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Expanding Ring Search for Route Discovery in LOADng Routing Protocol

Antonin Bas, Jiazi Yi, Thomas Clausen
Laboratoire d'Informatique (LIX) – Ecole Polytechnique, France)
antonin@antonin-bas.fr, jiazi@jiaziyi.com, Thomas@ThomasClausen.org

Abstract

LOADng is an on-demand routing protocol, derived from AODV, simplified for use in lossy, low-power and constrained environments, where the ability for devices to communicate is a commodity to their primary function, and where therefore not only the communications channel offers limited capacity, but also the resources available to the device's communications subsystem are limted.

LOADng simplifies AODV in a number of ways, notably the route discovery process by removing intermediate/gratuitous Route Replies – sacrificing that functionality in order to attain smaller control messages and less router state and processing. Alas, this comes at an expense: in some situations, LOADng produces increased control traffic overhead (as compared to AODV), and more control messages transmissions means tapping into the device's limited resources.

This paper presents a simple mechanism by which to integrate Expanding Ring flooding into LOADng. The mechanism is described, and the result of simulation studies are presented, showing that both in scenarios with "point-to-point" (any-to-any) traffic and in scenarios with "multipoint-to-point" (all traffic sent to the same destination, as in a data acquisition sensor network) traffic, considerable savings in control traffic overhead can be achieved – without loss in data delivery ratios.

1. Introduction

For on-demand routing protocols like AODV [1] and its derivatives (LOAD, LOADng [2]), the route discovery procedure is the most costly operation in the protocol. To discover a route to a certain destination, a Route Request (RREQ) message is flooded through the network. To reduce the flooding overhead and make use of existing routing information, AODV uses intermediate Route Reply (RREP) messages and Expanding Ring search, with the cost of more complex sequence numbers in the control packet to avoid loops.

LOADng [2] is a derivative of AODV, targeting routing in low-power and lossy networks, where the communications channel is characterized by a high risk of packet loss and (typically) very small frame sizes, very limited throughput, and where routers have strict bounds on memory, processing power and energy. This implies a requirement for a routing protocol of extreme simplicity: minimal state can be maintained, protocol operations must be simple, and control traffic must be minimal - both in terms of number of messages exchanged (each transmission takes energy and consumes network capacity better used for data) and in terms of the size of these messages, so as to avoid fragmentation. For example, using 6LoWPAN over 802.15.4 [3], leaves only 81 octets for payload in each frame transmitted – and, over a lossy network, fragmenting a packet naturally increases the risk of one of the frames in that packet being lost, thus loosing the whole packet.

LOADng simplifies AODV in a number of ways, as documented in [4] – and one of those simplifications is eliminating intermediate RREP, so as to guarantee loop freedom, and reduce the control message size and the complexity of protocol operation for constrained environments. A comparison of LOADng with RPL and AODV has been performed in [4, 5]. To avoid increasing control overhead too much in some scenarios, LOADng also introduces

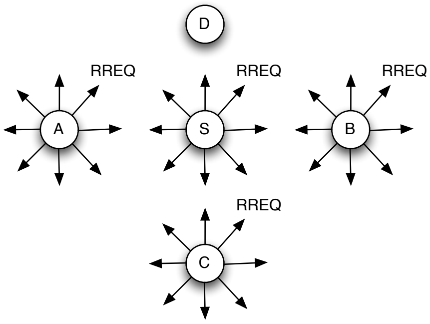

Figure 1: Route Discovery. *S* initiates an RREQ for *D*. *A*, *B* and *C* already know routes to *D*.

a new RREQ propagation scheme, called *SmartRREQ*, which takes advantage of existing routing information in intermediate routers.

1.1. Paper Outline

The remainder of this paper is organized as follows: section 2 describes the Expanding Ring flooding mechanism, as used in AODV. Section 3 describes LOADng - the derivative of AODV for low-power and lossy networks - as well as the *SmartRREQ* extension, the simple and efficient mechanism replacing the intermediate RREPs otherwise used in AODV. Section 4 presents how to integrate Expanding Ring search into LOADng – the performance of which is studied by way of network simulations, and presented in section 5. Section 6 concludes this paper.

2. AODV and Expanding Ring Flooding

The basic operation in AODV is *Route Discovery*. During *Route Discovery*, RREQ messages are flooded trough the network, indicating the address to which a route is sought. Upon receiving an RREQ, the router which is responsible for the address listed in the RREQ will respond with an RREP, sent in unicast to the source of the RREQ. In AODV, if an intermediate router receiving the RREQ has a (valid) route to the address listed in the RREQ, it may send an *intermediate RREP* to the source of the RREQ, as well as a *gratuitous RREP* to the intended destination (both as unicast), so as to establish a bi-directional route. This permits, in some cases, avoiding an RREQ being flooded through the entire network, with the ambition of reducing the control traffic incurring from Route Discovery, illustrated in figure 1, which shows 5 routers from an N-router network (where $N > 5$). *S* initiates an RREQ for *D*. The neighbors of *S*: *A, B, C* already have valid routes to *D*. Without intermediate RREPs, all routers other than the destination have to retransmit the RREQ, *i.e.,* there are at least $N - 1$ RREQ transmissions. In contrast, with intermediate RREP, route discovery will remain local to the neighborhood of *S*: *A, B, C* would generate intermediate RREPs to *S*. Although in this example, those RREPs would be discarded as providing longer routes, using intermediate RREPs would avoid RREQs being disseminated blindly through the whole network.

2.1. Expanding Ring flooding

In AODV, an Expanding Ring flooding mechanism is used for route discovery, in order to further avoid network-wide dissemination of RREQs. A router will at first send an RREQ with a reduced TTL – causing the RREQ to not be flooded through the entire network, but only up to a limited distance. Only if no intermediate RREP results, will the router attempt to flood the entire network. [1] recommends starting with TTL=1, then do successive floods with the TTL increasing by 2 each time until TTL=7 – after which classic flooding is employed.

Note that while this may be an advantage in some cases, this mechanism can be a double-edged sword, which may cause increased rather than decreased control traffic: if no router closer to the originator of an RREQ than the final destination has a route to the destination, much more control traffic can be generated by such repeated Expanding Ring floods.

3. LOADng and SmartRREQ

As a reactive distance-vector protocol and a light-weight derivative of AODV, LOADng [2] targets routing in low power and constrained environments. It inherits the basic properties and operations of AODV, including generation of Route Requests (RREQs) by a router (originator) for discovering a route to a destination, forwarding of such RREQs until they reach the destination router, generation of Route Replies (RREPs) upon receipt of an RREQ by the indicated destination, and unicast hop-by-hop forwarding of these RREPs towards the originator. If a route is detected broken, *i.e.,* if the forwarding of a data packet to the recorded next hop on the route to the destination is detected to fail, local route repair can be attempted, or a Route Error (RERR) message can be returned to the originator of that data packet.

Compared to AODV, LOADng prohibits intermediate RREPs, in order to reduce the size of control messages[1] and to reduce the state and processing required in routers in the network. Replacing intermediate RREPs, LOADng introduces an alternative route discovery scheme, denoted *SmartRREQ*, which introduces no additional signaling or data in RREQ/RREPs, nor any particular additional processing, yet permits taking the same benefits from the existing routing information present in intermediate routers, similar to what is done by intermediate RREPs. *SmartRREQ* works as follows: when a router receives an RREQ, it looks in its routing table for an already existing routing entry for the sought destination. If such an entry exists, and if its <next-hop> is not equal to the previous hop address of the RREQ, the RREQ is unicast to the <next-hop> instead of being broadcast.

In figure 2, Router *S* initiates a route discovery to Router *D*, while *A* and *B* have already available routes to *D*. On receiving the broadcast RREQ from *S*, *A* identifies that it already has a valid route to *D*, and so proceeds to unicast, rather than broadcast, the RREQ via the recorded path to *D*.

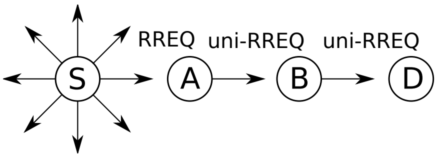

Figure 2: LOADng Route Discovery with smart RREQ. *S* initiates an RREQ for *D*. *A* and *B* already have an available route to *D*

SmartRREQ considerably reduces the overhead of RREQ dissemination, as illustrated in figure 3, and also enables a modified version of Expanding Ring flooding – described in section 4.

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[1] Low-power and constrained environments, typically, use network interfaces with very tiny MTUs: IEEE 802.15.4 with 6LowPAN, for example, accords an MTU of only 81 octets, rendering very small control messages a necessity, to avoid fragmentation.

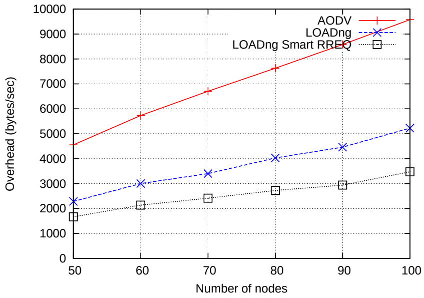


Figure 3: Average control traffic overhead, in bytes, in a network with from 50-100 routers, distributed randomly in a 1000m×1000m field, and subject to 30 concurrent and random (source, destination) traffic flows. All of the three protocols, AODV, LOADng and LOADng with *SmartRREQ* attained identical and 100% data delivery ratios.

4. Expanding Ring flooding for LOADng

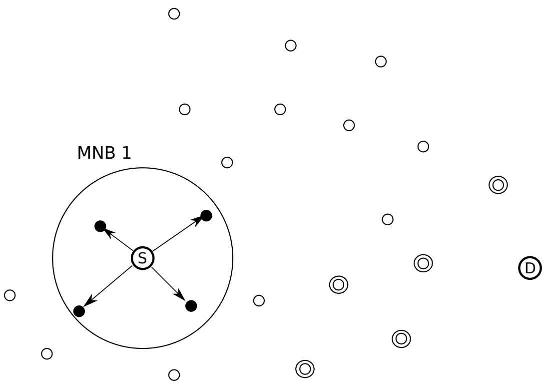
Because LOADng intermediate routers are not allowed to generate intermediate RREPs, Expanding Ring flooding in LOADng cannot be simply accomplished by progressively increasing an initially small TTL. Even if an intermediate router already has a valid route to the sought destination, the RREQ would still need to reach the destination – which would mean the TTL would have to be of a value at least equal to the distance between the source of the RREQ and the sought destination. Therefore, the TTL field in the IP header is not used for Expanding Ring flooding in LOADng. Rather, a new field is introduced in RREQ messages, denoted the MNB (Maximum Number of Broadcasts). This field is of the same size (8 bits) and behavior as the TTL field from the IP header, except that it governs only the number of broadcasts of RREQs permitted.

When initiating a route discovery in LOADng and with Expanding Ring flooding enabled, the originating router sets the MNB field to MNB_START (similar to AODV TTL_START), and sets the timeout for receiving an RREP to twice the value of the LOADng parameter NET_TRAVERSAL_TIME. If this timeout expires without a matching RREP having been received, a new RREQ is broadcast with a MNB field incremented by MNB_INCREMENT. This continues until the MNB set in the RREQ reaches MNB_THRESHOLD, beyond which the route discovery can either be declared a failure or continued with a MNB set to LOADng MAX_HOP_COUNT (*i.e.,* 255), which corresponds to a network-wide flooding. Each time, the timeout for receiving an RREP is twice NET_TRAVERSAL_TIME.

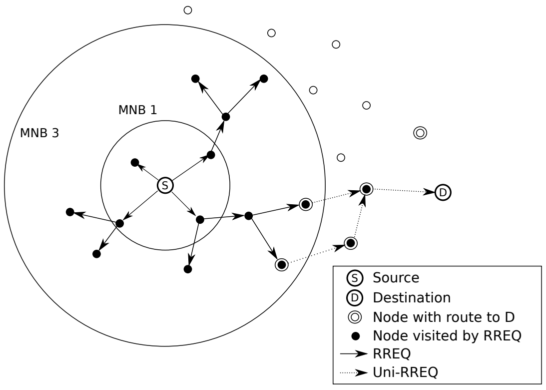
Unlike the TTL, the MNB is not decreased by one on each hop. When an intermediate router receives an RREQ, it performs the following procedure before transmitting it:

1. If the RREQ message is to be unicast, which with *SmartRREQ* means that the intermediate router has an available routing tuple to the destination router in the routing table and that the <next-hop> field of the corresponding routing tuple is not equal to the previous hop address of the RREQ, then the RREQ MNB field is left unchanged.
2. If the MNB field has reached 0, then the RREQ is discarded.
3. Otherwise, the RREQ MNB field is decreased by one (and the RREQ is broadcast normally).

Figure 4 illustrates situations, where Expanding Ring flooding can decrease control traffic overhead: router S initiates a route discovery for D, the routers with double circles already have a valid routes to D. In figure 4(a), MNB_START is set to 1, and the MNB_INCREMENT is set to 2, thus no RREP results from the first RREQ with MNB = 1. Then, in figure 4(b), S increases MNB by 2 – the RREQ reaches two routers which already have valid routes to D, and which therefore by way of *SmartRREQ* unicast the RREQ to D – which will respond by returning an RREP.



(a) MNB = 1



(b) MNB = 3

Figure 4: An example of Expanding Ring flooding initiated by *S* for *D*. The white routers are not visited by RREQs, but would have been without Expanding Ring flooding enabled.

Unlike for AODV, the RREQ timeout is constant and equal to twice NET_TRAVERSAL_TIME – which should correspond to the maximum time needed for an RREQ to traverse the whole network. The reason for this is, that regardless of the value of MNB, an RREQ in LOADng must travel all the way from *S* to *D* (and an RREP returned): in figure 4, a 5-hops route is found with an RREQ where MNB = 3.

With *SmartRREQ*, route discovery can be divided into two parts: (i) broadcast RREQ until a router with a valid route to the sought destination is encountered, then (ii) unicast RREQ towards the destination. Expanding Ring flooding tries to limit the number of routers impacted by (i), as well as the number of messages required by (i).

5. Simulation and Evaluation

This section presents the performance of LOADng using *SmartRREQ*, with and without Expanding Ring flooding enabled (MNB_START = 1, MNB_INCREMENT = 3), in two different traffic scenarios: sensor-to-root (multipoint-to-point - MP2P) traffic and sensor-to-sensor (point-to-point - P2P) traffic. The performance is evaluated by way of network simulations, using NS2 [6], with LOADng implemented in Java and using AgentJ [7] for interfacing the LOADng implementation with the NS2 network simulator.

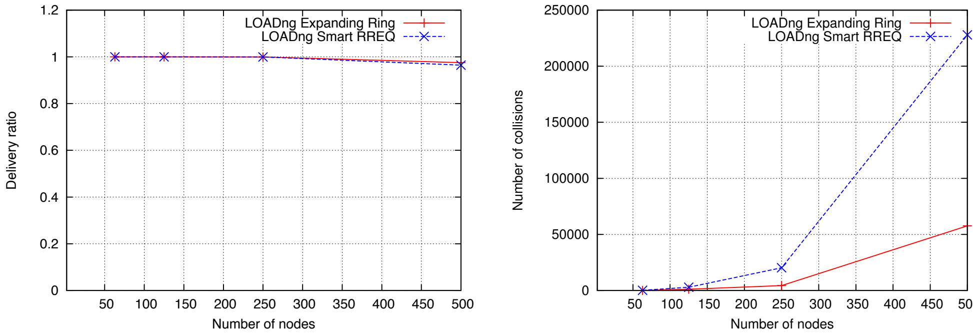
Simulations are run with 63, 125, 250 and 500 nodes. Networks are generated randomly in a square area, which grows with the number of nodes so as to maintain a constant density of nodes in the network. For example, with 63 nodes, we use a 1095 × 1095 m^2 area. The transmission radius is set to 250 m. No mobility is considered in the simulations.

The network is subject to point-to-point (P2P) traffic or multipoint-to-point (MP2P) traffic with routers generating 80 second bursts of 512-octet data packets every 5 seconds

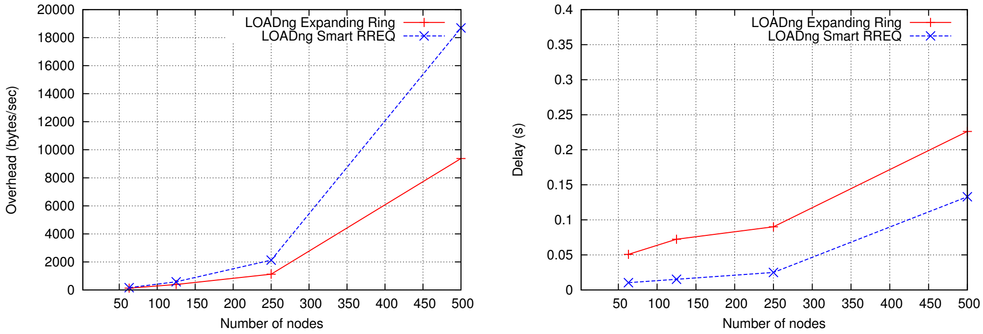
The number of layer 2 collisions, the average control overload and the average end-to-end delay are measured. The control overload includes RREQ and RREP messages, and the end-to-end delay is defined as the time between data packet generation and its arrival at the destination. The end-to-end delay reflects the time needed to find a route to the destination router, and the time it takes for the data packet to be delivered.

5.1. MP2P Performance

For MP2P traffic scenarios, all the routers establish a route to the designated root, and generate data traffic to the root. The data delivery ratio is illustrated in figure 5(a) – noting that identical data delivery ratios are obtained for LOADng with and without Expanding Ring flooding. The number of collisions, overhead and delays are presented in figure 5.



(a) Data Delivery Ratio, in MP2P scenarios (b) Number of collisions, in MP2P scenarios

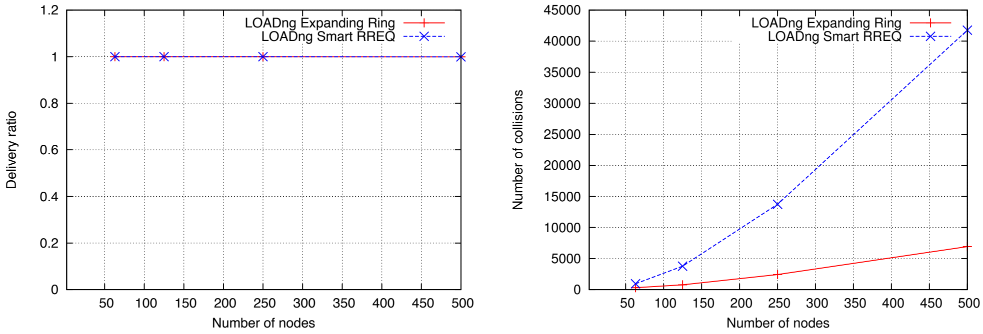


(c) Average overhead, in MP2P scenarios (d) Average end-to-end delay, in MP2P scenarios

Figure 5: The Performance of Expanding Ring search for a MP2P scenario

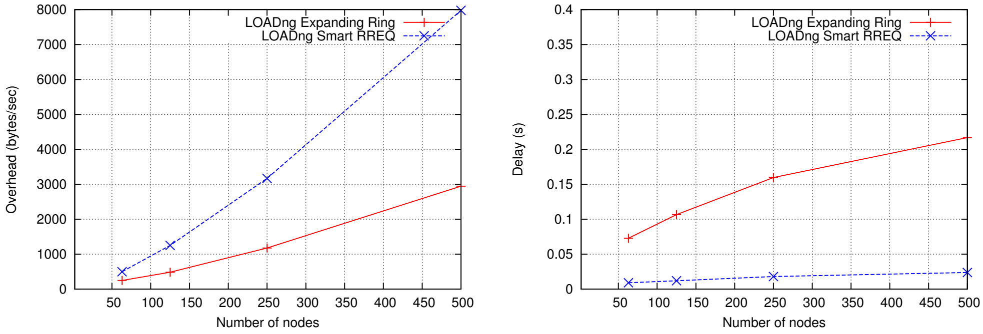
5.2. P2P Performance

The network was subject to 100 concurrent and random (source, destination) traffic flows. The data delivery ratio is illustrated in figure 6(a) – noting that identical data delivery ratios are obtained for LOADng with and without Expanding Ring flooding. The number of collisions, overhead and delays are presented in figure 6.



(a) Data Delivery Ratio, in P2P scenarios

(b) Number of collisions, in P2P scenarios



(c) Average overhead, in P2P scenarios

(d) Average end-to-end delay, in P2P scenarios

Figure 6: The Performance of Expanding Ring search for a P2P scenario

5.3. Discussion

In the scenarios studied, the control traffic overhead was noticeably reduced when Expanding Ring flooding was enabled. For multipoint-to-point traffic, LOADng without Expanding Ring flooding generates twice as much control overload as when using Expanding Ring flooding, as shown in figure 5(c). However, this comes at the expense of an increase in end-to-end delays, both for MP2P and P2P traffic, shown in figure 5(d) and figure 6(d), respectively. This is due to the (high) value of the RREQ timeout, which is necessarily equal to two times the NET_TRAVERSAL_TIME, even if the RREQ MNB value is low. This delay increase is less pronounced for multipoint-to-point traffic, due to the increased likelihood that somebody close has a route to the (single) destination – but may not be acceptable for networks where point-to-point traffic is predominant, and where Expanding Ring search increases route discovery time (and thus data packet delivery delays) dramatically.

6. Conclusion

Expanding Ring flooding is one of the features from AODV which has not been carried over in the core specification of LOADng, in part because LOADng does not support intermediate/gratuitous RREPs. This paper presents a way in which Expanding Ring flooding can be introduced into LOADng, by way of using *SmartRREQ* and introducing a single-octet of extra information in RREQ messages – but, without requiring additional router state and signaling. A performance study of networks subjects to MP2P and P2P traffic has been performed, by way of network simulations, comparing LOADng with and without Expanding Ring flooding. Whilst maintaining identical data delivery ratios of 100%, the introduction of Expanding Ring flooding considerably reduces the control traffic overhead, especially when faced with MP2P traffic but also for P2P traffic. The downside to the use of Expanding Ring flooding, as described in this paper, is increased average end-to-end delays.

Thus, Expanding Ring search can be highly advantageous in networks where MP2P traffic is predominant and where a slight increase in average data delivery delays is acceptable.

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