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RFID Based Non-Preemptive Random Sleep Scheduling in WSN

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Abstract: In Wireless Sensor Network (WSN), because battery and energy supply are constraints, sleep scheduling is always needed to save energy while maintaining connectivity for packet delivery. Traditional schemes have to ensure high duty cycling to ensure enough percentage of active nodes and then derogate the energy efficiency. This paper proposes an RFID based non-preemptive random sleep scheduling scheme with stable low duty cycle. It employs delay tolerant network routing protocol to tackle the frequent disconnections. A low-power RFID based non-preemptive wakeup signal is used to confirm the availability of next-hop before sending packet. It eliminates energy consumption of repeated retransmission of the delayed packets. Moreover, the received wakeup signal is postponed to take effect until the sleep period is finished, and the waken node then responds to the sending node to start the packet delivery. The scheme can keep stable duty cycle and then ensure energy saving effect compared with other sleeping scheduling methods.

Keywords: Sleep scheduling, RFID, partially connected, Delay Tolerant Network (DTN), wakeup, non-preemptive.

1 Introduction

The ubiquitous wireless sensor networks (WSN) through RFIDs, GPS, NFC and other wireless devices are capable of sensing the activities being carried around industrial environment so as to provide multifunctional service such as monitoring, data collection and processing [Qiu, Chai, Liu et al. (2018); Tan, Gao, Shi et al. (2018)]. Most of embedded nodes in the WSN are powered by battery [Yang, Cai and Guan (2016)]. Considering the current advancement of battery technology, total battery replacement can be prohibitively costly and sometime unfeasible. Therefore, the critical issue is to extend the network lifetime by energy saving schemes. Duty cycling the node activity and adopting a periodic sleep scheduling is an effective and direct way to reduce the energy consumption. Traditional sleep

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scheduling schemes are designed for fully connected networks where an always-awake communication backbone must be maintained which is complex and energy costly. If stable and low duty cycling is adopted, end-to-end communications will fail due to the break of the full connectivity. Random sleep scheduling schemes are more appropriate for sensor networks for the merits of stable duty cycle without need of global clock synchronization and being resilient to network dynamics [Kruse and Naumann (2018)]. However, delay tolerant routing protocol for partially connected network should be introduced to support delayed packet delivery when the next-hop is periodically disconnected [Ozkasap, Genc and Atsan (2009)]. In WSN, with random sleeping schedules, nodes must ensure the status of neighbors before packet delivery. The upstream node which has packet to forward to the downstream next-hop must pinpoint the neighbor node to know if it is available [Wang, Tian, Zhang et al. (2018)]. Repeated neighbor discovery requests should be sent to find the right time to forward the data packet which introduces more energy consumption for extra transmissions [Li, Li, Cheng et al. (2018)].

To reduce the overhead of the interaction among nodes, an out-band wakeup can be introduced. Radio Frequency Identification (RFID) is a means of contact-less, NLS (non-line-of-sight) item identification through electromagnetic transmission from reader to an RF compatible integrated circuit (tag). As RFID can operate at energy consumption of about three orders of magnitude lower than typical commercial radios, in this paper, an RFID based random sleep scheduling schemes for partially connected sensor network is proposed. RFID provides a low-power wakeup mechanism by sensing the existence and location of neighbors by RFID [Stojmenovic, Seddigh and Zunic (2002)]. It can pinpoint the sleeping neighbor with other packet communication modules turn off, which eliminates the idle listening to media and querying of neighbors. RFID can simply unicast (broadcast) a wakeup signal to one (all) of a node's neighbors within detected range (0-10 meters). It can also provide the capability to wakeup specific subset of nodes. Partially connected routing should support the random sleeping of nodes to resume communication when the RFID components sense the right time slot for packet delivery. In comparison with traditional fully connected routing and other sleeping scheduling without the RFID wakeup scheme, the proposed RFID wakeup enabled routing achieves stable and low duty-cycle and acceptable packet delivery ratio for energy constrained applications.

In Section 2, we firstly describe related approaches in these domains. We develop the RFID wakeup based scheduling and routing and show simulation results in Section 3. In SSction 4, we conclude the paper with further research directions.

2 Related work

A random deployment of sensor nodes cannot fully guarantee coverage of the sensing area, which leads to coverage holes in WSNs [Lou and Wu (2002)]. Thus, coverage control plays an important role in WSNs. What's more, connectivity of coverage area is often subject to unpredictable disconnection due to limited energy source and power supply. The network can't afford all nodes to keep in active and available communication states. The major source of power consumption in nodes is communication. Sensor nodes typically have four states of communication: transmitting, receiving, listening and sleeping. For Mica2 mote [Eimon, Hong and Suda (2006)], the power levels at different states are 81 mW, 30 mW, 30 mW and 0.003 mW respectively. To let the node sleep is one of main methods to save energy. Each node follows a periodic active/sleep cycle according to schedules, and the nodes that are close to one another may also choose to synchronize their active cycles together. However, sleeping of node will reduce the connectivity of topology. Especially for traditional routing protocol relying on fully connected topology, disconnection means failure and retransmission which incurs low performance and more energy consumption [Tian, Su, Shi et al. (2018)]. Achieving longer network lifetime while satisfying the latency constraints has long been recognized as a difficult task. For these protocols, the problem is which node and how many nodes should be put into sleep mode to maintain a fully connected backbone. This requires accurate synchronization among nodes which significantly wastes energy, if not impossible. Some protocols chose to set the node in listening mode instead of deep sleeping mode, because the node must keep listening the wakeup packets from the neighbors. The energy consumption of sending wakeup packet and keeping listening status is much higher compared with totally sleeping node. Further, the wakeup packet may disturb the previous sleep policy such as duty cycle and then affect the energy saving of WSN.

An optimization can be then performed over the duty cycle and delay. Duty cycle indicates to the proportion of time during which a device is active or awake. Sleep/wake scheduling is major means to reduce energy consumption in WSN. There are multiple variations of designs that arise because of several choices:

● Constraints of wakeup. The necessity of maintaining fully connected topology.

● When to wake up. The event triggering the wakeup action to activate the node.

● Means to wake up. The means to signal the neighbor.

We discuss each of these in turn. First, sleep scheduling schemes can be grouped into variations with or without maintaining full connectivity. Most schemes fall into the former group, because communication protocol always assumes that the network is fully connected. In SPAN [Chen, Jamieson, Balakrishnan et al. (2002)] and AFECA [Tseng, Ni, Chen et al. (2002)], nodes make sleep decisions based on their neighborhood to maintain a fully connected backbone. However, fully connected backbone involves more awake nodes with high duty cycle then consumes more energy. The paper by Gu et al. [Gu and He (2007)] proposes schemes to forward data in extremely low duty-cycle sensor networks with unreliable and intermittent connectivity.

Then, according to the time to wakeup nodes, there are three categories: time-based wakeup, on-demand wakeup, and random wakeup. In time-based wakeup [Schurgers, Tsiatsis, Ganeriwal et al. (2002)], when a node enters sleep mode, it sets a timer to wake up at a pre-determined point of time, on the basis of the costly synchronization protocol [Tian, Cui, An et al. (2018)]. In on-demand wake schemes, node may wake up neighbors when it has packets to send. However, nodes may have little chance to sleep when the traffic is busy. Random wakeup is first studied in Tseng et al. [Tseng, Hsu and Hsieh (2002)], where a node may sleep according to its time table in a random manner [Ocakoglu and Ercetin (2006)].

Last, there are many means to wakeup nodes. STEM [Schurgers, Tsiatsis, Ganeriwal et al. (2002)] uses the second paging channels. Nosovic et al. [Nosovic and Todd (2000)], and Skraba et al. [Skraba, Aghajan and Bahai (2010)] apply on-demand RFID to activate the sleeping neighbors.

There are many works on the evaluation of the performance of networks in terms of packet delivery ratio and mean delay. In most of these works, the authors assume the constant availability of connection with no sleep latency, which may not be true in real world sensor networks. And these are also not suitable for evaluation of the our proposed schemes. The paper by Ocakoglu et al. [Ocakoglu and Ercetin (2006)] offers a model of random sleep scheduling based on a two state Markov process, and computes the probability of the node being available for at least K slots in N consecutive slots to estimate the responsiveness of network. It doesn't evaluate the end to end responsiveness of multiple-hop network. A data forwarding method is proposed for low duty cycle sensor networks, and the recursive equation of the delivery ratio, end to end delay is offered [Gu and He (2007)]. Since only the transmission of sensed data by a given deadline is considered as successful delivery, the delivery ratio should be conditional on the delay time. However, the delivery ratio equation in Gu et al. [Gu and He (2007)] is time independent. It does not provide a computable formula to describe the relationship between the performance and the parameters such as duty cycle, status transition frequency and delay. The paper by Ocakoglu et al. [Ocakoglu and Ercetin (2006)] is based on time slot, the discrete model is not accurate on a continuous time basis.

In this paper, an RFID based random sleep scheduling schemes for partially connected wireless sensor network is proposed. The random sleeping can provide steady and guaranteed duty cycle as compared with on-demand RFID wakeup. With the aids of RFID, overheads of the interaction among nodes are reduced. The number of the waken neighbors can be dedicated by RFID reader's select option. This gives the protocol capability to control the scope of forwarding. It is not necessary to maintain full connectivity and can adopt very low duty cycle to achieve high energy efficiency. With the support of partially connected routing in a RFID based random sleep scheduling WSN, we achieve low duty-cycle and acceptable packet delivery ratio for energy constrained applications.

3 Node scheduling and routing designs

In this section, we firstly propose an RFID based random sleep scheduling scheme, which achieves stable low duty cycle and reduces wireless retransmission to ensure low power consumption. An RFID based wakeup scheme is used to confirm the availability of the next-hop before a node starts sending data packets. If the next-hop is awake, it will respond to the upstream node to start sending. If the next-hop is asleep, the RFID tag can still sense the incoming wakeup signal from the previous hop, even if communication module for packet receiving and transmission is turned off. However, the wakeup signal will not activate the sleeping node immediately, the node may keep their duty cycle and when it wakes up spontaneously, it responds to the previous node to start sending. In this proposed scheme, the partially connected routing protocol can sense and wait for the arability of next-hop before delivery which eliminates the unnecessary dropped packet and retransmission. The receiving node can postpone the response to the wakeup signal to keep their duty cycle from being changed. These both ensure the low overhead in terms of power consumption.

3.1 RFID based non-preemptive sleep scheduling

Random sleep scheduling can seek balance by adjusting the duty cycle to maintain the percentage of sleep period the nodes spend. Due to the independent sleep of nodes, the node will lose the knowledge of whether its neighbors are awake and available to receive the packets. The normal method is neighbor discovery procedure by broadcasting query packet to probe the active neighbors on a regular basis, which also incurs extra overhead of interaction and energy consumption. It has negative effect on the network operative lifetime. For those scheduling schemes that wakeup the sleeping next-hops, the wakeup packet should be transmitted and revived through the communication components. This also means extra energy cost. What's more, to receive the interaction packet (discovery packets or wakeup packets), the node must be set to listening mode instead of deep sleeping mode, because the node must keep listening to the wakeup packets from the neighbors. The sending of wakeup packet and activating listening mode will cost certain energy. Further, the wakeup packet will disturb the previous sleep policy and increase duty cycle [Chen, Tian, Cui et al. (2018)].

RFID provides a low-power interaction method among devices. RFID enabled sensor node can pinpoint and identify the status of the neighbors by reader-tag interactions according to the ISO standard which consumes extremely low power consumption. Nodes can notify the sleeping neighbors by pinpointing the tags attached to them. This out-band wakeup measure can reduce the power consumption and the overhead of neighbor discovery. Integrated products for RFID and wireless sensors are already available off-the-shelf [Skraba, Aghajan and Bahai (2010)]. Paper [Ruzzelli, Jurdak and O'Hare (2007)] offers an on-demand RFID based wakeup scheme, where the node will wake the neighbors if a packet is received. However, if the traffic is at high packet rate, this on-demand scheme will frequently disturb neighboring nodes and even deprive their sleep opportunities. The duty cycle of sleep scheduling may be increased due to frequent waking-up of nodes. A flood of wakeup signal will put almost all the nodes of WSN in an unnecessarily active mode and consume more energy.

This paper proposes an RFID based non-preemptive random sleep scheduling where nodes will ensure the availability of connection using out-band RFID signal while keeping independent duty cycle of nodes in WSN. It can achieve controllable schedule to supply a steady power source of WSN with stable duty cycle and minimal communication overhead of wakeup. We adopt the proposed RFID enabled sensor node circuits of Ruzzelli et al. [Ruzzelli, Jurdak and O'Hare (2007)]. The difference is that the wakeup strategy is on non-preemptive and random basis in contrast with the on-demand wakeup scheme. The RFID wakeup impulse will not deprive the sleeping opportunity of next hop and wake it up immediately when it receives the wakeup impulse. The node receiving wakeup impulse may choose to finish its sleep stage before it responses to the wakeup impulse and switches to awake status. The wakeup procedure is conducted in a polite and non-preemptive manner. This process is similar with the way of our real-life reservation when we visit somebody on leave (i.e., ring the master first and visit him after he finishes his vacation.)

The traditional interaction to achieve this process is shown as Fig. 1, where several interaction packets exchanging are involved to make sure the next hop is not in sleep and available before sending the data packet. Several query packets are missed by the neighbor means the deep sleeping of the next-hop. The upstream node keeps sending the query packets, and it will consume a lot of resource including energy. If it chooses to wake the downstream node to be active as the available next-hop, it should send wakeup packet and stop the sleeping period of the neighbor. What's more, to receive the interaction packet in time, the sleeping node may be put into listening mode from time to time during the sleeping period to be notified by the incoming packets. This process introduces stacks of overhead and related energy consumption.

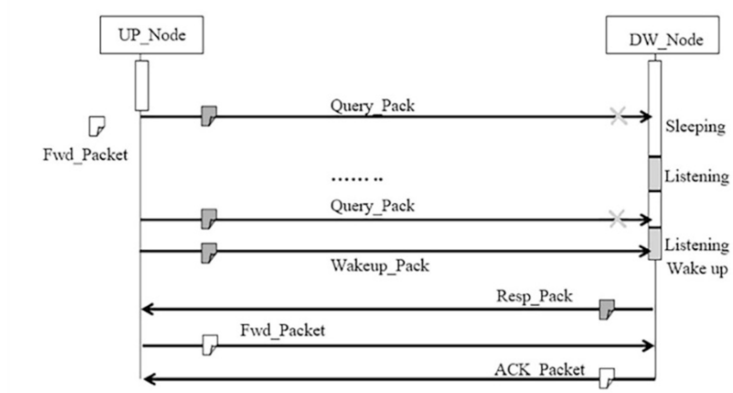

Figure 1: Interaction packets exchange needed in Non-RFID enabled WSN

As to the RFID enabled WSN, the process is shown as Fig. 2, where only low power RFID accessing is needed. When the upstream node has packet to forward, it will use the RFID reader to impulse the RFID tag of downstream next-hop node dedicated by the routing protocol. Even if the downstream node is in deep sleep (data transceiver is totally turned off), the RFID impulse can still be detected and recorded as an interrupt signal of wakeup request.

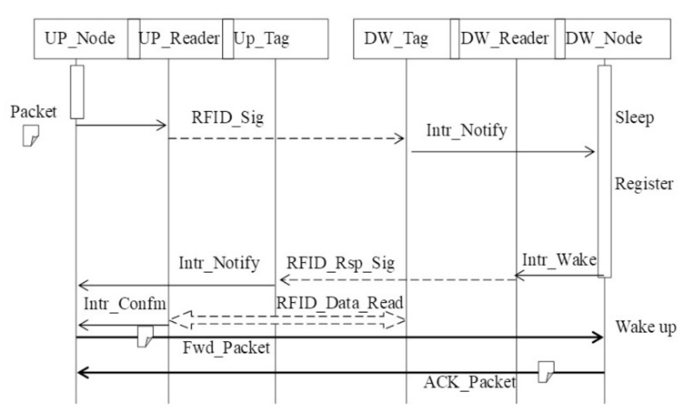

Figure 2: No extra packet exchange in RFID based wakeup scheme

The downstream node will not wake up at the impulse in a preemptive manner, because earlier wakeup of a great amount of sleeping nodes may cause unnecessary energy consumption. The wakeup procedure works in a non-preemptively 'friendly and polite' way if the applications doesn't require immediate notification of rare but urgent events.

The downstream node receiving the interruption signal still keeps sleeping for the rest of sleep period determined by its given duty cycle preset independently. When the downstream node is awake or finishes its sleep and wakes up spontaneously, it's RFID reader will send the response RFID signal to the correspondent to respond to the interruption of request recorded in the memory. The upstream node holding the packet may choose to keep awake until it detects the response. It then ensures the availability of the downstream next-hop node through RFID accessing before starting the normal packet forwards.

There are several merits of this scheme. Firstly, this scheme can avoid extra communication energy consumed by extra interaction packet over communication module to sense the availability of connection. Secondly, the RFID wakeup impulse will not disturb the given sleeping duty cycle so as to guarantee the effect of energy conservation. In this RFID based non-preemptive random sleep scheduling, if the sleeping node does not receive any RFID wakeup impulse during the sleep stage according to the given duty cycle, the node may choose to resume the sleeping mode until the upstream nodes notify it by RFID wakeup impulse. Extended sleep period means decreased duty cycle and better energy efficiency of WSN. It is only an option to be adopted, because in non-preemptive random sleep scheduling, the current sleep stage must be finished before the node can be activated for packet forwarding. It will increase the delay of WSN.

What's more, according to ISO standard RFID protocols, RFID protocols can provide back scattering delay mechanisms so that the RFID reader can detect the presence of several nodes at once. RFID enabled WSN nodes then can simultaneously broadcast a wakeup RFID signal to all of neighboring nodes or select specific subset of neighboring nodes to trigger. The wakeup of multiple nodes will increase the probability of success rate of packet forwarding and reduce the forwarding latency due to sleeping of nodes at cost of high energy consumption [Zhang, Li and Liu (2007)]. To improve the resource usage and throughput of long flows, Multipath TCP (MPTCP) can be adopted to enable transmission via multiple paths concurrently [Yang, Dong, Tang et al. (2018)]. Trade off should be made to achieve affordable network performance and low power consumption. Of course, this involves subtly designed multi-hop RFID based source routing with a robust routing decision scheme which will be discussed in the following sections.

3.2 Routing for RFID based random sleep scheduled WSN

The random sleep scheduling is an asynchronous wakeup scheme where nodes adopt independent scheduling policy such as sleep and wake interval. The node may sleep and wake according to its own time table without any central time synchronization or distributed coordination. As the nodes turn into sleep and are eliminated from the connected topology of WSN, the connectivity changes. When the duty cycle is low, the full connectivity will be broken and the network becomes partially connected. The end-to-end fully connected path between the source and destination may be broken frequently or even never appear. Most of existing WSN routing techniques are designed for fully connected networks assuming that the nodes of the end-to-end path are all available at the same time and will keep alive for certain period of time to finish the delivery process. Performance of existing routing protocols may degrade dramatically or even fail when the connectivity is getting worse due to the frequent time-out failure and repeated retransmission of dropped packets. This paper proposes a simplified partially connected routing protocol which can achieve high probability packet forwarding in RFID based random sleep scheduled WSN.

Although the RFID technique is independent from the routing protocol used, it can enhance efficiency of routing in a multi-hop environment. The route and forward process are based on store-wait-forward manner developed in our other works on partially connected routing [Zhang, Li and Liu (2006)]. The difference is that RFID tag information is appended to the route table. A source node will get a path identified by the sequence of RFID tag ID of the intermediate nodes after the route discovery process. The source node can select which neighbor to wakeup according to RFID tag ID in the route table with the aid of RFID technique according to the specification described in section 3.1. When packets arrive and nodes find the next hop neighbor is sleeping, packets are buffered for later transmission. When the sleeping node is wake up and response over RFID, upstream node may resume the forwarding. This process is repeated until the packet arrives at the destination.

We conduct a simulation of the RFID based random sleep scheduling scheme and routing protocol. The simulation is conducted in a 100 m×100 m fixed WSN with 200 nodes scattering homogeneously. In the simulation study, all nodes sleep and wakeup according to ON/OFF model of the same parameters with random and independent initial phase. The duration of the ON stage (awake stage) and OFF stage (sleep stage) follow an exponential distribution with parameter μ andλ respectively. All nodes are homogeneous with a packet transmission range of 10 m using Bluetooth that conforms to 802.15.1 based wireless radios. The transmission range of RFID reader and tag is about 10 m. There are 15 end-to-end traffic flows between randomly selected source-destination pairs within 10 hops path distance. Each source is a Constant Bit Rate (CBR) light traffic source with average packet rate 0.01 pps. The average packet length is 64 bytes and the user's tolerant delay is T=800 s. The simulation lasts for 48 hours. We assume that the sequence of router nodes is generated in the route discovery process and will not change during the simulation because of the infrequent mobility of WSN.

By simulation and calculation, we find that as compared to the full connected routing protocol (as AF_Simu and AF_Calc), the partially connected routing design (as AP_Simu and AP_Calc) can achieve much higher availability in term of packet delivery ratio in WSN with lower duty cycle within the given tolerant delay. Fig. 3 shows the variation of availability in respect of scheduling interval determined by sleep/wake period pair (with fixed and stable $E[TON]/(E[TON]+E[TOFF])=\rho/(1+\rho)$ $\rho=E[T_{ON}]/E[T_{OFF}]=1.5$, where $E[T_{ON}]$ is for awake period and $E[T_{OFF}]$ is for sleep period) within tolerant delay T=800 s. The path length n is10 hops. The result shows that under the same duty cycle (intensity of sleep activity), the partially connected routing can work well compared with fully connected routing. The fully connected routing can't work when switch interval is in time scale of second. However, the low switch interval means frequent switch from sleep to awake mode, and it will introduce extra power consumption due to the high electric current in power on/off stages of communication modular. While for partially connected routing with RFID based random sleep scheduling, even when the scheduling interval(sum of sleeping and awake period) is at long time scale level (500-600 seconds), the delivery packet ratio can reach 40% within tolerant delay (T=800 s). It is acceptable for energy constrained applications yet not sensitive to delay, such as remote environment monitoring in rural area.

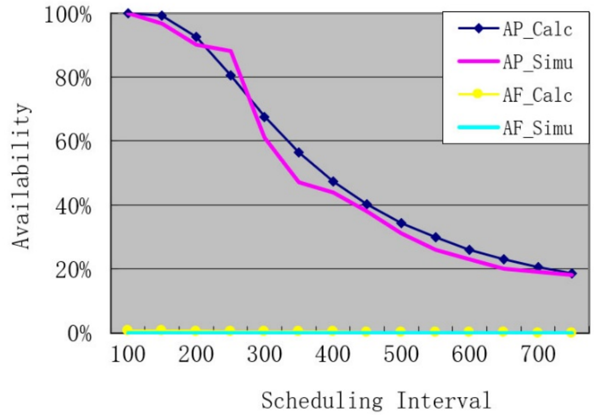

Figure 3: Performance under given duty cycle with different scheduling interval

We also investigate the variation of packet delivery ratio with respect to parameters of sleep scheduling and propose deployment policy applicable to scenarios insensitive to the delay but with tight budget of battery supply. This work helps to achieve network energy saving with affordable performance in term of delay and packet delivery ratio. Simulation results demonstrate that the proposed design improves end to end communication in stable low duty cycle WSN with acceptable packet delivery ratio and high energy efficiency.

4 Conclusions

In this paper, we design and develop an RFID based random sleep scheduling mechanism. We further evaluate and simulate the performance of protocol for WSN adopting RFID based random sleep scheduling mechanism. We find that as compared to the full connected routing protocol, the partially connected routing with RFID based wakeup mechanism design can achieve much higher packet delivery ratio and stable lower duty cycle within the tolerant delay. This work helps to achieve network energy saving with affordable performance in term of delay and packet delivery ratio. This scheme will introduce certain cost of the RFID readers and tags, but will achieve stable percentage of sleeping nodes which will ensure the determined energy saving effect. Moreover, due to the limited communication rage of RFID equipment, the RFID-based sleep scheduling is confined to short range application scenarios. It can be used in energy constrained application such as remote monitoring in some isolated area where power supply is limited. In this paper, nodes of WSN are presumed to be fixed in location. In the future study, node mobility will be introduced and performance of routing protocol in mobile WSN will be evaluated.

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