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Wireless Sensor Networks: An Overview from an Optimization Perspective

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Abstract: ***Wireless Sensor Networks (WSNs) have established themselves as the modern and future standard when it comes to networking applications. Wireless Sensor Networks (WSNs) are self-configured, infrastructure-less and consist of numerous nodes, which form the network structure. They have seen a variety of use in modern measurement and environmental analysis applications over the recent years and such applications of wireless sensor networks are being continuously studied and developed for even better overall performance. The nature and setup of wireless sensor networks allows for some important applications such as monitoring physical and environmental conditions like temperature, sound, vibrations, pressure and motion. As per the wireless sensor network structure, these measurements are then transferred to sinks and base stations from the nodes, for further study and analysis, basically the usage of data. This wireless sensor network standard does come with a few of its own problems, which range from coverage, topology, routing to energy efficiency. This paper discusses wireless sensor networks, and major problems related to the functioning of these networks and some related solutions. This paper also further proposes a theoretical solution to the energy efficiency problem of wireless sensor networks, and further studies how solving this problem can improve on some of the major existing applications of wireless sensor networks.***

Keywords: WSN, Energy Efficiency, Mobile Sink, WSN Clusters, Wireless Sensor Networks, WSN Optimization.

1. Introduction

Over the recent years, sensor networks have gained an increased level of interest in the mobile communications industries, owing largely to the dynamic organization and deployment of such networks, and the huge amount of applications and opportunities these networks are capable of.

Wireless sensor networks (WSNs) are networks consisting of hundreds of small devices called sensor nodes, which study and provide monitoring information. These networks are typically robust, self-organizing and do not have a defined rigid infrastructure. The nodes present in wireless sensor networks are basically low-cost, low-power and miniature devices capable of sensing the environment around them, due to the various sensors present in these nodes. Based on the sensor and collection of these nodes in a network, the overall function and application of the wireless sensor network can be determined. A typical wireless sensor network consists of nodes and one or more base stations, and in some cases, sink nodes. A base station is the gateway which receives the information from the sensor nodes and analyzes it to form meaningful results [1].

Because these sensors are really small and portable, they can be distributed or attached over a large area, thereby making many applications possible. The applications mostly perform environment monitoring functions. These could be used to measure temperature change over a geographical area, or to measure the pressure and intensity of earthquakes, and these even have military applications. Apart from environment monitoring, these WSNs have applications in healthcare, tracking and positioning, localization and so on.

On the one hand, where these WSNs enable new applications and new possibilities, there is always the downside of their design being affected by several factors. These factors include routing, energy efficiency in WSNs, topologies and network coverage to name a few. In fact, some of these factors are so critical, that if proper measures are not taken to effectively optimize a wireless sensor network, the entire network could fail.

This paper presents a discussion and review of the aforementioned aspects of WSNs. We start with exploring what WSNs are and also learning the architecture behind WSNs. The paper then presents a description of different problems associated with wireless sensor networks and how some other researches have looked into solutions for these problems. The paper also explores an additional proposed solution in theory, which could help optimize wireless sensor networks, by providing a higher level of energy efficiency for the network.

The remainder of the paper is organized as follows. Section 2 explores other works in this area. Section 3 presents a detailed overview and architecture of wireless sensor networks and their applications, followed by section 4, which provides an overview of the problems associated with wireless sensor networks. Section 5 analyzes some proposed solutions to these problems followed by section 6, which proposes another solution in theory to the energy efficiency problem of WSNs. Section 7 concludes the paper, presenting some ideas on future work.

2. Related Works

There have been several studies into wireless sensor networks and their potential and proven applications, as well as researches into optimization studies of wireless sensor networks, the associated problems and relevant solutions.

Werner-Allen et. al in their article present a study of how WSNs have been used to measure the intensity of an active volcano. This has been done by deploying heavy and high sensitivity wireless sensor nodes around an active volcanic region, which would measure seizures on land, and transmit the environmental data to a computer, which can then be analyzed to find out the time period and intensity of volcanic eruptions [4].

Shoaib and Song in their research describe how localization based wireless sensor networks can be deployed in an ad-hoc manner to facilitate communication between vehicles on a road which could share traffic and terrain information with each other. This category of information here is termed as hovering information, which is utilized in this research via a decision-making module using fuzzy logic [5].

Wisitpongphan in his paper has presented a study on how wireless sensor networks can be used with maximum efficiency in indoor environments using the ZigBee protocol [6]. This work is more of a wireless sensor network planning solution, which focuses more on the location of mobile nodes as well as routers to bring about maximum activity and efficiency of an indoor wireless sensor network.

Shaet. al present a study on a real life application of a wireless sensor network, in the field of Fire Rescue Applications. They outline a few specific requirements such as accountability of fire-fighters, real time monitoring, scheduling etc and propose a FireNet WSN based architecture to meet these requirements. Apart from discussing the potential of such an application and its benefits, they also discuss challenges in such an implementation, with regards to hardware and software [7].

Ko et. al explore the applications and implications of using wireless sensor networks to collect health care related information from people, and the challenges these applications introduce in the realms of privacy and security of medical data. They outline some prototype systems which demonstrate the potential of WSNs to enable early detection of sicknesses through real-time patient monitoring in hospitals. These prototypes, as described in this article, also enhance the medical practitioner's capability to provide emergency care in disaster situations [8].

Guerroumiet. al conduct their study on energy efficiency in wireless sensor networks. They propose a mobile sink structure as opposed to traditional wireless sensor networks, in which, a mobile data sink periodically moves to areas of higher frequency emissions in WSNs to collect data. This saves a lot of energy and eliminates the necessity of nodes in a WSN to be transmitting data at all times, which is a big negative hit to WSNs as far as optimization is concerned [9].

Mantoroet. al discuss energy efficiency mechanism for wireless sensor networks that involve deploying dual mobile base stations which move in a spiral pattern covering the entire WSN area, and which collect timely data from nodes based on shortest distance between base stations at a point and nodes, calculated by following an Euclidean Mathematical model [10].

Gupta and Sangwan in their paper, carry out a study based on maximum number of hops needed between nodes and Base Stations for successful data transmission from node to a base station. They calculate the minimum cost of transmission of data based on maximum number of hops needed between nodes and base stations. These contribute towards selecting the best transmission path, and developing the right algorithms for the same, which result in solutions which require very little computational time in any number of randomly generated WSN scenarios [11].

Goguet. al, discuss some fundamental optimization problems related to all WSNs, in the areas of coverage, routing and energy efficiency. They focus on the complexity of these issues and how these affect optimization in WSNs as a whole. The paper also presents a comparison between WSNs and traditional networks in lieu of these issues [14].

3. WSNs: Overview and Architecture

A wireless sensor network consists of two main device types - The sensor nodes and the Base Stations. Sensor nodes are low-cost, low-power, multi-functional and miniature devices, which can be spread across any geographical area in an ad hoc fashion. These can also be spread across a planned area infrastructure, where the positions of these nodes are more rigid and static. These nodes collaborate among themselves to establish a sensor network. These nodes can sense the environment and communicate the information gathered from any monitored field through wireless links. The data is then transferred or forwarded via multiple hops to a sink or a base station. The nodes can be stationary or moving, based on functionality required. The base station, or the sink, is the end point of a WSN where all the information which is transmitted by the different nodes, is analyzed further. The size of a typical wireless sensor network could range from a few nodes to thousands of nodes, depending on the reach, complexity of data and application of the network. A sensor network can provide information anytime by collecting, processing and analyzing the data. Thus, a WSN is an active participant in creating a smart networked environment [2].

The basic components of each sensor node include the sensing hardware, processor, memory, power supply and radio transceivers. The sensor nodes communicate among themselves using radio signals. The power supply in each sensor node determines basically the life of the node. Sensing hardware in nodes could consist of a single sensor or a collection of one or more sensors, depending again, on the environment being sensed and the application of the network. A typical usage of sensor nodes includes using the available sensor hardware to collect relevant data (based on the sensors), process this information and save it in memory; and when the time comes, to transmit this information via radio signals to neighboring nodes or base stations or mobile sinks.

The rate and manner in which information is retrieved in a WSN and transferred can entirely depend on the type of the network and the range of operations of the nodes. The working mode of sensor nodes can be broadly categorized as continuous or event driven [2]. In a continuous work mode, the sensor nodes are collecting and transmitting information at all times, mostly via an all-time active multi-hop infrastructure. Event driven work modes are prevalent in query based WSNs, where the base station or sinks, can also directly send queries to nodes to gather information. These nodes are more event driven in that they are only actively collecting and transmitting data based on requests. When there is no request present from the base stations, then these nodes are in a hibernation state, unlike those in continuous work mode networks, which are always in an active state. In event driven networks, the nodes can also be equipped with actuators to act upon certain conditions. Global Positioning Systems (GPS) and local positioning algorithms can be used to obtain location and positioning information of nodes.

When it comes to sink implementation in a WSN, there are two types. One is the traditional single-sink WSN, which consists of only one sink or base station, which receives information from all the other nodes in the network via multi-hopping. This type of scenario is less scalable, especially when dealing with a higher number of nodes on the same network, where the single sink would have to process a large amount of information, thereby resulting in performance bottlenecks.

A more general and widely preferred scenario is the deployment of multiple sinks in a WSN. Based on the density of nodes in a network, multiple sinks can be implemented which collect information from a group of nodes, thereby making the overall network much more scalable. The presence of multiple sinks also ensures better overall performance of the WSN.

A diagram comparing the two different types of sink based WSNs is shown below in Figure 1.

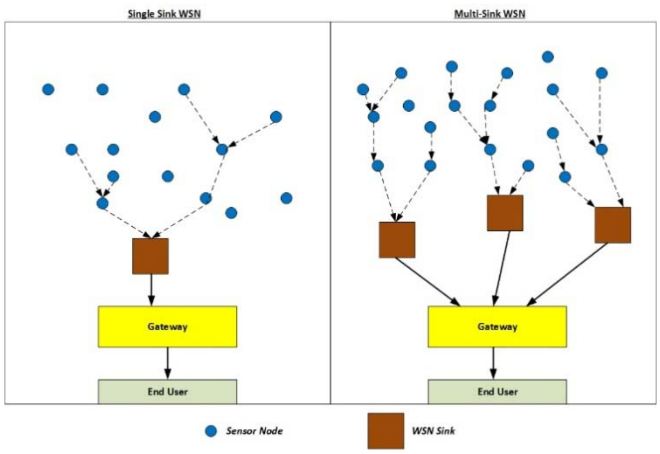

Figure 1: Single Sink and Multi Sink WSNs

Wireless sensor networks have a plethora of modern world applications due to their nature and cost of deployment as well as their rapid ability to collect large amounts of information from anywhere at any time. There have been many examples of sensor technology being adopted in areas where it's hard to find solutions using conventional means. These have mostly to do with environmental hazards, monitoring of remote terrain, customer behavior surveillance and future applications in what is termed as the 'Internet of Things'. WSNs have been used largely in researching the intensity of natural disasters [4], inter-vehicle communication applications for road terrain and disaster monitoring [5] or even creating indoor localization systems [6]. Sensors can be used in parking lots to determine the number of empty spaces v/s occupied spaces. Military sensor networks have applications in detecting war zones, enemy tracking and movement as well as early detection of potential terrorist attacks or threats. Lastly, WSNs have opened a vast area of applications in the field of medicine and health care, where it has become possible now to measure various characteristics of people ranging from physical, anatomical and even chronic, to recognize early symptoms of sicknesses and to provide rapid treatment [8].

4. Problems in WSNs

This section highlights some of the major challenges faced by all typical WSNs. We shall include a general description of the challenges faced, and at the end of this section, will identify one major problem area of WSNs. This problem area will be further analyzed in terms of some proposed solutions in the rest of the paper.

With all its advantages, a WSN does come with its own set of challenges when deployed in any environment. We have learned those sensors nodes basically communicate wirelessly, which are basically lossy lines with not much of an infrastructure, since the network itself in many cases is very ad hoc. Additional challenges are related to limited and usually non-renewable batteries, which determine the lifetime of a network [2]. Following section presents the discussion of these individual design issues in greater detail.

Fault Tolerance: The node failure rate in wireless sensor networks is much higher as compared to wired or infrastructure based wireless networks. The sensor nodes, being smaller, lighter and hence weaker are much more susceptible to physical damage. These nodes are usually deployed in an environment with often harsh conditions, and as such, there are higher chances of damage. This could mean that in a WSN, some random nodes might suddenly die off or get destroyed. This comes back to the protocols within a WSN, which should be robust enough to handle such failures, in a way that it does not compromise overall functionality of the network. One can also relate this to routing protocol design, which should at the end of the day, make sure that alternate routes are available for data transmission, provided one of the routes fails.

Scalability of WSNs: A WSN can vary in scale between having just a few nodes and having potentially several hundred thousand nodes. A large number of nodes is usually the case when high intensity or high resolution data needs to be collected continuously, which is generally the case in WSNs. This might result in networks where a single node has thousands of neighbors in transmission range. In such a case, the routing protocol has to make sure such a network is highly scalable and that data transmission adequately reaches the sinks in timely and efficient manner, so as to ensure an overall high performance of the network.

Production Costs: Sensor nodes are usually considered disposable devices. As such, if sensor networks need to compete with traditional networks in terms of information gathering, they need to be designed cheaply and the overall costs of deploying such networks has to be cheap. In most cases, it is.

Hardware Limitations: Sensor nodes at minimum contain a sensor unit, transmission unit, processor and a power supply, or battery. This is a general structure a sensor node is meant to support. However, in many cases, additional components are required and added to sensor networks depending on the application they are meant to perform and the nature of data being recorded. For instance, they might have additional built in sensors or localization devices. For every additional component, the price and energy consumption of the node would increase, and this needs to be paid special attention to, to ensure the sensor network at the end of the day is feasible financially and functionality wise.

Transmission Media: Sensor networks mainly use radio transmission to transmit data. However, in some networks, optical and infrared communication is used, which makes the network virtually interference free. This is still a challenge as such a practice is not wide spread. However, it is a very hopeful area of study, as it could greatly enhance the lifetime and routing paradigms of sensor networks.

Power Consumption: This is by far considered the most critical of challenges when it comes to WSNs. Most of the other challenges of WSNs revolve around the limitation of power resources. Everything from the size and functionality of the nodes, to the topology and routing protocols used, would affect the battery or power consumption of nodes in a WSN. Another reason this is a very critical limitation is because for something as small as nodes, battery power is already limited and cannot be increased beyond a certain value. So we are looking at power sources which do not change or increase much in capacity, also owing to the size and structure of the WSN architecture. This has opened up an entire area of study on WSNs, dedicated solely to managing energy efficiency and throughput in WSNs. It is said that those WSNs which are able to maintain a good level of energy efficiency throughout, are the most effective and sought after networks. Energy policies of WSNs also depend on the application, where in some applications it might be acceptable to turn off nodes to conserve energy, whereas other applications might require the nodes to operate continuously. For better energy conservation, the WSNs need a rigid and efficient energy policy which is in line with the WSNs objectives.

Routing: This is a classical graph flow problem and is related to energy efficiency. This is a limitation of all WSNs, where transmission has to take place through paths in the network which cost the least. The costs here can be in terms of time and hence in terms of energy. The routing problem is related to the energy problem, because if a proper and least cost route is introduced into a network, not only it helps in transmitting data faster, but that in turn also helps in saving more energy in the network. From a high level view. The routing problem is more like a Traveling Salesman Problem, where the aim is to find the shortest route to your next destination, which is basically the aim and solution of the routing problem in WSNs [14].

For the remaining sections, we will be concentrating and looking deeper into energy efficiency in WSNs as this is the most critical problem when it comes to this networks.A network which encompasses energy efficiency will already have most of the other challenges fall in place.

5. Analysis of Energy Efficiency Mechanisms

This section of the paper analyzes the different energy efficient mechanisms that have been researched and studied, and which we feel are some of the most prominent solutions to the energy efficiency issue for WSNs.

5.1 Mobile Sink + Cluster Head Deployment

This solution to the energy problem was suggested by Guerroumiet. al. This is a solution which is more applicable to event driven WSNs. The key assumptions which are made for this solution to work are that each node in the network has built in GPS and is aware of its location, these sensor nodes are stationary with constrained battery energy, and mobile sinks are the only devices which move along the network [9].

This implementation introduces a Mobile Sink Data Dissemination Protocol (MSDDP) which consists of two sub implementations. In the first implementation, a virtual grid is constructed around the network of sensors, and under each cluster or group, a header node is selected. This node is called the cluster head. The main function of this header node is to receive the data from other nodes in the group. The first energy saving practice we see here is that in splitting the network into clusters, it is made sure that all the other nodes do not have to transfer data via multi-hop structure. They essentially just transfer data directly via a single hop, to the cluster head node. Now, because the cluster head is very near to the group nodes, even further energy is saved, as the distance of transmission in all aspects of this implementation is reduced.

To further increase the network lifetime, mobile sinks are deployed in the network. These mobile sinks essentially move to the cluster heads of each group, and collect relevant data from the cluster heads, which is essentially the data from all nodes in that group. To further highlight the event driven nature of this model, the mobile sinks follow certain rules. The sink mobility occurs periodically, at set intervals. During each time period, the sink recognizes the group or cluster with the highest frequency of data dissemination, and based on the location of the group (which is made possible by the GPS sensor), the mobile sink moves towards the relevant cluster head and collects the data.

A visual representation of the above mechanism is given below in Figure 2.

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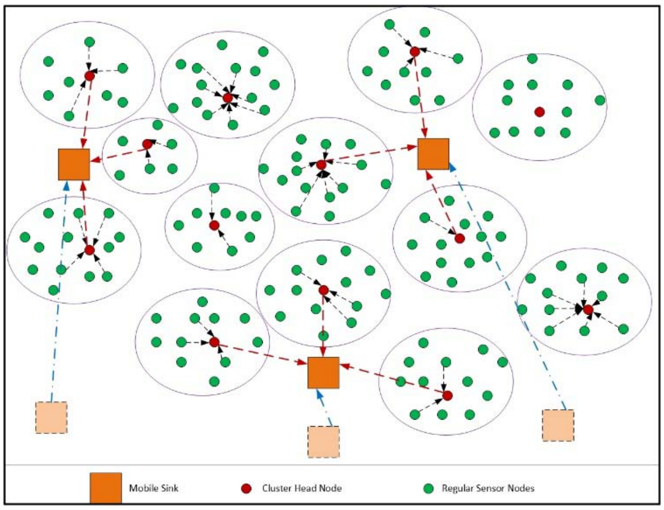

Figure 2: Mobile Sink based WSN with cluster head nodes

5.2 Radial Propagation WSN Structure

This energy efficient structure for WSNs has been proposed by Mantoroet. al in their paper. It differs from the previous implementation in that it does not utilize cluster heads, and as opposed to previous mechanism, where the movement of the sinks was random, this model has a defined movement structure which the mobile sink is supposed to follow for maximum energy efficiency.

In this implementation, the assumptions made are that the WSN consists of hundreds of nodes scattered randomly, without any structure. There are no groups or grids in this WSN, just randomly distributed nodes. This mechanism has a mathematical model of calculating the shortest distance between two particles in space, which is the Euclidean Distance. The nodes are assumed to have limited energy supplies, and are also assumed to be event driven in nature [10].

As for the mobile sinks, there is a dual mobile sink structure here. The 2 mobile sinks move around the entire network in alternate directions, following a radial or circular motion covering the entire WSN. The sensors, being event driven are mostly in sleep mode. However, this mechanism always keeps a calculation of the Euclidean distance between the radially propagated mobile sink and the various sensor nodes. If a sensor node, at any point in the sinks mobility, is at shortest Euclidean distance away from the mobile sink, then the sensor node wakes up for a short while, transfers data through the short distance, and goes back to being idle again. The nature of the sensor nodes in this network, where they only wake up when data transmission has to take place, and that too, over shortest possible distance, makes the overall network highly energy efficient. The combination of 2 mobile sinks moving around the entire network makes sure that every node experiences shortest distance between it and the sink at least once in each cycle. At the same time, this implementation also gets rid of multi-hop transmission via the limited energy nodes, as each node transmits data directly to the mobile base station, which also further aids in making the overall network very energy efficient. This WSN structure has been simulated on a network of 100 nodes to as high as 450 nodes, and in each simulation, it proved to be better and more energy efficient than traditional multi-hop networks.

A visual representation of the Radial Propagation WSN as taken from the paper, is given below in Figure 3.

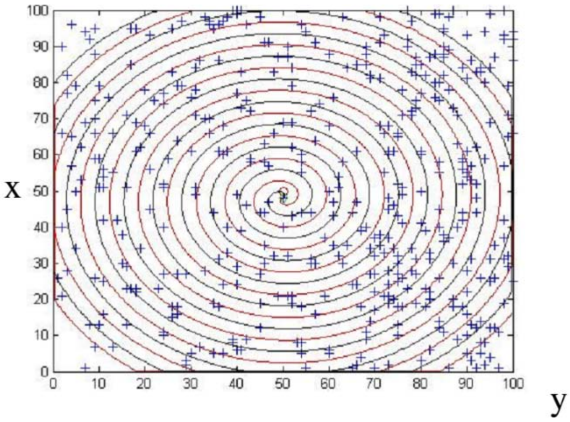

Figure 3: Radial Propagation sink based WSN

5.3 TRAMA

TRAMA stands for TRaffic-Adaptive Medium Access protocol, which was introduced by Rajendranet. al, which is an energy efficient routing protocol for WSNs. It saves energy by making sure that transmissions do not collide to each other in the WSN [12].

The basic theory of this protocol is that it firstly divides the WSN into sections of nodes called Transmitters and Receivers. The TRAMA protocol creates different time slots in the network, which it calls channels, to ensure there are no collisions. At each time slot, it selects the nodes which are ready to transmit data, as well as those nodes which are ready to receive the data. The transmission node activities are divided into transmission schedules, so as to ensure that not all transmitter nodes try transmitting the data at the same time, thereby resulting in collisions. Since these collisions are avoided in a timely manner, by introducing time slots, a lot of energy saving takes places. This ensures that only nodes which are meant to transmit data at a particular time slot, are active and transmitting, thereby others remaining at low power use. The TRAMA protocol maintains a schedule based on information or requests of transmission from nodes. So each transmission request is fit into a particular time slot. Similarly, the protocol also gives information to the receiving set of nodes at each time slot. So each time slot has a few nodes on the receiving end of data, while others have the choice of just being idle nodes, as the transmission is not supposed to be received by them. This method ensures that only relevant nodes are active at certain times, on both transmitting and receiving end, whereas others are idle. This practice of conditional, event driven activity among the nodes in a WSN, accounts for massive energy savings and overall efficiency and performance of the WSN. Finally, if the nodes do not have any data to send, then the protocol will not open any time slots, thereby further saving energy.

Depending on the load of the WSNs, simulations in the research show that nodes can sleep for up to 87% of the time in a WSN run by the TRAMA protocol, thereby producing significant energy savings.

6. Methodology of Proposed WSN Setup

In this section, we propose an alternate theoretical WSN setup, which utilizes best practices from some of the energy efficient mechanisms discussed earlier, in hopes of producing an overall WSN implementation which maximizes its limited energy resources, and thereby survives for a longer time.

The following are the aspects from the aforementioned energy efficient mechanisms we intend to use to form our proposed structure:

- The overall structure for the mobile sinks or base stations will employ the Radial Propagation Structure, as it provides maximum coverage of the entire area of the WSN due to the mobility pattern of the mobile sinks
- The principle of forming the entire WSN into multiple clusters or groups, with each cluster having its own cluster head, will be used. The cluster head here will be the node that receives data from other nodes in the same group.
- The TRAMA protocol will be utilized to create time slots for WSN activity, and also to measure and recognize if nodes are ready to transmit data or not.

In our proposed implementation of the WSN, we intend to use the Radial Propagation Structure for the movement of the base station or mobile sink throughout the network. This is mainly because this pattern of double mobile sinks covers the maximum area in shortest time, of the entire network. However, there is some minor energy expending disadvantages of the radial structure. In this structure, it is said that nodes will mostly be idle, but they will always be calculating the shortest distance (Euclidean Distance) between themselves and the mobile sink, in order to find the right moment to activate and transmit data. This leads to a small lack of energy efficiency, as the nodes always need to be calculating even when not in use, the calculation thereby, using up some minor energy in the process. This is something we try to avoid in our proposed structure. At the same time, this structure assumes that the WSN is continuous in nature, thereby remaining active even at times when the nodes might not have any data to transmit.

The proposed implementation will employ clustering or grouping of the WSN into various clusters, each with its own assigned cluster head. This cluster head is calculated based on the calculation that the node in a group is the shortest distance from all other nodes. This makes it easier and much quicker for other nodes within the group, to transfer their data to the cluster head. This setup will also have the advantage that the other nodes in a group can transfer their data to the cluster head only when needed, and as such, the WSN doesn't need to be one of a continuous nature. When the mobile sinks move along a circular path in the network to collect data, only the cluster heads will transfer the data to the base stations, based on shortest distance calculation. Apart from the time taken to transfer data to the cluster head in each group, the other nodes will always be in idle state. This ensures that the nodes in each group are in idle state for most of the time thereby preserving energy. At the same time, the cluster head only transfers data to the mobile sink based on shortest distance, which also helps in energy efficiency.

Lastly, because of the continuous nature of the previous radial structure of the WSN, the dual mobile sinks had to always move in circular direction whether the other nodes had any data to transfer or not. This leads to some wastage of energy as the mobile sinks would have to take round trips through the network and make the cluster heads calculate shortest distance even when there might be no data to transfer. This is where the application and time slot management of TRAMA protocol comes in. The TRAMA protocol here would first be able to create time slots at regular intervals. At the start of each of these time slots, this protocol will also be able to determine, whether any cluster head nodes in the network have any data transmission activity pending. The mobile sink will be released on its usual circular route to receive data from head nodes, only if the TRAMA protocol confirms that there are indeed cluster heads which await data transmission in the time slot. On the other hand, if the protocol finds out that there are no transmissions pending at any given time slot period, the WSN will cancel the circular propagation operation of the mobile sink for that time period, thereby saving more energy.

The above proposed structure of the WSN shifts from the usual continuous network as described in previous energy efficient mechanisms, and shifts to a more event driven network, where controlled events based on node groups, are driven based on time slots and the need to transmit information. This helps the proposed WSN to do minimal work, only when necessary, thereby saving much needed energy.

A diagrammatic approximation of the above proposed WSN structure is given below in Figure 4.

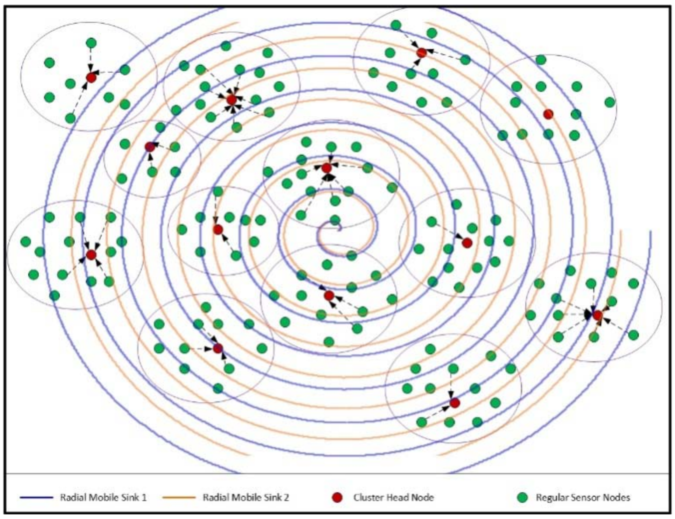

Figure 4: Radial Propagation applied on a clustered WSN (proposed)

7. Conclusion and Future Work

This paper presented a detailed review on the structure and nature of wireless sensor networks, their applications and inherent problems associated with WSNs. The paper also discussed some of the promising solutions suggested for energy efficiency in WSNs, followed by discussion of a theoretical proposed solution that might further help the energy resource issues in WSNs.

With all the different applications as discussed in section 3 of this paper, it is easy to imagine how important a part the WSNs play in our daily lives now and for the coming years. The applications of WSNs can only be fully realized if the critical problems associated with WSNs could be solved. The various applications mentioned in the form of environment and terrain monitoring, military and healthcare can only succeed if the WSN stays alive and working and is not brought down by things such as low energy or lack of resources. This is the main problem which this article tries to provide solutions to, so that future and current applications of WSN last longer and are more reliable, scalable and sustainable.

Future work in this field would include an alternate proposed theory for energy efficiency in WSNs, where the radial propagation structure of mobile sinks might be dropped in favor of mobile sinks which could just directly go to the cluster heads and get data. However, this would mean additional concerns such as the head nodes having GPS sensors for positioning information, which are also detrimental to battery life and hence life of the network. Future work in this area could also include applying or developing mathematical models and simulations to prove the performance measures for the proposed theoretical structure in WSNs in this paper.

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