Investigating Data Broadcast Performance in Mobile Ad Hoc Networks

Thomas Clausen, Laurent Viennot, Tue Olesen, Nicolai Larsen

Investigating Data Broadcast Performance In Mobile Ad-hoc NETworks

Thomas Heide Clausen*, Laurent Viennot
Project HiPERCOM, INRIA Rocquencourt
B.P. 105, 78153 Le Chesnay Cedex, France
{thomas.clausen, laurent.viennot}@inria.fr

Tue Olesen, Nicolai Larsen
MindPass Center for distributed Systems,
Department of Computer Science, Aalborg University
Frederik Bajers Vej 7E, 9220 Aalborg , Denmark
{tue, cbaoth}@cs.auc.dk

Abstract
In this paper, we investigate broadcasting in Mobile Ad-hoc NETworks (MANETs). We define broadcasting as being the process of delivering one packet, originated at one node, to (ideally) all other nodes in the MANET. We present specific problems related to broadcasting in MANETs, as well as four broadcast protocols aimed at providing MANET-wide broadcast. Further, three protocol-independent modifications are presented. One aimed at ensuring that a broadcast packet traverses at least the "shortest path" to its destinations, and two aimed at increasing the fraction of nodes which receive a broadcast packet.
Through simulation studies, we evaluate the performance characteristics of the broadcast protocols and generic modifications under different conditions.

Keywords
Wireless Ad-Hoc Networks, Broadcast, Performance Evaluation, Simulation.

INTRODUCTION
A mobile ad-hoc network (MANET) is a collection of – possibly mobile – nodes connected by wireless links, forming an arbitrary, dynamic graph. The physical size of a MANET is expected to be larger than the radio range of the wireless interfaces, thus introducing the requirement of routing to enable multi-hop communication.
There exists a selection of routing protocols, providing unicast capabilities in MANETs. Examples hereof include AODV [10], DSR [6], TBRPF [2] and OLSR [9]. AODV, DSR and OLSR all utilize some form of broadcasting in order to construct routes. AODV and DSR broadcast route requests when a route to a destination is needed and record the path taken by the route request to reach the destination, in order to provide unicast routes. In OLSR, each node periodically broadcasts topological information. TBRPF does not utilize broadcasting directly, although topology information is diffused in a MANET, adhering to the same basic principles as those of reverse path forwarding.
Thus we observe, that for AODV, DSR and OLSR, the overhead incurring from maintaining unicast routes depends on the performance of the broadcasting mechanism used. For AODV and DSR, we further note that the length of the paths taken by the route requests, determines the lengths of the unicast routes.
Other than the use for MANET unicast routing protocols, broadcasting is widely used for various purposes in current wired networks. E.g. in service discovery protocols such as dhcp, Mobile IP and others.
In this paper, we aim to evaluate the proposed broadcast algorithms in an application-independent manner. I.e. we do not specifically target our evaluation towards the protocols suitability for carrying a specific type of traffic.

Paper outline
The remainder of the paper is organized as follows: in the following section, general considerations regarding broadcasting in MANETs are presented. Next, related work is presented, followed by a presentation of the broadcasting algorithms and the generic modifications considered in this work. Finally, the simulations and simulation results are presented and the paper is concluded.

BROADCASTING IN MANETS
We define broadcasting as being the process of delivering one packet, originated at one node, to (ideally) all other nodes in the MANET. We notice that this has its equivalents in the wired Internet domain through limited and directed broadcast. While there are similarities with broadcasting in wired networks, there are a number of complicating factors setting MANET broadcasting aside.
A typical MANET node will forward a packet on the same wireless broadcast interface as the one on which it was received. I.e. a packet being forwarded by an intermediate node will disturb both "next hop" and "previous hop – or, in other words, a packet being forwarded will transverse each link twice. Thus, the actually available bandwidth is limited, and it is required for each node to perform duplicate elimination for all packets. Finally, MANETs inherently have a high amount of packet loss compared to wired networks [3].

RELATED WORK
To date, published work has focused on evaluating the suitability of the broadcasting mechanisms for diffusing control traffic in MANETS. [7, 5] present an analysis of the benefits of using MPR flooding for distributing of topological information in OLSR.
[1, 12] both evaluate, through simulations, different classes of

*Phone: +33 1 3963 5363, fax: +33 1 3963 5566

broadcasting protocols, and agree that location-based protocols are of preference, with respect to overhead and delivery.

BROADCAST ALGORITHMS

We investigate four algorithms for broadcasting data packets in MANETs. Some of these algorithms require an underlying unicast routing mechanism. For that purpose, we utilize the Optimized Link State Routing protocol (OLSR) [13, 14, 9]. The algorithms we propose are "Classical Flooding", "Reverse Path Forwarding" [4], "Multipoint-relay flooding" [11] and "Dominating Set Flooding".

Classical Flooding

In Classical Flooding (CF), a packet is forwarded only the first time it is encountered by a node. I.e. duplicate transmissions are eliminated while sub-optimal bandwidth utilization certainly is possible. Specifically, when a node receives a flooded packet, it obeys the following rule:

- a packet is forwarded by the node if:
  - the packet has not been received before.

Each broadcast is thus transmitted once by all nodes in the network.

MPR Flooding

Multipoint-relay Flooding (MPRF) and Dominating Set Flooding (DSF) is inspired by the transport mechanism used to carry OLSR control traffic: each node selects, independently, among its neighbor nodes a set of "multipoint-relays" such that the following condition is satisfied:

> a packet, originated by node n and relayed by its multipoint relays is received by all nodes two hops away.

This scheme requires a neighbor discovery mechanism which allows a node to acquire information about the nodes in its neighborhood as well as the neighborhood of these neighbor-nodes.

For MPRF, the rule for forwarding a broadcast packet is restricted as follows:

- a packet is forwarded by the node if:
  - the packet has not been received before, and
  - the node is selected as multipoint relay by the node from which it received the packet (the "previous hop" of the packet).

To reduce the number of transmissions involved in a broadcast, each node should select as few multipoint-relays as possible.

Dominating Set Flooding

We notice that using MPRF, each node in the network selects and utilizes its own "broadcast tree", spanning all nodes in the network.

In general, last-hop information for a received IP datagram can not be assumed available. To remove this dependency on last hop information, DSF selects from among the many possible broadcast trees in MPRF exactly one broadcast tree. OLSR nodes periodically floods topological information to all nodes in the MANET using MPRF. Hence, existing control traffic can be utilized to perform the task of a "selection message"[1]. For DSF, the rule for forwarding a broadcast packet is restricted as follows:

- a packet is forwarded by the node if:
  - the packet has not been received before, and
  - the node was forwarding the last "selection message".

The main difference between MPRF and DSF is thus, that broadcast traffic from different sources traverse different broadcast trees using MPRF, while use a common broadcast tree using DSF. Any performance difference can be anticipated to be congestion in the shared broadcast tree in DSF.

Reverse Path Forwarding

Reverse Path Forwarding Flooding [4] (RPF) augments the mechanism of CF by the requirement that a node may only forward a packet if the "previous hop" of the packet is on the shortest path to the source. An underlying unicast routing protocol is required to determine shortest paths.

For RPF, the rule for forwarding a broadcast packet is restricted as follows:

- a packet is forwarded by the node if:
  - the packet has not been received before, and
  - the last hop, from which the packet was received is on the shortest path from the node to the source.

GENERIC MODIFICATIONS

In this section, we present three modifications that can be applied to either of the broadcasting algorithms.

Super Flooding

Super Flooding loosens the forwarding rule by allowing a node to forward a flooded packet more than once, as follows:

- a packet is forwarded by the node if:
  - the packet has not been received before, or
  - the hop-count of the packet is smaller than the hop-count of any previously forwarded instance of the packet.

This requires that a node is able to get the hop-count for a received packet. This scheme ensures that, collisions disregarded, a packet will be delivered through at least the shortest path. This may be an advantage e.g. for route discovery in AODV and DSR, however at the cost of increased bandwidth consumption.

Multipacket Flooding

With Multipacket Flooding, the idea is that a source transmits the same packet multiple times and, that each intermediate node is permitted to forward the packet up to a specific number of times to increase the chance that a packet is actually delivered. Specifically, when a node receives a flooded packet, it obeys the following rule:

[1] Alternatively, a "selection message" can be issued explicitly by an agreed node

Simulator Parameters	
Propagation model	TwoRayGround
Network type	IEEE 802.11 (2 Mbps)
Transmission range	250 m
Scenario parameters	
Field size	1400m × 1400m
Number of nodes	100
Simulation time	300 seconds
Mobility model	Random waypoint
Node speed	Between 1 and 2 m/s
Node rest time	Between 7 and 15 seconds
Movement distance	Between 50 and 350 m

Table 1. Simulator and Scenario parameters.

- a packet is forwarded by the node if:
  - the packet has not been received more than M times before.

Data Packet Jitter

The purpose of introducing a small amount of Jitter when forwarding data packets is to reduce the chance of collisions when nodes within transmission range of each other forward packets that have been received from a common neighbor. Specifically, the following rule is applied:

- when a node has decided to forward a packet:
  - delay the actual transmission of the packet for a randomly selected period of time, between 0 and Max_Jitter seconds.

SIMULATIONS AND RESULTS

To evaluate the characteristics of the proposed broadcast algorithms, exhaustive simulations using the Network Simulator 2 (ns2) [8] were conducted.

Simulation scenarios

Table 1 lists the fixed scenario parameters used for all the the simulated scenarios.

Statistical significance

From each unique set of scenario parameters, 30 random scenarios are generated and simulations conducted, and the average values are computed. This reduces the chance that results are dominated by a single scenario which accidentally prefers one protocol over another.

All protocols are simulated using the same sets of 30 scenarios, hence the protocols are evaluated under identical conditions.

Basic protocols

This section presets the delivery rate and bandwidth consumption achieved by CF, MPRF, RPF and DSF. Each graph presents the average of seven different UDP byte rates, ranging from 192 B/s to 7680 B/s.

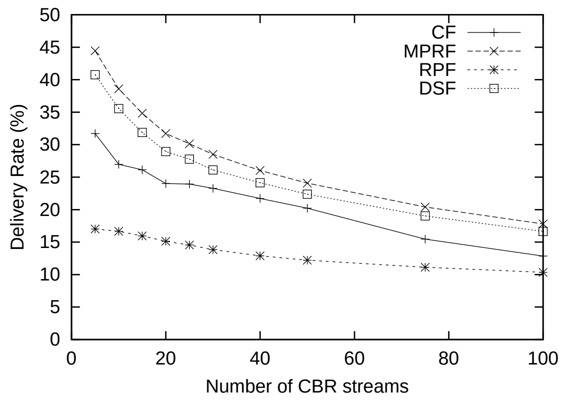

Figure 1. Delivery Rate of the four basic protocols.

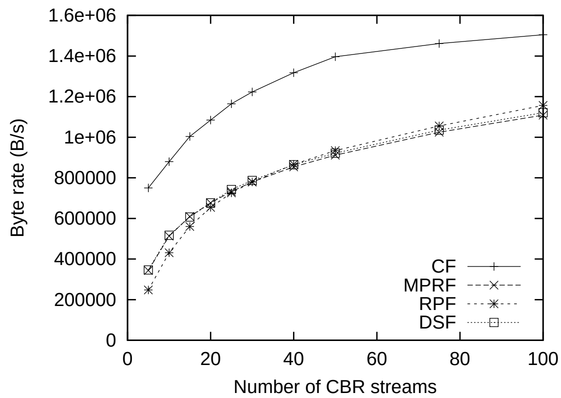

Figure 2. Bandwidth Consumption for the four basic protocols.

Delivery Rate

Figure 1 illustrates the average delivery rate for the basic protocols. MPRF achieves the best delivery rate, with DSF ranging 1-4% lower than MPRF. RPF achieves the lowest delivery rate, even compared to CF, which achieves delivery rates 2-14% higher than RPF.

Notice that the highest achieved delivery rate by any of the protocols is 45%, and this only under the lowest simulated load (5 streams at 192 B/s).

Bandwidth consumption

Figure 2 illustrates the average number of bytes per second transmitted by all interfaces throughout the simulation. CF is outperformed by the three other protocols - it consumes between 35% and 118% more bandwidth. protocols. RPF consumes 39% less bandwidth than MPRF and DSF at the lowest byte rate. With increased traffic, the bandwidth consumption of RPF rises to the point where it consumes 4.1% more bandwidth than MPRF and DSF.

The bandwidth consumed by MPRF, DSF and RPF includes the control traffic generated by OLSR (the underlying routing protocol utilized), whereas no additional control traffic is present for CF.

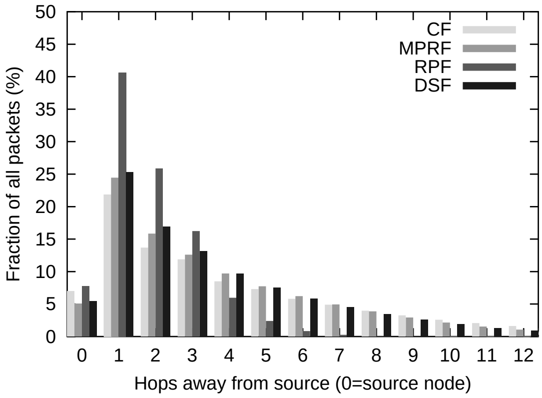

Figure 3. Fraction of packets delivered with varying path length.

Delivery Radius

Figure 3 illustrates the fraction of packets delivered at a certain radius, measured in hops, from the source node. RPF delivers 40% of the broadcast packet to immediate neighbors, while only 23%-25% of the packets are delivered here by the other protocols. At all hop radii above 3, RPF delivers less packets than the three remaining protocols, dropping below 1% deliveries already at 6 hops.

Generic Modifications

This section presents the simulation results obtained by combining two of the basic protocols, CF and DSF, with the generic protocol modifications proposed in a previous section. CF was selected to provide a point of reference. Though MPRF has been shown to perform slightly better than DSF, the latter was selected for testing the generic modifications, as DSF lends itself to less intrusive implementation in real-life MANETs than does MPRF.

Superflooding

Figure 4 illustrates the average minimal path length achieved by the basic CF and DSF protocols, as well as the path lengths when superflooding is applied to either protocol. As nodes may receive multiple instances of a packet, the minimal path length is calculated by considering only the path length of the packet arriving via the shortest path.

It is observed that the average minimal achievable path length for both CF and DSF augmented with Superflooding is lower than what is achieved by the basic protocols. Overall, the path length of CF is reduced significantly, while DSF experiences a smaller reduction.

Multipacket Flooding

Figure 5 illustrates the delivery rate of the basic CF protocol and CF augmented with three different versions of multi-packet flooding (with M=$\{2, 3, 5\}$ respectively).

We observe, that issuing redundant transmission does, in fact, degrade performance.

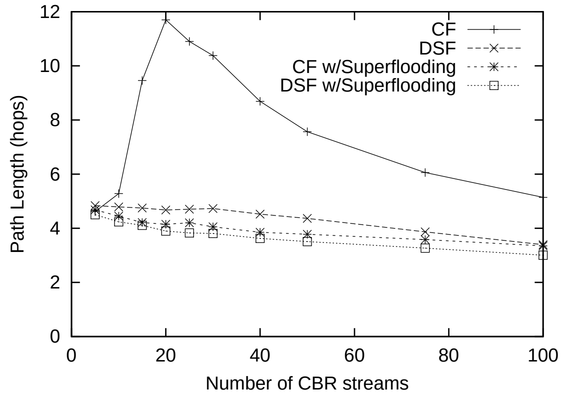

Figure 4. Path length (hops) with varying number of streams

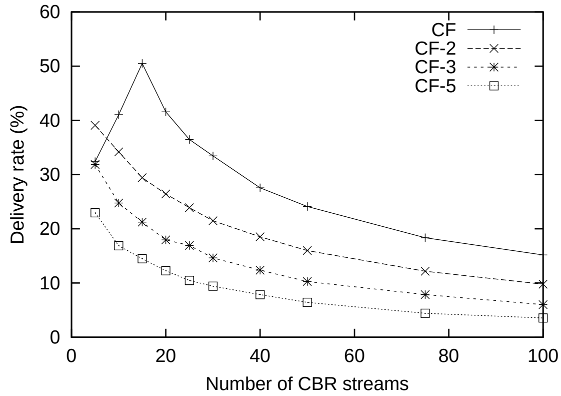

Figure 5. Multipacket Flooding: Delivery Rate of Classical Flooding

Data Packet Jitter

Figure 6 illustrates the delivery rate obtained by Dominating Set Flooding, with a traffic load of 768 B/s.

We observe that data packet jitter increases the delivery rate. At low traffic loads, a 73% improvement in delivery rate is observed, the improvement degrading with increased traffic load.

We note, that in none of our simulations did jitter yield a lower delivery rate than the unmodified protocol.

Adding more jitter does not change the delivery rate significantly, but the packet delay (measured as wall clock time) increases as a cause of delaying packet during transmission. Thus, small amounts of jitter is preferable to minimize this delay.

CONCLUSION

Four broadcast protocols have been proposed, to solve the task of delivering a data packet to all nodes in a MANET. Of these protocols, MPR Flooding achieves the highest delivery rate, while Reverse Path Forwarding consistently achieves the lowest. We note, that among the protocols, even the the protocol with the

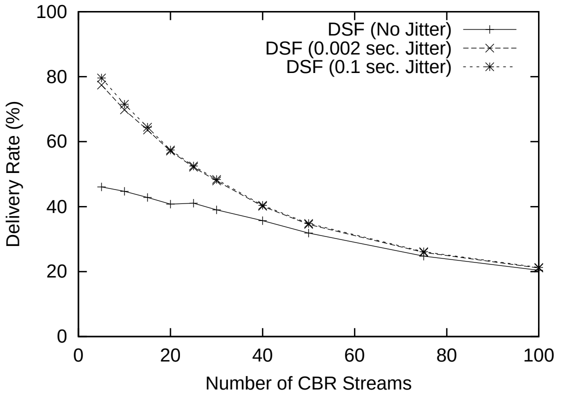

Figure 6. The Delivery Rate of Dominating Set Flooding is increased when data packet jitter is enforced.

highest delivery rate, MPR Flooding, provides a delivery rate of less than 50%.
Of the four protocol, Classical Flooding consumes the most bandwidth. MPR Flooding, Dominating Set flooding and Reverse Path Flooding consumes roughly identical amounts of bandwidth.
We note, that applying jitter on Dominating Set Flooding can increase the delivery rate in low-traffic scenarios while in high-traffic scenarios, the presence of jitter makes no significant difference.
Superflooding, applied to classical flooding, yields significantly shorter path-lengths at the expense of higher bandwidth consumption. Applied to Dominating Set Flooding, Superflooding yields only slightly shorter pathlengts, indicating that the MPR optimization already yields close to optimal paths.
Combined, we find that the MPR optimization combined with jitter provides a very feasible mechanism for providing broadcasting in MANETs.

ACKNOWLEDGMENTS

This work was, in part, supported by generous grants from the Oticon foundation and the Siemens foundation.

REFERENCES

[1] B. Williams and T. Champ. Comparison of broadcasting techniques for mobile ad hoc networks. In Proceedings of MOBIHOC 2002, Lausanne, Switzerland, July 2002.

[2] B. Bellur, R. G. Ogier, and F. L. Templin. Topology Broadcast based on Reverse-Path Forwarding (TBRPF), March 2002. Internet Draft, draft-ietf-manet-tbrpf-05.txt.

[3] S. Corson and J. Macker. Mobile Ad hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations, January 1999.

[4] Y. K. Dalal and R. M. Metcalfe. Reverse path forwarding of broadcast packets. Communications of the ACM, 21(12):1040–1048, 1978.

[5] P. Jacquet, A. Laouiti, P. Minet, and L. Viennot. Performance analysis of olsr multipoint relay flooding in two ad hoc wireless network models. Technical Report 4260, INRIA, 2001.

[6] J. G. Jetcheva, D. Johnson, D. Maltz, and Y. Hu. Dynamic source routing (dsr). Internet Draft, draft-ietf-manet-dsr-06.txt, November 21 2001, Work in progress.

[7] A. Laouiti, A. Qayyum, and L. Viennot. Multipoint relaying: An efficient technique for flooding in mobile wireless networks. In 35th Annual Hawaii International Conference on System Sciences. IEEE Computer Society, 2001.

[8] S. McCanne and S. Floyd. ns Network Simulator. Available at http://www.isi.edu/nsnam/ns/.

[9] P. Jacquet, P. Muhlethaler, A. Qayyum, A. Laouiti, L. Viennot and T. Clausen. Optimized Link-State Routing Protocol, March 2002. Internet Draft, draft-ieft-olsr-06.txt.

[10] C. E. Perkins, E. M. Royer, and S. R. Das. Ad hoc on-demand distance vector (aodv) routing. Internet Draft, draft-ietf-manet-aodv-09.txt, November 9 2001, Work in progress.

[11] A. Qayyum, L. Viennot, and A. Laouiti. Multipoint relaying: An efficient technique for flooding in mobile wireless networks. Technical report, Project HiPERCOM, INRIA Rocquencourt, 2000. INRIA research report RR-3898.

[12] S. Ni, Y. Tseng, Y. Chen and J. Shen. The broadcast storm problem in a mobile ad hoc network. In Proceedings of Mobicom'99, 1999.

[13] T. Clausen, G. Hansen, L. Christensen and G. Behrmann. The optimized link state routing protocol - evaluation through experiments and simulation. In Proceeding of Wireless Personal Multimedia Communications, September 2001.

[14] T. Clausen, P. Jacquet, A. Laouiti, P. Muhlethaler, A. Qayyum and L. Viennot. Optimized link state routing protocol. In Proceedings of IEEE INMIC, Lahore, Pakistan, December 2001.