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Evolution of Energy Efficient Wireless Sensor Network: A Survey on Energy and Clustering Issues

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Abstract

In different fields of human endeavor, wireless sensor networks (WSNs) are being developed to collect, aggregate, fuse, and send data collected by a wide range of sensors in real-time. When developing a wireless network's data transmission routing system, energy consumption is among the most essential components. Designing an energy-efficient (WSN) routing framework is challenging. Several energy-efficient routing algorithms exist for effectively transferring data packets between cluster members (CM) and cluster heads (CH). Some suggest the change of state of the nodes that made up the network from active to sleep in the event where the nodes are not sensing of sending data as a method of energy optimisation while others reduce the distance between the nodes because the distance between nodes is directly proportional to the amount of energy use during data transmission. Whatever the method may be, achieving reduced energy consumption in a WSN environment is an enormous task due to the need for both long network life and network efficiency. This paper reviews some research and energy saving techniques that had been carried out on WSN over a period of time.

Keywords: cluster head, cluster member, optimization, energy, wireless sensor networks.

Introduction

A sensor is a device which converts non-electric values to electrical values. It is equipped with a wireless transceiver or alternative wireless messaging device that transfers and take delivery of data over a wireless channel via electromagnetic wave. A sensor also has a regulator for controlling data and memory for keeping software and data for a little while. Sensors are micro-devices that sense or track physiological parameters like temperature, pulse, blood pressure, respiration rate, humidity, speed, motion, vibration and so on. It converts these parameters into signals. These signals over a network are rarely in human readable form; they are usually electric pulses of 0's and 1's. They are convened over a network for more

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investigation and vital decision making. Sensor nodes are the major constituent of WSN, because data collection and aggregation are done by the sensor nodes before data is sent to the gateway and base station. It senses or track data and stores it and also defines the path by which the data is transmitted and aggregated. Sensor nodes that constitute a sensor network is closely (and arbitrarily) deployed within the area in which is being observed. Every sensor node distributes the collected data to one or more neighbour node(s). Multiple hop communication model data are routed first to the sink and then, to the end-users. However, there are restrictions forced by the distinctive sensing devices, this makes solutions designed for multiple-hop wireless networks generally not suitable for sensor networks. Figure 1 shows a sensor node and its components.

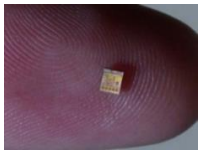

Figure 1a: A sensor Node (Ian ,2004)

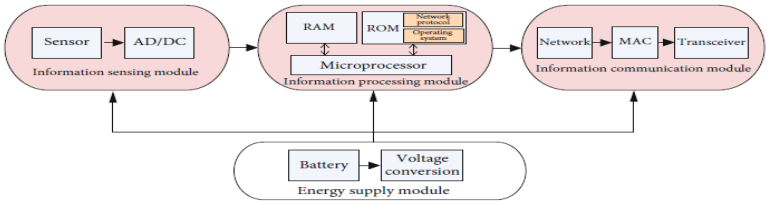

Figure 1b: A Sensor Node Component (Song, Liu, & He, 2020)

Sensor node is composed of four modules: sensing module, processing module, communication module, and an energy supply module (Song, Liu, & He, 2020). The function of the sensing module is for collecting and transforming data relating to an observed object, while processing module is in charge for processing and storing of sensed data. The communication module is liable for communicating with other nodes in the network for transmitting and receiving of data. The energy supply module provides energy to sensor nodes so as to carry out the activities performed by a sensor node. Nodes cannot be attached, without difficulty; to a wired power source in a lot of WSN applications during field operations, nodes therefore relay on an alternative source of power which are batteries have small or limited energy. This event makes energy efficiency of communication rules to be of critical concern since nodes always need to replenish its energy so as the extend the operation time of the network. The main contribution of this paper is to have a chronological review of researches in WSNs, with a view of finding the various approaches used in energy optimisation and why the problems of energy depletion and packet losses still persist.

Components of Sensor Nodes

Power Generator/ Unit: both the first and second generation of WSNs used an alkaline cell to power the battery, though in recent time, it harvests energy from the environment to power the sensor node.

Transceiver: it is the part of the node that has the function of receiving and sending packets from neighbouring devices to the CH and vice versa; the transceiver is used for wireless communication between nodes (intra and inter cluster).

Processing Unit: it is the part of the node that does the processing (data aggregation) and storage of the information gathered on the field.

Sensing Unit or modules: it is that part of the node that is responsible for tracking and sensing of the parameters and values which the network is to discover. It also houses the analog to digital converter (ADC); that covert analogue signals to digital signals.

WSN is made up of small devices known as sensor nodes, these nodes perceive, process, gather and transmits data to a base station or data-centre for decision making which affect man. They communicate with each other using wireless signals. Sensor node comprises of a small memory, transceiver, and microcontroller and power source. The microcontroller is responsible for data processing; the processed data is then stored in a small internal memory. Sensor nodes is majorly power by batteries, while in some cases energy that is harvested from the environment can be converted to a form which the node can make use of. WSNs are used in a number of fields of human endeavours, some of which are:

a) Environmental monitoring: weather predicting and forecasting, detecting and preventing of natural disaster like tremor and earthquake (Persson, 2019). One of the most frequently employed functions of WSN is environmental monitoring, which includes the management and oversight of infrastructure, including air, water, and soil monitoring.
b) Military Surveillance: monitoring of field operations to know when there is need for support and progression. It can also be used to detection chemical element used in making explosive; this will help in sensing of danger (Persson, 2019).
c) Home applications: controlling and monitoring of electronic devices and security systems (Persson, 2019). Small sensor nodes may now be implanted into commonplace items like home electronics and furniture for remote monitoring and control, thanks to the development of WSN-integrated integrated internet of things (IoT).
d) Medical monitoring: monitoring physiological signals remotely by medical practitioners, disease detection and diagnosis (Persson, 2019). Low-cost data collecting is used to monitor patients' health. Body Area Network (BAN) is an innovative subset of WSN developed specifically for healthcare that improves care while reducing costs. Patients' physiological, mental, and psychological data are tracked with WSNs while they engage in daily activities.
e) Transportation: for improved safety of both the highways and airways. When there is a traffic jam or other traffic hazard, WSN could alert motorists of the situation. Vehicle movements may be tracked in real-time to prevent congestion and crashes.

There are a number of simulations used to simulate WSNs and they are developed and written in different programming language; some of which are:

a) NS-2/ NS-3
b) GloMoSim
c) SensorSim
d) J-Sim
e) OMNeT++
f) Matrix Laboratory (MATLAB)

When designing a WSN, there are a number of factors that should be considered. The nature of data to collect, the application and the terrain where it will be deployed are vital. Other important factors are:

a) Security: the level of security of any network is very important, the confidentiality of the data collected showed not be tempered with, else user can lose confidence in the network. Unauthorized users should not have access of any information gathered and

transmitted by the network. Once there is a compromise with the data collected by a network, the network is no longer effective and reliable.

b) Cost: one reason why WSNs is gaining more attention is it low cost of installation and deployment. Sensors are relatively cheap and affordable and the networked is wireless in nature, hence the cost of cables have been eliminated.
c) Fault tolerance: an efficient network should be able to recover from failure or fault. Failure could be hardware, software, link (route) or environment centred. Any of these failures should not affect the overall performance of the network.
d) Power consumption: it is important for a sensor node to use its power efficiently else it could easily run out of power. Replacing sensor nodes battery during field operation is very difficult and, in some case, causes a temporary stoppage of transmission, there is need to increase either the rate at which sensor nodes are recharged with power without stopping transmission or ensure that the energy depleted is minimal.
e) Scalability: increase in the number of nodes in a WSN can lead to increased communication overhead; this sometimes results in data packet loss during communication. Hence, it is required WSN to support increase in the quantity of nodes in the network.
f) Network topology: WSN should be deployed in a way that node can decide to leave one (1) cluster and join another cluster; the issue of re-joining a cluster in the network makes it vulnerable to failure. For this reason, the protocol and topology used in deploying WSN should be one (1) which is able to handle the node mobility in network.
g) Robustness: it is deployed in harsh environment. The network should be able to operate optimally always, no matter the environmental or weather condition that maybe subjected to.
h) Transmission media: the transmission medium of data between nodes can be through waves or optical media. The choice of transmission media used in deploying a WSN is subject to the type of media variable, cost and nature of data to transmit (Persson, 2019).

Generations of WSN

WSN have evolved over the years, from the early 1980's till date. Due to these evolutions that have taken place, WSN is gaining more attention, in sensor and wireless communication. Table 1, shows the changes that have taken place over time.

Table 1: Generations of WSN

	First generation (1980s-1990s)	Second generation (Early 2000s)	Third generation (Late 2000s)
Size	Attache or Larger	Paper book or smaller	Small, even a dust particle
Weight deployment mode	Pound physically installed or air-dropped	Ounces hand placed	Grams or less embedded
Node architecture	Separate sensing, processing and communication	Integrated sensing, processing and communication	Fully integrated sensing, processing and communication
Protocols	Proprietary	Proprietary	Standard: Wi Fi, Zigbee, Mimax etc
Topology	Point to point, star and multi-hop	Client server and peer to peer	Fully peer to peer
Power supply	Large battery or line feed	AA battery	Solar or possibly nanotechnology based

Life span	Hours, days and longer	Days to weeks	Months

Clustering in WSN

Clustering is very important for lengthening the lifespan of resource-constrained WSN. It is a prominent technique used in making the dissemination of packets more effective. The grouping prototype splits the node devices into several groups or clusters. Every group in network has distinctive CH node, which direct the data to other devices in cluster. In such conditions, every clustering algorithm should be able to pick the best CH under various restrictions like less energy depletion, delay and so on (Dattatraya and Rao, 2019). Clustering (Zhu and Ma, 2018) is the tactic, which splits up the topographical area into small segments or sectors, it supports sensor nodes to allocate job among all the server nodes uniformly and single nodes be allotted as the head of the cluster, which is termed CH selection.

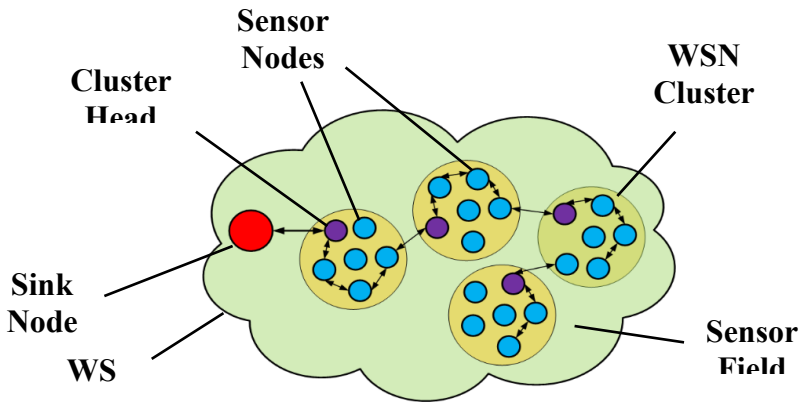

Figure 2: Clustering in WSNs (Munir and Gordon-Ross, 2011)

Singh, Pooja, & Varsha, (2017), communication in a cluster is regarded as intra-cluster communication, while communication between CHs and BS is regarded as inter-cluster communication. The function of the BS is to assemble the data from various CHs. Singh *et al.*, (2017), Clustering has the following advantages:

a) It decreases the size of the routing table by localising the path setup.
b) It preserves the communication bandwidth.
c) Cluster head boosts the battery life of the sensor device and the lifespan of the network as well as optimised managing strategies.
d) Clustering also cuts on topology maintenance overhead.
e) Cluster head does the aggregate process from several nodes and also remove the duplicate data.
f) A cluster head also decreases the rate of energy depletion.

Developments in WSN Research

Ardakani (2014), in his work titled "Wireless Sensor Network Routing Protocols for Data Aggregation" focused on reducing the number of transmission of data across the network, since a large amount of the energy used up in WSN is for data transmission, and in some cases redundant data. This redundancy was reduced both at the CH and CM ends so as to make the network routing protocol reliable. Some of the notable contributions of the research are:

a) Data combination routing aimed at maximising the amount of collected data models, while minimising energy depletion and data gathering delay.

b) Compare the energy consumed by different routing algorithms i.e Tree-Based Itinerary Design (TBID), The Near-Optimal Itinerary Design algorithm (NOID), LEACH and Directed Diffusion (DDiFF) over a geographical area and proved that using LEACH the research was able to minimise the energy consume by the Nodes.

Despite the positive contribution of the paper, it still has the following limitations:

a) This research was centred on replaceable battery which distorts communication.
b) Throughput was not considered in his research.

Najmeh (2015), proposed "Energy Efficiency in Wireless Sensor Networks". The research came up with a technique called know as Energy Driven Architecture (EDA) for minimising the energy depleted by the sensor node. The WSN architecture detects energy depleting components of the network. EDA when applied on WSNs helps in optimising energy consumption, guarantee energy balance and increase the network lifespan. The notable contributions of the research are:

a) Identification and classification of the components of energy depletion in a WSN.
b) Development of an algorithm based on EDA model which was energy efficient.

However, there was still some limitations in the work which are:

a) Static nature of network which does not create room of expansion.
b) It focuses only on components that deplete energy within the sensor node.

Solaimon (2015), in his work "Extending Lifetime and Optimising Energy of Wireless Sensor Network Using Hybrid Clustering Algorithm", used Particle Swam Optimisation (PSO) as a method for handling clustering issues associated with WSN which further prolong the network lifespan. It also developed a clustering aided toolbox used for simulating WSN. Some of the notable contributions of the research are:

a) The research discovers the advantages of hybridise clustering methods to provide well-organised and effective cluster techniques to cope with the dynamic nature of the Network.
b) The research demonstrated how LEACH can lessen the energy consumed with more rounds of data packet transmission (throughput).

Though the work came up with some positive, the following limitations:

a) The cluster approach used only works for static sensor nodes in WSN, hence it will work well for randomly deploy network and not uniformly deployed.
b) Its power source is a cell battery which must be replaced with time as the cell battery becomes low in energy.
c) Replacement of battery cannot be done while monitoring is on-going.

Kampen (2017), in her worked titled "Wireless Sensor Networks, Energy Efficiency and Path Recovery", investigated the relationship energy consumption and electromagnetic wave and it claimed and established that the major cause of energy depletion by a node is the energy needed to receive a data packet. The notable contributions of the research are:

a) Developed an algorithm to reduce energy consumption and path recovery.
b) Balance energy consumption across the nodes of the network.
c) Stated that Sensor nodes that are not transmitting messages should be made to enter a sleep state so as to conserve energy.

While the limitations are:

a) A node needs to be signalled to be awake in order to receive a packet.

b) Did not address the issue of throughput.
c) Could not address how sensor nodes can be recharged.

Jasvir, Sukhchandan & Sushma (2018), in their work titled "A Novel Energy Efficient Cluster Head Selection for Wireless Sensor Network", deployed nodes at random after which the nodes remains static throughout transmission. Some of the notable contributions of this research are:

a) Development of a Power Pollination Algorithm (PFA) for selection of Cluster Head.
b) Better performance of the algorithm developed when compared to different forms of enhanced LEACH protocols in relations to energy depletion, number of dead nodes devices and packet drop ratio.

While the limitations are:

a) It was centred only mobile charging of nodes during operation if the node is not pollinated (recharge), communication on the Network can be halted.
b) It can still recharge a Node in which residual energy is above the threshold, because there are no standard criteria for recharging a node within a cluster.

Thandapani, Arunachalam, & Sundarraj (2020), research titled "An energy-efficient clustering and multipath routing for mobile wireless sensor network using game theory", came up with a game-theoretical cluster procedure which was called Mobile Clustering Game Theory-1 (MGCT-1) which performs energy optimisation in a moveable sensing environment. Some of the notable contributions of the research are:

a) Modelled apportioning of reserved slots to moveable nodes as a cooperative game.
b) Delay and loss of data were reduced in the network.
c) Avoided network overload and network congestion.
d) Used energy prediction strategy to determine the most efficient route.
e) Algorithm works better when compared with others using the same performance evaluation metrics.

While the limitations are:

a) With high mobility rate and reserved slot allocation, there is high level of data collision and information loss.
b) Nodes have equal initial energy and cannot be replace or recharge during field operations.
c) CH choice was based on two (2) parameters: energy value and mobility speed.
d) The computational complexity of MCGT-1 algorithm was not considered and the algorithm does not work well on WSN with hybrid architecture.

Maheshwari, Sharma, & Verma (2020), also did research titled "Game theoretic application for energy efficient mobility handling in wireless sensor network", which investigated the problem associated with a new node joining a cluster, it also presents a model to addresses the problem of allocation reserved slots for potential members of a cluster. Evolutionary game theory (EGT) was used in allocation of slot for nodes joining the cluster; new cluster members (CH) and achieving Nash equilibrium. The notable contribution of the research is:

a) Used Game Theory to model slot allocation for mobile nodes.
b) Reduced delay and Network congestion.
c) Model was better than other in relations to Network lifespan, PDR and throughput.

While the limitations are:

a) Only node close to recharge point is recharge during transmission.

b) CH selection did not consider link quality and distance.
c) Time Division Multiple Access (TDMA) scheduling was the only techniques used for allocating reserve slot (RS); this technique is subject to multipath distortion. Also, there is a lot of interference when using TDMA.
d) With high mobility rate and reserved slot allocation, there is high rate of data collision and information loss.

There is need for further research that will use a better scheduling framework to reduce, information loss as a result of interference of the radio frequency (RF), reduce delay due to the multi hop nature of the network and reduce energy consumption across the network.
Zhanjun, Jiaojiao, Jianwu, Xiaochao & Nanjiang (2021), "Game algorithm based on link quality: Wireless sensor network routing game algorithm based on link quality", developed a game-founded routing algorithm centred on the quality of the link. The algorithm was able to create stability in energy consumption across the network and elongate the network lifespan. Some of the notable contributions are:

a) Algorithm provided a good route path based on link quality.
b) Extended the lifespan of the network by 16.8% when related to other algorithms used in the evaluation.

While the limitations are:

a) Algorithm did not do well in large scale networks with multi hop transmission.
b) Delay was not addressed.
c) Packet lost was not also addressed.

Segmentation/Clustering

Mohammed *et. al.,* (2022), in their work called Sector LEACH (S-LEACH); enhanced LEACH to address it limitations. The research decreased the transmission distance between nodes by splitting the area for communication into sectors centred on the BS. Considering the amount of energy required to transmit data is proportional to its distance, minimising the distance between nodes increases its lifespan.
Since a square contains four lines of symmetry, the theory of square symmetry was applied to construct sectors. In splitting the network, the theory of diagonal line symmetry was used by applying figure 5.

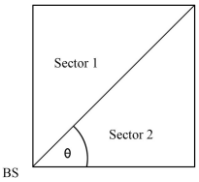

Figure 5: Sector formation

The equation for the group of nodes into sectors is given by equation 2.3.

$$\text{If } \left(\frac{y}{x} < \tan\theta\right) \quad \text{Sector 2} \quad \text{Else} \quad \text{Sector 1} \qquad (2.3)$$

The BS transmits sector information to all nodes, and then each node uses its geographical location to ascertain which sector it belongs to. After nodes have been arbitrarily placed across the communication location, the sector to which each one eventually belongs can be determined by comparing the node's location (X, Y coordinates) to that of the BS. The BS serves as the origin of the coordinate system, and the approach is applied to the remaining

sectors while accounting for the rotation of the X and Y axes about to the BS as seen from figure 6.

The research was able to balance the CH energy across the sectors and increase the lifespan of the network. With varying network size; fifty (50), one hundred (100) and one hundred and fifty (150) sensor nodes, it performed better than LEACH, Q-LEACH, I-LEACH, RCH-LEACH and ME-LEACH in terms of first dead round, last dead node round and number of packets transmitted to BS. The energy of the network was depilated completely after two thousand five hundred (2,500) rounds of transmission, for data with packet length of four thousand hundred (4000) bits. Despite this improvement it still had some limitations which are:

a) the routing algorithm is not intelligent.
b) there are still data packets drop with increase in the number of rounds of transmission.
c) Only the BS have constant power supply.
d) Irrespective of the network size, energy is completely depleted after two thousand five hundred (2,500) rounds of transmission.

Figure 6, shows how the sensor nodes are group into sectors in order to minimise the energy usage.

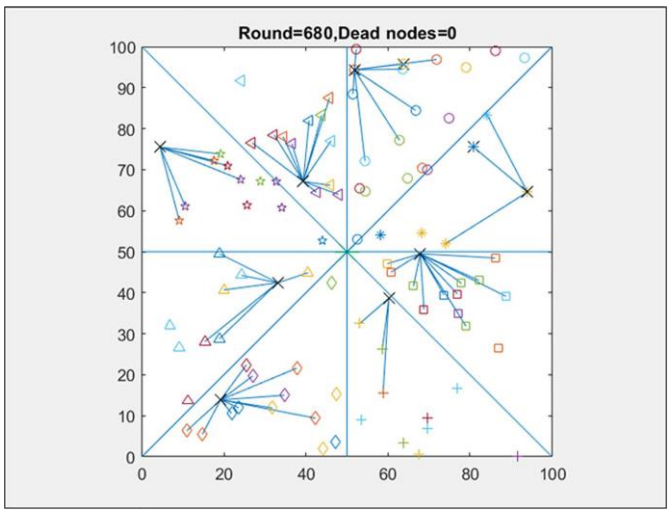

Figure 6: WSN in Sectors

Conclusion

With the ever-increasing need and deployment of WSN in different field of human endeavour to collect real time data that affect the decision taken by human beings. There will always be room to further research in WSN, especially as it relates to energy usage. Hence, the need for developing more robust energy aware routing algorithm. To this end, there is the need for a better CH selection algorithm in WSN, since a lot of energy is used by CH nodes for the perform more task that the CM. This will further elongate the network lifespan.

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