An Overview of Holes in Wireless Sensor Network

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***Abstract*-Sensor technology is implemented in a wide range of applications. The ability of wireless sensor network to work without being monitored by individual has made it favorite for deployment in hostile hazardous environment such as deep wild forests, battlefields and volcanic mountains. In such conditions, various factors can affect the node's performance and can even destroy it. Network hole appears in the network due to the destruction of group of nodes. This survey provides an overview of the holes appearing in wireless sensor networks. We highlight the impact of network holes over the performance of the network, the major causes of hole formation and the challenges in the detection of network holes. The survey also provides an overview of the work done in this area and the future challenges.**

Keywords- Wireless Sensor Networks, Network Holes, hole Boundary.

I. INTRODUCTION

The continual efforts of researchers to boost the MEMS (Micro-Electro-Mechanical Systems) and communication technologies make it possible to produce economical sensor nodes with reduced size and increased intelligence. A wireless sensor network is composed of a large number of tiny sensor nodes randomly deployed inside an area or close to it to inspect certain phenomena [1]. A wide range of wireless sensor networks applications can be found for monitoring hostile environments such as wild forests, in medical healthcare to promote health services, in household items to make living easy and in industries to obtain high quality management. There are still a number of research issues which the researchers are trying to resolve.

The communication amongst the nodes is generally performed using multi-hop routing. In such architecture, the nodes can communicate with each other and the data sent by a node travel through the nodes in-between to reach the destination. In wireless sensor networks, due to dense deployment of nodes, the neighbor nodes may be close to each other. Therefore, multi-hop communication is expected to consume less power than the traditional single-hop communication [1]. This multi-hop communication is affected and disturbed if the nodes in-between the sender and the receiver fail to operate. In such cases another alternative and relatively longer path needs to be defined for successful delivery. This affects the overall routing performance and the routing may suffer from some hard phenomena such local minimum phenomenon.

Sensor networks can be deployed in a variety of ways. For example, if the inspected area is vast and perilous for human involvement, such as deep forest, then sensor nodes are dropped down from aero-plane. However they can be deployed manually, probably when the inspected area is safe and sound. Typically wireless sensor networks are deployed in harsh remote environments where human interference is difficult. For example, a sensor network can be deployed in a battlefield to track the enemy movements or in a glacier to detect the impact of various dynamics of glaciers on global warming. In these kinds of vast and perilous environments, the sensor nodes are typically dropped down from aero-plane. In such environments, sensor networks are expected to operate for extended period of time without being attended by individuals [34]. However, there is always a chance of sensor node failure.

There are various factors that can affect the performance of sensor nodes. Due to fault tolerance characteristic of wireless sensor networks the failure of few nodes does not disturb the overall performance of the network. However, in certain conditions a group of sensor nodes stops working and the area occupied by these nodes do not take part in network operations thus affecting the overall network performance. The detection of these areas is important in order to achieve the maximum network performance.

This paper focuses on the various aspects which results in the creation of holes and the impact of holes on the network performance. The major contribution of this paper is to highlight the various causes of hole formation, its impact on network performance, and the major challenges researchers face when it comes to propose suitable solution for handling network holes. We also provide an overview of the work done for hole detection in wireless sensor networks. The paper is organized as follow:

Section II provides an overview of hole in wireless sensor network. Section III provides the definition of hole boundary and differentiate it from the network boundary. Section IV outlines the causes of hole formation. Section V defines different kind of holes that may occur in the network. Section VI highlights the importance of hole identification and its applications. Section VII outlines the challenges towards the hole identification. Section VIII sketches the work done in order to recognize the boundary of sensor network and detect holes in the network. Section XI concludes the paper.

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II. NETWORK HOLE

The detection of holes inside the wireless sensor networks is one of the major problems that need the attention of researchers. A group of sensor nodes gives rise to a hole in the network. Holes have sometimes been referred to as 'communication voids' as they act as an obstacle for communication [4].

Suppose an organization wants to conduct a survey about temperature and humidity changes in a huge wild forest [5]. A wireless sensor network is deployed in the whole forest by dropping down a large number of sensor nodes from aero-plane. Suppose the sensor nodes are specially designed to sense temperature and humidity at regular intervals. During the deployment, there is possibility that some sensor nodes fall down into a pond of water. Suppose the sensor nodes are not built as smart as to resist inside water. In such cases, the nodes fallen inside the pond do not take part in data collection. Suppose later at some stage an outbreak of fire in some part of the forest destroys a group of nodes. Such kind of destruction of group of nodes gives rise to a hole in the network. An area where a group of sensor nodes stops working and do not take part in data sensing and communication is termed as a hole in the network.

The nature of environment plays a vital role in the formation of network holes. Sometimes the environment is so hostile that holes are created very easy. For examples, in deep forest, the break out of fire can destroy a huge number of nodes. The detection of network holes is vital in order to obtain maximum network performance.

Fig.1 Illustrates a sensor network deployed inside a forest. The encircled areas illustrate two holes in this network. In first case the sensor nodes are destroyed by the outbreak fire and are completely destroyed. In second hole, a group of sensor nodes are dropped into the pond inside the forest and cannot take part in network functionalities.

Holes put immense impact over the sensor networks performance. The data collection is affected, since a major region does not sense the field. This results in inaccurate data gathering and affects the routing.

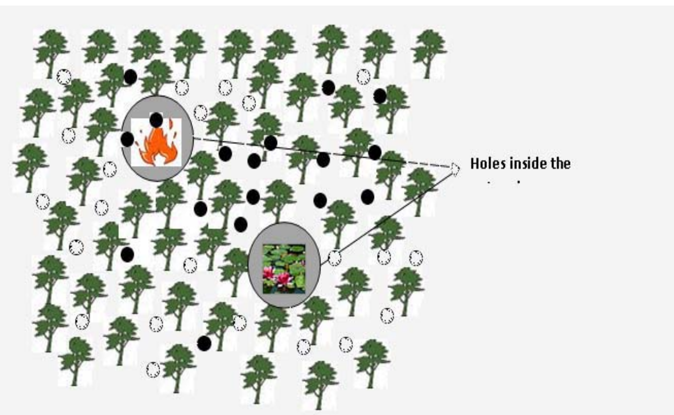

Figure 1. wireless sensor network with 2 holes deployed in a forest.

III. HOLE BOUNDARY AND NETWORK BOUNDARY

Generally the term boundary is used for both the hole boundary as well as the network boundary. The boundary of the sensor networks means the outer edges of the network, where the sensor field comes to an end. The nodes residing on the outer edges of a sensor network which encloses the whole network is considered as the boundary of the network. The identification of the nodes which resides at the boundary of wireless sensor networks is of greater importance and provides information about the shape and coverage range of the network.

The detection of hole boundary is important for improving wireless sensor networks operations. A hole can be defined by its boundary. The boundary of hole consists of working nodes which encloses the destroyed nodes. Therefore, in order to detect holes inside the network, its boundary should be tracked. Fig. 2 illustrates the hole boundary. The red sensor nodes are completely destroyed and form a hole. The shaded nodes illustrate the working nodes which surround destroyed nodes. The shaded nodes are on the boundary of the hole.

Clarifying the concept of hole boundary and formation of holes, we conclude that a wireless sensor network may have two kind of boundaries; the hole boundary and the network boundary. In most of the work done in the past, the researcher have considered both these issues. Most of the algorithms detect the boundary of the network as well as the boundary of the hole. Our topic of interest in this paper is restricted to the detection of available holes in the network and recognizing their boundaries.

IV. CAUSES OF HOLE FORMATION

Wireless sensor networks are deployed in hostile environments and left unattended for a relatively longer period of times. In certain worst conditions, a group of sensor nodes fails to carry out the network operations. The sensor node which fails to perform its assigned function and cannot communicate with other nodes is considered as a destroyed node.

In sensor networks, we may come across a type of node termed as faulty node. A node is considered to be faulty if it is giving results which significantly deviate from the results of the neighbor nodes [Staddon'02]. A faulty sensor works but produces abnormal results. Faulty nodes can be viewed as a special event which comprises the only point of the sensor itself [7]. Therefore, a destroyed node completely stops working and do not take part in network activities. On the other hand faulty node takes part in network activities but produces significantly abnormal results which are completely different from its neighbors.

We highlight the major reasons which lead to the destruction of sensor nodes resulting in the formation of network holes. The node destruction takes place either by some kind of external entity that physical destroys the nodes or it can happen due to the deployment of the network. Some of the major reasons for node destruction and hole creation are given in this section.

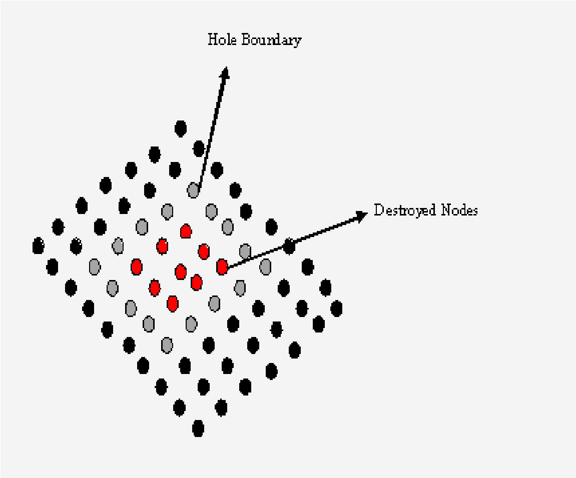

Figure2. Network hole and its boundary

A. *Power Depletion*

Power depletion is one of the major causes of node destruction [6]. Every sensor node is equipped with certain amount of power battery which provides it with energy to carry out the assigned tasks and maintain communication with other nodes in the network. Once deployed in the sensor field, it may be extremely difficult and high cost associated task to recharge nodes [8]. This task becomes more difficult when network is deployed in hostile regions such as battlefield, deserts and forests. In such networks human intervention is eliminated and is left unattended for a longer period of times.

A node consumes energy while performing the network operations. The battery of a sensor node gradually decreases proportional to its network activities and communication. At some stage, the available energy finishes and a node no more remain alive in the network. More power is used in communication than the computations [9].

In some regions of the network, a group of nodes are sometimes busier in computations and communications than nodes in the rest of the network. In such regions, the available energy of the nodes depletes quicker than nodes in other regions of the network. When the energy level of all the whole group comes to an end, all the nodes exhibits the properties of destroyed nodes. The affected region no more takes part in network and gives rise to a hole.

B. *Physical Destruction*

Another major reason of node destruction and hole formation is the physical destruction of sensor nodes [10]. Wireless sensor networks are deployed in remote hostile environments to achieve certain targets. For example a sensor network is deployed in enemy's territories to track their movement. In such networks, a group of nodes may be destroyed by means of warheads such as bombs, grenades or electromagnetic [11]. Similarly the unexpected outburst of fire can affect a large portion of the sensor network deployed in forest.

C. *Existence of Obstacles*

Wireless sensor networks are usually deployed blindly in the hostile regions. In similar cases there may be some areas in the environment where the sensor nodes are unable to operate. Suppose sensor nodes are deployed inside a deep forest then a pond of water can act as an obstacle if the sensor nodes are not so smart to operate in water. The nodes in the pond cannot operate and form a hole in the network.

D. *Lower Density Regions*

Since nodes are randomly deployed in sensor networks, in some regions the node density becomes relatively lower as compare to other parts. The network in such regions remains sparse and connectivity is lower than required. In such cases a group of nodes remain isolated from the remaining network. The lack of communication makes its existence inactive. The area between this group of nodes and the network serves as a hole. These holes are formed due to non-uniform deployment.

V. TYPES OF HOLES

N. Ahmed et al [25] have described various types of holes.

1) Coverage Holes: Coverage holes occurred if the target area is not fully covered with sufficient sensor nodes. No coverage hole exists if every point in the target area is covered by at least by required degree of coverage for a particular application. These holes usually occur due to the random deployment of sensor nodes. In some cases, certain areas in the network are not covered with sufficient sensor nodes.

2) Routing Holes: Routing hole consist of a region in the sensor network where either nodes are not available or the available nodes cannot participate in routing data. These holes affect the routing performance of the network because the routing paths need to be redefined to avoid destroyed nodes. Routing holes can also exist due to local minimum phenomenon, faced in geographic greedy forwarding [25].

3) Jamming Holes: This kind of holes occurs in the case when the object to be tracked is equipped with jammers, which are capable of jamming the radio frequency being used for communication among the sensor nodes [25]. In such cases nodes are still able to detect the presence of the object in the area but unable to communicate the occurrence back to the sink, due to communication jamming [25].

VI. IMPORTANCE OF HOLE IDENTIFICATION

The formation of holes affects the overall performance of wireless sensor networks. They give rise to a number of coverage and routing problems. We describe various effects of hole formation over the network performance and give major advantages of hole identification.

A. *Ensured Data Reliability*

Holes in a network reveal the general health of the sensor network [10]. In order to achieve accurate results from sensor network, the sensor field must be completely covered with sensor nodes and every point must be sensed by some nodes. This complete coverage ensures data reliability.

The formation of a hole affects data reliability. The destroyed nodes do not carry out their operations and thus data is not collected from a major part of the network. The hole identification can provide information about areas with insufficient nodes. Once the holes are identified, fresh nodes can be redeployed and better network coverage and data reliability can be achieved.

B. Virtual Coordinates System

The detection of holes can help in computing virtual coordinates. Virtual coordinates system assigns virtual coordinate to nodes in the network with respect to some chosen reference nodes.

Holes might obstruct the shortest paths between the nodes, and length of the hole cannot be taken as good estimation of the true geometric distance [5]. Once the holes are detected the virtual coordinate's assignment gets easy and thus geographical routing improves.

C. Geographic Greedy Forwarding

In simple geographic routing, a data packet is simply forwarded to the neighbors which are geographically closer to the destination [12, 13, 14]. The problem appears when a hole occurs in the network.

In a geographical greedy forwarding scheme, a source node knows the location of the destination node in two ways. The first method as discussed in [15] in which the source node acquires the destination location from a location service, or alternatively by computing it using a hash function in a data centric storage scheme [16]. In this scheme when a node receives a packet it checks among its 1-hop neighbors for the node which is closer to the destination than the current node. This process is repeated until the packet reaches the destination. In some cases, a packet gets stuck at a node if all its 1-hop neighbors are all farther away from the destination than the node itself [17]. In such cases it is difficult to forward the packet towards its destination. This problem is called as local minimum phenomenon.

Once holes are detected, alternate routes can be built along their boundaries to help the packet reach its destination. The locally stored information about the routes around the hole helps the packet get out of the local minimum phenomenon [4].

D. Geographic Multicasting

Holes identification can help in geographic multicasting [4]. In geographic multicasting a message is delivered from a single source node to a set of destination nodes in a geographic region [18]. The destination nodes are specified by region than by their addresses [4]. Multicasting schemes maintain group communication among a set of nodes in wireless sensor networks [19]. These protocols are used as an attempt to minimize the consumption of network resources [18]. Different mechanism for tackling holes problem in geographic routing are provided in [20, 13]. The formation of a hole affects geographic multicasting since major region does not take part in network operations.

E. GHT and Path Migration

In geographic routing the source node sends a message to the geographic location of the destination instead of using the network address. Each node can determine its own position. In data centric storage schemes, the location information of destination node is acquired from Geographic Hash Table (GHT) [16]. GHT hashes keys into geographic coordinates and stores a key-value pair at the sensor node geographically nearest the hash of its key [16]. Duplicates of stored data are periodically maintained to ensure persistence when nodes fail. Due to hole creation a wide area in the network is unable to participate in data routing; the shortest path routes are disturbed and inaccuracies occur in geographic hash table.

Hole detection is also useful in path migration [4]. Some of the sensor network applications require the maintenance of virtual connections among a set of moving objects. In the example of evader and pursuer [4], the network monitors the movement of evader. The communication paths between purser and evader need constant updates according to their movements. The existence of holes makes path migration based on 1-hop neighbor harder.

VII. HOLE DETECTION-CHALLENGES

The recognition of sensor network boundary and holes faces a number of challenges. The researchers are required to propose algorithms which can operate under these challenges. We describe some of the major challenges which appears in detection of sensor networks boundary and hole detection.

A. Energy Consumption

A major challenge sensor networks faces is the limited battery power of sensor nodes. Each sensor node is equipped with a power battery. The node uses this energy mainly for two purposes: to perform required in-node computations and for communication with other nodes. More power is used for communications than computations [9]. This restricts researchers to take care of energy consumption while designing algorithms.

The development of ultra low power electronics, MEMS and RF communications has encouraged the development of a number of alternative power sources [21]. There are several technologies which extract energy from the environments such as solar energy [22]. The proposed algorithms should be aware of energy consumption problems and must not involve enormous energy consumption.

B. Geographical Location

Generally, a sensor node is not equipped with any location awareness devices such as GPS-receivers. GPS [23] enabled devices put immense burden in terms of energy and cost over the sensor nodes and thus they should be avoided.

In certain applications a few nodes inside the network are equipped with GPS-receivers `. The rest of the nodes extract their coordinates with respect to these GPS-enabled nodes. GPS reception might be obstructed by climatic conditions, and there may be no reception when deployed indoors [24].

C. Hardware Limitations

Generally a node is built with limited processing power and storage. Computations require the use of energy. Since the node is equipped with limited processing power and storage capabilities, the proposed algorithms should not involve large number of computations. The avoidance of computations also saves energy of the node.

D. Topology Constraints

When a sensor network is deployed in regions such as in volcanic mountains and deep oceans, then it is difficult for individuals to manually configure the network. It is left unattended. In this case it is difficult to know the exact topology of sensor networks.

Based on these limitations hole detection algorithms must take care of energy consumption and other restrictions.

VIII. RELATED WORK AND FUTURE CHALLENGES

In this section we highlight the work done in order to detect holes inside the network. I.Khan *et al.* [2] give a detail description of work done for boundary recognition and hole detection in wireless sensor networks.

Fang *et al.* [4] detects holes inside the network by assuming that nodes are equipped with location awareness devices.

The algorithms [10, 26, 27, 28, 29, 30, 35] under this category, use the connectivity information of sensor nodes to detect the boundary of the sensor networks and detect holes inside the wireless sensor network. These algorithms utilize the available topological information and do not make any assumptions about the geographical locations of the nodes.

The algorithms [31, 32, 33] proposed under this category identify the nodes, as either inner or boundary nodes, by assuming that the node distribution in the network follows some statistical functions.

IX. CONCLUSIONS

Wireless sensor networks applications can be found in every field of life. The scientists have taken keen interest in the deployment of sensor networks in remote hazardous environments. One of the exigent problems occurring in such environment is the formation of network holes. We discussed the formation of network holes and the importance of its detection. It occurs when a group of nodes stop operating due to some reasons. Hole badly affect the general performance of the networks. A major part of the network destroys which leads towards problems in data reliability and data routing. We have discussed the advantages of hole detection. Hole detection ensures data reliability and efficient routing. Hole detection is also useful for measuring virtual coordinates, geographical multicasting and geographical greedy routing. The required algorithms should face some major challenges such as limited energy and limited hardware resources.

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