Energy Conservation in Wireless Sensor Networks Using Data Reduction Approaches: A Survey

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Abstract

Wireless Sensor Networks (WSN) which are battery powered, present a challenge of long term sustainability. So power management is an import concern which can be done at two levels such as sensor subsystems and network subsystem. This paper mainly concentrates on the network subsystem aspect of the power management touching the energy conservation schemes like duty cycling, data driven approaches and mobility. This in turn deals with the data driven approaches such as data reduction and energy efficient data acquisition. An in depth study of data reduction techniques is done in this paper which includes in network processing, data compression and data prediction. A proper comparison has been tabulated between the fore mentioned techniques based on certain parameters.

Keywords: *Wireless Sensor Networks (WSN's), Power Management, Data Driven approaches, Data Reduction, In Network processing, Data Compression, Data Prediction*

I. INTRODUCTION

A Wireless Sensor Network (WSN) can be defined as a [1] network of devices denoted as nodes that can sense the environment and communicate the information gathered from the sensor field through wireless links. The data is transmitted via multiple hops relaying to a sink that can use it locally, or is connected to other networks or cloud through a gateway. The nodes can be:

[1] stationary or moving
[2] aware of their location or not
[3] homogeneous or heterogeneous

A scheme of a WSN connected to the Internet is presented in Fig. 1. WSNs are implemented in a wide range of distributed, remote and wireless sensing applications in environmental monitoring, agriculture, production and delivery, military, structural health monitoring, ambient intelligence, medical applications, etc.

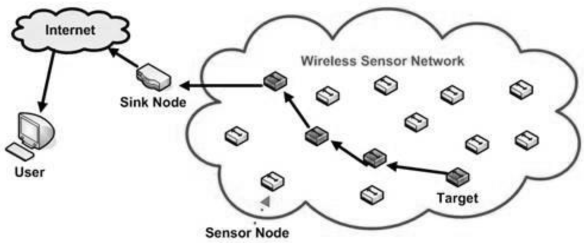

Fig 1: A wireless sensor network

Deployment of WSNs avoids installation costs due to wire depositions, introducing at the same time power efficiency as a main challenge. Wireless sensor nodes are mainly battery powered, thus having restricted amounts of energy. Even if they are equipped with power harvesting units (retrieving e.g. solar, vibrational or wind energy), energy is a critical point and should be tackled wisely. A WSN should be autonomous and self-sustainable, able to function for several years with a battery power supply. A node's lifetime is defined as the node's operating time without the need for any external intervention, like battery replacement. A *WSN lifetime*[2] can be defined as the lifetime of the shortest living node in the network. But, depending on the application, density of the network and possibilities of reconfiguration, it can also be defined as the lifetime of some other (main or critical) node. Anyway, in order to enhance a WSN lifetime, it is required to reduce the energy consumption of the nodes as much as possible and form an energy aware system.

The rest of the paper is organized as follows. Section II discusses the general approaches to energy conservation in sensor nodes, and introduces the three main approaches (*duty-cycling*, *data reduction*, and *mobility*). In Section III we break down this high-level classification, and highlight the *data driven approaches* that will be then described in detail in the following sections.Specifically, Section IV deals with schemes related to the *data reduction* approach. Finally, conclusions and open issues are discussed in Section V.

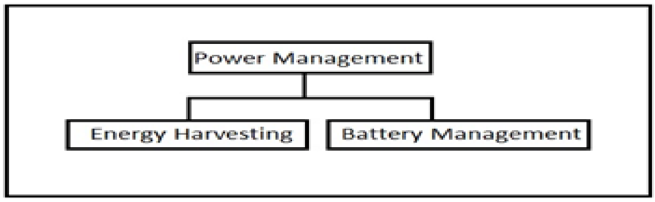

Fig 2: Ways of Power Management

II. POWER MANAGEMENT

As mentioned in the previous section and Fig. 2, power management in sensor networks can be done in two ways:

[1] Energy Harvesting

[2] Battery Management

Power management is an important concern in sensor networks, because a tethered energy infrastructure is not available and an obvious concern is to use the available battery energy efficiently. However, in some of the sensor networking applications, an additional facility is available to overcome the energy problem: *harvesting energy* [3] from the environment. Certain considerations in using an energy harvesting source are fundamentally different from that in using a battery because, rather than a limit on the maximum energy, it has a limit on the maximum rate at which the energy can be used. Further, the harvested energy availability typically varies with time in a nondeterministic manner. Thus energy harvesting is not an optimal solution where the sensor nodes are placed remotely.

So in order to prolong a WSN lifetime, it is required to reduce the energy consumption of the nodes as much as possible and, form an energy aware system which reduces the consumption of battery power i.e. *Battery Management*. It can be done at two levels:

[1] Sensor Subsystems

[2] Network Subsystems

From a sensor network standpoint, we mainly consider the model depicted in Fig. 1, which is the most widely adopted model in the literature.

2.1 Sensor Subsystems and Network Subsystems

Fig.3 shows the architecture of [4]a typical wireless sensor node.It consists of four main components: (i) a sensing subsystem including one or more sensors (with associated analog-to-digital converters) for data acquisition; (ii) a processing subsystem including a micro-controller and memory for local data processing; (iii) a radio subsystem for wireless data communication; and (iv) a power supply unit.

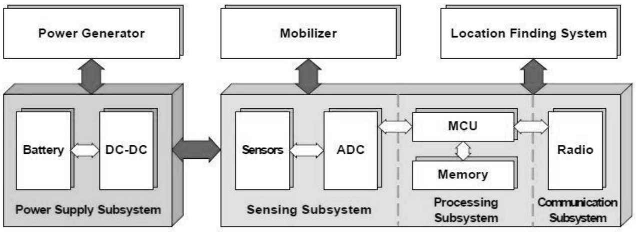

Fig 3: Architecture of sensor node

However, the *network subsystem* has much higher energy consumption than the sensor subsystem. It has been shown that transmitting one bit may consume as much as executing a few thousands instructions [5]. Therefore, communication should be traded for computation.The radio energy consumption is of the same order in the reception, transmission, and idle states, while the power consumption drops of at least one order of magnitude in the sleep state. Therefore, the radio should be put to sleep (or turned off) whenever possible. Depending on the specific application, the sensing subsystem might be another significant source of energy consumption, so its power consumption has to be reduced as well.

Based on the above architecture and power breakdown, several approaches have to be exploited, to reduce power consumption in wireless sensor networks. At a very general level, we identify three main enabling techniques namely, *duty cycling, data-driven approaches***,** and *mobility***.**

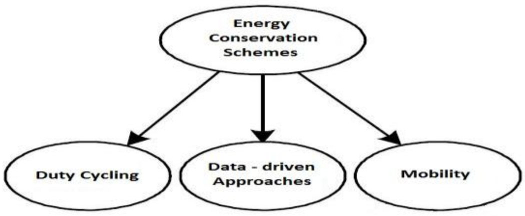

Fig 4: Energy conservation schemes in network subsystem

Duty cycling focuses on the networking subsystem. The most effective energy-conserving operation is to put the radio transceiver in the sleep mode whenever communication is not required. Ideally, the radio should be switched off as soon as there is no more data to send/receive, and should be resumed as soon as a new data packet becomes ready. In this way nodes alternate between active and sleep state depending on network activity. This behaviour is usually referred to as duty cycling, and duty cycle is defined as the fraction of time nodes are active during their lifetime. As sensor nodes perform a cooperative task, they need to coordinate their sleep/wakeup times. A sleep/wakeup scheduling algorithm thus accompanies any duty cycling scheme. It is typically a distributed algorithm based on which sensor nodes decide when to transition from active to sleep, and back. It allows neighbouring nodes to be active at the same time, thus making packet exchange feasible even when nodes operate with a low duty cycle (i.e., they sleep for most of the time) Duty-cycling schemes are typically oblivious to data that are sampled by sensor nodes. Hence, *data-driven approaches can b*e used to improve the energy efficiency even more. In fact, data sensing impacts on sensor nodes' energy consumption in two ways:

- Unneeded samples: Sampled data generally has strong spatial and/or temporal correlation [6], so there is no need to communicate the redundant information to the sink.
- Power consumption of the sensing subsystem: Reducing communication is not enough when the sensor itself is power hungry.

In the first case unwanted samples result in useless energy consumption, even if the cost of sampling is negligible, because they result in unneeded communications. The second issue arises whenever the consumption of the sensing subsystem is not negligible. Data driven techniques presented in the following are designed to reduce the amount of sampled data by keeping the sensing accuracy within an acceptable level for the application.

In case some of the sensor nodes are mobile, *mobility* can finally be used as a tool for reducing energy consumption (beyond duty cycling and data-driven techniques). In a static sensor network, packets coming from sensor nodes follow a multi-hop path towards the sink(s). Thus, a few paths can be more loaded than others, and nodes closer to the sink have to relay more packets so that they are more subject to premature energy depletion (funnelling effect) [7]. If some of the nodes (including, possibly, the sink) are mobile, the traffic flow can be altered if mobile devices are responsible for data collection directly from static nodes. Ordinary nodes wait for the passage of the mobile device and route messages towards it, so that the communications take place in proximity (directly or at most with a limited multi-hop traversal). As a consequence, ordinary nodes can save energy because path length, contention and forwarding overheads are reduced as well. In addition, the mobile device can visit the network in order to spread more uniformly the energy consumption due to communications. When the cost of mobilizing sensor nodes is prohibitive, the usual approach is to "attach" sensor nodes to entities that willbe roaming in the sensing field anyway, such as buses or animals.

III. DATA DRIVEN APPROACHES

As mentioned in the previous section, data driven approaches can be mainly classified as:

- Data Reduction
- Energy Efficient Data Acquisition

Data reduction mainly focuses on the data which is already present in the nodes, whereas energy efficient data acquisition mainly focuses on retrieving the data from the environment or surroundings efficiently using sophisticated algorithms.

3.1Data Reduction

Data reduction is the process in which the large entity of the collected data is converted to the smaller useful entity so that at a later stage the same data can be retrieved without any loss. This concept is very much important in power management as transmission of data by nodes uses up lot of power, thus by reducing the size of the data, power consumption can be reduced. At the same time, data reduction approach also concentrates on preventing the nodes from transmitting data to the sink, thus reducing the transmission load on the node as well as, reducing the communication and processing overhead at the sink side.
The above mentioned approach can be achieved in the following three ways as shown in Fig 5:

- In Network processing
- Data compression
- Data prediction

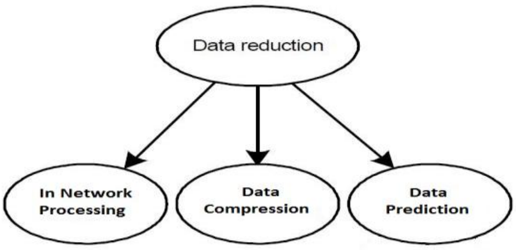

Fig 5: Data reduction techniques

In network processing is a technique wherein sensors are grouped into smaller clusters which in turn will have a special node called aggregator [8] that collects data from all the nearby nodes, processes it and broadcast it to the sink if needed.

In data compression, sensor nodes transmit data to neighboring nodes which has some correlated data, thus compressing the aggregated data with its own data reducing redundancy. Alternatively every node can compress the data on its own and transmit.

Data Prediction is an approach where, instead of transmitting data every now and then, the data is compared with the sampled model (based on previously sensed records). If the data lies within the expected range of the model, the model is considered valid. If not, the updated model is sent to the sink. Thus, reducing overall number of transmissions.

3.2Energy Efficient Data Acquisition

Energy efficient data acquisition is an approach where there is reduced data acquisition based on energy efficient algorithms. However this is not exclusive to reduce energy consumption through sensing. It also reduces the number of communication along with reduced sensed data.

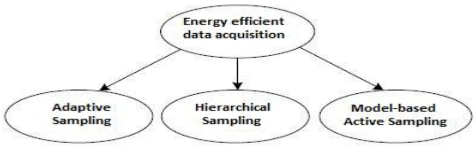

Fig 6: Taxonomy of energy efficient acquisition

Energy efficient data acquisition can be classified as follows:

- Adaptive sampling
- Hierarchical sampling
- Model based Active sampling

Adaptive sampling takes advantage of correlated and gradually changing data, thus reducing the number of data sensing. Hierarchical sampling looks into the dynamics of the nodes such as accuracy and energy consumption, thus ensuring a balance between afore mentioned attributes. Model based active sampling exploits the pre-sensed data by building upon the sampled models. Thus, reducing the number of acquisitions and also the number of communications between the nodes.

IV. DATA REDUCTION

As mentioned in the previous sections data reduction is an efficient approach to reduce power consumption. This section explains in detail the various approaches to data reduction and also compares them. A common way to facilitate data reduction is to follow predict and adapt models. These models can be applied at both the source and destination for the nodes. As this mechanism relies upon the data prediction and adaptation to the changing pattern of data, utilization of communication resources is drastically reduced, hence reducing the power usage. This is also a challenging approach as data exists in the form of continuous bits. Therefore, the predict and adapt models have to process the sensed data in real time with utmost accuracy. The spatial and temporal [9] characteristics of WSN's help the nodes to adapt to the environment and also predicting it, which aids to the data reduction. As mentioned in section 3.1 data reduction is subdivided as in network processing, data compression and data prediction.

4.1 In network processing

In network processing in large scale WSN's improves scalability, reduces data redundancy and also enhances the life time of the WSN. Sensor nodes are placed in an environment where usually the sensing regions of the nodes overlap. This leads to the data redundancy. The technique which can help to overcome this is *in network processing.* Here, as mentioned earlier, *aggregators* come into picture. These aggregators collect the data from the neighboring nodes, process them and combine correlated data into a single packet and send it to the sink. This is known as *data amalgamation.* The reverse process is known as *data dissemination* wherein the control message from the sink is transmitted to the *aggregators* and eventually to other sensor nodes. Fig.7 demonstrates the above scenario.

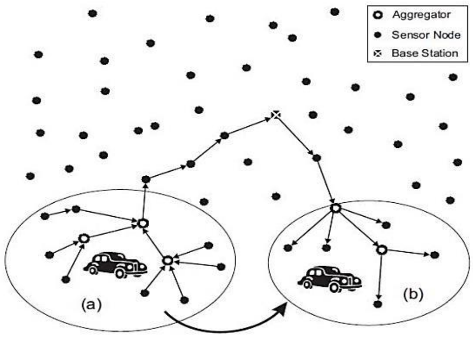

Fig 7: A tracking application using both (a) aggregation and (b) dissemination.

4.2 Data compression

This method basically compresses the received data and then transmits it when needed. Time sensitive phenomena like change in temperature needs to be constantly monitored and recorded. This results in large accumulation of redundant data. As there is redundant data, the transmission of such data to the base station or the sink requires tremendous amount of energy which could be reduced if there is less transmission load. This is where data compression is useful as it compresses the data at the nodes or *aggregators* and thus transmits only the required data. Some of the algorithms that are used for data compressions are:

- Lossless compression[10]
- Deterministic compression techniques[11]
- KEN[12]
- PREMON[13]
- Adaptive Model Selection (AMS)[14, 15]
- Dual Kalman filter[16]

4.3 Data prediction

As mentioned in section 3.1, this approach mainly depends on the previously sampled models. The efficiency of this approach is governed by the way the model is built. These models are sampled through any of the following techniques shown in Fig.8:

- Stochastic Approaches
- Time series forecasting
- Algorithmic approaches

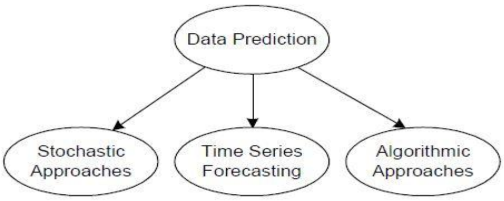

Fig 8: Data prediction approaches

Stochastic Approach mainly deals with the probability and statistical properties of the data. On one hand, the data is sampled as probability density functions (p.d.f) and data prediction can be done by combining these p.d.f's. Or on the other hand, data can be mapped as state space representations wherein the unpredicted sample can be discarded as noise.

Time series forecasting uses historical values for predicting future data in the series. It can be represented as a pattern which is characterized by long term variation and seasonality. Once this pattern is full-fledged it can be used to predict future values in the time series,

Algorithmic approaches rely on heuristics and state-transition model which derives methods and procedures to derive a model and update it based on the characterization.

4.4 Discussion

Specs	**In network processing**	**Data compression**	**Data prediction**
Accuracy	Very high	High	Moderate
Communication overload on node	Very high	Less compared to in network	Dependent on the input to the node
Communication overload on sink	Low	Slightly more than in network	Dependent on the input to the node
Processing overload	High	High	Dependent on the input to the node

Table 1: Comparison of the three data reduction approaches

In network processing is an accurate method as the data processing is done based on the inputs of all the nodes by a special node. This results in less overload of communication for the sink. However, the overhead on nodes is high due to the constant transmission of data from the nodes to the aggregator.

Data compression on other hand has high accuracy of the data but slightly less compared to that of the in network processing due to the fact that not all data is processed and there are chances of key data to be missed. As less data needs to be transmitted from the node, communication overload on the node is slightly less compared to that of in network processing. Whereas the load at the sink side is higher compared to that of in network processing as every node communicates with the sink. As lot of data compression is involved high processing is required.

As data prediction involves statistics and probability, data accuracy is compromised a bit. However the communication load on the node and sink mainly depends on the data sensed by the node. As it has the predefined range, any offset in the sensed data from the range results in communication or transmission of data to update the model.

V. CONCLUSION

In this paper we have surveyed the power management techniques in a wireless sensor network. Specifically we studied the various data driven approaches and went in deep with the data reduction.In data reduction we studied the three techniques such as: in network processing, data compression and data prediction. We also did a comparison of the three approaches based on certain parameters such as communication overload, processing overload and accuracy of the data.From the comparison we inferred that fusing the data compression and in network processing approaches at the nodes we can drastically reduce the communication overhead on them resulting in reduced power consumption. As WSN's have a wide variety of applications such as smart video surveillance, smart gas detection, health monitoring, natural hazard predictions as well as weather forecast, power management is a very important concern for a long lasting and sustainable network. Thus data reduction approaches have a huge impact on energy conservation.

VI. ACKNOWLEDGMENT

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