Routing and Broadcasting in Ad-Hoc Networks

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Abstract. In this paper, we introduce two protocols - a routing and a broadcasting protocol - for ad-hoc networks which are based on a new paradigm enabled by the broadcast property of the wireless propagation medium. Nodes simply broadcast packets such that forwarding decisions are no longer taken at the sender of a packet, but in a completely distributed manner at the receivers. Consequently, nodes do not require knowledge about their neighbors. In this way, control traffic can be eliminated almost completely which in turn conserves scarce network resources such as battery power and bandwidth. Furthermore, as these two protocols are almost stateless and nodes do not store network topology information they remain unaffected by even very high rates of topology change and prove highly scalable in terms of number of nodes.

1 Introduction

Ad-hoc networks consist of a collection of wireless hosts that operate without the support of any fixed infrastructure or centralized administration and are completely self-organizing and self-configuring. Nodes are connected dynamically and in an arbitrary manner to form a network, depending on their transmission ranges and positions. Network operations like routing and broadcasting are difficult tasks in such a dynamic environment and has been subject of extensive research over the past years.

Many such protocols designed for ad-hoc networks have been proposed in the literature. Basically, we can distinguish for both, routing and broadcasting protocols, between topology-based and position-based protocols. Overviews can be found in [1], [2], [3]. Like protocols in the Internet, topology-based routing protocols use routing tables and information about available links to forward packets based on the destination address. On the other hand, in position-based protocols (also known as geographical, geometric, or location-based routing protocols), the nodes' geographical positions are used to make forwarding decisions. Therefore, a node must be able to determine its own position and the position of the destination node. This information is generally provided by a global navigation satellite system and a location service [4], respectively. Furthermore, nodes obtain knowledge of their neighbors through beacons, short hello messages broadcasted periodically from each node.

In this paper,we present a position-based routing protocol for ad-hoc networks, called Beacon-Less Routing Protocol (BLR) [5] that allows nodes to route packets without having information about their neighboring nodes by introducing a concept of Dynamic Forwarding Delay (DFD). BLR is based on a new routing paradigm enabled by the broadcast property of the wireless propagation medium. Forwarding decisions are not taken at the sender of a packet, but in a completely distributed manner at the receivers and are solely based on the position of the destination and the receiving node itself. We also present the Dynamic Delayed Broadcasting Protocol (DDB) [6] that uses the same concept DFD, which allows locally optimal broadcasting without any prior knowledge of the neighborhood.

The remainder of this paper is organized as follows. In Section 2 and Section 3, we introduce the Beacon-Less Routing protocol (BLR) and the Dynamic Delayed Broadcasting Protocol (DDB), respectively, and provide some analytical and simulation results. Section 4 concludes the paper.

2 The Beacon-Less Routing Protocol (BLR)

2.1 Protocol Description

Like any other position-based routing algorithms, we assume that nodes are aware of their own positions and that the source has the possibility to locate the position of the destination node. However, as the fundamental difference to other position-based routing algorithms, nodes do not require information about their neighboring nodes, neither about their positions nor even about their existence.

BLR has two main mode of operations. BLR routes packets in greedy mode whenever possible. If greedy routing fails, BLR switches to backup mode to recover and route the packet further.

A node that has a packet to forward simply broadcasts it. Consequently, all neighbors receive the broadcast packet. The protocol ensures that just one of the receiving nodes relays the packet further. This is accomplished by different forwarding delays at different receiving nodes and restricting the nodes that are allowed to forward the packet to a certain area, called forwarding area. Nodes within this area can mutually receive each others transmissions. For the forwarding area BLR uses a circle with diameter r relative to the forwarding node S in the direction of the final destination D as depicted in Fig. 1. A receiving node can determine if it is within the forwarding area from its own position and the positions of the destination D and the previous node S, which are both stored in the packet header. Potential forwarders, e.g., A and B in Fig 1, calculate a Dynamic Forwarding Delay (DFD) in the interval $[0, Max\_Delay]$ depending on their position relative to the previous and the destination node. The DFD is calculated by (1) with r as the transmission radius of a node, p the node's progress towards the destination, and Max_Delay as a system parameter that indicates the maximum time a packet can be delayed per hop. Nodes outside the forwarding area simply drop the packet (node C).

$$Add\_Delay = Max\_Delay \cdot \left(\frac{r - p}{r} \right) \tag{1}$$

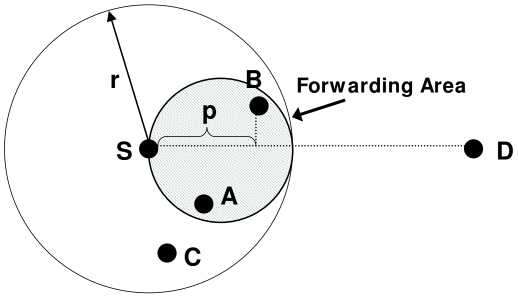


Fig. 1. Forwarding Area with potential forwarders A and B

According to this DFD function, the node with the most progress (e.g., node B), i.e., closest to the destination, calculates the shortest Add_Delay and thus rebroadcasts the packet first. This minimizes the number of hops to the destination. Note that the DFD may also be composed in order to optimize other parameters like battery power or end-to-end delay. The other potential forwarders (e.g., node A) overhear this further relaying and cancel their scheduled transmissions of the same packet. The rebroadcast packet is also received by the previous transmitting node and acknowledges the successful reception at another node. Simultaneously, the neighbors of the rebroadcasting nodes also received the packet and they determine if they are within the forwarding area relative to node B and destination D. Potential forwarders calculate an Add_Delay and compete to rebroadcast the packet again.

If no node is located within the forwarding area, greedy routing fails. This is detected if a node does not overhear a further rebroadcast within $Max\_Delay + \epsilon$ of its previously broadcasted packet. This node forwards the packet further in backup mode. Therefore, the node broadcasts a request for a beacon packet. All neighbors that receive this packet reply with a beacon indicating their positions. The packet is then forwarded to the replying node that is closest to the destination. If none of the neighbors is closer to the destination than the requesting node, the packet is routed according to the face routing algorithm based on the "right-hand" rule, a concept known for traversing mazes, on the faces of a locally extracted planar subgraph, see for example GOAFR [7] for more details. As soon as the packet arrives at a node closer to the destination than where it entered backup mode, the packet switches back to greedy mode.

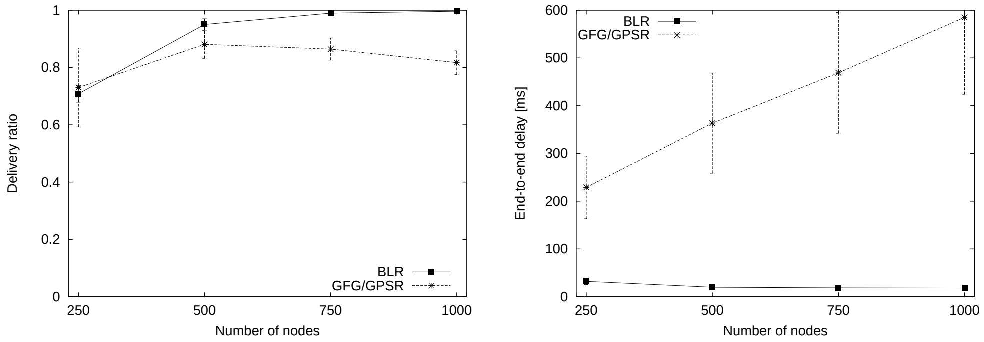
2.2 Simulations

We implemented and evaluated BLR in the Qualnet network simulator. The results are given with a 95% confidence interval. Radio propagation is modeled with the isotropic two-ray ground reflection model. The transmission power and receiver sensitivity are set corresponding to a nominal transmission range of

250m. We use IEEE 802.11b on the physical and MAC layer operating at a rate of 2 Mbps. The simulations last for 900s. The simulation area is 6000m x 1200m and nodes move according to the random waypoint mobility model.

The minimal and maximal speeds are set to 10% of an average speed of $20\,m/s$ for simulating a highly dynamic network. We consider speed as a proxy for any kind of topology changes, caused by either mobility, sleep cycles, interferences, adjustment of transmission and reception parameters, etc. The parameter Max_Delay is set to $2\,ms$.

We compare BLR with a standard position-based routing protocol, namely GFG/GPSR[8][9].



(a) Delivery ratio (b) Delay

Fig. 2. Comparison of BLR and GFG/GPSR

In Fig. 2, the delivery ratio and the end-to-end delay are shown for different network densities. For low-density networks, the delivery ratio of BLR and GFG/GPSR are almost equal because packets are routed frequently in backup mode. The backup mode of BLR is similar to face routing of GFG/GPRS, except for the fact that it is reactive. The low delivery ratio of both protocols is due to temporarily partition of the network. For denser networks, the delivery ratio increases for BLR to almost 100% whereas GFG/GPSR is not able to deliver more than 90%. BLR outperforms GFG/GPSR especially in terms of end-to-end delay. The delay remains unaffected by the node density and below 30ms. GFG/GPSR on the other hand has a delay of at least 200ms, which is even increasing for higher node densities. Extensive evaluations revealed that the reasons for the much longer delays of GFG/GPSR are mainly threefold. First, nodes broadcast beacons periodically and for a dense network this may congest the network. Secondly, for a higher node densities the chosen next hop is closer to the transmission range boundary and has a higher probability of not being available anymore and having left the transmission range. And third, due to the high mobility, packets loop between nodes as the stored position about neighbors does not correspond to the actual physical location of that node. For a more comprehensive description of the protocol and additional simulation and analytical results cf. to [10].

3 Dynamic Delayed Broadcasting Protocol (DDB)

3.1 Protocol Description

We assume again that nodes are aware of their own position through any kind of mechanism. The only information required by DDB in order to broadcast a packet throughout the network is that each node knows its position and the position of the last broadcasting node as given in the packet header. DDB achieves local optimal broadcasting by applying the principle of Dynamic Forwarding Delay (DFD) which delays the transmissions dynamically and in a completely distributed way at the receiving nodes ensuring nodes with a higher probability to reach new nodes transmit first.

Nodes that receive the broadcasted packet use the DFD concept to schedule the rebroadcasting and do not forward the packet immediately. From the position of the last visited node stored in the packet header and the node's current position, a node can calculate the estimated maximal additional area that it would cover with its transmission.

The explicit DFD function is crucial to the performance of DDB and should fulfill certain requirements in order to operate efficiently. The function should yield larger delays for smaller additional coverage and vice versa. In this way, nodes that have a higher probability to reach additional nodes broadcast the packet first. For simplicity reasons, we assume the unit disk graph as the network model and thus a transmission range scaled to 1. Taking into account the maximal additional covered area $AC_{MAX} \simeq 1.91$, which is achieved when a node B is located just at the boundary of the transmission range of node A, we propose a DFD which is exponential in the size of additional covered area, as it was shown in [11], that exponentially distributed random timers can reduce the number of responses. Let AC denote the size of the additionally covered area, i.e. $AC \in [0, 1.91]$,

$$Add\_Delay = Max\_Delay \cdot \sqrt{\frac{e - e^{\left(\frac{AC}{1.91}\right)}}{e-1}} \tag{2}$$

where Max_Delay is the maximum delay a packet can experience at each node. A node does not rebroadcast a packet if the estimated additional area it can cover with its transmission is less than a *rebroadcasting threshold* which also may be zero. The objective of (2) is to minimize the number of transmissions and at the same time to improve the reliability of the packet delivery to all nodes. Like for BLR, it might also be optimized again for other parameters like battery power or network lifetime.

If a node receives another copy of the same packet and did not yet transmit its scheduled packet, i.e., the calculated DFD timer did not yet expire, the node recalculates the additional coverage of its transmission considering the previously received transmissions. From the remaining additional area, the DFD is recalculated which is reduced by the time the node already delayed the packet, i.e., the time between the reception of the first and the second packet. For the reception of any additional copy of the packet, the DFD is recalculated likewise. Obviously, DDB can "only" take locally optimal rebroadcasting decisions as nodes receive only transmissions from their immediate one-hop neighbors and thus have no knowledge of other more distant nodes which possibly already partially cover the same area.

3.2 Analytical Evaluation

We want to calculate the expected size of the additional area AC that is covered by a node's transmission when using (2) as delay function.

Let $k \leq n$ denote the k-most distant neighbor of the sending node, i.e., $k = n$ and $k = 1$ yield the most distant and the closest neighbor respectively. Obviously, the k-most distant neighbor has also the k-largest additionally covered area.

The expected value E_{AC}^{nk} for the additional coverage of the k-most distant neighbor is then solely depending on the number of neighbors n, cf. [10] for a detailed derivation.

$$E_{AC}^{nk} = \frac{2\Gamma(n+1)\Gamma(k+\frac{1}{2})}{\Gamma(k)\Gamma(n+\frac{3}{2})} \tag{3}$$

We compare this result with the expected additional coverage E_{AC}^{*} of other broadcasting protocols where the sequence of neighbors' transmission is independent of their additional coverage. Then the expected additional coverage is independent of the number of neighbors n and the same for all neighbors and therefore is constant.

$$E_{AC}^{*} = \frac{4}{3}$$

In Fig. 3, the graph is plotted for E_{AC}^{nk} of DDB and E_{AC}^{*} of other broadcasting algorithms depending on the number of neighbors $n = 1 \ldots 30$. Again, $k \leq n$ denotes the k-most distant neighbor. E_{AC}^{*} is simply the plane at $\frac{4}{3}$. Already for very few neighbors, the "best" node, i.e., $k = n$, already covers almost the maximum size of additional area. Furthermore, the next $k \leq n$-best nodes cover normally more than $\frac{4}{3}$ what would be covered by a node's transmission with other stateless broadcasting schemes. We can conclude that we might expect an improved performance up to $43\% = \frac{1.91}{4/3}$ in terms of numbers of transmissions. However, the advantage of DDB is not only the reduction in number of transmissions, but also that the delay can be reduced as distant nodes which transmit first add almost no delay.

As it is difficult to assess the exact influence of the MAC layer and to take into account the dependencies between neighboring nodes when their transmission ranges overlap, this analysis only provide a rough kind of boundary for the performance. For a more comprehensive description of the protocol and additional simulation and analytical results again cf. to [10].

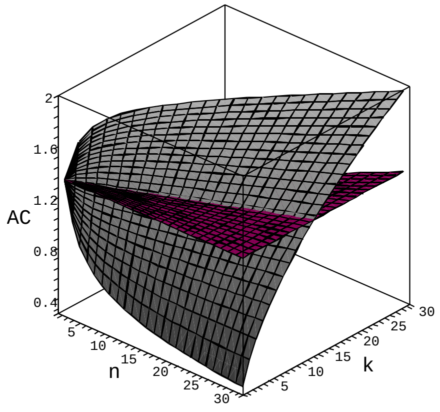


Fig. 3. Expected additional coverage

4 Conclusion

In this paper, we presented the Beacon-Less Routing Protocol (BLR) and the Dynamic Delayed Broadcasting Protocol (DDB) which are both based on a new paradigm where forwarding decision are no longer taken at a sender of a packet but in a completely distributed manner at the receivers. The paradigm is enabled by the broadcast property of the wireless medium such that packets are always simply broadcasted to all neighbors instead of addressing them to one specific neighbor. We implemented this new paradigm by a concept of Dynamic Forwarding Delay (DFD), where each receiving node dynamically delays the forwarding of received packets solely based on information given in the received packets and information available at this node itself. This new paradigm has three main advantages in ad-hoc networks.

- The fact that nodes do not require knowledge about their neighborhood allows reducing control traffic such as the broadcasting of beacons which can be reduced almost completely. This in turn conserves scarce network resources such as battery power and bandwidth and especially in dense networks allows the protocols to operate efficiently as no congestion occurs due to control traffic.
- In this paper we used a metric for DFD to reduce the number of transmission and hops as always the most ”distant” node forwarded the packet first. The concept of DFD however can also easily be adapted to support optimizations for other metrics such as battery level, network lifetime, end-to-end delay.
- The protocols are almost completely stateless as no information on the network topology is used and, thus, they are unaffected by even very high rates of topology changes and proves highly scalable in terms of number of

nodes. The delay can be reduced up to an order of magnitude compared to other position-based protocols where neighbor positions are very inaccurate in highly dynamic networks.

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