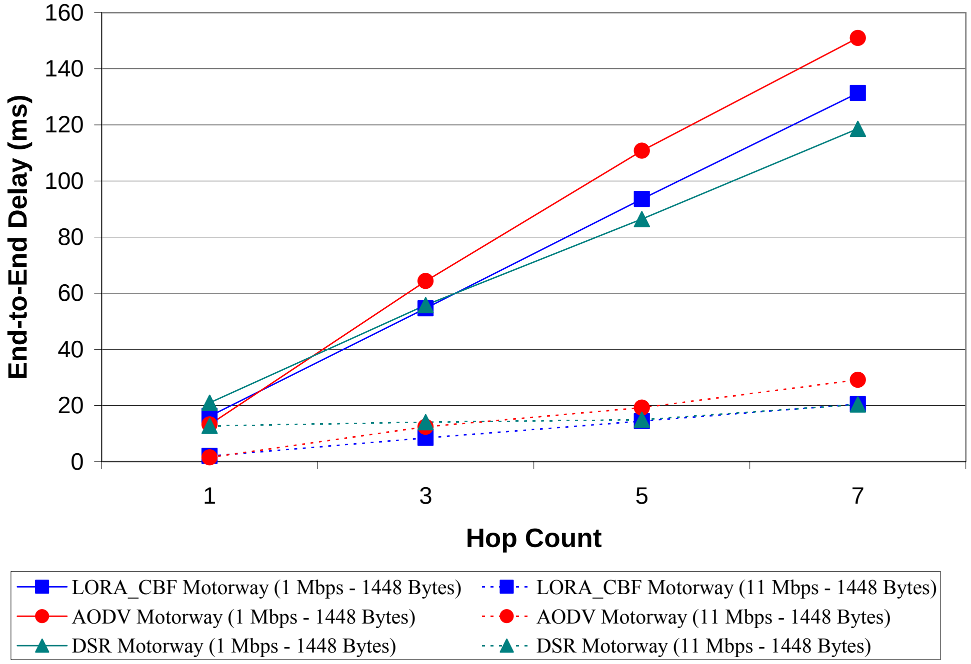


Fig. 7. End to End Delay (EED)

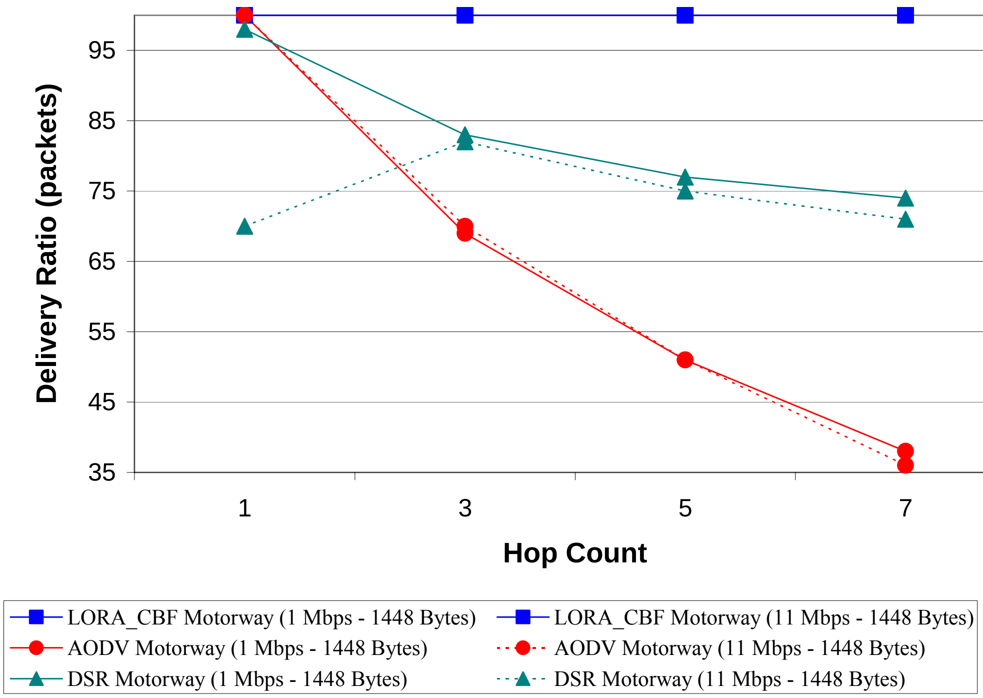


Fig. 8. Delivery Ratio

4.4 Related Work

Recent research related to our work is contained in [26], in which Holger Fübler et al. evaluate routing strategies in vehicular ad-hoc networks, where the authors consider Dynamic Source Routing (DSR) and GPSR (Greedy Perimeter Stateless Routing). To simulate the mobility of the vehicles, they employ ns-2 and the Ad-Hockey tool. In general, we have found similar results in terms of Delivery Ratio.

5 Conclusions and Future work

Innovatively, 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 a theoretical maximum data rate.

LORA_CBF possesses a hierarchical organization in which only gateway nodes can transmit information to neighbor clusters within a specified period of time. As a result, our simulations reproduce a non-causal environment within a circular environment as they do not consider vehicles entering and exiting the system, a straight line topology or different vehicular densities. The hierarchical nature of LORA_CBF, however, does improve scalability by declaring a specific cluster-head to control the access and dissemination of information packets. Therefore, vehicular density does not significantly affect the system because the cluster head controls access to the channel.

We have considered two non-positional-based routing algorithms (AODV and DSR) and one positional-based routing algorithm (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 better 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 as well as a worse packet delivery ratio because of more 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 regarding LORA-CBF includes the implementation of this algorithm in Linux and incorporating GPS into the routing scheme.

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