Mitigating Duty Cycle using Out-of-Band Wakeup Mechanism for Body-centric Networks

Moshaddique Al Ameen, Choong Seon Hong*
{ameen, cshong}@khu.ac.kr
Department of Computer Science and Engineering, Kyung Hee University, Korea

Abstract

A body-centric network (BCN) has small and resource constrained devices in and around the human body to monitor body functions. Power efficiency and lower delay are among the key design factors. The major technique in use to conserve power is the duty cycle mechanism. Duty cycle uses wakeup (radio on) and sleeps (radio off) procedure during each operation cycle. However, unnecessary wakeups can cause waste of power. An external wakeup radio based mechanism can mitigate the effect of duty cycle and lower power wastage through an on-demand wakeup scheme. In this paper, we present that a wakeup radio based system can improve the performance of a BCN in terms of power consumption and delay by mitigating traditional duty cycle scheme.

1. Introduction

Advancements in the field of Internet of Things (IoT) for healthcare have given rise to several applications in body-centric networks (BCN). A wireless BCN as shown in Figure 1 is a self-contained network in which the devices are usually placed on or in close proximity to the body [1].

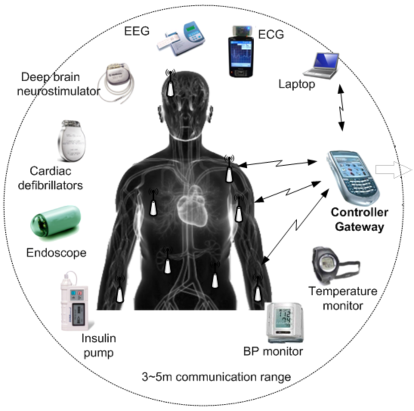

Figure 1. A typical body-centric network [2]

It is an established fact that power consumption in the sleep state is very less compared to the idle state. Authors in [3] reported the power consumption for a Mica2 Mote sensor as shown in Table 1. It is a predominant practice to put the radios to sleep mode, whenever there is no need for communication. These results in lower power consumption as all the unused components (e.g. transceiver) are turned off (sleep).

Duty cycle is among the most widely used mechanisms for designing power efficient protocols. In a duty cycle based protocol, a suitable sleep/wakeup mechanism is used to provide optimum performance. It saves power by controlling the sleep/wakeup time of a device in the network. It uses wakeup (radio on) and sleeps (radio off) procedure during each operation cycle.

Table 1 Power characteristics for a MICA2 Mote

Radio State	*Power Consumption (mW)*
Transmit	81
Receive/Idle	30
Sleep	0.003

However, unnecessary wakeups can cause waste of power. An out-of-band external radio triggered wakeup mechanism uses ultra-low power transceivers to reduce the power consumption. In this paper, we present mitigation of duty cycle using out-of-band external radio triggered scheme for BCN. The rest of the paper is organized as follows. In Section 2, we present related works. In Section 3, we present system design and performance analysis. In Section 4, we present results and discussion. Finally, conclusions are drawn in Section 5.

2. Related Works

2.1. Duty Cycle

In general terms, a duty cycle is the amount of time a system remains in an active state. In the case of a transceiver, this is the time it is on (wakeup), regardless of whether it is transmitting, receiving, or idly listening to a clear channel [4]. Suppose, during the period T, a device spends *w* amount of time in the active state. The duty cycle D can be calculated simply as the ratio, D = *w*/T as shown in Figure 2.

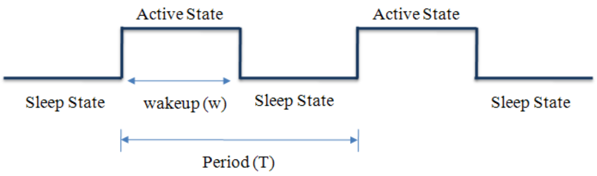

Figure 2. Duty cycle concept

A fixed duty cycle scheme uses fixed length period. Some of the earliest protocols (e.g. S-MAC [5]) use fixed duty cycle. In the adaptive duty cycle protocols such as WiseMAC [6], the sleep/wakeup time of a device is adaptively determined to save more power.

2.2. Out-of-band Radio Triggered Wakeup

In this concept, an additional ultra-low power transceiver is attached to the device. The goal is to minimize the idle listen period for the main radio. A dedicated wakeup receiver can monitor the channel, listening for a wakeup signal from other devices and activating the main receiver upon detection as shown in Figure 3. Use of a wakeup radio can improve overall network performance by maximizing sleep time of a device without compromising the delay.

The use of wakeup radio enables the receiver to turn off the main radio along with other necessary circuitry. Upon receiving the wakeup signal, the microcontroller is triggered on to interpret the message and then act accordingly. Since the main radio remains in sleep mode and wakes up only on-demand, it helps to save power.

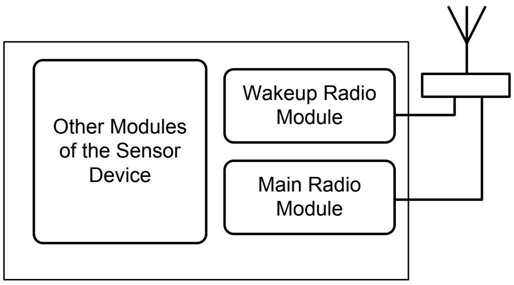

Figure 3. Wakeup radio and main radio

3. System Design and Analysis

In this section, we present system design and analysis.

3.1 Communication Process

The communication process between a device and the sink is presented in Figure 4.

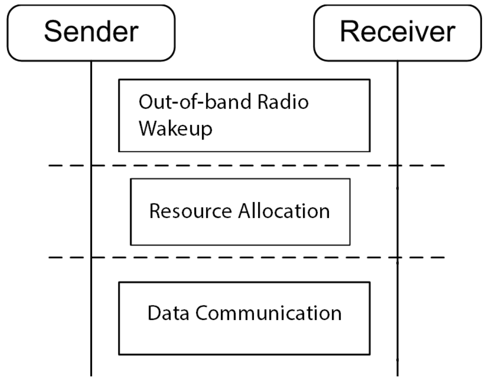

Figure 4. Communication Process

For the uplink communication process between a device and sink, which also acts as the controller at first, the sender transmits the wakeup radio signal to the sink. It allocates resources. For the downlink, the sink sends the wakeup radio signal along with resource allocation information to the device. In both the cases, the data communication takes place at the end.

3.2 Analysis

Now we present the analysis of the uplink communication of the out-of-band wakeup protocol. Let P_{tx}, P_{rx}, P_{sl}, P_{ov} be the power consumption in transmit, receive, sleep and overheads. Descriptions of parameters are presented in Table 2. We have used a beacon enabled mode of communication.

Table 2 Parameters

Description	Symbol	Value
Power required to transmit	P_{wtx}	*26mW*
Power required to receive	P_{wrx}	*13.5mW*
Time required for data packet TX	T_{data}	*Variable*
Time required for Ack packet TX	T_{ack}	*0.6mW*
Time required for Beacon packet TX	T_{beacon}	*2.2ms*
Power required for wakeup packet RX	P_{wkrx}	*910nW*
Time required for wakeup packet TX	T_{wk}	*1.4ms*
Setup power	P_{setup}	*0.0043mW*
Setup time	T_{setup}	*0.25ms*
Power consumed in sleep state	P_{sl}	*0.0015mW*
Time spend in sleep state	T_{sl}	*Variable*
Power required to switch transceiver	P_{sw}	*13.5mW*
Time required to switch transceiver	T_{sw}	*0.4ms*
Data rate of the radio	R	*40kbps*

The average power consumption (P) for uplink data communication is calculated as follows.

$$P = P_{tx} + P_{rx} + P_{sl} + P_{ov} \quad (1)$$

We have,

$$P_{tx} = \left(P_{wtx} \times \frac{(L_{ack} + L_{data})}{R} \right) / T \quad (2)$$

$$P_{rx} = \left(P_{wkrx} \times \frac{L_{wk}}{R} + P_{wrx} \times \frac{(L_{beacon} + L_{ack})}{R} \right) / T \quad (3)$$

$$P_{sl} = (P_{wsl} \times T_{sl}) / T \quad (4)$$

$$P_{ov} = (P_{setup} \times T_{setup} + P_{sw} \times 2T_{sw}) / T \quad (5)$$

The total sleep time is calculated as,

$$T_{sl} = T - (T_{wk} + T_{setup} + 2T_{ack} + T_{beacon} + T_{data} + 2T_{sw}) \quad (6)$$

The total delay (D) of the proposed MAC is calculated as follows.

$$D = T_{wk} + T_{setup} + 2T_{ack} + T_{beacon} + T_{data} + 2T_{sw} \quad (7)$$

4. Results and Discussion

To validate our model, we have compared the analysis and simulation results. The packet arrival rate (number of packets per second) is considered to evaluate the results of both simulation and analysis. We have used different size of payloads for evaluation.

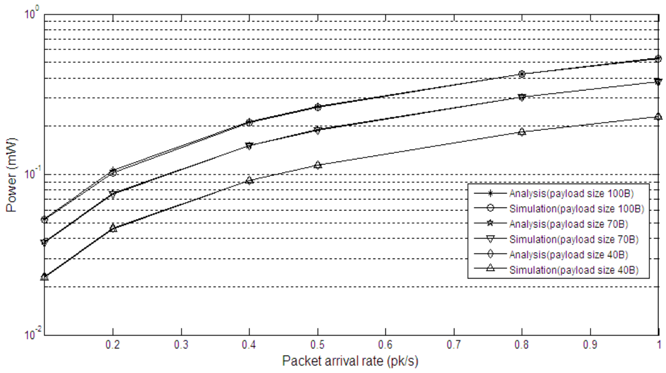

Figure 5. Power consumption

The Figure 5 shows low power consumption for the out-of-band radio triggered scheme. It mitigates the duty cycle and saves power by reducing the unnecessary wakeups of the devices.

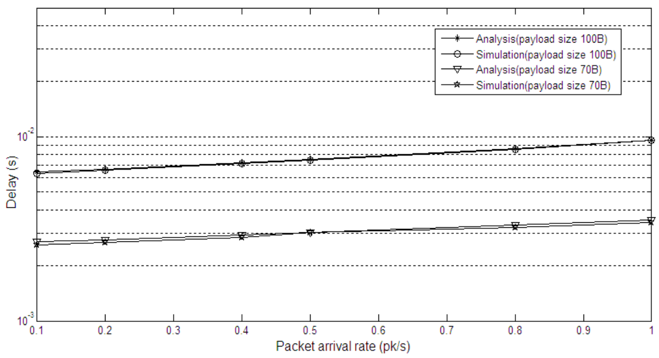

Figure 6. Packet delay

Similarly, Figure 6 shows very low packet delay for the on-demand scheme. The on-demand wakeup process is prompt. It reduces the waiting time for the receiver.

5. Conclusions

Duty cycle is a popular mechanism to conserve power. Adaptive duty cycle mechanism has more advantages than the fixed duty cycle mechanism. However, unnecessary wakeups cause extra power consumption. Even in adaptive duty cycle, devices can wakeup when no data transmission takes place. In this paper, we show that an out-of-band external radio triggered mechanism can reduce such power wastage through an on-demand transmission.

Acknowledgement

This research was supported by the MSIP (Ministry of Science, ICT and Future Planning), Korea, under the Grand Information Technology Research Center support program (IITP-2017-2015-0-00742) supervised by the IITP (Institute for Information & communications Technology Promotion)"
*Dr. CS Hong is the corresponding author

References

[1] S. L. Cotton, R. D'Errico and C. Oestges, "A review of radio channel models for body centric communications," in *Radio Science*, vol. 49, no. 6, pp. 371-388, June 2014.

[2] M. Al Ameen and C. S. Hong, "An efficient unscheduled communication for smart body centric networks," *2017 IEEE International Conference on Big Data and Smart Computing (BigComp)*, Jeju, 2017, pp. 280-283, 2017.

[3] L. Gu and J.A. Stankovic, "Radio triggered wake up for wireless sensor networks. *Real Time Systems*," vol.29, no.2-3, pp.157-182, March 2005.

[4] B. V. d. Doorn, W. Kavelaars, and K. Langendoen, "A prototype low cost wakeup radio for the 868 MHz band," *International Journal of Sensor Networks*, vol. 5, pp. 22-32, February 2009.

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

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