X-RAYING NEIGHBOUR DISCOVERY IN A WIRELESS SENSOR NETWORK COMPRISING OF NON-HOMOGENEOUS NODES

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ABSTRACT
In most wireless sensor networks, the nodes are often assumed to be stationary. However, network connectivity is subject to changes arising from interference in wireless communication, changes in transmission power or loss of synchronization among neighbouring network nodes. Hence, even after a sensor node is aware of its immediate neighbours, there is need for continuous neighbour discovery. In this paper, an attempt is made to distinguish between neighbour discovery during sensor network initialization and continuous neighbour discovery during the operational of life the network in question. Emphasis is placed on the latter which is viewed as a joint task involving all the nodes in every connected segment in the network. Each of the nodes employs a simple protocol aimed at reducing the amount of power consumed without increasing the time required to detect veiled sensors nodes in the network.

Keywords: Sensor, Neighbour, Node; Discovery, Continuous

INTRODUCTION

A wireless sensor network could constitute of a huge number of nodes deployed at some well-defined site called sensor field. In certain application areas, the structure of such a network could assume a mesh topology. In this scenario, some of the nodes act as routers, forwarding messages from one network node to another. The configuration of the nodes is such that the communication hardware can be turned on and off to minimize energy consumption. Therefore, it is imperative that for any two neighbouring sensor nodes to communicate, each of them must be in active mode simultaneously.

The wireless sensor network model adopted in this paper, assumed that the nodes are randomly deployed in the sensor field and their first task is to be able to detect their immediate neighbours (i.e., nodes that have direct wireless communication with them). In situations where the network is characterized by continuously heavy traffic the sensor nodes are not required to invoke any special neighbour discovery protocol. This is because any node that has lost connectivity to its neighbours can rediscover its neighbours by simply listening to the communication channel for a short time period. However, in wireless sensor networks characterized by irregular traffic, a special neighbour discovery scheme is needed instead. This is the fulcrum upon which this paper is based.

Despite the common assumption in many sensor network applications that the nodes remain stationary during their operational lifespan, connectivity is still subject to changes even after the initial establishment of the network. The sensor nodes are required to continuously look out for new neighbours due to the following:

a.) Clock drifts result in loss of local synchronization.
b.) Interference to wireless connectivity between adjacent nodes leading to the need to rediscover veiled nodes.
c.) The addition of new nodes, as a replacement for nodes that cease to function due to depletion in their energy reserves.
d.) The sudden change in the transmission power of some nodes, in response to certain unusual events.

For the aforementioned reasons, detecting new nodes and links in the wireless sensor network should be considered as a continuous process. In this work, we make a distinction between the detection of new nodes during the network initialization and during the normal operation of the network. While the former is referred to as initial neighbour discovery, the latter is referred to as continuous neighbour discovery. The need to separate the two stems from the following reasons:

1. When a sensor node has no clue about its immediate surroundings, an initial neighbour discovery is required to be performed. In this case, the sensor node can only perform limited tasks but not communicating with the gateway. It is expected that the node's immediate surroundings should be detected as soon as possible in order to establish a path from the node to the gateway and hence enable it contribute to the overall operation of the network. On the other hand, continuous neighbour discovery is required as soon as the sensor node becomes operational.
2. When the sensor node performs continuous neighbour discovery, it is already aware of its surroundings and hence its immediate neighbours. This can be performed in conjunction with neighbouring nodes in order to minimize energy consumption. In contrast however, initial neighbour discovery is often performed by each sensor node separately.

Fig. 1 depicts a neighbour discovery scheme in which the activity of a network node is determined by its duty cycle.

Suppose that the duty cycle is α at the Initial state and is β at the Normal state. The goal is to have $\beta << \alpha$
An active network node is required to transmit HELLO messages periodically and listen for similar messages from other nodes within its neighbourhood. As soon as a node receives a HELLO message from its neighbour, it responds accordingly and the two can now engage each other in a seamless wireless communication.

Technically, a typical node that is newly deployed is unaware of its immediate surroundings therefore, it is expected to remain relatively active for a longer period to enable it detect any neighbouring nodes. In Normal state however, the network node is expected to use a more efficient scheme in managing its activity in order to prolong its lifespan.

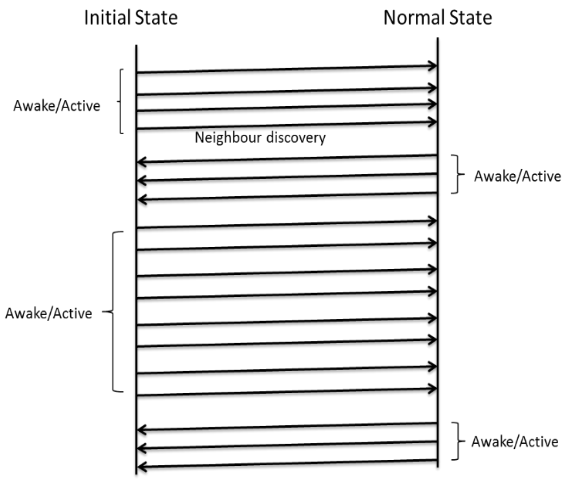

Fig. 1. Exchange of HELLO messages during neighbour discovery at the Initial and normal states

Fig.2 presents a graphical view of this idea. At the Initial state, node ***a*** is required to carry out initial neighbour discovery. After some predefined time period, the node is expected to discover a significant number of its neighbours (if any) and then moves to the Normal state, for continuous neighbour discovery. This paper refers to a node at the Initial state as veiled node while a node at the Normal state is referred to as an unveiled node.

The goal of continuous discovery is to effectively divide the task of finding a new node ***a*** among all the neighbouring nodes that can help node ***b*** to detect node a. The helping nodes possess the following features:

a. They are neighbours to node a
b. They have already detected one another
c. Node b is also within their neighbourhood

Let the number of these neighbouring nodes be ***deg(a).*** Effectively, this is the in-degree of a veiled neighbour to node ***a***.

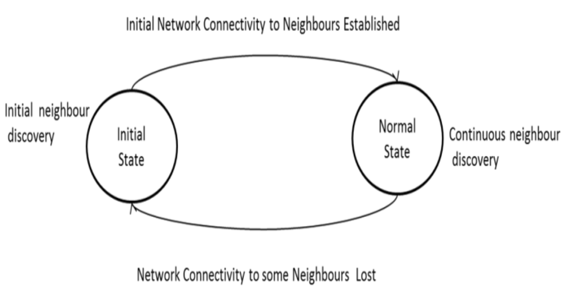

Fig. 2. Relationship between neighbour discovery at the initial and normal states

In order to utilize this neighbour discovery scheme, node b must be capable of estimating the value of ***deg(a).***

The rest of this paper is organized as follows: Section II presents related work on the subject area. Section III presents the problem definition as well as two standard methods for estimating the in-degree of a veiled neighbouring node together with an analysis of their accuracy. Section IV presents a case study in which the nodes are uniformly distributed in the sensor field. Section V presents the details of our continuous neighbour discovery scheme. Section VI presents simulation results as well as discussion of its efficiency. The paper is concluded in Section VII.

Related Works

In Wi-Fi- enabled networks, access points usually coordinate all activities related to the shared communication media. The transmission of messages takes place only between each node and the designated access point. In this scenario therefore, neighbour discovery is restricted to the base-station (i.e., access point) saddled with the responsibility of detecting any new nodes. Because energy is not often a concern for the base station node, the task of discovering new nodes is pretty straightforward.
Periodically, the access point broadcasts a special message and any node within the neighbourhood capable of receiving this special message can initiate a wireless communication process. A regular node has the prerogative of switching to the best frequencies/channels in order to meet its wireless communication needs. The choice of which frequency/channel to switch to might be dependent on the broadcasting access point, security or the quality of the Signal-to-Noise Ratio (SNR). Challenges of possible message collisions in such networks are addressed by the authors of [1]. Other researchers optimize the rate at which the HELLO messages are broadcast in order to reduce the amount of energy consumed in the process ((P. Huang, 2013),(S. Vasudevan, 2005) , (N. Baccour, 2011), (Hamida, et al., 2006) and (Nasipuri, et al., 2010)). In contrast to what obtains in Wi-Fi networks, neighbour discovery in sensor networks is performed by every node, implying that the veiled nodes cannot receive the HELLO messages when they are asleep.

Similarly, network nodes do not usually switch to a special sleep state in Mobile Ad-hoc Networks (MANETs). In such networks, any neighbouring nodes can communicate with each other when in close proximity. In ad-hoc on-demand distance vector (Kush, 2010) routing protocol for example, when a node wishes to communicate with another node, it sends a special RREQ (route request) message. Every network node that receives this special message for the first time rebroadcasts it. Aside from this special message which is used for both connectivity and route maintenance, no special neighbour discovery protocol is required.

Other technologies common in wireless communication such as Bluetooth (Ramachandran, 2014) are designed specifically with the objective of minimizing energy consumption. Neighbour discovery in Bluetooth is asymmetric, implying that any neighbouring node that wants to be discovered is required to switch to an inquiry scan mode (where it listens for a predetermined period on each of the 32 frequencies dedicated to neighbour discovery), while another node that wants to discover its neighbours switches to inquiry mode. This process is considered to be energy consuming and slow since each node has to switch intermittently between the two modes respectively.

Moreover, the 802.15.4 standard (Committee, 2003) provides a rather simple scheme for neighbour discovery. Under this scheme, every base station node is required to issue a special BEACON message such that any newly deployed node scans the available frequencies for such a message to enable it establish a connection. The standard also supports a beacon-less mode of operation whereby, a newly deployed node can transmit a beacon request on the available channel. Any network base station that receives such a request, answers with its beacon. This scheme however, suffers from lack of bound on the time required to discover a veiled neighbouring node.

The authors of (Madan & Lall, 2006)propose a neighbour discovery scheme in wireless sensor networks. In order to provide a guarantee that each node detects at least one of its neighbours using as little power as possible, they propose a policy for determining the transmission power of each sensor node in the network. Similar work by the authors of (Karthikeyan, et al., 2014)focuses on finding an energy-efficient routing method for neighbour discovery in wireless sensor networks.

In the work of (S. Vasudevan, 2005), the authors conducted a study focusing on neighbour discovery in wireless ad hoc networks using directional antennas. Their goal is to determine the optimal rate of transmission as well as reception by the nodes, considering the transmission directions.

The authors of (Hamida, et al., 2006) propose a random HELLO protocol for neighbour discovery in ad-hoc wireless networks. In their scheme, each node can either be in listening or talking states. Each node is considered to be discovered if its transmitted message does not collide with another node's. The goal is to determine the frequency of the message transmission as well as the duration of the neighbour discovery process.

The Disco algorithm proposed by the researchers in (P. Dutta and D. Culler, 2008) make a case for scheduling the wake-up times for any neighbouring nodes that wish to discover each other. In this scheme however, no mention is made of the need for multiple sensor nodes to collaborate in the task of neighbour discovery in order to cut down on energy consumption.

As mentioned earlier in the previous section, sensor network nodes spend the greater part of their operational time in sleep/idle mode, without any activity. Consequently, the ability of a node to discover a new neighbour is dependent on when both are active.

The B-MAC protocol (Heinzelman, 2010)allows for the transmission of a packet preceded by a special preamble, which is long enough for effective discovery provided that each node carries out periodic sampling of the communication channel. However, this scheme is neither suitable for initial neighbour discovery nor continuous neighbour discovery, because of the requirement that the node remains awake throughout the time it takes searching the neighbourhood for a new node.

Problem Definition

In the problem formulation the following assumptions are made:

1. Any two network nodes are considered to be neighbours provided there is a direct wireless connectivity between them
2. All the nodes have identical transmission range
3. Bi-directional transmission is possible among neighbouring nodes
4. The network model is a unit disk graph

For any two nodes in the network, a direct connection between exists provided that they have discovered each other and are familiar with each other's wake-up schedules. A connection is also said to exist between two nodes if there is a direct path linking them. A network segment is made up of a set of connected nodes in the network.

Consider the scenario in Fig. 3 where neighbouring nodes are unaware of the existence of a direct wireless connectivity between them although they share the same network segment. It is obvious from the diagram that some of the nodes are effectively unknown or veiled since they are actually within the network segment but are yet to be discovered by the remaining known nodes. Two basic methods that can help the nodes to discover the veiled or unknown wireless link include: (a) Synchronization message (SYNC) transmitted to all nodes within the connected segment and (b) HELLO messages useful for detecting new neighbours.

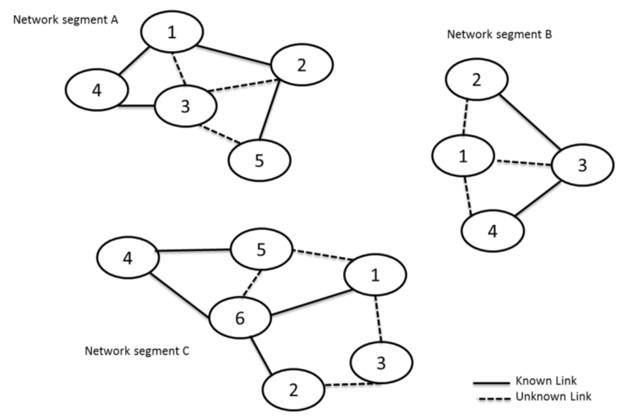

Fig. 3. Network segments with known and unknown links

In the message synchronization (SYNC) method, whenever a new node is discovered by one of the known or unveiled nodes within the segment, a special SYNC message is issued by the node to others within the segment, requesting them to terminate their sleep schedules and periodically broadcast HELLO messages. This synchronous broadcast is guaranteed to ensure that every wireless link within the neighbourhood of the segment is detected.

In order to demonstrate how beneficial the aforementioned method of neighbour discovery is, it is imperative to compare its performance to that of another algorithm in which each node discovers its veiled neighbours (if any) independent of other nodes within the network segment. When the message synchronization method is used, the discovery of an unknown or veiled node is made by all of its neighbours as soon as one of the nodes made the first discovery. In contrast however, when the message synchronization method is not employed, the veiled/unknown node is effectively discovered only when the last node in the network segment detects it. In order to analyse the time slots at which the discoveries of the veiled nodes are made.

Suppose that the time axis is divided into slots such that the probability that a sensor node discovers a veiled neighbour is p. Consider a node x with y veiled neighbours. The probability that node x discovers its first unknown/hidden neighbour only at slot m+1 is given by equation (1).

$$p_{y(m)=(1-p)^{y^m}(1-(1-p)^y)} \quad (1)$$

The expected amount of time required to elapse before the first discovery of a veiled/unknown neighbour is given by equation (2).

$$E^y = \frac{(1-p)^y}{1-(1-p)^y} \quad (2)$$

In the absence of the first scheme, the discovery of all the veiled/unknown neighbours of the given node x proceeds sequentially. The expected delay in this scenario is therefore the expected delay until the first discovery in a set of y neighbours (E^y) plus the expected delay until the first discovery in a set of y-1 neighbours (E^{y-1}).

IV. Case Study: Uniformly Distributed Nodes In the Sensor Field

In this section, we examine a scenario where the nodes are uniformly distributed within the sensor field. Here, the degree of each network node has a binomial distribution, where the probability of success p is given as the probability of a node u is within the transmission range of another node v. This probability can be expressed as the ratio of the area covered by node v and the entire network area. In this case, the variance of the distribution is given by (3).

$$\mu = np(1 - p) \quad (3)$$

where n is the total number of nodes in the network and p is the probability of success.

The in-segment degree of the nodes v and u respectively is a function of the distribution of the nodes in the network. Let X and Y be two uniform random variables indication the in-degree of nodes v and v respectively which we want to estimate.

Recall that the Mean Square Error (MSE) of this distribution (which is same as the variance) is given by the expression in equation (3). The term np in (3) is the expected degree of the node. Considering this case, the correlation of X and Y is given by (4).

$$cor(X, Y) = \frac{cov(X,Y)}{var(X)} \quad (4)$$

Equation (4) can be expressed as shown in (5).

$$cor(X, Y) = \frac{E(X,Y)-\mu^2}{var(X)} \quad (5)$$

where E(XY) is the joint expectation of X and Y which can be given by the expression in (6).

$$E(XY) = \sum_y \sum_x xyP(X = x, Y = y) \quad (6)$$

The expression in (6) can be written as follows:

$$E(XY) = \sum_y [y\, P(Y = y) E(X|Y = y)] \quad (7)$$

In order to show that the expected number of neighbours of node v given that the neighbours of node u are y, we divide the set of neighbours of node v into two subsets. While the first subset is made up of neighbours of node v that are also neighbours of u; the second subset on the other hand contains neighbours of node v that are not neighbours of node u. Similarly, the set of neighbouring nodes to u can be divided into two subsets such that the first subset is the same as the first subset of node v, while the second subset contains neighbours of node u that are not neighbours of v respectively.

For a uniformly distributed network of nodes in the sensor field, the relationship (R) between the respective neighbours of nodes u and v is given by (8). The proof of equation (8) can be found in (S. Vasudevan, 2005).

$$R = 1 - \frac{3}{4\pi}\sqrt{3} \quad (8).$$

RESULTS & DISCUSSION

The importance of in-depth knowledge about the characteristics of rainfall in Lokoja cannot be over emphasised as it is useful for environmental planning, engineering construction and agricultural practices. flash flooding tends to be major issue in the urban areas, in such an area, the intensity-duration-frequency will be a good model for flood forecast as it will provide data and accurate knowledge about rainfall characteristics like intensity, duration and how frequent a particular storm of a known duration is likely to re-occur. This will help in determining the type and size of hydrological structures to be constructed.

This section presents a simulation set-up for the neighbour discovery strategy presented in the paper. A sensor network comprising of nodes distributed randomly and uniformly over a two-dimensional sensor field. It is assumed that the nodes are capable of transmitting at a specific range. Communication among the nodes is bidirectional.

It is also assumed that prior to the commencement of the simulation significant proportions of the nodes has already discovered each other and has transited to the continuous neighbour discovery state accordingly.

For the purpose of this simulation, 1,000 sensor nodes were randomly placed over a 10,000 x 10,000 grid representing the sensor field. The transmission range for the sensors is set to be r units. Any two nodes within the sensor field are said to be connected if the Euclidean distance between them is less than or equal to r. A small portion of the nodes which is uniformly distributed within the sensor field is chosen and set as veiled. In a given period of time T, every veiled node in the sensor field can be detected with a probability P. In the simulation, r is chosen to be 100 units and the probability of detection (P) values range from 0.3 to 0.7. The detection time period (T) is set as 100 time units.

All the veiled nodes are at the initial neighbour discovery state and are expected to wake up randomly, every T_I time units to exchange HELLO messages with other nodes within a time period of H. A node v in the continuous neighbour discovery state, randomly wakes up every $T_N(v)$ time units within the time period H , in order to discover veiled nodes. It is assumed that in order to discover each other, two neighbouring nodes are expected to have active periods that overlap by at least δ; $0 < \delta < 1$. For this simulation, $T_I = 5$, $H = 1$ and $\delta = 0.5$ are used. Whenever a veiled node is detected, it joins the network segment that detects it and learns about its neighbours based on the scheme discussed in the previous section.

Figure 4 below depict the progressive decrease in the ratio of veiled nodes over time while P = 0.3.

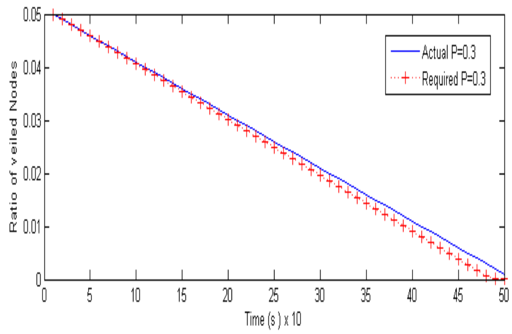

Fig. 4: The variation in the ratio of veiled nodes over time

From the result in Fig. 4, it is evident that within the sampling period, the actual as required values are very close.

The relationship between the random wakeup time for each node in the network over the simulation period for two different P values (i.e., 0.3 and 0.5) is given in figure 5.

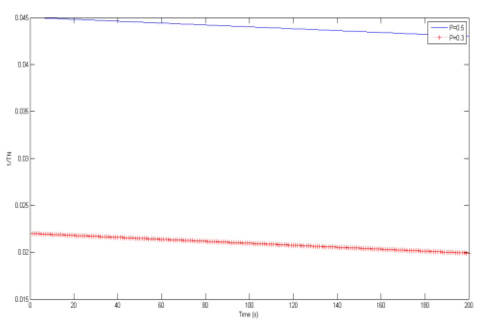

Fig. 5. Changes in T_N over time

In the simulation that produced the result in Fig 5, 50% of the nodes were veiled at the initial state. The figure shows the variation in the average frequency of the HELLO message intervals over time for the two distinct values of P. It is obvious from the figure that the smaller value of P (0.3), the frequency is about75% lower than the frequency for the larger value of P (0.5). Moreover, it is easy to see that for any given value of P, the average frequency of the HELLO message exchange interval decreases with time. This is due to the fact that the scaling of a segment implies a corresponding increase in the number of nodes participating actively in the discovery process.

Fig. 6 shows the ratio of veiled nodes for sensor networks with different transmission ranges, and hence different node average degrees. By comparing the scheme discussed in this paper to a trivial scheme that does not take the network density into consideration. For the trivial scheme, all the nodes have the same wake-up frequency. The actual values, which depend on the wake-up frequency of the nodes, are not important. The comparison shows that the trivial scheme is more aggressive in dense networks than in sparse ones.

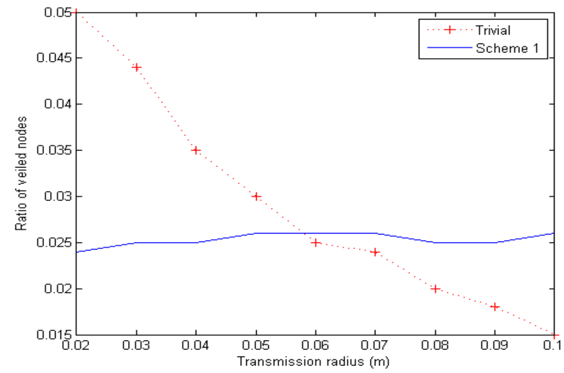

Fig. 6: Comparison with a Trivial Neighbour Discovery Scheme

Although the goal of our scheme is not to discover nodes as quickly as possible, our interest is in imposing an upper bound on the discovery time while minimizing energy consumption in the network. In this respect, we can say that our scheme performs better because its discovery rate is fixed, and its overall energy consumption rate is relatively constant. The simulation begins with 5% of the nodes as veiled, with an initial configuration of P = 0.5. For all transmission ranges, our scheme ensures that after T time units, the percentage of veiled nodes decreases by about half. The trivial scheme on the other hand discovers half of the veiled nodes only when the transmission range is about 0.06 units. With shorter transmission range, the trivial scheme discovers a smaller fraction of the veiled nodes. For transmission range of 0.03 for example, the ratio of veiled nodes contracted from0.05 to 0.04. When the transmission range is however greater than 0.06 units, more nodes are discovered by the trivial scheme. This feat is however achieved at an increased energy cost compared to the scheme implemented in this paper.

CONCLUSION

This paper examines the problem of continuous neighbour discovery in wireless sensor network comprising of non-homogeneous nodes. This paper asserts that continuous neighbour discovery becomes crucial in the event that the sensor nodes remain static throughout their lifespan. If the nodes in a connected network segment collaborate on the task, veiled nodes are guaranteed to be detected within a specified timeframe T with a certain probability P. We showed in this paper that this is possible if every node connected to a network segment estimates the in-segment degree of its possible hidden neighbours.
Specifically, the paper presented a continuous neighbour discovery algorithm that determines the frequency with which every node enters the HELLO period. Simulation results showed that when the veiled nodes are uniformly distributed in the sensor field, the simplest estimation algorithm is good enough. However, when the veiled nodes are concentrated around some specific areas, the algorithm requires every node to not only take into account its own degree, but also the average degree of other nodes in the segment.

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