VOL. 11, NO. 21, NOVEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

PERFORMANCE ANALISIS OF THE LEMR-MULTICHANNEL PROTOCOL

Albeiro Cortés Cabezas
Department of Electronic Engineering, Surcolombiana University Grupo de Tratamiento de Señales y Telecommunications - GTST
Street 1, Pastrana Av. Neiva, Colombia
E-Mail: albecor@usco.edu.co

ABSTRACT

It is very challenging to overcome the known limitations of the current wireless sensor networks in terms of throughput, delay, and jitter while being energy efficient, in order to support multimedia applications. Nonetheless, the LEMR-multichannel (Latency, Energy, MAC and Routing) protocol has recently been proposed as a solution to address these issues over multi-hops wireless sensor networks. LEMR-multichannel addresses the typical interference problems found in wireless networks and includes an energy-efficient new dynamic duty cycle multi-channel medium access mechanism and a coordination strategy that uses the different channels available in the single radio transceiver devices to enhance the throughput capability of the network. This article provides an analytical model to compute the most important performance metrics of the LEMR-multichannel protocol. The model is also validated through simulation experiments.

Keywords: throughput, latency, wireless multimedia sensor network, MAC.

1. INTRODUCTION

It is well-known that supporting multimedia applications over wireless sensor networks (WSNs) is a very challenging problem since commonly used transceivers limit the network throughput to very low values. For example, the widely usedCC2420 transceiver included in many wireless sensor devices has a maximum transmission bit rate of 250 kbps [1]. If in addition, we include the inefficiencies brought in by the wireless media and the communication protocols on top of the physical layer, the throughput seen by the application becomes considerably lower than this raw transmission rate.

In order to address the performance needs of multimedia applications in terms of throughput, delay, and jitter while maintaining the low cost of the sensor nodes, the LEMR-multichannel protocol was proposed in [2], [3]. In order to increase the network throughput, LEMR-multichannel address the typical interference problems found in wireless networks using several of the available frequency channels provided by the CC2420 radio transceiver [1] and an appropriate strategy that coordinates when packets are injected into the network.

This paper provides an analytical model to analyze the performance of the LEMR-multichannel protocol. The model allows the computation of the transmission probability, average throughput, average number of failing attempts before a successful transmission, and average service time. Part of this model is inspired in the work published in [4]

The rest of the paper is organized as follows. Section II presents an overview of the LEMR-multichannel protocol. Section III presents the analytical model of the protocol. Section IV presents the performance evaluation results. Finally, Section V concludes the article.

2. THE LEMR-MULTICHANNEL PROTOCOL

The LEMR-multichannel protocol consists of a cross-layer design that involves physical layer information, a contention based medium access control mechanism, and a network layer forwarding mechanism working together to achieve high transmission reliability, low energy consumption, low latency, and higher throughput. LEMR-multichannel adopts the *Clear Channel Assessment* (CCA) and Low Power Listening (LPL) strategies along with a *channel polling* energy-saving strategy [5], which is a very energy-efficient method that involves the physical and MAC layers.

The node coordination function is the most important feature of the LEMR-multichannel protocol, as it is the responsible for its low latency and higher throughput performance. It is based on hop-distance to the sink node. To minimize packet latency toward the sink, collisions, and interference, those nodes n hops away from the sink periodically poll the channel Δ seconds after the channel polling is performed by those nodes $(n + 1)$ hops from the sink, where Δ is the minimal time necessary to transmit one packet completely. In this manner, intermediate nodes do not have to wait for a complete channel polling cycle to forward the packets toward the sink.

Throughput enhancing strategy

LEMR-multichannel dynamically allocates additional cannel polling opportunities to transmit and receive packets utilizing different frequency channels and therefore, achieves higher throughput. To minimize latency and jitter and achieve better throughput performance, when a node receives a packet, it has to retransmit it to the next hop immediately; therefore, the time between two consecutive cannel polling periods has to be 2Δ.

Adaptive duty cycle

In order to reduce the energy consumption of LEMR-multichannel, the idea of an Adaptive Multi-Channel Polling(*AMCP*) timer is introduced. Instead of polling each channel on a periodic manner, LEMR-multichannel polls one channel only while there is no traffic in the network and polls all the channels otherwise.

ARPN Journal of Engineering and Applied Sciences

Thus, if $T_{CP}$is the channel polling time,$T_{Frame} = N\Delta$ isthe frame time, and k is the number of frequency channels allocated, where k is the minimal integer closer to *N/2*,the duty cycle will be equal to$\frac{T_{CP}}{T_{Frame}} * 100$when no trafficis detected, and$\frac{k*T_{CP}}{T_{Frame}} * 100$otherwise.All nodes begintheir operation polling on one channel, thesame base channel. Upon receiving a packet, a node expects more packets be subsequently sent over the other channels; therefore, the node sets the AMCP timer and start polling on all channels.

Channel assignment

When traffic is detected, each node polls a different channel every 2Δseconds during each frame time. Frequencies are assigned sequentially beginning with the base frequency. So, packet one is sent using the *Base frequency*, packet2 using *f1*, packet 3 using *f2*, and so on until the frequency *fk*, when the cycle repeats. Note that each packet received over each frequency is immediately transmitted to the next node, minimizing latency and jitter. For the routing of packets, when one node wishes to send packets to the sink, it chooses a node, among all one-hop nodes, that are closer to the sink as the next hop. The selected one-hop node is the one that maximizes the following cost function:

$$C_{ij} = c_1 E_j + c_2 RSSI_{ij} (1)$$

Where, $E_j$is the remaining energy of the receiver, and$RSSI_{ij}$is the measured power level during the SYNCprocess. Theconstantsc_1 andc_2 are weights given to each variable according to the application requirements.

3. MODELING AND PERFORMANCE ANALYSIS

In this section, we present the analytical model to analyze the performance of the LEMR-multichannel protocol. Initially, the transmission probability will be derived considering the contention windows size, the number of surrounding nodes, and its channel access probability at each time step. Right after, the average number of attempts before a successful transmission, the average service time, and the queuing analysis will be derived. Finally, the model will be validated with simulation results.

Since each node starts its multichannel operation immediately after traffic is detected, the analysis considers the particular case when a node has its AMCP timer set. Under this condition, the node will use a Δ time interval to receive packets and another right after Δ time interval to transmit using the same channel. Therefore, to this model the time step will be equal to 2 Δ. In addition, nodes will use a different frequency channel during each subsequent time step. Figure-1shows all possible states of a node during each time step.

When the receiving interval starts, the node is sleeping. Right after the channel polling operation starts, and if there is network activity, the node waits for a possible packet receipt. If there is a packet, the receiving operation starts. Otherwise, the node goes to sleep again. When the transmitting interval starts, then ode is sleeping. If there is not a packet to be sent, the node keeps sleeping. Otherwise, the node tries to transmit the packet reserving a slot into the contention window to start the transmission. A collision may occur if at least one additional node tries to transmit at the same time.

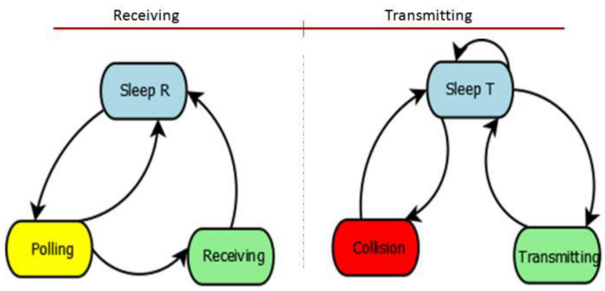


Figure-1. LEMR-multichannel diagram states.

LEMR-multichannel node model

Figure-2 shows the node model of the LEMR-multi channel protocol. As the figure shows, two classes of packets may arrive at the queue, packets from transit traffic, coming from other nodes which selected the *nodeI* as next hop and internal traffic packets, which come from the upper layers.

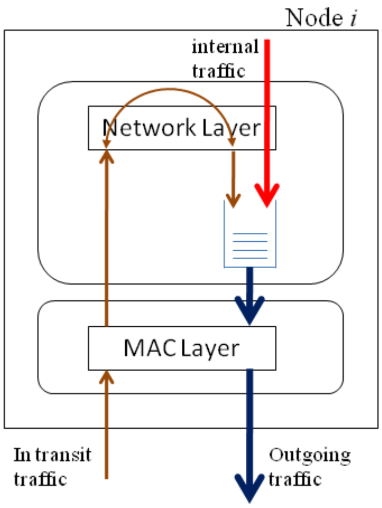


Figure-2. Node model.

Figure-3shows the incoming and outgoing traffic pattern. Notice that atmost one transit packet may arrive at each time step; however, the average number of internal packets arriving at each time step depends of the application running at the upper layers. On the other hand, at most one packet departure or packet transmission may occur at the end of each time step.

LEMR-multichannel model assumptions

In order to facilitate the development of the analytical model for the LEMR-multichannel protocol, the following assumptions were considered:

VOL. 11, NO. 21, NOVEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

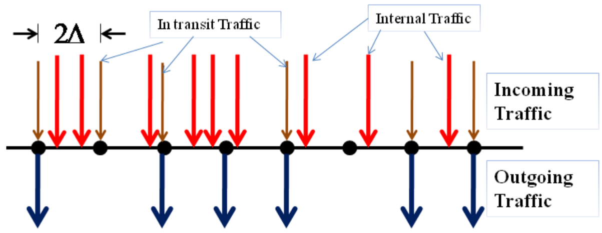


Figure-3. Incoming and outgoing traffic model.

- The network is assumed homogeneous and its density is equal to *N*. However, in LEMR-multichannel each node will contend with at most *M-1* nodes only, where *M=N/3*. This is because LEMR's coordination strategy classifies the neighbor nodes into *N0*, *N1*, and *N-1* categories (nodes at the same distance, nodes one hop further, and node one hop closer to the sink, respectively), and each node contends only with nodes at the same hop distance to the sink.
- All parameters in this model are calculated from the point of view of one particular node *k*.
- All nodes contending with node *k* require the channel at each time step with probability a.
- All nodes requiring the channel have equal probability to win the contention.
- The contention window (*CW*) consists of *w* slots, as shown in Figure-4.
- At most *m* packet arrivals from internal traffic may occur at the queue.
- In transit packet arrival probability at the queue is given by u. This probability depends of the channel requirement probability of nodes which selected the node as next hop.
- A FIFO queue with size *B* is assumed.
- *Pt* is the transmission probability which is also the packet departure probability at the queue.
- Packets arriving at a time step might be served immediately at the same time step. So, LEMR-multichannel achieves very low delay.

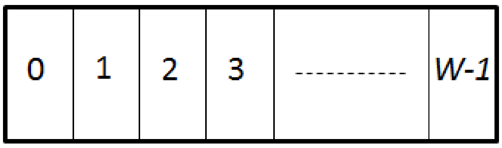


Figure-4. LEMR-multichannel contention window.

Transmission probability

At the beginning of one time step, the probability that anode with data to send reserves a particular slot to starts the transmission is given by

$$\alpha = \frac{1}{w} \quad (2)$$

And the probability that a node with data to send does not reserve a particular slot is therefore given by

$$\beta = 1 - \alpha = 1 - \frac{1}{w} (3)$$

Consider a particular node containing packets to transmit in a particular time step, and assume that it reserves a slot into the contention window. This node will win the contention and transmit a packet only if no other node reserves the same slot that it reserved or a previous one. So then, the transmission probability which is also the packet departure probability will be given by

$$Pt = \alpha\beta^{a(M-1)} + \alpha\beta^{2a(M-1)} + \cdots + \alpha\beta^{wa(M-1)} (4)$$

The first term on the right hand side of the equation is the probability that the first slot be reserved by the node and no other nodes require transmitting during that slot. These condterm is the probability that the second slot be reserved and no other nodes require transmitting at that slot or at the first slot, and so on.

Alternatively, this transmission probability can be rewritten as

$$Pt = \alpha \sum_{j=1}^{w} \alpha\beta^{aj(M-1)} = \frac{1-\beta^{wa(M-1)}}{1-\beta^{a(M-1)}} \alpha\beta^{a(M-1)} (5)$$

Average number of failing attempts before a successful transmission

In order to adjust the average packet loss, it is important to know the average number of attempts before a successful transmission ($\bar{I_a}$) to set the number of retries at the MAC layer. Since *Pt* is the successful transmission probability, *1-Pt* will be the failing probability. In theory, a node may fail from *j=0*up to *j=∞* times before achieving a successful transmission. Therefore, the average number of attempts before a successful transmission is given by

$$\bar{I_a} = \sum_{j=0}^{\infty} j\,(1-Pt)^j Pt = \frac{1-Pt}{Pt} \quad (6)$$

Notice that$\bar{I_a}$ is a geometric random variable withprobabilitydistribution function given by

$$p(I_a = n) = Pt(1-Pt)^n \; (7)$$

Where *n* represents the number of failed attempts.

Average service time

The average service time ($\overline{R_a}$) is the time that a node spends after the packet is de queue and relayed to the MAC layer until it is transmitted. Since during each failing attempt the node spends 2Δ and additionally 2Δ during the transmission, then the average service time will be given by

$$\overline{R_a} = 2\Delta * \bar{I_a} + 2\Delta = \; 2\Delta(\bar{I_a} + 1) \; (8)$$

Alternatively, this equation can be written as

$$\overline{R_a} = \; 2\Delta \sum_{j=0}^{\infty} (j+1)(1-Pt)^j Pt = \frac{2\Delta}{Pt} (9)$$

It means that the service time Ra of the LEMR-multichannel protocol is also a geometric random variable and its probability distribution function is given by

ARPN Journal of Engineering and Applied Sciences

$p(R_a = n * 2\Delta) = Pt(1-Pt)^{n-1}$(10)

for n = *1; 2; 3*

Queuing model

According to the LEMR-multichannel assumptions atmost(m+*1*) arrivals and at most one departure may occur at each time step. Therefore, the queue size can increase by more than one, but can only decrease by one at each time step. So then, if i_j is defined as the probability of j arrival during a time step due to the internal traffic, $0 \le j \le m$ and u as the arrival probability due to in-transit traffic, then P_n the jointprobability of n arrival due to the in-transit and internal traffic at a time step will be given by

$$P_n = (1-u)i_n + ui_{n-1} = u(i_{n-1} - i_n) + i_n (11)$$

Where $0 \le n \le (m+1)$ and $i_n = 0$ for $n < 0$.

The condition for the stability of the queue is given by

$$\sum_{n=0}^{m+1} nP_n < Pt (12)$$

It means that the average number of arrivals at a given time is less than the average number of departures. The vector states of the queue is given by

$$\boldsymbol{s} = \{s_0, s_1, s_2, \dots, s_B\} \ (13)$$

The state transition matrix is a *(B +1)*(B +1)* diagonal
matrix given by

$$P = \begin{bmatrix} x & t_0 & 0 & \dots & 0 & 0 \\ t_2 & t_1 & t_0 & \dots & 0 & 0 \\ t_3 & t_2 & t_1 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ t_B & t_{B-1} & t_{B-2} & \dots & t_1 & t_0 \\ h_B & h_{B-1} & h_{B-2} & \dots & h_1 & h_0 \end{bmatrix} (14)$$

Where,

$$x = P_0 + P_1 * Pt (15)$$

$$t_i = P_i * Pt + P_{i-1}(1-Pt) (16)$$

$$h_i = P_i(1-Pt) + \sum_{n=i+1}^{m+1} P_n \ (17)$$

The difference equations for the steady-state distribution vector are obtained from the equation

$$P\boldsymbol{s} = \boldsymbol{s} (18)$$

And

$$\sum_{i=0}^{B} s_i = 1 (19)$$

Queuing performance

In this section the three most important queuing performance parameter will be derived. These parameters are throughput, average queue size, and average waiting time. To calculate the throughput of the LEMR-multichannel protocol it is necessary to consider the queue in two situations, when it is in $s_0$state or empty and whenit is in another state. When the queue is in s_0 state the throughput in packets by time stepis given by

$$Th_0 = (1-P_0)Pt (20)$$

This is the arrival probability of one or more packets for the departure probability. When the queue is in any other state the throughput is given by

$$Th_i = Pt (21)$$

Where $1 < i \le B$.

So then, the average throughput is calculated as

$$\overline{Th} = \sum_{i=1}^{B} Th_i s_i \ (22)$$

The throughput in units of packets/s is given by

$$avTh = \overline{Th}/2\Delta (23)$$

The average queue size measured in packets is given by

$$avQ = \sum_{i=0}^{B} is_i \ (24)$$

The waiting time is the average number of time steps that a packet spends in the queue before it is delayed to the MAC layer. It can be estimated invoking the Little's result as [4]

$$\overline{W} = \frac{avQ}{\overline{Th}} (25)$$

The waiting time in seconds is given by

$$avW = \frac{avQ}{avTh} (26)$$

4. MODEL EVALUATION

Transmission probability and average time service

In order to evaluate the model at the MAC layer level in this section the transmission probability, the average service time and the average number of failing attempts before a successful transmission will be estimated. Several one-hop scenarios using different number of nodes (M varies from 1 to 10 in our simulations) were implemented in Qualnet® simulator, as shown in Figure-5(a).

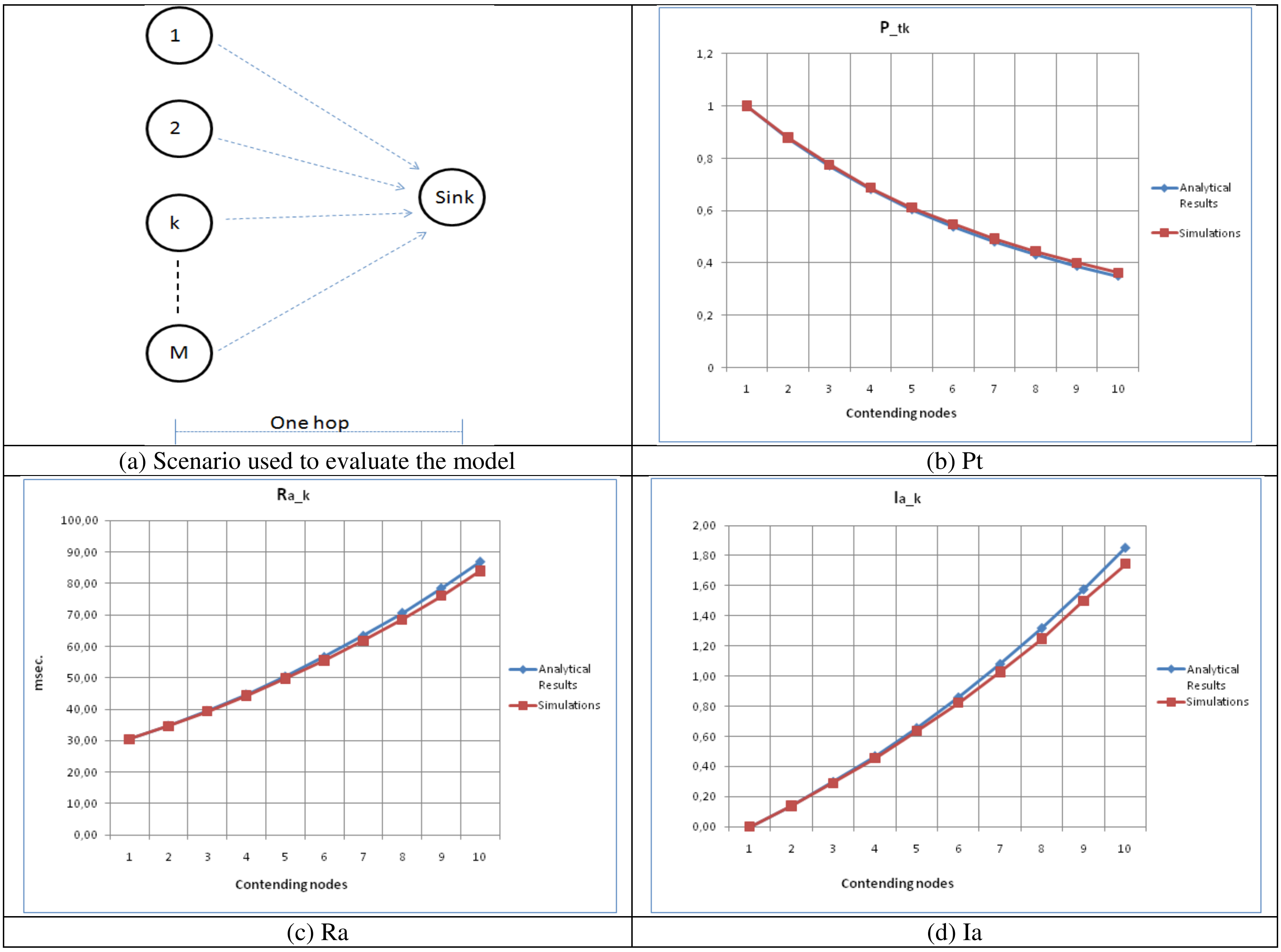
In this model the time step, 2Δ = 0.03047*sec*. In the simulations, node k generates traffic with 95 bytes packets and average rate λk = 33packets/s. It means that its channel requirement probability a, is equal to 1. Other

VOL. 11, NO. 21, NOVEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

nodes generate *Poisson* traffic with 95 bytes packets and average rateλ= 6.6packets=s, it means *a*=0.2.

Figures 5(b) and 5(c) compare the transmission probability and the average service time obtained by node *k* obtained using the analytical model and the simulations. Figure-5(d) shows the average number of attempts before packets is sent while the traffic load increases. As it was expected, these figures show that in all cases the simulation results fit very well the analytical model results.



(a) Scenario used to evaluate the model (b) Pt

(c) Ra (d) Ia

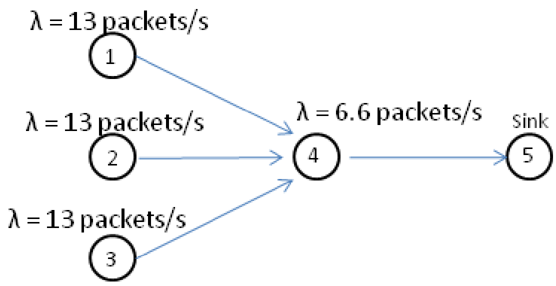
Figure-5. Model evaluation results.

Queuing performance simulations

In order to evaluate the model at the network layer level in this section queuing performance parameters as average throughput, average queue size and average waiting time will be estimated. A scenario of five nodes was implemented in Qualnet® simulator, as shown inFigure-6. In this scenario *m=1* is assumed and the internal traffic packet arrival probability will be given by *v*. Nodes1, 2 and 3 require the channel at an average rate λ =13packets/s and use the node 4 as next hop. It means that *a*= 0.4. Upper layers of node 4 generate traffic at an average rate λ = 6.6 packets/s, it means that *a*= *v* = 0.2.Finally, *B*=15 to all nodes. Table-1 shows the arrival probabilities. Notice that at node 4 *Pt* = 1.

The state transition matrix is a 16x16 diagonal matrix as shown in Figure-7. In this matrix *f* = 1-*Pt*,$P_0 = (1-u)(1-v)$,$P_1 = v(1-u)+u(1-v)$ and $P_2 = uv$. Tocalculate thein-transit packet arrival probability *u* at node4 due to nodes1, 2 and 3 note that the probability that *k* of *N* contending nodes attempt a transmission during a given reservation slot is given by

$$b_k = \binom{N}{k}\left(\frac{a}{w}\right)^k\left(1-\frac{a}{w}\right)^{N-k} \quad (27)$$



VOL. 11, NO. 21, NOVEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Figure-6. Simulation scenario.

Table-1. Arrival probabilities.

Arrivals number	Probability
0	(1-u)(1-v)
1	v(1-u)+u(1-v)
2	uv

Where $0 \leq k \leq N$, $N = 3$ for this scenario and $w = 5$ in LEMR-multichannel protocol. A packet will arrive to node 4if only one node reserves the first slot or if only one node reserves the second slot and no any other reserves this one or the first, and so on. Therefore, the probability u that one packet arrives at node 4 is given by

$$u = b_1 + b_1 b_0 + b_1 b_0^2 + \ ... + \ b_1 b_0^{w-1} = \frac{b_1(1-b_0^w)}{1-b_0} \quad (28)$$

Due to$b_0 = 0.78$, $b_1 = 0.20$and $w = 5$then $u = 0.66$. So then,

$$\sum_{n=0}^{m+1} nP_n = u + v = 0.86 < Pt \quad (29)$$

It means that the average number of arrivals at a given time is less than the average number of departures; therefore, the stability condition is assured. Figure-8shows the state probabilities and Table-2 shows the theoretical and simulation parameters results. As it was expected, this table shows that in all cases the simulation results fit very well the analytical model results.

$$P = \begin{pmatrix} P_1Pt + P_0 & P_0Pt & 0 & \cdots & 0 & 0 \\ P_1f + P_2Pt & P_1Pt + P_0f & P_0Pt & \cdots & 0 & 0 \\ P_2f & P_1f + P_2Pt & P_1Pt + P_0f & \cdots & 0 & 0 \\ 0 & P_2f & P_1f + P_2Pt & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \cdots & P_1Pt + P_0f & P_0Pt \\ \vdots & \vdots & \vdots & \cdots & P_1f + P_2 & P_0f + P_1 + P_2 \end{pmatrix}$$

Figure-7. Transition states matrix.

s0 =	0,53572
s1 =	0,24873
s2 =	0,11548
s3 =	0,05362
s4 =	0,02489
s5 =	0,01156
s6 =	0,00537
s7 =	0,00249
s8 =	0,00116
s9 =	0,00054
s10 =	0,00025
s11 =	0,00012
s12 =	0,00005
s13 =	0,00002
s14 =	0,00001
s15 =	0,00001

Figure-8. State probabilities.

Table-2. Theoretical and simulations results.

Parameter	Theoretical	Simulation
avTh	21.3 kbps	22.3 kbps
avQ	0.87 packets	0.86 packets
avW	31.2 msec	31.1 msec

5. CONCLUSIONS

This paper presents an analytical model to evaluate the performance of LEMR-multichannel protocol, which is designed to support multimedia applications over wireless sensor networks. The model includes the most important metrics for multimedia applications such as latency and throughput.

In wireless multi hop networks, channel assignment methods may reduce but not eliminate the contention. For example, even though LEMR-multichannel uses several frequency channels, nodes still have to contend with other nodes at the same hop distance to the sink.

As expected, the simulation results show that the transmission probability and throughput decrease with the number of contending nodes.

Simulation results also show a very low queuing occupation. This is because LEMR-multichannel rapidly retransmits the packets upon receiving them at the same time step. Additionally, this means that LEMR-multichannel strategies not only improve the throughput, latency and jitter, but also the memory resources.

As future work, we will utilize the local traffic information to adjust the AMCP timer and the time frame duration, in order to achieve a better energy consumption without deteriorate the latency performance and we will also include some strategies of service differentiation.

ACKNOWLEDGEMENTS

This work was funded in part by the Newton Fund, The University of the Andes, Colciencias and Surcolombiana University in Colombia.

REFERENCES

[1] Chipcon. Cc2420 datasheet. Available in http://www.chipcon.com, 2005.

[2] A. Cortes, N. M. Pena and M. Labrador. 2009. An adaptive multi-channel approach for real-time multimedia wireless sensor networks. In: Proceedings of IEEE LatinCom.

[3] A. Cortes, N. M. Pena and M. Labrador. 2010. An adaptive multi-channel approach for real-time multimedia wireless sensor networks. IEEE LatinAmerican Transactions. 8(4): 370-376.

[4] F. Gebali. 2008. Analysis of Computer and Communications Networks. Springer.

[5] W. Ye, F. Silva and J. Heidemann. 2006. Ultra-low duty cyclemac with scheduled channel polling. In Proceedings of the 4th International Conference on Embedded Networked Sensor Systems.