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RESEARCH ARTICLE

Dynamic Clustering Based Time Efficient Protocols for Neighbor Discovery in Wireless Ad Hoc Networks

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ABSTRACT: Neighbor Discovery (ND) is a basic and crucial step for initializing wireless ad hoc networks. A fast, precise, and dynamic clustering based time efficient protocols has significant importance to subsequent operations in wireless networks. However, many existing protocols have high probabilities to generate idle slots in their neighbor discovering processes, which prolongs the executing duration, and thus compromises their performance. In this paper, we propose a novel randomized protocol FRIEND, a pre-handshaking neighbor discovery protocol, to initialize synchronous full duplex wireless ad hoc networks. By introducing a pre-handshaking strategy to help each node be aware of activities of its neighborhood, we significantly reduce the probabilities of generating idle slots and collisions. Moreover, with the development of single channel full duplex communication technology [1, 2], we further decrease the processing time needed in FRIEND, and construct the first full duplex neighbor discovery protocol. Our theoretical analysis proves that FRIEND can decrease the duration of ND by up to 48% in comparison to the classical ALOHA-like protocols [3, 4]. In addition, we propose HD-FRIEND for half duplex networks and variants of FRIEND for multi-hop networks and duty cycled networks. Both theoretical analysis and simulation results show that FRIEND can adapt to various scenarios and significantly decrease the duration of ND.

Index Terms— Wireless Ad Hoc Networks, Neighbor Discovery Full Duplex Technology, Randomized Algorithm

1. INTRODUTION

Wireless ad hoc networks have attracted a lot of interest from both academia and industry due to their wide range of applications. In many scenarios, nodes are deployed without the support of pre-existing infrastructures for communication. As a result, nodes in a wireless ad hoc network need to cofigure themselves through their own communication activities to form a reliable infrastructure during the initialization for further operations. For each node, the knowledge of its one-hop neighbors (the nodes it can directly communicate with) has significant importance to the upper layer protocols like MAC protocols, routing protocols, etc. Consequently, Neighbor

Discovery (ND) is designed to discover a node's one-hop neighbors and thus is momentous and crucial for configuring wireless networks. Compared with existing deterministic [11] and multi-user detection-based [12] protocols, randomized protocols are most commonly used to conduct ND process in wireless networks [3–8]. In those protocols, each node transmits at different randomly chosen time instants to reduce the possibility of the collision with other nodes. Usually, researchers discuss Dynamic clustering based time efficient protocols s under a synchronous system, and focus on a clique with n nodes, e.g., the famous Birthday Protocols [3]. In birthday protocols, at each single slot every node independently chooses to transmit discovery message by probability p and listen by probability 1 p (the optimal value of p is proven to be 1=n). By reducing the problem to Coupon Collector's Problem [16], Vasudevan et al. [4] proved that the upper bound of expected time of birthday protocol is neH n , where H is the n-th Harmonic number. Many subsequent researches on time efficient protocols are based on birthday protocols. For example, the authorsin [4] proposed solutions to scenarios for unknown neighbor numbers, asynchronous systems, and systems with reception status feedback mechanisms. Zeng et al. [5] discussed the performance of birthday protocols with multipack reception (MPR). You et al. [8] discussed discovery time's upper bound when nodes have a low duty cycle by reducing the problem to K Coupon Collector's Problem. However, the family of birthday protocols has a vital
Drawback. The probability of generating an idle slot is given by

$$p_0 = (1 - \frac{1}{n})^n.$$

When n = 10, p 0 _ 0:349. When n ! +1, p ! 1=e _ 0:368. Therefore when the number of nodes is large, the probability that no node transmits in a slot is about 37%. We must point out that the probability that there is only one node transmitting is

$$p_1 = \binom{n}{1} \frac{1}{n} (1 - \frac{1}{n})^{n-1} \geq \frac{1}{e}.$$

The last inequality comes from the Lemma 2 which we will present in later sections. We can see that compared with the probability that a node successfully transmits its discovery message, the probability of idle slots is as large as it, and they contribute about 73% to the all possible scenarios. Furthermore, the probability of collisions also increases the iterations running in the protocols. For instance, two nodes transmitting simultaneously in a slot has a probability 1=(2e) _ 0:184, 1=(6e) 0:06.Comparing the relatively small probability of collisions, the idle slot probability is unacceptably high. If we can effectively reduce the probability of idle slots, the neighbor discovery time will be tremendously reduced. Fortunately, with the development of full duplex wireless communication technology [1, 2], we can design more time-efficient protocols, i.e., protocols that consume less time, to cope with this issue if nodes can transmit and receive simultaneously in a single slot.

Our key idea is twofold. On one hand, we introduce a prehandshaking strategy to help each node be aware of activities of its neighborhood before normal transmissions, such that the system can have higher probabilities to avoid collisions and idle slots. To conduct this pre-handshaking, we add some tiny sub-slots before each normal slot. With the help of full duplex technology, at each sub-slot, every node will decide whether to transmit the discovery message in a normal slot by transmitting. An anonymous election signal and catch its neighbors' signals simultaneously. With different transmitting-receiving scenarios, we design an effective strategy for each node to determine how to behave in normal slots. Correspondingly, we assign the behaviors of each node in the normal slots to complete the ND process. On the other hand, the reception status feedback mechanism is ameliorated by using full duplex wireless radios. Originally in [6], a sub-slot is added after the normal slot, and receivers will give feedback signals to transmitters in this subslot. In our design this overhead can be eliminated by using full duplex nodes. If a receiver finds that two or more nodes are transmitting simultaneously, it will transmit a warning message immediately to inform other transmitters the failure of their transmissions.

2. RELATED WORK

Sensor networks considered with more number of sensor nodes that process in single primary station. Recent technologies can be developed for doing this type process in wireless sensor networks. Sensor node take signal from different other nodes present in ireless sensor networks. Each sensor node is capable of only a limited amount of processing. But when coordinated with the information from a large number of other nodes, they have the ability to measure a given physical environment in great detail. Thus, a sensor network can be described as a collection of sensor nodes which co-ordinate to perform some specific action. Unlike traditional networks, sensor networks depend on dense deployment and co-ordination to carry out their tasks.

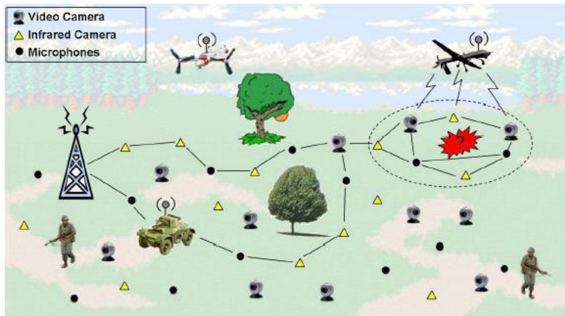

Figure 1: Wireless Sensor Networks

These networks have the potential to enable a large class of applications ranging from assisting elderly in public spaces to border protection that benefit from the use of numerous sensor nodes that deliver multimedia content. In the sensor network model considered in this work, the nodes are placed randomly over the area of interest and their first step is to detect their immediate neighbors - the nodes with which they have a direct wireless communication - and to establish routes to the gateway.

The lack of servers hinders the use of centralized addressing schemes in ad hoc networks. In simple distributed addressing schemes, however, it is hard to avoid duplicated addresses because a random choice of an address by each node would result in a high collision probability, as demonstrated by the birthday paradox. Nevertheless, if the number of bits in the address suffix is smaller than number of bits in the MAC address, which is always true for IPv4 addresses, this solution must be adapted by hashing the MAC address to fit in the address suffix. Hashing the MAC address, however, is similar to a random address choice and does not guarantee a collision-free address allocation. The first node in the network, called prophet, chooses a seed for a random sequence and assigns addresses to any joining node that contacts it. The joining nodes start to assign addresses to other nodes from different points of the random sequence, constructing an address assignment tree. Prophet does not flood the network and, as a consequence, generates a low control load. The protocol, however, requires an address range much larger than the previous protocols to support the same number of nodes in the network. Moreover, it depends on the quality of the pseudo-random generator to avoid duplicated addresses.

The emerging wireless ad hoc network paradigm enables a new type of network in which collaborating devices relay packets from one device to another across multiple wireless links in a self-organizing manner. A number of applications based on this type of network have been established or are expected in the near future, such as environmental and building monitoring, disaster relief and military battlefield communication. Due to the self-organizing nature of ad hoc networks, every node in the network can be alternately functioning as transmitter or a receiver. Oftentimes, a node can communicate directly with only several other nodes around itself, which are called its “neighbors”. In absence of a central controller, every node has to discover its neighbors before efficient routing is possible. The process for a node to identify all its neighbors is called neighbor discovery, which is a crucial first step of constructing reliable wireless ad hoc networks. Neighbor discovery in ad hoc networks is a critical and non-trivial task. Algorithms such as “birthday protocol” [1], directional antenna neighbor discovery [2], [3] and slotted random transmission and reception [4] have been proposed to enable all nodes in a network to find out their neighbors either synchronously or asynchronously. These algorithms can be categorized as random access discovery, which requires nodes to be randomly in a “transmitting” or “listening” state in each time slot so that each node gets a chance to hear every neighbor for at least once in a sufficient amount of time. Such random access discovery schemes allow one transmission to be successful at a time, and hence generally require a large number of time slots until reliable neighbor discovery is achieved.

Timely discovery of a node's neighbors is a critical issue in wireless networks, especially when the nodes are mobile. References [5]–[7] suggest solution of the neighbor discovery problem from the multiuser detection perspective. The idea is to let all neighbors simultaneously send their unique signature waveforms which identify themselves, and let the center node detect which signatures are at presence. The advantage is rapid detection achieved using multiuser detectors, which are well-understood in the context of code-division multiple access (CDMA). However, the difficulties of scaling the scheme as well as implementing coherent detection without training have not been adequately addressed (training for channel estimation is evidently impossible before the discovery of neighbors).

In this work, we propose a novel scheme based on group testing, which is highly scalable, only requires. Simple non-coherent (energy) detection and incurs small overhead. A CDMA-like on-off signaling is proposed, where the signature of each user is a randomly produced binary sequence of 0's and 1's. The difference with the usual direct-sequence CDMA with frequency- or phase shifted keying spreading sequence is that, during the chips or mini-slots corresponding to 0's in the sequence, the node transmits zero energy. The receive node simply detects whether there is energy in each chip, and infer About which nodes are present as neighbors based on the overall on-off pattern. The underlying assumption is of course that transmitters can switch on and off as frequently as the chip rate. This is feasible using today's technology because appliers have sharp response time. Interestingly, the neighbor discovery scheme using on-off signatures can be viewed as a group testing problem. In general, the classical problem of group testing is to identify defective items out of a set of objects by exercising tests over a sequence of object pools. The aim is to discover all defective items with the fewest number of tests. Application of group testing to the design of efficient algorithms for contention resolution in random multiple-access communication systems has been studied (e.g., [8], [9]). It is shown that by querying a sequence of subsets of all the users, a central controller can identify all active users and resolve collision very quickly. Furthermore, the group testing techniques are extended to multiple-access systems with heterogeneous population of users, where different users may have different probabilities of being active [10]. Note that multiple-access based on group testing relies on a central controller to roll out an optimal plan of queries, whereas in ad hoc networks such controller is not available. Also, unlike the works in [8] and [10], the sequence of tests used in this paper predetermined, which does not change over time. The rest of the paper is organized as the following. In Section II, we describe the group testing technique and how it is applied to neighbor discovery. A direct algorithm for neighbor discovery based on group testing is proposed in Section III along with an upper bound on its error performance. A second algorithm with lower complexity is also proposed in the section. Both algorithms are shown to be efficient and effective using numerical results in Section IV. Section V concludes the paper.

Neighborhood of node 0. The problem of neighbor discovery is to collect the indices of the nodes which Are in the neighborhood of node 0. An ALOHA type Of random access discovery scheme is often considered, where each user sends its index through random access of the channel upon receipt of a beacon signal from node 0. Typically, it takes a number of transmissions to resolve contention and finish the discovery process. In order for more rapid discovery, one can take advantage of the multiple access channel and let nodes simultaneously send their coded identity information in response to a beacon signal from node 0. The neighbor discovery problem is fundamentally a multiuser detection problem. Let X k is a neighbor of node 0, i.e., X indicate whether node k =1denotes that node k is directly connected with node 0, whereas X k =0denotes otherwise. Suppose X k 1 ,...,X independent and identically distributed (i.i.d.) Bernoulli random variables with parameter p. We also assume that node 0 typically has no more than a small number of neighbors, so that the vector X =[X is sparse. The goal of neighbor discovery is to infer about the elements of X based on the observation.

3. ALOHA-like algorithm

In this section we describe the following things for accessing services in wireless sensor networks. The analysis of the ALOHA-like algorithm in this paper can also be extended to the case when nodes have directional antennas. It must be noted that in addition to reducing neighbor discovery time, using directional antennas also reduces the overall energy consumption, since nodes require less power to communicate over the same distance as compared to Omni-directional antennas.

3.1 Feedback-based Algorithms for Multi-Hop Networks

There are two important obstacles that need to be overcome in this regard. 1) In a clique setting, when a node i, hears its ID back, it knows that all other nodes in the clique have discovered i, thus allowing it to drop out. In the multi-hop case, however, the presence of hidden terminals may cause a subset of i's neighbors to not receive i's transmission. Thus, i cannot drop out despite hearing its ID back. 2) In the multi-hop setting, i's dropping out needs to be signaled to its neighbors allowing them to increase their transmission probabilities, which appears nontrivial.

The ALOHA-like algorithm is a randomized algorithm that operates as follows. In each slot, a node independently transmits a DISCOVERY message announcing its ID, with probability pxmit, and listens with probability 1 - pxmit. A discovery is made in a given slot only if exactly one node transmits in that slot

3.2 Neighbor Discovery As Coupon Collector's Problem.
We first describe how the neighbor discoveryproblem maps into the classical Coupon Collector'sProblem. The process of neighbor discovery can be then be treated as a coupon collector's problem in the following manner. Consider a coupon collector C drawing coupons with replacement from an urn consisting of n distinct coupons, each coupon corresponding to a distinct node in the clique. In each slot, C draws one of the n coupons (i.e. discovers a given node) with probability p, and draws no coupon
(i.e., detects an idle slot or a collision) with probability 1 - np. It is easy to see that when C. collects n distinct coupons, this can be interpreted aseach node in the clique having discovered all of its n – 1 neighbors.

3.3 Unknown Number of Neighbors The key idea here is that nodes geometrically reduce their transmission probabilities until they enter the phase of execution appropriate for the population size n.

```
Algorithm    Collision Detection-Based ND(i,n)
  b ← 0 //Number of neighbors discovered by node i
  flag ← 0 //Has node i been discovered by other nodes?
  NbrList ← [ ] //List of neighbors of node i
  loop
    p_xmit ← 1/(n − b)
    if ((flag = 0) and (Bernoulli(p_xmit) = 1)) then
      Transmit DISCOVERY(i) in first sub-slot
      if energy detected in second sub-slot then
        flag ← 1 //"Drop out"
      end if
    else
      if successful reception in first sub-slot then
        Transmit bit "1" in second sub-slot
        NbrList[b++] ← DISCOVERY.source
      end if
    end if
  end loop
```

Figure 3: Neighbor detection process in wireless sensor networks.

This occurs when nodes enter the ⌈ log n⌉ -the phase. During this phase, each node transmits with probability 1/n for duration of 2ne ln n slots.

4. PERFORMANCE ANALYSIS

In this section we describe the following things for Accessing services in wireless sensor networks.

4.1 Neighbor Discovery Using Directional Antennas

The analysis of the ALOHA-like algorithm in this paper can also be extended to the case when nodes have directional antennas. It must be noted that in addition to reducing neighbor discovery time, using directional antennas also reduces the overall energy consumption, since nodes require less power to communicate over the same distance as compared to Omni-directional antennas.

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5. CONCLUSION

Our neighbor discovery algorithms do not require estimates of node density and allow asynchronous operation. Furthermore, our algorithms allow nodes to begin execution at different times and also allow nodes to detect the termination of the neighbor discovery phase. A number of avenues for future work remain open. Our analysis shows a gap between the lower and upper bounds on the running time for neighbor discovery in the network case. Clearly, the quest for an order-optimal neighbor discovery algorithm remains an intriguing prospect. We design and analyze several algorithms for neighbor discovery in wireless networks. Starting with the setting of a single-hop wireless network of n node s, we propose a ALOHA like neighbor discovery algorithm when nodes cannot detect collisions, and an order-optimal _(n) receiver feedback-based algorithm when nodes can detect collisions.

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