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Lifetime Enhancement in Wireless Sensor Networks: A Theoretical Review

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Abstract—A Wireless Sensor network (WSN) is defined as network of devices that is used to monitor the physical conditions and gather the information from the complex geological range through wireless link. These networks are powered using batteries which are difficult to recharge. In WSN, energy can be consumed usefully or wastefully and toimprove the efficiency of WSN it is necessary to minimize the wastage of energy thereby improving the lifetime of network. Energy conservation is used to minimize the consumption of energy in several intermediate nodes to enhance the lifetime of network. This paper presents a brief overview of architecture of WSN and highlights the area where energy is consumed wastefully and usefully. Some of the techniques which are used for enhancing the network's lifetime by reducing energy consumption are analyzed in detailed.

Keywords—WSN (Wireless Sensor Network), Energy conservation, Energy consumption, BS (Base Station), CH (Cluster Head), subsystem, LEACH (Low Energy Adaptive Clustering Hierarchy), Routing, Energy efficiency CSMA (carrier sense multiple access), CSMA/CA (carrier sense multiple access/collision avoidance) etc.

I. INTRODUCTION

WSN is a group of sensors for recording and monitoring the physical conditions of the environment like sound, pollution level, temperature, wind, humidity, etc. and organizing the collected data at the central location. The emergence of WSN can finally bridge the gap between digital and physical world. WSN consists of number of nodes called wireless sensors that are arranged in clusters and have limited power. Each cluster has a master node, which is called Cluster Head (CH) and remaining sensor nodes as members of it. The CH is a high bandwidth sensing node used to perform the fusion and the aggregations, senses the collected data directly to base stations (BS) from target environment. BS is also a node for sending and receiving the data from the clusters even in a remote area [1]. The sensed data can also be received by some sink nodes which have access to internet that is infrastructure network. Finally, the sensed data can be remotely fetched by the end user through satellite or internet. The architecture of the WSN is shown in figure1. The figure depicts two types of networks namely flat sensor network and another one is clustered sensor network [2] [3].Various applications of WSN include area monitoring, health care monitoring, environment sensing, industrial Monitoring etc.

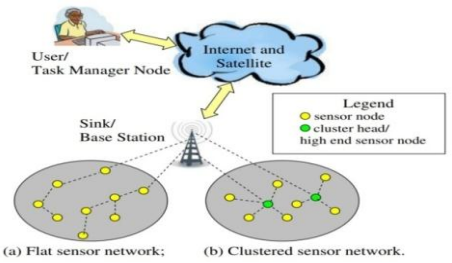

Figure 1. WSN Architecture

Sensor node is the very important element in WSN that is usedfor sensing the data and convert it to digital sequence. It is needed to be equipped with some physical resources in order to fulfill all these requirements that are classified into four subsystems:

1. Sensor Subsystem –Sensor subsystems are used to sense values and convert them into digital sequences.
2. Processor Subsystem– Processor subsystems are used to store, gather and configure data in local memory and executes their functions accordingly.
3. Communication Subsystem- Communication subsystems are used to enable node to interchange messages with other nodes.
4. Power Subsystem– Power subsystems are used to supply the other subsystems with power from battery.

In WSN, all these subsystems as well as their proper implementation effects the network's performance and their common network performance attributes, such as frame loss rate, bandwidth, quality of service (QoS) are accompanied by another very important one that is power consumption. High power consumption of sensor nodes is a major issue which needs to be tackled. Therefore, they have to be equipped with batteries, which have to be replaced with fresh ones occasionally. These periods may differ from few days to years. Sensor nodes are often placed in areas with low accessibility, hence it is very important to take into consideration the power consumption attribute while dealing with WSN [4] [5]. Therefore, to cope up issues of power management in WSN, it is necessary to study various management planes of WSN as shown in figure 2.

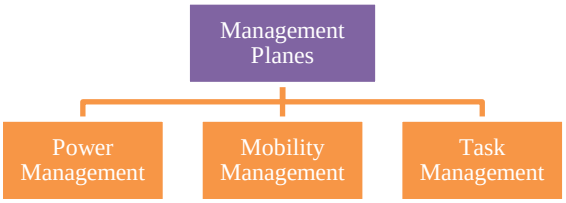

Figure 2. Management planes of WSN

Energy consumption is the major issue in sensor networks. A large amount of energy is consumed in several subsystems of the sensor nodes during transmission of data. Various techniques are described below for decreasing this loss of energy. The energy consumption in WSN can be minimized to a much greater level by implementing these techniques. This surely helps in the working of sensor network. Hence optimum efficiency can be obtained [6].

The rest of the paper is organized as Section II of the paper describes various techniques used for conservation of energy in order to enhance the life time of the network including duty cycling, Data-driven approaches, Energy-Efficient MAC protocols, Solar Aware Routing etc. Paper is concluded in Section III.

II. Energy Conservation in WSN

In WSN, Energy can be consumed usefully or wastefully. It is consumed usefully while transmitting and receiving data, forwarding data, processing data and queries. It is wasted in collision, over-hearing, over-emitting and Idle-Listening. Hence for improving the efficiency of WSN it is necessary to minimize the wastage of energy thereby improving the lifetime of network. In the WSN, to improve the energy efficiency many schemes are used in order to enhance battery lifetime and network efficiency.

The lifetime of nodes functioning depends upon the battery life or power supply. In order to achieve longer operation of sensor nodes optimizing the energy consumption is an essential factor [7]. Various techniques used for energy conservation in WSN are discussed further.

1. **Duty Cycling-**A sensor node has four types of operating modes including idle listening, transmission, reception, and sleep. Transmission mode has the greatest power consumption among all. Power consumption of idle and receiving mode is approximately same. For saving the energy in WSNs, idle mode is very significant. The least power consumption is due to sleep mode.
   Node switches between active and sleep modes based on the activities of the network and this behavior is called as duty cycling. Whenever communication is not going on, the radio transceiver is put into sleep mode. Duty cycling is defined as the percentage of time nodes are active during the total lifetime. The nodes in the duty cycle that are recently not used can go to sleep and preserve energy. Duty cycle can be defined as

$$\text{Duty Cycle} = \frac{\text{Duration for which nodes are in active Mode}}{\text{Total lifetime of nodes}} \quad \ldots (\text{Eq. } 1)$$

   There are two approaches for implementation of the techniques mainly including topology control and power management scheme.

   1.1 Topology Control Scheme- It reduces the several nodes involved in forwarding and routing packets created by the other nodes without minimizing network coverage and connectivity. It ensures that nodes which are not currently required for connectivity can go to sleep and save energy therefore enhancing the lifetime of network.

   1.2 Power Management Scheme- It involves MAC (Media Access Control) protocols namely TRAMA (Traffic-Adaptive Medium Access), B-MAC (Berkeley-MAC) and ZMAC (Zebra-MAC) with low duty cycling and a wakeup scheduling scheme.

2. **Data-driven Approaches** -This technique uses the concept of data sensing and provide the continuous data and are classified into energy efficient data acquisition and data reduction schemes as depicted by figure 3[8].

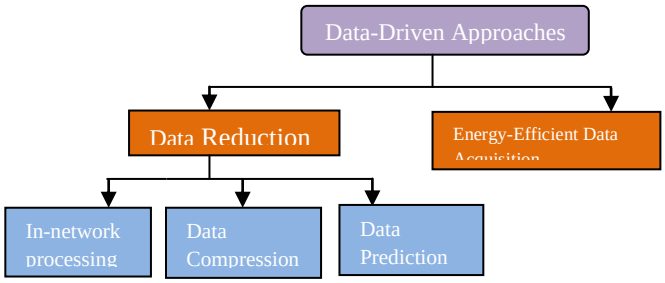

Figure 3. Classification of Data Driven Approaches

2.1 Data reduction scheme- Unneeded samples are addressed by this scheme. Data reduction is classified into following categories:
a) In-network processing- Performs data aggregation at intermediate between sink and source.
b) Data prediction- Builds an abstraction of a sensed phenomenon.
c) Data compression- Reduces the information sent by the source node.

2.2 Energy-efficient data acquisition schemes. The main goal is to reduce the energy spent by the sensing subsystem and also reduce the data samples by minimizing the number of communications. The lifetime of sensor node is connected to the volume of data which is sensed, processed and reported. At high temporal and spatial resolutions, sensor network allows environmental monitoring [9].

3. **Energy-efficient MAC Protocols-**
It is a sub-layer of data link layer that provides channel access control mechanisms for many terminals to communicate within the multiple access networks that incorporates a shared medium like Ethernet. They are used for transmitting and receiving the frames, removing, appending, and padding the bits etc. On the basis of MAC protocols, they are divided into TDMA based, contention based and hybrid MAC protocols for energy conservation.

3.1 TDMA based MAC protocol- They are used for assigning a unique time slot to receive and send the data for each node that avoids collisions and saves energy. While resending the data, the saved energy would be wasted due to discarding and collision.

3.2 Contention based MAC protocol- They are based on CSMA and CSMA/CA that do not require any type of coordination between the nodes. In case of collision the nodes wait for a moment before resending the packets. Two types of MAC protocols are S-MAC (Sensor MAC) and T-MAC (timeout MAC).

a) S- MAC: In a time-frame, active and sleep are two states. It uses sleeping and periodical listening in order to reduce the energy wastage. S-MAC is more probable to be asleep than continuously listening to the channels when the node is idle. It minimizing the listen time by letting go the node into periodic sleep mode.

b) T-MAC: It is an enhanced version of previous protocol in which the periods of sleep and wake are adjusted depending upon the traffic. It minimizes the inactive time of the sensors and also more energy efficient instead of S-MAC.

3.3 Hybrid Contention based- It has longer energy saving and offers the better flexibility and scalability. It has advantages of both the above protocols [10].

4. **Solar- Aware Routing-** It is routing protocol that routes the traffic through nodes using solar powered batteries. Energy level of sensor nodes depends upon the architecture of network and their processing model. It uses the solar power battery which is automatically charged to provide the energy for sensor nodes in WSN. The node which have high energy level having more traffic and get transferred through that node. Low energy level having very less traffic or sometimes they will not have any traffic, for balancing the network energy. It is weather dependent but cost effective which is the main advantage of solar aware routing.

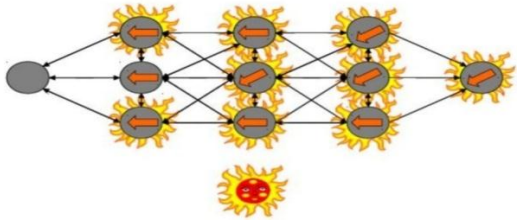

Figure 4. Solar Aware Routing in WS

5. **LEACH Protocol**- It is a TDMA-based MAC protocol which is integrated with a simple routing and clustering in WSN. It is basically a hierarchical routing protocol representation i.e. self- organized and self- adaptive. The main goal of this is to enhance the lifespan by reducing the energy in WSN. It consists of two phases, set-up phase and steady phase as shown in below figure.

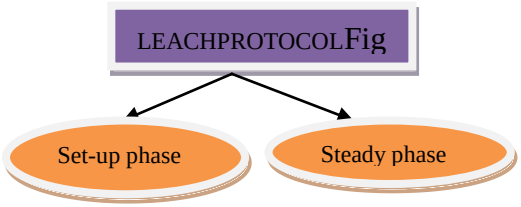

Figure 5. Types of LEACH protocol

5.1. Set-up Phase- it is used to make the cluster and select the CH for each cluster by choose the sensor node with greatest energy. It involves three basic steps as shown in figure 6.

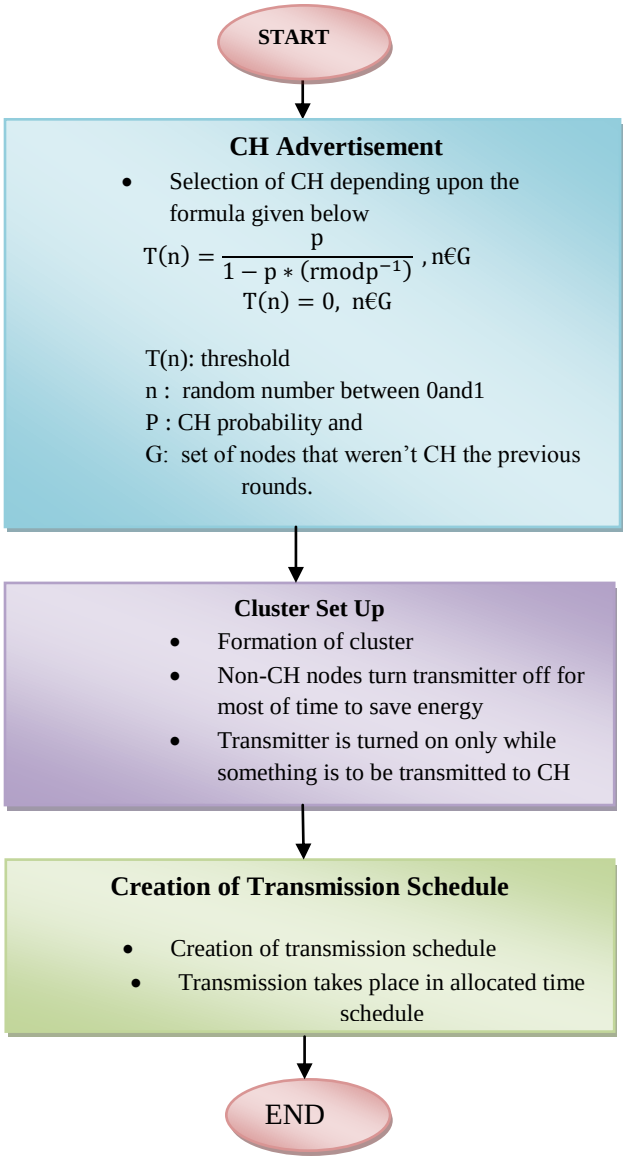

Figure 6. Flow chart of set-up phase

5.2. Steady Phase- cluster node sends its data to CH in steady phase. The member sensor can communicate only with CH in each cluster through single hop transmission. CH collected all the data and sends it to the BS. The network again goes to the first step i.e. set-up phase after the predefined time[6]. TDMA schedule for LEACH operation is shown in Figure 7 [11].

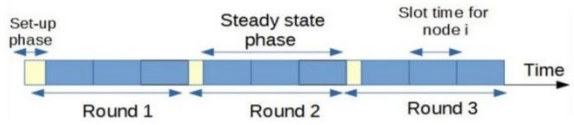

Figure 7. TDMA schedule for LEACH operation

6. **Multi-Hop Hierarchical Clustering (MHHC) -** In MHHC algorithm, clustering of sensor nodes is done according to number of clusters and nodes. At different level, it creates a hierarchy of networks. At the side of sender from low level to top level and at the side of receiver from top level to low level, it follows the sequence of clusters while in communication. It improved the lifetime of network by 22% as compared to LEACH protocol after simulating MHHC algorithm. This algorithm depends on the three factors including distance, energy level and number of neighbors. The throughput will be changed if any one of the aforementioned factors is changed. At particular time instance, energy model and time model are very essential to find these factors. MHHC algorithm is classified into three phases including initial, hierarchical and final phase.

6.1 Initial Phase- clustering of sensor networks is done to different hierarchical level by sending the start message to all neighbors. Then all neighbors send this start message to their neighbors. In this way, this message is conveyed to all the nodes.

6.2 Hierarchical Phase- according to number of neighbors, it forms clusters after receiving start message and each cluster select their CH according to energy level of nodes and number of neighbors.

6.3 Final Phase- the path for sending data from source to destination will be finalized here according to the hierarchical path.

For sending any type of information, it does not follow the different path from source to destination which is the advantage of this technique. The main drawback of this technique is some nodes are used repeatedly in the communication due to static path.

7. **SPIN-I Protocol-** Sensor Protocol for Information via Negotiation (SPIN) is a routing protocol used for reducing the energy wastage. It is type of data-centric routing protocol that is designed for lossless transmission based on metadata. SPIN protocol gives the new solution for reducing energy consumption which is more uniform in the whole network. It is used to manage the network resources very efficiently and avoid the redundant transmission of data. It is suitable for small and medium-sized networks not for large networks which is the drawback of SPIN protocol [12].

It mainly focuses on 'blindly forwarded' and 'data inaccessible' problems. Here blindly forwarded means, all the neighbors receive the data packets from the source node and broadcast this packet to all the entire neighbors. The process will be repeated until the receiver does not receive the message. But the disadvantage of this process is that many nodes don't require actually for communications are part of it. Due to it most of energy is consumed and the network's performance and lifetime is reduced. Data inaccessible means the information is unable to be accessed by the network that losses the meaning of application[13].

In order to solve aforementioned problems, it is first necessary to select the next node for communication and check its energy level before packet is broadcast. For this all the nodes have same energy level and their links are also symmetric. This energy level will be spread in all the direction by wireless signals. The working mechanism of SPIN-I is classified into three stages including data broadcasting stage, data requesting stage and data transmission phase. In energy conservation case, SPIN-I got the success up to certain level and enhanced the lifetime of networks. But main demerit of SPIN-I is the transmission time is longer than the SPIN protocol because each node does some calculation before selecting the next hop transmission and also helps to balance the energy of nodes rather than saving it[14].

Energy consumption is very important factor for determining the network's lifetime where sensor nodes are battery driven and use very low energy resource that makes energy optimization more complex in WSN because it involves reduction in energy consumption and prolong the network's lifetime[15]. In this paper, we analyzed the recent developments of WSN, including their design constrains, applications, and life estimation models. Recent developments in technologies have enabled the manufacturing of low-cost, low-power, less-size and multifunctional sensor nodes in WSN. The main objective of energy conservation is to enhance the lifetime of sensor network while not compromising data delivery.

III. CONCLUSION

WSN has attracted significant attention from last few years. They are very valuable in different domains by considering the growing scopes of WSN and its applications such as military and civil, especially in hostile and remote areas. The main approaches of conservation of energy in WSN are analyzed in this paper. Among the various approaches of energy saving for sensor nodes, each approach is having some advantages as well as drawbacks. MHHC is very easy for implementation but requires some additional processing thereby increasing complexity. SPIN-I and MHHC both having the good results but extra proceeding overhead are present. LEACH is a MAC protocol that has some advantages such as it is distributed completely, it saves the energy and doesn't required any type of control information but as clusters are randomly divided and are useless if CH dies.

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