

Predicting Hidden Sensors in Wireless Sensor Networks

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Abstract

In most sensor networks the nodes are static. Nevertheless, node connectivity is subject to changes because of disruptions in wireless communication, transmission power changes, or loss of synchronization between neighboring nodes. Hence, even after a sensor is aware of its immediate neighbors, it must continuously maintain its view, a process we call continuous neighbor discovery. In this work we distinguish between neighbor discovery during sensor network initialization and continuous neighbor discovery. We focus on the latter and view it as a joint task of all the nodes in every connected segment. Each sensor employs a simple protocol in a coordinate effort to reduce power consumption without increasing the time required to detect hidden sensors.

Keywords

Wireless Sensor Networks, Hidden Sensors, Wireless Communication

I. Introduction

Smart environments represent the next evolutionary development step in building, utilities, industrial, home, shipboard, and transportation systems automation. Like any sentient organism, the smart environment relies first and foremost on sensory data from the real world. Sensory data comes from multiple sensors of different modalities in distributed locations. The smart environment needs information about its surroundings as well as about its internal workings; this is captured in biological systems by the distinction between exteroceptors and proprioceptors. The challenges in the hierarchy of: detecting the relevant quantities, monitoring and collecting the data, assessing and evaluating the information, formulating meaningful user displays, and performing decision-making and alarm functions are enormous. The information needed by smart environments is provided by Distributed Wireless Sensor Networks, which are responsible for sensing as well as for the first stages of the processing hierarchy. The importance of sensor networks is highlighted by the number of recent funding initiatives, including the DARPA SENSIT program, military programs, and NSF Program Announcements. The figure shows the complexity of wireless sensor networks, which generally consist of a data acquisition network and a data distribution network, monitored and controlled by a management center. The plethora of available technologies makes even the selection of components difficult, let alone the design of a consistent, reliable, robust overall system. The study of wireless sensor networks is challenging in that it requires an enormous breadth of knowledge from an enormous variety of disciplines. In this chapter we outline communication networks, wireless sensor networks and smart sensors, physical transduction principles, commercially available wireless sensor systems, self-organization, signal processing and decision-making, and finally some concepts for home automation.

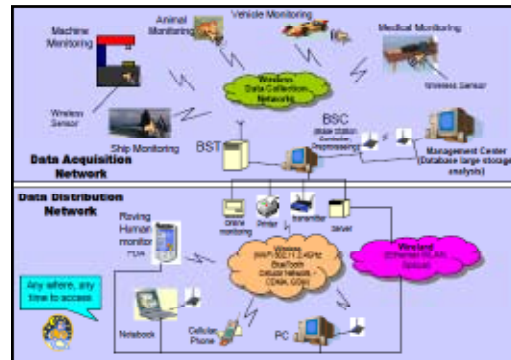


Fig. 1:

de, called an access point, coordinates access to the shared medium. Messages are transmitted only to or from the access point. Therefore, neighbor discovery is the process of having a new node detected by the base station. Since energy consumption is not a concern for the base station, discovering new nodes is rather easy. The base station periodically broadcasts a special HELLO message¹. A regular node that hears this message can initiate a registration process. The regular node can switch frequencies/channels in order to find the best HELLO message for its needs. Which message is the best might depend on the identity of the broadcasting base station, on security considerations, or on PHY layer quality (signal-to-noise ratio). Problems related to possible collisions of registration messages in such a network are addressed in [4]. Other works try to minimize neighbor discovery time by optimizing the broadcast rate of the HELLO messages [1,5], [6-7]. The main differences between neighbor discovery in WiFi and in mesh sensor networks are that neighbor discovery in the former is performed only by the central node, for which energy consumption is not a concern. In addition, the hidden nodes are assumed to be able to hear the HELLO messages broadcast by the central node. In contrast, neighbor discovery in sensor networks is performed by every node, and hidden nodes cannot hear the HELLO messages when they sleep. In mobile ad-hoc networks (MANETs), nodes usually do not switch to a special sleep state. Therefore, two neighboring nodes can send messages to each other whenever their physical distance allows communication. AODV [9], is a typical routing protocol for MANETs. In AODV, when a node wishes to send a message to another node, it broadcasts a special RREQ (route request) message. This message is then broadcast by every node that hears it for the first time. The same message is used for connectivity management, as part of an established route maintenance procedure, aside from which there is no special neighbor discovery protocol.

II. Existing System

Two nodes are said to be neighboring nodes if they have direct wireless connectivity. We assume that all nodes have the same transmission range, which means that connectivity is always bidirectional. During some parts of our analysis, we also assume that the network is a unit disk graph; namely, any pair of nodes that are within transmission range are neighboring nodes. Two nodes are said to be directly connected if they have discovered each other and are aware of each other's wake-up times. Two nodes

are said to be connected if there is a path of directly connected nodes between them. A set of connected nodes is referred to as a segment. Consider a pair of neighboring nodes that belong to the same segment but are not aware that they have direct wireless connectivity. See, for example, nodes *a* and *c*. These two nodes can learn about their hidden wireless link using the following simple scheme, which uses two message types: (a) SYNC messages for synchronization between all segment nodes, transmitted over known wireless links; (b) HELLO messages for detecting new neighbors. Scheme 1 (detecting all hidden links inside a segment): This scheme is invoked when a new node is discovered by one of the segment nodes. The discovering node issues a special SYNC message to all segment members, asking them to wake up and periodically broadcast a bunch of HELLO messages. This SYNC message is distributed over the already known wireless links of the segment. Thus, it is guaranteed to be received by every segment node. By having all the nodes wake up almost at the same time, for a short period, we can ensure that every wireless link between the segment's members will be detected. To better understand the benefit of Scheme 1, we now compare its performance to the performance of a trivial algorithm where every node discovers its hidden neighbors independently. When Scheme 1 is used, a hidden node is discovered by all of its in-segment neighbors as soon as it is discovered by the first of them. In contrast, when Scheme 1 is not used, the hidden node is discovered by all of its in-segment neighbors only when it is discovered by the last of them. To analyze the time slots at which these nodes are discovered. Suppose that the time axis is divided into slots such that the probability that a node discovers a given hidden neighbor is p . Consider a node u with m in-segment hidden neighbors. The probability that u discovers its first in-segment hidden Neighbor only at slot $k + 1$

$$P_m(k) = (1 - p)^{m^k} (1 - (1 - p)^m).$$

A random wake-up approach is used to minimize the possibility of repeating collisions between the HELLO messages of nodes in the same segment. Theoretically, another scheme may be used, where segment nodes coordinate their wake-up periods to prevent collisions and speed up the discovery of hidden nodes. However, ending an efficient time division is equivalent to the well-known node coloring problem, which is NP-hard and also cannot be well approximated. Since the time period during which every node wakes up is very short, and the HELLO transmission time is even shorter, the probability that two neighboring nodes will be active at the same time is practically 0. In the rare case of collisions, CSMA/CD can be used to schedule retransmissions. By Scheme 1, the discovery of an individual node by any node in a segment leads to the discovery of this node by all of its neighbors that are part of this segment. Therefore, discovering a node that is not yet in the segment can be considered a joint task of all the neighbors of this node in the segment. As an example, consider fig. 4(a), which shows a segment S and a hidden node u . In this figure, a dashed line indicates a hidden wireless link, namely, a link between two nodes that have not yet discovered each other. A thick solid line indicates a known wireless link. After execution of Scheme 1, all hidden links in S are detected. The links connecting nodes in S to u are not detected because u does not belong to the segment. Node u has 4 hidden links to nodes in S . Hence, we say that the degree of u in S is $\deg_S(u) = 4$. When u is discovered by one of its four neighbors in S , it will also be discovered by the rest of its neighbors in S as soon as Scheme 1 is re invoked. Consider one of the four segment members that are within range of u , node v say. Although it may know about the segment members within its

own transmission range, it does not know how many in-segment neighbors participate in discovering u . In the next section we study three methods that allow v to estimate the value of $\deg_S(u)$ for a hidden node u , and compare their accuracy and applicability.

III. Proposed Work

In this section we present an algorithm for assigning HELLO message frequency to the nodes of the same segment. This algorithm is based on Scheme 1. Namely, if a hidden node is discovered by one of its segment neighbors, it is discovered by all its other segment neighbors after a very short time. Hence, the discovery of a new neighbor is viewed as a joint effort of the whole segment. One of the three methods presented in Section IV is used to estimate the number of nodes participating in this effort. Suppose that node u is in initial neighbor discovery state, where it wakes up every T_I seconds for a period of time equal to H , and broadcasts HELLO messages. Suppose that the nodes of segment S should discover u within a time period T with probability P . Each node v in the segment S is in continuous neighbor discovery state, where it wakes up every $T_N(v)$ seconds for a period of time equal to H and broadcasts HELLO messages. We assume that, in order to discover each other, nodes u and v should have an active period that overlaps by at least a portion δ , $0 < \delta < 1$, of their size H . Thus, if node u wakes up at time t for a period of H , node v should wake up between

$t - H(1 - \delta)$ and $t + H(1 - \delta)$. The length of this valid time interval is $2H(1 - \delta)$. Since the average time interval between two wake-up periods of v is $T_N(v)$, the probability that u and v discover each other during a specific HELLO interval of u is $\frac{2H(1-\delta)}{T_N(v)}$.

Let n be the number of in-segment neighbors of u . When u wakes up and sends HELLO messages, the probability that at least one of its n neighbors is awake during a sufficiently long time interval is $1 - (1 - \frac{2H(1-\delta)}{T_N(v)})^n$. (8)

For the sake of our analysis, consider a division of the time axis of u into time slots of length H . The probability that u is awake in a given time slot is $\frac{H}{T_I}$, and the probability that u is discovered during this time slot is $P_1 = \frac{H}{T_I} (1 - (1 - \frac{2H(1-\delta)}{T_N(v)})^n)$. Denote by D the value of $\frac{T}{H}$. Then, the probability that u is discovered within at most D slots is $P_2 = 1 - (1 - P_1)^D$. Therefore, we seek the value of $T_N(v)$ that satisfies the following equation:

$$1 - (1 - P_1)^D \geq P,$$

which can also be stated as

$$P_1 \geq 1 - \sqrt[D]{1 - P}.$$

Since $P_1 = \frac{H}{T_I} (1 - (1 - \frac{2H(1-\delta)}{T_N(v)})^n)$, we get

$$\frac{H}{T_I} (1 - (1 - \frac{2H(1-\delta)}{T_N(v)})^n) \geq 1 - \sqrt[D]{1 - P},$$

and therefore

$$T_N(v) \leq \frac{2H(1-\delta)}{1 - \sqrt[n]{1 - \frac{T_I}{H}(1 - \sqrt[n]{1-P})}}. \quad (9)$$

Since node v does not know the exact value of n , it can estimate it using the methods presented in Section IV.

We now give a simple example for the proposed algorithm. Suppose that nodes in the Init state remain active until they enter the Normal state. Suppose also that the requirement is to discover a hidden node within 10 time units with probability 0.5. Consider a segment node in the Normal state, where continuous neighbor discovery is performed, that estimates the degree of its hidden neighbor as 1. Following our definitions, $D = 10$, $T_I = H = 1$ and $n = 1$. Substituting these values into Eq. 9 yields $T_N \approx 15$. Note that the intuitive value of $T_N = 20$ is wrong because it would yield a detection probability of $1 - (1 - \frac{1}{20})^{10} \approx 0.4$ to discover a hidden node within 10 time units.

If one needs to enforce not only the expected hidden neighbor discovery delay but also an upper bound on it, each node can be assigned a wake-up period according to the rules described in [13].

In Figure 6 we present two graphs that show the dependency between T and $T_N(v)$. We assume that a hidden node wakes up once every $100H$ time units on the average, and that $T_I = 100$, $H = 1$, and $\delta = 0.5$. In Figure 6(a) the estimated value of n is 10. The curves present the value of $T_N(v)$ as a function of the desired discovery time T for 3 different values of P : 0.5, 0.8 and 0.95. In Figure 6(b) P is set to 0.8 and n varies between 5 and 50. Again, $T_N(v)$ is calculated as a function of the desired discovery time. As expected, the nodes have to work harder to achieve a greater discovery rate in less time, while the increase in the density of segment nodes allows to a greater $T_N(v)$ to be chosen. In both graphs the dependency between $T_N(v)$ and T is almost linear and, as, the slope of the curves is almost linear in the value of n as well. This means that a node v can use linear approximation to compute the value of $T_N(v)$.

IV. Results

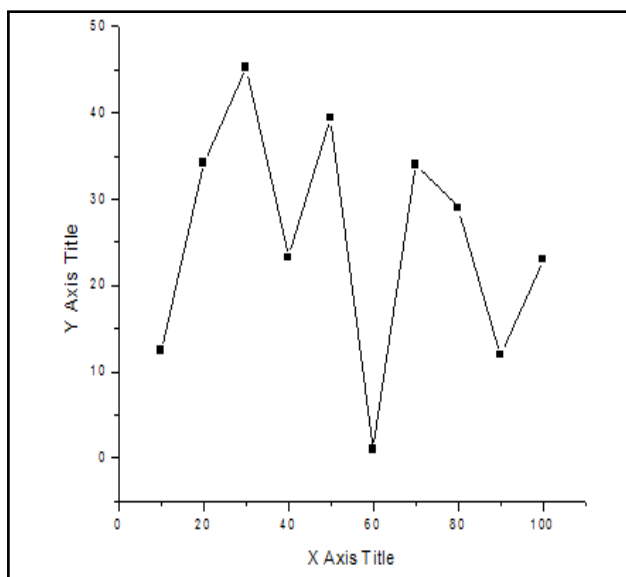


Fig. 2:

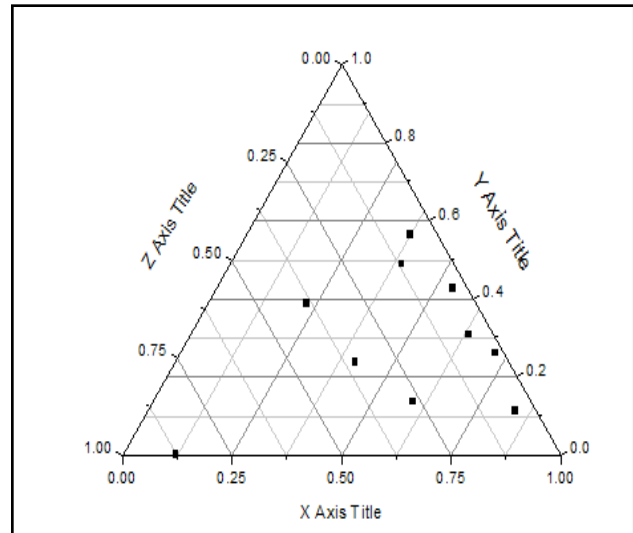


Fig. 3:

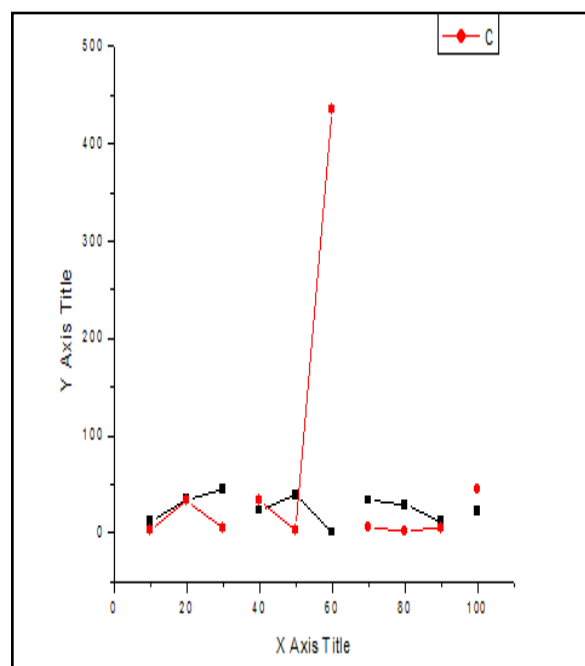


Fig. 4:

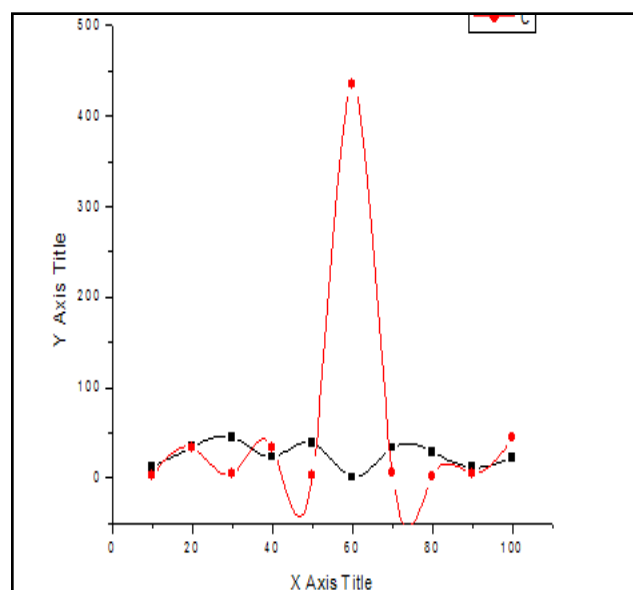


Fig. 5:

V. Conclusions

We exposed a new problem in wireless sensor networks, referred to as ongoing continuous neighbor discovery. We argue that continuous neighbor discovery is crucial even if the sensor nodes are static. If the nodes in a connected segment work together on this task, hidden nodes are guaranteed to be detected within a certain probability P and a certain time period T , with reduced expended on the detection. We showed that our scheme works well if every node connected to a segment estimates the in-segment degree of its possible hidden neighbors. To this end, we proposed three estimation algorithms and analyzed their mean square errors. We then presented a continuous neighbor discovery algorithm that determines the frequency with which every node enters the HELLO period. We simulated a sensor network to analyze our algorithms and showed that when the hidden nodes are uniformly distributed in the area, the simplest estimation algorithm is good enough. When the hidden nodes are concentrated around some dead areas, the third algorithm, which requires every node to take into account not only its own degree, but also the average degree of all the nodes in the segment, was shown to be the best.

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