# Increasing Intelligent Wireless Sensor Networks Survivability by Applying Energy-Efficient Schemes

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**Abstract.** Intelligent Energy efficiency is an important research topic for ad-hoc Wireless Sensor Networks (WSN). Power saving makes it possible to guarantee basic levels of system performance, such as connectivity, throughput and delay, in the presence of both mobility-immobility and a large number of sensor nodes. A large variety of approaches for intelligent energy-efficient schemes have been proposed in the literature focusing on different performance metrics. This article presents a comprehensive survey of recent energy-efficient schemes in ad-hoc wireless sensor networks, the application of which increases nodes' lifetime and thus, network connectivity and survivability.

## 1 Introduction

Wireless Sensor Networks (WSNs) have been increased dramatically the recent years as they are used more and more in the daily life. Such ad-hoc wireless sensor networks find applications in medical, military, motion tracking, environmental control etc. Wireless Sensor Networks consist of a great number of small in size, inexpensive, low-power intelligent sensor nodes, which are densely and randomly distributed either inside the phenomenon or very close to it. Sensor nodes consist of sensing, processing and communicating components because their function is to collect and disseminate critical data while their position need not be predetermined [1]. Network lifetime is very important issue in the WSNs. The energy problem

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becomes harder in ad-hoc wireless sensor networks; due to their limitations arising from their nature. In order to guarantee the WSNs survivability and increase network lifetime in such special purpose environments intelligently, various energy-efficient schemes have been proposed in the literature. This paper presents and evaluates recent energy-efficient schemes; where their efficient choice extends the nodes' lifetime and therefore the network data communication and survivability.

The rest of the paper is organized as follows: Section 2 discusses the survivability issues arising from the application of energy-efficient schemes. Section 3 proposes and analyzes various energy-efficient schemes in Ad-hoc intelligent wireless sensor networks and Section 4 presents a performance evaluation. Finally, Section 5 concludes the paper.

## 2 Survivability Issues by the Application of Energy-Efficient Schemes in Intelligent Wireless Sensors

The main performance issues of mobile ad-hoc sensor networks include the speed and ease of deployment, efficient data delivery and efficient use of device battery life. Data delivery is intimately related to the routing protocol used the aim of which is to maintain network connectivity in an efficient manner. Battery life is a major player in such networks and also an important limiting resource. Battery power is used to run local applications on a device as well as to send, receive and relay data. Conserving battery life is an important consideration in maintaining network connectivity. Such a network requires a lightweight energy-management framework that does not burden the resource-limited network nodes with undue processing needs. Thus, in order to guarantee the WSNs' survivability and increase network lifetime in various environments, many energy-efficient schemes have been proposed. In some cases, wireless sensors are expected to be able to operate for a long period of time in the idle mode, and transmit the gathered data, when required, as soon as possible. Under theses assumptions, most of the time the sensor nodes waste energy by listening continuously to the wireless channel, even though no useful information is being transmitted. Why are the energy-efficient schemes so important for the intelligent sensors?

Given the dynamic nature of most sensor networks, an efficient energy-management framework enhances the overall survivability of the network. For that reason, using stable communication links is crucial for establishing stable paths between sensor nodes. Rerouting is especially costly in these networks without infrastructure, since it usually results in (at least partly) flooding the network. The stability of a communication link is given by its probability to persist for a certain time span, which is not necessarily linked with its probability to reach a very high age. For example, consider a number of sensor nodes randomly spread over in a hostile area where the target of interest is moving. Consider also, that the sensors' density depends on operation scope (motion detection, tracking etc.) of the sensor as well as the land morphology. Also, the replacement frequency of the sensors or the sensors' battery is very rare, due to replacement cost. Moreover, the existence of alternative routing improves the survivability of communication. It minimizes failures and the packet delivery delays. It increases network complexity and the energy spent in each sensor node. In order to track the specific target intelligently, metrics from at least two nodes are required. In case that one sensor is out of battery, the system cannot come to the result and thus the intelligent system fails to attain its goal. Therefore, energy is a valuable commodity in wireless networks due to the limited battery of the portable devices. It does not only extend network communication but guarantees intelligent system's performance.

# 3 Energy-Efficient Schemes in Ad-hoc Intelligent Wireless Sensor Networks

Several Energy-Efficient Schemes have been proposed in the literature. The Energy-Efficient Scheme may be classified into two main categories: Active and Passive. Active refers to mechanisms that achieve energy conservation by utilizing energy-efficient network protocols, and Passive refers to mechanisms that save a node's power by turning-off the radio (transceiver) interface module [2]. However our research work considers only the Passive ones.

## 3.1 Power-Aware Multi-Access with Signaling (PAMAS)

PAMAS (Power-Aware Multi-Access with Signaling) is a new multi-access protocol for ad-hoc radio networks based on the original MACA protocol with the addition of a separate signaling channel [3]. It saves nodes' battery power, by turning-off the nodes which are not in active transmission or sending packets. In PAMAS protocol the receiving mobile nodes transmit a busy tone (in a separate control channel) when they start receiving frames so that other mobile nodes know when to turn-off. When a mobile node does not have data to transmit, it should power itself off if a neighbor begins transmitting to some other node. A node should turn-off even if it has data to transmit if at least one of its neighbor-pairs is communicating. A mobile node, which has been turned-off when one or more of its neighbor-pairs started communicating, can determine the length of time that it should be turned-off by using a probe protocol. In this protocol, the node performs a binary search to determine the time when the current transmission will end. However, the loss of probe frames may cause significant power wastage.

## 3.2 Sensor-MAC (S-MAC)

S-MAC (Sensor-MAC) is an intelligently distributed protocol, which gives the possibility to nodes to discover their neighbors and build sensor networks for communication without being obliged to have master nodes. [4]. There are no clusters or cluster heads here. The topology is flat. This solution, proposed by Wei Ye et al. [5], focuses mainly on the major energy wastage sources while achieving good scalability and collision avoidance capability. The major energy wastage sources may be classified into overhearing, idle listening, collisions and control packet overhead [6]. S-MAC introduces the following two techniques to achieve the reduction of energy consumption. Firstly, neighboring nodes are synchronized to go to sleep periodically so that they do not waste energy when a neighboring node is transmitting to another node or by listening to an empty channel. The overhearing problem is avoided this way. Secondly, the control packet overhead of the network is kept low because synchronized neighboring nodes form virtual clusters to synchronize their wake-up and sleep periods. Actually, there is no real clustering and no inter-cluster communication problem. Also, S-MAC consists of three components: Periodic Listen and Sleep, Collision and Overhearing Avoidance and Message Passing. In Periodic Listen and Sleep Neighboring nodes are synchronized in such a way as to listen together and sleep together. In Collision and Overhearing Avoidance, collision is avoided through the adoption of a contention-based scheme. In Message Passing, the indicated method is the fragmentation of long messages into smaller ones and their transmission in a burst.

### 3.3 Dynamic Voltage Scaling (DVS)

The application of turn-off techniques can produce substantial energy savings in idle system states; however, additional energy savings are possible through the optimization of the sensor node performance in the active state. Dynamic Voltage Scaling (DVS) is an effective tool for reducing to the minimum the CPU energy [7], [8]. If we recognize that peak performance is not always required, then we can achieve significant energy savings. This implies the dynamic adaptation of the processor's operating voltage and frequency based on instantaneous processing requirements. The main idea behind DVS is to adapt the power supply to the changes of the workload. In other words, this approach varies the processor voltage under software control to meet dynamically varying performance requirements. More analytically: DVS allows devices to dynamically change their speed and voltage, while in operation, and thus trade-off energy for delay. This allows the processor to provide the minimum required (necessary) clock frequency with the maximum possible energy efficiency. To do this, DVS requires intelligent algorithms, termed voltage schedulers, to determine the operating speed of the processor at run-time. The goal of DVS is to adapt the power supply and operating frequency to match the workload. This way, the visible performance losses are not of importance. The hard part of the problem lies in the fact that future workloads are often non-deterministic. So the efficiency depends on predicting the future workloads.

### 3.4 Dynamic Power Management (DPM) in Wireless Sensor Networks

An operating-system-directed power management technique, contributing to a dynamic increase of the lifetime of the sensor node, is proposed by Sinha et al. [9]. This model of sensor node deals with switching of node state in a power-efficient manner. Once the system has been designed, additional power savings can be obtained by using Dynamic Power Management (DPM). DPM is an effective tool in reducing system power consumption without significantly degrading performance. The basic idea behind this scheme is to turn sensor node components (sensor with A/D converter, Processor, Memory and Transceiver) OFF when not required (if no events occur) and get them back (wake them up) when necessary. Such event-driven power consumption is critical to maximum battery life. Although this power-saving method seemingly provides significant energy gains, we should not overlook the fact that sensor nodes communicate with each other using short data packets [4]. The shorter in length the packets are, the more the consumption of start-up energy is achieved. This is because the switching of a node, from one state to another, takes some finite time and resource. More analytically, sleep-state transitioning has the overhead of storing processor state and turning-off power. Waking-up also takes a finite amount of time. Therefore, if we keep turning the transceiver OFF during each idling slot, over a certain period of time, then we might end-up consuming more energy than if the transceiver had been left ON. So, the operation in a power-saving mode is energy-efficient only if the time spent in that mode is greater than a certain threshold. It is obvious that the implementation of the correct policy for sleep-state transitioning is critical for DPM success. The authors propose a workload prediction strategy based on adaptive filtering of the past workload profile and analyze several filtering schemes.

### 3.5 Energy-Efficient Communication Protocol for Wireless Micro-Sensor Networks (LEACH)

The authors [10] focus on communication protocols, which can have significant effect on the overall energy dissipation of these networks. The analysis of the advantages and disadvantages of the conventional routing protocols proved that these protocols of direct transmission, minimum transmission energy, multi-hop routing, and static clustering might not be optimal for wireless micro-sensor networks. LEACH (Low-Energy Adaptive Clustering Hierarchy) [10] is an intelligent self-organizing, clustering-based protocol which minimizes energy dissipation in wireless micro-sensor networks by using randomized rotation of the high-energy cluster-head position in such a way as to rotate among the various sensors in order to distribute the energy load evenly among the sensors in the network. This rotation allows the energy requirements of the system to be distributed evenly among all the micro-sensors and thus, not draining the battery of a single sensor. LEACH randomly selects micro-sensor nodes as cluster heads, so the high energy dissipation in communicating with the base station is spread to all the sensor nodes in the micro-sensor network. Once all the nodes are organized into clusters, each cluster head creates a schedule for the nodes in its cluster. This allows the radio components of each non-cluster-head node to be turned-off at all times except during their transmit time, thus minimizing the energy dissipated in the individual sensors. In addition, LEACH is able to perform local computation in each cluster head to reduce the amount of data that must be transmitted to the base station. This achieves a large reduction in the energy dissipation, as computation is much cheaper than communication. LEACH can achieve as much as a factor of 8 reduction in energy dissipation compared with direct communication and a factor of 4 to 8 reduction in energy compared with MTE (Minimum Transmission Energy) routing. In addition to reducing energy dissipation, LEACH successfully distributes energy usage among the nodes in the network such that the nodes die randomly and at essentially the same rate.

### 3.6 Intra-Super-Frame Power Management for IEEE 802.15.3 WPAN

Since Power Management (PM) is an important issue for the battery-powered portable devices, the proposed scheme should satisfy the following objectives: To assist the devices to sleep and, to reduce the wakeup time as much as possible. There have been several works in literature on the MAC design for power management in wireless systems. Most of them were based on the MAC layer of 802.11 WLAN and there has been no work report on IEEE 802.15.3 systems so far. IEEE 802.15.3 [11] has gained much research attention recently and it is to enable a high-speed and low-power wireless connectivity among portable devices within a Wireless Personal Area Networks (WPAN). PM is critical for the portable devices in IEEE 802.15.3 WPAN. Due to the property of TDMA-based MAC of 802.15.3, one of the key issues for power management is to schedule the order of the multiple streams among multiple users to minimize the total wakeup times. Thus, it is revealed that this power management problem is in general a Hamilton path problem. Using the graph theory, the authors define the lower bounds and upper bounds for minimum wakeup times. An efficient Minimum-Degree Searching (MDS) Algorithm is proposed to find the suboptimal order.

### 3.7 TDMA Scheduling for Energy Efficiency in Wireless Sensor Networks

TDMA Scheduling Schemes can be used for energy-efficiency in WSNs. Sleep-mode synchronization schemes (like S-MAC) unavoidably introduce sleep-mode related delay that increases with the achieved power conservation. TDMA scheduling in ad-hoc wireless sensor networks is equivalent to the Broadcast Scheduling Problem (BSP), which is a well-known NP-Complete problem. Thus, intelligent algorithms are required for providing near-optimal solutions. Both distributed and centralized algorithms may be introduced to solve this problem of TDMA scheduling. Even though distributed algorithms are more suitable for wireless sensor networks, centralized TDMA scheduling allows more flexibility. In case the centralized approach is used, the gateway gathers the connectivity information between all the sensor nodes in the network, and uses existing energy-efficient routing algorithms to calculate the paths from every sensor node to the gateway. Then, the gateway constructs a TDMA frame that ensures collision avoidance. This schedule is broadcasted back to the sensor nodes, allowing them to know when they can transmit or receive a packet. On the other hand, if a distributed TDMA scheduling scheme is used, the TDMA frame is constructed locally based on information exchanged between neighbors. The basic concept of the proposed scheme is to optimize the operation of these schemes, in order to minimize the end-to-end delay. In the proposed scheme the sensor nodes are normally in sleep mode. Network connectivity is ensured by scheduling TDMA-based wakeup intervals, which are used for propagating WakeUp messages, prior to data transmissions. Appropriate scheduling of the WakeUp intervals allows the data packets to be delayed by only one sleep interval for the end-to-end transmission from the sensors to the gateway. More specifically, the proposed algorithm [12] can create a TDMA schedule appropriate for WU transmissions in wireless sensor networks. The TDMA scheduling algorithm assigns a transmission slot for every node in the sensor network, and a number of reception slots for every forwarding sensor node, one for each corresponding transmitting sensor node. Moreover, possible transmissions, to the same destination, should be assigned in different time slots. Sensor nodes, which are not one-hop neighbors, should receive at the same time, in order to achieve the reduction of the total frame length to the minimum possible.

## 4 Performance Evaluation

For both DPM and DVS schemes, the operation in a power-saving mode is energy-efficient only if the time spent in that mode is greater than a certain threshold. It is obvious that the implementation of the correct policy for sleep-state transitioning is critical for energy saving. However, the authors propose a workload prediction strategy based on adaptive filtering of the past workload profile and analyze several filtering schemes. On the other hand, sleep-wakeup strategies like PAMAS, S-MAC and TDMA do not require this kind of predictions, but the energy conservation is limited by other factors such as the access delay and/or hardware complexity. For the PAMAS scheme, simulation results showed that power saving in the range from 10% (for sparsely connected networks) to almost 70% (for fully connected networks) could be achieved without affecting the delay-throughput behavior. The main disadvantage of the PAMAS scheme is that it requires a separate signaling channel, and thus requiring more complicated hardware. In addition to that the power losses of the signaling channels should be taken seriously into account. However, since the PAMAS scheme does not affect the delay, it can be useful for delay-critical wireless sensor networks. On the other hand, the S-MAC algorithm is fully distributed, and relies on local exchange of neighboring information. The periodic listen and sleep of the S-MAC algorithm can achieve significant power saving, at the cost of the end-to-end delay that becomes excessive for multi-hop communications. Finally, the TDMA scheme is balanced between the two previous schemes, and can achieve the lowest end-to-end delay for a specific power conservation level in some wireless sensor network configurations (almost static topology, very low traffic load). These wireless sensor networks, that are typical in environmental monitoring and disaster WSNs are expected to have a longer lifetime and the application of the S-MAC scheme can be the best solution. For the other WSNs topologies, where the main problem is how to schedule the order of the multiple streams among multiple users to minimize the total wakeup times, the MDS algorithm can be a suboptimal solution. The simulation results for the MDS algorithm show that it is usually near-optimal (more than 95%) and it can actually achieve the lower bound for the minimum wakeup times in most cases, presenting remarkable performance.

## 5 Conclusions

Intelligent sensor system's efficiency is based on the data obtained by the sensors. Sometimes the information received by one sensor is not enough to perform a measurement correctly (e.g. track a moving object) and the simultaneous data receipt from two or more sensors is required. Also, in various application schemes, replacement of power resources might be impossible. Therefore, sensor node lifetime shows a strong dependence on battery lifetime and intelligent sensors' system performance, depending on the energy-efficient schemes, obtains additional significance. In this paper, several passive energy-efficient schemes were presented, analyzed and evaluated. Although each scheme is well-suited for certain scenarios, it is not guaranteed that any of them is the best for all situations. Intelligent energy-efficient algorithms can not only increase the lifetime of a specific node, but also intelligent scheduling can increase the network lifetime in relation to the required number of nodes for performing a measurement. Thus, the efficient choice of the proper energy-efficient scheme extends the nodes' lifetime, assures network survivability and connectivity and thus the overall system's performance for a specific measurement is accomplished.

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