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Approaching green sensor field using queue-based optimization technique

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ABSTRACT

Toward green sensor field, power consumption emerges to be an important issue in wireless sensor network (WSN), where sensors are likely to operate on limited battery power. Sensors nearer the sink have to take forwarding traffic load for sensors far away from the sink. Hence nodes of inner shells centered at the sink would deplete their energy budget faster, leading to what is called an energy hole problem (EHP) around the sink. The operational lifetime of sensor network is deteriorated because of such an uneven node power consumption patterns. To model the proposed approach for qualitative analysis, a Petri Net model was developed to configure all relevant system aspects in a concise fashion. On quantitative work, a comprehensive mathematical analysis on power profile has been made in detail. For approaching greener technique, the power consumption patterns are concentrated on the nodes located in the innermost shells of WSN, which dominated the EHP issue. Network simulation results validate that the proposed green scheme indeed provides a feasibly cost-effective approach for lifetime elongation of sensor networks.

1. Introduction

Attracted by the popularity of cost-effectiveness in IT industry, wireless sensor network (WSN) are appealing to researchers due to their wide range of ever-growing application potential in areas such as target detection and tracking, environmental monitoring, danger alarm, patient monitoring, wildlife tracking and security surveillance, industrial process monitoring and so on (Akyilidiz et al., 2002; Zhang and Varadharajan, 2010; Hadjidj et al., 2013; Virágy et al., 2013). A typical configuration of WSN consists of sensors working unattended and transmitting their monitoring information to some data collecting node, the so-called sink node. Unlike other wireless networks, it is generally difficult or impractical to charge/replace exhausted batteries after deployment. As long as the on-board power supply is exhausted, the sensor node is expired. Conserving power prolongs the lifetime of a node and also the lifetime of the network as a whole. Hence, one of primary design goals is to conserve power consumption and to increase the operational lifetime of sensor nodes as long as possible (Jiménez and Le Gall, 2015; Choi et al., 2012; Abreu et al., 2014).

Power conservation is an effective approach to both make the WSN greener and elongate its operational lifetime as well. A sensor node without rechargeable facility is composed of four basic components, as shown in Fig. 1: a sensing unit, a processing unit, a transceiver unit (radio unit) and a power unit (Akyilidiz et al., 2002). The energy-constrained power unit provides operational power to other three units as shown by power lines (depicted by double-head dashed arcs). Power consumption can hence be divided into three domains: sensing, radio communication and data processing. The radio communication, usually the most energy-intensive operation a node performs, must contend a share of limited bandwidth (Zhang and Varadharajan, 2010). And also most of sensor nodes play the dual roles of data originator and data forwarder. The power consumption due to forwarding task conducted by inner-ring nodes would even deteriorate lifetime of the non-rechargeable battery.

Due to the limited transmission range, sensors that are far away from the sink deliver their data through hop-by-hop communications that data are forwarded by the nodes located in the inner-shell around the sink. Inevitably, the nodes around the sink would deplete their energy faster, leading to what is known as an *energy hole problem* (EHP) around the sink (Li and Mohapatra, 2005). No more data packets can be delivered to the sink in case an energy hole appears. In the static sink models, for large networks, Lian et al. (2006) reported that after the lifetime of a sensor network is over, there is a great amount of energy left unused,

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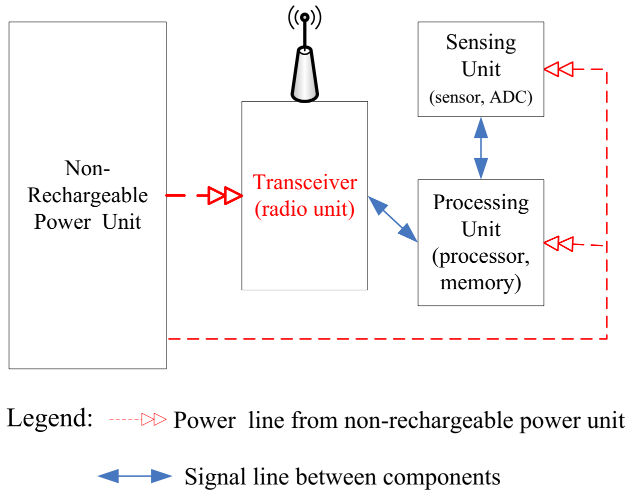

Fig. 1. Operational profile for power consumption of a generic sensor.

which can be up to 90% of the total initial energy. The simulated experiments (Wadaa et al., 2005) showed the dramatic impact incurred from the EHP. For example, in the 6th corona, the power expended by a node is less than 10% of the energy expended by a node in the first corona. And also by the time the sensor one hop away from the sink exhaust their energy budget, sensors farther away (e.g., in the seventh corona) still have up to 93% of their initial energy budget.

The power-saving technique is approached by dynamically alleviating the average times of accessing medium in the wireless environment for sensors. A queued threshold, N, is specified and used to control the average times of turning on the radio transmitter for the buffered data packets. In other words, when the queue holds N packets, the sensor triggers the radio transmitter to start medium-contention phase and then proceeds with the packet-transmission routine as soon as the sensor gains the medium-accessing rights in the wireless channel. The queue-based scheme provides two key advantages. One is that it can mitigate the total average times of contending the medium among sensor nodes. The other is that it can alleviate the total times of switching between active mode and idle mode of radio transmitter.

Based on the research from Shih et al. (2004), the startup time can have a large impact on the average energy consumed since wireless sensor nodes tend to communicate using short packets. The transitional energy when switching from one mode to another significantly impacts the total power consumption. Hence, the proposed queue-based scheme can alleviate these negative impacts and the power-saving advantage can be approached accordingly. Obviously, the queue-based scheme would incur latency delay of forwarding packets inevitably, another decision parameter T is considered to avoid long-term waiting in case of sparse arrival scenario. Combining these two parameters, an effective and feasible greener technique is proposed to prolong lifetime of sensor network using Min(N,T) policy M/G/1 queuing theory (Gakis et al., 1995).

The key contributions of this paper are threefold: (i) with little management cost, the proposed scheme provides the sensor network administrator with a feasible and greener technique to prolong operational lifetime of WSN (ii) a Petri Net model has been designed for qualitative analysis. The queue-based technique is adopted and relevant theoretical background is formulated for the proposed approach. And also data simulations on optimal queued values for mitigating power consumption are conducted (iii) this work proposes a detailed analysis on the average traffic load per node on regular planar sensor network, and conduct network simulation on lifetime elongation metric.

The rest of the paper is organized as follows: Section 2 describes related works. In Section 3, an Min(N,T) policy M/G/1 queuing model is elaborated after a Petri Net design is given for showing operational flow of a generic node. Following this, in Section 4, the optimal policy is further addressed in terms of total average power consumption, which data simulations are conducted as well for the feasibility of the proposed scheme. In Section 5, the average traffic load per node is analyzed on regular planar sensor network. To validate the proposed scheme, network experiments are also conducted. Finally, concluding remarks are made in Section 6.

2. Related work

The CSMA/CA (Carrier Sense and Multiple Access/Collision Avoidance) distributed algorithm of IEEE 802.11 specification (Wireless LAN, 1999) is designed to reduce the collisions due to multiple-source transmitting simultaneously. If the channel is sensed as busy, the node defers transmission till the end of the ongoing transmission under the exponential backoff mechanism. Although this backoff method can contribute the collision avoidance, it does not address the issue how to alleviate the total average times of medium contention for each sensor node. In other words, it triggers packet transmission as long as there is any one arriving packet in its buffer. The goal of the IEEE 802.15.4 (IEEE Standard 802, 2003) is to provide a standard, which has the characteristics of ultra-low complexity, low-cost and extremely low-power for wireless connectivity among inexpensive, fixed, and portable devices such as sensor networks and home networks. An IEEE 802.15.4 network can work in either beacon-enabled mode or non-beacon-enabled mode, which a slotted CSMA/CA channel access mechanism and an unslotted CSMA/CA channel access mechanism are specified respectively. Intuitively, both of them have similar access mechanism to conventional contention-based scheme of IEEE 802.11 standard.

SMAC (Ye et al., 2002) is a heavyweight MAC protocol for sensor networks that relies on time synchronization and scheduling among nodes to enforce periodic sleep and listening schedules. SMAC reduces energy consumption and provides scalability at the cost of per-hop fairness, throughput, and latency. B-MAC (Polastre et al., 2004) is a carrier sense media access protocol for wireless sensor networks that provides a flexible interface to obtain ultra-low power operation, effective collision avoidance, and high channel utilization. B-MAC protocol makes use of CSMA-based scheme with duty cycles to conserve energy. Using two-radio channel, STEM (Ye et al., 2002) provides a topology management technique that trades off power savings versus path setup latency in sensor networks. It emulates a paging channel by having a separate radio operating at a lower duty cycle. Upon receiving a wakeup message, it turns on the primary radio, which takes care of the regular data transmissions. In the work of Castiglione et al. (2015), an analytic energy model had been addressed for secure communication among multi-mode terminals. This model describes the energy consumption of mobile terminals operating within a dynamic network scenario. On the whole, the issues regarding alleviating the total average times of triggering packet transmission during node's lifetime are not a concern for these open literatures (Wireless LAN, 1999; IEEE Standard 802, 2003; Ye et al., 2002; Polastre et al., 2004; Schurgers et al., 2002; Castiglione et al., 2015).

To approach greener scheme by mitigate the total average times of triggering packet transmission, A queue-based threshold (N) is specified in the design of the proposed queued wakeup