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A SURVEY ON STRATEGIES TO MITIGATE HOT SPOT PROBLEM IN WIRELESS SENSOR NETWORKS

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ABSTRACT

The imbalance of energy consumption of the nodes in Wireless Sensor Networks causes some nodes to die prematurely leading to network partitions. The nodes near the base station suffer from such a problem called the “hot spot problem or energy hole problem”. These nodes die due to heavy load on them to relay other nodes’ traffic towards the base station. Hence an important issue in the design of wireless sensor networks is to beat this problem. This paper reviews all of the proposed solutions to overcome the hot spot problem.

Keywords: Hot Spot, Multihop, Clustering

1. INTRODUCTION

A Wireless Sensor Network (WSN) [1],[2] is a network formed by a large number of densely deployed sensor nodes. The rapid development of wireless communication technology, low cost sensing devices and miniaturization of these devices has led to the increased use of these networks in many areas like military, traffic management, medical, industry, etc [27]. The architecture of a sensor network generally consists of a set of sensor nodes and a sink. The sensor nodes sense data in their surroundings and send this data to the sink node where the user accesses this data. The sensor nodes also act as relay nodes as these forward data of other sensor nodes to reach the sink.

Sensor nodes have various constraints [3] of processing power, memory, battery, etc. Since these networks are deployed mainly in unattended environments, it becomes nearly impossible to replace the batteries of the nodes once these are drained out. Therefore the constraint of battery is highly considerable and energy efficient mechanisms that preserve the battery of these nodes needs to be employed.

If a sensor node runs out of battery, it loses its functionality and affects the communication capability of the neighboring nodes. This eventually creates network partitions and makes the sensor network non-functional thereby reducing network lifetime. The problem is much more severe in nodes near the base station as they are responsible for relaying the network traffic to the sink. The area comprising this set of sensor nodes is called the hot spot region.

The rest of the paper is organized as follows: Section 2 describes the hot spot problem in WSNs. Section 3 discusses techniques to mitigate them. Section 4 concludes the paper.

2. HOT SPOTS IN WSN

In multihop networks, nodes closer to base station are responsible for additional work of forwarding the data of the nodes those are farther from the base station. This many-to- one traffic pattern overloads the nearby sensor nodes thereby draining their batteries at faster rate. Wadaa et al [4] claims that by the time the nodes which are one hop away from the sink exhaust their energy, sensors farther from sink can have 93% of their initial energy. The area surrounding sink where the nodes die prematurely is referred as hot spot region as shown in Figure 1.

Figure 1

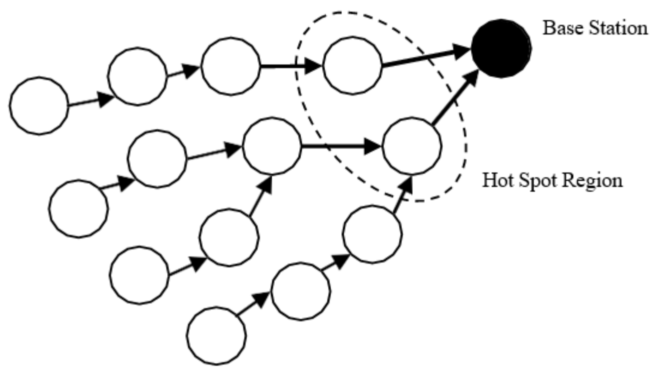

Figure 1 Hot Spot Region

"Hot spot or energy hole problem" is defined as the isolation of sink node due to power exhaustion of sink close-by nodes [4].

3. TECHNIQUES TO MITIGATE HOT SPOT PROBLEM THERE EXISTS A LARGE BODY OF RESEARCH WORK WHICH FOCUSES

on reducing or removing the hot spot problem in WSNs. In the following section, some of the existing approaches have been discussed.

1) Transmission Power Control

With an increase in a node's distance from a base station the amount of data that needs to be transmitted by it increases considerably [23][25]. Use of intelligent transmission power control policies such as allowing node to support multiple transmission ranges [5] can solve this problem. In this approach, nodes that are away from sink transmit their data over longer distances (though not directly to sink). When a node is distributing its outgoing packets over multiple distances, it must use minimum transmission power required to send packets at different distances. But this

$$r_{1.opt} = \begin{cases} \sqrt[a]{\frac{4Ee}{(a-2)\epsilon}}, & 2 < a \leq 6 \\ T_x, & a = 2 \end{cases}$$

approach uses the energy of some nodes inefficiently.

2) Clustering mechanisms

In clustering mechanisms, a cluster head aggregates the data received from the member nodes of its cluster. The cluster head then sends its aggregated data towards the sink via a single hop or multiple hops. Hence there exist two types of communication viz. intercluster and intracluster communication. Keeping in mind delay and energy consumption, direct transmission is employed for intracluster communication while for intercluster communication multi-hop communication paradigm is preferred over single-hop communication. But this multi- hop communication causes many-to-one traffic pattern which results in the hot spot problem. CHs near the base station have a huge amount of traffic, causing a hot spot in that area and thereby decreasing the network lifetime [25].

Ye et al. [6] propose a technique to create an optimal size where a is path loss exponent, Tx is the transmission range and Ee & ϵ are parameters of transmitting and receiving circuitry.

Yu et al. [7] present Energy Aware Distributed Unequal Clustering (EADUC) protocol that solves the energy hole problem in WSNs. Each round in the protocol consists of two phases: setup phase and data transmission phase. The setup phase consists of three subphases: neighbor node information collection phase, cluster head competition phase and cluster formation phase. The algorithm elects CHs based on the ratio of average residual energy of neighboring sensor nodes and residual energy of the node itself. It builds smaller clusters near the sink so that the energy of the nodes nearer to the sink can be consumed for relaying the intercluster data. These unequal cluster sizes are formed based on the competition radius RC, calculated by each node as follows: of hot spot so that lifetime of the network can be increased. The technique is applied on a clustered network, where the sensing field is in the form of a disk of radius R with base station at the center of the field. This disk field is divided

$$R_c = [1 - \alpha \frac{d_{max} - d(s_i, BS)}{d_{max} - d_{min}} - \beta (1 - \frac{E_r}{E_{max}})] R_{max}$$

into m disjoint concentric sets called coronas, with m concentric circles of radii 0 < r1 < r2 < …< rm = R. In each round, the network is organized into clusters where sensors transmit their data to respective CHs and CHs forward the aggregated data from coronas Ci to Ci-1 until the data reaches C0 i.e. the BS as explained in Figure 2.

Figure 2

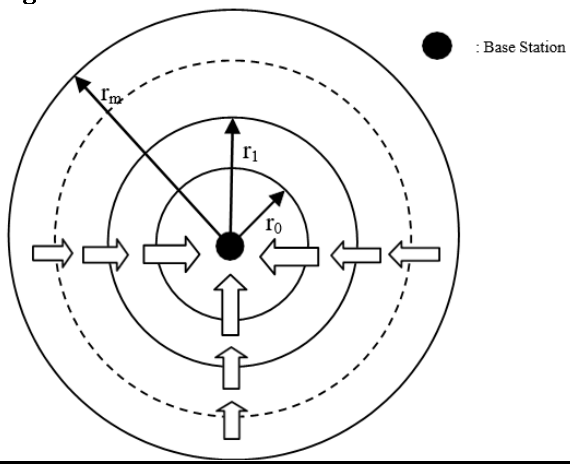

Figure 2 Data Forwarding from Outer Coronas to Inner Coronas

where d (si, BS) is distance from node si to BS, α and β are weighted factors in [0,1], Er is the residual energy of node si, Rmax is the maximum value of competition radius. For large values of d (si, BS) and Er, corresponding value of RC is large, which implies that CHs with high residual energy and farther from BS will control larger cluster areas. The approach is highly scalable and reliable, has acceptable algorithm overhead and has no isolate points.

Nurhayati et al. [8] propose a Weight-Based Unequal Clustering Routing (WBUCR) Protocol that uses a weight metric to choose CHs. This weight metric takes into account the residual energy of the node, distance of node to the BS, difference in degrees of node, number of neighbor nodes and number of node difference. The sensing field is organized into different partitions (Pi) as shown in figure 3 where each partition is divided into clusters. Clusters near the BS are smaller than clusters that are far away.

It can be seen that the lifetime of the network depends on the lifetime of corona C1 as it carries the relay traffic. Thus lifetime of C1 must be maximized which can be done by optimizing the size of C1 and the number of clusters in the network.

The optimal value of r1 is:

Figure 3

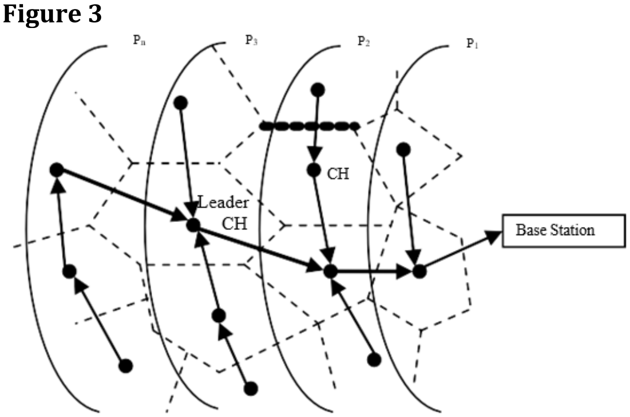

Figure 3 Weight Based Unequal Clustering Routing Protocol

In every partition a cluster head leader is elected so as to transmit data between different partitions. The protocol consists of two phases: set-up phase and data transmission phase. Set-up phase involves selecting CH and associating nodes to them. In data transmission phase, cluster members send the sensed data to respective CHs where the data is aggregated and is sent to leader CH. The leader node sends this data to the leader node in next partition closer to the sink and this continues until data reaches the sink.

3) Node Mobility

Node mobility can be exploited in mobile WSNs to provide an efficient solution to hot spot problem. Mechanisms that utilize node mobility can be classified into three categories namely, mechanisms using mobile sink, mechanisms using mobile relays and mechanisms using mobile node [9].

- **Using mobile sink:**

Nodes forward their data to sink when mobile sink gets closer thus shortening the multi-hop delivery paths. The path followed by sink should be decided judiciously otherwise the whole concept of mobile sink will be destroyed. Sink can either move autonomously Mobile Sink based Routing Protocol (MSRP) for extending network lifetime in clustered WSN. The protocol works in two phases: Setup phase and steady phase. In the setup phase, CH aggregate data received from a sensor node or on predetermined paths. Babar Nazir et al [10] propose within its cluster and then, wait for mobile sink to come near its vicinity. When mobile sink reaches new location, it broadcasts the beacon message containing their location so that nearby CHs can sense its presence and can send their respective data to sink. After intercepting a beacon message, CH send registration message to sink. In steady phase, sink assigns time slots to all registered CHs. During the allotted time slot interval, CH can send its data to sink. Sink collect data from cluster head within its vicinity and then move to a new location. The residual energy of CH is also piggybacked along with sensed data so as to aid mobile sink in deciding a new location. Mobile sink moves in such a way that it is always in neighborhood of high energy CH nodes.

Saad et al. [11] present an Adaptive Moving Strategy (AMS) for mobile sink to increase the network lifetime in hierarchical sensor networks. Recognizing points through which sink must pass and optimizing path are two primary tasks of this strategy. After dividing the network into clusters and electing CHs, it calculates the centroid of the clusters. Sink moves along a path that passes through centroid of each cluster. Bees' algorithm is used to optimize path.

Bi et al. [12] propose Half-quadrant-based moving strategy (HUMS) for mobile sink in flat sensor networks. Before moving to a new location sink analyzes information about the residual energy of sensor nodes received during the data gathering process. To achieve balanced energy distribution sink, move towards the node that has the highest residual energy. Sink can move only one hop in each round.

A group of nodes having lowest residual energy in the network is termed as quasi-hotspots. If the sink is far from destination, then it should adapt its trajectory so as to avoid regions containing quasi-hotspots. There may be a case where a node has highest residual energy just because it has less neighbors and it is forwarding data on behalf of few nodes. Such nodes can partition the network; therefore they are blacklisted. If a node with highest energy lies in the vicinity of quasi-hotspots, then also it is added to the blacklist.

- **Using mobile nodes:**

In uniform deployment, sensor nodes that are near to the base station consume more energy as they have to forward data from other far away nodes. This uneven energy consumption leads to formation of energy holes in the target region. These holes can be healed by relocating sensor nodes after initial deployment in such a way that node density is high in areas that are closer to sink while minimizing total sensor moving distance. Cardei et al [13] present some solutions to relocate sensors so as to prolong the network lifetime. The primary objective in Integer Programming (IP) method is to reduce total sensor moving distance. If the no of sensors in a region is greater than, less than or equal to the required no of sensors then it is a source, hole and neutral region respectively. The whole idea is to move sensors from the source region to hole region so as to become neutral region. The localized matching method is a three way mechanism where hole region broadcast no of sensors to become neutral. Source then responds with the number of sensors that it can provide. Finally, hole region selects which sensors to take and notifies their respective source region so that actual movement can take place.

- **Using mobile relays:**

In order to improve network lifetime, mobile nodes can be used as mobile relays to carry data to sink. Mobile nodes can perform sensing, transmission and receiving functions on behalf of co-located static nodes [14], allowing them to enter into a sleep state.

Banerjee et al. [15] exploit mobility of cluster heads to deal with hotspot problem in cluster based sensor networks. Each cluster contains static sensors with CH being mobile. CHs cooperate with each other to allow fair load distribution. Static nodes send their sensed data to CH within its vicinity which then delivers it to static sink. Author proposed three mobility schemes for mobile CHs namely, event driven, energy efficient and hybrid. In the event driven mobility scheme, CHs move to the location where some event has occurred. In the energy efficient scheme, CH move towards nodes having high residual energy. The Hybrid scheme combines advantages of both event driven and energy efficient scheme where initially CH move towards the event and then consider residual energy for later movements.

4) Multiple sink:

One of the solutions to hot spot problem in large scale WSNs is to decrease the path length a sensor's data has to travel to reach the sink node. This can be achieved by deploying multiple sinks in network. Each sink communicates with sensors that are certain no of hops away, thus decreasing the average energy consumption of each sensor node and lowering the latency. The basic idea is to divide a sensor network into clusters and then assign a sink for each cluster in such a way that the average hop distance between each sensor node and nearest sink is least possible value. Clusters should be equal in size to allow even load distribution.

As the no of sink nodes in the network is constrained, therefore their positioning is a very challenging issue. Problem to find optimal sink positions in WSN has proved to be NP-complete [16]. The simplest algorithm to find multiple sink location in WSN is k-means clustering [17] where the network is partitioned into k disjoint clusters and sinks are deployed at the centroids of clusters. This algorithm does not guarantee fair partitioning. Deepak R Dandekar et al. [18] propose another solution based on Particle Swarm Optimization (PSO) for optimal multi-sink placement problem. Initially, K-mean clustering is used to generate k clusters and then PSO is used to determine optimal sink locations. Fitness parameters used are average hop distance and sink's 1-hop connectivity. The exhaustive search used by PSO is computationally expensive.

5) Hybrid Scheme

The energy consumption of the nodes increase as their distance from the sink decreases and reaches maximum when these nodes fall in the hot spot area. The amount of data generated by the nodes in a hot spot area is far less than the data that needs to be relayed by them to the base station. Therefore, the data flowing in the hot spot area must be reduced. Abdulla et al. [19] propose a hybrid scheme where hierarchical multi-hop routing is used outside the hot spot region and flat multi-hop routing is used within the hot spot region as explained in Figure 4.

Figure 4

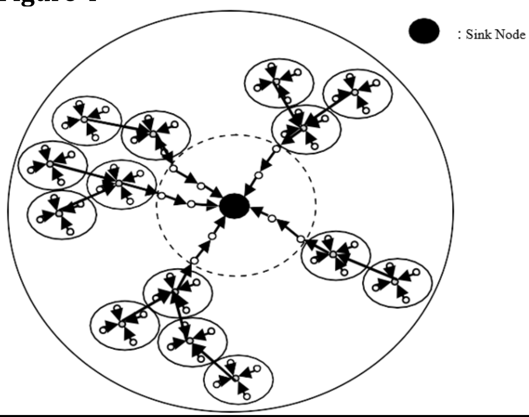

Figure 4 Hybrid Multi-Hop Routing

The hierarchical multi hop routing takes the advantage of data correlation among neighboring sensor nodes and compresses this correlated data which reduces the amount of data entering the hot spot region. Inside the hot spot area flat multi-hop routing is used so as to decrease the transmission distance in the hot spot area.

6) Query trees

Routing in query trees causes collisions at the internal nodes of the tree as there are many incoming streams of data into them. A lot of energy of these nodes is wasted in retransmissions which reduce the lifetime of the network. Chatzimilioudis et al in [20] propose a distributed Minimum Hotspot Query Routing Tree (MHS) that reduces collisions at these internal nodes by balancing their degrees. Nodes count the degrees of the candidate parent nodes and choose the one as parent which has least degree. MHS algorithm reduces query execution time, prolongs the network lifetime and increases coverage. It is simple, parameter free and has minimum communication overhead.

7) Other methods

One of the simplest strategies to prolong the network lifetime is biased distribution of sensor nodes i.e. deploy more number of nodes in the gateway area near base station [21]. This approach provides better results than uniform deployment as network connectivity is dependent on the lifetime of nodes near sink. It helps in balancing the energy but is not practical in real applications. Babaei et al in [22] explain an adaptive data centric storage approach which uses a decision function to select a suitable method that consumes less energy for storing data. This method adapts dynamically as the rate of event and query production changes.

4. CONCLUSION

In this paper a survey of current strategies for solving the hot spot problem is presented. These approaches increase the network lifetime by utilizing the energy of the network in an efficient way.

Table 1

Table 1 Highlights the Advantages and Disadvantages of Each of Them

Technique	Papers	Advantages	Disadvantages
Transmission Power Control	[5]	Simple	Inefficient use of energy resources
Clustering mechanisms	[6], [7], [8]	Balanced energy consumption	Finding optimal number of cluster heads is difficult
Node Mobility	[10], [11], [12], [13], [15]	Improve network lifetime, throughput	Inappropriate in real scenarios due to space and energy constraints
Multiple Sink	[17], [18]	Lower latency, average energy consumption per node is decreased	More deployment cost, finding optimal multiple sink location is a challenge
Hybrid Scheme	[19]	High reliability, less power consumption	Finding optimal distance where to replace multihop routing with flat routing
Minimum Query Tree	[20]	Distributed, minimum communication overhead	Complex
Biased Deployment	[21]	Cost effective	Impractical in real applications

CONFLICT OF INTERESTS

None.

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