# Polling-based Medium Access Control Scheme for Wireless Body Sensor Network

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**Abstract** - *The performance of polling-based MAC scheme for Wireless Body Sensor Networks (WBSN) is investigated in this paper. The objective is to study the suitability of the polling mechanism to gather the quasi real-time data from sensors placed in a human body. The main parameters used for study are packet loss, packet waiting time and buffer size at sensor nodes. To accomplish the objectives, a simulation platform is developed in C++ where the polling mechanism, the buffers and the sensor sources are all implemented. Due to the lack of sensor node models for WBSN applications, five sensor sources are developed based on the On/Off source model. The simulation results showed that the polling method is a very promising access scheme for the scenarios examined. The results also showed that source configurations can greatly affect the network performance.*

**Keywords:** Wireless Body sensor network; polling; performance; simulation; On/Off sources

## 1 Introduction

Wireless Sensor Networks (WSN) are composed of tiny electronic devices performing remote monitoring and have applications in different areas, such as, environment, plantation, human body, and others. In the near future these networks will be more present in various environments and scenarios.

With the great development of the microelectronic field, the sensors that are the nodes of WSNs became smaller, and some models can be referred to as nano-sensors. Due to the small size of the nodes and batteries, in addition to the the limited energy storage capacity, the sensors can be placed in locations of limited access, resulting in difficulties recharging or exchanging the batteries. Thus, the sensor nodes, apart from the operation with features designed, must mainly save energy.

Among the tasks performed by the sensors, one that more degrades the battery is the communication. Since the environment of transmission among the sensors is the air, if more than one node begins to transmit packets simultaneously, collisions will occur, and packets must be retransmitted. In the case of WSNs where the sensors are distributed over large geographic areas, these communications are complex because in addition to try to reduce the collisions, each node must discover a route and forward the packets to the next node. For wireless body sensor networks (WBSN), where the sensors are located in a restricted area (human body), the use of the centralized node or sink node is more convenient because it simplifies the communication, and it is able inclusive to avoid completely the collisions. Using the centralized or star configuration, the medium access control (MAC) scheme can be ordered, preventing that more than one node begin to transmit packets at the same time, avoiding packet collisions.

The main MAC scheme proposed in the literature for the WBSN is the standard 802.15.4 with beacon enabled star configuration which provides very low energy consumption [1]. However, since the scheme is not designed for WBSN applications some drawbacks have been pointed out [2] and recently many schemes of MAC protocols specifically for WBSN have been proposed [2-16]. Some proposals are variation of standard 802.5.4 [5], [8] and [11] and others are based on TDMA access technique [3], [4], [7], [10], [14], [15] and [16]. Each of the proposals explores some special features based on medical needs. For instance in [3-4] to deal with the light and heavy loads in the normal and urgent situations, a context aware MAC is proposed. To guarantee QoS of a WBSN in [12] it is proposed a MAC protocol based on random access technique. The proposal presented in [10], the heart beating is used for the purpose of clock synchronization. In [6] the beacon used for wake-up sensor nodes is used for battery charging, increasing the network life time.
In all of the above proposals, the nodes must be woken up periodically to synchronize the node clock with the centralized node clock using the beacon signal.

In this paper, the polling-based access scheme that avoids the need for periodical synchronization is examined. The polling access technique inspects each node in a predetermined sequence. At each inspection, if the sensor has data, it is transmitted - If not, the next node of the cycle is inspected, and so on, until the last node is completed. The

* This work was partially supported by FAPESP under grant No 2011/12463-0

cycle starts again once all nodes have been inspected. When a node is not inspected it can be in an "Off" state, thus saving energy. Another advantage of the polling access technique is that it allows for a different order of access to the sensors enabling QoS capability in WBSN.

This paper is divided into five sections. The second section is related to the operation of the polling access scheme for the wireless body sensor network. In the third section, five different sources developed and the scenarios to be analyzed are described. The simulation results obtained in different scenarios are presented in section four. Finally, the main conclusions are presented in section five.

# 2 WBSN and Scheduling

A WSN composed by biological sensors designed to monitor vital signs of a human body is usually called Wireless Body Sensor Network (WBSN). The WBSN - composed of many sensor nodes with processing, communications and limited energy capabilities - has the function of monitoring various activities of the human body, facilitating the attendance of patients who require remote medical attention.

Fig. 1 shows the configuration of a WBSN as proposed in [17]. As it can be seen in Fig. 1 the human body was divided into many regions: the head (region 1), thorax (region 2), two upper members (regions 3 and 4), abdomen (region 5) and two lower members (regions 6 and 7). Many sensors can be inserted in these regions.

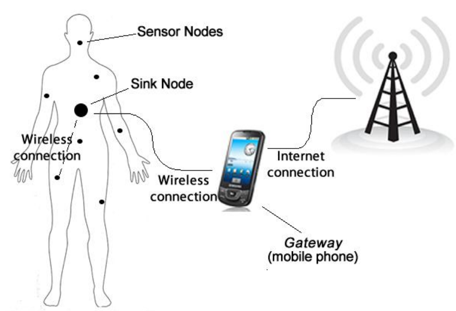


Figure 1. Environment of the WBSN studied.

Basically, there are two classes of MAC mechanisms: ordered and random access. In the former, a centralized node (or sink node) is used to organize the dispute for the output link. In the latter, each node transmits packets randomly to the physical medium and collisions may occur. For the WBSN, a centralized node is more convenient because collisions can be avoided, thus saving energy.

In this paper, an ordered MAC mechanism called polling is used. The idea is to use the similar time sharing system connecting the mainframe computer to the terminals in early times of computing. This scheme is chosen because it does not need frame synchronization as TDMA requires and still can keep almost a real-time treatment of messages for a reasonable amount of nodes. Fig. 2 shows the polling scheme proposed in this paper. The sink node, in normal operation, defines a cycle to attend the nodes. Based on this cycle, the sink node interrogates each sensor individually to check if there are packets to transmit. If there are, the sensor node receives a permission to start transmission while the others wait their turns. Thus, while a sensor node transmits packets, the others are performing their monitoring activities, awaiting their turns to transmit, and can store the generated packets in the buffer. After data transmission, a sensor node can await sleeping, thus saving energy.

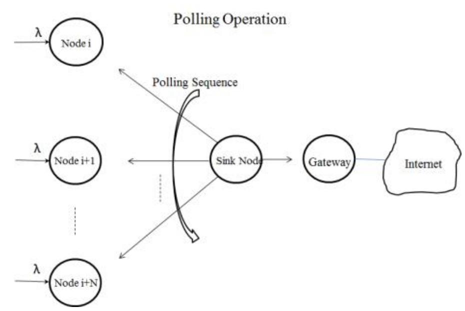


Figure 2. Polling Operation.

The communication protocol for the polling access scheme proposed in this paper can be simplified using the fact that the sensors are located near to the sink node. In normal operation the sink node broadcasts a packet carrying the node number to be investigated, i.e., it is sending an authorization to a sensor node to transmit the packets. This authorization packet has in the header enough bits for bit and frame synchronizations of a node. If a node has packets to transmit, it recognizes the node number and starts to transmit. After the transmission, the sensor node waits for acknowledgement in case of the need for retransmission. If a node doesn't have a packet to transmit, the transceiver can stay in an off state and only switches to on state if it has a packet to transmit. The sink node recognizes that a node is in an off state after the transmission of an authorization packet and waiting for a while. If the data packet from the polled node doesn't arrive, the sink node infers that the node doesn't have a packet to transmit and goes to another node in sequence to poll. Thus, in this protocol, the sink node does almost all the communication function, leaving the sensor node with only the packet transmission function.

The incoming packets to the sink node are queued at the output buffer to be relayed to the Internet or to a dedicated network where data are processed and stored as shown in Fig. 2.

# 3 Source Models and Description of the Scenarios for Analysis

For the analysis of the proposed polling-based MAC scheme, the sensor node modeling as the packet sources is very important. Five different source models are proposed in this paper - all using the On/Off scheme for performance evaluation by simulation.

The first one is called Constant On/Off Source. This source generates one packet at each on interval, and the packet has a fixed size so that the intervals have an equal length obtained by dividing the packet size by the peak rate. In the off interval case, an average value is defined, and the off intervals are generated using negative exponential distribution.

The Constant On/Off Source operates in continuous monitoring mode, in which the sensors are always collecting the information and sending it to a sink node or a server. The sensors are processing all the time so they may have a shorter lifetime, but all the measurements are sent.

Four different sources based on the Constant On/Off Source that target energy saving have also developed. These sources have features that represent the behavior of sensors in the event-driven monitoring mode, where sensors send only relevant information to the event observer. The idea, for instance, is to define a sensor that is monitoring body temperature and send only those measurements that are above a certain value. The other criterion could be to transmit just the packets that are outside a certain range.

Based on these assumptions, a function that generates random values representing the measurement performed by the sensor was created. To select the packets that must be transmitted or discarded, the value generated is compared to a parameter supplied during the source configuration.

Table 1. FEATURES OF THE DEVELOPED SOURCES

| | |
|---|---|
| **Constant On/Off Source** | Send all packets generated. |
| **Threshold On/Off Source** | Send only packets carrying information above a threshold. |
| **Controlled Threshold On/Off Source** | Send only packets containing information above a threshold or next packet when discarded packets reached a predefined number. |
| **Out-range On/Off Source** | Send only packets carrying information that are outside a certain range. |
| **Controlled Out-range On/Off Source** | Send packets satisfying Out-range On/Off Source criterion or next packet when discarded packets reached a predefined number. |

To simulate sensors sending only measurements that are outside a certain range, two parameters should be informed to calculate that interval. These parameters are the average value and the percentage variation of this value. For example, in a sensor responsible for heart-beat monitoring, it is wished that only the measurements representing risks for a patient's life be sent. For instance, the normal heart-beat for a particular patient is 100 beats per minute, and it can vary between 80 and 120 per minute, then should be informed to the program the average value 100 and the percentage variation of 20%. Thus, in this case, only packets showing heart-beat measurements less than 80 or greater than 120 should be sent.

In the above-mentioned criteria, it is possible that there may be a hiatus where the nodes do not transmit any packet because no measurement satisfies the specified criteria for the transmission. Thus, to avoid a long silence of the sources, the discarded packets are counted and when this counting reaches a certain value the next packet is sent, regardless if the measurement satisfies the criteria established or not.

Tab. 1 shows the features of each developed source.

The following parameters shown in Tab. 2 are used for the generation of the five traffic sources.

Table 2. PARAMETERS FOR TRAFFIC GENERATION

| | |
|---|---|
| Packet size | 904 bits |
| Peak rate | 39322 bits/sec |
| On Interval | 22.989 msec |
| Off Interval | 206.901 msec |

The used packet size is the average packet sizes presented in the papers [18], [19] and [20]. The value of the peak rate was obtained in [21] and [22]. The On interval in Tab. 2 corresponds to the packet size divided by the peak rate. The Off interval is obtained considering that the sensors stay in the off state for 90% of the time [23]. From the sink node, the data are transmitted to a gateway, which can be a mobile device, as shown in Fig. 2. The sink node also contains the FIFO scheduler. The gateway forwards the information to the server. Different types of the sensor nodes, listed in Tab. 1, are placed in several parts of the body regions according to Tab. 3.

Table 3. SCENARIOS CONSIDERED

| | *Scenario 1* | *Scenario 2* | *Scenario 3* |
|---|---|---|---|
| ***Region 1 (node 1)*** | *Constant Source* | *Constant Source* | *Constant Source* |
| ***Region 2 (node 2)*** | *Constant Source* | *Constant Source* | *Threshold Source* |
| ***Region 3 (node 3)*** | *Constant Source* | *Constant Source* | *Controlled Threshold Source* |
| ***Region 4 (node 4)*** | *Constant Source* | *Threshold Source* | *Controlled Threshold Source* |
| ***Region 5 (node 5)*** | *Constant Source* | *Controlled Threshold Source* | *Out-range Source* |
| ***Region 6 (node 6)*** | *Constant Source* | *Out-range Source* | *Controlled Out-range Source* |
| ***Region 7 (node 7)*** | *Constant Source* | *Controlled Out-range Source* | *Controlled Out-range Source* |

Tab. 3 shows the three scenarios considered in the simulations, which aim to verify the performance of the

WBSN proposed. In Scenario 1, the Constant Source is used in many body parts to study the performance of the polling scheme to deal with heavier packet traffic, since the source constantly generates the packets. In the second scenario, mixed sources are configured having mostly Constant Sources. The third scenario is mixed with different types of proposed sources.

Each source was simulated with 10,000 packets, and the buffer sizes used are one, three, five or one thousand position(s). The choice of these values is justified by the fact that the nodes have little memory, and the last situation is equivalent to a fictitious buffer due to the limited energy of the nodes and can be considered infinite depending on the generation rate of packets. Since there are not frequent variations in measurements of physiological signals such as temperature and pressure, some losses can be accepted without impact to the system. A buffer of one-to-three positions was also used in [18].

At the sources using the controlled parameters, a signaling packet indicating the sensor node is active is sent every ten packets not transmitted.

The same output link of 250 Kbits/sec used in [21] is adopted. The data for statistical analysis are collected after discarding the first 2,000 packets to guarantee that statistical equilibrium is reached.

# 4 Analyses of Results

To analyze the behavior of the WBSN presented in Fig. 1, the three scenarios shown in Table III are studied. The aim is to analyze packet loss and queue time at sensor nodes using the polling medium access control. Moreover, the goal is also to verify the influence of the different sensor configurations in the WBSN performance.

Fig. 3 shows the simulation results for Scenario 1, according to the packet loss.

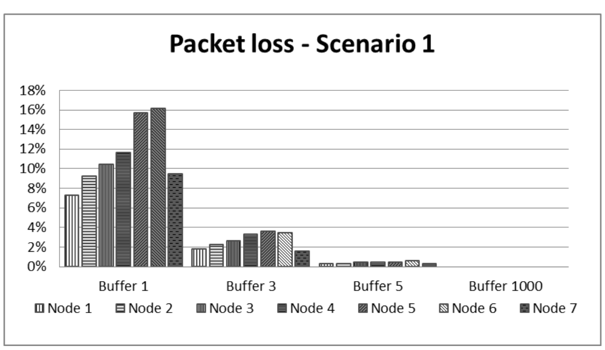


Figure 3. Packet loss in the first scenario.

As can be seen in Fig. 3, the packet losses in all nodes are very high - ranging from 7 % in node 1 to 16% in node 6 - for the buffer with one position because all the generated packets are transmitted. However, because of the increase in the buffer size for three positions, the packet losses become reasonable, reaching at most 4%. It shows that a buffer size with five positions has losses less than 1% and for one thousand positions no packet loss is observed. The packet loss using Constant Source types is not critical because the sources are sending packets constantly and any lost packet can be interpreted at the final server using an interpolation technique.

In Fig. 4 the average queuing time of packets is shown.

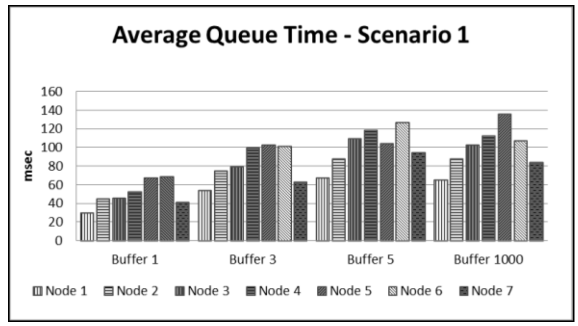


Figure 4. Waiting time of packets in first scenario

The minimum waiting time is about 30 msec in node 1 for one buffer size and the maximum is about 140 msec in node 5 for the one thousand buffer size as can be seen in Fig. 4. The waiting times are not long and are appropriate for quasi real-time processing.

In the simulations of all scenarios it has not considered the walk-time necessary, after the transmission of a packet, to move the inspection from one node to another node. This time in the case of WBSN is small and could be considered a constant value. The propagation time from a node to a sink node is also not considered.

Fig. 5 shows the simulation results for Scenario 2, according to the packet loss.

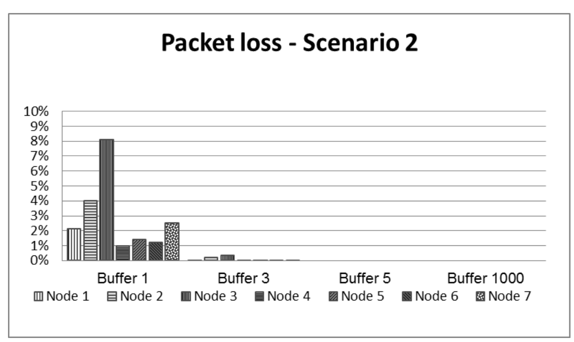


Figure 5. Packet loss in Scenario 2.

In the second scenario - where the traffic is generated in three sensors using the Constant Sources, in which all the generated packets are transmitted - it can be seen the nodes 1, 2 and 3 have more significant packet loss, reaching 8.14% at node 3. This fact is justified considering that all three sources have been configured with the parameters shown in Table II and, thus, the arrival times of packets will be similar. Since the service is cyclical, beginning with the first node, followed by the nodes 2, 3 and so on, node 3 has to wait for two nodes to be attended to in order for its turn to come, thus having much more loss, which is confirmed in the Fig. 5, with one buffer position. In other nodes, with one buffer position, the loss reached is at most 2.50% at node 7, which uses the Controlled Out-range Source for the generation of packets.

Comparing these values with the simulations using larger buffer sizes, the discarding has decreased considerably, and when the buffer size is set at five or one thousand positions, the packet loss has not happened in any of nodes.

Fig. 6 shows the percentage of packets not transmitted due to the restriction imposed at the sources.

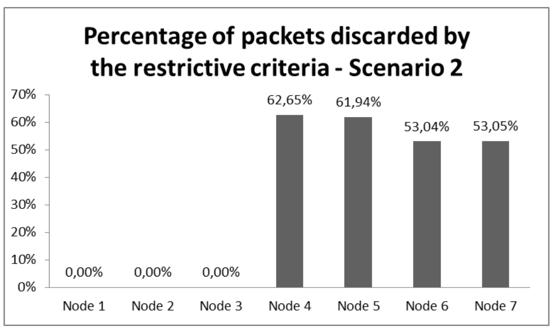


Figure 6. Percentage of packets discarded in Scenario 2 by the restrictive criteria.

Due to the use of Constant Sources in nodes 1, 2 and 3 there are no rejected packets in these nodes as can be seen in Fig. 6. In other nodes using sources with restrictive criteria, the rejection percentage exceeds 50% in all nodes, being the largest one in node 4 using the Threshold Source.

It can be pointed out that the figures presented in Fig. 6 are not affected by buffer sizes because the packet rejections are done using restrictive algorithm before the queuing in the node buffer.

It can also be concluded that the implementation of the restrictive algorithm is very important to save energy, considering the high energy consumption in a packet transmission.

Fig. 7 presents the simulation results of the queue time in the buffer for Scenario 2. The same influence of polling attendance of Fig. 4 is also observed - in this case with node 3 having more time to wait to transmit its packets. In other sources not using Constant Sources, the waiting times are smaller due to controlled packet generations.

When the buffer size is increased the waiting times are longer and have similar behavior, showing that the big buffer sizes are not necessary. A buffer with 3 positions is enough for low packet loss and capable to transmit almost all packets generated.

Fig. 8 shows the packet loss for Scenario 3 in function of the buffer sizes.

In Scenario 3, as the number of sensors with Constant Source is restricted to Sensor 1, the number of packets transmitted is reduced. Consequently, the packet loss is decreased.

Fig. 9 shows the average percentage of packets not sent due to the restrictive criteria applied at the sources for Scenario 3.

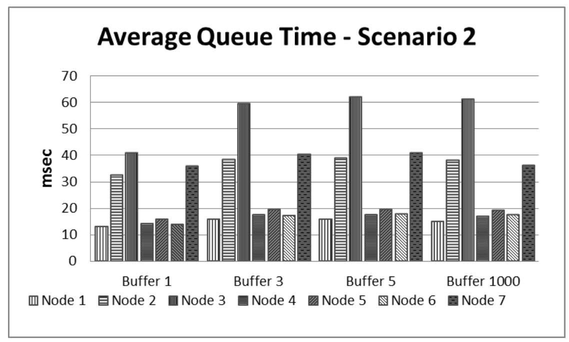


Figure 7. Waiting time of packets in second scenario.

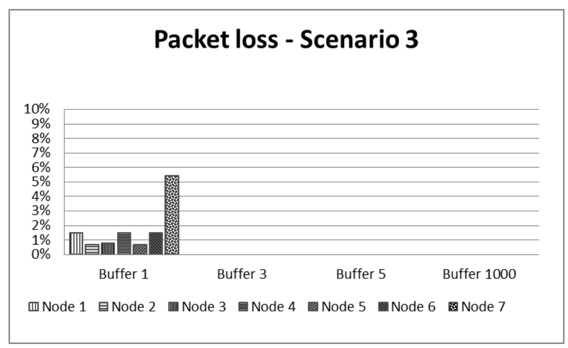


Figure 8. Packet loss in the second scenario.

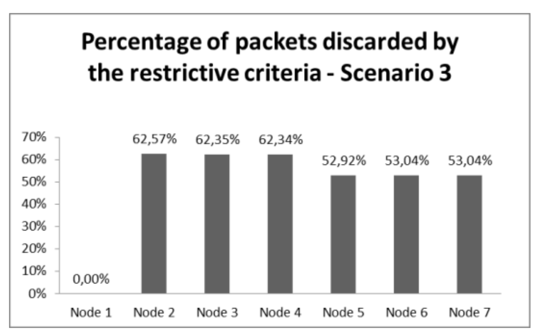


Figure 9. Percentage of packets discarded in Scenario 3 by the restrictive criteria.

Comparing Scenarios 2 and 3 in relation to the discarding of packets, nodes 1, 2 and 3 using Constant Sources have higher losses in Scenario 2, as is expected. Furthermore, since the cyclical service starts at node 1, this node becomes the most favored of the three nodes having lowest discarding. In the third scenario, since a diversity of sources is used - mainly those using the controlled parameters - the node that produces the highest discarding is node 7. This node is the last to be attended to in the cyclic polling so it has a longer waiting time to transmit and may even not transmit any packet in a given cycle, discarding all packets because they are inside of the predefined range or below of a threshold.

It can be seen in Fig. 9 that there is no rejected packet in node 1 due to the use of Constant Source as also observed in Fig. 6. However, the rejection percentages are high in other nodes using sources having restrictions to send packets as occurred in Scenario 2. The Threshold and Controlled Threshold Sources have higher rejection percentages ranging from 62.57% to 62.34% as can be seen in nodes 2, 3 and 4. Fig. 9 shows the Out-range and Controlled Out-range Sources also have significant losses reaching about 53% for all three sources as can be observed in nodes 5, 6 and 7.

Energy saving can also be observed in Scenario 3 by avoiding the packet transmission, although some energy is spent for the processing of restrictive algorithm.

In Fig. 10 the queue times for the third scenario are illustrated.

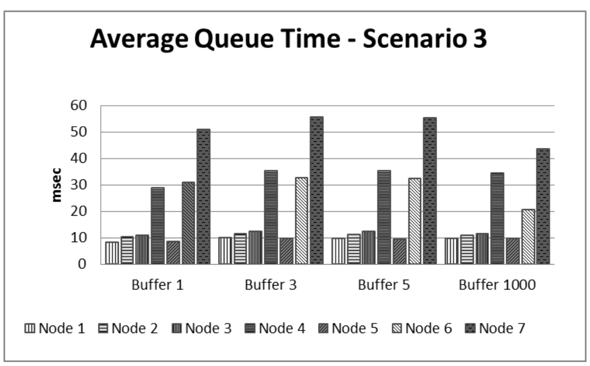


Figure 10. Waiting time of packets in third scenario.

By reducing the number of transmitted packets, the queue times are reduced in Scenario 3 compared to Scenarios 1 and 2, as expected. The reduction is significant in most of the nodes as can be verified in Fig. 10. In Scenarios 1 and 2, the average queuing times are 50.43 and 23.87 msec, respectively, while in Scenario 3 it is 21.21 msec, considering a buffer with one position. Moreover, the worst cases for Scenarios 1 and 2 occurred in node 5 (or 6) and in node 3, with queue times of 68 and 40.89 msec, respectively, while in Scenario 3, the longest queue time is 50.93 msec in node 7 using Controlled Out-range Source.

The use of diversity of the traffic sources is beneficial to the queue time and packet loss in most of the nodes. Moreover, the predominance of event-driven types of sources is also important. For the WBSN applications, a maximum of three buffer positions may attend the expectations of QoS for the packet discarding and queue time.

On the other hand, it is observed that for five and one thousand positions of buffer sizes, there is a similarity between Scenario 2 and 3 in the queue times because there are no significant variations in the values presented.

Since the polling mechanism has the function of traffic admission controller and by using a link of 250 Kbits/sec at the sink node there are no packets waiting at FIFO buffer for the three scenarios studied. The service time or system time is 3.5 msec in all analyzed scenarios.

# 5 Conclusions

In this paper the polling access scheme for Wireless Body Sensor Network (WBSN) was studied. The main technical advantage of the polling access mechanism is the non-necessity of frame synchronization and it has centralized control of sensors convenient for WBSN. The objective of the paper is to study the suitability of the polling mechanism to gather the almost real-time data from sensors placed in a human body. Thus, the main parameters used for study are packet loss and waiting time at the buffer of a sensor node. Since the sensor node for WBSN needs to save energy, the minimum buffer size needed to keep the packets before their transmissions was also examined. To accomplish the above objectives, a simulation platform was developed in C++ Builder where the polling mechanism, the buffers and sensor sources were all implemented. Since there is little sensor node models for WBSN applications in the literature, five sensor sources were proposed, all based on the On/Off model. One of the sensor sources developed was Constant On/Off Source which forwards the information continuously in the on interval and stays silent in off interval. The other sensor sources are event-driven, in which the information is transmitted only if it satisfies a certain condition. In addition, to facilitate the status management of the sensors, two other event-driven sources were developed in which a message is sent after a certain number of packets are not transmitted, regardless if the requirement for the transmission of data has been met or not.

The proposed human body environment for study consisted of seven sensors placed in different parts of body, forming a star topology, with the sink node at the network core. In this environment, three scenarios were proposed. The first scenario used a configuration with Constant Source in all nodes, while in the second scenario three Constant Sources are mixed with other types of sources. In the last Scenario five sources are mixed in different parts of body.

The simulation results for Scenario 1 in relation to the packet loss, considering only one position buffer at sensor node showed high losses ranging from 7% to 16%. The losses became reasonable for three or greater buffer sizes.

In Scenario 2 the packet losses for three Constant Sources are also high, reaching more than 8% in one of the nodes and about 2% in the most favored node of the polling scheme. However, these losses may not be critical for Constant Sources, because they are constantly sending the packets so that some lost information may be interpreted at the final server using some interpolation technique. But these sources must be used with care because of the high intensity of packet generation. For the other four sensor nodes in Scenario 2 the losses are smaller ranging from 1% to about 2%. But in these cases the losses may be critical because the sensors are already doing some kind of data selection. To overcome this situation, the results showed that for a buffer of three positions the losses are almost insignificant.

For Scenario 3, in a mixed situation of sources, the losses are more controlled reaching in the worst case about 5% for one position buffer and no loss in the case of buffer with three or more positions.

The simulation results for average queuing times at the sensors showed low waiting times for Scenarios 1, 2 and 3, ranging from 8 to 140 msec considering all buffer sizes. It was not considered the walk and propagation times in the simulations because they are small and constant values. It can be concluded that the polling access scheme is adequate for quasi real-time applications.

The simulation results also showed that at the sink node using the FIFO scheduler, no loss had occurred or no packet was waiting in the buffer because the polling access mechanism works as the admission controller and only one packet is processed each time.

The polling access scheme showed a very promising technique for WBSN applications but other scenarios will be investigated and compared to other access schemes in future works.

**Acknowledgement**

The authors would like to thank Allison Linn Davidson and Renato Motoyama for assistance in English revision.

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