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A PERFORMANCE EVALUATION OF YMAC A MEDIUM ACCESS 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 article studies the main performance characteristics of the YMAC protocol, a medium access control protocol for sensor networks (WSN) that uses multiple frequency channels for data transmission. YMAC was designed taking into account the energy shortage characteristics of the sensor nodes and seeking to achieve good performance under various traffic conditions. Our contributions through this work are as follows: 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 YMAC 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 advances in micro-electro-mechanical systems (MEMS) and low-power digital electronics have made possible the development of wireless sensor networks - WSN. A WSN is typically constituted by a large number of small wireless sensor devices (sensor nodes) powered by batteries and deployed on a physical environment, which cooperate with each other to carry out one or more monitoring tasks.

There is a wide variety of applications designed for wireless sensor networks, which commonly involve some type of environmental monitoring or control activities such as precision agriculture, health, surveillance, wildlife monitoring and military applications [1- 2]. In a WSN the data collected by each sensor node is transmitted to a common device called the sink as shown in Figure-1. Additionally, the data of several nodes can be combined on the way to the sink to avoid redundancies, as well as for save energy.

The sensor nodes present limitations in terms of communication capacity, processing, storage and energy resources. Additionally, WSNs are commonly deployed in areas of difficult access where human intervention is almost impossible, for this reason, the preservation of energy resources is an aspect of extreme importance to extend the life of the network.

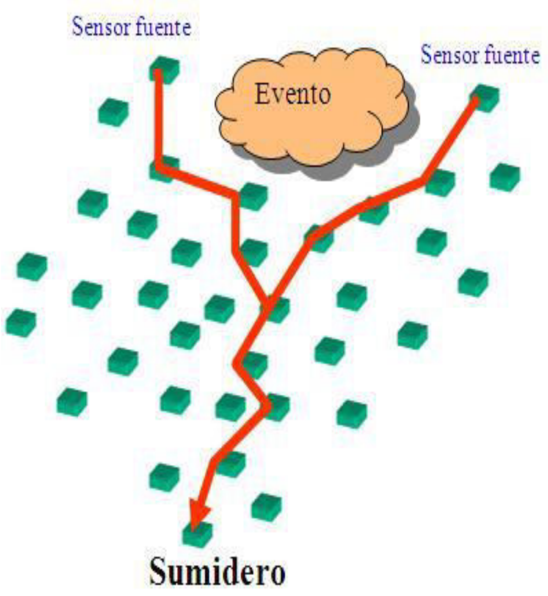

Figure-1. Typical wireless sensor network.

In WSN and ad hoc networks in general, tasks associated with the radio transmitter/receiver are responsible for the highest energy consumption [3-4]; 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 waste of energy [1, 5-6]:

- 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 we present a detailed performance evaluation of the YMAC protocol [7]. There are lights about the performance characteristics of the protocol, which as far as we know have not been presented in the literature found.

YMAC PROTOCOL

In order to face the limitations of current hardware, research efforts have also recently focused on the design of multichannel protocols to exploit the availability of the multiple frequency channels supported by the radio transmitters of the current sensor nodes. Transmission through multiple channels is one of the most promising strategies in the pursuit of better performance in terms of flow and delay in WSN [8].

There are two strategies that every multichannel protocol should include, first, a channel allocation strategy and second, a strategy of access to the medium. The channel assignment strategy can be static or dynamic. When a static channel assignment strategy is chosen, a frequency channel is assigned to each node to transmit or receive at each moment. When the channel allocation strategy is dynamic, a different frequency channel can be assigned to each node to transmit or receive at each moment according to an allocation or negotiation algorithm. The strategy of access to the medium can be contention or contention-free. In WSN, it is important that the channel allocation strategy be dynamic in order to use more channels to transmit and receive during periods of high traffic and few channels during periods of lower traffic.

YMAC is a protocol of access to the medium through multiple frequency channels, which uses LPL (Low Power Listening) to mitigate the problem of idle listening and saving energy. In YMAC time is divided into cycles and each cycle is subdivided into slots. Some slots are used for transmission by broadcast and the others for transmission to a specific node (unicast). Figure-2 shows YMAC's time division and operation strategy.

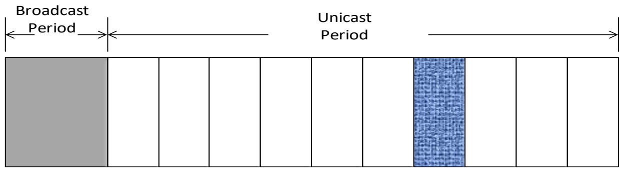

Figure-2. Time division strategy and operation of YMAC.

YMAC uses a dynamic light channel jump mechanism in which no fixed channels are assigned to the nodes. Initially, messages are exchanged on a base channel. When a burst of traffic occurs, a receiver and possible emitters jump to one of the other available channels, according to the jump sequence. As these messages are transported through additional channels, it is guaranteed that each node will receive at least one message on the base channel.

IMPLEMENTATION OF YMAC IN QUALNET®

The implementation of the YMAC protocol was performed in Qualnet® according to the description of the protocol presented in [7]. The communication of YMAC 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. Our YMAC implementation uses five frequencies channels, the channel polling is set to 3ms, a slot length of 15.2ms and ten slots per frame time, therefore the duty cycle is 3.9%.

Implementation of the physical layer model

At the physical layer level, a model was implemented to simulate the CC2420 radio [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.

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

In addition, the implemented model allows to calculate 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.

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-3.

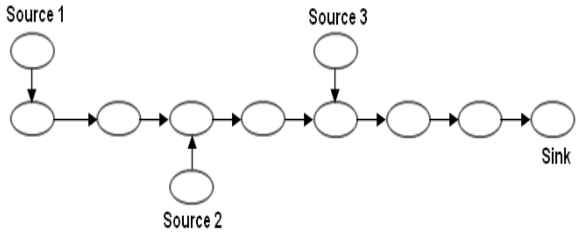

Figure-3. Chosen scenario for the simulation.

Performance evaluation under containment with light traffic

In the simulations, each source node sends 100 packets of 90 bytes each to the sink, with a fixed time interval between packet generation from 1 to 10s, which is a typical scenario in WSN. The nodes are physically separated by a distance of 80m, therefore, each node can only listen to its neighbor next door or to the neighbors located up or down, if there is one. Each experiment is repeated 30 times to collect enough data for statistical confidence. Each simulation is run for a time of 3000s. It is assumed that the nodes have sufficient capacity in the buffers to avoid packet losses during periods of congestion.

Figure-4 shows the average power consumption in the nodes of the network and Figures 5, 6 and 7 show the average delay experienced by each of the three sources.

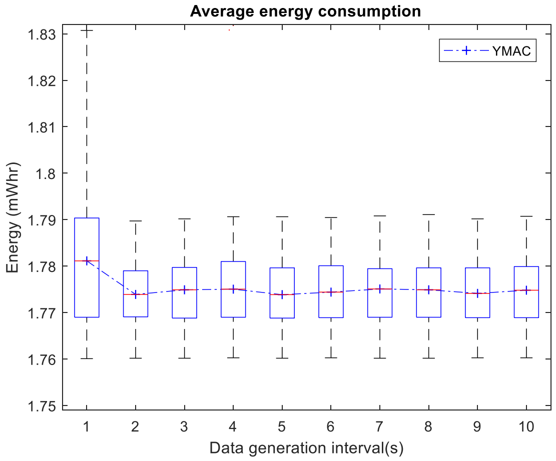

Figure-4. Average power consumption in the network nodes.

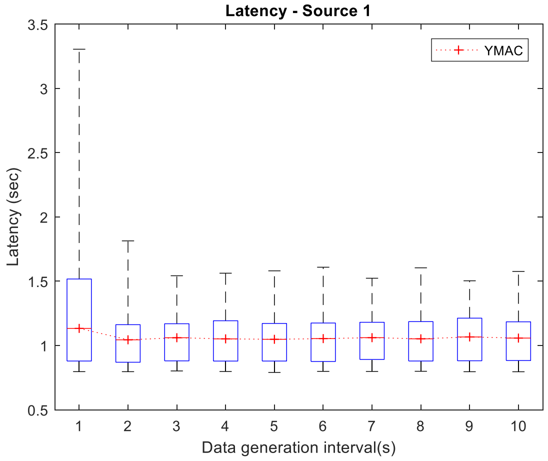

Figure-5. Average delay experienced by source 1.

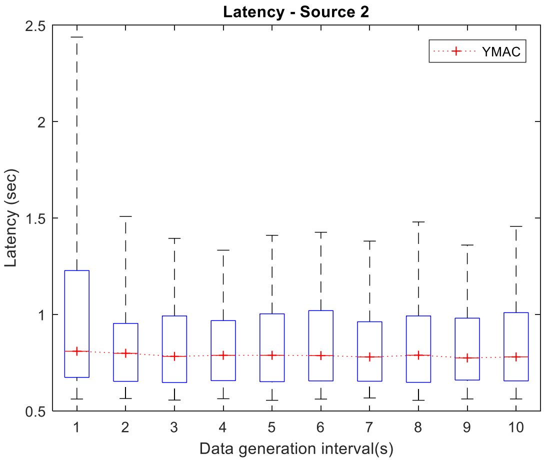

Figure-6. Average delay experienced by source 2.

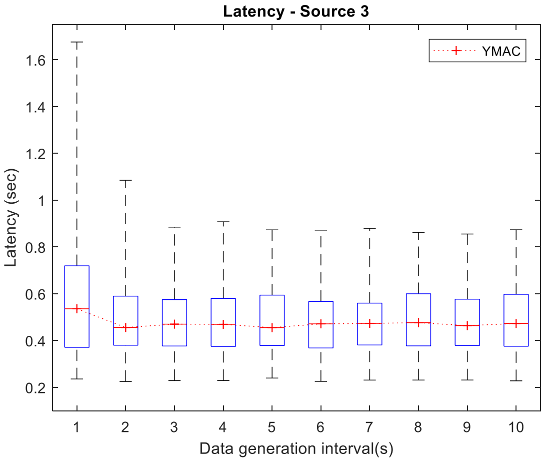

Figure-7. Average delay experienced by source 3.

The results of the simulations show a great variability in each one of the variables. Especially for the interval between generation of packets equal to one second, which is due to greater congestion in the network. However, the averages are very similar for all cases, which indicates that YMAC can respond appropriately and in a similar way for different traffic conditions in the network. It is important to note that the use of several channels, although it increases the variability of the results in average terms, presents good results.

Performance evaluation under containment with multimedia traffic

In order to study the performance of the three protocols under consideration with multimedia traffic, the same scenario as in the previous section was used. However, for the purpose of simulating multimedia traffic, each source node generates and sends 200 packets of 95 bytes each to the sink node with a variable time interval (traffic with Poisson distribution was used) between packets generated with average 0.12 seconds (6.333kbps each).

Figure-8 shows the average energy consumption. In this scenario, the average energy consumption is slightly higher than the average consumption of the previous scenario. Which indicates that for light traffic conditions and heavy traffic conditions YMAC behaves practically the same. It can be concluded then that YMAC presents a good performance in terms of energy and this is due to the use of the LPL strategy and the use of several frequency channels.

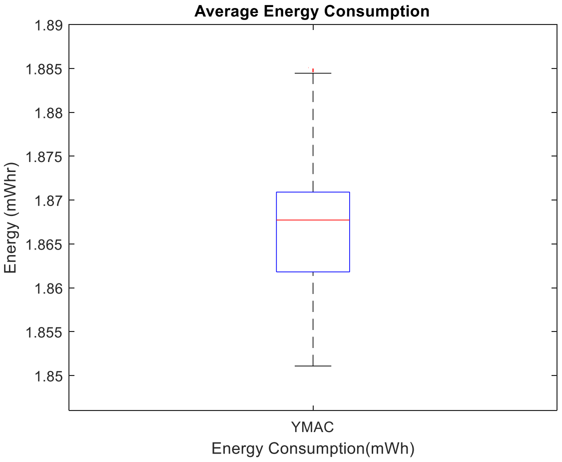

Figure-8. Average energy consumption

Figure-9 shows the average delay experienced by the sources. If we compare the average in this scenario with the averages of the previous scenario we see that the performance deteriorated considerably. From this it is concluded that in terms of delay YMAC does not present the best performance under heavy traffic conditions or low bursts of sudden traffic. However, YMAC can be used in WSN applications where little traffic is generated or where the delay is not a parameter of maximum importance.

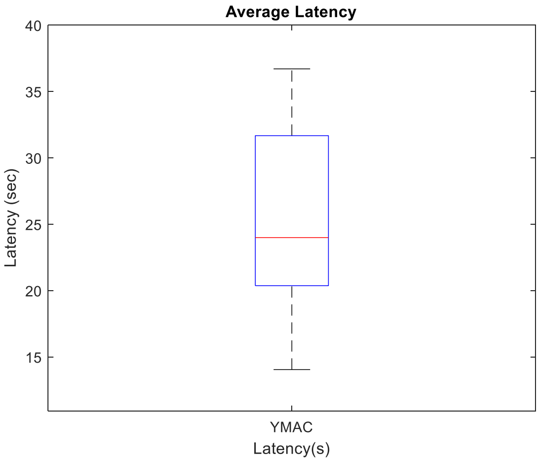

Figure-9. Average delay experienced by the three sources.

CONCLUSIONS

This article presents a simulation study of YMAC 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 and delay. We observe that the performance of YMAC is very dependent on the traffic present in the network. For heavy traffic the delay presents deterioration while the power consumption rises slightly. We conclude finally that YMAC 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. In situations of heavy traffic or bursts YMAC does not present the best performance.

ACKNOWLEDGEMENT

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