A Survey on Duty Cycling Schemes for Wireless Sensor Networks

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***Abstract*—A Wireless Sensor Network (WSN) is a network that is composed of large number of low cost, low power sensor nodes that are interconnected by means of wireless medium and it finds major application in the field of environment monitoring, target tracking, vehicle tracking and surveillance. The unique characteristics of WSNs such as limited bandwidth, computing capacity, data delivery delay and severe energy constraints make their design more challenging. A critical issue in wireless sensor networks is the limited availability of energy and many researches are carried out to for optimizing energy. The best way to improve the network lifetime is by turning the node on/off as per the functionalities. This paper provides a survey on different duty cycling schemes for maximizing the lifetime of the wireless sensor node.**

Keywords-*Wireless sensor network; energy; duty cycling; network lifetime*

I. INTRODUCTION

A sensor network model consists of one (or more) sink(s) and a high number of sensor nodes deployed over a large geographic area (sensing field). Data are transferred from sensor nodes to the sink through a multi-hop communication paradigm. The architecture of a typical wireless sensor node is shown in Figure 1. 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. Depending on the specific application, sensor nodes may also include additional components such as a location finding system to determine their position, a mobilizer to change their location or configuration (e.g., antenna's orientation), and so on. The battery source is very important to improve the network lifetime and hence many techniques have been introduced to prolong the network lifetime.

Applications

Wireless Sensor Networks have broad applications like environment monitoring, target tracking and surveillance. Unlike Mobile Ad-hoc NETworks (MANETs), WSNs are usually application-specific. The areas where WSNs finds its major applications are:

Area monitoring

Area monitoring is a common application of WSNs. In area monitoring, the WSN is deployed over a region where some phenomenon is to be monitored. An example in the military application is the use of sensors to detect enemy intrusion; a civilian example is the geo-fencing of gas or oil pipelines. When the sensors detect the event being monitored (heat, pressure), the event is reported to one of the base stations, which then takes appropriate action (e.g., send a message on the internet or to a satellite). Similarly, wireless sensor networks can use a range of sensors to detect the presence of vehicles ranging from motorcycles to train cars.

Air pollution monitoring

Wireless sensor networks have been deployed in several cities to monitor the concentration of dangerous gases causing air pollution. These can take advantage of the ad-hoc wireless links rather than wired installations, which also support mobility for testing readings in different areas.

Forest fire detection

A network of sensor nodes can be installed in a forest to detect the occurrence of forest fire. The nodes can be equipped with sensors to measure temperature, humidity and gases which are produced by fires in the trees or vegetation. The early detection is crucial for a successful action of the fire, the fire brigade will be able to know how the fire spreads.

Greenhouse monitoring

Wireless sensor networks are also used to control the temperature and humidity levels inside commercial greenhouses. When the temperature and humidity drop below specific levels, the greenhouse manager must be notified via e-mail or cell phone text message, or host systems can trigger misting systems, open vents, turn on fans, or control a wide variety of system parameters.

Landslide detection

A landslide detection system makes use of a wireless sensor network to detect the slight movements of soil and changes in various parameters that may occur before or during a landslide. With the data gathered it may be possible to know the occurrence of landslides long before it actually happens.

Machine health monitoring

Wireless sensor networks have been developed for machinery condition-based maintenance as they offer significant cost savings and enable new functionalities. In wired systems, the installation of enough sensors is often limited by the cost of wiring. Previously inaccessible locations, rotating machinery, hazardous or restricted areas, and mobile assets can now be reached with wireless sensors.

Water/wastewater monitoring

There are many opportunities for using wireless sensor networks within the water/wastewater industries. Facilities not wired for power or data transmission can be monitored using industrial wireless Input/Output (I/O) devices and sensors powered using solar panels or battery packs and also used by pollution control board.

Agriculture

Using wireless sensor networks within the agricultural industry is increasingly common; using a wireless network frees the farmer from the maintenance of wiring in a difficult environment. Gravity feed water systems can be monitored using pressure transmitters to monitor water tank levels, pumps can be controlled using wireless I/O devices and water use can be measured and wirelessly transmitted back to a central control center for billing. Irrigation automation enables more efficient water use and reduces waste.

Structural monitoring

Wireless sensors can be used to monitor the movement within buildings and infrastructure such as bridges, flyovers, embankments and tunnels and thus enable monitoring of assets remotely with out the need for costly site visits, as well as having the advantage of daily data, whereas traditionally this data was collected weekly or monthly, using physical site visits, involving either road or rail closure in some cases. It is also far more accurate than any visual inspection that would be carried out.

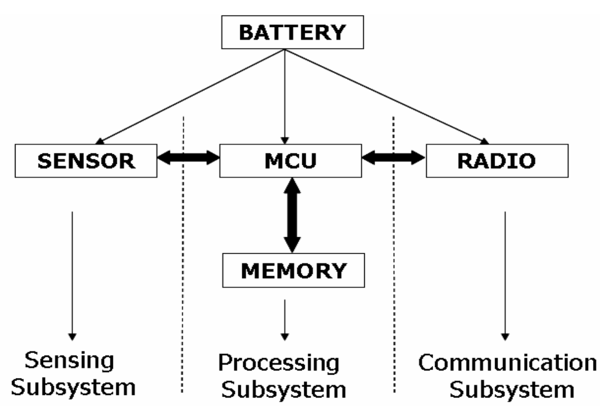

Figure 1. Architecture of a typical wireless sensor node

Duty cycling is one such scheme where the nodes alter between on and off states to minimize the energy consumption. The rest of this paper is organized as follows. Section 2 describes the taxanomy of duty cycling schemes, section 3 describes the power management techniques and the conclusion is presented in section 4.standard paper components have been specified for three reasons: (1) ease of use when formatting individual papers, (2) automatic compliance to electronic requirements that facilitate the concurrent or later production of electronic products, and (3) conformity of style throughout a conference proceedings. Margins, column widths, line spacing, and type styles are built-in; examples of the type styles are provided throughout this document and are identified in italic type, within parentheses, following the example. Some components, such as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

II. TAXONOMY OF DUTY CYCLING SCHEMES

Duty cycling can be achieved through two different and complementary approaches. Nodes that are not currently needed for ensuring connectivity can go to sleep and save energy. Finding the optimal subset of nodes that guarantee connectivity is referred to as topology control. Therefore, the basic idea behind topology control is to exploit the network redundancy to increase the network longevity. On the other hand, active nodes (i.e., nodes selected by the topology control protocol) do not need to maintain their radio continuously on. They can switch off the radio (i.e., put it in the low-power sleep mode) when there is no network activity, thus alternating between sleep and wakeup periods. Throughout it is referred to duty cycling operated on active nodes as power management. Therefore, topology control and power management are complementary techniques that implement duty cycling with different granularity. In the following two subsections, finer classifications of topology control and power management technique are discussed briefly.

III. POWER MANAGEMENT

Power management techniques can be subdivided into two broad categories depending on the layer of the network architecture they are implemented. Power management protocols can be implemented either as independent sleep/wakeup protocols running on top of a MAC protocol (typically at the network or application layer), or strictly integrated with the MAC protocol itself. The latter approach permits to optimize medium access functions based on the specific sleep/wakeup pattern used for power management. On the other hand, independent sleep/wakeup protocols permit a greater flexibility as they can be tailored to the application needs, and can be used with any MAC protocol.

Independent sleep/wakeup protocols

Independent sleep/wakeup protocols can be classified in three broad categories, depending on the general approach they take to decide when sensor nodes should be switched on. They are

- On-demand
- Scheduled rendezvous
- Asynchronous protocols

It may be worthwhile to recall here that sensor nodes must coordinate their wakeup periods in order to make multi-hop communication feasible and, hopefully, efficient.

On-demand

On-demand protocols [1] take the most intuitive approach to power management. The basic idea is that a node should wakeup only when another node wants to communicate with it. This maximizes energy saving since a node remains active only for the minimum time required for communication. In addition, there is only a very limited impact on latency because the corresponding node wakes up immediately as soon as it realizes that there is a pending message.

The main problem associated with on-demand schemes is how to inform the sleeping node that some other node is willing to communicate with it. Typically, such schemes use two different radio channels. The first channel is used for normal packet exchange (data radio), while the second one is used to awake a node when there is message ready for it (wakeup radio). The data radio is normally off, and is switched on only when a signal is received through the wakeup radio. Clearly, the wakeup radio should have a limited impact on the node's consumption. Different on- demand schemes differ in the way they use the wakeup radio. In many cases the power consumption of the wakeup radio is not very different from that of the data radio. Duty cycling scheme is thus used on the wakeup radio as well. Other works assume that the wakeup radio is very low-power and can thus be always on. The drawback is that the low-power wakeup radio typically has a communication range smaller than the data radio. This is a strong limitation since two neighboring nodes may be within each other's data radio transmission range but not within the wakeup radio range. When a second (wakeup) radio is not available or convenient, an alternative is using a scheduled rendezvous approach.

Scheduled rendezvous

The basic idea behind scheduled rendezvous schemes is that each node should wakeup at the same time as its neighbors. Typically, nodes wake up according to a wakeup schedule, and remain active for a short time interval to communicate with their neighbors. Then, they go to sleep until the next rendezvous time. Different schemes differ in the sleep/wakeup pattern followed by nodes. A drawback of the scheduled rendezvous schemes is that energy saving is obtained at the expense of an increased latency experienced by messages to travel through several hops. An additional drawback is that nodes must be synchronized.

In the literature several clock synchronization protocols (e.g., [2]) have been proposed to keep nodes synchronized. However, maintaining a tight synchronization among nodes requires a high overhead in terms of exchanged control messages. This, of course, results in energy consumption. The basic assumption behind scheduled rendezvous schemes is that the energy spent for keeping nodes synchronized is largely compensated by the energy saving achieved through power management.

Asynchronous protocols

To avoid node synchronization an asynchronous sleep/wakeup protocol can be used [3]. In the asynchronous protocols a node can wakeup when it wants and still be able to communicate with their neighbors. This goal can be achieved by designing a sleep/wakeup scheme such that any two neighboring nodes always have overlapped active periods within a specified number of cycles. Asynchronous schemes are generally easier to implement and can ensure network connectivity even in highly dynamic scenarios where synchronous schemes (i.e., scheduled rendezvous) become inadequate. This greater flexibility is compensated by lower energy efficiency. In the asynchronous schemes nodes need to wakeup more frequently than in scheduled rendezvous protocols. Therefore, asynchronous protocols usually result in a higher duty cycle for network nodes than their synchronous counterparts. In other words, they trade energy consumption for ease of implementation and robustness of network connectivity.

MAC protocols with low duty cycle

MAC protocols with low duty cycle can be broadly subdivided into three main categories:

- TDMA-based
- Contention-based
- Hybrid protocols

TDMA-based

TDMA (Time Division Multiple Access) schemes [4] naturally enable a duty cycle on sensor nodes as channel access is done on a slot-by-slot basis. Time is slotted and slots are arranged in frames. Within each frame slots are assigned to individual nodes and can be used for transmitting/receiving packets to/from other nodes. Nodes need to turn on their radio only during their own slots and can sleep during slots assigned to other nodes. In principle, this allows to limit the energy consumption to the minimum required for transmitting/receiving data. In practice, TDMA- based protocols have several drawbacks that compensate the benefits in terms of energy saving. They lack flexibility, have limited scalability, and require tight synchronization among network nodes. In addition, it is hard to find a slot assignment which avoids interferences between neighboring nodes because the interference range is larger than the transmission range and, above all, it is time-varying. Moreover, TDMA-based protocols perform worse than contention-based protocols in low traffic conditions. For all the above reasons they are not frequently used as stand-alone protocols.

Contention-based

Contention-based protocols are the most popular class of MAC protocols for wireless sensor networks. They achieve duty cycling by tightly integrating channel access functionalities with a sleep/wakeup scheme similar to those described above. The only difference is that in this case the sleep/wakeup algorithm is not a protocol independent of the MAC protocol, but is tightly coupled with it.

Hybrid protocols

Finally, hybrid protocols [5] try to combine the strengths of TDMA-based and contention-based MAC protocols while offsetting their weaknesses. The intuition behind hybrid protocols is to adapt the protocol behavior to the level of contention in the network. They behave as a contention-based protocol when the level of contention is low, and switch to a TDMA scheme when the level of contention is high.

IV. CONCLUSION

Sensor nodes are powered by battery and since they are deployed at large numbers where human finds difficult to go, it is tedious to replace battery. Hence, some mechanisms are required to improve the lifetime of the sensor network. This paper describes the duty cycling methods to prolong the sensor network lifetime. Power management protocols can be implemented either as independent sleep/wakeup protocols running on top of a MAC protocol or strictly integrated with the MAC protocol itself.

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