An Efficient Unscheduled Communication for Smart Body Centric Networks

Moshaddique Al Ameen
Department of Computer Science and Engineering
Kyung Hee University
Yeongin-si, Korea
ameen@khu.ac.kr

Choong Seon Hong
Department of Computer Science and Engineering
Kyung Hee University
Yeongin-si, Korea
cshong@khu.ac.kr

***Abstract*—Applications of smart wearable devices to monitor human body functions are on the rise. In such networks, devices usually have limited resources. Therefore, energy efficiency is among the most crucial design issues. Efficient energy management strategies must be devised at device and network levels to prolong the network lifetime as much as possible. In a typical network, devices employ schedules to wakeup for communication. In this work, we present design and analysis of a protocol to reduce the energy consumption and delay. The proposed scheme manages the network by taking into account the device buffer capacity, packet drop probability and retry limits. It is observed that the proposed scheme is able to improve the performance in terms energy consumption and delay. We also present a comparative study with some of the state-of-the-art protocols.**

Keywords— wearable; smart devices; healthcare; body-centric networks; scheduling

I. INTRODUCTION

Advancements in technology have reduced cost, size and affordability of smart sensor devices for healthcare [1], [2]. Numerous applications focused on monitoring health status of patients have been researched and various projects are on the development and implementation stages [3], [4]. They can significantly reduce the cost and increase affordability.

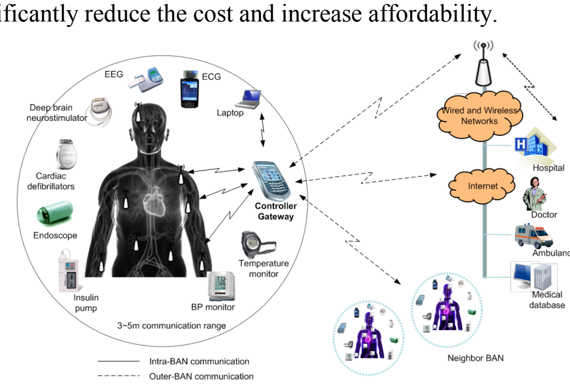

Fig. 1. A typical architecture of smart wearable network.

A majority of the wearable devices must be energy efficient so that it works for longer duration. This is particularly true if the user is far away from any energy source. Some other key design factors are low delay, security and reliability etc. A typical architecture is shown in Fig. 1 [5].

This work deals with design and analysis of energy efficient protocol for smart wearable device communication. The rest of the paper is organized as follows. In Section II, we present a present related works and motivation behind our works. In Section III, we present the system model. In Section IV, we present performance analysis. In Section V, we present performance evaluation and comparative study along with results and discussion. Finally, the conclusions are drawn in Section VI.

II. RELATED STUDIES

Various wakeup mechanisms [6] have been proposed for MAC protocols to increase the network performance. A common schedule can be employed by coordinating all the devices in a network. Schedules are established so that neighboring devices have synchronous sleep and wakeup periods. The time slots can be shared or allocated individually for data communication. In shared time slots, a group of devices contends for same time slot.

Several MAC protocols are proposed based on various wakeup schemes viz. S-MAC [7], T-MAC [8], B-MAC [9], WiseMAC [10], X-MAC [11] and so on. These protocols can be used in a wearable environment to manage the wearable devices. However, these MAC protocols have several shortcomings from the perspective of using for wearable device communications in a network. Our aim is to design a simple to implement a mechanism by reducing the demerits of the above protocols. In the next sections, we present design and analysis of such a protocol.

III. SYSTEM MODEL

In this section, we describe the proposed model in detail. The devices send data to the controller and vice versa. We have assumed that every device has finite buffer capacity. The devices are configured in a star like topology. We used a slotted scheme for packet transmission.

The proposed model uses a superframe structure consists of time slots as shown in Fig. 2. The superframe is repeated in cycles.

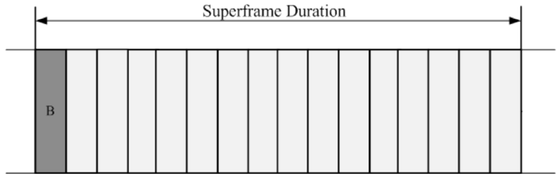

Fig. 2. A superframe with time slots.

The MAC frames used are inspired by the IEEE802.15.4 MAC frames. We have modified the frames to meet the needs of the proposed model. The MAC frame, MAC header, and ACK frames are shown in Fig. 3.

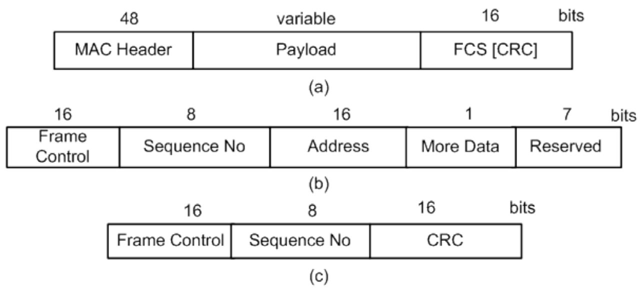

Fig. 3. MAC frames.

We have used a simplified model for data communication that uses channel sensing along with back-off mechanism to mitigate collision. In the back-off mechanism, a device chooses the value from the range [0, B], where B is the maximum value. Packet is dropped after it reaches the attempt limit.

IV. Performance Analysis

In this section, we provide analysis of the proposed protocol. The traffic is modeled using Poisson distribution with arrival rate λ and service time μ. We have used single queue with finite buffer size k. If a new packet finds the queue full, it is blocked. For analysis, we used packet blocked probability (p_b), packet dropped probability (p_d), utilization factor (σ_q), retry limit (R) and average number of retransmissions (α).

The packet blocked probability (p_b) for a M/M/1/K system is given by,

$$p_b = \frac{(1-\rho)\rho^k}{1-\rho^{k+1}} \tag{1}$$

We define as the steady state probability that a tagged device transmits in a random time slot given that it has packet to transmit. For buffer not empty, it is given by,

$$\tau = \frac{\rho(1-p_b)}{\overline{B}+1} \tag{2}$$

where is the average number of slots a device waits (back-off) before it transmits.

It is given by,

$$\overline{B} = \frac{B-1}{2} \tag{3}$$

Service time is calculated from the time a packet arrives at the head of the queue until it is out from it. It is given by,

$$\frac{1}{\mu} = (\alpha+1)\overline{B}T_{slot} + \alpha T_{co} + (\alpha+1)T_{cca} + T_{su} \tag{4}$$

where T_{slot}, T_{su} and T_{co} are the duration of a slot, duration of successful and collision transmissions respectively.

The average number of retransmissions is given by,

$$\alpha = \frac{1-p_c}{1-p_d}\left[\frac{p_c\left[(R-1)p_c^R - Rp_c^{R-1} + 1\right]}{(p_c-1)^2}\right] \tag{5}$$

Now we calculate the energy consumption for successfully transmitting a packet.

The average energy consumption consists of the energy consumption in transmitting packet (E_{tx}), energy consumption in receiving acknowledgement packet (E_{rx}), energy consumption during back-off (E_{bo}), energy consumption during channel sensing (CCA) (E_{cca}), energy consumption during sleep state (idle period) (E_{sleep}), and energy consumption in overheads (transceiver switching) (E_{ov}).

Let P_{tx} be the transmitting power, P_{rx} be the receiving power, P_{active} be the power consumption in active (on) state, P_{cca} be the power consumption in sensing state and P_{sleep} be the power consumption in sleep state.

The average energy consumption E_{avg} is calculated as the ratio between energy consumption during one cycle E_{cycle} and average length of the cycle T_{cycle} as follows,

$$E_{avg} = \frac{E_{cycle}}{T_{cycle}} \tag{6}$$

Energy consumption during a cycle is calculated as follows,

$$E_{cycle} = N_{pkt-b}\left(\frac{L_{pkt}}{r}P_{tx} + \frac{L_{ack}}{r}P_{rx} + (\alpha+1)\overline{B}T_{slot}P_{active} + (\alpha+1)T_{cca}P_{cca} + 2(\alpha+1)T_{sw}P_{sw}\right) + \frac{1}{\lambda}P_{sleep} \tag{7}$$

where N_{pkt-b} is the average number of packets served in busy period.

The average length of a cycle is calculated as follows,

$$T_{cycle} = \frac{1}{\lambda} + \frac{1-\rho^K}{\mu(1-\rho)} \tag{8}$$

The average packet delay (D_{pkt}) is calculated as follows,

$$D_{pkt} = \frac{q_n}{\lambda(1-p_b)} = \frac{\rho\left[1+K\rho^{K+1}-(K+1)\rho^K\right]}{(1-\rho)(1-\rho^{K+1})} \Big/ \left[\frac{1}{\lambda(1-p_b)}\right] \quad (9)$$

where (q_n) is the average number of packets in queue.

It is given by,

$$q_n = \frac{\rho\left[1+K\rho^{K+1}-(K+1)\rho^K\right]}{(1-\rho)(1-\rho^{K+1})} \quad (10)$$

V. Performance Evaluation

The performance evaluation of proposed model in terms of energy consumption and delay is presented. The input parameters for the evaluation are presented in Table I. We have simulated the works in Network Simulator NS-2 (release v2.31) [12]. We used Tcl script and C++ to write the codes for the simulation. We have used packet arrival rate (λ) for performance evaluation.

TABLE I. Input Parameters

Symbol	Value
Ptx	26mW
Prx	13.5mW
Ldata	Variable
Lack	10 B
r	25kbps
B	32

A performance comparison is done for the proposed model with T-MAC, S-MAC and WiseMAC. The aim is to find the relative performance of these protocols. The size of RTS and CTS packets for S-MAC is taken 10 Bytes each. The duration of preamble for WiseMAC and B-MAC is 20ms and 86.7ms respectively. The wakeup duration for WiseMAC and B-MAC is 400ms.

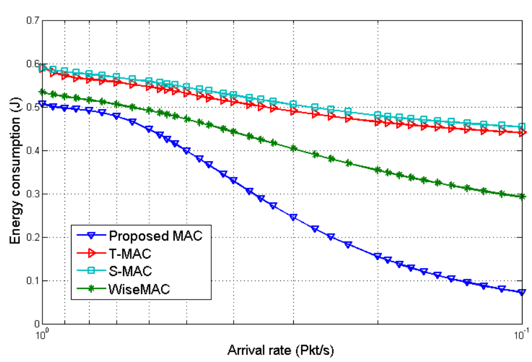

Fig. 4. Energy consumption comparison.

It is observed that the proposed model has better performance in terms of energy consumption and delay as shown in Fig. 4 and Fig. 5. S-MAC has control packet overheads (RTS and CTS packets before communication). Similarly, the preamble sampling of WiseMAC increases the delay and waste of energy. The long wakeup preamble causes extra overheads in energy consumption and delay. The early sleep problem of T-MAC decreases its performance. Overhearing also causes waste of energy in these protocols. The long preamble of B-MAC imparts a very high energy cost on the network.

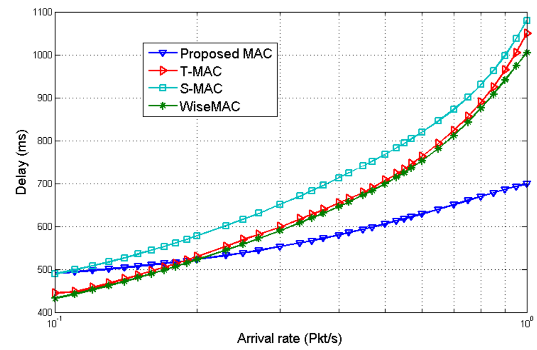

Fig. 5. Delay comparison.

VI. Conclusions

A smart network of wearable devices has huge potential for growth. Wearable device is a major part of a body centric network. Such network can take advantage of slotted contention based access mechanism to improve the performance. In this paper, we present an analysis of such a protocol for smart wearable body-centric network. We have analyzed and simulated the energy consumption, delay and lifetime of the proposed protocol. The comparative performance shows lower energy consumption and higher lifetime at low packet arrival rate. The delay results show that the proposed scheme can be used in delay sensitive applications. Our future work includes modeling to include priority for different types of traffics in the network.

Acknowledgment

"This research was supported by the MSIP, Korea, under the G-ITRC support program (IITP-2017-R6812-15-0001) supervised by the IITP." *Dr. CS Hong is the corresponding author.

References

[1] C. Hu, H. Li, Y. Huo, T. Xiang, and X. Liao, "Secure and efficient data communication protocol for wireless body area networks," IEEE Transactions on Multi-Scale Computing Systems, vol. 2, no. 2, pp.94–107, April 2016.

[2] F. Wang, F. Hu, L. Wang, Y. Du, X. Liu, and G. Guo, "Energyefficient medium access approach for wireless body area network based on body posture," China Communications, vol. 12, no. 12, pp. 122–132, December 2015.

[3] J. P. Varkey, D. Pompili, and T. A. Walls, “Human motion recognition using a wireless sensor-based wearable system,” Personal and Ubiquitous Computing, vol. 16, no. 7, pp. 897–910, 2012.

[4] K. M. Thotahewa, J.-M. Redoute, and M. R. Yuce, “A low-power wearable dual-band wireless body area network system: Development and experimental evaluation,” 2014.

[5] M. A. Ameen and C. S. Hong, “An on-demand emergency packet transmission scheme for wireless body area networks,” Srnsors, vol. 15, no. 12, pp. 30 584–30 616, December 2016.

[6] M. Miller and N. Vaidya, “A MAC protocol to reduce sensor network energy consumption using a wakeup radio,” IEEE Transactions on Mobile Computing, vol. 4, no. 3, pp. 228 – 242, 2005.

[7] W. Ye, J. Heidemann, and D. Estrin, “An energy-efficient MAC protocol for wireless sensor networks,” in INFOCOM 2002. Twenty-First Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings., 2002.

[8] T. van Dam and K. Langendoen, “An adaptive energy-efficient mac protocol for wireless sensor networks,” in Proceedings of the First ACM Conference on Embedded Networked Sensor Systems, 2003.

[9] J. Polastre, J. Hill, and D. Culler, “Versatile low power media access for wireless sensor networks,” in Proceedings of the 2nd international conference on Embedded networked sensor systems, ser. SenSys ’04. New York, NY, USA: ACM, 2004, pp. 95–107.

[10] A. El-Hoiydi and J. D. Decotignie, “WiseMAC: An ultra low power MAC protocol for the downlink of infrastructure wireless sensor networks,” in Ninth International Symposium on Computers and Communications, 2004. Proceedings. ISCC 2004., 2004.

[11] M. Buettner, G. V. Yee, E. Anderson, and R. Han, “X-MAC: A short preamble MAC protocol for duty-cycled wireless sensor networks,” in Proceedings of the 4th international conference on Embedded networked sensor systems, ser. SenSys ’06. New York, NY, USA: ACM, 2006, pp. 307–320.

[12] NS-2, “The network simulator,” Documentation, http://www.isi.edu/nsnam/ns/ns-documentation.html, 2011.