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PERFORMANCE EVALUATION OF THE SCP-MAC: A MEDIUM ACCESS CONTROL PROTOCOL FOR WSN

Albeiro Cortés Cabezas and José de Jesús Salgado Patrón
Department of Electronic Engineering, Surcolombiana University, Neiva, Colombia
E-Mail: albecor@usco.edu.co

ABSTRACT

This paper studies the main performance characteristics of the SCP protocol, a medium access control protocol for sensor networks (WSN). SCP-MAC was designed taking into account the characteristics of energy shortage and processing capacity of the sensor nodes and seeks to reduce the consumption of energy at the expense of other performance parameters such as delay, flow and bandwidth. Our contributions through this work are the following: first, a physical layer model corresponding to the radio transmitter/receiver CC2420 was implemented in Qualnet®, including a model of energy consumption and a model of the SCP protocol based on the specifications of the authors; second, a detailed performance analysis of the protocol was made based on different metrics.

Keywords: wireless sensor network, medium access control, delay, flow, energy, scheduling, channel, polling.

INTRODUCTION

The rapid technological advance seen in recent years in the areas of micro-electromechanical systems and low-power digital electronics has made possible the development of wireless sensor networks - WSN. Wireless sensor networks have been designed to support scalar variable monitoring applications such as temperature, pressure, movement, and others. A wireless sensor network is typically composed of a large number of small wireless devices powered by batteries and deployed in a physical environment, which cooperate to perform one or more monitoring tasks. These wireless devices are very limited in terms of communication capacity, processing, storage and energy resources. In addition, these devices are usually deployed in areas of difficult access, so the preservation of energy resources is of utmost importance.
Because in wireless sensor network applications events occur with low frequency, a common practice in the design of protocols for these networks has been to save energy at the expense of performance guarantees and quality of service (QoS) more relaxed, such as, low flow and greater delays. A consequence of this design strategy is that many of these protocols, although they are energy efficient, limit the use of wireless sensor networks to those applications where a quick response time is not important. Although this may be a good practice for many applications of wireless sensor networks, there are other applications such as surveillance systems and real-time control systems for which wireless sensor networks not only need to be energy efficient but also provide better performance in terms of flow and delay, mainly.

In WSN and ad hoc networks in general, the tasks associated with the radio transmitter/receiver are responsible for the highest energy consumption [1-2]; Therefore, the strategy of access to the environment is one of the most critical aspects when optimizing the operation of the network. While in operation within the network, these radios can be in one of four modes: transmitting, receiving, listening (but without receiving or transmitting data) or off (low power mode). It has been adopted as the main method to put the radio in off mode as long as possible to achieve greater reduction in energy consumption. On the other hand, the following have been identified as the main causes of energy waste [3-5]:

- **Collisions:** When a package is corrupted by collision it must be discarded, making it necessary to retransmit it, generating extra energy consumption.
- **Over listening:** (listening to transmissions directed to other destinations). Since the transmission medium is broadcast, the nodes receive packets that are destined to other nodes, which must be discarded.
- **Excessive headers and control packages:** Sending and receiving control packages may mean additional energy consumption. Therefore, it is necessary to use the least number of headers possible, as well as the minimum number of control packages.
- **Idly listening:** (Listening when there is nothing to hear). A node in this state is ready to receive a packet that may not have been sent. This is a state of considerable energy consumption, which should be avoided when there is no data to be received.

In this article it is presented a detailed performance evaluation of the SCP-MAC protocol [6]. Lights are given about the performance characteristics of the protocol, which as far as we know have not been presented in the literature found.

SCP-MAC PROTOCOL

SCP-MAC is a protocol of access to the medium for wireless sensor networks, which has as main objective the conservation of energy and the self-configuration of the network; Latency, transmission speed and bandwidth utilization are less important. SCP-MAC tries to reduce energy consumption by attacking its four main sources of

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waste: collisions, over listening, excessive headers and control packages and idle listening.

SCP-MAC uses the LPL (Low Power Listening) technique to mitigate the problem of idle listening and save energy. This strategy consists of transmitting a preamble in front of each package to notify the need for transmission of the same. Each node periodically awakens each TP seconds to verify for a short period of time if there is activity in the channel (channel polling). If a node finds that the channel is free, it goes back to the inactive state. If a preamble is detected the receiver remains on and continues to listen until the packet is received. Figure-1 shows the operation strategy of SCP-MAC. This strategy has also been used with some variations in the BMAC [7], and X-MAC [8] protocols. While in other protocols of access to the medium for WSN the useful cycle is typically equal to 10%, in SCP-MAC this can be reduced to 0.3% with a similar performance in terms of delay [6]. It should be noted here that the fact that the useful cycle of this protocol is below 10% indicates that the channel utilization and the expected flow will be low. SCP-MAC includes a strategy to reduce a bit the delay of the packages called Adaptive Channel Polling and Multi-hop Streaming which consists in adding n high frequency soundings in the same Tp frame when traffic is detected. In this way it is possible to transmit more than one packet during a frame.

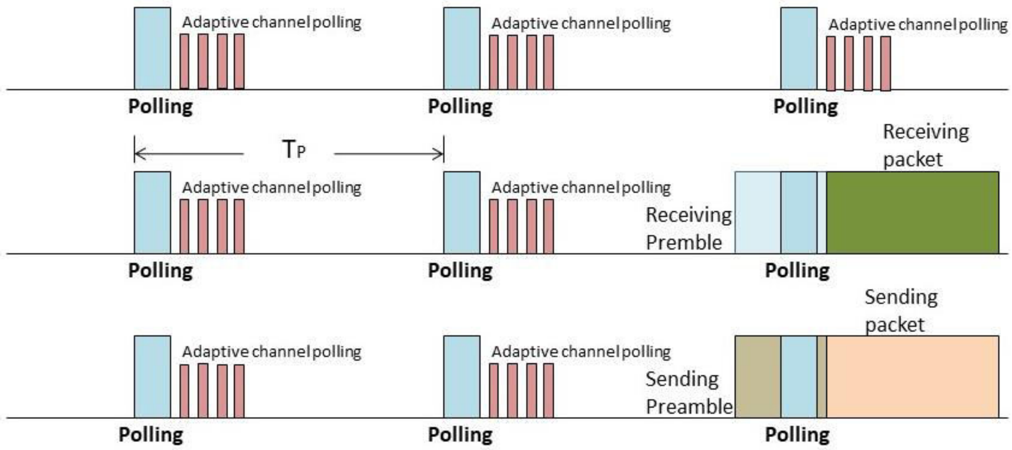

Figure-1. Time division strategy and operation of SCP-MAC.

IMPLEMENTATION OF SCP IN QUALNET®

The implementation of the SCP-MAC protocol was performed in Qualnet® according to the description of the protocol presented in [6]. The communication of SCP-MAC with the other layers of the network is done through the APIs included in Qualnet, making it compatible with the other protocols of the different levels of the stack. In addition to the standard APIs to communicate with the physical layer, which include the functions for reception and sending of packets between the two layers, an additional function is included that allows the change of the physical layer's status from the MAC layer, in order to control the turning on and off of the radio. The function that makes the change of state is within the model of the physical layer. The implementation of SCP-MAC uses adaptive channel polling, the duration of the polling interval is equal to 3ms and the cycle duration is 300ms, therefore the useful cycle is 1%;

Implementation of the physical layer model

At the physical layer level, a model was implemented to simulate the radio CC2420 [9] designed by Chipcon [10] for low power and low voltage wireless applications. With the CC2420 model in the physical layer, the packet reception model can be used based on the signal-to-noise ratio, which was used in the simulations, or based on the bit error rate. The radio can be found in one of five possible states: "idle", "sensing", "receiving", "transmitting", or "sleep". The "sleep" state simulates the radio off, in this state it is not possible to receive or transmit packets. The characteristics of the model are adjusted to the specifications of the CC2420 radio, whose main parameters are presented in Table-1.

In addition, the implemented model allows calculating the energy consumption of the node during the simulation. The calculation of the energy consumed is based on the time spent by the node in each of the states; the total energy consumed from the beginning of the simulation to the time t_n can be expressed simply as:

$$E_{tn} = \sum_i \overline{E}_\iota t_i$$

Where:

E_{tn} : energy consumed by node up to time t_n
$\overline{E}_\iota$: average energy consumed during state i
t_i : time of node in state i up to time t_n

The power consumed in each one of the states are those shown in Table-1. The energy consumption is updated during the simulation dynamically at each change of state.

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Table-1. Characteristics of CC2420 radio.

Parameter	Value
Transmission power	10 dBm
Sensitivity	-95 dBm
Reception threshold	-77 dBm
Transmission rate	250 kbps
Time of change Rx-Tx	192 µseg.
Energy consumption (at 25°C)	59.1 mW in Rx state 91.4 mW in Tx state 59.1 mW in "Idle" state 15 µW in "Sleep" state

EVALUATION OF PERFORMANCE AND RESULTS OF THE SIMULATION

In this section we present the simulation scenario chosen for our evaluation and the results obtained. The linear network was used with three sources and a sink shown in Figure-2. In simulated cases, each source node sends 100 90-byte packets to the sink, with time intervals between packet generations from 1 to 10 s, which is a typical scenario with light traffic in sensor networks. The nodes are physically separated by a distance of 80m, so that each node can only listen to its side neighbors, located up or down. Each experiment is repeated thirty times to collect enough data, and the total simulation time is 3000s in each case. It was assumed that the buffer size is large enough to avoid packet loss during periods of congestion.

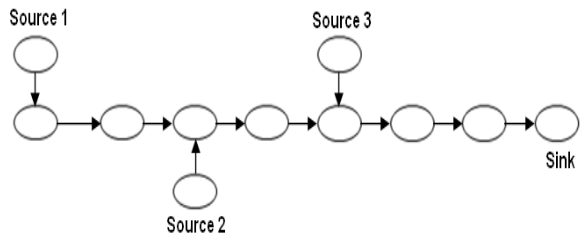

Figure-2. Scenario chosen for the simulation.

The evaluation metrics chosen in this article were: energy, delay and flow.

Energy consumption

In Figure-3can be seen the average energy consumption of the nodes during the simulation with respect to the time between generation of packets at the source. Note that as the interval between packet generation decreases the average power consumption and the variation. This is because when the interval between packet generations is small, the adaptive channel polling is really used to send more packets. When the intervals between generations of packages grow, the adaptive channel polling is activated, but it is used to send in many cases a single packet which represents additional energy consumption. We can conclude here that in energy terms, the adaptive channel polling is only effective when generating packets with high frequencies or during periods when there are bursts of traffic.

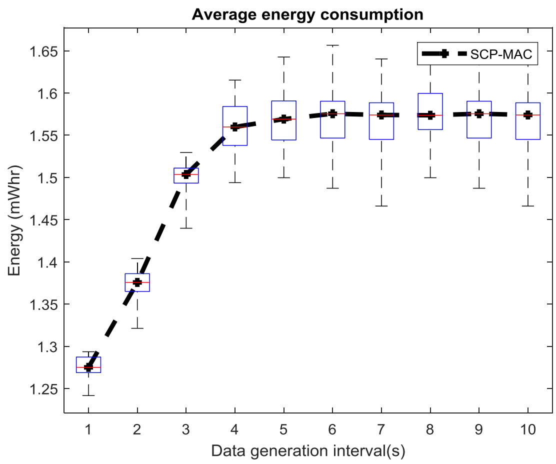

Figure-3. Average power consumption in the network nodes.

Time delay

Figures 4, 5 and 6 show the average delay experienced by each of the three sources.

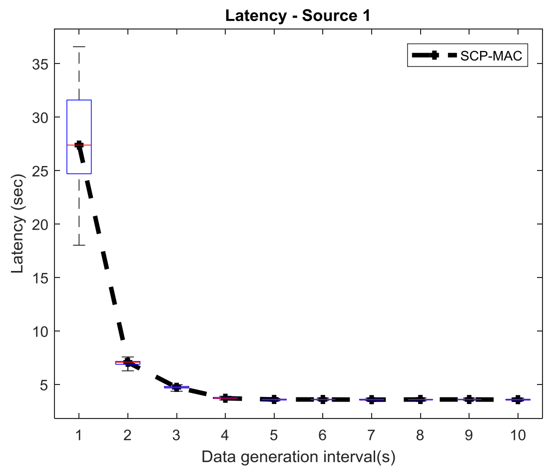

Figure-4. Average delay experienced by source 1.

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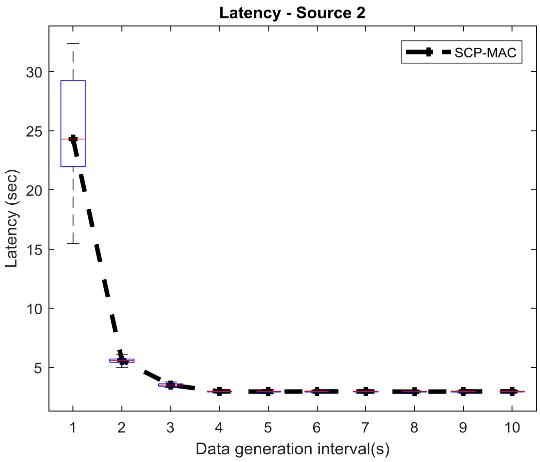

Figure-5. Average delay experienced by source 2.

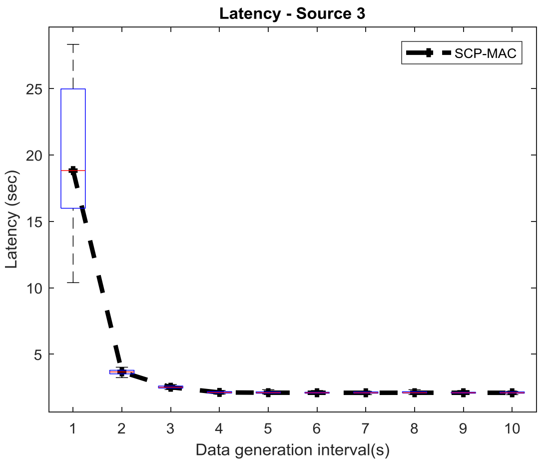

Figure-6. Average delay experienced by source 3.

As expected, for intervals between the generation of small packets, the delay experienced is not only greater, but also has greater variability. This is due to the fact that at a higher frequency of traffic generation, the nodes of the network will experience greater congestion. For intervals between generations of larger packets, the network experiences little congestion and packets can transit more quickly because they have little to contend with on the channel. As a result, under this situation the average energy consumption and its variability is considerably lower. The variability in the delay for intervals between generations of short packets can also be justified due to the higher level of containment by the channel under these conditions. Unfortunately, the simulation results show that the strategy of adaptive channel surveys may not be very effective for light traffic bursts.

Flow

Figures 7, 8 and 9 show the average flow rate experienced by each of the three sources.

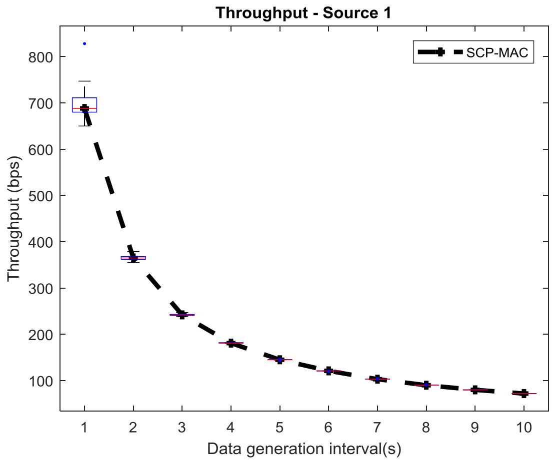

Figure-7. Average throughput experienced by source 1.

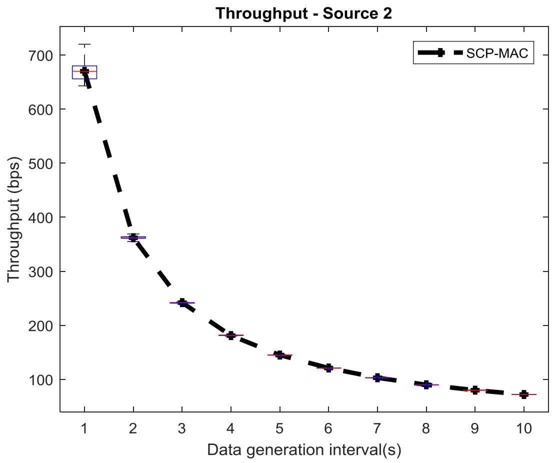

Figure-8. Average throughput experienced by source 2.

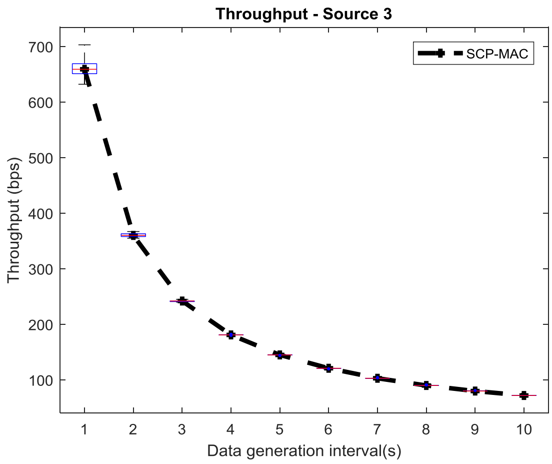

Figure-9. Average throughput experienced by source 3.

As can be seen, again the variability increases for the interval between packet generations of one second. This is also due to the presence of greater traffic in the network and therefore greater demand of the channel. Due to this presence of greater traffic it is also reasonable to observe a much higher average experienced flow. For the caudal variable, no special situations or different from those expected were observed. This really happens because SCP-MAC was not designed to achieve maximum flow but to achieve lower energy consumption and lower delay compared to its predecessors.

CONCLUSIONS

This article presents a simulation study of SCP-MAC with Qualnet® and presents specific details of the models implemented in this simulation tool. The results of our study and the models implemented allow us to reveal the relationship between energy consumption, delay, flow and the variability of each of these variables. This can be useful for sensor network engineers when adjusting their design parameters. We observe that the performance of SCP-MAC is very dependent on the traffic present in the network. For heavy traffic, the performance metrics studied here show deterioration and greater variability. It was also observed that, in terms of energy and delay, the adaptive channel polling is only effective when generating packets with high frequencies or during periods when there are bursts of traffic. Finally, we conclude that SCP-MAC can perform well in light traffic applications, with scalar sensors that tolerate delays, such as agriculture in the measurement of temperatures, pH and other environmental variables.

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