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Neighbor discovery in wireless networks with sectored antennas ☆

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ABSTRACT

Directional antennas offer many potential advantages for wireless networks such as increased network capacity, extended transmission range and reduced energy consumption. Exploiting these advantages requires new protocols and mechanisms at various communication layers to intelligently control the directional antenna system. With directional antennas, many trivial mechanisms, such as neighbor discovery, become challenging since communicating parties must agree on where and when to point their directional beams to communicate.

In this paper, we propose a fully directional neighbor discovery protocol called Sectored-Antenna Neighbor Discovery (SAND) protocol. SAND is designed for sectored-antennas, a low-cost and simple realization of directional antennas, that utilize multiple limited beamwidth antennas. Unlike many proposed directional neighbor discovery protocols, SAND depends neither on omnidirectional antennas nor on time synchronization. SAND performs neighbor discovery in a serialized fashion allowing individual nodes to discover all potential neighbors within a predetermined time. SAND guarantees the discovery of the best sector combination at both ends of a link, resulting in more robust and higher quality links between nodes. Finally, SAND reliably gathers the neighborhood information in a centralized location, if needed, to be used by centralized networking protocols. The effectiveness of SAND has been assessed via simulation studies and real hardware implementation.

1. Introduction

Performance improvement through directional antennas in wireless networks has been discussed extensively in the literature [1–4]. Directional antennas, as opposed to omnidirectional antennas, concentrate the transmission power towards a certain direction with limited beamwidth around this direction. As a result, directional antennas lend many promising features to wireless networks. First, interference between neighboring nodes is greatly reduced which increases the simultaneous transmissions in the neighborhood and network capacity [5]. Second, signal to interference and noise ratio (SINR) is increased due to higher directional gain allowing transmissions a higher data rates. Finally, for a given transmission power, the communication range is greatly extended. Alternatively, lower transmission power is needed to cover the same transmission range covered by an omnidirectional antenna.

One of the simplest realizations of directional antennas is sectored antennas where a fixed number of fixed beamwidth antenna elements are mounted to cover the whole azimuth. One major advantage of sectored antennas compared to other types of directional antennas is its low-cost and implementation simplicity. Switching sectors is done by simply selecting an antenna element as shown in Fig. 1.

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Protocol design for wireless networks with directional antennas is a challenging problem due to the problems related to directional antennas such as "Directional Hidden Terminal" problem [6] and the "Deafness" problem [7]. In addition to these problems, basic network operations such as neighbor discovery become more complicated, as well.

Neighborhood information plays an important role in multihop wireless networks for routing, clustering and MAC operation. Neighbor discovery is a relatively simpler problem when omnidirectional antennas are used since a simple broadcast can reach all nodes within the transmission range. The problem, however, becomes more challenging when directional antennas are used due to the following reasons: (i) The limited radial range of the beamwidth of the directional antenna that covers only a fraction of the azimuth. This limitation requires the neighbor discovery scheme to be repeated in different directions to cover the whole azimuth. (ii) Neighboring nodes must know when and where to point their directional beams to discover each other. (iii) Due to non-ideal realizations of directional antennas (i.e., the existence of side lobes), two neighboring nodes might find multiple links between themselves through different Sector-to-Sector (S2S) links.

Many neighbor discovery protocols have been proposed for wireless networks that use directional antennas. The main objective of the these protocols is to discover the neighbors around a node and store the neighborhood information locally. In the literature, three main approaches were used to perform the neighbor discovery. A set of proposed protocols utilize an omnidirectional antenna to bootstrap the neighbor discovery process [8–10]. Other protocols require time synchronization to perform neighbor discovery [8,11,12]. Finally, random schemes [13] perform the neighbor discovery by sending Hello packets through different random directions and then listening to another random direction. As discussed in Section 2, all these approaches are associated with significant shortcomings.

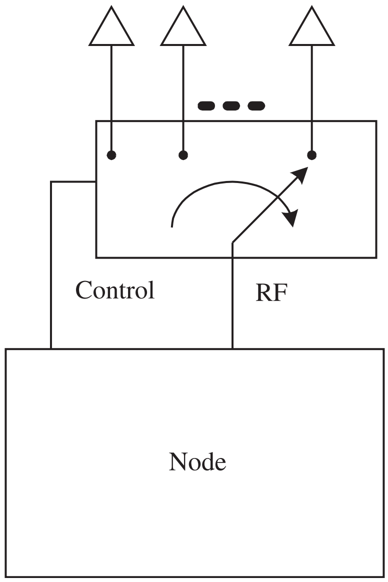

Fig. 1. Node architecture with sectored antennas.

In this paper, we introduce the Sectored-Antenna Neighbor Discovery (SAND) protocol, an integrated neighbor discovery mechanism that allows individual nodes to discover their neighbors and report their neighborhood information back to a centralized location for later use. The key idea of our proposed protocol is to serialize the neighbor discovery process among all nodes. This allows each node to perform neighbor discovery in a bounded time and reliably relay the neighborhood information. Unlike many other directional neighbor discovery protocols, SAND does not require an omnidirectional antenna or external global synchronization. Moreover, SAND discovers all S2S links between nodes that they can communicate over using a systematic approach. SAND can be utilized with any distributed or centralized routing or MAC protocol that uses directional antennas since neighborhood information is available both centrally and locally.

2. Related work

The performance improvements through directional antennas are well explored in the literature [1–4] for ad hoc wireless networks, mesh networks [14] and sensor networks [15,10]. To exploit these advantages many protocols have been proposed for MAC layer [3,16–18], routing [19,20] and topology control [21,22]. Several neighbor discovery schemes have been proposed in the literature, as well. Some of the schemes utilize an omnidirectional antenna to bootstrap the neighbor discovery process like in [8–10]. Utilizing a secondary omnidirectional antenna for neighbor discovery has several disadvantages. First, differences in the omnidirectional and sector antenna gain patterns could result in different sets of discovered neighbors. Second, when discovering neighbors in SAND, we are not only interested in the identity of potential neighbors, but in measuring the link quality for the various Sector-to-Sector (S2S) links. This additional consideration cannot be realized using omnidirectional antennas. Finally, the cost of a secondary antenna system, along with the associated hardware required to support it, is undesirable in cost-sensitive networks. These schemes also assume that the discovering node knows its geographical location and can include this information in the advertisement packets which may be an expensive option for some wireless network implementations.

To eliminate the need for omnidirectional antennas, other proposed neighbor discovery schemes assume that nodes are time synchronized to guarantee that all nodes switch their sectors synchronously such as in [11,13,23]. While time synchronized neighbor discovery schemes eliminate the usage of omnidirectional antennas, they require time synchronization for all nodes which may increase the hardware and control overhead burden on the wireless network. Furthermore, achieving time synchronization in a distributed manner is also very unlikely without an initial communication infrastructure and solely based on directional/sectored antennas.

Asynchronous and fully directional neighbor schemes were proposed in [2,13] where each node listens in a random direction for a random time and then transmits a