A Short Review on Sleep Scheduling Mechanism in Wireless Sensor Networks

Zeyu Zhang[1], Lei Shu[1,2](✉), Chunsheng Zhu[3], and Mithun Mukherjee[1]

[1] Guangdong Provincial Key Lab of Petrochemical Equipment Fault Diagnosis, Guangdong University of Petrochemical Technology, Maoming 525000, China
zeyu-zhang@outlook.com, mithun.mukherjee@outlook.com

[2] School of Engineering, University of Lincoln, Lincoln, UK
lshu@lincoln.ac.uk

[3] Department of Electrical and Computer Engineering, The University of British Columbia, Vancouver, Canada
cszhu@ece.ubc.ca

Abstract. As a common train of thought to save energy, sleep scheduling which turns sensor nodes on and off has become a significant method to prolong the lifetime of wireless sensor networks (WSNs). In recent years, many related sleep scheduling mechanisms with diverse emphases and application areas for WSNs have been proposed. This paper reviews those mechanisms and further classifies them in different taxonomies as well as provides an insight into them.

Keywords: Sleep scheduling · Wireless Sensor Networks (WSNs) Insight

1 Introduction

In wireless sensor networks (WSNs) [1–4], most sensor nodes generally have to rely on unrechargeable power sources, e.g., batteries, to provide the necessary power. For certain cases, e.g., outdoor monitoring, it is even difficult to replace the batteries that run out of power. Thus, the power management of sensor nodes is very crucial for WSNs. To address the energy shortage which is generally a bottleneck restricting the applications of WSNs [5], substantial attention have been devoted to sleep scheduling approaches, which have long been used in a wide variety of devices to save energy consumption and prolong the lifetime of equipments, such as air-conditioning compressors, pumps and electric motors [6].

Specifically, as for WSNs, most existing hardware, e.g., CC2420, can support several modes, i.e., transmission mode, idle mode and sleep mode [7]. The power consumption for idle listening is in the same order for transmitting. In other words, if the radio keeps listening for incoming messages, most of the battery energy will be consumed. For example, as much as tens to thousands times the current consumed energy can be drained if the sensor nodes are in the idle listening state for a certain period [8]. Thus, the major goal of sleep scheduling mechanism in WSNs is to reduce the energy consumption of idle listening state on the condition of guaranteeing network connectivity.

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2 Sleep Scheduling

Sleep scheduling means that there is a ratio between the wake up time length in a predefined period and the total length of the period [9]. For example, for a period which is 1 s, if one node stays active for 0.1 s and sleeps for 0.9 s, then the ratio is 0.1.

Sleep scheduling mechanisms for WSNs can be classified into three categories generally, i.e., synchronous schemes, semi-synchronous schemes, and asynchronous schemes.

– **Synchronous Schemes:** For synchronous schemes, such as S-MAC [10], T-MAC [11], sleeping nodes wake up at the same time periodically to communicate with one another, which means the network has to keep a global synchronization.
– **Semi-Synchronous Schemes:** Regarding semi-synchronous schemes (e.g., [12–14]), sensor nodes are generally grouped into clusters. In the same cluster, sensor nodes wake up or go to sleep at the same time. But clusters act together with others asynchronously.
– **Asynchronous Schemes:** In terms of asynchronous schemes, such as [15–17], each sensor node has its own wake-up and sleep schedule.

3 Recent Research

There are a few surveys (e.g., [8]) about sleep scheduling in the last four years. This section summarizes the main conclusions after reviewing recent papers published from 2015 to 2017 about sleep scheduling for WSNs, as shown in Table 1. From the table, we can further observe that most papers focus on the asynchronous scheduling schemes. And machine learning is more widely applied into this field.

4 Future Directions

Sleep scheduling for WSNs aims at saving the energy consumption of WSNs. We list some potential directions in terms of this topic.

1. **Mobile relays and sinks for WSNs:** Sensor nodes around the sink node ran out of energy easily, which can lead to energy hole. Mobile relays and sinks can mitigate this kind of problem. The mobile relay or mobile sink, just like a mobile robot, can travel around to gather information, which offers a good trade-off between energy consumption, latency and delivery delay.
2. **Clustering for WSNs:** For semi-synchronous sleep scheduling schemes, network is generally divided into several clusters, and cluster heads are responsible for communicating with other clusters. In such a way, the cluster heads might need to consume more energy compared with normal sensor nodes. Therefore, how to save the energy consumption for cluster heads is very important.

Table 1. Analysis of recent sleep scheduling mechanisms for WSNs

	Aim	Network structure	Energy	Solution	Advantages
Kordafshari *et al.* [18]	Trade-off between energy conservation and network throughput	Static	Non-rechargeable battery	Evolutionary game theory	Achieve a stable and optimal schedule
Ye *et al.* [9]	Multi agent	Static	Non-rechargeable battery	Fussy logic and Q-learning algorithm	Dynamical adjustment
Mosta-faei *et al.* [19]	Partial coverage and preserve connectivity	Static	Non-rechargeable battery	Learning automation	Adaptive control, global optimization and robustness
Chen *et al.* [20]	Reduce to-sink data transmission delay while lifetime is improved	Static	Non-rechargeable battery	Comparison and adjust duty-cycle	Dynamic adjustment and consider energy hole
Kumar *et al.* [21]	Minimize the active time period of every node	Multi-channel and static	Non-rechargeable battery	Integer linear programming	Less energy consumption and minimize the network latency
Wang *et al.* [12]	Sleep scheduling for critical nodes	Grouped and static	Non-rechargeable battery	Depth first search-based algorithms and k-means cluster algorithm	Maintain group-connectivity
Fang *et al.* [13]	Trade-off between energy harvesting and data transmission	Static, multi-sink, and tree-based	Rechargeable battery and solar energy	Comparative and random scheduling	Lower control overhead and avoid energy hole
Khalil *et al.* [11]	Energy hole and data recovery	Mobile, tree topology	Non-rechargeable battery	Oriented method based on TDMA	Less data collision and save transaction time
Chen *et al.* [22]	Desired area coverage and balance energy consumption	Static	Rechargeable battery and solar energy	Reinforcement learning	Dynamic scheduling and high coverage ratio
Xie *et al.* [23]	Trade-off among the network lifetime, transmission delay and packet loss ratio	Static	Non-rechargeable battery	Based on residual energy	Adjustable schedule
Oller *et al.* [15]	Decrease overhearing and idle listening	Static	Non-rechargeable battery	Wake-up radio	Reduce unnecessary energy waste
Baba *et al.* [16]	Improve the energy efficiency	Static	Replaceable battery	Progressive sleep scheduling and opportunistic routing	Less energy overhead and increase the routing quality
Gupta *et al.* [17]	Minimize the number of active nodes in a field of interest	Three dimensions and static	Non-rechargeable battery	Estimate the probability of a sensor being redundant	Lower energy waste and maintain sensing coverage
Xu *et al.* [24]	Make some nodes sleep and maintain monitoring accuracy	Clustering and static	Non-rechargeable battery	Sentinel nodes and select the cluster head randomly	Effectively balance the energy consumption and extend network lifetime

3. **Energy Harvesting for WSNs:** As a common train of thought to prolong the network lifetime, sleep scheduling can only save energy consumption but cannot generate energy. Thus, energy harvesting becomes a promising area, which can further mitigate the problem of energy shortage.
4. **Wireless charging for WSNs:** Wireless charging provides a convenient way to power electrical devices, which can become a very helpful method to supply the energy.
5. **Cloud computing for WSNs:** Cloud computing can be utilized to process the data and share the data processing results with users. Therefore, cloud computing can be incorporated into WSNs to reduce the energy consumption in terms of delivering data to WSN users.
6. **Cross-layer design for WSNs:** Compared to the layered approaches, cross-layer design might achieve better energy efficiency, via utilizing the interaction among different layers.

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