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Latency-Energy Optimized MAC Protocol For Body Sensor Networks

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***Abstract*—This paper presents a self organized asynchronous medium access control (MAC) protocol for wireless body area sensor (WBASN). The protocol is optimized in terms of latency and energy under variable traffic. A body sensor network (BSN) exhibits a wide range of traffic variations based on different physiological data emanating from the monitored patient. For example, electrocardiogram data rate is multiple times more in comparison with body temperature rate. In this context, we exploit the traffic characteristics being observed at each sensor node and propose a novel technique for latency-energy optimization at the MAC layer. The protocol relies on dynamic adaptation of wake-up interval based on a traffic status register bank. The proposed technique allows the wake-up interval to converge to a steady state for variable traffic rates, which results in optimized energy consumption and reduced delay during the communication. A comparison with other energy efficient protocols is presented. The results show that our protocol outperforms the other protocols in terms of energy as well as latency under the variable traffic of WBASN.**

***Index Terms*—wireless body area sensor networks (WBASN); dynamic MAC protocol; traffic-aware MAC protocol; adaptive duty cycle MAC protocol; traffic status register; optimized energy and latency;**

I. Introduction

A wireless body area sensor network (WBASN) has promise to be the core of next generation information technology (IT) infrastructure in health care sector [1]. WBASN can be considered for various scenarios such as monitoring of an individual patient from home, monitoring of few patients from intensive care units and monitoring of many patients from hospital wards. Importantly, different nodes connected inside or on the body have great variation in terms of data rate. For example, in an emergency room for heart patients, continuous monitoring of electrocardiogram (ECG), oxygen, body temperature and blood pressure could be required. In such a case, the sensors connected for these purposes have huge variations in their data transmission rate as presented in [2].

WBASN is a special purpose wireless sensor network (WSN), that typically consists of small network with single-hop communication through star or clustered-based topologies [3], [4]. Energy consumption is the most important design constraint in WBASN as the sensors are powered by limited battery. Moreover, the nodes that are implanted inside the body require very high energy efficiency and longer lifetime. In a typical WBASN platform, the radio transceiver consumes most of the power. Radio activity is controlled by the medium access control (MAC) layer, therefore it is necessary to design an ultra low power MAC protocol that can meet the time constraints of BSN.

Time division multiple access (TDMA) based MAC protocols are generally considered as the most suitable for WBASN [5]. In TDMA based schemes, time synchronization of the frame and packets cost significant delay and overheads which results in extra energy waste. Each time slot is separated with *guard time* which is necessary to avoid clock drifts but this costs significant delay in real-time high data rate constraints. Moreover, the variability due to the huge traffic variations of different physiological signals being observed demands complex synchronization and extra overheads.

In this regard, a novel latency-energy optimized MAC protocol is proposed that allows each node to efficiently self organize with respect to the traffic variations of WBASN (we call it traffic-aware dynamic MAC (TAD-MAC) protocol). The wake-up interval is the most important design parameter of the duty cycle MAC protocols [6]. In our proposed technique, every node adapts its wake-up interval (WUInt) dynamically with due account of the amount of traffic (i.e. data packets) it receives and consequently optimizes the energy consumption by reducing idle listening and unnecessary wake-up beacon (WUB) transmission. Results show that the WUInt converges to a steady state value after several wake ups for fixed traffic and the proposed algorithm also converges very fast whenever the data rate changes due to the variations within the physiological data of monitored activity. Finally, a network simulator (WSNet) is used for comparison with other low power MAC protocols. Time spent by various protocols in transmit *Tx*, receive *Rx* and *Idle* states are evaluated for ten different nodes (connected on the body), for fixed and variable traffics.

The rest of this paper is organized as follows. In Section II, a state of the art on the MAC protocols is presented, followed by the design and simulation results of latency-energy optimized MAC protocol presented in Section III. Performance evaluation based on comparison with other energy efficient protocols are presented in Section IV. Finally, the paper ends with the conclusion.

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II. State of the Art

In the context of energy efficient MAC protocols, three classes of MAC protocols are widely used in WBASN: the preamble sampling protocols, protocols with common active period and scheduled protocols. The channel polling approach including low power listening or cycled receiver protocols are part of a broader class of protocols called preamble sampling protocols [6]. These protocols are most popular in distributed asynchronous wireless sensor networks because there is no requirement of synchronization and they are easily adaptable to various applications. Preamble sampling category includes energy efficient MAC protocols such as Cycled Receiver i.e. RICER (Receiver Initiated Cycled Receiver) [7], TICER (Transmitter Initiated Cycled Receiver) [7], LPL (Low Power Listening) [8], BMAC (Berkeley MAC) [8], XMAC [9], WiseMAC [10], etc. These protocols reduce the cost of extra overheads (in comparison with schedule based protocols) and synchronizations by having single or multiple preambles. In addition, a protocol such as WiseMAC can efficiently adjust the duty cycle based on the 'wake up time' of the neighbor nodes, which results in a great reduction of idle monitoring, preamble size and probability of collisions [10]. On the other hand protocols with common active period such as S-MAC [11], PMAC [12] and the T-MAC [13] introduce predefined fixed and variable periodic listening and sleep schedule to avoid collision, overhearing and also reduce idle listening. Finally, schedule based protocols such as *IEEE 802.15.6* [14], SS-TDMA [15], PicoRadio [16], etc., achieve energy efficiency by having contention free time slots at an extra cost of synchronization.

With regards to MAC protocols for WBASN, various studies exist in the literature. For example various proposals from different research centers and companies were presented to *IEEE 802.15.6 TG6* (WBAN Task Group) in [17]. Similarly [4] presents an improved *IEEE. 802.15.4* MAC protocol with an adjustment of beacon traffic according to packet arrival rate. The presented scheme performs better in terms of energy consumption with regards to classical *IEEE. 802.15.4*. TDMA-based energy efficient MAC protocol for WBASN presented in [3] is based on centrally controlled synchronized protocols. In this paper, master-slave based network topology is used, where master is synchronized with slave based on time slots for fixed traffic. However, in [5] after receiving a synchronization each node can transmit over multiple time slots to increase the throughput and energy efficiency, but it demands two level of synchronization (i.e. frame and packet) which is costly in terms of delay and energy. For example, the *guard time* required for packet synchronization is 4 ms in [5], which is significant in high rate signals such as *medical images*, *EMG*, *EEG*, etc.

Very few papers in the literature explore the application dynamics in context with variation in the traffic rate for different sensor nodes connected with the body. There exist significant variations in the data rate of the same monitored parameter such as ECG, EEG, body temperature, blood pressure, etc., depending upon the health state of a patient. [2] presents a scenario-based traffic model and gives details of variation in the traffic of human body signals through ten different references which reinforce the strong need of traffic-aware dynamic MAC protocol that can adapt a sensor node in an energy efficient manner. In this regard, [18], which is one of the proposal presented to WBAN Task Group, proposes a traffic-based secure WBAN MAC protocol. This proposal considers three traffic levels i.e. normal, on-demand and emergency traffic. Further the body network coordinator (BNC) adjusts its wake-up schedule based on wake-up patterns from low traffic to high traffic and vice versa. Moreover, it utilizes wake-up radio for on-demand and emergency traffic. This proposed technique leads to extra hardware cost by adding wake-up radio and second, it does not specify any mechanism for the coordinator to adapt to the variable traffic. Therefore, there exists a strong requirement for a novel energy efficient traffic-aware MAC protocol design for WBASN to deal with the all types of variable traffic that can reduce the energy consumption and improve the latency.

III. A Novel Energy-Latency Optimized MAC Protocol

In the context of energy efficient WBASN protocols, the preamble sampling method is an attractive option for variable traffic [6], [19]. Preamble sampling MAC protocols are based on non-scheduled mechanisms without any synchronization among the nodes, which means that each node is completely independent of its own active/sleep strategy. The general mechanism of a preamble sampling protocol is shown in Fig. 1. The initialization of the communication between sensors can be initiated by either a transmit or a receive node (depending upon the specific protocol being used).

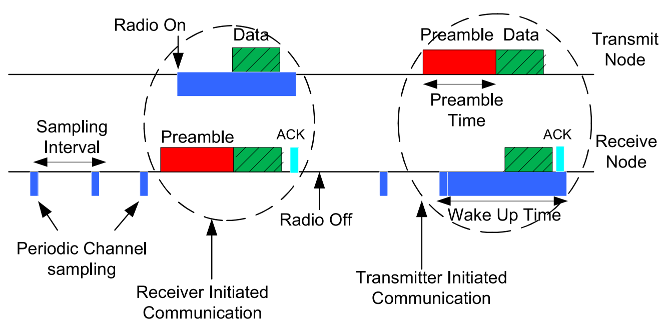

Fig. 1. General mechanism of preamble sampling protocols.

Wake-up interval is the most important design parameter in preamble sampling class of MAC protocols. For periodic sensing, variable sensing or even event-driven applications it is usually kept fixed, which results in degrading the performance as well as the energy efficiency. In [20], it was concluded that adaptive wake-up interval can help to optimize the energy consumption by reducing idle listening (which can consume up to 100 times more energy in comparison with the rest of a complete communication between transmit and receive nodes) and it is the most significant energy waste in asynchronous sensor networks. In this paper we propose a novel latency-energy efficient MAC protocol that adapts the wake-up interval based on the traffic variations to minimize the idle listening.

A. Protocol Description

The basic principle of the proposed protocol which is initiated by the receive node and based on a star topology is shown in Fig. 2. The figure is divided into two phases (i.e. before convergence and after convergence), that sketch the results for the nodes attempting to transmit data (TxN1 to TxN3) to a receive node R. During the evolution phase (shown in Fig. 2-a) before reaching a steady state, each transmit node (TxNi) waits for the beacon signal from the coordinator before sending its data to the coordinating node. The beacon transmitted from the coordinator contains the specific node ID (Identifier). Other intending transmit nodes continue to wait for the next beacon if the next wake-up time is very close, otherwise they can go to sleep mode and wake-up just before the next wake-up beacon (WUB). The next wake-up time is embedded inside the beacon frame that all the transmit nodes receive, but only the specified node will respond with the data.

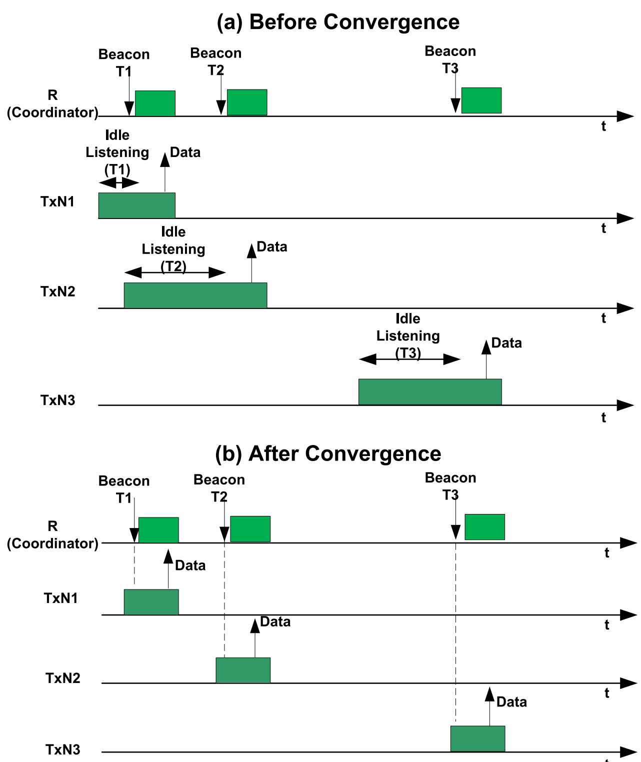

Fig. 2. Energy-latency optimized MAC protocol is divided into two phases; the evolution phase which is before convergence (a) and steady state phase which is after convergence (b).

After several wake-ups of the coordinating node for various transmit nodes, the coordinator will adapt its wake-up interval (WUInt) based on the statistics of the traffic it receives from each individual node and reaches to a steady state as shown in Fig. 2-b. The receive node (coordinator) has adapted its WUInt schedule in such a way that idle listening is minimized and consequently energy and delay are optimized. In order to cater for the clock drift and hardware latencies, the receive node sends the wake-up beacon (WUB) slightly after its scheduled time to ensure that the intending transmit node is already awake.

For the adaptation of WUInt, each node contains a traffic status register (TSR) bank as shown in Fig. 3 to keep the traffic status of all the neighbor nodes. TSR is divided into two halves in order to consider dominant impact from the most recent traffic (which resides in the $most\ significant\ (MS)$ half) in comparison to relatively old traffic (which is in the $least\ significant\ (LS)$ half). Each register corresponds to a node and is updated on the reception of data in response to the wake-up beacon sent by the receive node. If the receive node receives data at time t_i, the register (of that specific node) is filled with a $'1'$ and if it does not receive data, TSR is filled with a $'0'$. The new status (either 1 or 0) is filled in the 1^{st} index of the register. The register contents are shifted one bit right before inserting a new status. The receive node wakes up and sends its beacon to the node which has the nearest WUInt time. This beacon contains the information about the specific node ID which should transmit its data.

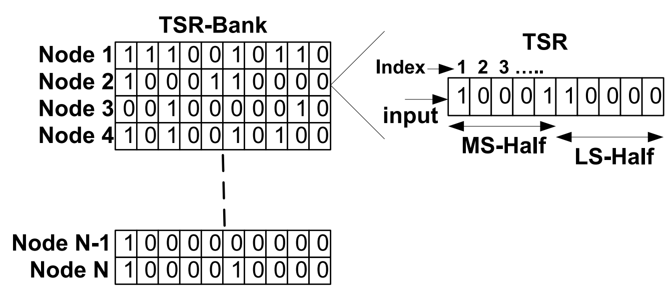

Fig. 3. Traffic shift register bank: it contains N registers for N neighbor nodes.

As the node wakes up, it sends the wake-up beacon and then it computes the next wake-up interval based on the TSR. wake-up interval is updated for the time instant $(t_i + 1)$ based on the values of $WUInt$, μ and e at time instant (t_i) as

$$WUInt(t_{i+1}) = WUInt(t_i) + (\mu(t_i) + e(t_i)) \cdot t_{ref}. \quad (1)$$

In order to have unique reference of time among $WUInt$, μ and e, t_{ref} is multiplied with μ and e, and it is defined with reference to the system/simulator clock. The update factor $\mu(t_i)$ is calculated based on most significant $(X_1(t_i))$ and least significant $(X_2(t_i))$ halves computations along with positive constant weighting factor α as

$$\mu(t_i) = \alpha \cdot X_1(t_i) + (1 - \alpha) \cdot X_2(t_i), \quad (2)$$

where, α value ranges from zeros to one, $X_1(t_i)$ and $X_2(t_i)$ are

$$X_1(t_i) = \frac{N_{0,1}}{L/2} \cdot Nc_{0,1} - \frac{N_{1,1}}{L/2} \cdot Nc_{1,1}, \quad (3)$$

and

$$X_2(t_i) = \frac{N_{0,2}}{L/2} \cdot Nc_{0,2} - \frac{N_{1,2}}{L/2} \cdot Nc_{1,2}. \quad (4)$$

where, $N_{0,j}$, $N_{1,j}$, $Nc_{0,j}$ and $Nc_{1,j}$ are the number of zeros, number of ones, occurrence of consecutive zeros and occurrence of consecutive ones in X_j respectively, further, j is either 1 or 2. The optimization parameter L is the length of the TSR.

The adaptive wake-up interval algorithm is illustrated in Fig. 4. After the weighting average algorithm computation of the wake-up interval $\mu(t_i)$ through (2) to (4), a cross correlator is used to smooth the output of the weighting average algorithm. The correlator is fed with the current contents of TSR and it computes a correlation error after a comparison with the reference patterns that can be either [10101010...] or [11111111...]. The correlator provides the output error either positive (which means that the TSR sequence contains more zeros than ones, hence, the correlator output should contribute to increase the wake-up interval) or negative (which means that the TSR sequence contains more ones than zeros, hence, the correlator output should contribute to decrease the wake-up interval). Consequently it guides the adaptation of wake-up interval towards the desired sequence. Finally, the previous wake-up interval value is added with $\mu(t_i)$ and $e(t_i)$ to compute the next wake-up interval at the output.

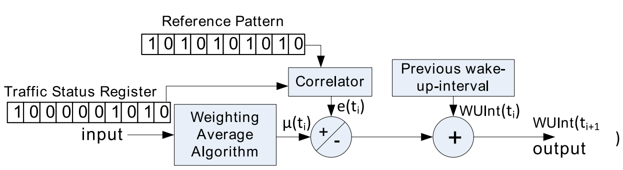

Fig. 4. Adaptive system for wake-up interval algorithm.

In the proposed algorithm, the most influential parameter is Nc (occurrence of consecutive zeros or ones). Even though there are multiple ones or zeros in the TSR they will not make an impact on the update value of wake-up interval until there are back-to-back zeros or ones. Multiple consecutive zeros employ that the next wake-up interval should be increased in comparison to the previous value, whereas multiple consecutive ones imply that the next wake-up interval should be decreased.

B. Simulation Results

In this section simulation results of the proposed adaptive wake-up interval algorithm are presented for fixed and variable traffic. Let us consider a typical body area network with five nodes connected on the body including a coordinating node. The coordinating node acts as a receive node for all the sensor nodes connected on the body to relay the information to the local or remote monitoring station. It uses the status register bank to adapt its wake up interval according to the traffic of all the transmit nodes with the purpose to reduce the energy consumption and latencies of all the nodes in the network. The status register bank includes individual status registers corresponding to each transmit node and accordingly the coordinating node evaluates different wake-up intervals for each transmit node. Moreover, the selection of a specific transmit node (for the beacon transmission) is calculated at the coordinator based on the immediate next wake-up-time of a node among all the transmit nodes.

The algorithm is designed such that it converges to a steady state value of wake-up interval when the TSR contains a sequence of [10101010...] pattern. This typical sequence seems the best trade-off between the optimal wake-up interval [11111111...] (i.e. when each wake-up of the node is followed with a successful data reception), and too frequent wake-up [100010001...]. The optimal sequence contains the probability that it may miss a data as soon as there will be a change in the traffic rate and will result in degrading the performance whereas, the sequence [10101010...] ensures that no data is missed as it can incorporate variable traffic and afterwards adapt to another wake-up interval in order to converge to a steady state value. In this context, it is important to note that too frequent wake-ups waste the energy consumption by transmitting unnecessary wake-up beacons.

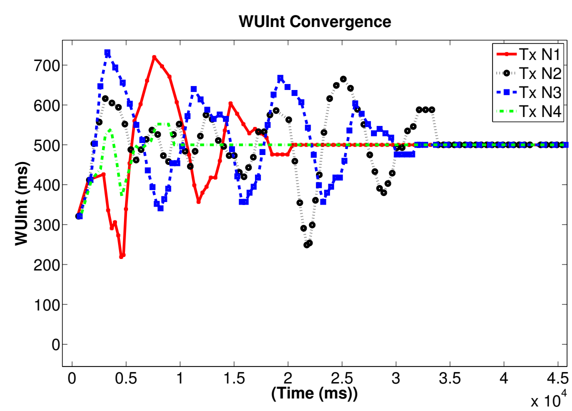

Fig. 5. Receive node adaptation with respect to transmit nodes based on the wake-up interval for a fixed data rate i.e. 1s. It is to mention here that the reference clock increment is 1 (ms), therefore all the time values are in ms.

Fig. 5 shows the adaptation of the receive node wake-up interval towards a steady state value for four transmit nodes. It can be seen in Fig. 5 that there exists an oscillation pattern before reaching a steady state. This is due to the fact that during the evolution phase the receive node receives multiple data from the same transmit node (which means multiple consecutive ones in the TSR), at that instant the wake-up interval value reduces significantly. Similarly, during the evolution phase, the receive node also receives multiple back-to-back zeros in TSR, which results in an increase of wake-up interval. After a certain number of wake-ups, the receive node converges to a steady state. Fig. 5 shows that the wake-up interval for all the transmit nodes converges to 500 ms within

35 s for a fixed traffic rate of 1 s.

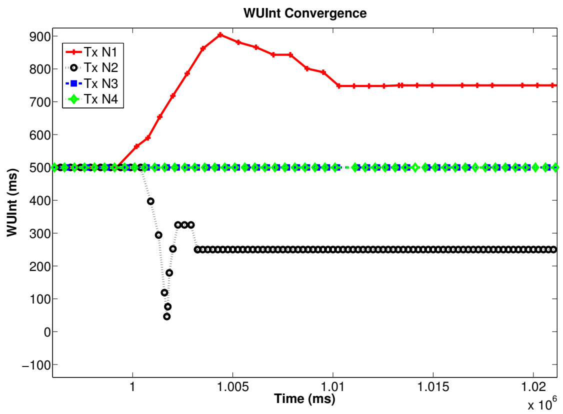

Fig. 6. Convergence of wake-up interval towards a steady state value for variable sensing rates.

Figure 6 shows the convergence of wake-up interval for different traffic rates (one example is highlighted here but various variations of the traffic rates are simulated which are presented in Figure 7). The traffic rate for node 1 and node 2 changes from 1 s to 1.5 s and 500 ms respectively whereas, for node 3 and node 4 sensing rate remains fixed i.e. 1 s during the entire simulation. The proposed adaptive technique converges to steady state values for all the traffic loads.

In Figure 7, extended results are presented for very low and medium-to-high traffic rates. *TSR Length* is an optimization parameter, whereas *initial wake-up interval value* and the weighting parameter α are two tuning parameters. After several simulations with variations from (0.1 to 1.0) the best value of α is found to be 0.7 (which remains constant during different traffic variations), whereas, the optimization parameters vary according to the traffic rates. Generally, if the length is too short, the convergence speed is faster, but in the case of variable traffic rates, the chance of convergence reduces. On the other hand, too long TSR takes much longer time to converge which is more energy consuming. The data packet contains a field called *data-type* which gives the information about the traffic rate whether it is burst, normal or very low and accordingly as the traffic switches, the receive node adjusts the length of TSR.

It is worth mentioning that the above results after convergence to a steady state value consider zero energy consumption due to idle listening but for the real-time physical implementation there will be very little energy waste due to clock drift and hardware latencies. Also, the energy consumed by wake-up beacon transmission is reduced significantly as the number of unnecessary wake-up beacons are avoided through the proposed technique. The proposed technique can be applied to both transmitter initiated and receiver initiated MAC protocols of preamble sampling category for various applications.

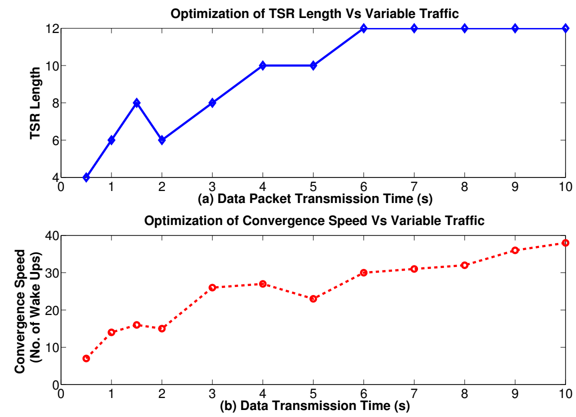

Fig. 7. Optimization of TSR length and corresponding convergence speed for different data transmission rates.

IV. Performance Evaluation

In this section the energy and latency estimation of different energy efficient MAC protocols is presented for comparison. The network simulator *WSNet* [21] is used to evaluate the time spent by different MAC protocols in various states. Typical WBASN exhibits huge variations in traffic rates emanating from various sensors connected on the body. For example, there are 30 times more packets per second from *ECG* monitoring in comparison to *pulse rate* or *body temperature* monitoring [2]. The simulation setup consists of 10 nodes including a coordinating node based on a star topology. The simulation runs for 50 minutes. During the simulation, it is assumed that the network traffic follows Poisson distribution and uses a Rayleigh fading channel model. Four different physiological data are transmitted to the coordinator node, these include *ECG-compressed* (10 packets/s), *oxygen saturation* (1 packet/s), *temperature* (1 packet/s) and *heart rate* (2 packets/s).

For the selected protocols, i.e. XMAC, RICER and our latency-energy optimized MAC, the average time spent by transmit and receive nodes are evaluated as shown in Table I. Idle listening is the main cause of latency and energy consumption in all preamble sampling protocols. The energy consumption is estimated based on the characteristics of the widely used radio chip *cc2420* [20].

XMAC [9] improves the energy waste by replacing the long preamble with multiple short preambles that being transmitted at short intervals and as soon as the transmit node receives the acknowledgment from the destination, it transmits the data. With these optimizations, XMAC reduces the idle transmission cost as well as the overhearing cost. The transmission and reception time values are 0.0120 ms and 0.0128 ms respectively, whereas the idle transmission time is 100.052 ms. RICER [7] is a receiver initiated protocol in which the transmit node waits for the wake-up beacon from the destination before it transmits the data. The transmit node spends maximum energy in idle listening (for waiting the wake-up beacon). The

TABLE I
ENERGY CONSUMPTION AND LATENCIES OF X-MAC AND RICER PROTOCOLS VERSUS TAD-MAC UNDER VARIABLE TRAFFIC OF WBASN.

	X-MAC [9]		RICER [7]		TAD-MAC	
States	**Energy (J)**	**Latency (s)**	**Energy (J)**	**Latency (s)**	**Energy (J)**	**Latency (s)**
$Tx.$	6.5×10^{-7}	1.2×10^{-5}	3.7×10^{-5}	7.3×10^{-4}	3.7×10^{-5}	7.3×10^{-4}
$Rx.$	7.5×10^{-7}	1.2×10^{-5}	4.3×10^{-5}	7.3×10^{-4}	4.3×10^{-5}	7.0×10^{-4}
Idle	$\mathbf{5.1 \times 10^{-3}}$	$\mathbf{1.0 \times 10^{-1}}$	$\mathbf{3.0 \times 10^{-3}}$	$\mathbf{5.1 \times 10^{-2}}$	$\mathbf{0.1 \times 10^{-3}}$	$\mathbf{2.5 \times 10^{-3}}$
$Total$	5.1×10^{-3}	1.0×10^{-1}	3.0×10^{-3}	5.2×10^{-2}	0.2×10^{-3}	3.9×10^{-3}

transmission and reception time values are 0.73 ms and 0.73 ms respectively, whereas the idle transmission time is 51.3 ms. The transmission and reception time values for our proposed protocol are 0.73 ms and 0.71 ms respectively, which is nearly the same as other protocols but the idle transmission time is only 3.2 ms which results in significant improvement of packet delay. Further the energy consumption of the different MAC protocols is also illustrated. After optimizing the idle listening it can be seen that our protocol consumes 15 to 25 times less energy in comparison with RICER and XMAC protocols respectively.

Finally, a small comparison with energy efficient low duty cycle TDMA-based protocol [5] is presented. It considered a TDMA frame of 1 s, packet size of 1250 bits with 80 bits of overhead sampling rate of 125 samples/s. It achieves 4.51 % duty cycle but each node requires 48.3 ms to completely transmit its data packet. This total time includes; *packet transmit*, *waiting time*, *ACK. received* and *guard time*, which is much more in comparison with our TAD-MAC protocol under *ECG* transmission at 1.2 kbps.

V. CONCLUSION

In this paper we proposed a novel latency-energy optimized MAC protocol that allows the sensor nodes to adapt themselves efficiently according to the traffic. Each node has a traffic status register bank (TSR-bank) which contains the traffic status according to the data received from all the neighbor nodes. A body area network with star topology is considered, which is suitable for both invasive and non-invasive BAN. First, the simulation results of fixed and variable traffic are presented, it is shown that the wake-up interval converges efficiently to a steady state value for different traffic rates. Optimization parameter *TSR Length* is adjusted in order to obtain fast convergence and its values for various variations of traffic rates are presented. Second, performance evaluation of different energy efficient preamble sampling MAC protocols for WBASN are presented. Proposed protocol outperforms the other protocols in terms of energy and latency under variable traffic.

REFERENCES

[1] H. Mamaghanian, N. Khaled, D. Atienza, P. Vander, "Compressed Sensing for Real-Time Energy-Efficient ECG Compression on Wireless Body Sensor Nodes," *IEEE Trans. on Biomed. Engg.*, Vol. 58, No. 9, Sep. 2011.

[2] A. Ahmad, A. Riedl, W. J. Naramore, N. Y. Chou and M. S. Alley, "Scenarios-based Traffic Modeling for Data Emanating from Medical Instruments in Clinical Environment," *in Proc. of the World Congress on Computer Sci. and Info. Eng.*, vol. 01, pp. 529-533, 2009.

[3] O. Omeni, A. C. W. Wong, A. J. Burdett and C. Toumazou. "Energy Efficient Medium Access Protocol for Wireless Medical Body Area Sensor Networks," *IEEE Trans. on Biomed. Circuits and Syst.*, vol. 2, no. 4, pp. 251-259, Dec. 2008.

[4] S. Ullah and K. S. Kwak, "Performance Study of Low-Power MAC Protocols for Wireless Body Area Networks," *IEEE 21st Int. Symp. on Personal, Indoor and Mobile Radio Comms.*, pp. 112-116, Sep. 2010.

[5] S.Marinkovic, E. Popovici, C. Spagnol, S. Faul, W. Marnane, "Energy-Efficient Low Duty Cycle MAC Protocol for Wireless Body Area Networks," *IEEE Trans. on Info. Tech. in Biomed.*, Vol. 13, No. 6, Nov. 2009.

[6] A. Bachir, M. Dohler, T. Watteyne, and K. K. Leung, "MAC Essentials for Wireless Sensor Networks," *IEEE Communications surveys & Tutorials*, vol. 12, no. 2, pp. 222-248, 2010.

[7] E. Y. Lin, A. Wolisz, and J. Rabaey, "Receiver Initiated Rendezvous Schemes for Sensor Networks," *In Proc. of IEEE Global Telecom. Conf.*, vol. 5, pp. 6.-3122, 2005.

[8] J. Polastre, J. Hill and D. Culler, "Versatile Low Power Media Access for Wireless Sensor Networks," *in Proc. of ACM Conf. on Embedded Network Sensor Systems*, pp. 95-107, USA, 2004.

[9] M. Buettner, G. Yee, E. Anderson and R. Han, "X-mac: A short preamble mac protocol for duty-cycled wireless sensor networks," *in Proc. of ACM Conf. on Embedded Network Sensor Systems*, pp. 307-320, USA, 2006.

[10] A. El-Hoiydi and J.-D. Decotignie, "WiseMAC: an ultra low power MAC protocol for the downlink of infrastructure wireless sensor networks," *in Proc. of the Ninth Int. Symposium on Computers and Communications*, vol. 2, pp. 244-251, USA, 2004.

[11] W. Ye, J. Heidemann and D. Estrin, "An Energy-Efficient MAC Protocol for Wireless Sensor Networks," *in Proc. of IEEE Int. Conf. on Computer Communications*, pp. 1567Ű76, USA, July 2002.

[12] T. Zheng, S. Radhakrishnan and V. Sarangan, "PMAC: An adaptive energy-efficient MAC protocol for Wireless Sensor Networks," *in Proc. of 19th IEEE Int. Parallel and Distributed Proc. Symposium*, April. 2005.

[13] T. V. Dam and K. Langendoen, "An Adaptive Energy-Efficient MAC Protocol for Wireless Sensor Networks," *in Proc. of ACM Conf. on Embedded Network Sensor Systems*, pp. 171Ű80, USA, Nov. 2003.

[14] "IEEE 802.15.4. Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs)," 2003.

[15] S. Kulkarni and M. Arumugam, "SS-TDMA:A self-stabilizing MAC for sensor networks," *In Sensor Network Operations*,IEEE press edition, 2006.

[16] J. M. Rabaey, M. J. Ammer, J. L. da Silva, D. Patel, S. Roundy, "PicoRadio Supports Ad Hoc Ultra-Low Power Wireless Networking," *IEEE Computer Magazine*, vol. 33(7), pp. 42Ű48, 2000.

[17] K. S. Kwak,M. A. Ameen, D. Kwak, C. Lee and H. Lee, "A study on proposed IEEE 802.15 WBAN MAC protocols," *in Proc. of 9th Int. Conf. on Communications and Info. Tech.*, pp. 834 - 840, USA, 2009.

[18] K. S. Kwak, S. Ullah, X. An, M. A. Ameen, J. Liu, B. Kim, H. Lee, J. Kim, (2009 May). *A Traffic-based Secure MAC Protocol for WBAN with Bridging Function* [Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)]. [Online]. Available: https://mentor.ieee.org/802.15/dcn/09/15-09-0366-00-0006-inha-mac-proposal.pdf.

[19] M. M. Alam, O. Berder, D. Menard, T. Anger, O. Sentieys, "Traffic-aware adaptive wake-up-interval for preamble sampling MAC protocols of WSN," *in Proc. of 3rd International Workshop on cross layer design*, pp. 1-5, France, Nov. 2011.

[20] M. M. Alam, O. Berder, D. Menard, T. Anger, O. Sentieys, "A Hybrid Model for Accurate Energy Analysis for WSN nodes," *EURASIP Journal for Embedded Systems*, vol. 2011, pp. 4.1-4.16.

[21] INRIA Research Center, "WSNet Simulator", [Online]. Available: http://wsnet.gforge.inria.fr/download.html.