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Energy Conservation in Wireless Sensor Network

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Abstract

An ad-hoc network is a local area network (LAN) that is built spontaneously as devices connect. Instead of relying on a base station to coordinate the flow of messages to each node in the network, the individual network nodes forward packets to and from each other. In Latin, "Ad-hoc" is actually a Latin phrase that means "for this purpose." It is often used to describe solutions that are developed on-the-fly for a specific purpose. In computer networking, an ad hoc network refers to a network connection established for a single session and does not require a router or a wireless base station.

Keywords : Wireless Sensor Network

Introduction

An ad-hoc network is a collection of wireless mobile hosts forming a temporary network without the aid of any stand-alone infrastructure or centralized administration. Mobile Ad-hoc networks are self-organizing and self-configuring multi-hop wireless networks where, the structure of the network changes dynamically. This is mainly due to the mobility of the nodes. Nodes in these networks utilize the same random access wireless channel, cooperating in a friendly manner to engaging themselves in multihop forwarding. The node in the network not only acts as hosts but also as routers that route data to/from other nodes in network [1]. The main limitation of ad-hoc systems is the Availability of power. In addition to running the onboard electronics, power consumption is governed by the number of processes and overheads required to maintain connectivity [2]. The disadvantage of ad hoc network is that the nodes should be in range of a base, so that these nodes can receive the information and transmit it for further devices. If these nodes are not available, the whole network would fail [1]. There is cooperation between networks so that they should all be ready to receive and transmit data. Also, a single node can receive data from multiple other nodes, without the other nodes knowing about each other. Ad-hoc network is a multi-hop wireless network, which consists of number of mobile nodes [5]. The key challenges of Ad-hoc networking are resource management, scalability, and especially security.

Although ad hoc networks have several advantages over the traditional wired networks, on the other side's they have a unique set of challenges.

Firstly, adhoc networks face challenges in secure communication. For example the resource constraints on nodes (viz. power consumption) in ad hoc networks limit the cryptographic measures that are used for secure messages. Thus it is susceptible to link attacks ranging from passive eavesdropping to active impersonation, message replay and message distortion.

Secondly, mobile nodes without adequate protection are easy to compromise. An attacker can listen, modify and attempt to masquerade all the traffic on the wireless communication channel as one of the legitimate node in the network.

Thirdly, static configuration may not be adequate for the dynamically changing topology in terms of security solution. Various attacks like DoS (Denial of Service) can easily be launched and flood the network with spurious routing messages through a malicious node that gives incorrect updating information by pretending to be a legitimate change of routing information .

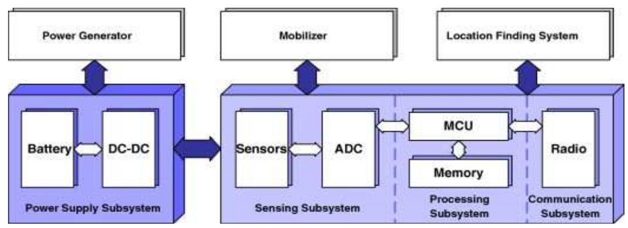
Sensor Network Architecture

In this paper we will refer mainly to the sensor network model depicted in and consisting of one sink node (or base station) and a (large) 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. We will consider first the case in which both the sink and the sensor nodes are static (static sensor network). Then, we will also discuss energy conservation schemes for sensor networks with mobile elements in Section , in which a sparse sensor network architecture – where continuous end-to-end paths between sensor nodes and the sink might not be available – will be accounted as well.

Experimental measurements have shown that generally data transmission is very expensive in terms of energy consumption, while data processing consumes significantly less . The energy cost of transmitting a single bit of information is approximately the same as that needed for processing a thousand operations in a typical sensor node. The energy consumption of the sensing subsystem depends on the specific sensor type.
In many cases it is negligible with respect to the energy consumed by the processing and, above all, the communication subsystems. In other cases, the energy expenditure for data sensing may be comparable to, or even greater than, the energy needed for data transmission. In general, energy-saving techniques focus on two subsystems: the networking subsystem (i.e., energy management is taken into account in the operations of each single node, as well as in the design of networking protocols), and the sensing subsystem (i.e., techniques are used to reduce the amount or frequency of energy-expensive samples).Presenting a complete set of networking protocols for wireless sensor networks. The lifetime of a sensor network can be extended by jointly applying different techniques. For example, energy efficient protocols are aimed at minimizing the energy consumption during network activities. However, a large amount of energy is consumed by node components (CPU, radio, etc.) even if they are idle. Power management schemes are thus used for switching off node components that are not temporarily needed. In this paper we will survey the main enabling techniques used for energy conservation in wireless sensor networks. Specifically, we focus primarily on the networking subsystem by considering duty cycling. Furthermore, we will also survey the main techniques suitable to reduce the energy consumption of sensors when the energy cost for data acquisition (i.e. sampling) cannot be neglected. Finally, we will introduce mobility as a new energy conservation paradigm with the purpose of prolonging the network lifetime. These techniques are the basis for any networking protocol and solution optimized from an energy-saving point of view.

General Approaches to Energy Conservation

From a sensor network standpoint, we mainly consider the model depicted in, which is the most widely adopted model in the literature. On the other side, the architecture of a typical wireless sensor node, as usually assumed in the literature. 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. However, as the latter components are optional, and only occasionally used, we will not take them into account in the following discussion.



Architecture of typical wireless sensor mode

Obviously, the power breakdown heavily depends on the specific node. In it is shown that the power characteristics of a Mote-class node are completely different from those of a Star gate node. However, the following remarks generally hold.

•The communication subsystem has an energy consumption much higher than the computation subsystem. It has been shown that transmitting one bit may consume as much as executing a few thousands instructions . Therefore, communication should be traded for computation.

•The radio energy consumption is of the same order of magnitude 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, even simultaneously, 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.

Duty cycling is mainly focused on the networking subsystem. The most effective energy-conserving operation is putting the radio transceiver in the (low-power) 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 periods 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).

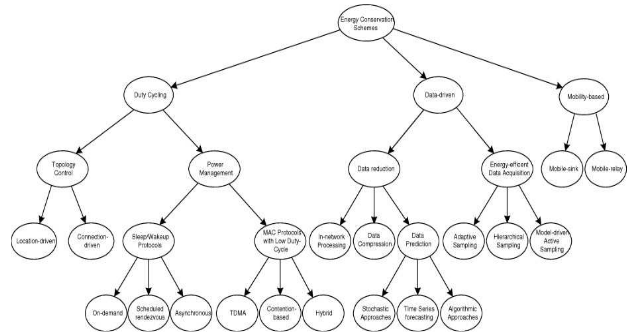
Duty-cycling schemes are typically oblivious to data that are sampled by sensor nodes. Hence, data-driven approaches can be used to improve the energy efficiency even more. In fact, data sensing impacts on sensor nodes' energy consumption in two ways:

•Unneeded samples. Sampled data generally have strong spatial and/or temporal correlations, 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 unneeded 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). 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 communication takes 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 will be roaming in the sensing field anyway, such as buses or animals.

Mobile Relay Based Approaches

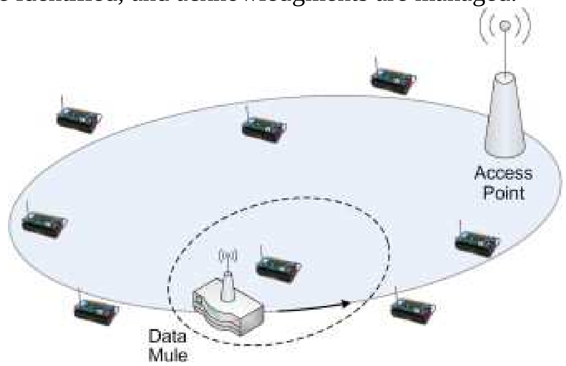
The Mobile Relay (MR) model for data collection in multi-hop ad hoc networks has already been explored in the context of opportunistic networks. One of the most well-known approaches is given by the message ferrying scheme. Message ferries are special mobile nodes which are introduced into a sparse mobile ad hoc network to offer the service of message relaying. Message ferries move around in the network area and collect data from source nodes. They carry stored data and forward them towards the destination node. Thus, message ferries can be seen as a moving communication infrastructure which accommodates data transfer in sparse wireless networks.

A similar scheme has also been proposed in the context of sparse wireless sensor networks through the data-MULE system. In detail, the data-MULE system consists of three-tier architecture.

(i)The lower level is occupied by the sensor nodes that periodically perform data sampling from and about the surrounding environment.

(ii)The middle level consists of mobile agents named Mobile Ubiquitous LAN Extensions, or MULEs for short. MULEs move around in the area covered by sensors to gather their data, which have previously been collected and temporarily stored in local buffers. Data MULEs can be for example people, animals, or vehicles too. Generally, they move independently from each other and from the sensor positions by following unpredictable routes. Whenever they get within reach of a sensor they gather information from it.

(iii)The upper level consists of a set of Access Points (APs) which receive information from the MULEs.They are connected to a sink node where the data received is synchronized and stored, multiple copies are identified, and acknowledgments are managed.



Sensor nodes – which are supposed to be static – wait for a MULE to pass by and send data to it. Sensor-to-MULE transmissions make use of short-range radio signals and hence energy consumption is low. While moving around, the MULE eventually passes by any AP and transmits the data collected from sensors to it.In fact, changing the trajectory of the MR is not always possible in case of sensor networks because sensors may be deployed in places with obstacles, on rough terrain, or generally where unmanned vehicles can move only in certain directions. Sensor nodes which are located in proximity of the MR path send their data directly to the MR when passing by. Nodes which are far apart from the path followed by the MR send their data over a multi-hop path towards the MR when it passes by or alternatively to one of the nodes which are positioned near to the path of the MR. These nodes act as data caches until the MR passes and finally collects all stored data. Energy saving is addressed in that a large number of nodes is visited by the MR and can thus transmit data over a single hop connection using short range radio. The other nodes which are not in proximity of the path followed by the MR send their data over a multi-hop path which is however shorter, and thus cheaper, with respect to the path established towards a fixed sink node in a classical dense wireless sensor network. To manage this kind of data collection, nodes self-organize into clusters where cluster heads are the nodes which are nearer to the path of the MR whereas the other nodes of the cluster send their data to the cluster head for storage until the next visit of the MR. Data from the sensor nodes of the cluster travel towards the cluster heads according to the directed diffusion protocol. Election of the cluster heads is kept after the first traversal of the MR. During this traversal the MR does not collect any data. Transmissions from cluster heads to the MR occur only when the MR is in proximity so as not to waste energy in useless transmissions. As the trajectory of the MR is assumed to be fixed, it can be controlled only in time. The MR can move at a constant speed worked out, for example, depending on the buffer constraints of the cluster heads. Each cluster head is thus visited before its buffer runs out of space. However, better performance is experienced when the MR alternates between two states: moving at a certain constant speed or stopping. So MR moves fast in places with no, or only a few, sensors and stops in proximity of cluster heads where sensor deployment is denser. The determination of places where sensor deployment is denser (congested regions) is done at each traversal of the MR.

Thanks to the short-range radio communication, the Data MULEs architecture is an energy-efficient solution for data gathering in sparse sensor networks. It also guarantees scalability and flexibility against the network size. Unfortunately, this solution has a couple of limits, both depending on the randomness of the MULEs' motion. First, the latency for data arrival at the sink may be considerable, because (possibly) long time intervals elapse from the sampling instant to the moment the MULE takes the data, and then till the time the MULE actually reaches the AP and delivers the data to it. The second drawback is the fact that sensors have to continuously wait for any MULE to pass and cannot sleep. This leads to energy wastage. Finally, energy-efficient approaches based on a single data mule have limited scalability. To this end in the previous work of is extended by considering multiple mobile elements. An example application of this model in the context of underwater sensor networks is given by, where Underwater Autonomous Vehicles are exploited to monitor and model the behavior of the underwater ecosystems.

The architecture of systems described so far assumes an heterogeneous network composed by MRs and static nodes. There are also examples of sensor networks where all nodes are placed on mobile elements. An example of this kind is Zebranet, a system for wildlife tracking focused on the monitoring of zebras. A system similar to Zebranet, SWIM, is presented in the context of a wildlife telemetry application for monitoring of whales. We present the more interesting aspects of Zebranet in detail below. The animals are equipped with special collars embedding sensor nodes, each including a GPS unit and a dual radio. One of the radio is used for short-range communication, e.g. it is used when zebras gather around water sources. The other radio is used to reach the access point and the animals which are far away from the others. The access point is a vehicle which sometimes traverses the monitored area to gather data. It is worth noting that in this kind of system all nodes are mobile, i.e. both the sink and the sensor nodes, and zebras act as MRs. Zebras act as peers, so that they exchange data during encounters. As zebras are mobile, it is likely that after some time the animals will find other contacts and exchange data again. When, a zebra reaches the area covered by the access point, it uploads the data it is carrying – i.e. its own data and data collected from the encountered peers. A possible solution for data exchange consists in a simple flooding protocol, so that data are pushed to neighbors as soon as they are discovered. Even though this approach can lead to a high success rate (in terms of the number of data collected by the access point), it has excessive bandwidth, capacity and energy demands. In order to save energy, a history-based data collection and dissemination protocol is proposed. Each node is assigned to a hierarchy level, where the level expresses the likelihood of a node being close to the access point. In detail, a level of a node depends on its ability to have successfully transmitted data to the access point in the past. In fact, nodes which have recently been in the range of the access point are likely to relay messages directly or, at most, through a limited number of other nodes. When a node encounters other peers, it first asks their hierarchy level, then it sends data to the one with the highest level. The hierarchy level of a node is increased when it comes in the range of the access point. Conversely, the level is decreased as nodes remain far from the access point. The history-based data dissemination protocol is proved to be efficient in terms of energy and success rate by simulation.

Conclusion

In this paper we have surveyed the main approaches to energy conservation in wireless sensor networks. Special attention has been devoted to a systematic and comprehensive classification of the solutions proposed in the literature. We did not limit our discussion to topics that have received wide interest in the past, but we have also stressed the importance of different approaches such as data-driven and mobility-based schemes. It is worth noting that the considered approaches should not be considered as alternatives, they should rather be exploited together.

We can draw final observations about the different approaches to energy management. As far as "traditional" techniques to energy saving, an important aspect which has to be investigated more deeply is the integration of the different approaches into a single off-the-shelf workable solution. This involves characterizing the interactions between different protocols and exploiting cross-layer interactions.

Another interesting point is that most of the solutions proposed in the literature assume that the energy consumption of the radio is much higher than the energy consumption due to data sampling or data processing. Many real applications, however, have shown the power consumption of the sensor is comparable to, or even greater than, the power needed by the radio. In addition, the sampling phase may need a long time – especially if we compare it to the time needed for communications – so that the energy consumption of the sensor itself can be very high as well. We think that the field of energy conservation targeted to data acquisition has not been fully explored yet, so that there is room for developing convenient techniques to reduce the energy consumption of the sensors.

Finally, we observe an increasing interest towards a sparse sensor network architecture. In many practical applications such a network can be very efficient and robust if communication protocols can appropriately exploit the mobility of collector nodes. We are persuaded that this class of approaches will get an even greater importance and attention within the research community in the next years.

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