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, China, 525000
[2] School of Engineering, University of Lincoln, UK
[3] Department of Electrical and Computer Engineering, The University of British Columbia, Canada
zeyu-zhang@outlook.com, lshu@lincoln.ac.uk, cszhu@ece.ubc.ca, mithun.mukherjee@outlook.com,

Abstract. Sleep scheduling, also known as duty cycling, which turns sensor nodes on and off in the necessary time, is a common train of thought to save energy. Sleep scheduling has become a significant mechanism to prolong the lifetime of WSNs and many related methods have been proposed in recent years, which have diverse emphases and application areas. This paper classifies those methods in different taxonomies and provides a deep insight into them.

Key words: Wireless Sensor Networks (WSNs), Sleep Scheduling, Duty Cycling

1 Introduction

In WSNs, most sensor nodes have to rely on unrechargeable power sources, e.g., batteries, to provide the necessary power. In most cases, it is difficult to charge or replace the batteries, especially in outdoor monitoring. Thus, their power management has become crucial. Energy shortage is always the bottleneck restricting the development of WSNs applications [1]. As an engineering practice, sleep scheduling or duty cycling approaches have long been used in a wide variety of devices to save energy and prolong the lifetime of equipments, such as air-conditioning compressors, pumps and electric motors [2].

As for WSNs, most existing hardware, e.g., CC2420, can support several modes, i.e., transmission mode, idle mode and sleep mode [3]. The communicating radio circuitry is still turned on but will not transmit or receive data in the idle mode. The idle listening will drain as much as tens to thousands times the current consumed during the sleeping state [4], thus, the major goal of duty cycling or sleep scheduling mechanism is to reduce the idle state energy consumption on the condition of guaranteeing network connectivity.

2 Duty Cycling

Duty cycle is the ratio between the wake up time length in a predefined period and the total length of the period [5], e.g., a period or a slot is 1 s and one node stays active for 0.1 s and sleeps for other 0.9 s, the duty cycle is 0.1.

Duty cycling mechanism can be classified into three categories commonly, i.e., synchronous wake-up methods, asynchronous wake-up methods, and semi-synchronous wake-up methods, as shown in Fig.1.
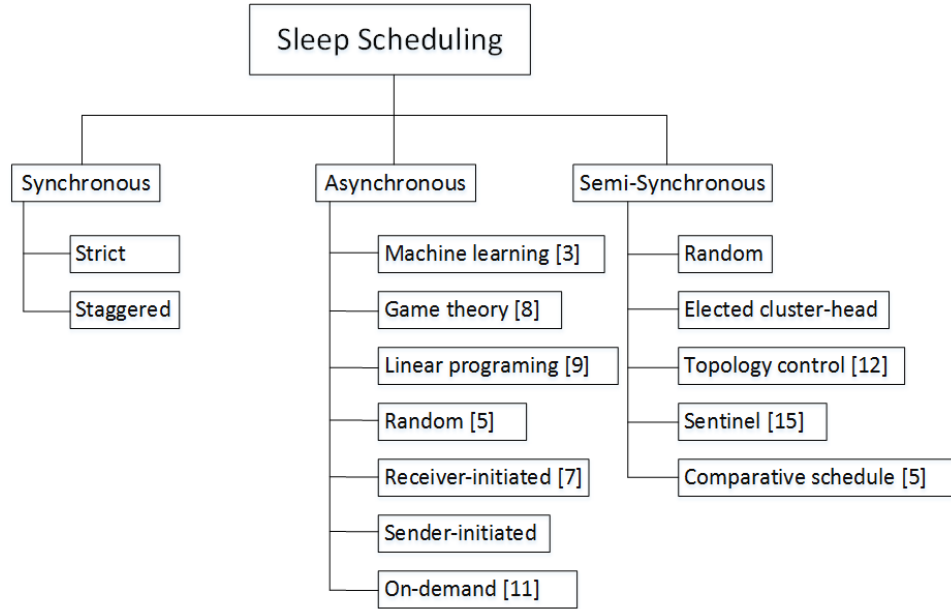

Fig. 1. The taxonomy for sleep scheduling methods

– **Synchronous Schemes**, In synchronous schemes, such as S-MAC [6], T-MAC [7], sleeping nodes wake up at the same time periodically to communicate with one another, which means the networks have to keep a global synchronization. This kind of methods is intuitive and straightforward but requires synchronization mechanism which demands more extra control traffic.
– **Semi-Synchronous Schemes**, Semi-synchronous schemes, also known as cluster synchronization, such as [8–10], is a local synchronous method. In this method, sensor nodes are grouped into synchronized clusters. In the same cluster, sensor nodes wake up or go to sleep at the same time. But clusters act together with others asynchronously. Compared with synchronous schemes, group-synchronization is easier to achieve.
– **Asynchronous Schemes**, In asynchronous wake-up mechanisms, such as [11–13], each node has its own wake-up and sleep schedule, which demands the

wake-up slot should overlap among neighbors, or the message cannot be transmitted. To satisfy this requirement, the sensor nodes may have to wake up more frequently than in synchronous wake-up approaches.

3 Recent research conclusion

To the best of our knowledge, the most important survey of sleep scheduling is [4] in last four years, this section summarizes the main conclusions of papers published from 2015 to 2017, as shown in Table 1. From the table, we can see most papers focus on the asynchronous scheduling theory, less papers focus on the semi-synchronous theory. And machine learning is becoming the main trend of this field. We lists some potential directions below.

4 Future directions

Most papers and literature illustrate a clear trend of development in sleep scheduling algorithms, i.e., complexity and diversity. Sleep scheduling aims at maximizing the network lifetime, actually there exists several techniques that can do the same work.

1. **Mobile relays and sinks**, low duty-cycle can prolong the lifetime of WSNs, but can also bring about message missing or delivery delay. And the nodes around the sink node ran out of their energy quickly, which can lead to energy hole. Mobile relays and sinks can solve this kind of problem. The 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**, clustering is the first step of most semi-synchronous theory. In this kind of methods, network is divided into several clusters, and cluster heads are responsible for communicating with other clusters. Actually, the cluster heads are always common nodes and have high duty cycle compared with other nodes. How to balance the energy consumption among them is very important in the future research.
3. **Energy Harvesting**, as a common train of thought to prolong the network lifetime, sleeping scheduling can only save energy but cannot generate energy. But the harvested energy is not stable and abundant. Thus, energy harvesting becomes another promising area to interact with sleep scheduling, which can solve the the problem of energy shortage to some degree.
4. **Wireless charging**, wireless charging provides a convenient, safe and reliable way to power electrical devices, which can become a dependable method to balance the energy consumption in the network. As we know, the nodes far away from the sink nodes are always responsible for collecting data and do not have to relay data, their energy will ran out at length. How to make most of the energy is very important for the lifetime of the network.

5. **Cloud computing**, the cloud computing can be used to process the data collected from WSNs and share the results with mobile users, which is a promising orientation to collaborate with sleep scheduling.
6. **Cross-layer designs**, cross-layer designs try to exploit a more complicated interaction among communication layers to achieve better performance compared to the layered communication approaches which separate communication tasks within several layers. Extensive cooperation among layers can promote the energy efficiency in WSNs.

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Table 1. Analysis of Existing Protocols With Respect to Different Sleep Scheduling

Author	Key Issues	Network Structure	Energy	Solution	Advantages	Disadvantages
Kordaf-shari et al. [14]	trade-off between energy conservation and network throughput	static	non-rechargeable battery	evolutionary game theory	achieve an stable and optimal schedule	serious assumption and slow convergence
Ye et al. [5]	multi agent non-cooperative game	static	non-rechargeable battery	fussy logic and Q-learning algorithm	dynamical adjustment	slow convergence
Mosta-faei et al. [15]	partial coverage and preserve connectivity	static	non-rechargeable battery	learning automation	adaptive control, global optimization and good robustness	slow convergence
Chen et al. [16]	reduce to-sink data transmission delay while lifetime is also improved	static	non-rechargeable battery	comparison and adaptation duty-cycle control	dynamic adjustment and consider energy hole	lacks comparison of algorithms in the same type
Kumar et al. [17]	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	hard handoff of channel cause ping-pong effect
Wang et al. [8]	critical nodes sleep scheduling	grouped and static	non-rechargeable battery	depth first search-based algorithms and k-means cluster algorithm	maintain group-connectivity	not consider network latency
Mukher-jee et al. [9]	a trade-off between energy harvesting and data transmission	static, multi-sink, and tree-based	rechargeable battery and solar energy	comparative and random scheduling	intuitive, lower control overhead and avoid energy hole	more complex hardware and not consider networking network latency
Khalil et al. [7]	energy hole and data recovery	mobile, tree topology	non-rechargeable battery	received oriented method based on TDMA	no data collision and save transaction time	prone to cause energy hole
Chen et al. [18]	desired area coverage and energy consumption balance	static	rechargeable battery and solar energy	reinforcement learning	dynamic scheduling and high coverage ratio	high cost for hardware and not comparing with other energy harvested algorithms
Xie et al. [19]	a trade-off among the lifetime of network, transmission delay and packet loss ratio	static	non-rechargeable battery	based on residual energy	adjustable schedule	not considering network latency
Mukher-jee et al. [9]	maintain the network connectivity	software defined network (SDN) and static	non-rechargeable battery	SDN-ECCKN algorithm	energy management and low faulty ratio	not considering network latency
Oller et al. [11]	decrease degrees of overhearing and idle listening	static	non-rechargeable battery	wake-up radio	reduce unnecessary energy waste, e.g., idle listening	add extra hardware
Baba et al. [12]	improve the energy efficiency	static	replaceable battery	progressive sleep scheduling and opportunistic routing	less energy overhead and increase the routing quality	not considering communication collision and energy hole
Gupta et al. [13]	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	not considering network latency
Xu et al. [20]	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	sentinel nodes run out of energy quickly