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Relay Nodes: Enhancing Network Lifetime and Throughput in Wireless Sensor Networks

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ABSTRACT

Recent advances and researches in field of WSN have enabled the development of low-cost, low-power, multifunctional sensor nodes having functionalities such as self-organizing, data processing & aggregation etc. As these sensors are battery- operated, so it is very crucial to use this limited energy in an efficient way. Node mobility factor gave rise to sensor networks that have many potential applications now days. In this paper, we have observed the phenomenon of unequal energy depletion rates within sensor nodes which lead to the "Energy Hole" problem in many-to-one WSNs. Each node routes the sensed data to the sink which depends upon the network infrastructure i.e. single-hop or multi-hop architecture. Each node consumes the more energy in communicating and in finding an optimal route for data transmission to the sink or base station. Due to the fact, nodes which are placed close to the sink drain their energy soon because they have to transmit the data gathered from the whole network and as well as their own sensed data up to the base station. As a result, these nodes may become isolate from the network leaving a "Hole" in the network. This hole or a connectivity gap causes the early dysfunction of whole network. To avoid this problem, we have incorporated some additional nodes called as Relay Nodes in the nearby region of sink. In this scheme, we have implemented an energy efficient clustering & routing protocol LEACH supporting node mobility. Clustering is handled by base station. Imposed relay nodes will relay the data generated by the network up to sink and maintain the balanced energy consumption and load balance across the network. Simulation results validates the proposed methodology in terms of performance metrics such as energy efficiency, high throughput and less packet delay resulting in enhanced overall network lifetime and connectivity.

Keywords:- Energy Hole, LEACH, Relay Nodes, Unequal Energy Depletion Rate, WSN.

I. INTRODUCTION

A wireless sensor network is typically composed of a large number of sensor nodes which are deployed densely within the sensing region or very close to that. Each node in the sensor network may consist of one or more sensors, wireless interface, portable power supply (energy) and possibly localization hardware such as a GPS unit or a ranging device [Jun Zheng & Abbas Jamalipour, 2009].These sensor nodes are capable of sensing the data within targeted area, processing, communicating and route data back to the sink often called as Base Station. Base station is powerful enough and may be operated independently to provide connectivity with outer world such as internet etc. Each WSN has certain characteristic and deployed accordingly in order to accomplish a specific task. These networked sensors have many potential civil and military applications i.e., they can be utilized for object tracking, intrusion detection, habitat and environmental monitoring, disaster recovery, traffic control, inventory management and health related applications etc. [Chee-Yee Chong and Srikanta P. Kumar, 2003] [J. N. AI-Karaki, A. E. Kamal, 2004] Unlike traditional networks, a WSN has its own design and resource constraints. Resource constraints include limited energy, short communication range, limited processing and storage capacity in each node. Design constraints are application specific and depend on the environment to be monitored. Network connectivity, throughput, load balancing and energy conservation are the primary requirements in designing a wireless sensor network [Jennifer Yick, Biswanath Mukherjee & Dipak Ghosal, 2008]. A critical portion of available energy is consumed in data transmission by sensor nodes. Hence it is the desired feature of sensor nodes that they must adopt a reliable and feasible path for data transmission across the network. Fault tolerance, self-route discovery and self-organizing are other prime responsibilities of sensor nodes in order to maintain the network connectivity. Mostly a WSN is designed and implemented for an unreachable Tran, so it becomes so difficult or nearly impossible to replace a node that has gone out of its energy. To avoid this, a set of valid communication and routing protocols are designed so far that distinguish a wireless sensor network from other networks like cellular and ad-hoc networks [Jamal N. Al-Karaki & Ahmed E. Kamal, 2004]. Furthermore, multiple sensing nodes transmit their data to a single sink which in turn lead to data redundancy at the sink. A data aggregation mechanism is also needed in between to remove redundancy for easy data processing [J. N. Al-Karaki, Younis O & Fahmy S 2004]. In this paper, we have proposed a methodology for many-to-one sensor networks in which some special sensor nodes that are full of energy and high transmission ranges are simply placed across the nearby region of sink to balance the traffic load and energy consumption. These special nodes are termed as the "Relay Nodes". The whole network is get partitioned into grids to from clusters in a hierarchical manner using LEACH. The process of forming clusters and cluster head is done by base station. Number of cluster heads are formed so far depends upon the total number of nodes deployed within sensing area. Nodes can move as per the application requirements or can move across the clusters and this node mobility is supported by this protocol. These assisting nodes are placed in the inner radius of the sink. They assist the cluster heads and receive the data from cluster heads and forward to base station without any significant delay. Nodes within a cluster transmit their data to the their cluster head using single-hop fashion and cluster heads forward that data to the relay nodes via single or multi-hop fashion. A relay node utilizes its energy in performing just data receiving & forwarding and does not take part in data sensing. In next section previous researches are briefly reviewed. Section III describes the proposed methodology and section IV and section V report about the results and performance of proposed methodology and conclusion respectively.

II. RELATED WORK

Different approaches considering analytical studies on energy hole, energy efficient routing protocols, relay node deployment methods etc. have been studied in the literature.[Guichai Chan & Jie Wu, 2009] [D. Yang, S. Misra, X. Fang, G. Xue & J. Zhang, 2010] [Degan Zhang, Guang Li & Xuechao Ming, 2013] [Bing Hong Liu, Yeu Xian Lin & Wei ShangWang, 2014] [Y. Moeen, N. Javaid, F. Saleem & M. Akbar, 2014] [Jihed Eddine Said, Lutful Karim & Jalal Almhana, 2014] [D. Yasin, K. Saghar & S. Younis, 2015]. A two-tiered relay node placement to reduce energy consumption was developed. It specified grid intersection points as possible imposed location of relay node placement by using the constraints such as the maximum hop count, communication path selection criteria and relay node communication capacity to formulate a greedy rule [Wang Zhu & Shao Xianhe, 2013]. A relay node placement problem in wireless sensor networks that where to position a limited number of available nodes that can act as relays were considered in this work. They formalized the problem by defining a linear, mixed integer mathematical programming mode including a number of constraints and penalty components. The model was efficiently solved using a standard solver, CPLEX and outputs both relay node positions and routing paths to base stations [Gianni A. Di Caro & Eduardo Feo Flushing, 2011]. To establish multi-hop communication between every pair of terminals and presented a novel relay node placement heuristics called Incremental Optimization based on Delaunay Triangulation (IO-DT) was presented. Advantage of the Discrete Fermat Point (DFP) optimization by considering groups of three non-collinear terminals has been taken. IO-DT has been shown to have O (n 2) time complexity [Fatih Senel & Mohamed Younis, 2012]. WSNEHA, a Wireless Sensor Network's Energy Hole Alleviating Algorithm that analyzed the energy consumption model, data transmission model and the energy consumption distribution model of sensor nodes was developed which was based on the data forwarding and router selection strategy. WSNEHA efficiently balanced the energy consumption of the sensors in the first radius range of the sink and that the lifetime of a WSN was extended [Yu Xue, Shuiming Zhong, Yi Zhuang & Xiangmao Chang, 2014]. Energy consumption intensity of relay nodes was used and the algorithm proposed ensured a fault tolerant network. A local search procedure was used for scheduling sensors resulted in a fault tolerant network by developing a k-connected graph. The heterogeneity of the nodes was maintained by issuing random values for sensing range, transmission range and the battery power of the nodes and their behavior was studied for extending the network lifetime [Mrs. Suganthi K & Dr. Vinayaga Sundaram B, 2012]. E-HORM, an Energy-efficient Hole Removing Mechanism that uses the sleep and awake mechanism for sensor nodes to save energy was developed. This approach found that maximum distant nodes to consume the maximum energy for data transmission. Every node first checks its energy level for data transmission against the threshold value and after that it can be allow transmitting its data. This methodology was tested upon LEACH, TEEN, DEEC and SEP protocols also [M. B. Rasheed, N. Javaid, Z. A. Khan & Q. Quasim, 2013]. Low Energy Adaptive Clustering Hierarchy (LEACH), Multi-hop LEACH, LEACH-C, Grid- LEACH, TB-LEACH, Sensor Protocols for Information via Negotiation (SPIN), Energy Balanced Routing Protocol (EBRP) are energy efficient hierarchical routing protocols designed so far for static and mobile sensing nodes using certain network characteristics [Wendi B. Heinzelman, Anathan P. Chandraska & Hari Blakrisshnan, 2002] [Hu Junping & Jin Yuhui, 2008] [FengyuanRen, Jiao Zhang, Tao He, Chuang Lin & Sajal K. Das, 2011] [D. Hema Sumitha, M. Alamelu Mangai & M. Vivek Kumar, 2013].

III. PROPOSED PROTOCOL

In our proposed protocol, it is considered that the sensor nodes deployed within a sensor network have moderate mobility and the base station (sink) is static and powerful enough. Hierarchical routing is an efficient way to lower energy consumption within a cluster, performing data processing & aggregation in order to reduce the data redundancy among the transmitted messages up to the base station. The whole network is divided by implementing the LEACH [Jamal N. Al-Karaki & Ahmed E. Kamal, 2004]. Initially, the sensor field is divided into virtual grids of equal size. These grids collaborate with each other in order to exchange the information about number of nodes present in each grid. The base station forms the clusters and selects a cluster head for each cluster. Cluster heads are used to process and route the information, while nodes within a particular cluster used to perform the sensing in the proximity of the targeted area. The size of the clusters may vary depending on the mobility of the sensor nodes and only 5 percent of the deployed nodes need to act as cluster heads. In this proposed methodology, assisting nodes are inserted in the inner region of sink which is stationary. Nodes are organized and managed across the network in three categories based on the amount of energy level they have at the current time. These nodes are assumed to divide the whole network into layers based on the distance from the base station and consume energy accordingly.

1) Ordinary Nodes (Outer Layer)
2) Cluster Heads (Inner & Middle Layer)
3) Relay Nodes (Relay Node Layer)

Ordinary Nodes: The ordinary nodes consist of a communication unit and power unit. These nodes are located very close to the target area and far away from the base station. Ordinary nodes simply sense or capture the data from external environment and communication unit relays that data from node to node until it arrives at the cluster heads.

Cluster Heads: Cluster Heads are the nodes having similar components as the ordinary nodes along with high energy level and some additional capabilities such as data processing and data aggregation. Initially, each node is considered as the ordinary node until a node is declared as cluster head by the base station. A cluster head collects data within its own cluster, process that data according to application demands, aggregates that data and transmit to the relay nodes.

Relay Nodes: Relay Nodes are the special nodes having high energy levels and transmission range and placed intentionally between cluster heads and sink. They just collect the data from various cluster heads and forward that data to the base station. These nodes help in maintaining network connectivity by balancing the traffic load and conserving energy consumption by reducing the data transmission path between cluster heads and base station.

Before proceeding, in the rest of paper we make some reasonable assumptions as follows:

1) In a many-to-one sensor network, each sensor node sense & generate the data at constant bit rate (CBR) and send towards a common sink.
2) All sensing nodes have the same and fixed transmission range.
3) We are assuming that there is no collision occurs within the clusters and hence no retransmission is required before performing the simulation validation.
4) Nodes are equipped with location sensing devices such as GPS to find the relevant location of a sensor node across the network.
5) We are also assuming that whole network is fully connected before a network start performing its desired operations.

System Model:

The system model considered in this is composed of two types of models termed as radio model and mobility model. The radio model describes about the nodes communication and the energy requirements for signal transmission and reception through wireless interface. The mobility model considers the node mobility of nodes.

Radio Model: We consider the radio model as used in LEACH [Wendi B. Heinzelman, Anathan P. Chandraska &

Hari Blakrisshnan, 2002]. We assume that the energy consumption of the sensor is due to data transmission and reception. According to this model, the energy loss is proportional to d^2, where d is taken as the physical distance between the transmitting and receiving node. Here, Fig.2 is depicting the radio transmission model. According to this radio model [W.B.Heinzlman ,A.P.Chandrakasan, H.Balkrishn, 2000] [Wendi B. Heinzelman, Anathan P. Chandraska & Hari Blakrisshnan, 2002], in order to transmit a k bit message over up to a distance d, the energy expenditures is as given in following mathematical equation.

$$E_{Tx}(k, d) = E_{Tx\text{-}elec}(k) + E_{Tx\text{-}amp}(k, d)$$

$$E_{Tx}(k, d) = E_{elec} * k + E_{amp} * k * d$$

Similarly, in order to receive this message energy expenditure is described as mentioned below according to this radio model:

$$E_{Rx}(k) = E_{Rx\text{-}elec}(k)$$

$$E_{Rx}(k) = E_{elec} *$$

Mobility Model: In the proposed protocol, the sensor nodes have random mobile. The sensor nodes move in the sensor filed as per the random waypoint mobility model [Tracy Camp, Jel Boleng, Vanessa Davies, 2002]. Here, the movement of a node following a random waypoint mobility model in positive x-axis is shown.

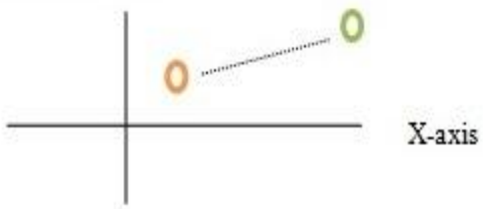

Fig.1 Random sensor node mobility in 2-D plane

Phases of methodology: We have divided our methodology in 6 basic phases based upon the functionality of LEACH. These phases are shown below in a step by step sequence with the help of flow chart:

1. Forming the Virtual Grids: The whole sensor field is divided into square shape Virtual Grids of equal size so that we are assuming that sensor nodes are distributed in a uniform manner. Number of grids generated is based on the assumption that which is made earlier that only 5% of the total deployed nodes can be chosen as cluster heads. So let us consider that the number of sensor nodes deployed be 140. As only 7 sensor nodes can become cluster heads, we calculate a threshold value equal to or greater than (140/7=20).

13	15	8	10
11	07	20	12
10	09	05	04
06	03	07	00

Fig.3 Grids of equal size (4*4=16)

This threshold value plays a significant role in forming the clusters and nearly uniform distribution of sensor nodes within each cluster as shown above.

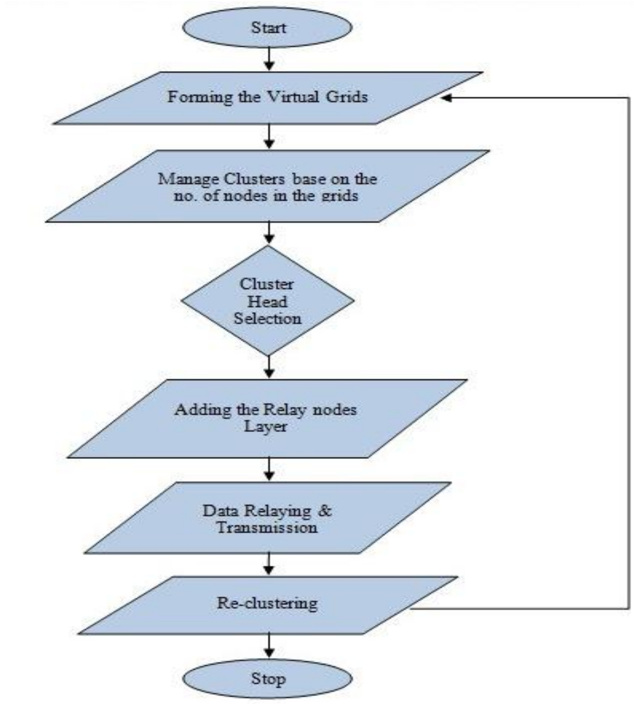

Fig.3 Flow chart showing different phases

2. Manage Clusters base on the no. of nodes in the grids: Next step is the formation of clusters which is depends upon the virtual grids formed so far. All the grids are scanned from top to bottom to check if the number of sensor nodes inside each grid is greater than or lower than the threshold value. If it is greater, then the grid is capable to form a cluster else the neighboring grids are combined together to form a cluster. This process continues until the entire grids are scanned and clusters are formed.

3. Cluster Head Selection: As the sensor nodes are mobile, sensor nodes may move away from their clusters. If a sensor node does not move away from the cluster, then the parameters like the ***maximum energy*** and the ***minimum distance*** of it from the base station are considered for selecting it as a cluster head for each round [Hiren Kumar Deva Sarma, Prativa Rai, Bhupesh Deka, 2014]. A cluster head node should have energy more than a level (threshold level). Essentially, the cluster head node must have to remain within the boundary of its cluster to communicate with nodes residing within the cluster in spite of its mobility. Apart from this all, a cluster head node should always have a high amount of residual energy at the time of cluster head selection since it needs to perform additional tasks and has to maintain the connectivity across the network.

4. Adding the Relay nodes: After choosing the cluster heads by base station as per the selection parameters are defined above, next phase is to randomly deploy relay nodes between the cluster heads and base station. These deployed nodes form an inner layer around the base station. Each cluster head choose a shortest path to its nearly located relay node. Relay nodes deliver the data packets to the base station. No data sensing, data processing and aggregation tasks are performed by these nodes.

5. Data Relaying & Transmission: For data relay and transmission, TDMA based scheme is used [W.B.Heinzlman, H.Balkrishn, 2000][Wendi B. Heinzelman, A.P. Chandraska & Hari Balkrishna, 2002].This helps in conserving the energy of nodes and cluster head by avoiding unnecessary transmissions whenever they have no data to send. A Cluster head may use multi-hop data transmission also for relaying the data to a relay node.

6. Re-clustering: After the completion of each round of above phases, clusters and cluster heads are re-computed by using the same method on the basis of current position of the sensor nodes and residual energy levels they have at that time. This is done by the base station. There is a possibility that number of clusters may vary during each round just because of the node mobility.

IV. RESULTS AND DISCUSSION

In order to check the effectiveness of our proposed algorithm and to verify our approximation analysis, we also extend the study using NS-2 simulator. In this section we present the simulation setups and their results. During the simulation experiments, we assume that the MAC layer is ideal such that there is no collision and retransmission, which can result in extra energy consumption. Our focus is on investigating the "Energy Hole" problem, so we also assume that each wireless link always has enough capacity to transfer the data. In simulation, we adopt the energy model described in Section III and DSDV as underlying routing protocol. We have considered some of the following performance metrics.

1. Network lifetime: Network lifetime can be defined as the minimum time until a sensor network stops performing its desired functions or time until a very first sensor node has gone out of its energy level thus resulting in the network connectivity hole. Our main research contribute is in increasing the overall network lifetime and smooth functioning of a wireless sensor network.

2. Throughput: Throughput refers to the amount of data packets transferred from a sender to a receiver in a given time and usually measured in bits/bytes per second. It tells about the average rate of successfully delivered data packets across the network. It is affected by many factors and the importance of throughput does vary in different applications.

3. Packet loss: Packet loss means that unsuccessful delivery of packets from a sender node to receiver node. It may occur due to the connectivity or energy hole arises in between the network and a sending node becomes fail to deliver a packet up to its destination often called as base station.

4. Energy consumption: Energy consumption is the amount of the total energy consumed by all the nodes for sensing, communicating and transferring the data across the network. If amount of energy consumed become less, lifetime of a network is automatically get increased.

5. Load balancing: Load balancing is balancing the burden of relaying network traffic across the network because heavy traffic load causes a node to deplete its battery power at faster rate. For performing the simulation of the proposed protocol, we have taken an area of 800x800 m^2 for the network deployment of 31 nodes and considered the following parameters table.

Parameters	Value
Channel	Wireless Channel
Propagation Model	Two-Ray Ground
Queue	Pri Queue
Mac	802.11
No. of Mobile nodes	31
No. of Sink	1
Routing Protocol	DSDV
Sensor Field Region	800*800
Data packet size	250 Bytes

Fig.4 Simulation Parameters Table

Based on these parameters, we have studied the energy consumption in sensor nodes, throughput and packet loss across the network by applying proposed methodology as shown through various graphs (Fig.5- Fig. 7).

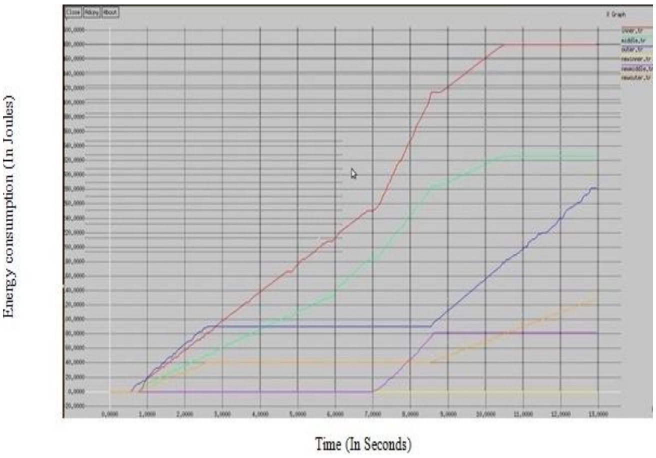

Fig.5 Energy Consumption comparison

Fig.5 shows that the amount of energy consumed across the network in different hierarchical layers as per stated in section III before and after applying our proposed methodology till the end of simulation period. Through this methodology, a shorter data transmission path becomes available for cluster heads reduces the energy consumption.

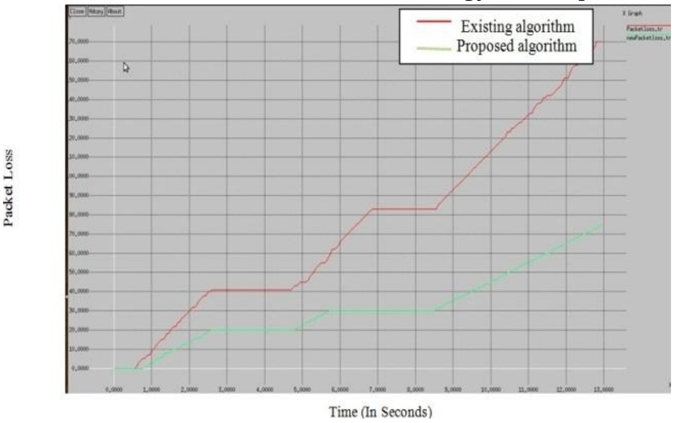

Fig.6 Less Packet v/s Time

Fig.6 demonstrates that number of data packet get loss become less in case of proposed methodology due to elimination of energy hole. Earlier, a large number of data packets got lost whenever a node became isolated from the network. Now, relay nodes deliver the data packets successfully to the base station and results in smooth flow of data across the network.

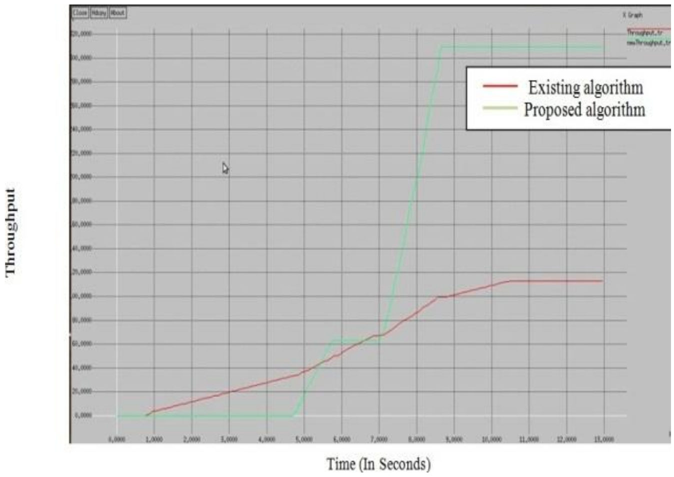

Fig.7 Increased Throughput Rate

Fig.7 shows the increased throughput rate after applying our methodology. As the number of data packets delivered successfully increases, throughput also increases in a WSN which is a very significant and desired performance metric in various applications.

V. CONCLUSION AND FUTURE SCOPE

Our proposed protocol is a cluster based hierarchical protocol which considers the node mobility also. The simulation results show impact of proposed methodology on energy consumption, throughput, packet loss and thus on the overall network lifetime and connectivity during the operation of the network. The performance of the proposed protocol against existing protocol can be explained through the points discussed ahead:

1. Energy consumption across the network is decreased because a straight and shorter path for data transmission is provided.

2. Critical desired performance metric, load balancing is achieved as cluster heads become free form the heavy burden of data delivery to the base station and thus can utilize that energy in performing other tasks such as data processing & aggregation.

3. Network connectivity is prolonged because the elimination of the connectivity hole and isolated nodes from the network.

4. As there is no connectivity hole arises, packet loss is also get decreased as compared to existing protocol.

5. Throughput is also increased in this methodology as number of data packets delivered successfully increases in the network.

The protocol can be extended to handle the issues related to relay nodes such as relay node failure and their mobility also. It will help in providing a scalable solution for the routing problem in large WSNs and can be analysed through mathematical modelling and more rigorous simulation experiments.

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