

Methods of Mitigating Hotspot problem in Wireless Sensor Networks

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ABSTRACT

Minimizing energy consumption of sensor nodes in a WSN plays an important role in enhancing network lifetime. Hotspot problem often occurs as a result of unbalanced energy consumption in the network, leading to network partition and lifetime reduction. It occurs in both the single-hop and multi-hop communication pattern. In designing energy-efficient routing algorithms for a WSN, it is also important to mitigate the effect of the hotspot problem. In this paper, a survey was carried out on some energy-efficient routing protocols that considered mitigating hotspot problem in WSN. A summary of possible methods for mitigating hotspot problem was outlined.

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INTRODUCTION

Energy consumption is a major issue in WSNs, because of the limited energy of the nodes. Hotspot problem is a condition that often results in isolation or network partition, due to unbalanced energy consumption (Nguyen *et al.*, 2018; Balamurali & Kathiravan, 2016). It reduces the network lifetime (Wankhade *et al.*, 2016); as such it is a critical point of focus when considering energy efficiency in WSNs. Most design of routing algorithm in a WSN does not consider the effect of hotspot problem that may result in network

partition. In addition to achieving energy efficiency in the network, it is also necessary to mitigate hotspot problem (Balamurali & Kathiravan, 2016). The process of transferring data from the sensor nodes to the base station in a WSN often adopts single-hop or multi-hop communication. Hotspot problem occurs in both single-hop and multi-hop communication. In single-hop transmission pattern, the CH nodes that are much afar from the base station deplete their energy faster because of long haul transmission as shown in Figure

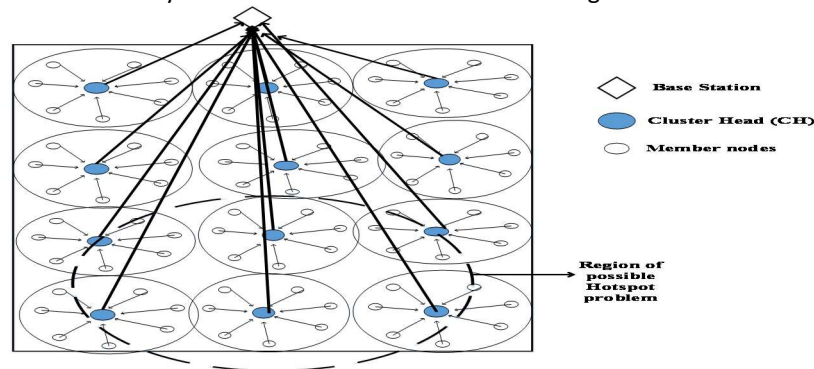


Figure 1: Hotspot Problem in Single-hop Inter Cluster Routing

The region of possible occurrence of hotspot problem that may occur due to single-hop inter cluster routing is shown in Figure 1. In multi-hop transmission pattern, CH nodes close to the base station consume more energy due to intra-cluster transmission, data aggregation and inter-

cluster relay as shown in Figure 2. Therefore, they drain out energy faster than the CH nodes much afar from the base station. This often disrupts the network connectivity. As a result the network may get isolated and useful information are lost.

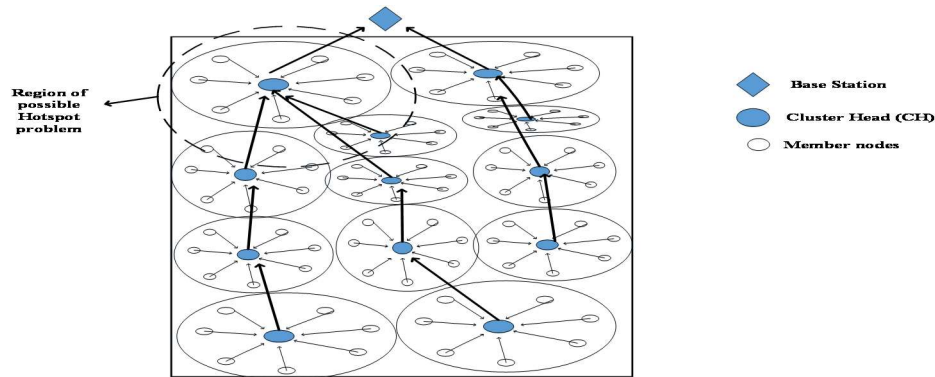


Figure 2: Hotspot Problem in Multi-hop Inter Cluster Routing

The region of possible occurrence of hotspot problem that may occur due to multihop inter cluster routing is shown in Figure 2. In a large-scale WSN, multi-hop transmission is more energy-efficient than the single-hop transmission. This is because some CH nodes may be unable to reach the base station as a result of the limited transmission range.

ENERGY-EFFICIENT ROUTING PROTOCOLS THAT ADDRESSED HOTSPOT PROBLEM.

Some papers that considered mitigating hotspot problem in WSNs are highlighted as follows: Li, Ye, Chen, & Wu, (2005), developed an unequal clustering mechanism for WSNs. The protocol is a distributed competitive algorithm, where CH nodes were chosen by localized competition. They addressed hotspot problem using unequal clustering approach. The mechanism partitioned the sensor nodes into clusters of unequal size. The cluster sizes closer to the base station have smaller sizes than those farther away.

Moreover, for the inter-cluster communication they proposed an energy-aware multihop routing. Simulation results showed that their approach balanced energy consumption among the nodes, thereby achieving an enhancement in network lifetime.

Perillo *et al.*, (2005), analyzed strategies for mitigating hotspot problem in WSN. They studied multiple strategies that could mitigate hotspot problem in WSN, as a result of the many-to-one traffic pattern. They suggested transmission range optimization; whereby nodes with different range of transmission were used depending on distance to the base station, so as to evenly distribute energy consumption. Thereby, extending network lifetime. Moreover, they proposed deployment of multiple base stations, so as to share the network traffic. Also, they proposed usage of mobile sensor nodes and base stations, in order to effectively balance the energy consumption.



Rivas *et al.*, (2006), proposed an efficient method to mitigate hotspot problem in WSNs. They mitigated hotspot problem by placing extra sensor nodes in the hotspot area around the base station. Using a simple mathematical model, they discussed the benefits of adding the supplementary nodes to the network. They analytically proved that by adding a limited number of nodes around the base station, the lifetime of the network could be increased.

Yang & Cardel, (2007), proposed a scheme for enhancing network lifetime. They proposed a method of mitigating hotspot problem by regulating the density of the sensor nodes based on the distance to the base station. A centralized redeployment scheme relocated the mobile sensor nodes. The network area was splitted into coronas. The coronas that were near the base station have higher densities than those farther away. Simulation results showed that their approach effectively prolonged the network lifetime.

Chen *et al.*, (2009), developed a routing protocol to mitigate hotspot problem in WSNs. They addressed hotspot problem using unequal cluster-based routing. The protocol organized the network into unequal cluster sizes. More uniform energy consumption was obtained among the CH nodes, because of the reduction in number of nodes in clusters near the base station. The protocol showed improvement in network lifetime compared to HEED (Hybrid Energy Efficient Distributed) algorithm.

Jaichandran *et al.*, (2010), proposed a novel approach to handle hotspot problem in WSNs with better connectivity and network lifetime. They deployed additional nodes near the base station. The additional sensor nodes were deployed based on the network coverage area. They performed experiment in various grid sizes and with different number of

sensor nodes. The result obtained showed significant improvement in network lifetime.

Ever *et al.*, (2012), proposed a clustering algorithm that mitigates hotspot problem. Their algorithm was based on HEED algorithm, which forms equal size clusters. They used a formula that created unequal clusters, based on the distance of the CH node from the base station. Furthermore, they demonstrated that hotspot problem existed in equal size clusters (HEED). Simulation results showed that their protocol effectively mitigated hotspot problem and balanced the energy levels of CH nodes in the network.

Abdulla *et al.*, (2012), proposed an algorithm for extending the WSN lifetime. The proposed algorithm considered the effect of hotspot problem, so as to attain an increased network lifetime. They used a hybrid multihop routing algorithm that employed a hierarchical multihop routing outside the hotspot area, to reduce data flow in the area. Also, they used a flat multihop routing within the hotspot area, in order to decrease the transmission distance of node in the area. The performance of the algorithm was analyzed via simulations. Their approach decreased energy consumption, by reducing the amount of data forwarded to the hotspot area.

Selvi & Manoharan, (2013), developed an unequal clustering algorithm for WSN. The proposed energy aware clustering was used to mitigate hotspot problem in WSN. The algorithm divided the sensor nodes into unequal size clusters. Simulation results showed that their algorithm outperformed HEED by balancing the energy consumption among the sensor nodes.

In (Chattopadhyay & Vijayalakshmi, 2014), a method to improve network lifetime in WSN was developed. The method mitigated hotspot problem by using multiple base stations, with an



energy-efficient routing algorithm. In their proposed method, the network was divided into two regions. Each base station was assigned to a particular region. A sensor node can only send data to the nodes and base station within its region. Those nodes having maximum residual energy were selected to forward data to the base station. Using multiple base stations, the hop count between data-source node and the sink was reduced, thereby reducing energy consumption. The simulation results showed improvement in network lifetime.

Kumaramangalam *et al.*, (2014), proposed a routing protocol for WSNs. They used a multihop data-forwarding model to achieve hotspot-free sensor network. Their approach created even size clusters. At each round, all the CHs disclosed the following information; location ID, residual energy, distance to base station, number of messages relayed earlier. Based on the information, the relaying CH node for that particular round was selected. Therefore, ensuring an energy-efficient multihop communication. Their multihop communication mechanism enabled invariable energy dissipation among CHs. With proper relay CH selection, the algorithm achieved uniform energy consumption and avoided hotspot problem. The algorithm was simulated using Castalia simulator and evaluated in terms of network lifetime and energy consumption.

Gosavi & Wankhade., (2015), developed a clustering algorithm for heterogeneous WSN. They proposed a method that mitigated hotspot problem using unequal clustering. The algorithm worked in three phases; clustering phase, rotation phase and re-clustering phase. In the clustering phase, the CHs were selected based on their distance to the base station. During the rotation phase, the residual energy of the nodes was evaluated. Then, new CHs were selected based on the residual energy. Re-clustering only occurred

when any node completely depleted its energy.

Balamurali & Kathiravan, (2016), proposed an energy-efficient routing protocol that mitigated hotspot problem in WSNs using Tier-based quantification algorithm. The sensor nodes around the base stations were divided into tiers. Those closer to the base station formed tier1, the next closer formed tier2, and so on. The tier formation consisted of two phases. In the quantification algorithm, it was assumed that if there are x node in the outer tier, then the next inner tier should have $2x$ nodes and the next inner tier should have $3x$ node and so on. The first tier, which was closer to the base station, should have nx nodes, where n is the total number of tiers. The algorithm reduced the impact of hotspot problem by providing an approximate count for the required nodes in each tier.

Wankhade *et al.*, (2016), developed an unequal clustering algorithm for WSN that mitigated hotspot problem. The protocol organized the network into unequal size clusters. They decreased the nodes in clusters near the base station, so as to maintain uniform energy consumption among CH nodes. Simulation was carried out using NS2 simulator and the performance showed improvement compared to LEACH and EEUC.

In Rao & Banka, (2016), a novel optimization based clustering algorithm for WSNs was proposed. The algorithm was based on novel chemical reaction optimization (nCRO) paradigm. They developed a potential energy function using: average neighbor node distance, energy ratio and average sink distance. They mitigated hotspot problem using unequal clustering. Moreover, they evaluated their protocol using network lifetime, number of alive nodes, packets receipt and convergence rate as performance metrics. Simulation results



showed that their proposed algorithm outperformed other existing algorithms.

Sneha & Kannan, (2017), developed a grid clustering based protocol for larger network area. The proposed protocol used a centralized approach with fixed clustering. The network was divided into unequal fixed rectangular shaped clusters. The cluster varies depending on distance to the base station. Data aggregation was performed to minimize energy consumption in transmitting duplicate data, using the concept of Fermat point. Simulation was carried out using NS2 simulator. The protocol provided better solution to hotspot problem, thereby improving the network lifetime.

Nguyen *et al.*, (2018), proposed an algorithm for mitigating hotspot problem in WSN based on enhanced diversity pollen in Flower Pollination Algorithm (PFA) was proposed. They used a metaheuristic approach inspired by mimicking flower pollination process. In the optimization algorithm, the populations were divided into sub-population equitable to cluster formation of the randomly deployed nodes in WSN. The optimal group of nodes were selected as CH nodes and modeled as fitness function. To mitigate hotspot problem, applying FPA performed load balancing among the CH nodes.

Neamatollahi & Naghibzadeh, (2018), developed a clustering algorithm for large-scale WSN. The algorithm employed fuzzy logic to adjust the cluster radius depending on distance to the base station and density of nodes. They proposed an unequal clustering algorithm. To avoid hotspot problem, the network workload was distributed uniformly among the sensor nodes, by rotating the CH role among them and tuning the cluster size. The network was splitted into unequal size clusters having an approximate equal workload. Simulation results showed significant

improvement in energy conservation and network lifetime.

Wang *et al.*, (2018), proposed an enhance power efficient algorithm. The algorithm alleviated hotspot problem by using mobile sink. They adjusted the sensor nodes communication distance based on their distance to the mobile sink, so as to improve the network performance. Moreover, they performed numerous simulations showing how their algorithm outperformed other existing works. Although, using their approach hotspot problem was not completely eliminated.

Yi & Yoon, (2019), developed a technique that uses a drone as a mobile base station to mitigate hotspot issue in WSNs was developed. The drone collected aggregated data from selected anchor nodes, to prevent heavy loads in hotspot area. The anchor nodes were selected considering the energy capacity of the drone and the size of the network. The drone supplied energy to low-energy anchor nodes, so as to improve the network connectivity and mitigate hotspot problem.

Nguyen *et al.*, (2019), proposed an algorithm for WSNs. They developed a novel optimization algorithm for unequal clustering, to avoid hotspot problem in WSN. They used a metaheuristic-based approach that simulated the behavior of the bat species for searching prey. A probabilistic model was used to generate a new candidate solution in search space using the algorithm. Cluster sizes vary based on the distance from the base station. Experimental results demonstrated the effectiveness of the proposed algorithm.

In (Balamurugan *et al.*, 2019), an efficient and reliable routing protocol for WSN was developed. They proposed a method that mitigated hotspot problem using multiple mobile base stations. The network was divided into several clusters, and the influence of mobile base stations on the network was analyzed. The CHs were



selected using residual energy and sensor nodes distance to the base station. The sensor nodes with maximum weight, which are closer to the mobile base station, were chosen as the CH nodes for that round. Simulation result showed improvement over some existing works.

DISCUSSION

A summary of possible methods for mitigating hotspot problems are outlined as follows:

1. Use of mobile base stations. This will effectively balance the energy consumption in the network, by moving from one CH node to the other within the hotspot area and collecting data.
2. Deployment of multiple base stations. This will ensure efficient sharing of network traffic among the base stations.
3. Use of mobile sensor nodes. The mobile nodes can adjust their positions in areas that have high transmissions, so as to balance energy consumption and mitigate network partition.
4. Adding supplementary nodes within the hotspot area using intelligent power control techniques.
5. Using metaheuristic (nature-inspired) approaches to ensure optimal load balancing among the CH nodes.
6. Incorporating unequal clustering mechanism into the routing algorithm. In single-hop routing, clusters further away from the base station should have smaller sizes than those closer to the base station, so as to reduce intra-cluster communication and reserve more energy for long haul transmission. In multi-hop routing, clusters closer to the base station should have smaller sizes than those further away, so as to reduce intra-cluster communication and reserve

more energy for inter-cluster data transmission.

CONCLUSION

Routing protocols can be designed to enhance energy efficiency and extend network lifetime, but cannot effectively deal with hotspot problem unless a mechanism is devised or incorporated into it, to handle the problem. In conclusion, any of the above aforementioned technique or mechanism can be used or incorporated into the routing algorithm, in order to effectively mitigate the hotspot problem.

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