A Performance Study of Multicast Routing Algorithms on Wireless Ad Hoc Networks

Un Estudio sobre el Funcionamiento de Algoritmos de Enrutamiento de Difusión Múltiple en Redes Ad hoc Inalámbricas

Raúl Aquino Santos, Arthur Edwards Block and Miguel García Ruiz
Facultad de Telemática
Universidad de Colima
C. P. 28040, Colima, Colima, México
aquinor@ucol.mx, arted@ucol.mx, mgarcia@ucol.mx

Article received on November 16, 2006; accepted on December 07, 2007

Abstract
This paper presents a performance analysis of topological and geographical multicast routing algorithms for mobile wireless ad hoc networks. Flooding and On-Demand Multicast Routing Protocol (ODMRP) are simulated and compared with two novels protocols proposed: Topological Multicast Routing Protocol (ToMuRo) and Geographical Multicast Routing Protocol (GeMuRo) in pedestrian and vehicular scenarios. The scenarios evaluated consider one multicast transmitter and one, two, and three multicast receivers under various mobility and transmission ranges. The behavior of 250 nodes is evaluated in terms of End to End Delay (EED), Jitter and packet delivery ratio and overhead. Results show that ToMuRo is suitable for pedestrian scenarios due to its tree-based architecture and GeMuRo is proper for vehicular scenarios because it is based on a mesh topology.
Keywords: Multicast routing algorithms, multi-hop wireless networks, wireless ad hoc networks, topological routing algorithms, geographical routing algorithm.

Resumen
Este trabajo presenta un análisis sobre el funcionamiento de algoritmos de enrutamiento de difusión múltiple topológico y geográfico para redes ad hoc inalámbricas. El protocolo de enrutamiento de difusión múltiple sobre-demanda (ODMRP) y la inundación son simulados y comparados con dos nuevos protocolos propuestos: Protocolo de enrutamiento de difusión múltiple topológico (ToMuRo) y el protocolo de enrutamiento de difusión múltiple geográfico (GeMuRo) en escenarios pedestre y vehicular. El escenario evaluado considera un transmisor y uno, dos y tres receptores de difusión múltiple sobre varios rangos de movilidad y transmisión. El funcionamiento de 250 nodos se evalúa en términos del retardo punto a punto (EED), distorsión de fase (Jitter), la taza de entrega de paquetes y el sobre-procesamiento. Resultados muestran que ToMuRo es adecuado para escenarios pedestres debido a su arquitectura basada en árbol y GeMuRo es conveniente para escenarios vehiculares debido a que esta basado en una topología de malla.
Palabras Clave: Algoritmos de enrutamiento de difusión múltiple, redes inalámbricas multi-salto, redes ad hoc inalámbricas, algoritmos de enrutamiento topológicos, algoritmos de enrutamiento geográfico.

1 Introduction

Multicast routing algorithms have become increasingly important in the field of wireless ad-hoc networks because they effectively communicate and coordinate sets of nodes. Multicast routing algorithm, for example, performs better than multiple unicast routing strategies in ad-hoc environments, where bandwidth resources are at a premium. Multicast provides a more efficient routing strategy for multimedia applications in mobile environments (e.g. mobile learning, audio/video broadcasting, etc.) with large numbers of simultaneous receivers. The major impediment, therefore, is that nodes in multicast networks move omni-directionally, causing frequent and unpredictable topological changes. In a conventional ad-hoc environment, network hosts work in pairs to accomplish a given task. Multicast network algorithms, however, must transmit information packets to several hosts simultaneously, which then must discern if their role is to receive or forward the packets. Although multicast network algorithms are desirable in many situations, their forwarding mechanism and network resource consumption make them significantly less efficient than unicast routing algorithms. Packet delivery ratio, jitter and end-to-end delay are the principal performance variables taken into account when considering QoS applications and network resource management.

Tree and mesh-based multicast algorithms, among others, have been proposed for ad-hoc wireless networks as shown in [1-13]. Because tree-based multicast routing algorithms have only one path between the source-receiver pair, it is more efficient than mesh-based multicast routing algorithms. In a mesh-based multicast routing algorithm, however, there may be more than one path between a source-receiver pair, thus making it more robust than tree-based multicast routing algorithms.

Multicast Protocols developed for static networks, such as Distance Vector Multicast Routing Protocol (DVMRP) [1], Multicast Open Shortest Path First (MOSPF) [2], Core Based Trees (CBT) [3], and Protocol Independent Multicast (PIM) [4], do not function very well in ad-hoc network environments because of their continuous dynamic changes. The one major drawback of the above-mentioned multicast protocols is that they possess an inherently volatile tree structure. This volatile tree structure obliges this type of networks to continuously update their link status in response to topology changes. Additionally, typical multicast trees usually require a link state or distance vector global routing substructure that can result in significant packet loss. Furthermore, continuous topology changes caused by the frequent exchange of routing vectors or link state tables can also result in excessive channel and processing overhead, which can significantly increase network congestion. As a result, constraints related to bandwidth resources, power consumption, and host mobility makes multicast protocol design particularly challenging.

In response to these difficulties, several multicast routing protocols have been proposed for use in wireless ad-hoc networks, including Ad-hoc Multicast Routing Protocol (AMRoute) [5], On-Demand Multicast Routing Protocol (ODMRP) [6], Ad-hoc Multicast Routing protocol utilizing Increasing id-numberS (AMRIS) [7], Core-Assisted Mesh Protocol (CAMP) [8], Multicast Ad-hoc On-Demand Distance Vector (MAODV) [9], and Adaptive Demand-Driven Multicast Routing protocol (ADMR) [10]. However, the critical disadvantage of these topological multicast routing algorithms is that their data delivery strategies do not guarantee efficient transmission in highly mobile environments such as vehicular ad-hoc networks (VANET´s). This dificiency, precisely, has resulted in the development of geographical routing algorithms, including: A Novel Location-Based Multicast Protocol for Ad-hoc Networks [11], A Novel Position Based Reliable Unicast and Multicast Routing Method using Coloured Petri Nets [12], A Power-Aware Multicast Routing Protocol for Mobile Ad-Hoc with Mobility Prediction [13].

This work presents a performance analysis of topological and geographical multicast routing algorithms for mobile wireless ad-hoc networks. Flooding and ODMRP are simulated and compared with two novel protocol proposed: Topological Multicast Routing Protocol (ToMuRo) and Geographical Multicast Routing Protocol (GeMuRo) in pedestrian and vehicular scenarios.

The remainder of this paper is organized as follows: Section 2 provides the state of the art literature related to some common topological and geographical multicast routing protocols that are commonly proposed for wireless ad-hoc networks. Section 3 provides simulation details of ODMRP, ToMuRo and GeMuRo. Section 4 provides a discussion of the scenarios simulated and results obtained. Finally, Section 5 summarizes our work and proposes future research.

2 State of the art of Topological and Geographical Multicast Routing Algorithms

The Ad-hoc Multicast Routing Protocol (AMRoute) represents a novel approach for robust IP Multicast in mobile ad-hoc networks because it exploits user-multicast trees and dynamic logical cores. It creates a bidirectional, shared tree for distributing data by using only group senders and receivers as tree nodes.

One of the main improvements of AMRoute is that it has improved scalability because it uses shared trees and only requires one tree per group. Furthermore, AMRoute is also independent of any underlying unicast routing protocol and it floods a small signaling message instead of actual data, thus significantly reducing the size of the packets being transmitted and possibly reducing the number of collisions. The major disadvantages of AMRoute, however, is that it suffers from temporary loops and creates non-optimal trees when mobility is present, in part, because upon tree creation, the core node periodically unicasts TREE_CREATE messages to all mesh links. [14] Other drawbacks of AMRoute are that it assumes the existence of an underlying unicast routing protocol that can be used for unicast IP communication between neighboring tree nodes, and that it periodically floods JOIN_REQ messages using an expanding ring search.

In ODMRP, group membership and multicast routes are established and updated by the source on demand. Similar to on-demand unicast routing protocols, ODMRP consists of a request phase and a reply phase. When a multicast source has to send a packet, it must first flood a multicast request packet with the corresponding data payload attached. This packet, called JOIN_DATA, is periodically broadcasted throughout the entire network to refresh the membership information. The advantage of ODMRP is that it performs well in terms of packet delivery ratio in highly dynamic environments, primarily because ODMRP provides route redundancy with a mesh topology [14]. The main disadvantage in ODMRP is that group membership and multicast routes are established and updated by the source on demand, which can create congestion due to the higher processing load each node must handle.

The most significant feature of AMRIS is that each participant in the multicast session has a session-specific multicast session member id (msm-id). The msm-id provides each node a “logical height” in the multicast delivery tree.

The principal drawback of AMRIS is that nodes must send periodic beacons to signal their presence to neighboring nodes, making it very sensitive to mobility and traffic load [14]. The primary reasons for its poor performance are the number of necessary retransmissions and beacon size, both of which significantly increase overhead and can cause increased congestion.

CAMP possesses adequate control traffic scalability to facilitate the increasing size of a multicast group. Since JOIN_REQUESTS only propagate until they reach a mesh member, CAMP does not incur exponential growth of multicast updates as the number of nodes and group members increase, which represents a significant advantage regarding bandwidth allocation and energy consumption. However, it employs a unicast routing protocol to handle network convergence and control traffic growth in the presence of mobility. The main disadvantages of CAMP are that it presupposes the availability of routing information from a unicast routing protocol and that it assumes that the correct distances to known destinations can be determined within a specified time. In addition, a mapping service must exist to provide routers with the addresses of groups identified by their names.

The advantages of MAODV are that it employs the same RREQ/RREP messages as AODV. However, the main disadvantage of MAODV is that it suffers from high End-to-End Delay (EED) [15] because packets must travel across longer paths within the shared tree and because the larger number of control and data transmissions create a higher network, thus increasing network congestion.

The advantages of ADMR are that it reduces the overhead of the routing protocol and it reacts quickly to network topology changes. The main disadvantage of ADMR, however, is how it monitors packet loss, as its routing structure can cause network congestion when it attempts to repair routes suffering from high packet loss [16].

Several publications compare the topological multicast routing algorithms mentioned previously [14] [15] [16] [17]. In [14] the authors compare AMRoute, ODMRP, AMRIS, CAMP, and Flooding. Studies report that AMRoute performs well in stationary conditions, but it suffers from loops and inefficient organization trees under even minimal mobility. AMRIS is effective with light traffic loads and no mobility, but its performance is significantly affected by heavier traffic loads and moderate mobility. CAMP shows better performance when compared to tree protocols, but increased mobility causes excessive control overhead, resulting in congestion and consequent performance degradation. ODMRP is very effective and efficient in most simulation scenarios. However, the protocol shows a tendency to rapidly increase overhead as the number of senders increases.

In [15] the authors compare ADMR, ODMRP and MAODV. ADMR generates up to 14 times less control packet overhead than MAODV and up to 5 times less overhead than ODMRP. The high control overhead in MAODV is due to periodic flooding by the group leader and the significantly greater number of neighbor “Hello” packets. ODMRP´s high overhead results from its periodic source flood and response cycles, with the response part of the cycle growing proportionally to the number of receivers.

In [16], authors compare ODMRP and ADMR. ADMR induces higher overhead as node speed increases because ADMR attempts to repair routes as packet loss increases. Authors in [17] compare AMRIS and ODMRP.

ODMRP delivers a higher percentage of correctly received packets when compared to AMRIS; around 20% for lower node speeds, and around 70% when node speed increases, confirming that ODMRP is more robust than AMRIS.

On the other hand, to the best of our knowledge, little research has compared different geographical multicast routing algorithms. In [11], a location-based multicast routing protocol for ad-hoc networks is proposed. This protocol, however, is an extension of the unicast GPSR protocol, which considers each cluster as a single node for packet forwarding. Authors in [12] modeled a position-based unicast routing protocol supported by an extension of the distributed Grid Location Service (GLS) and extended their position-based unicast protocol to a scalable and resource-efficient multicast routing protocol. In [12] the authors combine the multicast protocol location service concept of GLS with ODMRP. They also chose ODMRP protocol because of the very efficient and effective simulation results published in [14]. Lastly, in [13] the authors propose a Power-aware Multicast Routing Protocol (PMRP) with mobility prediction. In this scheme, the authors consider power requirements and the transmission time needed to send packets between two connected mobile nodes using GPS and to select the routing paths with the longest transmission time to increase routing reliability.

This paper compares flooding and ODMRP with the ToMuRO and GeMuRo algorithms because the literature reports that ODMRP possess one of the most effective multicast routing protocols and flooding is the simplest multicast routing algorithm.

3 Limitations of Multimedia Applications

The increasing bandwidth requirements of multimedia applications such as Video on Demand (VoD), videoconference, and many WWW-based applications, have created a great deal of interest in providing seamless multimedia access in a multicast protocol supported by ad hoc networks. Quality o service guarantees are needed because multimedia applications are very sensitive to available network bandwidth limitations, jitter and delay. The notion of Quality-of-Service (QoS) is a guarantee by the network to satisfy a set of predetermined service performance constraints for the user in terms of end-to-end delay statistics, available bandwidth, probability of packet loss, and so on. The challenge of providing QoS is even more substantial for ad-hoc networks that support both best effort services. In this work, we attempt to tackle this critical issue by presenting the ToMuRo and GeMuRo, two multicast routing protocols that employ topological and geographical mechanisms in their routing strategies.

3.1 On-Demand Multicast Routing Protocol (ODMRP)

In ODMRP, group membership and multicast routes are established and updated by the source on demand. Similar to on-demand unicast routing protocols, ODMRP has both a request phase and a reply phase. When a multicast source sends packets, it uses a flooding strategy to transmit a member advertising packet to all the members of the group. This packet, called JOIN_DATA, which also carries the payload, is periodically broadcast to the entire network to refresh the membership information and update the routes. When a node receives a non-duplicate JOIN_ DATA, it stores the upstream node ID into the routing table and rebroadcasts the packet. When the JOIN_DATA packet reaches a multicast receiver, the receiver creates and broadcasts a JOIN_TABLE to its neighbors. When a node receives a JOIN_TABLE, it verifies that the next node ID of one of the entries matches its own ID. If it does, the node realizes that it is located at an intermediate point between the source and receiver and recognizes that it must forward the packet. It then sets the FG_FLAG (Forwarding Group Flag) and broadcasts its own JOIN_TABLE based on matched entries. The JOIN_TABLE is thus propagated by each forwarding group member until it reaches the multicast source via the shortest path. This process constructs (or updates) the routes from sources to receivers and builds a mesh of nodes [6].

3.2 Topological Multicast Routing Protocol (ToMURo)

ToMuRo applies on-demand routing mechanisms to avoid channel overhead and improve scalability. It uses the concept of "multicast relay," a set of nodes designated for forwarding multicast data on shortest paths between any multicast transmitter- multicast receiver pair to build a forwarding tree for each multicast group.

A. Multicast Route and Membership Maintenance

In ToMuRo, group membership and multicast routes are established and updated by the receiver on demand; a request phase and a reply phase comprise the protocol (Figure 1).

When a terminal receives a multicast data packet, it floods a multicast request packet throughout the network. When a node receives a non-duplicate multicast request packet, it stores the upstream node ID and rebroadcasts it. If a node within the transmission range of the multicast transmitter receives the multicast request packet, it replies back with a multicast reply packet. When a node receives a reply packet, it verifies that the next node ID matches its own ID. If it does, the node recognizes that it is on the path to the receiver and is part of the forwarding group. It then sets the Multicast-Relay flag and forwards the packet to the upstream node. This process constructs the routes from a multicast transmitter to a multicast receiver node and builds a tree of nodes.

We have described the forwarding group concept in which the forwarding group is a set of nodes that forward multicast data packets. This forwarding group supports the shortest path between any multicast transmitter and multicast receiver pair. All nodes pertaining to the multicast group (multicast receivers, multicast relays, and a multicast transmitter) forward multicast data packets.

B. Data forwarding

After forming a node group and implementing a route construction mechanism, a multicast transmitter can broadcast packets to multicast receivers via selected routes and forwarding groups. When receiving a multicast data packet, a node forwards it only if it is a not duplicate packet and the setting of the multicast-relay flag for the multicast group has not expired. This process minimizes traffic overhead and prevents packet transmission through stale routes. In ToMuRo, no explicit control packets need to be sent to join or leave the group. If a multicast receiver leaves the group, it can do so without any additional control packets.

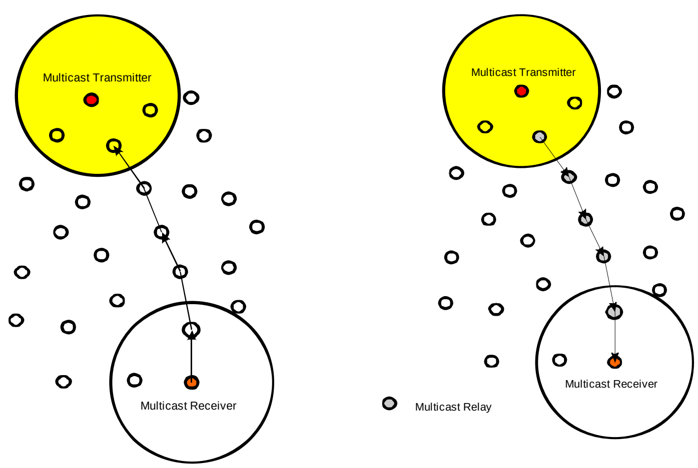

Fig. 1. Multicast request and reply packets

Figure 2 shows the ToMuRo topological routing algorithm, which has four states: undecided, multicast relay, multicast receiver, and multicast transmitter. The multicast transmitter sends packets in broadcast mode and multicast relay nodes retransmit the data packets. Undecided nodes are employed to avoid retransmissions of unwanted multicast data packets. Undecided nodes also record the location of the multicast transmitter in their tables to more efficiently answer multicast request packets. When a multicast receiver receives a multicast data packet, it broadcasts a multicast request packet. If an undecided node receives the multicast request packet and it has a fresh route to the multicast transmitter, it sends a multicast reply packet to create the forwarding group.

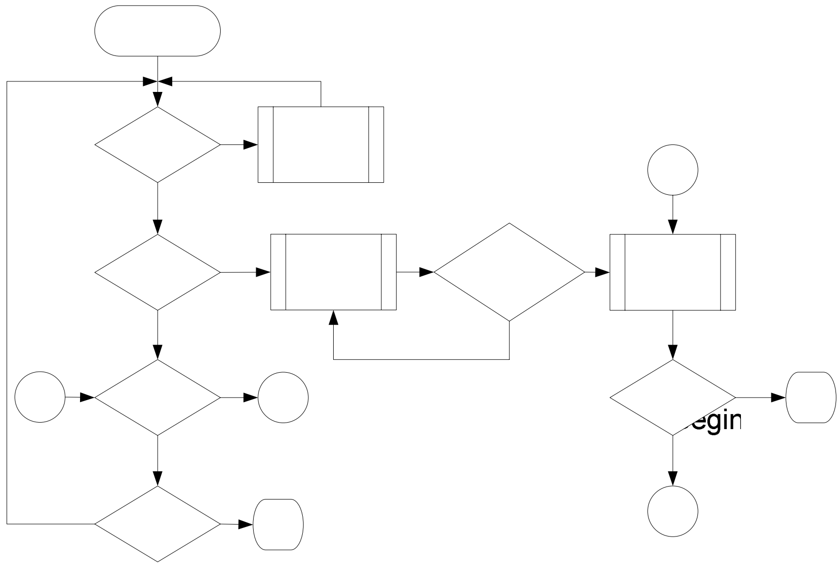

Fig. 2. Flow diagram of the ToMuRo algorithm

3.3 Geographical Multicast Routing Protocol (GeMuRo)

GeMuRo establishes and updates the receiver's multicast routes on demand. Similar to ToMuRo, a multicast request is initiated by the receiver and a reply phase is sent back by an undecided node that is receiving multicast data packets from the transmitter. The reply phase is performed using the greedy strategy, where individual nodes select the neighbors closest to the receiver.

ToMuRo routes packets in the geographical direction of nodes belonging to the receiver multicast group. When a node within the transmission range of the multicast transmitter receives the multicast request packet, it replies back with a multicast reply packet. When a node receives a reply packet, it confirms that its geographical position is in the direction of the multicast receiver. If it is, the node recognizes that it is on the path to the multicast receiver, sets the Multicast-Relay flag, and forwards the packet to the downstream node. This dynamic process constructs the routes from a multicast transmitter to multicast receiver nodes and builds a mesh of nodes.

In particular, the greedy strategy can be implemented as follows: for each destination node, the next hop is selected according to Most Forward within Radius (MFR) technique; that is, among the current hop's neighbors, the nearest node to the destination node is selected as next hop, with the condition that it is near than the current hop to the destination node.

The main difference between ToMuRo and GeMuRo is that ToMuRo is a tree-based routing algorithm and GeMuRo is a mesh- and location-based routing algorithm.

4 Performance Evaluation

Flooding, ODMRP, ToMuRo and GeMuRo were simulated using OPNET Modeler [20]. OPNET Modeler is an important network simulator that can be used to design and study communication networks, devices, protocols, and applications.

4.1 Scenarios Modeled

Our simulations model a 250 node wireless network in two different scenarios. The first scenario evaluates wireless nodes uniformly distributed within a 1200m x 1200m area. The node movements are based on the random-waypoint model (RWP). The IEEE 802.11b MAC protocol was used with an 11 Mbps channel capacity and a simulation time of 100 seconds. A pause time of 1 second was also applied in the RWP model. This scenario considers one multicast transmitter and one, two, and three multicast receivers under various mobility and transmission ranges. In the simulation, node speeds of 0, 5, 10, 15, and 20 meters per second were chosen, and a constant bit rate (CBR) for data flow and a uniform payload size of 512 bytes was also selected. The simulation parameters for the scenario 1 are listed in Table I.

Table I. Simulation parameters for ToMuRo

Parameter	**Value**
Simulation area	**1200 m x 1200 m**
Total nodes	**250**
Movement model	**Random-waypoint model**
Channel capacity	**11 Mbps**
Maximum speed	**0, 5, 10, 15, 20 m/sec**
Pause time	**1 second**
MAC protocol	**IEEE 802.11b**
Packet flows	**Constant bit rate (CBR)**
Packet payload	**512 bytes**

A second scenario, based on a microscopic traffic model and developed in OPNET, was used to simulate 250 mobile nodes traveling on a 6,283 m circular motorway (Figure 3). The circular scenario is an acceptable representation of motorway traffic because real-life road curvature is usually less pronounced, allowing vehicles to maintain a more constant velocity. A non-causal model was also employed that prohibited vehicles from entering or exiting the system, as well as an arbitrary vehicular speed of 42 m/s (95 miles/hour) was established. The IEEE 802.11b Distributed Coordination Function (DCF) was used as the medium access control protocol. The simulation parameters for scenario 2 are listed in Table II.

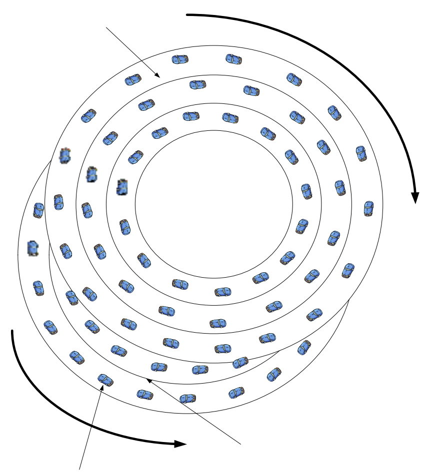

Fig. 3. Representation of the second scenario

Table II. Simulation parameters for GeMuRo

Parameter	Value
Simulation area	**6283 m**
Total nodes	**250**
Movement model	**Microscopic Traffic Model**
Channel capacity	**11 Mbps**
Maximum speed	**42 m/s**
MAC protocol	**IEEE 802.11b**
Packet flow	**Constant bit rate (CBR)**
Packet payload	**512 bytes**

4.2 Simulation Results

Figure 4 represents the End-to-End Delay (EED) for the first scenario; the horizontal line indicates the node speed in m/s and the label numbers under the graph (Flooding_1, Flooding_2, etc.) represent the number of receivers under simulated conditions. In general, flooding creates more End-to-End Delay (EED) due to its lack of a control mechanism. ToMuRo shows a slightly more EED than ODMRP, but its performance is more constant with one, two, and three receivers.

Figure 5 shows jitter for the three multicast routing algorithms. Jitter is a critical variable for applications that are sensitive to delay as excessive jitter can cause phase distortion during packet reception. Flooding reports good results in terms of jitter because it employs multiple paths. ToMuRo improves its performance as the speed and number of nodes increases, thus improving spatial diversity as node speed increases. On the other hand, ODMRP also improves its performance as the number of nodes increases. However, ODMRP is significantly more affected by the speed of the nodes.

Figure 6 represents the packet delivery ratio. In contrast to the previous figures, flooding performs poorly as the number of receivers increases. However, although, ODMRP improves its behavior as the number of receivers increase, it still does not perform as well as ToMuRo. The performance of ToMuRo remains satisfactory when the number of receivers increases.

Figure 7 represents the overhead. This metric shows the efficiency of the algorithm in retransmitting data packets throughout the network. Flooding shows the worst behavior of the three algorithms because of its data packet retransmission mechanism. ToMuRo and ODMRP have similar behavior for one receiver, but for two and three receivers, ODMRP performs slightly lower than ToMuRo.

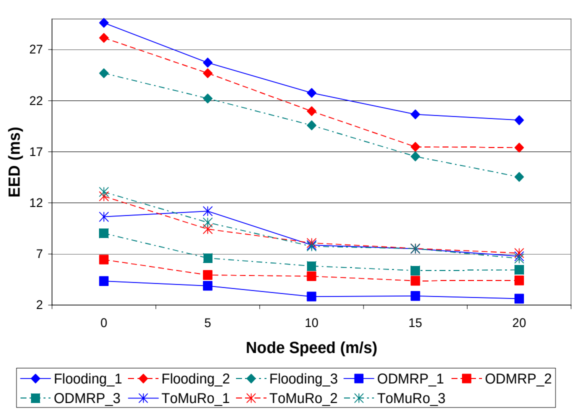

Fig. 4. End-to-End Delay (EED) for ToMuRo

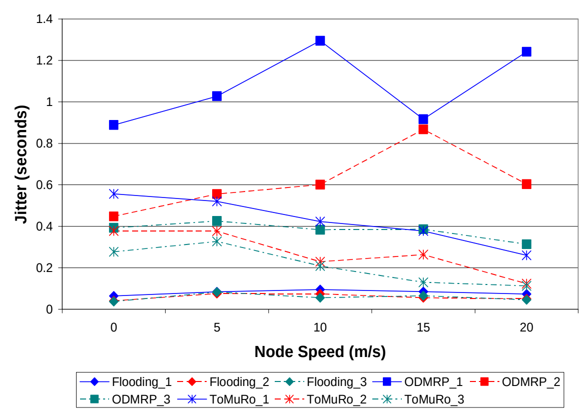

Fig. 5. Jitter for the ToMuRo

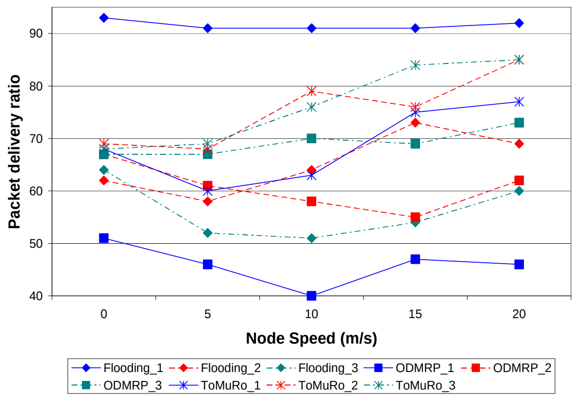

Fig. 6. Packet delivery ratio for ToMuRo

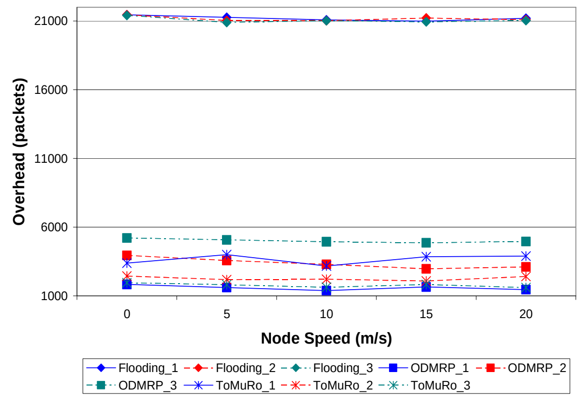

Fig. 7. Overhead for the ToMuRo

Figure 8 represents the End-to-End Delay (EED) for the second scenario. Flooding creates more End-to-End Delay due to the retransmissions of all the network nodes. GeMuRo and ODMRP show similar behavior in general, however, there is one significant difference: for distances of fewer than three hops between the transmitter-receiver pair, GeMuRo has a better EED. Importantly, however, after three hops, GeMuRo increases its EED because of its location-based strategy.

Figure 9 represents jitter for the multicast routing algorithms evaluated. Flooding and GeMuRo perform well regarding jitter. However, ODMRP has high jitter for one receiver, although it improves as the number of receivers increases. Regardless, at no point does ODMRP outperform Flooding and GeMuRo.

Figure 10 shows the packet delivery ratio of the three multicast routing algorithms. Flooding has the best performance compared to GeMuRo and ODMRP. GeMuRo reacts very well with one and two receivers, but with three receivers its performance significantly deteriorates. ODMRP performs poorly because of its lack of location information.

Figure 11 represents the data sent throughout the network during the simulation period. Flooding performs the worst of the three algorithms because of its data packet retransmission mechanism, which is characterized by considerable redundancy. GeMuRo, on the other hand, has a higher probability of receiving data because it transmits a greater number of data packets.

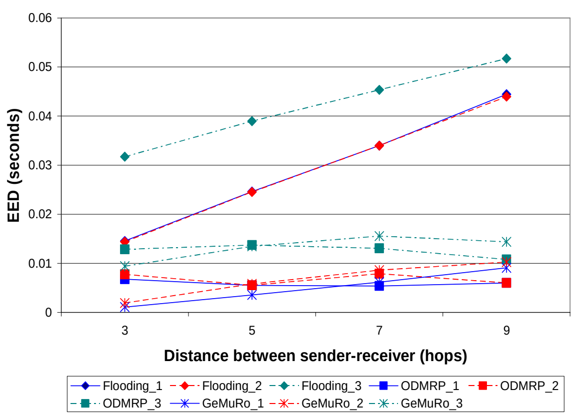

Fig. 8. End-to-End Delay (EED) for GeMuRo

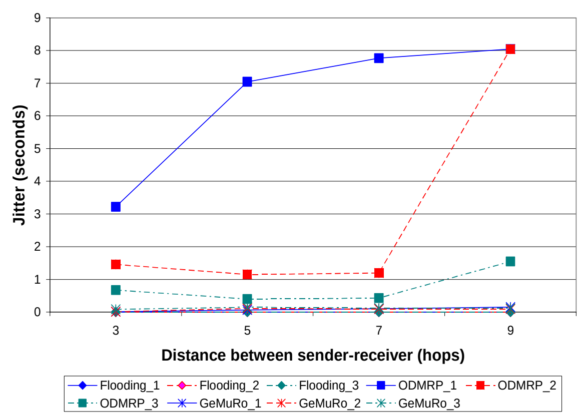

Fig. 9. Jitter for GeMuRo

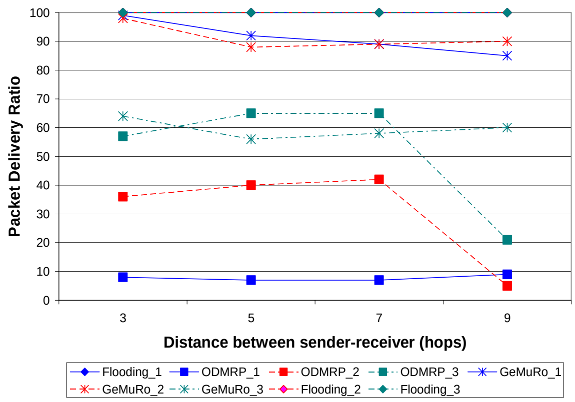

Fig. 10. Packet delivery ratio for GeMuRo

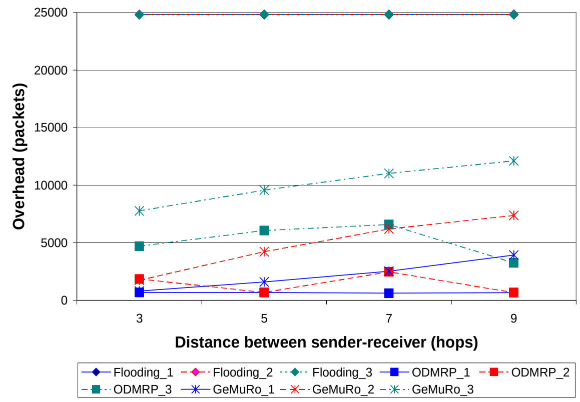

Fig. 11. Overhead for GeMuRo

5 Conclusions

This paper has presented ToMuRo, a topological multicast routing protocol and GeMuRo, a geographical multicast routing protocol. ToMuRo has been compared with Flooding and ODMRP in a pedestrian scenario. On the other hand, GeMuRo has been compared with Flooding and ODMRP, but in a vehicular scenario. Significantly, simulation results of the pedestrian scenario show that the ToMuRo algorithm performs better than the ODMRP algorithm in terms of jitter and packet delivery ratio. The performance of ToMuRo, when compared with ODMRP, improves as node speed and the number of receivers increases. On the other hand, simulation results of the vehicular scenario show that the GeMuRo algorithm performs better than ODMRP in terms of jitter and packet delivery ratio. In terms of EED, GeMuRo and ODMRP perform similarly. However, Flooding shows significantly better performance in term of jitter and packet delivery ratio. Results show that Flooding might provide a viable option for vehicular ad-hoc networks with high mobility and density. Our future work will implement and compare ToMuRo and Flooding in a tesbed.

6 Acknowledgments

The authors acknowledge the support received by the Mexican National Council of Science and Technology (CONACYT) under project grant No. 48391.

References

1. **S. E. Deering, D. R. Cheriton.** Multicast Routing in Datagram Inter-networks and Extended LANs. ACM Transactions on Computer Systems, vol. 8, no. 2, pp. 85-110, 1990.
2. **J. Moy.** Multicast Routing Extensions for OSPF. Communications of the ACM, vol. 37, no. 8, pp. 61-66, 1994.
3. **T. Ballardie, P. Francis,** and **J. Crowcroft.** Core Based Trees (CBT) – An Architecture for Scalable Inter-Domain Multicast Routing. In Proceedings of ACM SIGCOMM´93, pp. 85-95, 1993.
4. **D. Deering, D. L. Estrin, D. Farinacci, V. Jacobson, C. G. Liu, and L. Wei.** The PIM Architecture for Wide-Area Multicast Routing. IEEE/ACM Transactions on Networking, vol. 4, no.2, pp. 153-162, 1999.
5. **Xie J, Talpade R, Mcauley A, Liu M.** AMRoute: Ad Hoc Multicast Routing Protocol.Mobile Networks and Applications, vol. 7, no. 6, pp. 429- 439, 2002.
6. **Sang Ho Bae, Sung-ju Lee, William Su, Gerla M.** The Design, Implementation, and Performance Evaluation of the On-Demand Multicast Routing Protocol in Multihop Wireless Networks. IEEE Network, pp. 70-77, 2000.

7. **C. W. Wu, Y. C. Tay.** AMRIS: A Multicast Protocol for Ad hoc Wireless Networks. Proceedings of IEEE MILCOM´99, 1999.
8. **Garcia-Luna-Aceves, J.J., Madruga E.L.** The Core Assisted Mesh Protocol. IEEE Journal on Selected Areas in Communications, vol. 17, no. 8, 1999.
9. **Elizabeth M. Royer, Charles E. Perkins.** Multicast Operation of the Ad-hoc On-Demand Distance Vector Routing Protocol. Mobile Computing and Networking, pp.207-218, 1999.
10. **Jorjeta G. Jetcheva, David B. Johnson.** Adaptive Demand-Driven Multicast Routing in Multi-Hop Wireless Ad-Hoc Networks. Proceedings of the second symposium on Mobile Ad Hoc Networking and Computing (MobiHoc 2001), 2001.
11. A Novel Location-Based Multicast Protocol for Ad-hoc Networks. **Giuseppe Caizzone, Walter Erangoli, Paolo Giacomazzi,** and **Giacomo Verticale.** International Symposium on Personal, Indoor and Mobile Radio Communications, pp. 1-5, 2006.
12. Modeling and Performance Analysis of a Novel Position-based Reliable Unicast and Multicast Routing Method Using Coloured Petri Nets. **Fazli Erbas, Kyandoghere Kyamakya, Klaus Jobmann**. Vehicular Technology Conference (VTC 2003-Fall), vol. 5, pp.3099-3104, 2003.
13. A Power-Aware Multicast Routing Protocol for Mobile Ad-Hoc Networks with Mobility Prediction. Nen-Chung **Wang** and **Yu-Li Su.** Conference on Local Computer Networks, 2005.
14. **Sung-Ju Lee, William Su, Julian Hsu, Mario Gerla,** and **Rajive Bagrodia.** A Performance Comparison Study of Ad-Hoc Wireless Multicast Protocols. Proceedings of the IEEE INFOCOM , pp. 565-574, 2000.
15. **Jorjeta G. Jetcheva** and **David B. Johnson.** A Performance Comparison of On-Demand Multicast Routing Protocols for Ad Hoc Networks. CMU-CS-04-176, 2004.
16. **Manoj, Pandey** and **Daniel Zappala.** A scenario-Based Performance Evaluation of Multicast Routing for Ad Hoc Networks. Proceeding of the Sixth IEEE International Symposium on a World of Wireless Mobile and Multimedia Networks (WoWMoM´05), 2005.
17. **M. Malaguti, C. Taddia, G. Mazzini, M. Zorzi.** Analysis of Performance of Multicast Routing Protocols over 802.11b, IEEE Vehicular Technology Conference, vol, 5, pp. 3165-3169, 2004.
18. **Abhayawardhana, Wassell, Crossby, Sellars** and **Brown** Comparison of empirical propagation path loss models for fixed wireless access systems. University of Cambridge, UK.
19. **Barry, Mclarnon.** VHF/UHF/Microwave Radio Propagation: A Primer for Digital Experimenters. Ottawa.
20. **http://www.opnet.com**

Raúl Aquino Santos *received his MS degree in Telecommunications from the Centre for Scientific Research and Higher Education in Ensenada, Mexico in 1990. He holds a PhD from the Department of Electrical and Electronic Engineering of the University of Sheffield, England. His current research interests include wireless and sensor network.*

Arthur Edwards Block *is a Senior Professor at the College of Telematics of the University of Colima, where he is involved in developing educational software. His primary fields of interest include usability engineering and mobile learning.*

Miguel Ángel García Ruiz *received his MS degree in Computer Science from the University of Colima, México in 1997. He holds a PhD from the University of Sussex, England. His current research interests include virtual reality and artificial intelligence.*