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Performance evaluation tools for QoS MAC protocol for wireless sensor networks

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ABSTRACT

In this paper, we propose tools for modeling and evaluating our EQ-MAC protocol based on Stochastic Automata Networks (SAN) and Colored Petri Nets (CPN) model. EQ-MAC protocol is an energy efficient and quality of service aware medium access protocol designed for wireless sensor networks. To extract some results from the developed model, we used analytical resolution, GreatSPN and WNSIM tools. Results demonstrate the efficiency of our protocol. This work demonstrates the usefulness and the possibility of using SAN or CPN for modeling and evaluating any other MAC protocols for wireless sensor networks.

1. Introduction

A Wireless Sensor Network (WSN) consists of a number of small sensor devices that communicate wirelessly to accomplish a certain task such as environment monitoring and report the collected data to a center node (or sink node). WSNs can serve many civil and military applications that include target tracking in battlefields [2], habitat monitoring [3], civil structure monitoring [3] and factory maintenance [4]. In these applications, reliable and real time delivery of gathered data plays a crucial role in the success of the sensor network operation. Sensor nodes usually carry a limited and generally irreplaceable power source. Hence, WSNs must have built-in trade-off mechanisms enabling the sensor network to conserve power and give to end user the ability of prolonging network lifetime at the cost of lower throughput and/or higher latencies. The energy constraints of sensor nodes and the need for energy efficient operation of a wireless sensor network have motivated a lot of research on sensor networks which led to the development of novel communication protocols in all layers of the networking protocol stack. The radio transceiver unit is considered as the major consumer of energy resources of the sensor node, especially when the radio transceiver is turned on all the time and so a large amount of energy savings can be achieved through energy efficient media access control (MAC) mechanisms. Due to this fact, energy consideration has dominated most of the research at the MAC layer level in wireless sensor networks [5]. However, the increasing interest in real time applications of sensor networks has posed additional challenges in protocol design. For example, handling real time traffic of emergency event, triggered in monitoring based sensor network, requires that end-to-end delay is within an acceptable range and the variation of such delay is acceptable [6]. Such performance metrics are usually referred to as quality of service (QoS) of the communication network. Therefore, collecting sensed real time data requires both energy and QoS aware MAC protocol in order to ensure efficient use of the energy resources of the sensor node and effective delivery of the gathered measurements. However, achieving QoS guarantees in sensor networks is a challenging task, because of the strict resource

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constraints (limited battery power and data memory) of the sensor node and the hostile environments in which they must operate [7].

This paper introduces a Petri Nets model and stochastic automata networks to evaluate the performance of our EQ-MAC protocol [1]. EQ-MAC protocol is an energy efficient and quality of service aware MAC protocol for wireless sensor networks. EQ-MAC utilizes a hybrid approach of both scheduled (TDMA) and contention based (CSMA) medium access schemes. In addition to this, EQ-MAC differentiates between short and long messages; long data messages are assigned on scheduled TDMA slots (only those nodes, which have data to send are assigned slots), whereas short periodic control messages are assigned random access slots. This technique limits message collisions and reduces the total energy consumption by the radio transceiver [5]. Perhaps the greatest advantage of EQ-MAC besides the efficient node's battery usage is its support for quality of service based on the service differentiation concept. Service differentiation is done through a queuing model, consisting of four different priority queues. This model allows sensor nodes to do some type of traffic management by providing a greater chance to highest priority traffic of acquiring the channel and hence the highest priority traffic is rapidly served with minimum delay. Formal modeling and analyzing techniques, such as Petri Nets (PN) and stochastic automata networks (SAN), have the advantage to be used for performance evaluation of networking protocols and model verification. Such techniques are widely used in traditional networks. Using PN and SAN techniques in modeling wireless networking protocols presents many challenges. Some of them are addressed in this paper. The PN technique of EQ-MAC protocol is given in [19]. The SAN technique is developed in this paper.

The rest of this paper is organized as follows. We present in Section 2 the related works. In Section 3, we describe our EQ-MAC protocol. Section 4, is devoted to the modeling of our proposed service differentiation mechanism using stochastic automata networks. We describe the transmission process of EQ-MAC protocol using Petri Nets tool in Section 5. Finally, we conclude the paper in Section 6.

2. Related work

Power management of the radio transceiver unit of a wireless device has gained significant importance with the emergence of wireless sensor networks as the radio unit is the major consumer of the sensor's energy [1]. It has been shown that the energy consumed in transmitting one bit is several thousand times more than the energy consumed in executing one instruction [16]. Recently, several MAC layer protocols have been proposed to reduce the energy consumption of the sensor node radio unit. Refer to [5] for some examples.

However, the increasing interest in real time and multimedia applications of sensor networks requires both energy efficient and Quality of Service (QoS) aware protocols in order to ensure efficient use of the energy resources of the sensor node and effective delivery of the gathered measurements.

Perhaps the most related protocols to our EQ-MAC protocol are presented in [17,8]. In [17], Iyer and Kleinrock developed an adaptive scheme for each sensor to determine independently whether to transmit or not so that a fixed total number of transmissions occur in each slot. The protocol accomplishes its task by allowing the base station to communicate QoS information to each sensor node within the network through a broadcasting channel and by using the Gur Game mathematical paradigm, optimum number of active sensors can be dynamically adjusted. The protocol has a trade-off between the required number of sensors that should be powered-up so that enough data is collected in order to meet the required QoS and number of sensors that should be turned-off to save a considerable amount of energy thus maximizing the network's lifetime. The concept of QoS in [17] and our EQ-MAC are completely different; in [17] the QoS is defined as the total number of transmissions that should occur in each slot in order to gather enough data. In other words, QoS in [17] is expressed as the quantity of gathered sensory data that should be enough for the command center to make a decision, regardless of the delay requirement. Consequently maximizing the protocol throughput, while minimizing energy consumption. Contrasting to this, in EQ-MAC the QoS is defined as classifying network traffic based on its importance into different classes in order to provide better service (in terms of delay and throughput) for certain traffic classes (e.g. real time traffic).

In [8], authors proposed Q-MAC scheme that attempts to minimize the energy consumption in a multi-hop wireless sensor network while providing quality of service by differentiating network services based on priority levels. The priority levels reflect the criticality of data packets originating from different sensor nodes. The Q-MAC accomplishes its task through two steps; intra-node and inter-node scheduling. The intra-node scheduling scheme adopts a multi-queue architecture to classify data packets according to their application and MAC layer abstraction. Inter-node scheduling uses a modified version of MACAW [18] protocol to coordinate and schedule data transmissions among sensor nodes.

Unlike Q-MAC, our EQ-MAC uses a more energy efficient way to coordinate and schedule data transmissions among sensor nodes through a hybrid approach utilizing both scheduled and non-scheduled schemes. A significant amount of energy could be saved through this approach.

In order to investigate the performance of networking protocols, there is a clear need to use simulation tools or formal methods to validate the protocol performance or functionality prior to implementing it in a real environment. Using formal modeling and analyzing techniques (such as Petri Nets) have the advantage to perform both performance evaluation and model checking. Such techniques are widely used in traditional networks. Using formal techniques in modeling wireless networking protocols presents many challenges, some of which are addressed in [11]. We have used Petri Nets in modeling our protocol, then the rest of this section describes some work in modeling using Petri Nets. In [20], a high level Petri Net named as finite population queuing system Petri Nets (FPQSPN) is introduced for modeling and simulation of