A New Back-off Mechanism for the S-MAC Protocol with Applications in Healthcare

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***Abstract*—In this paper, a modified S-MAC protocol incorporating a new back-off mechanism applicable to body sensor networks (BSNs) is proposed. The proposed protocol alleviates the drawback associated with the back-off mechanism which is currently utilized in the original S-MAC protocol in addition to its derivatives. Also, the cross-layer technique is used so as to achieve a better energy consumption and a reduced delay which are both accomplished by adjusting the contention window adaptively. Performance analysis of the modified S-MAC protocol is evaluated in a network simulator (i.e., NS-2) by monitoring the energy efficiency, delay and throughput parameters in an example BSNs. The obtained results show a significant improvement with the proposed protocol performance compared to the original counterpart.**

***Index Terms*—Healthcare, body sensor networks (BSNs), S-MAC, back-off.**

I. INTRODUCTION

RECENTLY, wireless sensor networks (WSNs) have been widespread due to their applications in habit and environmental monitoring, disaster management and healthcare [1]. The Body Sensor Networks (BSNs), interdisciplinary applications of WSNs in healthcare, have gained the attention of many researchers whose focus is on telemedicine and remote healthcare. Typically, a given BSN incorporates a number of miniaturized wearable or implanted physiological sensors as well as a data storage and a communication device which are networked together in order to establish a continuous monitoring system for recording the human body vital signs [2]. Besides many similarities between these two types of networks, the BSNs' characteristics are intrinsically different from WSNs' in variety of details that latency, energy, reliability and also the data rate are amongst. As a consequence, the protocols which are widely used in WSNs seem to be generally incapable of fulfilling the requirements in BSNs. Therefore, a new sets of protocols for maintaining a high reliable performance in the BSNs needs to be designed or sometimes obtained by modifying existing ones [2].

In BSNs, medium access control (MAC) protocols play a pivotal role in handling the time and duration in which sensor nodes are allowed or prioritized to communicate via the wireless medium. Performance measures such as delay and energy efficiency in addition to latency and reliability are generally considered while a MAC protocol is being designed. Generally speaking, MAC protocols are mainly classified into two categories namely, time division multiple access (TDMA) and contention-based protocols [3]. TDMA-based protocols are subject to an increased level of delay particularly when the number of sensor nodes exceeds. Also, the protocol overhead which is an inevitable part of the implementation of TDMA-based protocols can significantly increase power consumption in BSNs. Therefore, it can be deduced that the best alternative is to use contention-based protocols instead of TDMA ones in BSNs where data rates are presumingly at a moderate level and the delay increase can be tolerated to a good extent.

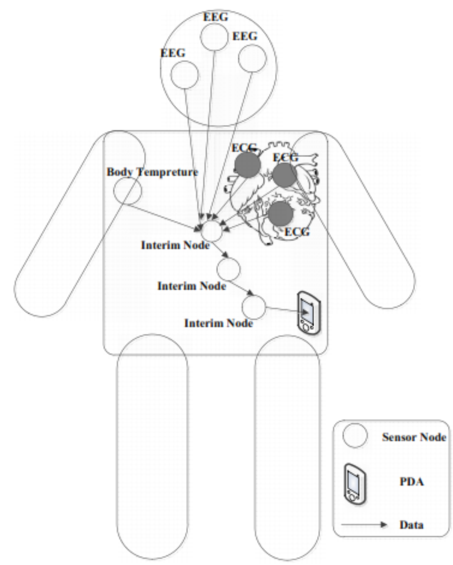

Fig. 1. An example BSN used in telemedicine.

The S-MAC protocol [4], as one of the contention-based MAC protocols, has shown a unique energy efficiency and a reasonable end-to-end delay which are both desired in BSNs. Such the characteristics can be achieved by enforcing the sensor nodes to sleep periodically and wake-up based

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on a preassigned schedule. This protocol and its derivatives are widely used in WSNs, however, maintaining the QoS requirements such as reliability and latency at desired level is not guaranteed. The reduced reliability and latency level are mainly due to fixed duty and inefficient back-off mechanism (fixed CW size) used in the original S-MAC protocol. These two problems are mainly associated with the setting of the frame in the original S-MAC protocol which consists of two separate parts namely, listen and sleep periods and delays in accessing the wireless medium such as back-off delay. Since the listen period is constant and directly driven by the protocol, the duty cycle which is defined as the ratio of the listen period to the frame length, the reliability and latency of the original S-MAC protocol cannot be guaranteed due to the occurrence of excessive delays. Hence, in order to deal with the aforementioned problems, the simplest and intuitive approach is to modify the back-off delay so that it takes random values and select an optimum value for duty cycle. The back-off delays is defined, in a scenario when two or more nodes intend to transmits data over the wireless medium at the same time and a collision occurs, the amount of time the nodes stay idle before retransmitting data. In the early version of the S-MAC protocol, the back-off delay is calculated by Eq. 1, as it can both be theoretically and also experimentally shown the calculated back-off delay is not optimum. Since, proper selection of the back-off delay can adverse the performance of a given BSN by degrading the throughput and consequently increases the end-to-end delay and the network agility.

As Eq. 1 shows, the size of the contention window (CW) in the conventional S-MAC protocol plays an effective role in achieving an optimum back-off delay time which is of importance in realizing a reliable BSN utilized for monitoring the human vital signs.

$$BT = Random(0, CW) \times \ ST \tag{1}$$

where BT, CW and ST are the back-off time delay, contention window size and the size of slot time, respectively.

The main drawback associated with the original S-MAC protocol is its fixed contention window size (63 slot time). The fixed CW size can degrade the performance of this protocol significantly as it can be seen in the following two examples. In a network including two active nodes, the amount of timer needs to be set can become comparably long. As a consequence, the throughput decreases. Another example to show the effect of the CW size is of the size of the timer is a network consisting a large number of nodes. In such a network, the timer cannot be sufficient in order to avoid repetitive collisions. Therefore, one can suggest a mechanism be able to alleviate the drawbacks associated with the original S-MAC protocol and its derivatives that enables the S-MAC protocol adjusts the CW size for attaining efficient communications.

In Ref. [5], the authors tried to solve the problems mentioned earlier by considering the level of energy remains for a node for suggesting a CW size. Later, the number of packets which are queued for transmission was used as a measure for

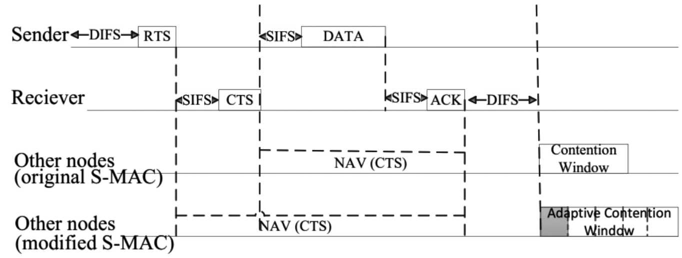

Fig. 2. The modified S-MAC incorporating the new back-off mechanism.

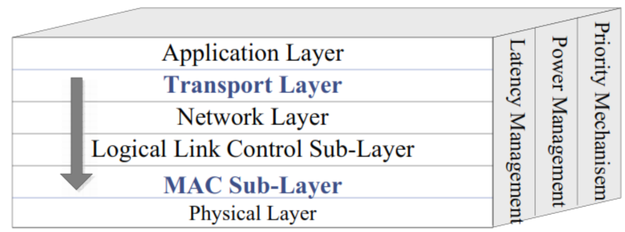

Fig. 3. The cross-layer mechanism used in the proposed back-off mechanism.

the calculation of CW [6]. In [7] a new RTS (Request-to-Send) mechanism was proposed in which contention state of neighboring nodes was taken in to account. The cross-layer design was also utilized in the S-MAC protocol in order to adjust the contention window which is based on the number of packets a node holds in queue [8].

Despite considerable amount of efforts spent in solving the drawbacks associated with the S-MAC protocol, the proposed solutions are not able to systematically deal with the drawbacks. In this paper, a new back-off mechanism based on the priority of packets is introduced. Additionally, the mechanism uses the concept of cross-layer design that it enables the lower layer of a given network with the information about the priority of packets provided from higher layers, e.g, the transport layer.

II. Proposed Back-Off Mechanism

In the proposed back-off mechanism, the contention window size can be automatically adjusted depending on the data type (transmitted packet) and the network conditions. Fig. 2 represents a version of S-MAC protocol consisting of the new back-off mechanism. As discussed earlier, the proposed mechanism utilizes an implementation of the cross-layer approach in which the MAC layer receives relevant information about the packets priority from higher layers of the network (i.e., transport layer) as schematically represented in Fig. 3. Moreover, configurations of the cross-layer allow the network parameters to be optimized depending on the network requirements [9].

According to the type of a data set and its priority the CW can be estimated as represented in Fig. 4. In the modified protocol, packets are classified in two different priority levels; 1) The packets contain vital information such as information related to a patient's brain (EEG signs), 2) The packets carrying low priority information such as body temperature.

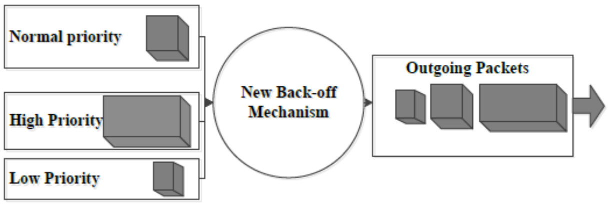

Fig. 4. Priority mechanism.

The algorithm used in the modified S-MAC protocol, as shown in Fig. 1, adjusts contention window size to CWmin, if the data priority is classified without considering a *prior* information of its contention window. Therefore, the probability of transmitting data with high level of priority is remarkably increased by granting a minimum contention window. Nodes with low level of priority even if they succeeded in previous round are enforced to wait longer as the algorithm assigns them a maximum value equivalent to a half of the current window size (CW/2) and CWmin. Otherwise, the size of the current window size is selected from maximum values of CWmax and double of current contention window value (2×CW). This adjustment can decrease the latency with respect to high priority data. Last but not least, it can be mentioned that nodes carrying important data (i.e., high priority) are assigned contention window with a reduced size whereas longer contention window will be used for data with lower priority. As consequence, packets with high priority will be delivered with a lower delay compared to packets including normal or low priority data.

III. Simulation And Results

This section deals with the simulation results of the proposed back-off mechanism in terms of latency, energy consumption and throughput. Also, the results obtained from the modified protocol are compared with its original counterpart.

A. Simulation Setup

In general, BSNs consist of a number of physical devices which are mainly involved in sensing and communicating the measured data to a central entity wirelessly. In order

Algorithm 1 The algorithm utilized for adjusting the contention window.

if $packet \in high\ priority\ traffic$ **then**
  $CW \leftarrow$CWmin
end if
if $packet \notin high\ priority\ traffic\ and\ node\ successes\ to\ transmit\ in\ last\ try$ **then**
  $CW \leftarrow$max(CWmin , CW/2)
end if
if $packet \notin high\ priority\ traffic\ and\ node\ fails\ to\ transmit\ in\ last\ try$ **then**
  $CW \leftarrow$min(CWmax , 2×CW)
end if

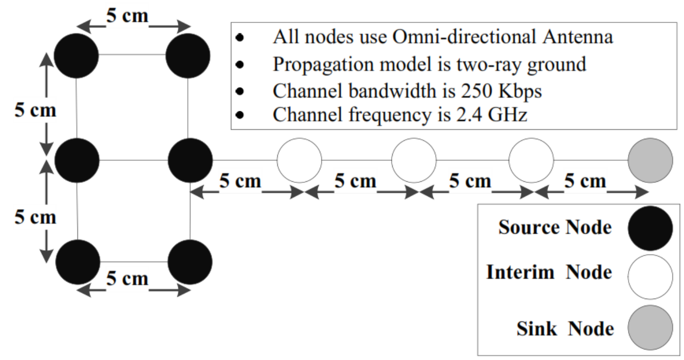

Fig. 5. Schematic depicting the simulated network topology.

to evaluate the modified S-MAC protocol an example BSN such the one demonstrated in Fig. 5 was used. This network composes of 10 nodes which are assigned to accomplish different tasks namely, measuring physiological signs (i.e., source node), transmission (i.e., interim node) as well as a collecting node or the sink node. Without loss of generality, the nodes are located with a distance of 5 cm from each other as shown in Fig. 5. Based on this topology, the measured data is communicated with the sink node in a multip-hop fashion rather than direct communication in order to keep the transmission power as low as possible in addition to maintaining safety issues.

The BSN as represented in Fig. 5 was simulated by using a network simulator (i.e., NS-2.35) [10] for a duration of 1000 seconds where the CW size was varied from 3 to 127 time slots. In the performed simulations, the consumed power for idle state, sleep, transmission, reception modes are equal to 1.4×10^{-2}, 1.5×10^{-5}, 3.6×10^{-2}, 1.4×10^{-2} watts, respectively.

In the considered BSN, each node incorporates an omni-directional antenna operating at at 2.45 GHz, which is one of the ISM (Industrial, Scientific and Medical) frequencies. In simulations, the propagation model used by the simulator is the two-ray model in which two paths between a pair of communicating nodes are considered; One path stands for direct communication and the other one for the reflections comes from the surface on which the network is situated. In BSNs, the reflections are due to proximity to the human body.

B. Discussion

To study the improvement obtained by using the proposed back-off mechanism in the original protocol, i.e., S-MAC, parameters such as latency, energy consumption as well as the throughput were monitored in simulations performed in NS-2. In the conducted simulations, the focus is mainly on the duty cycle and traffic load variations. In the beginning, the original S-MAC protocol was assessed while the duty cycle was set to take 10% and 20% active period with respect to the overall frame size. The S-MAC protocol with the duty cycle of 10% was chosen to be used as the reference point to which the modification was applied. It is worth mentioning that the S-MAC protocol with duty cycle near 10% can be considered as the optimum setting for a BSN used in healthcare where loads are moderate in addition to low power consumption. Also, it should be noted that the performance of the S-MAC protocol directly depends on the setting of the duty cycle. For instance, the S-MAC protocol with 20% duty cycle consumes more energy compared to case the duty cycle is set to be 10%. The message inter-arrival time (MIT) parameter as a measure for evaluating the modified protocol is defined by the time interval between two consecutive packets which are generated. The MIT can vary from 1 to 10 that the low and high values indicate heavy and low traffic, respectively.

The end-to-end delay values obtained from simulation is also shown in Fig. 6 with respect to the traffic level (i.e., load). As it can be seen in Fig. 6, the modified S-MAC protocol deals with a lower latency compared to its original counterparts with 10% and 20% duty cycle. Besides the improved latency level , the performance of the proposed protocol is of no progress at low traffic level. Moreover, it can be inferred that latency gradually increases when the traffic load is high. In the other words, a high traffic load corresponds to low MIT values as shown in Fig. 6. The reason behind such the degradation in the desired value for latency can be stated that the ratio of the listen period of the frame size is fixed and obviously it does not take an optimal value. Moreover, the S-MAC with no sleep period encounters with less latency compared to the other derivatives of the S-MAC protocol. In this case, the S-MAC protocol with no sleep period consumes considerable amount of energy (Fig. 7). Performance analysis of the S-MAC protocol with different settings for the duty cycles was also studied in addition to the energy consumption level. Table II summarizes the values of energy consumption obtained from simulations.

The throughput as the essential measure in assessing the performance of MAC protocols was also investigated in the example BSNs. Fig. 8 represents the throughput values for the proposed MAC protocol in addition to those of two S-MAC protocols with %10 and %20 duty cycle while different loadings were applied. It can be seen in Fig. 8 that the S-MAC protocol with high duty cycle takes more time in listening the channel as opposed to the S-MAC with lower duty cycle. As a consequence, the former protocol attains a higher level of throughput level in heavy traffic load whereas the S-MAC with smaller duty cycles is only able to provide a lower level of throughput. Similar to the effect of sleep period on latency, the same behavior can be observed for the throughput while the

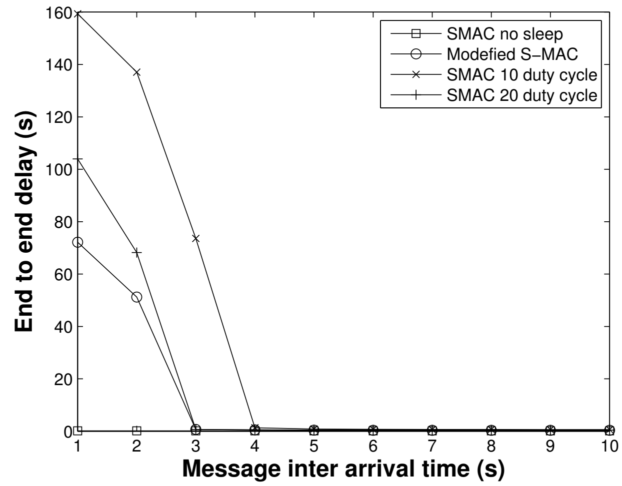

Fig. 6. Variation of the end-to-end delay obtained from simulation with respect to MIT.

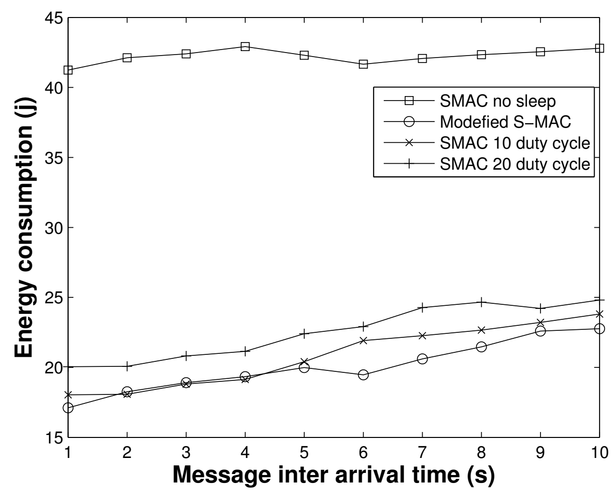

Fig. 7. Energy consumption obtained from simulation against MIT.

TABLE I
SIMULATION SETTING AND PARAMETERS

Simulation Parameters	Values
Chanel bandwidth	250-Kbps
Number of nodes	10
Simulation time	1000-second
CWmin	3-slot
CWmax	127-slot
CW	63-slot
Initial power	100-joule
Transmission range	5-cm
Packet size	100-Byte
Idle power	0.01-W
Sleep power	0.000015-W
Transition power	0.036-W
Receiving power	0.014-W
Antenna	Omni-directional antenna
Channel frequency	2.4-GHz

TABLE II
ESTIMATED ENERGY CONSUMPTION IN THE S-MAC PROTOCOL.

Traffic load	The S-MAC derivatives
High	S-MAC no sleep $\gg$ 20% S-MAC > 10% S-MAC 10% S-MAC $\simeq$ 10% modified S-MAC
Low	S-MAC no sleep $\gg$ 20% S-MAC > 10% S-MAC 10% S-MAC > 10% modified S-MAC

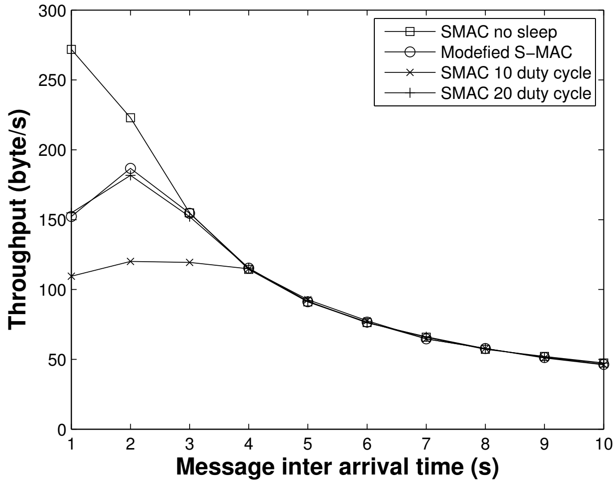

Fig. 8. Estimated throughput versus different values for MIT.

S-MAC with no periodic sleep is assumed as the comparison reference. The throughput analysis of the proposed S-MAC protocol can confirm that it will be an effective protocol for BSNs where traffic loads are moderate.

IV. Conclusions

In this paper, a modified version of the S-MAC protocol has been proposed. The modified protocol was equipped with a new back-off mechanism, which is able to adjust the back-off window size depending on the data type and and its priority. This protocol was evaluated by using a network simulator (i.e., NS-2) while parameters such as latency, throughput and energy efficiency were observed. The obtained results from a number of extensive simulations showed that the proposed protocol is able to fulfill the medium access control requirements in the BSNs by improving the throughput approximately 16%, energy consumption near 3% and the latency better than 66%. Also, the performance analysis of the protocol implemented in an example BSN demonstrated that proposed protocol can be a suitable candidate to be used in BSNs, where energy consumption and latency are significantly important.

References

[1] J. Yick, B. Mukherjee, and D. Ghosal, "Wireless sensor network survey," *Computer networks*, vol. 52, no. 12, pp. 2292–2330, 2008.

[2] M. Chen, S. Gonzalez, A. Vasilakos, H. Cao, and V. C. Leung, "Body area networks: A survey," *Mobile Networks and Applications*, vol. 16, no. 2, pp. 171–193, 2011.

[3] M. A. Yigitel, O. D. Incel, and C. Ersoy, "Qos-aware mac protocols for wireless sensor networks: A survey," *Computer Networks*, vol. 55, no. 8, pp. 1982–2004, 2011.

[4] W. Ye, J. Heidemann, and D. Estrin, "Medium access control with coordinated adaptive sleeping for wireless sensor networks," *Networking, IEEE/ACM Transactions on*, vol. 12, no. 3, pp. 493–506, 2004.

[5] C. Cho, J. Pak, J. Kim, I. Lee, and K. Han, "A random backoff algorithm for wireless sensor networks," in *Next Generation Teletraffic and Wired/Wireless Advanced Networking*, pp. 108–117, Springer, 2006.

[6] J. Q. Lu, W. X. Wang, and Z. H. Lin, "The analysis and improvement of s-mac protocol for wireless sensor networks," *Advanced Materials Research*, vol. 291, pp. 2699–2703, 2011.

[7] W. Zou, E. Wang, Z. Zhou, W. Li, and Y. Ye, "A contention window adaptive mac protocol for wireless sensor networks," in *Communications and Networking in China (CHINACOM), 2012 7th International ICST Conference on*, pp. 566–570, IEEE, 2012.

[8] Q. Hu and Z. Tang, "An improved adaptive mac protocol for wireless sensor networks based on cross-layer architecture," in *Wireless Communications & Signal Processing, 2009. WCSP 2009. International Conference on*, pp. 1–5, IEEE, 2009.

[9] I. F. Akyildiz and M. C. Vuran, *Wireless sensor networks*, vol. 4. John Wiley & Sons, 2010.

[10] K. Fall and K. Varadhan, "The network simulator (ns-2)," *URL: http://www. isi. edu/nsnam/ns*, 2007.