Simulation-Based Comparison of Three Wireless Multicast Routing Protocols: MOST, MOLSR and SMOLR

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Abstract. In this paper, we study multicast protocols for Mobile Ad-Hoc Networks, and specifically OLSR networks. We describe and compare three multicast protocols, namely MOST (Multicast Overlay Spanning Tree), MOLSR (Multicast OLSR) and SMOLSR (Simple Multicast OLSR), with different approaches and properties with respect to scalability. Our approach is simulation-based: through different scenarios and configurations, we evaluate the performance of each protocol in terms of average packet delivery ratio and average packet retransmissions. We interpret the results in terms of key design properties and applicability of the protocols.

1 Introduction

Multicast is a different form of communication from the ubiquitous unicast communications used in client-server protocols (which includes HTTP, i.e. the Web). It consists in sending a stream of data from a *source* to several receiver nodes (*client*) in the network. The source and the client forms a *multicast group*. Audio or video conferencing, push-to-talk, and multimedia content distribution are examples requiring multicast communications, which in turn, require a multicast routing protocol.

In mobile ad hoc networks (MANET), different approaches have been followed for designing multicast protocols for wireless networks and the existing protocols vary depending on the group structure, the nature of transmissions, the reliance (or not) on an underlying unicast routing protocol, etc. A survey of some MANET multicast protocols with a complete classification can be found in [1] and [3]; and [4] for instance for broadcast protocols. These differences are expected to have an impact on protocol performances and the goal of this article is to highlight this impact in case of three multicast MANET protocols proposed as an extension of the OLSR unicast routing. In this article, we evaluate and compare performances of MOST (Multicast Overlay Spanning Tree), MOLSR (Multicast OLSR) and SMOLSR (Simple Multicast OLSR) through NS2 simulations. Our focus is on evidencing the different behaviors of different families of protocols rather than optimizing the performance of one family of

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protocols, and to identify the key properties of multicast algorithms[1]. The rest of the document is organized as follows:

Section 2 presents a brief description of the three multicast protocols. In Section 3, we present a simulation-based comparison of these multicast protocols in various scenarios with different network configurations. Protocols are evaluated in terms of delivery ratio, average number of packet retransmissions for different group sizes, different rates of the multicast sources and different mobility scenarios. Finally, Section 4 discusses the adequacy of features of each family of protocols to different scenarios, taking into account the performance evaluation reported in the previous section, discusses multicast protocol design and concludes this document.

2 Multicast Protocols Description

The three studied multicast protocols are representative of different approaches to multicast in MANETs [3]:

– SMOLSR: optimized broadcast to the entire network
– MOLSR: shortest-path tree from source to every client, using *neighborcast*
– MOST: (overlay) unicast tree joining all group members

We denote *neighborcast*, the action of transmitting the same packet to several neighbors at the same time: it is the usual method for benefiting from the *wireless multicast advantage*.

The table 1 is a summary of the properties of the protocols, and the Figure 1 illustrates the outcome of three protocols on the same sample topology.

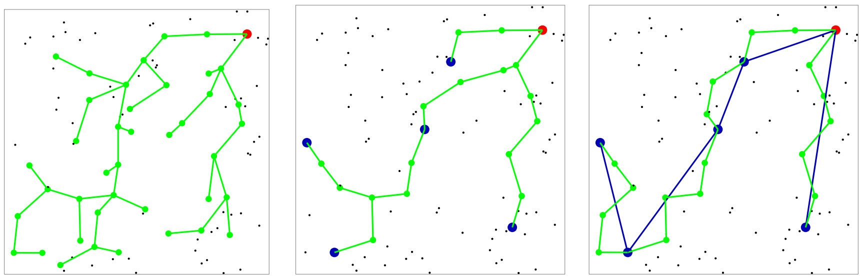
Table 1. Main properties of the protocols (OLSR assumed as unicast routing protocol)

Name	Method	Transmissions	Additional Protocol Overhead
SMOLSR	broadcast	neighborcast	none (already built into OLSR)
MOLSR	source-rooted tree	neighborcast	overhead for tree creation/maintenance
MOST	spanning tree	unicast	group membership announcement

2.1 SMOLSR

SMOLSR (for Simple Multicast OLSR) [9] is a simple multicast forwarding protocol. It is an optimized flooding which uses the MPRs (Multi Point Relay) to disseminate the multicast data to the entire network[2]. Thus, the knowledge of multicast groups and membership is not required. The MPR concept used in OLSR is summarized as follows. A node selects a subset of its 1-hop symmetric neighbors that cover all the nodes that are at two hops from it. This subset

[1] One of our motivations, related to the report [7] for French MoD, is indeed to identify appropriate protocols for different military applications in different scenarios.
[2] In the IETF proposal SMF [10], it is also called “Source-based Multipoint Relay”.



(a) SMOLSR: 41 (neighborcast) transmissions

(b) MOLSR: 18 (neighborcast) transmissions

(c) MOST: 22 (unicast) transmissions - dark lines represent virtual links

Fig. 1. The three multicast protocols on the same topology (1 source and 5 clients)

is referred to as MPR set. Upon *first* receipt of a multicast packet, the node must determine whether it should forward the packet or discard it. If this node belongs to the sender's MPR set, then the packet is forwarded.

Doing so, only a subset of nodes relay the data packets: they form a connected dominating set. It belongs to the family of optimized broadcast protocols (see [4] for a survey). Note that this connected dominating set is not static nor optimal (see [4] for alternatives): it is dynamically formed, and thanks to *dynamic self-pruning*, it offers some resilience against losses.

2.2 MOLSR

MOLSR (for Multicast OLSR) [11], allows each node of a multicast group to receive the information from a multicast source. For this purpose, it maintains a tree per pair (multicast source, multicast group), taking advantage of the topology information provided by the OLSR unicast routing protocol. MOLSR builds a source-dependant tree and ensures that any multicast client is reached by the shortest path. The trees are updated whenever a change in the topology is detected. A multicast tree is built and maintained for any tuple (source, multicast group) in a distributed manner without any central entity.

Tree Building, Maintenance and Detachment. Once a source wants to send data to a specific multicast group, it sends a SOURCE_CLAIM message enabling nodes which are members of this group to detect its presence and to attach themselves to the associated multicast tree. This message is flooded within the ad hoc network using the optimized flooding technique of OLSR. Branches are built hop by hop in a backward manner as follows. When a group member receives a SOURCE_CLAIM message and it is not already a participant of this (source, multicast group) tree, it attaches itself to the tree and designates the next hop to reach the source in a shortest path as its *parent* in the multicast tree and sends a CONFIRM_PARENT message to it. The parent node receiving this message attaches itself to the (source, multicast group) tree, if it is not already a participant to this tree. The trees are periodically refreshed, by means of the SOURCE_CLAIM message and the CONFIRM_PARENT message. Notice that topology changes are still detected by the exchange of topology control messages which is done naturally by OLSR. Thus, trees updates are triggered by the detection of topology changes.

Routing Decision and Encapsulation. For any non-duplicate received packet, the MOLSR node determines whether it should forward the packet or discard it. If this node is attached to the associated tree as a *parent*, then it forwards the packet (with neighborcast), otherwise the packet is not routed.

2.3 MOST

A third multicast protocol, called MOST (Multicast Overlay minimum Spanning Tree) was proposed in [6] and operates on the OLSR protocol. MOST belongs to the category of Application-layer Multicast (ALM) protocols [2] (also called virtual multicast protocols) defined for wired networks and it inherits most of their advantages. For instance, only machines involved in multicast must be equipped with multicast capabilities unlike conventional protocols, where all the machines on the network must integrate the multicast capabilities (implement the protocols). In wireless networks, some overlay multicast protocols were proposed [1], but in contrast to these protocols, MOST was motivated by analytical results on the achievable capacity of multicast communication in ad hoc networks (the theoretical capacity bounds proved in [5]).

The MOST algorithm [5] consists in building a minimum spanning tree connecting all the clients of a given multicast group. Unlike MOLSR, MOST builds a so-called group-shared tree, which implies the existence of one single tree per multicast group, whatever the source. A branch - also called *a logical link* is a unicast path (of one or several hops) between two clients. Tunneling is performed on these links to route packets. Like MOLSR, MOST requires an underlying link state unicast routing protocol to determine unicast paths between any two nodes in the network. To proceed to the computation of the overlay tree, multicast nodes need to have knowledge of the membership of their multicast groups. A message called *most* including the list of multicast groups to which the node belongs is periodically sent to the entire network like OLSRv2 TCs (using MPR optimization).

Tree Computation. MOST operates in a distributed manner, and periodically, it computes the overlay tree for each multicast group based on the group membership and the network topology (by means of a single modified Dijkstra route computation [6]). In order to reduce losses caused by topology changes, a logical neighbor in any tree in the past is retained for a given holding time.

Routing Decision and Encapsulation. for any non-duplicate packet, MOST determines which node(s) the packet must be forwarded to. The destinations are nothing else than the set of the logical neighbors except the one which the packet was received from. The data packet is then encapsulated in a unicast UDP packet and sent in unicast to each logical neighbor.

2.4 Generic Multicast Architecture

We now present the generic architecture that is used by the three multicast protocols, for the real implementation of the protocols. This architecture, given in [7] presents the advantage of separating the topology control and the multicast structure management from the multicast data routing, here called GMF (Generic Multicast Forwarder). The different modules entering in the design of the three protocols are represented in Figure 2 with their interactions.

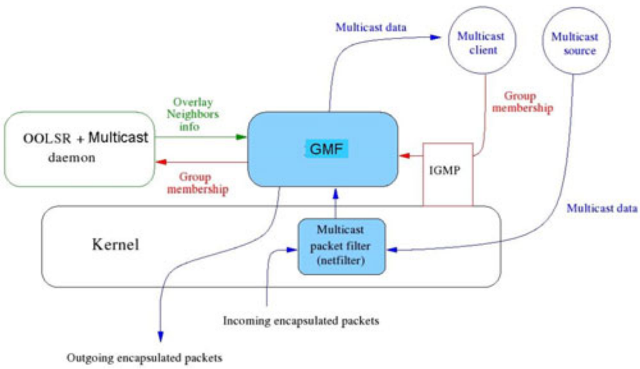


Fig. 2. Generic multicast architecture

- **OOLSR, Object Oriented OLSR**, [15], is INRIA's implementation of the OLSR protocol [13].
- **Multicast:** the module in charge of maintaining the multicast structure needed for multicast routing. This module uses control messages specific to the multicast protocol chosen. In practice, this module represents either the SMOLSR, MOLSR or MOST daemon.
- **GMF, Generic Multicast Forwarder:** this module is responsible for capturing and encapsulating multicast packets to be forwarded according to the multicast protocol chosen. For instance, multicast packets are forwarded to the entire network in case of SMOLSR, and inside a multicast tree in case of MOLSR or MOST. Forwarding rules are specified by the multicast protocol.
- **IGMP, Internet Group Management Protocol**, [16]**:** this module maintains the group membership.

The core functioning of OOLSR and Multicast described above is implemented in a shared library which is also used in NS2 within the OLSR routing agent. Thus for simulations, the architecture is identical, except that the GMF/IGMP/Kernel parts which are replaced by NS2 equivalents.

3 Performance Evaluation of Multicast Protocols

The performance evaluation of the three multicast protocols studied is done by means of simulations with NS2.

3.1 Simulation Parameters and Evaluation Criteria

Simulation parameters For the simulations, we adopt the parameters listed in Table 2:

Table 2. Simulation parameters

Run	Duration	300s
Configuration	Network area	1850m x 1850 m
	Number of nodes	200 or 100
Multicast	Group size	5 or 10 or 20
	Number of groups	1 or 2 or 3 or 4
	Number of sources	1 source per group
Mobility	Model	Random Way-point
	Maximum speed	0 or 1m/s or 5m/s or 10m/s
	Pause time	10 s
Traffic	Type	CBR
	Rate	64 or 150 or 200 or 250 kbps
	Packet size	1200 bytes
OLSR	HELLO interval	1s
	TC interval	5s
MAC	IEEE 802.11b	11Mbps
	Broadcast (neighborcast) rate	2 or 11 Mbps
PHY	Transmission range	250m
	Propagation model	Two-ray ground

Evaluation Criteria. We will evaluate the delivery ratio for the three multicast protocols considered. In order to have an estimate of the overhead generated, we will also evaluate the average number of packet retransmissions, also called average packet forwarding.

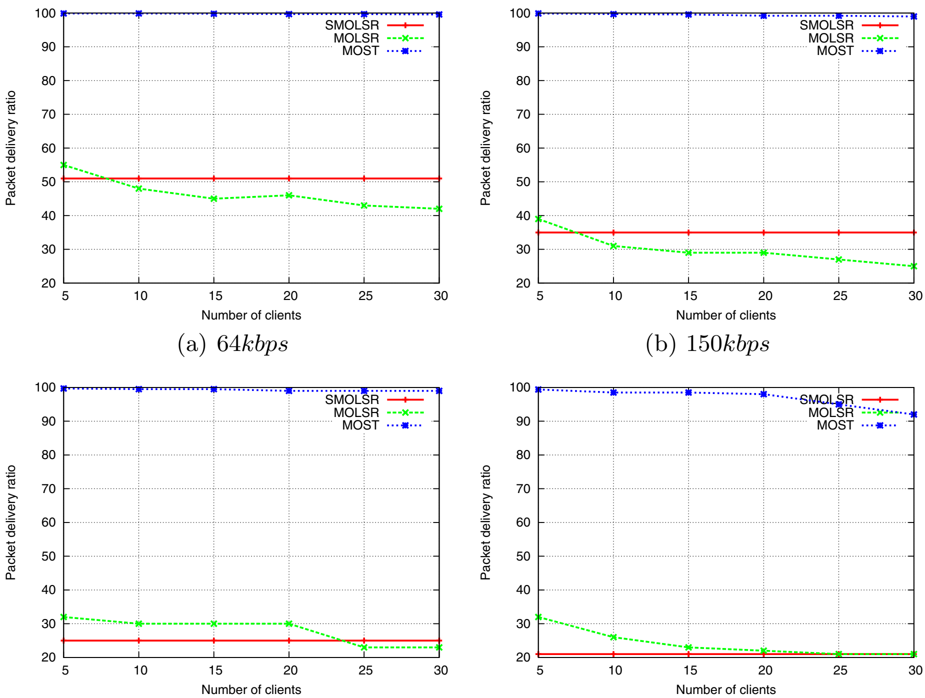
We consider different scenarios and study the impact of the:

- group size,
- number of groups,
- source rate,
- node mobility.

In order to obtain reliable results, simulations are iterated several times (7 on average) and the mean value is computed.

3.2 Packet Delivery Ratio versus Throughput

Simulations are conducted to determine the impact of the source rate on each protocol in term of packet delivery ratio. Since the goal here is to find the saturation point of the network, we consider a static topology. We consider a 200 wireless nodes network in a 1850×1850m^2 area, with one multicast group. We vary the number of clients as well as the source bit rate and evaluate the packet delivery ratio (in short PDR). Results are depicted in Figure 3.



(a) $64kbps$ (b) $150kbps$ (c) $200kbps$ (d) $250kbps$

Fig. 3. Comparison of multicast packet delivery ratio between the 3 protocols

As expected, MOST offers better packet delivery ratio than both MOLSR and SMOLSR in all cases (whatever the source rates or the number of multicast clients). This is explained by the use of unicast transmissions of data packets by MOST whose advantage is double. First, packets are sent at a higher rate ($11Mbps$, versus $2Mbps$ for multicast transmissions) which reduces significantly the channel occupancy. Second, packets are retransmitted when they are lost increasing the packet delivery ratio. For instance, we notice that with MOST the source node can transmit with a rate up to $200kbps$ with a very high delivery ratio. For higher transmission rates (from $250kbps$), the packet delivery ratio remains good for small groups but decreases for large group sizes.

MOLSR leads to a maximum PDR equal to 55% which in itself is not satisfactory. This means that the channel has reached saturation although the source rate is low ($64kbps$). Moreover, this rate significantly decreases either when we increase the source rate or the group size. For instance, the PDR falls to 20% for a $250kbps$ rate with 25 clients.

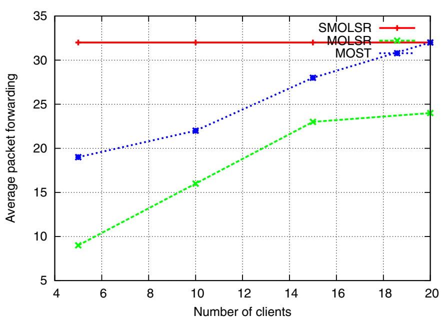
SMOLSR results are the same order of magnitude as MOLSR but some differences can be noted. For small group sizes, we notice a slight advantage for MOLSR. This is because SMOLSR floods the entire network regardless the group size which increases the global load. However, for large groups and small source rates, for example a $64kbps$ rate, SMOLSR gives better packet delivery ratio (around 40% for MOLSR and 50% for SMOLSR).

⟹ The key property (from table 1) is the nature of transmissions: unicast versus neighborcast. Overall, unicast offers smaller channel occupancy and better reliability.

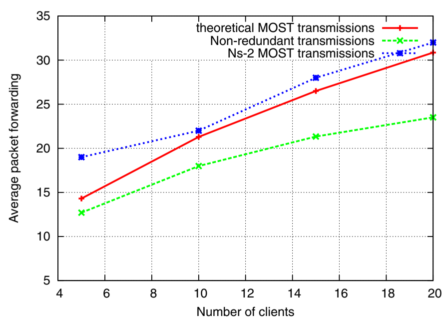
3.3 Comparison of Average Packet Forwarding

By average packet forwarding we denote the average packet retransmissions in the network. The measure of average packet forwarding is useful in evaluating the impact of the multicast traffic on the global network load.

For this purpose, we consider a randomly generated topology of 100 wireless nodes forming an ad hoc network, in a area of $1500m * 1500m$. We consider group sizes ranging from 5 to 20 nodes (not including the source). One source sends a traffic of $64kbps$ during 150 seconds of simulated time. We use in turn SMOLSR, MOLSR and MOST. Simulation results are depicted in Figure 4(a).



(a) Average number of retransmissions per multicast packet



(b) Comparison between MOST average number of retransmissions and Non-redundant transmissions

Fig. 4.

As we know, the main drawback of SMOLSR is to flood the entire network. As a result, with small groups, the average packet forwarding is higher than the two other protocols.

The average packet forwarding relies on three factors:

1. The number of forwarders (nodes on the tree that relay packets to the clients).
2. The ratio of received packets on each forwarder. This in turn depends on the loss probability on each branch on the tree.
3. The transmission nature i.e Unicast (like with MOST) or Multicast (like with MOLSR).

With MOST, the cost includes the redundant unicast transmissions and increases with the number of clients. On the other hand, MOLSR takes advantage of neighborcast transmissions which cost one transmission for the entire neighborhood. As a result, MOLSR provides the best packet forwarding whatever the group size. To highlight this idea, we reproduce the same scenario on a graph simulator with MOST protocol. As the packet delivery ratio is equal to almost 100% with MOST, the average packet forwarding is equal to the average number of forwarders in the MOST tree. This is depicted in Figure 4(b). First, we can notice that the average packet forwarding obtained via NS-2 and the one obtained theoretically are close. Second, we subtract the cost of redundancy due to unicast transmissions to consider its impact on the average packet forwarding for MOST. By comparing Figure 4(b) and Figure 4(a), we notice that the curve "Non-redundant transmissions" is close to MOLSR average packet forwarding.

However, the neighborcast transmission is not the only reason for reducing the packet average forwarding for MOLSR. In fact, packet loss itself reduces the number of retransmissions since not all packets reach all forwarders on the path in order to be routed. This is why, both packet delivery ratio and average packet forwarding must be considered as performance criteria.

In our scenario, MOLSR offers better average packet forwarding but with more losses, while MOST gives better packet delivery ratio, as summarized in Table 3.

Table 3. Packet delivery ratio in a 100 nodes network, and a 64*kbps* source rate

Number of clients	PDR(%) MOLSR	PDR(%) MOST
5	91	99.9
10	88	99.9
15	83	99.9
20	83	99.9

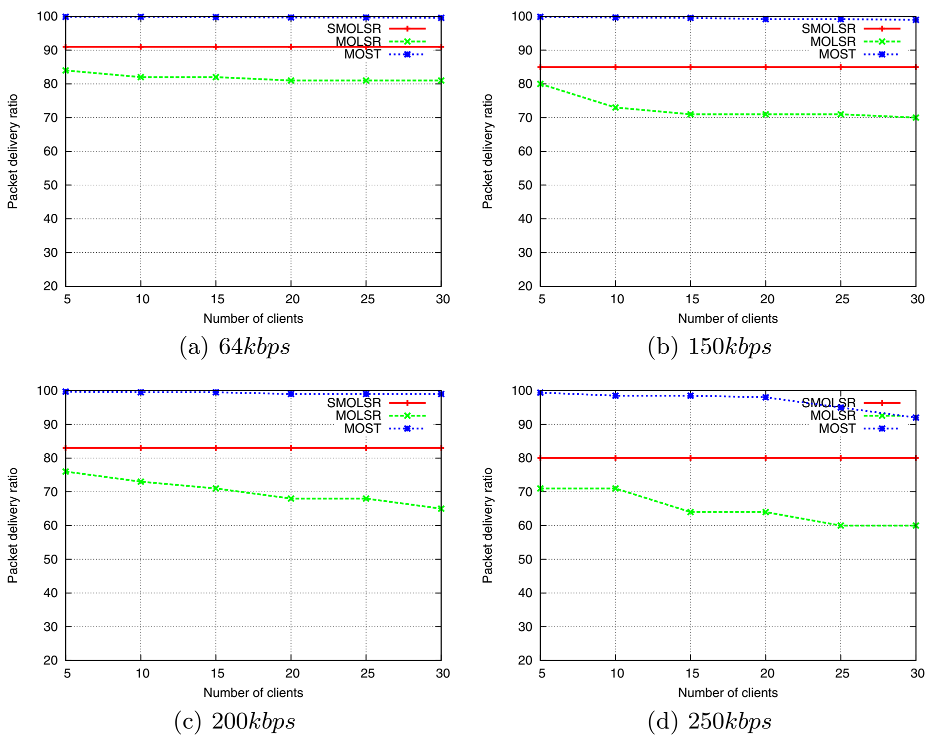
$\Longrightarrow$ **Here, the key properties (from table 1) for the number of forwarders are the nature of the transmissions (unicast vs. neighborcast) and the method (broadcast vs. multicast). It is minimized with neighborcast and multicasting.**

$\Longrightarrow$ **The key property for reliability is still the nature of transmissions: unicast is more reliable.**

3.4 Setting Neighborcast Basic Rate to 11Mbps

As we saw in previous section, MOST protocol supports higher throughputs than MOLSR and SMOLSR due to the use of unicast transmissions sent at $11Mbps$. Recall that the reason of setting the default 802.11 broadcast (neighborcast) rate to $2Mbp$s is to ensure reliability. In fact, it is important to maximize the chance of packets to be received at once since no retransmission is allowed. However, only low modulation rates are able to ensure that goal. Indeed, a high modulation rate requires an excellent signal quality otherwise it generates a lot of losses. That said, it seems to us important to compare the three protocols in the same context, i.e using the same modulation of $11Mbps$. Of course, the context of such a configuration would be an indoor network with good links quality. We set the multicast rate to $11Mbps$, and run simulations, the results are shown in Figure 5.

For MOLSR, the best packet delivery ratio is around 85% when it was only 50% with the classical $2Mbps$ broadcast (neighborcast) rate). The same impact is observed using SMOLSR with a PDR up to 90%. As we can notice, MOST still takes advantage on MOLSR and SMOLSR because although multicast packets are now transmitted with a higher rate, retransmissions are not performed like



(a) $64kbps$ (b) $150kbps$ (c) $200kbps$ (d) $250kbps$

Fig. 5. Comparison of PDRs with 11Mbps neighborcast rate

with unicast packets which has necessarily an impact on the packet delivery ratio.

$\Longrightarrow$ **Even when factoring out the higher data rate of unicast, the nature of transmissions was found to be decisive with better reliability of unicast even if it incurs more transmissions.**

3.5 Protocols Performance versus Number of Groups

We now run simulations by fixing the number of clients to 10 and varying the number of groups. In each group, a source is transmitting a CBR traffic with a $64kbps$ rate. We evaluate the impact of the number of groups on the packet delivery ratio. Results are illustrated in Figure 6. For MOST, a very high PDR is recorded until the number of groups reaches 8. For MOLSR, PDR decreases from 45% to 22% whereas it decreases from 51% to 14% for SMOLSR. As expected, when we increase the rate, MOLSR behaves better than SMOLSR.

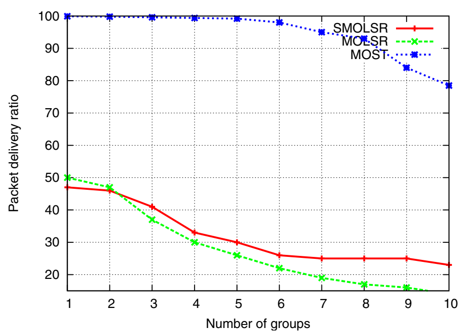
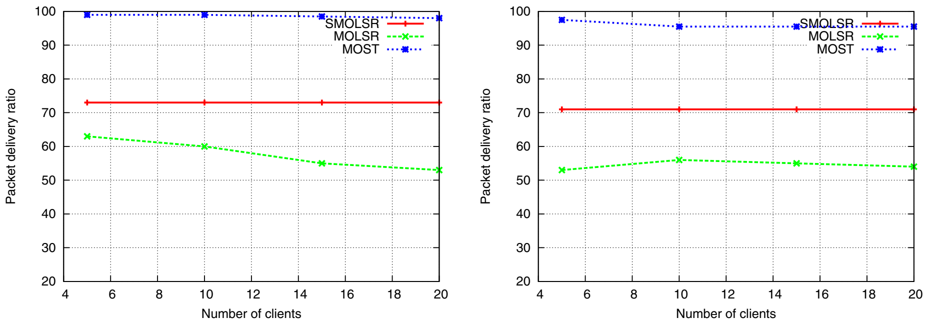


Fig. 6. PDR versus number of groups

$\Longrightarrow$ **Here, the key property for PDR is indirectly the method of transmission (broadcast vs. multicast). With multicast, congestion occurs later than with broadcast, and thus offers better PDR.**

3.6 Protocols Performance with Mobility

In order to evaluate each protocol performance with mobility, we consider the same scenario in which an arbitrary source node sends a CBR traffic of $64kbps$ for 300 seconds. The number of clients ranges from 5 to 20 nodes and the maximum mobility speed varies from $1m/s$ to $10m/s$. The mobility model is the random way-point with a pause time of $10s$: nodes choose a random point in the network area and move to it with a constant speed chosen at random between $1m/s$ and the maximum defined value; after they have reached their destination, they remain static for a period equal to the pause interval and then the same procedure is repeated.



(a) $1m/s$.   (b) $10m/s$.

Fig. 7. Comparison of MOST/MOLSR/SMOLR pdr in a mobile network

We first evaluate the impact of mobility on the packet delivery ratio. As we can see, MOST delivery ratio remains very high whatever the speed. However, as the speed increases, traffic load due to duplicate packets increases to reach more than 10%. A duplicate packet means that there was a transient loop. This transient loop is due to link breakage followed by a rebuilding of the multicast tree caused by mobility.

With SMOLSR, packet delivery ratio is not affected by mobility for reasonable speeds (up to $10m/s$). With MOLSR, performance decreases when we increase mobility with small groups, but PDR is no more affected by mobility for bigger groups with reasonable speeds (up to $10m/s$). SMOLSR delivery ratio is better than MOLSR in case of mobility.

Arguably, the complexity of the protocol exchanges is a factor: SMOLSR is the simplest (immediately available with OLSR), MOST is simple since it consists in a declaration of membership (independent from the topology), MOLSR is the most complex since the source tree must be updated and maintained.

$\Longrightarrow$ **The key property for resilience to mobility is the protocol: results suggest that it is related to the complexity of protocol exchanges in reaction to topology changes**

4 Conclusion

The performance evaluation of the three multicast protocols, allows us to draw some conclusions for the design and the choice of a multicast routing protocol. The absolute value for results obtained from MOLSR and SMOLSR is around 50% PDR, for our arguably reasonable scenarios and simulation parameters with a single $64kbps$ source: it illustrates the fact that wireless channel congestion cannot be considered as a non-issue for multicast.

The first observation is that the key performance parameter in several simulations was found to be the choice between unicast and neighborcast. In theory, neighborcast allows for less transmissions by benefiting from the wireless multicast advantage. On the other hand, in practice, in many wireless technologies (including 802.11b,g,...): unicast benefits from higher data rates, from automatic rate adaptation and from reliability features (such as acknowledgments and repetitions), whereas such sophisticated features are not available off-the-shelf for neighborcast. This was reflected in our scenarios and our simulations, with overall higher reliability and lower congestion for the protocol using unicast transmissions, MOST[3]. Hence, these features, actually MAC and physical layer features rather than multicast protocol features, were found to tilt the balance in favor of unicast, and are a crucial design factor.

Note also that even with some cross-layer improvements for neighborcast (such as for instance [17]), in sparse networks or in networks where the density of the multicast group is moderate[4], there are not many opportunities for benefiting from the wireless multicast advantage, and unicast overlay approaches remain excellent contenders.

A second observation is that some multicast protocols (SMOLSR and MOST) are almost built into the underlying routing protocol (OLSR)[5]: we hypothesized that this contributed greatly to their better behavior with respect to external changes in the network (mobility).

Overall, for applications with moderate density of group members, we conclude that approaches such as MOST are overall an excellent choice for multicast, as much for technological and practical reasons as for algorithmic ones.

For high density of group members, the studied protocols and our simulations do not point towards a definite protocol family or conclusion. Still we observe that, by itself, the network-wide broadcast exemplified by SMOLSR is costly when members are concentrated in some areas (with results worse than MOLSR). In such scenarios, a localized broadcast such as geocasting, or the approach of broadcasting in a limited area from source to destinations (for SMOLSR: [18]) should be considered.

In general, for high member density, simulations illustrated the fact that neighborcast is beneficial when the number of transmissions is considered, (which could be for instance even improved in MOLSR, with better tree construction), but the issues remain low data rate (by default) and reliability. These could be overcome by methods accepting a high data rate neighborcast at the price of lower reliability. The trade-off would be worthwhile when loss recovery/compensation has low cost in the broadcast method. One possibility is broadcast with network coding (see DRAGONCAST [19] for an example).

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[3] Notice that although neighborcast can be simulated by several unicast transmissions for MOLSR, SMOLSR or any protocol, the gain upon MOST is uncertain since MOST builds a minimum unicast spanning tree anyway (see also [5]).

[4] According to the conducted simulations, the performances of MOST remain good as long as the group size does not exceed 20% of the network size.

[5] MOST requires only the additional knowledge of the group membership (performed through proper proactive advertisements).

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