Maximizing the Delivery of MPR Broadcasting Under Realistic Physical Layer Assumptions

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Abstract It is now commonly accepted that the unit disk graph used to model the physical layer in wireless networks does not reflect real radio transmissions, and that a more realistic model should be considered for experimental simulations. Previous work on realistic scenarios has been focused on unicast, however broadcast requirements are fundamentally different and cannot be derived from the unicast case. Therefore, the broadcast protocols must be adapted in order to still be efficient under realistic assumptions. In this paper, we study the well-known multipoint relay broadcast protocol (MPR), in which each node has to choose a set of 1-hop neighbors to act as relays in order to cover the whole 2-hop neighborhood. We give experimental results showing that the original strategy used to select these multipoint relays does not suit a realistic model. On the basis of these results, we propose new selection strategies solely based on link quality. One of the key aspects of our solutions is that our strategies do not require any additional hardware and may be implemented at the application layer, which is particularly relevant to the context of ad hoc and sensor networks where energy savings are mandatory. We finally provide new experimental results that demonstrate the superiority of our strategies under realistic physical assumptions.

Keywords ad hoc network, multipoint relay broadcasting, realistic physical layer, sensor network

1 Introduction and Motivation

Although wireless networking is now essential in everyday’s life, the most deployed technology is still the WiFi technology. While it ensures reliable wireless communications, it is very restrictive since users must stay close to fixed access points. For the purpose of overcoming such issues, wireless ad hoc networks have been broadly studied during the past few years. They are formed by autonomous devices which operate in a self-organized manner and communicate together using radio interfaces. In such networks, because of the path loss of radio communications, only close hosts may directly communicate to each other. Long-distance communications require messages to be forwarded by multiple intermediate nodes.

Along with routing, broadcasting is one of the most important communication tasks in those networks, as it is used for many purposes (e.g., route discovery, synchronization). In a straightforward solution to broadcasting, hosts blindly relay packets upon first reception to their neighborhood, leading to a full coverage of the network (providing, of course, that the latter is connected). However, due to physical phenomena, this solution leads to the well-known broadcast storm problem\(^{[1]}\). Moreover, this is a totally inefficient algorithm, since most of the retransmissions are redundant and not needed to ensure the delivery of the packet, leading to a huge amount of wasted energy.

Almost all of the alternative broadcast schemes have always been studied under ideal scenario, where the unit disk graph is used to model wireless communications. In this model, two hosts can communicate with each other if the distance between them is no more than a given communication radius. Packets never get lost and are always received without any error. This model has recently been more and more criticized since it does not correctly reflect the behavior of radio transmissions in a real environment\(^{[2]}\). Indeed, signal strength fluctuations have a significant impact on performance, and thus cannot be ignored in designing communication protocols.

In this paper, we focus on the well-known multipoint relay broadcast protocol (MPR)\(^{[3]}\), used for broadcasting in ad hoc networks. We consider its default behavior under a more realistic scenario where the probability of correct reception of a packet smoothly decreases with the distance between the emitter and the receiver(s).
To achieve this, we replace the unit disk graph model with the lognormal shadowing model[6]. Since the experimental results demonstrate the needs for a more suitable algorithm, we propose several modifications to MPR in order to improve it by maximizing the delivery of the broadcast packet.

One of the key aspects of our solutions is that they highly fit ad hoc networks since they do not rely on any other specific hardware, and may be applied to any kind of wireless devices. All the modifications to MPR that we propose are indeed entirely based on link quality between neighboring nodes, which may be easily evaluated by software methods. We also show by simulations that while our solutions do not imply structural changes to the MPR algorithm, they provide very good results under the considered realistic scenario, actually they are better than the original MPR protocol.

The remainder of this paper is organized as follows. In the next section we provide the needed network definitions and then in Section 3 we present a detailed description of MPR broadcasting. In Section 4, we present the lognormal shadowing model that we use throughout this paper. In Section 5, we provide an analysis of the behavior of the original algorithm used in MPR with the realistic physical layer. We then describe in Section 6 some original solutions that better fit the realistic scenario. We finally conclude in Section 7 and give some directions for future work.

Preliminary version of this paper appeared in [5].

2 Preliminaries

The common representation of a wireless network is a graph $G = (V, E)$, where $V$ is the set of vertices (the hosts, or the nodes of the network) and $E \subseteq V^2$ the set of edges which represents the available communication links: there exists an ordered pair $(u, v) \in E$ if the node $v$ is able to physically receive packets sent by $u$ (e.g., in a single-hop fashion). The neighborhood set $N(u)$ of the node $u$ is defined as:

$$N(u) = \{ v \in V \mid v \neq u \land (u, v) \in E \}. \quad (1)$$

The size of this set, $|N(u)|$, is also known as the degree of node $u$. The density $d$ of the network is the average degree of the nodes. To distinguish between nodes, each of them must be assigned a unique identifier which may be any arbitrary value (e.g., a MAC or an IP address).

We assume that nodes are aware of the existence of each neighboring node within a distance of 2 hops (we call this a 2-hop knowledge). In ad hoc networks, the neighborhood discovery is generally done by small control messages (i.e., the well-known HELLO messages) which are regularly sent by each host. A 2-hop knowledge may easily be acquired thanks to two rounds of exchanges: nodes can indeed insert the identifiers of their neighbors into their own beacon messages.

3 MPR Broadcasting Protocol

As aforementioned, the easiest way to broadcast a packet is to have all the nodes forward it at least once to their neighborhood: this method is known as the blind flooding. However, such a simple behavior has a lot of drawbacks, among which we can cite the high energy consumption. Many other alternative solutions have been proposed, and an extensive review of them can be found in [6]. They may be classified into two categories.

• Centralized algorithms, that require a global knowledge of the network to be applied to (i.e., each existing node and communication links).

• Localized algorithms, that only require nodes to maintain local knowledge about their spatially nearby network nodes (their neighbors).

Obviously, localized message forwarding is a resource-efficient communication paradigm which is well tailored to ad hoc networks due to their decentralized architecture. Among all these localized solutions, we chose to focus on the multipoint relay protocol (MPR)[3] for several reasons.

• It is efficient using the unit disk graph model.

• It is used in the well-known standardized routing protocol OLSR[7].

• It may be used for other miscellaneous purposes (e.g., computing connected dominating sets[8]).

In this algorithm, it is assumed that the nodes have a 2-hop knowledge: they are aware of their neighbors (1-hop distance), and the neighbors of these neighbors (2-hop distance). Its principle is as follows. Each node $u$ that has to relay the message must first elect some of its 1-hop neighbors to act themselves as relays, in order to reach the 2-hop neighbors of $u$. The selection is then forwarded within the packet and receivers can thus determine if they have been selected or not: each node that receives the message for the first time checks if it has been designated as a relaying node by the sender, and if so the message is forwarded after the selection of a new relaying set of neighbors. A variant exists where nodes proactively select their relays before having to broadcast a packet, and selection is sent within HELLO messages.

Obviously, the tricky part of this protocol lies in the selection of the set of relays $MPR(u)$ within the 1-hop neighbors of a node $u$: the smaller this set is, the smaller