

## **Analysis of Topological and Geographical Multicast Routing Algorithms on Wireless Ad Hoc Networks**

**R. A. Santos<sup>1</sup>, A. González<sup>1</sup>, L. Villaseñor<sup>2</sup>, M. García-Ruiz<sup>1</sup>, V. Rangel<sup>3</sup>,  
A. Edwards<sup>1</sup>**

<sup>1</sup>*Faculty of Telematics, University of Colima,*

*Av. Universidad # 333, C.P 28400, Colima, Col., México, phone: +52 312 3161165; e-mail: aquinor@uclm.mx*

<sup>2</sup>*CICESE Research Centre,*

*Carr. Tijuana-Ensenad, km 113. C.P. 22860; phone: +52 312 3161165; e-mail: luisvi@cicese.mx*

<sup>3</sup>*Department of Telecommunications, University Nacional Autónoma de México,*

*C.P. 04510, México, D.F., phone: +52 312 3161165; e-mail: victorr@fi-b.unam.mx*

### **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 deficiency, 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 the 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 simulation details of ODMRP, ToMuRo and GeMuRo. Section 3 provides a discussion of the scenarios simulated and results obtained. Finally, Section 4 summarizes our work and proposes future research.

### 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 of 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.

### 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].

### 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.

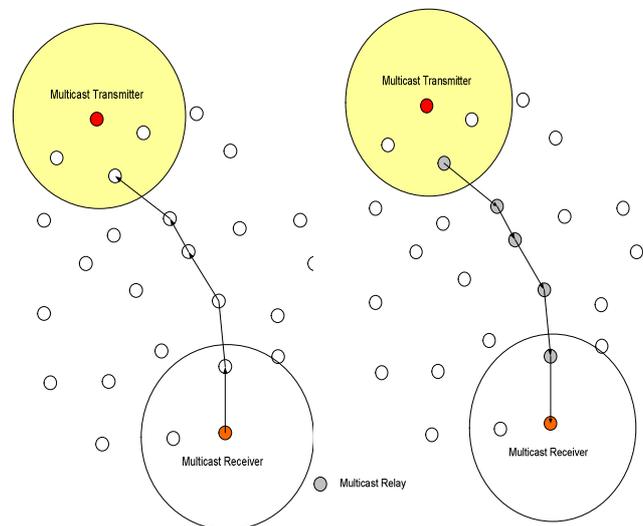


Fig 1. Multicast request and replay packets

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.

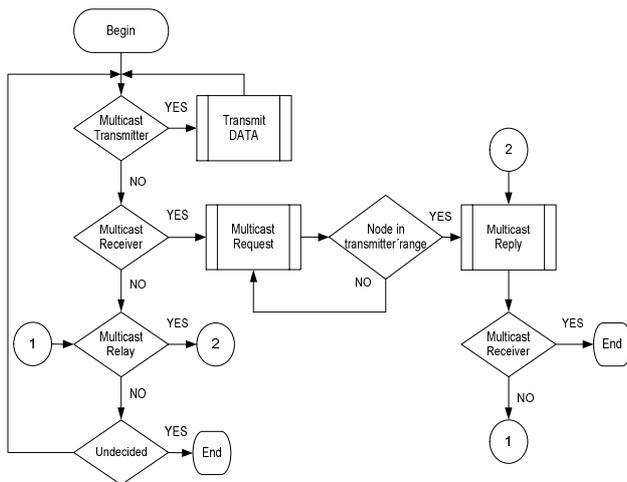


Fig. 2. Flow diagram of the ToMuRo algorithm

Fig. 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.

### 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.

## 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.

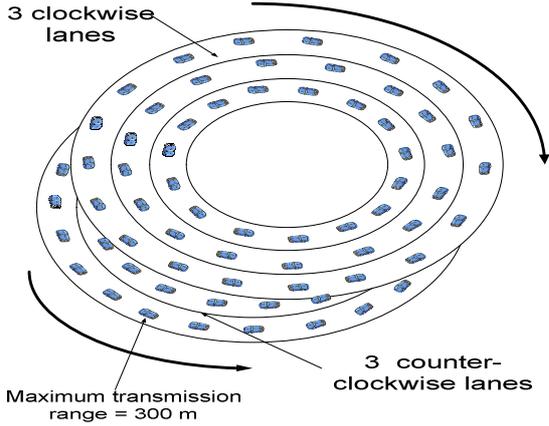
### Scenarios modeled

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 1.

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 (Fig. 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 2.

**Table 1.** 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



**Fig. 3.** Representation of the second scenario.

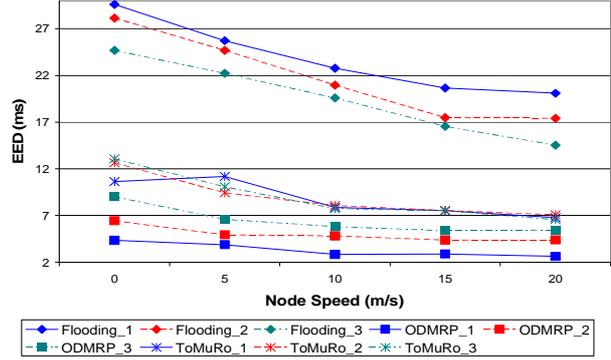
**Table 2.** Simulation parameters for GeMuRo

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

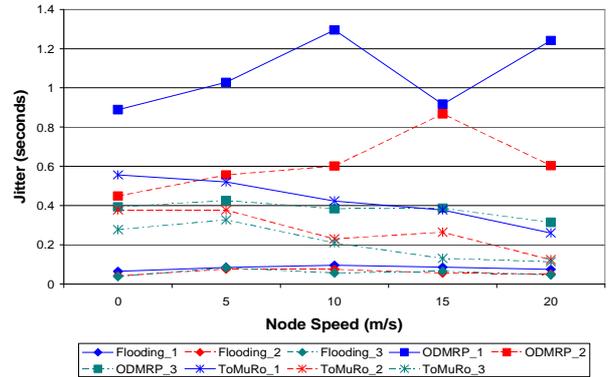
Fig. 4 represents the End-to-End Delay (EED) for the first scenario; the horizontal line indicates the node speed in m/s and the label numbers under the graph (Flooding\_1, Flooding\_2, etc.) represent the number of receivers under simulated conditions. In general, flooding creates more End-to-End Delay (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.

Fig. 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.

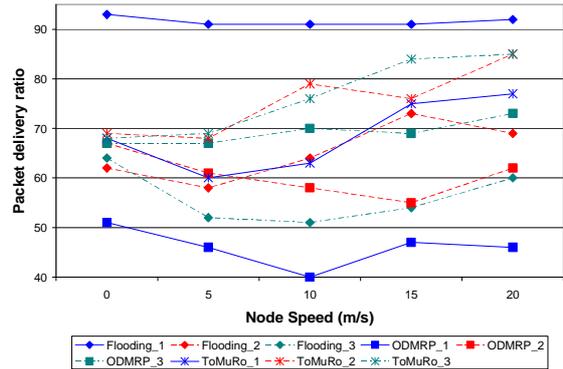


**Fig. 4.** End-to-End Delay (EED) for ToMuRo



**Fig. 5.** Jitter for the ToMuRo

Fig. 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.



**Fig. 6.** Packet delivery for ToMuRo

Fig. 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.

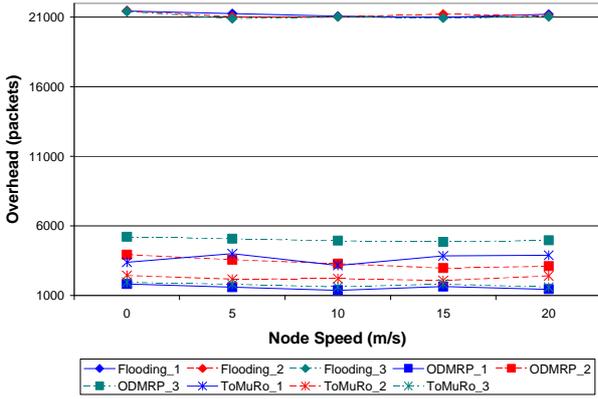


Fig. 7. Overhead for the ToMuRo

Fig. 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.

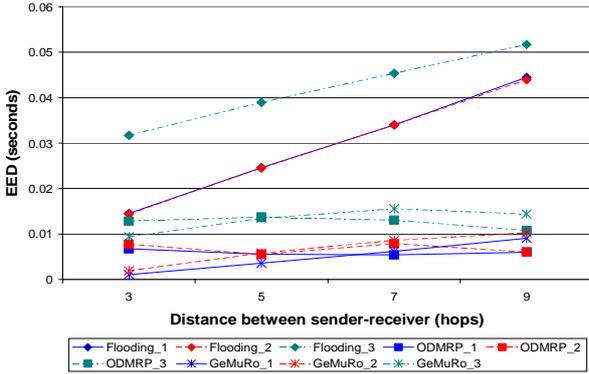


Fig. 8. End-to-End Delay (EED) for GeMuRo

Fig. 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.

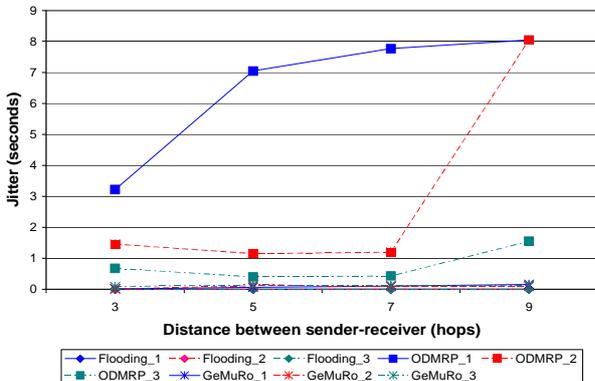


Fig. 9. Jitter for GeMuRo

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.

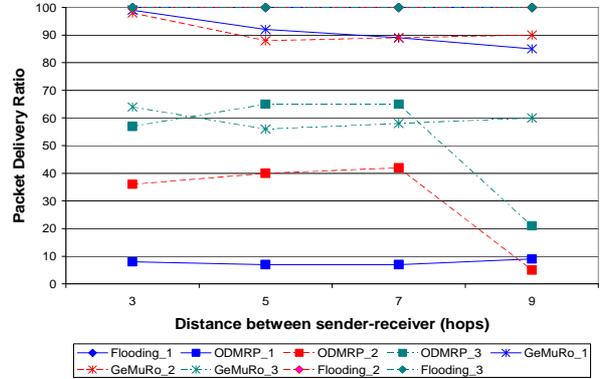


Fig. 10. Packet delivery for GeMuRo

Fig.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.

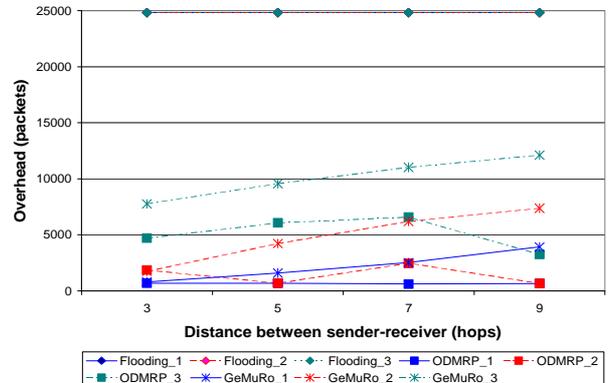


Fig. 11. Overhead for GeMuRo

## Conclusions

ToMuRo, a topological multicast routing protocol and GeMuRo, a geographical multicast routing protocol were presented in this paper. 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 testbed.

## Acknowledgements

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## References

1. **Deering S. E., Cheriton D. R.** Multicast Routing in Datagram Inter-networks and Extended LANs // ACM Transactions on Computer Systems. – 1990. – Vol. 8, No. 2. – P. 85–110.
2. **Moy J.** Multicast Routing Extensions for OSPF // Communications of the ACM. – 1994. – Vol. 37, No. 8. – P. 61–66.
3. **Ballardie T., Francis P. and Crowcroft J.** Core Based Trees (CBT) – An Architecture for Scalable Inter-Domain Multicast Routing // Proceedings of ACM SIGCOMM '93. – 1993. – P. 85–95.
4. **Deering D., Estrin D. L., Farinacci D., Jacobson V., Liu C. G., and Wei L.** The PIM Architecture for Wide-Area Multicast Routing // IEEE/ACM Transactions on Networking. – 1999. – Vol. 4, No.2. – P. 153–162.
5. **Xie J, Talpade R., Mcauley A., Liu M.** AMRoute: Ad Hoc Multicast Routing Protocol // Mobile Networks and Applications. – 2002. – Vol. 7, No. 6. – P. 429– 439.
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. – 2000. – P. 70–77.
7. **Wu C. W., Tay Y. C.** 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. – 1999. – Vol. 17, No. 8.
9. **Elizabeth M. Royer, Charles E. Perkins.** Multicast Operation of the Ad-hoc On-Demand Distance Vector Routing Protocol // Mobile Computing and Networking. – 1999. – P. 207–218.
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. **Giuseppe Caizzone, Walter Erangoli, Paolo Giacomazzi, and Giacomo Verticale.** A Novel Location-Based Multicast Protocol for Ad-hoc Networks // International Symposium on Personal, Indoor and Mobile Radio Communications. – 2006. – P. 1–5.
12. **Fazli Erbas, Kyandoghene Kyamakya, Klaus Jobmann.** Modeling and Performance Analysis of a Novel Position-based Reliable Unicast and Multicast Routing Method Using Coloured Petri Nets // Vehicular Technology Conference (VTC 2003-Fall). – 2003. – Vol. 5. – P. 3099–3104.
13. **Nen-Chung Wang and Yu-Li Su.** A Power-Aware Multicast Routing Protocol for Mobile Ad-Hoc Networks with Mobility Prediction // Conference on Local Computer Networks. – 2005.

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**R. A. Santos, A. González, M. García-Ruiz, A. Edwards, L. Villaseñor, V. Rangel.** Analysis of Topological and Geographical Multicast Routing Algorithms on Wireless Ad Hoc Networks // *Electronics and Electrical Engineering*. – Kaunas: Technologija, 2008. – No. 2(82). – P. 23–28.

Performance analysis of topological and geographical multicast routing algorithms for mobile wireless ad-hoc networks is presented. Flooding and On-Demand Multicast Routing Protocol (ODMRP) are simulated and compared with two novel protocols: Topological Multicast Routing (ToMuRo) and Geographical Multicast Routing (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, 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. Ill. 11, bibl. 13 (in English; summaries in English, Russian and Lithuanian).

**P. A. Сантос, А. Гонзалес, М. Гарциа-Руиз, А. Эдвардс, Л. Вилласенор, В. Рангел.** Анализ топологических и географических трансляционных алгоритмов маршрутизации в децентрализованных радио сетях // *Электроника и электротехника*. – Каунас: Технология, 2008. – № 2(82). – С. 23–28.

Анализируется работа топологических и географических алгоритмов маршрутизации для мобильной децентрализованной радио сети. Имитируется протокол ODMRP. Он сравнивается с двумя протоколами: ToMuRo и GeMuRo. Протоколы сравнены в различных сценариях и когда используется различное количество приемников. Результаты показывают, что ToMuRo является подходящим для пешеходных сценариев из-за его архитектуры на основе ветвей дерева, и GeMuRo имеет преимущество в автомобильных сценариев из-за его сетевой топологии. Ил. 11, библи. 13 (на английском языке; рефераты на английском, русском и литовском яз.).

**R. A. Santos, A. González, M. García-Ruiz, A. Edwards, L. Villaseñor, V. Rangel.** Topologinių ir geografinių transliacinių maršrutizavimo algoritimų decentralizuotuose bevieluose tinkluose analizė // *Elektronika ir elektrotechnika*. – Kaunas: Technologija, 2008. – Nr. 2(82). – P. 23–28.

Pateikta topologinių ir geografinių transliacinių mobiliųjų bevielų decentralizuotųjų tinklų maršrutizavimo algoritimų veikimo analizė. Imituotas ODMRP protokolas. Jis palygintas su dviem naujais protokolais –TeMuRo ir GeMuRo. Analizuoti du skirtingi scenarijai, kurių kiekvieno našumas buvo vertinamas esant skirtingam imtuvų skaičiui, skirtingoms mobilumo sąlygoms ir esant skirtingam perdavimo atstumui. 250 mazgų tinklo veikimas vertintas pagal EED, triukšmų, paketų pristatymo koeficiento ir pertekliaus kriterijus. Rezultatai rodo, jog ToMuRo tinkamesnis pėsčiųjų scenarijui, nes jame naudojama išsišakančio medžio architektūra, o GeMuRo tinkamas transporto scenarijui, nes jis paremtas tinkelio topologija. Il. 11, bibl. 13 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).