A Comprehensive Model for Energy Consumption in Wireless Sensor Network using the Markov Model

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Summary
Due to the availability of energy-efficient sensors, microprocessor and radio frequency circuits for data transfer, wireless sensor network developed rapidly and spread. Wireless sensor networks that include thousands of low-cost sensor nodes are used in various applications such as as health surveillance, battle field surveillance, and environmental monitoring. The sensor node non-rechargeable, non-replaceable and limited power supply is considered as the main challenges of this type of networks. With completion of the node's power supply, the node actually remains unused. Sleep-wake scheduling is used to reduce energy consumption and extend the life of nodes. We in this paper try to investigate sleep-wake scheduling in sensor nodes with Markov Model. In probability theory, a Markov model is a stochastic model used to model randomly changing systems where it is assumed that future states depend only on the current state not on the events that occurred before it (that is, it assumes the Markov property). Generally, this assumption enables reasoning and computation with the model that would otherwise be intractable. For this reason, in the fields of predictive modelling and probabilistic forecasting, it is desirable for a given model to exhibit the Markov property. It is expected that proposed Markov Model covers all aspects of sleep/wake scheduling in wireless sensor networks.
Keywords:
Wireless Sensor Network, Markov Model, Scheduling, Sleep/Awake.

1. Introduction

Recent advances in the design of the electrical circuits, causing expanding the use of wireless sensor network. The wireless sensor network consists of many small devices called sensor nodes have the restricted ability to sense, process and communication [1]. The sensor nodes sense environmental data, if necessary, carry out partial processing on the data. Then the sensor node sends the sensed information by a specific method to the base station in order to overall processing and deciding on the status of entire network. The base station is connected to AC power and it has no hardware limitation.

Sensor node in terms of hardware is weak due to economic issues. This node has memory with low capacity, poor processor, relatively short-range antenna and most importantly the restricted, non-rechargeable and irreplaceable power supply [2]. With the completion of the power supply node, the node is practically useless and so called dies. To avoid quick extinction nodes, two main strategies to reduce energy consumption have been suggested that are optimal routing and sleep / wake scheduling. The nodes exposure to long-term sleep situation, in which at least possible circuit-switched and other circuits switched off, play an important role in reducing energy consumption and extend the lifetime of wireless sensor network [3].

It is required to a model for checking the nodes sleep-wake process and its impact on energy consumption. It is necessary to study all existing aspects of the sleep-awake process and propose a perfect model for this process. Among modeling tools, Markov model [4] due to its robust mathematical basis, can be selected as the sleep-wake process modeling tool. We in this paper propose a comprehensive model using Markov model for the node sleep-wake process in a wireless sensor network with respect to all available aspects. It is expected that the proposed model make evaluation of sleep-awake process easier and be regarded as a reference in the field.

The rest of the paper is organized as follows. Section II describes the related work. The Markov model in order to model the sleep-awake process is presented in Section III. Section IV presents the results of the performance evaluation of the proposed scheme including the comparison with the existing schemes, followed by the conclusion in Section V.

2. Related Works

There are few papers on sleep-awake modeling using Markov model. The previous papers listed are about Markov model and sleep-awake scheduling separately or mainstream.

In [5] the proposed scheme is improved by controlling the node operation based on the sleep-and-wake up mechanism for energy efficiency. In this paper an event detection scheme with WSN is introduced, which adopts a hierarchical structure to efficiently integrate the spatial and temporal correlation of sensor data. Here a fusion algorithm considering both the weight of the sensors and spatial information is applied to Markov random field to properly fuse the decisions of the

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neighboring nodes. Markov chain is also adopted to effectively extract the temporal correlation after the spatial correlation is decided.

The contribution of [6] is three-fold. First a new attack decision criterion is proposed which exploits the spatial–temporal characteristics hiding in the generation mechanism of wakeup packets. Second, a Hidden semi-Markov Model (HsMM) is presented that captures the spatial–temporal characteristic of a control server's signaling behavior. Third, an advanced LTE signaling attack detector is proposed and prove its superiority by various simulations. It is shown that the proposed detector results in much less frequent false alarms.

In order to improve power efficiency and meet of users of cognitive wireless sensor network (UCWSNs) in distributed cognitive wireless sensor network, according to the difference and independence of channel sensing results among UCWSNs, a game-theoretic power control mechanism based on Hidden /Markov Model (HMM) is proposed in [7]. By the HMM mode, UCWSNs can infer the set of competitors accurately and choose an optimal policy of transmission power. Simulation results indicate that the game-theoretic power control mechanism based on HMM can incur better power efficiency on the premise of QoS requirement compared with others, which is on the expense of implementation cost.

A MAC protocol have presented for WSN in [8] that is based on the ON/OFF Markov model. The key idea is to adapt the radio activation time based on the network traffic. The passage from passive to active mode is set according to the transition probability from OFF to ON state. Based on this probability, the period that the transceiver can stay in sleep mode is given.

By developing a stochastic Markov model of the sensor node of WSNs and applying the stochastic method, the explicit expression of the distribution of the number of data packets in a sensor node is derived in [9].Numerical analysis was provided to validate the proposed model and the results obtained. The proposed model and analysis method are expected to be applied to the design and analysis of various WSNs, taking the times spent in active and sleep modes into consideration.

In [10], a new general analytical Markov model for a thinning scheme in wireless cellular networks is presented where channel holding times for new calls and handoff calls are distinctly distributed with different average values. For the proposed model, the closed matrix product-form solutions for the stationary probability were derived.

3. Proposed Method

In this section the proposed method has been discussed. The main structure of this paper is on [9] where a sleep/awake schaduling was introduced. Let's a WSN in which each sensor node may stay in three major modes, i.e., active, semiActive and sleep modes. The active mode which is called the full-active phase denoted by phase R and the other phase is called the semi-active phase that denoted by phase N. The sleep mode is mentioned as phase S. Figure 1 provides a brief description the transition relationship between these phases.

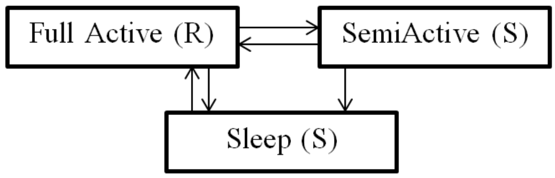

Figure 1. The sensor node status change diagram

The Figure 1 illustrates that the sensor node can switch from the full-active mode to the semi active mode viceversa. It can also change its mode from the full-active to the sleep mode viceversa. Finally, the semi active mode can only switch to sleep mode in one direction. The proposed method is described by following assumptions:

(a) The duration of a sensor in a sleep mode is distributed exponentially with a mean of $1/\beta$. The sensor node which is in sleep mode, consume minimum energy and almost all its components is off. After the sleep duration the sensor node turn on its components and changes to full active mode.
(b) The duration that a sensor spends in the full-active phase is a random time that has an exponential distribution with a mean of $1/\alpha$. When a sensor node is in active mode may beget packets pursuant to a Poisson process at a rate of λ; or relay packets receiving from other sensor nodes with regards to a Poisson process at a rate of λE; or process (transmit or relay) data packets with random exponential time with a mean of $1/\mu$.
(c) After the period spent in the full-active phase, The sensor node's mode is change to either the semi-active phase or the sleep after full active mode. The node is changed to semi-active mode if there is atleast one data packet. The sensor node can only transmit data packets with random exponential time with a mean of $1/\mu$ in the semi-active phase, and it cannot beget or receive any data packets. In our proposed model, in each step in semi-active mode, it is possible that the semi-active is changed to full-active in accordance to a Poisson process at a rate of γ.

(d) Each node has not sufficient space, or a buffer with infinite size, to store the data it generated forwarded from other nodes for relaying purposes.

In [9] model which is shown in figure 2, it is assumed that sensor nodes have sufficient space or a buffer with infinit size to store data. It is obvious that this assumption is not correct. We modified the [9] model by considering fixed size for buffer which is illustrated in figure 3.

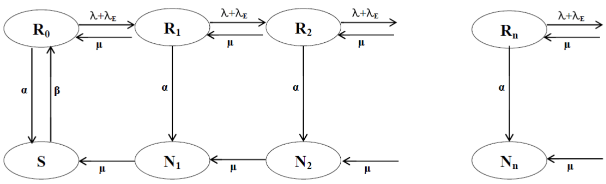

Figure 2. Imperfect Markov Model presented in [9].

In [9] model which is shown in figure 2, after processing all data packets in the semi-active phase, the senor node will move to the sleep mode automatically. The model proposed in [9] is not considered supervised active commands which are emerged by the base station or any other sensor node.

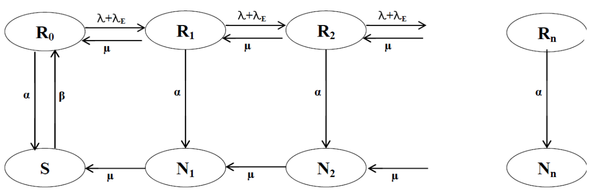

Figure 3. Markov Model with finit buffer size

Ignoring supervised commands in order to change nodes situation in active phase is another drawback in model [9]. By considering these weaknesses we propose complete markov model in order to describe sleep/awake situations of a sensor node. Figure 4 shows our proposed markov chain.

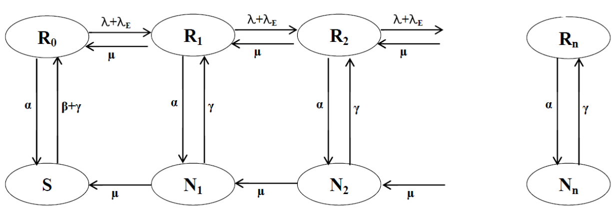

Figure 4. The complete markov chain

In wireless sensor networks due to restricted, non-rechargeable and non-replacement power supply, the nodes' energy consumption is a critical issue that needs to be investigated. The energy consumption is occurred in sending and receiving data packets and context switching between modes. The following notations show all energy consumption states.

etfa: the transmitter power consumption per data packet in the full-active mode;
etsa: the transmitter power consumption per data packet in the semi-active mode;
eofa: the operation power consumption per unit time in the full-active mode;
eosa: the operation power consumption per unit time in the semi-active mode;
eos: the operation power consumption per unit time in the sleep mode;
efasa: the power consumption when the sensor switches from the full-active mode to the semi-active mode;
efas: the power consumption when the sensor switches from the full-active mode to the sleep mode;
esas: the power consumption when the sensor switches from the semi-active mode to the sleep mode;
esafa: the power consumption when the sensor switches from the semi-active mode to the full-active mode;
esfa: the power consumption when the sensor switches from the sleep mode to the full-active mode.
efafa: the power consumption when the sensor switches from the full-active mode to the full-active mode; and
esasa: the power consumption when the sensor switches from the semi-active mode to the semi-active mode;

In addition to energy consumption, the number of packets sent is another measure in order to evaluate sensor nodes. Where sensor node is in Rc situation in which c is the buffer size, by a rate of λE packets may be lost. The evaluation of proposed method in terms of energy consumption and packet transmission is discussed in next section.

4. Evaluation

We use MATLAB 2015b in order to simulate Markov chain. Before running simulation, the numerical parameters have to be set. Table 1 listed the Markov chain parameters among with their values.

Table 1. Value of parameters used in numerical analysis

Parameter	*Value*
etfa	31 µw
etsa	11 µw
efafa	31 µw
eofa	25 µw
eosa	23 µw
eos	0.3 µw
efas	0.01 µw
esfa	0.5 µw
λE	0.2

μ	0.5
β	0.05
α	0.1

First, we evaluate buffer size. The generation rate λ and initial energy of sensor node are set to 0.05 and 0.5 joule respectively. The sensor node will continue its activities until it has energy. Figure 5 and 6 illustrate number of drop and sending packets respectively by increasing the buffer size from 5 to 20. It is obvious that whatever buffer becomes larger, the number of drop packets becomes lower and the number of drop packets becomes greater.

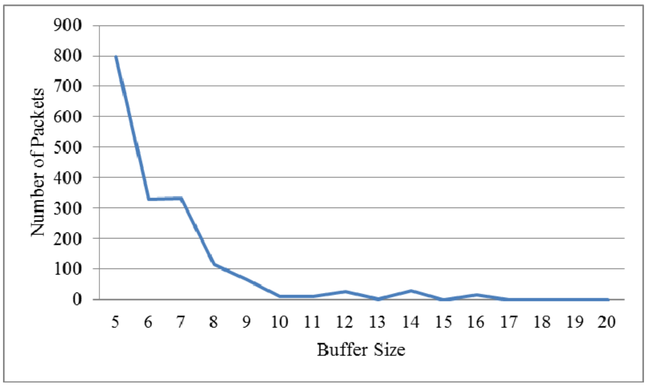

Figure 5. Number of drop pakcets

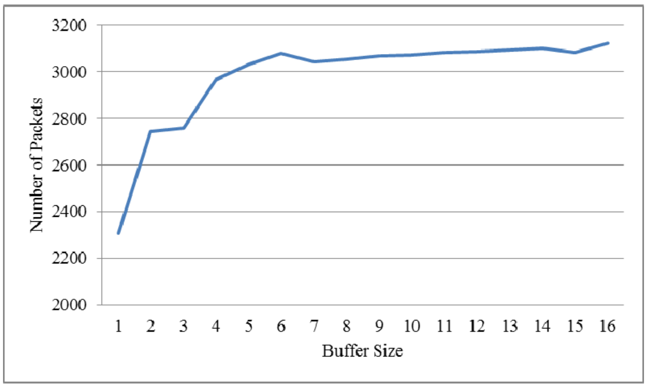

Figure 6. Number of sending packets

According to simulation resualts, the buffer size is set to 15. The energy consumption of the sensor node in sleep, active and semi-active modes are respectively illustrated in figures 7, 8, and 9. The sensor data generating rate (λ) is changed from 0.05 to 0.5 by 0.05 steps.

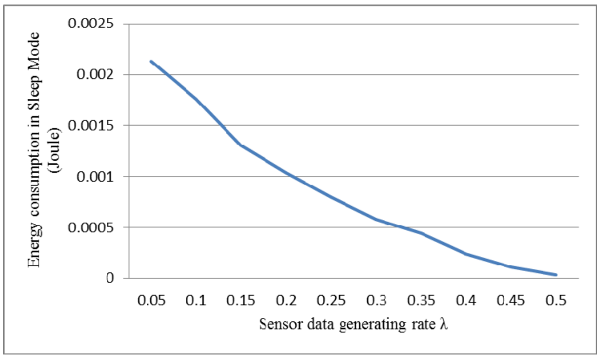

Figure 7. Energy consumption in sleep mode

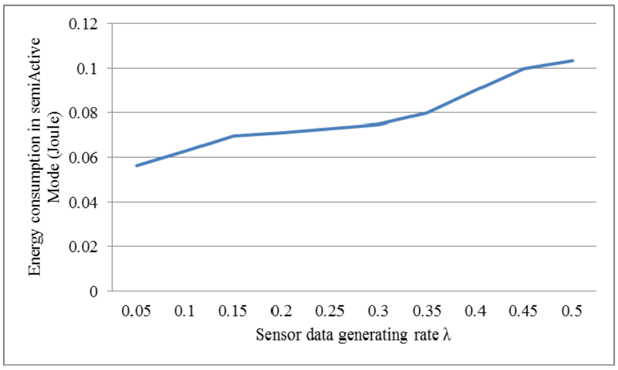

Figure 8. Energy consumption in semi-active mode

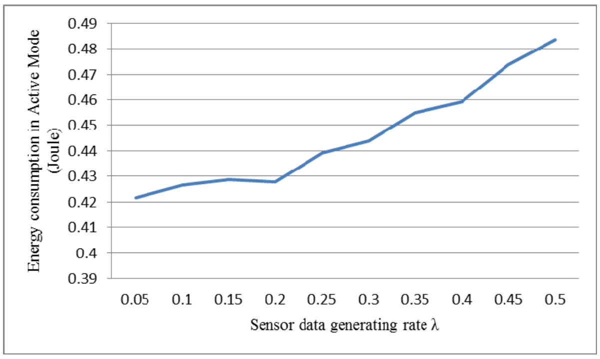

Figure 9. Energy consumption in full-active mode

It is evident that sensor data generating rate has significant affects on energy consumption in various phases. According to figure 7, 8, 9, by increasing the sensor data generating rate, the sleep mode energy reduced and the sleep mode energy rose. These fluctuations are done due to the change in packet generation speed.

5. Conclusion

Our aim of doing this research was to report the results of our study of the energy consumption in WSN. By developing a stochastic model of the sensor node of WSNs and applying the stochastic method, we derived the explicit expression of the distribution of the number of data packets in a sensor node. Then, we determined several important performance matrices related to the sensor node's energy consumption. Numerical analysis was provided to validate the proposed model and the results obtained. The results show that the energy consumption for switching between the active mode and sleep mode does not depend significantly on the number of data packets. However, the energy consumption for transmitting the data packets depends on the rate at which data packets are generated, which means that transmitting high-density data requires the expenditure of more energy. The proposed model and analysis method are expected to be applied to the design and analysis of various WSNs, taking the times spent in active and sleep modes into consideration.

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