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APPLICATION OF WIRELESS SENSOR NETWORKS FOR MONITORING ELECTRICITY TRANSMISSION LINES : A SURVEY

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ABSTRACT

Wireless sensor nodes are low-powered and highly essential entities of wireless sensor networks (WSNs) used for monitoring areas of interest. WSN finds application in tracking, monitoring of industrial processes, detection of unwanted events, and so on. Due to the low-cost, low-storage, and low-processing power requirements of sensors, the nodes are mostly embedded with batteries of limited energy. When the nodes are exhausted, their batteries need to be recharged or replaced. There are three popular paradigms of WSN: those whose nodes' batteries cannot be replenished, those whose nodes' batteries can be replenished wirelessly by a recharger, and those whose nodes' scavenge energy from the ambient environment. Faults on medium-voltage lines can be precisely located using WSN thereby reducing effort and time wasted in manually tracing of faults. This paper provides a comprehensive state-of-the-art survey of WSN paradigms and suggests the most suitable paradigm for deployment in monitoring electricity transmission lines.

1. INTRODUCTION

Wireless sensor networks (WSN) serve as a means of integrating the physical world with the cyber-world, as such, they are deployable in a lot of applications. Sensor nodes are embedded with batteries of limited capacities. When their batteries are exhausted, the network is grounded until they are replaced or recharged. Replacing non-rechargeable batteries is not always easy because some nodes are deployed in unfriendly environments. As a result, most algorithms for WSN target increasing overall network lifetime by adopting an economical-use of their energies [1]–[4].

Techniques for fault detection on transmission lines, especially in Nigeria, involves tedious processes with a high possibility of time wastage. In most cases, especially in Nigeria, technical workers are dispatch to move along transmission lines to locate faults, thus increasing the time for restoring supply to end-users. Besides, during the long period of detecting the location of faults, generated electricity is wastage since electricity cannot be easily stored. With the advancement in technology, faults can be located easily by deploying wireless sensors along the transmission lines.

There are many network paradigms of WSN. The first is a WSN whose nodes are embedded with non-rechargeable batteries. A second category contains nodes embedded with batteries that can be recharged wirelessly by a mobile recharger. The last categories involve nodes that harvest energy for their operation from the ambient environment. There exist lots of algorithms and huge advancements have been made in the three network paradigms.

Thus, in this paper, we conducted a review of WSN paradigms and recommends the best paradigm, based on research advancements of the paradigm, for possible deployment on electricity transmission lines for easy locating of faults.

2. LITERATURE SURVEY

This section provides a literature review of the three famous network paradigms.

2.1 Wireless sensor network schemes using nodes embedded with non-rechargeable batteries

The nodes in this paradigm are embedded with non-rechargeable batteries. Thus, nodes have to use minimal energy during their operation so that the overall network lifetime can be maximised. Network lifetime is normally improved via minimizing nodes' energy usage through either of the following methods: minimum energy routing or clustering. In minimum energy routing, each sensor node sends its sensed data to another sensor node nearest to it. The data are then aggregated (with the present node's data) and forwarded to another node in the direction of the sink. Aggregation and forwarding continue until the data reach the sink. This method is adopted to prevent low power sensor nodes from long-distance communication to the base station (BS) that will drain their batteries quickly, which may result in a low network lifetime [5]. Most schemes on minimum energy routing focus on improving the quality of aggregated data [6], [7]–[9], and [10]–[13]. An alternative for providing ubiquitous connectivity in wireless sensor networks is using clustering. In clustering, the entire network is divided into clusters. Each cluster consists of sensing nodes and a cluster head (CH). The cluster head is responsible for receiving data from the sensor nodes via either one-hop or multi-hop communication, aggregate and transmit the data to the BS via another one-hop communication [14]–[17]. In some scenarios involving hierarchical clustering, a CH in a cluster aggregates and forward to another CH. The latter CH may forwards to a BS or another CH until the data finally reaches the sink. Thus, the energy of the CH is critical to the network lifetime because it decreases faster than those of other nodes. An example of a clustered network is as in Figure 1. Thus, existing schemes on clustering focus on algorithms for the selection of CH among other nodes to improve network lifetime.

LEACH algorithm, one of the famous algorithms that proposed deployment of nodes in clusters and formulated a cluster head selection algorithm has been proposed by [18]. In the clustering approach, nodes in the same cluster select another node, within themselves, that acts as a cluster head for a certain period. The nodes send data to the cluster head (either via one-hop or multi-hop communication) and the cluster head sends the collected data to a sink (a base station) for further processing. However, in the LEACH approach, cluster heads are selected randomly without considering residual energies, the distance of nodes away from the cluster heads, and other network parameters. As such, more algorithms that enhanced cluster selection in LEACH were further proposed. Some of the algorithms that enhanced LEACH, with the factors considered in the selection of CH, and the network entity that does the CH selection are shown in Table 1. The drawbacks and suitability of each scheme to homogeneous or heterogeneous nodes (nodes with different energy capacity) are also contained in the table.

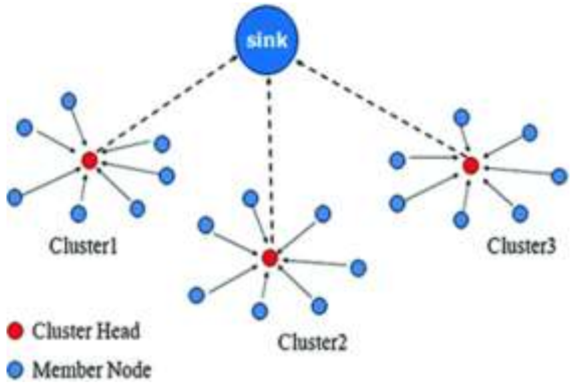

Fig. 1:WSN with nodes in clusters and a base station [24]

2.2 Wireless sensor network schemes using nodes embedded with rechargeable batteries and replenished wirelessly by a recharger

The schemes in section 2.1 use a passive approach in conserving energy usage of nodes. The solutions proposed only considered how the network lifetime can be maximised by minimizing nodes' energy consumption. When the nodes are exhausted, the schemes can no longer extend the network lifetime. Moreover, replacing exhausted batteries is not always ease. Even when batteries can be replaced, network operation is interrupted during the period they are being replaced. As a result, a wireless rechargeable sensor network (WRSN) has been proposed.

Table 1:WSN schemes using nodes embedded with non-rechargeable batteries

Research Work	Techniques	Limitations
[19]	Similar to LEACH: nodes report their attributes to BS that does the selection of CH.	Centralized and too much overhead for the BS.
[20]	Based on the LEACH approach. Only that the BS selects a node as CH if it has enough energy to support a certain number of rounds.	Centralized and not suitable for a heterogeneous network
[21]	LEACH approach in addition to considering residual energies, distances of nodes, and the number of neighboring nodes in a cluster when choosing a CH.	Uses a judgment parameter whose value is subjective when selecting a CH.
[22]	Considered a heterogeneous network. BS elect CH based both node quality index	Centralized since only BS can elect CH.
[23]	selection of CH is based on local density and distance using the data point approach.	A selected CH will not be changed until it is exhausted. This creates a dead zone in the network earlier than in LEACH.

In WRSN, nodes can be replenished via wireless energy transfer using an off-the-shelve wireless transmitter, TX91501 (Greene, 2017), inductive coupling, or magnetic resonance coupling [26], [27]. Since the batteries can be recharged in this paradigm, the Low Energy Adaptive Clustering Hierarchy (LEACH) and its variant solutions are inappropriate for WRSN. An example of WRSN is in Fig. 2. Some advantages of the WRSN paradigm include: (1) reduction in system cost as batteries contribute greatly to overall system cost especially for large networks, so replacing them in WSN will incur huge cost; (2) Allows deployment of sensors to inaccessible areas as periodic replacement of batteries is unwarranted; (3) enables perpetual lifetime for sensing and communication as an interruption when replacing depleted batteries of energy-limited nodes no longer exist.

Despite the advantages mentioned, WRSN presents researchers with new challenges, one of which is how to provides ubiquitous connectivity because nodes need to devote some time to sensing and some other times to recharge their batteries. Secondly, should nodes be allowed to perform sensing and energy-recharging activities simultaneously, they will require more processing power. They may need two circuitries: one for replenishing their energies and the other for performing sensing functions. Having two circuitries will upset the desirability to maintained nodes at low-cost, low-processing power requirements, and so on. In this section, schemes that assumed concurrent recharging and sensing functions, and those that assumed the tasks cannot be performed simultaneously will be examined. In both cases, nodes can be replenished periodically or based on demand.

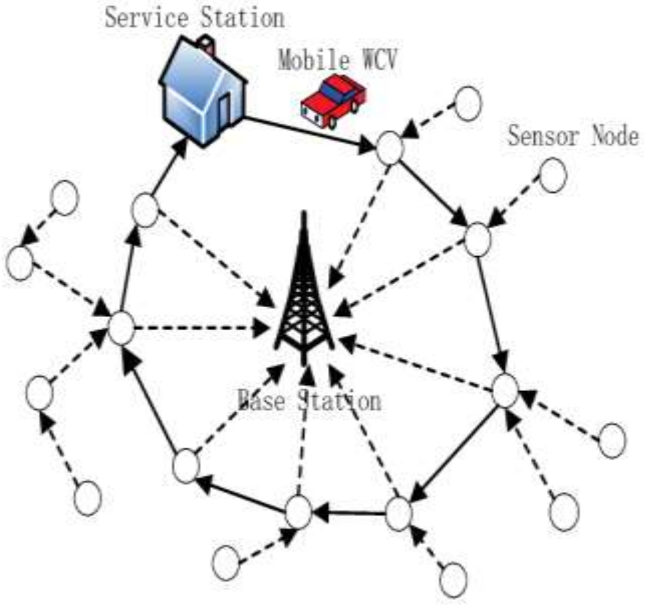

Figure 2:WRSN with a mobile charger that recharger that replenishes the energy of exhausted nodes [26]

2.2.1. Periodic charging schemes

In periodic charging schemes, a recharger is assigned a task of periodically moving around a network to replenish the nodes within the network. Periodic charging schemes mostly find a Hamilton path, to be a path of a recharger (robot car) within the network, by transforming a Travelling Salesman Problem (TSP) [28]. In this scheme, the robot car can replenish one node at a time (usually using TX91501 [29] transmitter attached to the robot car) or multiple nodes at a time (usually using a magnetic resonance coil attached to the robot car). The latter scheme has higher energy efficiency than the former. Some schemes such as [30] and [31] have employed the concept of small enclosing disk (SEC) for planning a traversing path for a robot car. These schemes assigned the overlapping regions of concentric circles as the locations the robot car stops to recharge sensor nodes. However, these schemes are not suitable for large networks due to their huge network overheads. To overcome this drawback, [32] took the advantage of nodes redundancy and proposed a low-network-overhead scheme for periodic recharging, but by allowing some nodes to be temporarily exhausted. The main drawback of this scheme is that it requires explicit knowledge of network information such as nodes locations, nodes' transmission time slots location within each time frame, and so on. These parameters may not easily be obtained for the realistic deployment of sensor networks [30].

2.2.2. On-demand recharging scheme

In this recharging scheme, also called non-deterministic or non-periodic, sensor nodes send their requests (for energy recharging) to a pool. A sink within or outside the sensing field commands one or more robot cars, attached with a wireless recharger, to supplements the energies of the nodes. Most on-demand schemes only concentrate on providing energy to nodes without or with little attention given to how data flow in the network. That is, they consider energy replenishment independent of data flow in a network. A first-come-first-serve scheme (FCFS) approach, where nodes are attended to, based on the time of arrival of their requests at the pool, has been considered in [33]. This scheme has high charging latency because it only considered the temporal (time of arrival or requests), but not spatial properties (geographical location of nodes) of requests. It may also lead to a high number of exhausted nodes in the network. The high charging latency is due to the large geographical distance between nodes whose requests are next to each other. To overcome this problem, [34] proposed a nearest job with pre-emption (NJNP), a scheme that considered both temporal and spatial network properties of requests. In this scheme, a robot car is allowed to defer attending to a node that is farther away from its real-time position (even if it is the node to be attended to, based on FCFS) and attends to other nodes closer to the location of the robot car (whose requests have been received). Despite the improvement in the charging latency, NJNP can cause starvation of nodes farther away from others. Moreover, as the number of nodes increases, the process of planning how such nodes should be replenished becomes NP-hard. Due to these reasons, [35] presented a heuristic, novel gravitational search algorithm (GSA) to efficiently plan and design how sensor nodes should be attended to, considering both spatial and temporal properties of requests. However, the GSA scheme suffers from high preemption that may lower charging efficiency. Thus, [36] proposed a two-algorithms scheme using double warnings. This further improved charging efficiency by efficient prioritization of charging requests to be attended to by a robot car. The authors in [26] considered multi-node energy replenishment using magnetic resonance. Nodes were divided into clusters using k-means clustering. A recharging path planning was developed so as to maximizes the ratio of time a robot car stops at the service centre to the total journey time of the robot car. Simulation results show an improvement in charging efficiency.

By considering hardware limitation of sensor nodes, Optimal operation state scheduling in RF-Powered internet of Things has been proposed by [29]. Since simultaneous target monitoring and energy harvesting is not possible due to the low-manufacturing cost requirement of IoT devices, optimally scheduling IoT devices either working or wireless recharging was proposed. It was observed that in a small network, where data from a sensor node can reach a sink via one-hop communication, the network topology does not change with operational state scheduling. However, for a large network where data from a sensor node reaches a sink station via multi-hop communication, the network topology is dynamic due to the coupling between operation state scheduling with the network topology (routing path). As a result, a state scheduling algorithm (SSA) that maximizes network throughput was designed to decouple the primary problem by defining a dynamic energy threshold vector that schedules a node to a desirable state according to its energy level. Moreover, [37] proposed a scheme that recharges nodes when they are not in the state of sensing and transmission.

2.2.3. Mobile data gathering

To further improve the network lifetime of the sensor network, mobile data gathering schemes have been proposed. In these schemes, a sink/BS is attached to a robot car. The robot car moves around the network so that the sink can collect data from nodes over small distances, thereby reducing energy usage of CHs. The authors in [38] considered data gathering using the mobile sink. The mobile sink moved in a straight line within the sensing field. The authors aimed to jointly optimized power allocation, relay selection, and time slot scheduling, though they assumed data collection can occur simultaneously with energy replenishment by using different time slots, different frequencies (2 circuitries within each sensor). Using two circuitries within each sensor will increase the energy consumption and processing power requirement of the sensor nodes. The main challenge of mobile BS is a huge data delay, thus making WSN unsuitable for emergency data collection. Emergency data need to have a low delay. Hence [39] proposed an emergency data gathering scheme in WSN with a mobile sink using clustering. The network is divided into grids and a spanning tree is designed using a breath-first search algorithm. Normal data is collected by a mobile sink that moves around the grid and collects data from the cluster heads in each grid. To balance network load (prevent quick exhaustion of CHs), the robot car has two paths within each grid for data collection: one for an odd number of rounds and the other for an even number of rounds. Emergency data (tagged with some data anomaly) are recognized by each node and forward through multi-hop until it reaches the nodes close to the BS (BS outside sensing field). Other mobile gathering schemes include [40]–[42]. Mobile gathering schemes using unmanned aerial vehicles (UAV) include [43]–[45]. All these schemes assumed nodes have the capability of simultaneous recharging and data gathering.

2.3. Battery_free wireless rechargeable sensor network (BF-WRSN)

In addition to WRSN, BF_WRSN has also been proposed. In BF-WRSN, nodes are not embedded with batteries. The nodes obtain energy for their operations by harvesting it from ambient power sources such as wind energy, solar energy, and RF-signals [46]–[48]. The nodes use a super-capacitor, that can be recharge for an unlimited time, to store harvested energy [49]–[51]. Unlike in traditional WSN where nodes can continuously monitor their targets, in BF-WRSN, nodes can only do that if they had harvested enough energy for the task. Moreover, the sources of energy in BF-WRSN are unstable due to the impact of the ambient environment. Unlike in WRSN where the recharging rate is higher than the consumption rate, in BF-WRSN the reverse is the case. Thus, BF-WRSN has a theoretically unlimited network lifetime. The main challenge is BF-WRSN is coverage: who nodes can provide good coverage despite the uncertainty in availability of the source of energy and lower recharging rate [52], [53].

3. AN APPROPRIATE WSN SCHEME FAULT LOCALIZATION IN ELECTRICITY TRANSMISSION LINES

Based on advances made in the three WSN paradigms, WRSN is more appropriated to be adopted in localization of faults in transmission lines. To do so, sensor nodes can be deployed at strategic points along the transmission lines. The sensors monitor the lines, A flying robot can be assigned the task of flying and traveling to the nodes to collect sensed data and recharges the sensor nodes.

4. CONCLUSION

In this paper, we reviewed recent literature on three popular wireless sensor networks paradigms namely: wireless sensor networks (WSN), wireless rechargeable sensor networks (WRSN), and battery-free wireless sensor networks (BF-WRSN). Based on the advances made in the paradigms, we suggested the deployment of wireless rechargeable sensor networks for application in fault localization on electricity transmission lines. With its deployment, a manual and tedious technique of dispatching technical workers to locate faults will be unwarranted.

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