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Energy Management in Wireless Sensor Networks-A Review

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Abstract: Wireless Sensor Networks in recent times have been intensively studied owing to their ubiquitous nature, small size and limited resources. Decreasing size along with smart technological advances have enabled them to be applied extensively ranging from ecological monitoring, target tracking to the vast fields of defence and security. Wireless Sensor Networks comprise of small sensor nodes which are networked in such a way that they are capable of sensing, processing and communicating information for human welfare. As the sensor nodes are primarily battery driven and usually operative in inaccessible areas therefore manual replacement of batteries for such kind of small devices is practically impossible. Therefore Wireless Sensor Networks face acute energy shortage which constrains their network lifetime. Lifetime Enhancement, judicious and efficient energy utilization are therefore major areas where research is going on. In this paper a comprehensive and holistic view of energy management and optimization techniques have been discussed. The goal of this paper is to analyse different approaches to energy conservation prevalent at the present time which include duty cycle, data driven and mobility based approaches. We have concluded the paper by suggesting some future research strategies for energy optimization and enhancing the life time of the network.

Keywords: Wireless Sensor Networks, Duty Cycling, Mobility, Data acquisition, Data Driven.

1. INTRODUCTION

Wireless sensor networks are self-configured primarily static Adhoc wireless networks comprising of hundreds of sensor nodes which are capable of sensing, computing and communicating the information over long distances. The nodes have low computational capability and are provided with limited energy resources [1]. Recent advances in Micro Electrical Mechanical Systems (MEMS) have left huge impact on the application areas of Wireless Sensor Networks making it hot area of research in recent times. Ubiquitous computing has largely increased the application areas of Wireless Sensor networks. These application areas include environmental monitoring, health monitoring, industrial monitoring, and military applications. The sensor networks consist of small sensor nodes which sense the environmental variations that may be in the form of variation in temperature, pressure, velocity, humidity, light energy, sound etc. and transmit the sensed information to a sink node or a gateway after some processing, the gateway transmits this information to the base station which in turn may be connected to the internet through a link (say satellite link). The typical architecture of a sensor node and a sensor network is given in figure 1a.and figure1b.

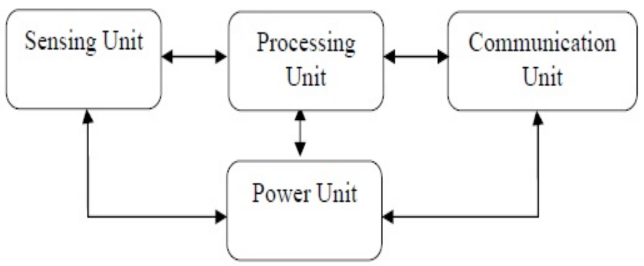

Figure 1a. Wireless Sensor Node Structure[1]

As the sensor nodes are very tiny devices hence there is natural limitation to the provided energy resources. The attached batteries must incorporate energy generators or

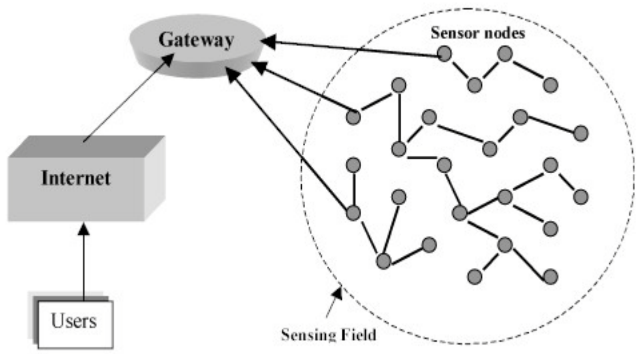

Figure 1b. Wireless Sensor Network Structure[2]

batteries which in practice do not last for long periods resulting in reduction of the lifetime of the network. Moreover the sensor nodes are operational in the areas which are least accessible to the human beings therefore it is not feasible to replace the batteries merely by human intervention unlike devices in other mobile Adhoc devices. In fact the lifetime of the network should be enough to fulfill the application requirements. For this the network should have sufficient energy for efficient transmission and processing of the sensed data. Ever since the Wireless sensor networks came to existence many strategies have been developed to efficiently and judiciously utilize the energy resources both at the node and network level. Efficient energy management in wireless sensor networks is an important research issue, because of the limitations in size of the sensor nodes [2]. The huge no of sensor nodes employed in the field requires efficient and reliable mechanisms to conserve energy because a tethered energy infrastructure is usually not present which puts a limit to the use of available energy. Various approaches have been adopted to optimize the energy consumption both at the hardware and software level in the Wireless Sensor Networks. Some of the techniques in this regard are Radio and network resource management, orthogonal frequency division multiplexing, cognitive radio, network coding etc. The communication subsystem has shown that wireless networks operate on the battery supplied power. In sensor networks the system is expected to operate for long time, hence energy resources prove to be bottle neck and hence much effort is being put in force for efficient utilization of power [3]. The energy consumption in the process of communication is far higher than the computational processes. It is pertinent to mention here that transmitting a single bit of data over the sensor network consumes as much power as the thousands of instructions consume in the computational process. Similarly the radio energy consumption is of the same order of magnitude in the transmission, reception and idle states. The idle state power consumption can be reduced by putting the radio in off state or sleep mode whenever it is possible [4]. The purpose of these techniques is to provide a basis for developing and designing networking protocols for optimized energy usage. In the next section we will present some of these techniques in detail [5]

2. ENERGY CONSERVATION SCHEMES IN WIRELESS SENSOR NETWORKS

The Energy conservation schemes can be broadly classified into the following three categories

1) Duty Cycle approaches
2) Data Driven approaches
3) Mobility based techniques

2.1 Duty Cycle approaches

Duty cycling is mainly focused on the networking subsystem. Duty cycling is actually a combination of topology and power management. By duty cycling it is meant that the nodes remain active for a small fraction of time during lifetime of the node. This can be done by putting the radio transmitter and receiver (transceiver) in the sleep or off mode whenever sensing and communication processes are not required. The duty cycling technique comprises of two techniques which are topology control protocols and power management which are termed as two complimentary approaches of energy saving in Wireless Sensor Networks. Let us discuss these techniques in detail

2.2.1 Topology Control Protocols:

Topology control technique presumes to maintain a global graph which strictly links the network nodes for reducing the data redundancy which in case of denser networks is much higher. The aim of this technique is to dynamically change the nodes while reducing the power consumed by node transceivers. Another advantage of this technique is the positive effect of limiting contention when accessing the wireless channel [6]. In fact when the nodes have relatively short ranges, many nodes can transmit simultaneously without interfering with each other. That is why transmitting ranges are ideally set to the minimum value such that the graph that represents the communication links between the units has minimum weight. The topology control in Wireless Sensor networks can be further divided into homogenous or non-homogenous types. Homogenous topology control is to simple and easy to analyze and comprehend where nodes are presumed to utilize the same transmitting range resulting in reduction of critical transmitting range. In case of non-homogenous topological control nodes can choose different transmitting ranges. It can further divided into following three categories.

a) **Location Driven control**: Location driven control describes, which of the nodes should be turned ON or OFF based on the location of the sensor node which is assumed to be known. [7]. This information is either used by a centralized authority to compute a set of transmitting range assignments which optimizes a certain measure or it can be exchanged between the nodes and used to compute an “almost optimal” topology in a fully distributed manner [8].
b) **Direction based Control**: In this case the nodes can easily estimate the relative direction of each of the neighbors but they do not know their position.
c) **Neighbor based control:** Neighbor based control presumes that the nodes only know the ID of the neighbors and thereby are able to order them in terms of some predefined criterion(say distance or link quality)

2.2.2 Power Management:

In Wireless Sensor Networks battery power is considered as an essential source of energy. It has been observed that in ad hoc networks, energy consumption does not reflect the communication activities in the network. Many existing energy conservation protocols based on electing a routing backbone for global connectivity are oblivious to traffic characteristics [9].Power management protocols can be implemented either as independent sleep/wakeup protocols running on top of a MAC protocol, or strictly integrated with MAC protocol itself [10]. These protocols can be further divided into three main sub categories which are explained below.

a) **On Demand Schemes**:

The main aim of this scheme is manage the energy resources by effective management of traffic patterns in the network. This is being done by reacting to the changes in these patterns. The nodes that do not carry any data for transmission can be made to opt out of using any amount of energy. The adaptivity of the network load can be varied, this makes a balance by trading off between latency, throughput and energy consumption. On Demand power management principally believes in the idea of triggering communication events in terms of routing messages, data packets and transitions from active mode to power saving mode using the soft state timer. The soft-state timer is refreshed by the same communication events that trigger a transition to active mode [11].

b) Scheduled Rendezvous Schemes:

In a more straightforward way Scheduled Rendezvous scheme wishes to minimize the power consumption per node by switching the node Off as often and as long as possible. It is therefore important to arrange simultaneous ON-Time for nodes wishing to communicate. It should be stressed that determining which node (partner) a given node should rendezvous with in order to forward a packet is the realm of the routing scheme [12]. This task of scheduling rendezvous between the various nodes can be done purely on synchronous, Asynchronous or Pseudo Synchronous basis. Purely Synchronous scheme nodes are synchronized in time and are made to agree on certain transmission time slots. In Purely Asynchronous Scheme nodes can accomplish the task of waking up one another on demand. Although this scheme has the capability of lowest power consumption but it requires extra hardware such as a wake up radio [13]. In Pseudo Asynchronous or cycled receiver scheme the nodes are capable of establishing rendezvous on demand by using a predetermined periodic wake up scheme.

c) Asynchronous Schemes:

Asynchronous power management is reliable and efficient means to minimize the power dissipation on a wireless sensor network. Algorithms can be formulated to maximize the sensing region. It is similar to the coverage-based off-duty eligibility rule, but we can easily avoid the situation that there are more than two nodes making off-duty decisions simultaneously [14]. By employing this scheme it is very easy to save energy in a dense sensor network. Asynchronous schemes allow the nodes to wake up independently of the other nodes by guaranteeing that neighbors always have overlapped active periods with specified number of cycles [15].

2.3 Data Driven Approaches:

Data Driven schemes may be considered as the efficient data Acquisition and data reduction approaches. Data to be sampled may be reduced in accordance to the sensing accuracy in specified acceptance levels. Data reduction addresses the case of unneeded samples. Energy efficient data acquisition schemes tend to reduce the energy consumption of the sensor nodes in the node sensing subsystem.

2.2.1) Data Reduction:

The data prediction models employed here refrain from collection of direct sensed data by answering the queries using the models instead of sensed data. There are two instances of a model in the networks, the one which resides at the sink and other one at the source node. The model at the sink is used to respond to the queries sans any communication, thereby reducing the power consumption. Data prediction is a further classification of data reduction schemes, which are focused on building an abstraction of the sensed data, or in other words, a model for future data prediction. Data prediction schemes can be further divided into stochastic approaches, time series forecasting and algorithmic approaches [16]. The Stochastic scheme works on the phenomenon of stochastic characterization as elaborated by Ken Solution where protocols are involved in high level computations such as aggregating, with the expense of enormous computational costs. These approaches are feasible in situations where powerful sensor nodes are available in the network, thus requires larger battery size [17]. The second approach of data prediction namely time series forecasting involves the use of historical values, which are obtained by periodical sampling in chronological order. The main schemes in this approach are Moving average (MA) and Auto Regressive moving average methods. Both these methods are simple and light weight in implementation and hence provide satisfactory results in terms of accuracy. They are basically Probabilistic Adaptable Query System [18]. The third approach is algorithmic approach which is a heuristic or state transition model describing the sensing phenomenon. One such example is Prediction Based Monitoring in Sensor Networks (PREMON). These techniques are considered case by case as they are more application specific schemes. In addition, few energy prediction algorithms and dynamic duty cycling based on the available harvested energy are also proposed[19].Some authors have taken a different approach to data prediction which can be termed as behavioral, by means of Energy Efficient Data Collection(EEDC) mechanism[20]. Here each node associates lower and upper bound, the difference between the two shows the accuracy of readings. These bound are sent to the sink which stores them for each sensor in the network. The sensors check these samples against the bounds for acquiring the information. Whenever they fall outside the expected precision, an update is sent to the sink by the nodes. Further the sink receives queries which have user defined accuracy associated. Whenever the user defined accuracy in not in accordance with the actual accuracy provided by the value limits, the sink acts in response applying the cached range [21]. This kind of interaction is called consumer initiated request. To sum up algorithmic techniques are considered case by case as they more application specific.

2.2.2) Energy Efficient Data Acquisition:

Energy conservation of energy subsystems cannot be neglected as it can outnumber the energy consumption in radio or the sensor nodes. Power Hungry transducers, A/D converters and active sensors consume a lot of energy. The long acquisition time in the order of hundreds of milliseconds is a concern as energy consumed cannot be neglected even if the sensor power consumption is reasonable. The energy efficient data acquisition protocols are further divided into adaptive sampling, hierarchal sampling and model based active sampling. Adaptive sampling, the primary concern is to reduce the amount of data to be acquired from the transducer based on either spatial or temporal correlation between data.

This scheme minimizes the energy consumption of the sensors and radio and requires the design of adaptive measurement systems. It maintains a very high accuracy of collected data. Simulation experiments have shown that the suggested adaptive algorithm can reduce the number of acquired samples up to 79% with respect to a traditional fixed-rate approach [22]. These schemes are general and have very high efficiency; they are mainly employed in centralized fashion and require high computations. Hierarchical sampling employs various types of sensors are installed on the nodes. Although these schemes are energy efficient but they are application specific and require extra transceiver which adds to the cost of the network. The model based approaches are very similar to data prediction schemes and their goal is to minimize the number of data samples by employing computed models and save energy through data acquisition. Protocols namely Barbie-Q(BBQ)[23] and Adaptive sampling Approach to Data Collection(ASAP) (86 of khan) implement such schemes.

2.3) Mobility based techniques

Consider in a network some nodes to be mobile; the traffic can be influenced if the mobile devices can be accountable for data collection from the stationery nodes. The result is that ordinary nodes can save energy because path length and forwarding overheads can be reduced as well [24]. Based on the behavior, the nodes on one hand can be part of network infrastructure in which their mobility is fully controllable or generally a robotized one and these nodes might follow a predictable pattern of mobility.

On the other hand, they can be part of the environment, in which nodes mobility is uncontrollable and unpredictable. However, in some cases they might follow a mobility pattern that is neither predictable nor random in general [25].

Mobility based schemes generally comprises of two types, one being the mobile sink based approach and other Mobility based algorithms can be further divided in two categories. A mobile sink based approach and a Mobile Relay based Approach which is elaborated below.

2.3.1) **Mobile Sink Based Approaches**:

The Sink mobility based approaches are useful for multiple applications, the one being the target tracking and intrusion detection. In this scheme sensors are installed in strategic places enabling them to monitor the areas of interest. The sink represents an important component of a wireless sensor network as it acts as a gateway between sensors and the end-user [26]. Sink mobility improves the network connectivity by enabling the retrieval of measurements from various parts of the sensor field. The network life time can also be increased by spreading the overhead of nodes that are in proximity to the sink location. Mobile sink nodes improve the network lifetime by 5-10 times than the static sink nodes but the latency associated with the arrival of data at the sink node should be taken into consideration. The residual energy at sensors and the routing guidelines may have to be taken into consideration while designing the protocols. Greedy Maximum Residual Energy (GMRE) and Scalable Energy Efficient Asynchronous Dissemination (SEAD) are protocols of this genre.

2.3.2) **Mobile relay based Approaches**:

Mobile relay based approaches use message ferries for collection of data from the source nodes [27]. Message ferries move in the field , collect data and carry the stored data to the destination nodes. It is similar in function to Mobile Ubiquitous LAN Extension (MULE) approaches [28]. The vehicles periodically visit a network to collect data. The Mobile Relay approach for data collection has been extensively explored in the context of opportunistic networks [29]. Here the sensors have to be continuously in wake up mode while waiting for the MULE to arrive for data collection and the transmission schedule needs to be defined in order to address the issue of the amount of time a MULE has to wait for data coming from static nodes. Zebra Net is one such example [30].

3. CONCLUSION

This paper has reviewed some of the approaches of energy saving methods in the Wireless Sensor Networks. Enhancing the lifetime and providing nontrivial application functionality still remains the primary challenge faced by the WSN designers. Some research designs have been presented in this paper in order to properly manage the energy resources in the Wireless Sensor Networks. The paper has analyzed the duty cycling, data driven and mobility based approaches of energy saving. Some possible improvements have also been suggested for energy optimization. As there are many issues to be resolved pertaining to the energy management schemes. Among these issues is data aggregation at the node level and information management at the network level. Solution of this issue may help us to further reduce the energy consumption. Our analysis reveals that is worth to renew energy and not to rely on fixed energy which is already coupled with the nodes at the time of network deployment. The harvest of ambient energy of the environment which is still at the research level provides a future insight of the development which may help us to address the energy issue in Wireless Sensor Networks.

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