Impact of Source Parameters and Link Capacity on WBSN Based on Polling Access Scheme

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***Abstract*—The analysis of the impact of the number of sensor nodes, the transmission rate, buffer size, source types and the authorization packet in a Wireless Body Sensor Network (WBSN) based on polling technique is carried out in this paper. A simulation platform is developed in Matlab, contemplating different models of sensor nodes with limited buffer and the polling mechanism to control the transmission to the centralized node. The used performance parameters are the packet loss and the packet waiting time in the queue. The obtained results show that the transmission rate has the greatest influence in the network. Additionally, the ideal configuration obtained uses fourteen sensor nodes with three buffer positions and mixed sources.**

***Keywords*—WBSN; parameters; polling; waiting time, packet loss.**

I. INTRODUCTION

The Wireless Body Sensor Network (WBSN), currently in developing, is a special network for medical application which needs very low energy consumption, very low packet loss and an insignificant packet delay. To achieve such characteristics in a network, the Medium Access Control (MAC) is the most important. There are many MAC proposals based on IEEE 802.15.4 standard with beacon - enabled star configuration for WBSN [1]. However, since this standard is not designed for WBSN applications, some drawbacks were presented in [2] which led to new MAC proposals [2] - [16]. Some of these are variations of the standard [3] - [5]. Others are based on Time Division Multiple Access (TDMA) technique [3] [6] - [11]. All of them exploit some specific medical needs. For example, in [6] [12] MAC protocols that deal with light and heavy loads considering normal and emergency situations are proposed. A MAC based on random access technique is proposed in [13] to ensure the Quality of Service (QoS) of a WBSN. The heart beating is used for clock synchronization in the proposal described in [8]. In [14], to increase the network lifetime, the battery is charged using the beacon that wakes up the sensor nodes. In the 802.15.6, which is the standard for the wireless body area network [17], one of operation mode, the non-beacon mode without superframe boundaries, can be based on polling access technique. A MAC based on hierarchical polling scheme for WBSN is proposed in [18]. The first level of proposed hierarchical MAC consists of sensors nodes divided into groups, and the communication among sensor nodes of a group and a sink node (an external device) is carried out by using the polling technique. In the second level of hierarchy, the sink nodes communicate with a master node that collects data by using also the polling technique. The performance of the proposed scheme is studied by analytical modeling, and studies show its efficiency in WBSN application.

In [19], the MAC scheme based on flexible polling guaranteeing QoS for WBSN is proposed. The proposed MAC has two modes of operation: normal and urgent. In the normal mode each sensor is polled once in each cycle and in the urgent operation a priority of sensors is defined and the higher priorities sensors are served first. The performance analysis was carried out using mathematical models and the results for normal mode showed that the exhaustive service is better than the single buffer in terms of waiting time and the transfer times. For the urgent mode the analysis showed that for light input load the scheme works very well, but for heavier load the system operates in unstable conditions.

A MAC scheme based on polling denoted Fast Polling is proposed in [20]. A simple modification is proposed by adding the authorization packet into ACKnowledgement (ACK) packet. The analysis carried out using OMNeT ++ simulator showed that the throughput improved and the latency was reduced.

The Human Energy Harvesting Medium Access Control Protocol (HEH-BMAC) is proposed in [21] as MAC suitable for WBSN for capturing human energy. The HEH-BMAC is based on two MACs: i) namely polling (polling-ID) and ii) Probabilistic Contention (PC). The idea is to adapt its operation to the different energy and state (active/inactive) variations that the sensor nodes may capture.

The MAC based on polling for WBSN is analyzed in [22] using different scenarios, verifying the packet loss and waiting time in the buffer of a sensor node. The study is carried out through a simulation platform developed in C++ Builder, containing different types of sources. Three scenarios were composed by seven sensors placed in different parts of the body, forming a star topology, with sink node in the network core. 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 results showed that three positions buffer is sufficient for WBSN applications using seven sensors.

The impact of source parameters and link capacity on WBSN using polling access technique is investigated in this paper. More specifically, a numerical study using Matlab is carried out to understand the relationship between the polling access scheme and i) the number of sensors on the human

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body, ii) sensors' parameters (such as traffic types and buffer size), and iii) the radio link capacity between the sensors and the sink. This study is conducted measuring the packet waiting time and loss in the sensor node buffer.

The paper is organized in five sections. In Section 2, the concepts underlying the functioning of WBSN and the choices made for the simulation are presented. The models and parameters of the sources for the study are described in Section 3. In Section 4, the analysis of results is presented. Finally, in Section 5, the conclusions are evidenced.

II. WBSN AND POLLING ACCESS SCHEME

WBSN consists of many sensor nodes with limited capacity attached at different locations of a human body, and are continuously monitoring the vital signs of a patient for diagnosis and prescription. WBSN provides real-time updates of patient medical records via Internet, being an economical solution to health systems [23].

A WBSN is illustrated in Figure 1.

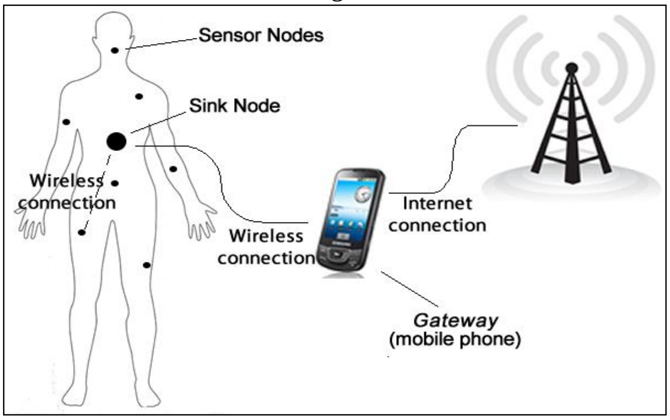

Figure 1. Environment of the WBSN studied.

As shown in Figure 1, several sensor nodes are arranged in the human body to monitor various activities. The sensor nodes collect information and send to the sink node, which has greater storage capacity and processing. In its turn, the sink node works as interface among sensors and external networks.

Since the sensor nodes transmit their information to the sink node, and according to [24] the structure of the network is a star, the sink node is inserted in the middle of the sensor nodes as in [21].

In the polling used in this paper, the sink node establishes the cycle of service to the sensor nodes. Based on this cycle, the sink node interrogates individually the sensor node to see if there are packets to transmit. If there are, the sensor node receives permission to start transmission while others wait their turn. Thus, while a sensor node transmits packets, the others are performing their monitoring activities, waiting their turn to transmit and may store the generated packets in the buffer. After data transmission, the sensor node can activate the sleeping mode, saving energy.

The limited polling is a kind of polling that constrains packet transmission, either in time or in number of packets, so when the limit is reached, the current sensor node stops to transmit and the permission passes to the next sensor node, independent the state of the buffer of the current sensor node. The limited polling is adopted in this paper because can save energy.

III. MODEL AND PARAMETERS OF SOURCE AND LINK CAPACITY

The need for an accurate traffic model to evaluate the performance of the whole system is very important [25]. Since there are no practical traffic traces yet, some assumptions are made. In the practical environment that will be considered the sensors are divided into two types: continuous and event oriented modes. The continuous mode of operation is the case where data are generated continuously as the sensors measuring the heart beating, body temperature or blood pressure constantly. This kind of traffic is called Constant Bit Rate (CBR) source. In the event oriented mode the event occurs occasionally. This kind of traffic could be the measurement of body temperature outside of a range, that is, a sensor sends information only in abnormal situation. In the event oriented mode, the sources can be modeled with intervals On (with packet transmission) and Off (no packet transmission). It is important to mention that the On/Off exponential traffic model for each source is simple to implement and, moreover, the aggregate of these sources represents with good approximation the self-similar traffic. For this reason the model On/Off exponential is adopted in this paper.

The five On/Off exponential sources developed in [22] are used in this paper. A summary of developed sources is shown in Table I.

TABLE I. 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.

The parameters used for setting sources are shown in Table II.

TABLE II. PARAMETERS FOR TRAFFIC GENERATION

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

The packet size used in Table II is the average of the packet sizes presented in eight papers as mentioned in [22].

The packet peak rate corresponds to the Mica2Dot which is used in most of the literature. The On time corresponds to the packet size divided by the peak rate. The Off time is obtained considering the sensor nodes are 90% of time in the Off state [26][27].

The transmission rates adopted among the sensor nodes and sink node in the simulation are 19.2 Kbits/sec used in Mica2Dot [28], 38.4 Kbits/sec also used in Mica2Dot and 250 Kbits/sec used in MicaZ [28] [29] which is mentioned in most of the literature.

The numbers of sensor nodes adopted in the simulation for this work are seven (7), fourteen (14), twenty-one (21) and twenty-eight (28).

The buffer sizes in the sensor nodes are restricted in one (1), three (3), five (5) and one thousand (1000) positions, the latter being equivalent to infinite buffer. In the First In, First Out (FIFO) buffer at the sink node is adopted ten positions for packet storing.

To calculate the confidence interval, each simulation was performed three times and an average of the results obtained is presented. 10.000 packets are generated in each sensor, and the transient period is discarded. Thus, the initial 2000 packets are discarded for statistical purposes. Moreover, the sources that use the control parameter, in a group of ten packets not transmitted, a packet indicating that the sensor is active is sent.

To assure that the results are reliable, the results were compared to those obtained in [22]. In [22], three scenarios are analyzed with the same sources and parameters, using seven sensors in the system, and the simulator was developed in C++ Builder.

In [22], the analyzed scenarios are based on five sources listed in Table I, configured with the same parameters showed in Table II of this work. However, it was not considered the walk and propagation times, which is taken into account in the present work. The three scenarios were consisted of: a) only constant sources; b) three constant sources and other four sources using different kind of sources listed in Table 1; c) mixed sources. The analysis was made based on the output link of 250 kbits/sec, and one, three, five and thousand buffer positions. The performance parameters were the packet loss and the average waiting time in the queues of the sensor nodes.

The results of the simulations in the scenarios of paper [22] are consistent with those obtained in this new program because, it was found that the polling performs certain admission control, and with the FIFO scheduler the queue time is zero and there are not packet losses. For the polling, a summary of some of the results obtained in [22] are shown in Table III.

TABLE III. RESULTS OBTAINED IN PAPER [22]

	Scenario I		Scenario II		Scenario III	
Buffer Size	Buffer 1	Buffer 3	Buffer 1	Buffer 3	Buffer 1	Buffer 3
Average Queue Time (msec)	165,18	221,68	96,63	111,6	223,82	281,62
Packet Loss	1699	72	623	6	1761	45

As shown in Table III, the smaller the buffer size is,the higher the number of dropped packets is, but the queue time is less. In this sense, depending on the application being performed is important to consider the ideal buffer size.

The packet losses are small if compared to the amount of packets on the system, corresponding to 70000 packets. It is noteworthy that most sources do not transmit all packets, which is achieved only by the constant source. In this respect, if the loss occurs in one of the sources that transmitted only relevant data, although being an approximate percentage of 7%, this value can be prohibitive.

Analyzing scenarios regarding the packet loss and the queue time, the ideal is the Scenario II.

IV. ANALYSIS OF RESULTS

The first result to observe is that the polling access scheme performs a kind of admission control in relation to the sink node buffer and regardless of transmission rate, buffer size and number of sensors, there is no packet loss and the queue time is zero.

Figure 2 shows the packet discarding in the sensor nodes by using polling access scheme. In the figure, the discarding is plotted as a function of buffer size, link capacity and number of sensors.

From Figure 2 it can be seen that using transmission rate of MicaZ, that is, 250 Kbits/sec, there are no dropped packets, regardless of the buffer size or the number of sensors.

It is also noted that with the rate of 38.4 Kbits/sec, corresponding to the Mica2Dot the discarding with seven sensors is small, or 97 packets lost with one buffer position and none if the buffer is increased. Increasing the number of sensor nodes to fourteen, the discarding is 2503, 48, 2, 0 for the buffer sizes 1, 3, 5 and 1000, respectively. There is no longer impact with twenty-one sensor nodes in the system, because with three and five positions in the buffer the difference in the loss is the nine packets, which is negligible. With twenty-eight sensors in the system the same occur, where the discarding is less with one thousand buffer positions which resulted in 48460 discarded packets.

The packet loss increases considerably if the capacity is reduced by half to 19.2 Kbits/sec. For seven sensors and one position buffer the lost is 1909 packets, whereas the loss for twice of the capacity is only 97. For fourteen sensors in the system the discarding is approximately 19000 for one, three and five positions buffer and the 10000 packets for thousand positions. For twenty-one sensors and twenty eight sensors in the system the discarding has similar behavior but higher than last case analyzed as is shown in Figure 2.

It can be concluded that the transmission rate and number of sensor nodes are the most impacting factors regarding to the packet loss in a WBSN based on polling access scheme. The analysis shows that the capacity of 250 Kbits/sec has better performance, but there are no studies yet showing the influence of this rate in the human body in the literature searched. Thus, it seems that the capacity of 38.4 Kbits/sec is most appropriate for a WBSN in study.

In relation to the number of sensors, the human body could be divided into seven regions and two sensors could be placed in each region, totaling fourteen sensors, giving a system without considerable loss. At last, the buffer with three positions could be chosen because there is no much difference in packet loss between three and five positions when the number of sensors exceeds twenty.

Table IV shows the results of the queue waiting time in function of the buffer size, the number of sensors and the channel capacity.

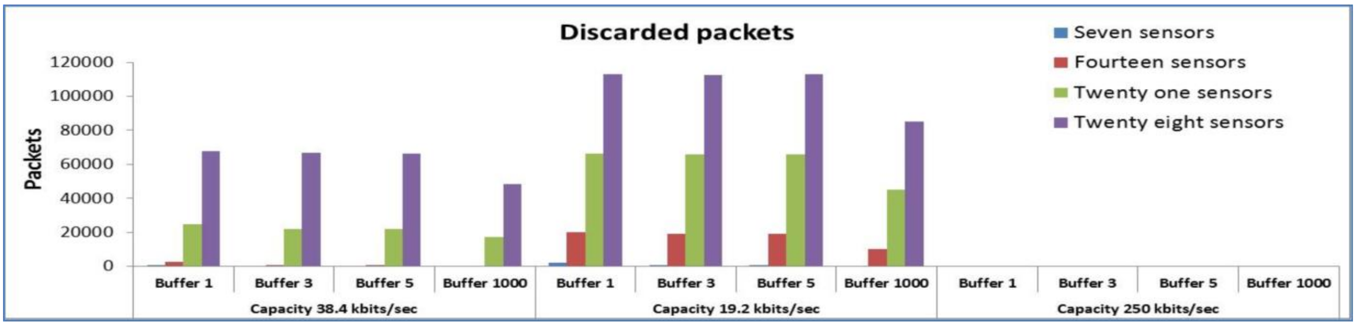

Figure 4. Discarded packets using the polling

The channel capacity is the parameter that most affect the queue waiting time as can be observed in Table IV. The use of transmission rate of 250 Kbit/sec becomes the waiting time almost insensitive to the variations of number of sensor nodes or buffer sizes, keeping very low from 1.55 to 7.93 msec. For the transmission rate of 38.4 Kbit/sec, up to fourteen sensor nodes the waiting time is low from 7.10 to 39.77 msec for any size buffer. However, for number of nodes of 21 and 28, the waiting time increases drastically for 1000 size buffer, meaning that load is too high for the system. For the transmission rate of 19.2 Kbit/sec, the waiting time is reasonable only for 7 sensor nodes; for other cases the waiting times are prohibitive.

TABLE IV. ANALYSIS OF QUEUE WAITING TIME (IN MSEC)

Transmission Rate	Buffer	Seven Sensors	Fourteen Sensors	Twenty one Sensors	Twenty eight Sensors
38.4 Kbits/sec	1	7.10	28.47	116.20	261.84
	3	7.28	39.10	564.59	1232.02
	5	7.25	39.86	1003.44	2311.25
	1000	7.42	39.77	105980.61	357482.20
19.2 Kbits/sec	1	36.51	203.70	535.00	860.10
	3	101.50	1050.40	2309.50	3360.60
	5	61.15	2046.70	4213.20	5932.80
	1000	60.13	262351.10	664652.20	923507.70
250 Kbits/sec	1	1.55	3.29	5.42	7.93
	3	1.56	3.29	5.40	7.91
	5	1.56	3.31	5.41	7.93
	1000	1.56	3.30	5.41	7.93

Keeping the tradeoff between queue waiting time and the transmission rate, it seems that the number of fourteen sensor nodes and the transmission rate of 38.4 Kbits/sec are good choices for WBSN based on polling access scheme.

The third parameter analyzed is the number of authorization packets as shown in Figure 3.

As can be noticed in Figure 3, higher the transmission rate is greater is the amount of authorization packets. This occurs because the data packets are quickly transmitted and not always that the sensor authorized to transmit has the data packets in the queue at that time. In addition, none packet is dropped.

If the network is operating with low load, in stable condition, there is no significant variation in the amount of authorization packet when buffer sizes are considered. For example, considering the transmission rate of 250 Kbits/sec, seven sensors in the system and one position of the buffer, the amount of authorizations is the 5392633. Whereas considering thousand positions in the buffer the amount is 5481470. With fourteen sensors in the system this difference is 2683 packets, which indicates that fourteen sensor nodes are best for the WBSN based on polling access scheme.

Another factor analyzed is the source models. Considering the transmission rate of 250 Kbits/sec and any kind of source there is no packet loss. For other rates, the loss is greater in constant source, because it sends all packets generated. For example, the loss considering transmission rate of 38.4 Kbits/sec is shown in Table V.

TABLE V. ANALYSIS OF DISCARDS PER SOURCES

	Buffer 1			Buffer 3		
Packet Loss	Seven Sensors	Fourteen Sensors	Twenty one Sensors	Seven Sensors	Fourteen Sensors	Twenty one Sensors
Constant	43	1114	14310	0	43	18014
Threshold	8	180	1530	0	1	382
Controlled Threshold	10	355	2508	0	0	596
Out-range	13	288	2463	0	1	1070
Controlled Out-range	24	567	4116	0	3	1854

As can be seen in Table IV, the packet loss in the constant source is higher than any other type of sources, especially when there are more sensors in the system.

Since there are twice more sources with the control parameter, the packet loss in these sources is divided by two, and the influence of these sources is few. This division is necessary to compare equally the amount of packets generated by all sources. The packet loss in the oriented event sources is small until fourteen sensors and similar. However, it can be representative, since only packets indicating changes in measurements are send.

In Table V, it can also be seen that fourteen sensors and the three positions buffer in the system is better if the system is in stable operation. However, with twenty-one sensors the system is already operating in overload condition, so that the discards are greatly increased, and the same occurs when using the rate of 19.2 kbits/sec. This fact can be seen in Figure 2, while in Table IV it is evident that the constant source has higher losses.

Analyzing the influence of source types in queue time, it can be noticed that for transmission rate of 250 Kbits/sec, the

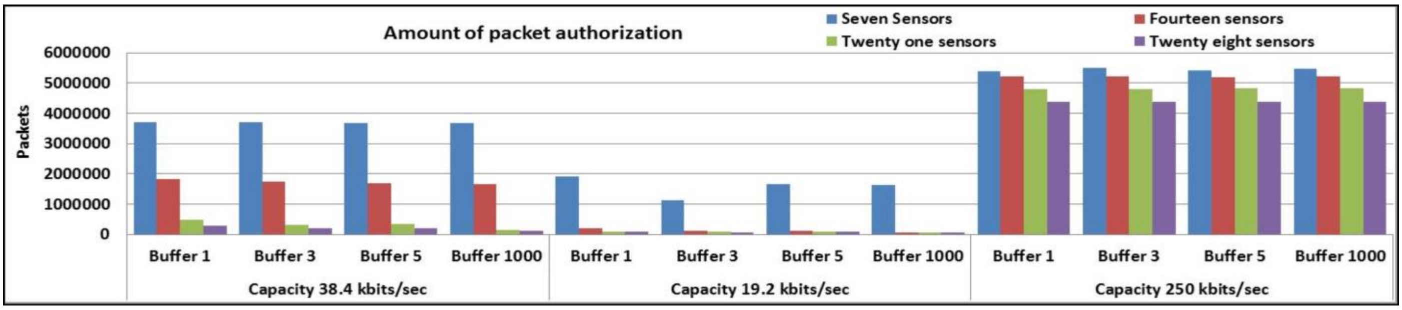

Figure 5. Analysis of the amount of authorization packets.

impact is low independent of the buffer sizes, since all have the same time, which is 1.55 sec with seven sensors, 3.3 sec with fourteen sensors, 5.5 sec with twenty-one sensors and with twenty eight sensors is 8 sec.

For other transmission rates, the behavior of the queue times is similar to the packet discarding. For example, with the rate of 38.4 Kbits/sec, seven sensors, independent of the buffer size and type of the source, the queue time is 7.33 sec. For fourteen sensors in the system the average queue time does not have many differences between sources, which are 36.5 sec. However, from fourteen sensors and the rate of 19.2 Kbits/sec, where the system is already operating in overload condition, the variations are considerable, and the constant source has the longest waiting time. The influence of other source types is low because they don't transmit all data generated and the degradation occurs in the following order: Controlled Out-range, Out-range, Controlled Threshold, Threshold.

V. CONCLUSIONS

The impact of source parameters and radio link capacity on a WBSN based on polling access scheme was analyzed in this paper. The influence of different source types and link capacities on packet waiting time and packet loss at sensor node buffers was examined. A simulation platform was developed in Matlab to carry out the study. The used parameters were the number of sensor nodes, the transmission rate, number of positions in the buffer, amount of authorization packet and the source type.

The first result is that the polling access scheme performs a kind of admission control in relation to the sink node because at output buffer of sink node does not occur packets loss and the queue waiting time is zero regardless of the scenario considered.

When the system is in stable operation, the amount of packets discarded is little or nonexistent, as occurs using the transmission rates of 250 Kbits/sec and 38.4 Kbits/sec with seven and fourteen sensor nodes. However, if the system is operating in overload condition, a significant packet loss is observed. The analysis of results shows that the use of three position buffer and fourteen sensors for a WBSN based on polling access scheme are recommended when the packet waiting time and packet loss are considered. These results can be used to establish practical environment when using polling access scheme, ie, do not used transmission rates under of 38.4 Kbits/sec, more than fourteen sensor nodes and the five position buffer with this scheduler.

It was observed that the constant source generates more packets discarded, and packet waiting time is longer. This is because all packets are transmitted. However, in other types of source that send only controlled information, the packet loss, although smaller, can be more critical because there is no redundancy in the transmitted data. Therefore, the use of mixed sources is more recommended.

In future work, the impact of polling cycle of the sensor nodes on packet waiting time and loss will be analyzed in function of source types, as well as changing the size of the authorization packet. The problems of interference of many people who wear a WBSN based on polling scheme and gathered in a small area such as a coach will be also investigated.

REFERENCES

[1] B. Latré, B. Braem, I. Moerman, C. Blondia, and P. Demeester, "A survey on wireless body area networks," Wireless Networks, Kluwer Academic Publishers Hingham, MA, USA,vol. 17, n° 1, pp 1-18, Jan. 2011. DOI: 10.1007/s11276-010-0252-4. [retrieved: November, 2011. http://dl.acm.org/citation.cfm?id=1938079]

[2] B. Otal, L. Alonso, and C. Verikoukis, "Design and analysis of an energy-saving distributed MAC mechanism for wireless body sensor networks," EURASIP Journal on Wireless Communications and Networking - Special issue on Design, Implementation, and Evaluation of Wireless Sensor Network Systems, Feb. 2010, pp. 1-13. DOI: 10.1155/2010/571407. [retrieved: February, 2010. http://dl.acm.org/citation.cfm?id=1957973]

[3] K. A. Ali, J.H Sarker, and H.T Mouftah, "Urgency-based MAC protocol for wireless sensor body area networks," Proc. IEEE International Conference on Communications Workshops (ICC), IEEE Press, May 2010, pp. 1- 6, doi:10.1109/ICCW.2010.5503911. [retrieved: May, 2010. http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5503911&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5503911]

[4] L.M. Borges, F. J. Velez, and A.S. Lebres, "Performance evaluation of the schedule channel polling MAC protocol applied to health monitoring in the context of IEEE 802.15.4," Proc. 11th European Wireless Conference - Sustainable Wireless Technologies (European Wireless), April 2011, pp. 94-101. [retrieved: April, 2011. http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=5898073]

[5] X. Zhu, S. Han, P. Huang, A.K. Mok, and D. Chen, "MBStar: a real-time communication protocol for wireless body area networks," Proc. 23rd Euromicro Conference on Real-Time Systems (ECRTS), July 2011, pp. 57-66, doi: 10.1109/ECRTS.2011.14. [retrieved: July, 2011. http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6001646&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6001646]

[6] B. Liu, Z. Yan, and C. W. Chen, “CA-MAC: A Hybrid context-aware MAC protocol for wireless body area networks,” Proc. 13th IEEE International Conference on e-Health Networking Applications and Services (Healthcom), IEEE Press, June 2011, pp. 213-216, doi: 10.1109/HEALTH.2011.6026748. [retrieved: June 2011 http://csi.dgist.ac.kr/uploads/Seminar/1306_CA-MAC_KDH.pdf]

[7] Y. Tselishchev, “Designing a medium access control protocol for body area networks,” Proc. IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM), IEEE Press, June 2011, pp. 1-3, doi: 10.1109/WoWMoM.2011.5986216. [retrieved: June, 2011. http://dl.acm.org/citation.cfm?id=2196748]

[8] L. Huaming and T. Jindong, “Heartbeat-driven medium-access control for body sensor networks,” IEEE Transactions on Information Technology in Biomedicine, vol. 14, n°. 1, pp. 44-51, Jan. 2010. DOI: 10.1109/TITB.2009.2028136. [retrieved: Jan., 2010. http://dl.acm.org/citation.cfm?id=1248062]

[9] G. Fang and E. Dutkiewicz, “BodyMAC: energy efficient TDMA-based MAC protocol for wireless body area networks,” Proc. 9th International Symposium on Communications and Information Technology (ISCIT 2009), Sept. 2009, pp. 1455-1459, doi: 10.1109/ISCIT.2009.5341045. [retrieved: Sept., 2009. http://dl.acm.org/citation.cfm?id=1790311]

[10] S. Marinkovic, C. Spagnol, and E. Popovici, “Energy-efficient TDMA-based MAC protocol for wireless body area networks,” Proc. Third International Conference on Sensor Technologies and Applications (SENSORCOMM '09), June 2009, pp. 604-609, doi: 10.1109/SENSORCOMM.2009.99. [retrieved: June, 2009.http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5210842&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5210842]

[11] S. S. Oliveira and S. Motoyama, “Applications oriented medium access control protocols for wireless sensor networks,” IEEE Latin America Transactions, vol. 7, n° 5, pp. 586-593, Sept. 2009. DOI: 10.1109/TLA.2009.5361197. [retrieved: Sept., 2009. http://ieeexplore.ieee.org/xpl/abstractAuthors.jsp?arnumber=5361197]

[12] Z. Yan and B. Liu, “A context aware MAC protocol for medical wireless body area network,” Proc. 7th International Wireless Communications and Mobile Computing Conference (IWCMC), July 2011, pp. 2133-2138, doi: 10.1109/IWCMC.2011.5982864. [retrieved: July, 2011. http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5982864&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5982864]

[13] k. A. Ali, J. H. Sarker, and H. T. Mouftah, “QoS-based MAC protocol for medical wireless body area sensor networks,” Proc. IEEE Symposium on Computers and Communications (ISCC), IEEE Press, June 2010, pp. 216-221, doi: 10.1109/ISCC.2010.5546523.[retrieved: June, 2010. http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5546523&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5546523]

[14] D. Layerle and A. Kwasinski, “A power efficient pulsed MAC protocol for body area networks,” Proc. IEEE 22nd International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC), IEEE Press, Sept. 2011, pp. 2244-2248, doi: 10.1109/PIMRC.2011.6139917. [retrieved: Sept., 2011.http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6139917&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6139917]

[15] S. Kutty and J.A. Laxminarayan, “Towards energy efficient protocols for wireless body area networks,” Proc. International Conference on Industrial and Information Systems (ICIIS), Aug. 2010, pp. 31-34, doi: 10.1109/ICIINFS.2010.5578739. [retrieved: Aug., 2010. http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5578739&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5578739]

[16] X. Zhang, H. Jiang, X. Chen, L. Zhang, and Z. Wang, “An energy efficient implementation of on-demand MAC protocol,” Proc. Medical Wireless Body Sensor Networks IEEE International Symposium on Circuits and Systems (ISCAS 2009), May 2009, pp. 3094-3097, doi: 10.1109/ISCAS.2009.5118457. [retrieved: May, 2009. http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5118457&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F5076158%2F5117665%2F05118457.pdf%3Farnumber%3D5118457]

[17] K. S. Kwak, S. Ullah, and N. Ullah, “An overview of IEEE 802.15.6 standard,” in ISABEL, Rome, Italy, pp. 1-6, Nov. 2010. DOI: 10.1109/ISABEL.2010.5702867. [retrieved: Nov., 2010.http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5702867&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5702867]

[18] S. Motoyama, “Hierarchical Polling-based MAC scheme for Wireless Body Sensor Network,” The 2013 International Conference on Wireless Networks (ICWN’13), Las Vegas, USA, July 2013, pp. 103-109. [retrieved: July, 2013. http://worldcomp-proceedings.com/proc/p2013/ICW2953.pdf]

[19] S. Motoyama, “Flexible Polling-based Scheduling with QoS Capability for Wireless Body Sensor Network,” Proc. 37th Annual IEEE Conference on Local Computer Networks (LCN 2012), IEEE Press, Clearwater, USA, Oct. 2012, pp: 745-752, doi: 10.1109/LCNW.2012.6424059. [retrieved: , Oct., 2012. http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6424059&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6424059]

[20] Z. Lu, Z. Khan, and M. A. Iqbal, “Fast Polling Mechanism for Baseline BAN MAC (802.15.6) of Body Area Networks,” The 4th International Conference on Ambient Systems, Networks and Technologies (ANT 2013), vol. 19, pp. 944‑949, June 2013. DOI:10.1016/j.procs.2013.06.130. [retrieved: June, 2013. http://www.sciencedirect.com/science/article/pii/S1877050913007382]

[21] E. I. Ramirez, A. Antonopoulos, E. Kartsakli, and C. Verikoukis, “HEH-BMAC: Hybrid Polling MAC Protocol for Wireless Body Area Networks Operated by Human Energy Harvesting,” Springer Telecommunication Journal, Dec. 2012, pp. 1-29. [retrieved: Dec., 2012. http://www.cttc.es/publication/heh-bmac-hybrid-polling-mac-protocol-for-wireless-body-area-networks-operated-by-human-energy-harvesting/]

[22] T. A. Pazeto, L. Refatti, and S. Motoyama, “Polling-based Medium Access Control Scheme for Wireless Body Sensor Network,” 11th International Conference on Wireless Networks (ICWN'12), Las Vegas, Nevada, USA, July 2012, pp. 87-93. [retrieved: July 2012. http://www.gbv.de/dms/tib-ub-hannover/739345141.pdf]

[23] S. Ullah et al., “A Review of Wireless Body Area Networks for Medical Applications,” Int. J. Communications, Network and System Sciences, vol 2, pp. 797-803, Aug. 2010. DOI: 10.4236/ijcns.2009.28093. [retrieved: Aug., 2010. http://arxiv.org/pdf/1001.0831.pdf]

[24] G Zhou, J. Lu, C-Yih Wan, M. D. Yarvis, and J. A. Stankovic, “BodyQoS: Adaptive and radio-agnostic QoS for body sensor networks,” The 27th Conference on Computer Communications (INFOCOM 2008), April 2008, pp. 565-573. DOI: 10.1109/INFOCOM.2008.105. [retrieved: April, 2008. http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=4509700&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D4509700]

[25] H. Liu and F. Ju, “A Novel Packet Scheduling Algorithm based on Self-Similar Traffic in WSN,” Proc. International Conference on Wireless Sensor Network, Nov. 2010, pp: 312 – 316, doi: 10.1049/cp.2010.1072. [retrieved: Nov., 2010. http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5741114&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F5738676%2F5741058%2F05741114.pdf%3Farnumber%3D5741114]

[26] C. Otto, A. Milenkovic, C. Sanders, and E. Jovanov, “System Architecture of a Wireless Body Area Sensor Network for

ubiquitous health monitoring," Journal of Mobile Multimedia, vol. 1, n°. 4, Jan. 2005, pp. 307-326. [retrieved: Jan., 2005. http://dl.acm.org/citation.cfm?id=2010502]

[27] M. L. Sichitiu, "Cross-Layer Scheduling for Power Efficiency in Wireless Sensor Networks," Proc. of INFOCOM 2004, Hong Kong, March 2004, pp. 1740 – 1750 vol.3, doi: 10.1109/INFCOM.2004.1354585. [retrieved: March, 2004. http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=1354585&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D1354585]

[28] Crossbow. MicaZ Datasheet. Available in: http://www.xbow.com/Products/Product_pdf_files/Wireless_pdf/MICAz_Datasheet.pdf, 2008.

[29] K. Chakrabarty and S. S. Iyengar, "Scalable infrastructure for distributed sensor networks," Springer-Verlag, 2005, 194 p., ISBN 978-1-84628-213-3.