An Out-of-band Wakeup using Contention Access for Wearable Device Communication

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Abstract

Wearable device communication is a major research field in Internet of Things (IoT) domain. An autonomous network of wearable devices has both medical and non-medical applications. Energy efficiency is among the most crucial aspects of a wireless wearable network. By managing the wakeup schedule of the devices, we can reduce the energy consumption and delay. In this work, we present an out-of-band wakeup scheme using the contention access mechanism. We used a superframe based scheme for the media access control by utilizing time slots for multiple access. We present analysis and simulation study of the out-of-band wakeup with contention access and compared it with the existing IEEE802.15.4 MAC protocol.

1. Introduction

The rise of Internet of Things (IoT) has enabled development of applications for miniaturized medical and non-medical wearable devices on and around the human body [1,2]. A network of wearable devices can be easily formed to monitor body functions as well as non-medical tasks such as listening to music and watching videos.

Energy efficiency is a major requirement for wearable networks. To save energy, a device is turned off. In such a scenario where the sleeping device is the intended receiver, the sender has to wait until the time the receiver device wakes up. Therefore, either the device must be in an always-on/standby state or needs periodic sleep/wakeup mechanism to automate the process. The standardized IEEE802.15.4 MAC [3] protocol has no such mechanism to directly communicate with a sleeping device. We try to solve this problem by using external wakeup mechanism.

An external wakeup mechanism uses an out-of-band scheme to communicate. A wearable device can be easily triggered on by an external wakeup signal. Recent development shows the wakeup radio puts very little extra cost in terms of power consumption [4].

The purpose of this study is to investigate the use of wakeup radio for communication using contention access scheme. Our aim is to use wakeup radio for different arrival rate (particularly focused on low arrival rate).

The IEEE 802.15.4 standard is devised to support low data rate, low power networks. The IEEE 802.15.4 MAC adopts carrier sense multiple access with collision avoidance (CSMA/CA) as the channel access mechanism.
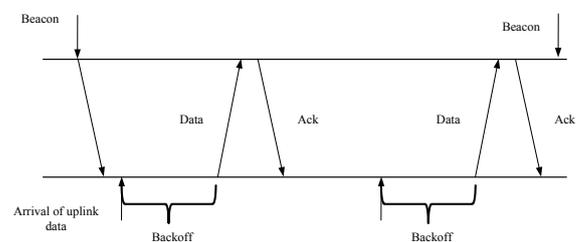

Fig 1. IEEE802.15.4 beacon enabled communication.

It supports star topology and can be easily implemented in a typical wearable network. As the size of the network is small, all the devices can be in range for carrier sensing. The data transfer model for the uplink in the beacon enabled mode (considered in this study) is shown in Fig 1. Devices in a wearable network usually have low arrival rate. This allows a device more time to sleep. Use of wakeup radio can reduce the need of periodic wakeup of a device to check for the message intended for it. This increases the sleep time of the devices and saves energy.

The rest of the paper is organized as follows. In Section 2, we present system design. In Section 3, we present performance analysis. In Section 4, we present results and discussion. Finally, conclusions are drawn in Section 5.

2. System Design

The IEEE802.15.4 uses two clear channel assessment (CCA) before transmitting a packet. We have used one CCA in our scheme. The proposed contention access based scheme has the following features,

– It uses Wakeup Radio/Wakeup-ACK/Data/ACK operation
– It uses carrier sensing in a slotted CSMA
– There are N devices in the system with all of them in range
– It uses wakeup radio to enable communication with a sleeping device
– It increases sleep time of a device by reducing idle wakeup and idle listening time

The three main variables used in the beacon-enabled IEEE802.15.4 slotted CSMA MAC are, number of backoffs (NB), contention window (CW) and backoff exponent (BE). A random back-off is used to reduce the collision probability. NB is the number of time the CSMA/CA algorithm is required to back-off while attempting the current transmission. BE is the back-off exponent. When a device has packet to transmit, it first waits for a random amount of time (back-off) by choosing a value between (0, $2^{BE}-1$), where BE initially set to 2. The device then senses the channel to ensure the medium is idle for a duration known as contention window (CW). If it finds the medium busy, it increases its back-off counter by 1. It again senses the channel and repeats the process until BE = aMaxBE, where aMaxBE is maximum back-off with default value 5.

3. Performance Analysis

We computed the energy consumption and delay of the IEEE8021.5.4 and the proposed scheme. Let P_{tx}, P_{rx} are the transmitting and receiving power respectively. Let T_{data}, T_{ack}, T_{wk}, T_{cca}, T_{tr}, T_{sl}, T_{sw} and T_b are the data transmission time, acknowledgement time, wakeup time, CCA time, transition time, sleep time, switching time and beacon time respectively.

For IEEE802.15.4, the average energy consumption is given by,

$$E_{ie-pkt} = \left(P_{rx}\left(2T_{wk}+T_b\right) + P_{tx}T_{data} + P_{rx}T_{ack} \right)\Big/T \tag{1}$$

The average overhead energy consumption is given by,

$$E_{ie-ov} = \left(P_{sl}T_{sl} + P_{tr}T_{tr} + 2\left(P_{sw}T_{sw} + P_{rx}T_{cca}\right) + P_{rx}\left(N-1\right)\left(2T_{wk}+T_b\right) + P_{rx}T_{px} \right)\Big/T \tag{2}$$

where,

$$T_{px} = \left(2T_{wk}+T_b\right)\frac{T}{T_{wk}} \tag{3}$$

The delay is given by,

$$D_{ie} = T_{data} + T_{ack} + T_b + 2\left(T_{sw}+T_{cca}\right) + T_{tr} \tag{4}$$

Let, P_{rwbn}, P_{twack}, T_{wbn}, T_{twack} be the wakeup radio transmitting and receiving power and wakeup and wakeup ack packet time respectively. For the proposed scheme, the energy consumption is calculated as follows,

$$E_{wk-pkt} = \left(\left(P_{rwbn}T_{wbn}\right) + \left(P_{twack}T_{twack}\right) + P_{tx}T_{data} + P_{rx}\left(T_b+T_{ack}\right)\right)\Big/T \tag{5}$$

The average overhead energy consumption is calculated as follows,

$$E_{wk-ov} = \left(P_{sl}T_{sl} + P_{tr}T_{tr} + 2P_{sw}T_{sw}\right)\Big/T \tag{6}$$

The delay is calculated as follows,

$$D_{wk} = T_{data} + T_{ack} + T_b + 2T_{sw} + T_{tr} + T_{wbn} + T_{wack} \tag{7}$$

4. Results and Discussion

In this section, we present the performance results for energy consumption and delay.

4.1 Simulation Setup

We have used the Network Simulator NS-2 (release v2.31) and TCL scripts to simulate the network and MAC protocol [5]. A sample topology is shown in Fig 2. Device 0 acts as the controller. Rests of the devices are randomly placed in a 3m x 3m area. Each device is assumed to have a wakeup radio transceiver.
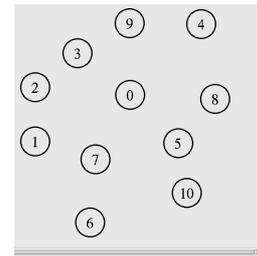

Fig 2. A sample network topology generated in NS-2.
The simulation parameters are presented in table 1.

Table 1. Simulation parameters

Parameters	Value
Network dimension	3m X 3m
Total no. of devices	10
Data rate	25kbps
Packet size	70bytes
Controller range	5m
Traffic type	Poisson

Fig 3 shows performance for energy consumption. It is observed that the wakeup radio based system is able to match the performance of IEEE802.15.4 MAC at low arrival rate (<0.1 packet/s). The performance slightly degrades at high arrival rate (1 packet/s) due to saturation.
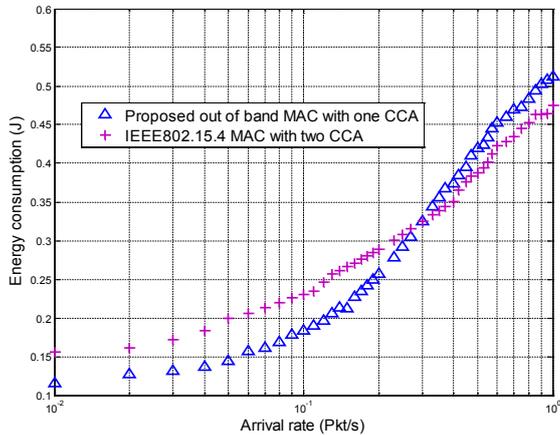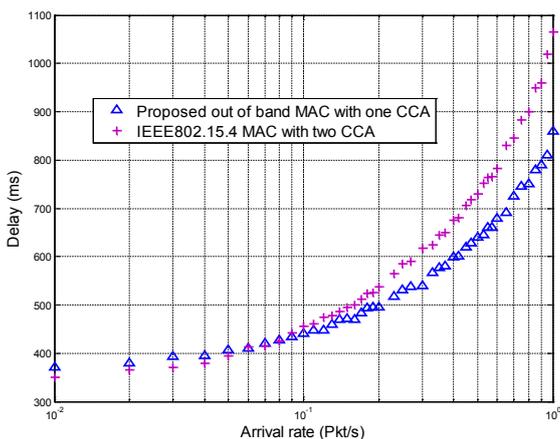

Fig 3. Energy consumption

Fig 4. Delay

Figure 4 shows delay performance. It is observed that reasonably low power consumption is supported by lower delay for the proposed scheme. One reason for the higher delay of the two CCA scheme after 0.1 packet/s is due to increase in the back-off delay. As the arrival rate increases beyond 0.1 packet/s, the number of packets available for transmission also increases. In the proposed model, by reducing the CCA, a device gains access to the channel earlier. In IEEE802.15.4 MAC has to defer for two CCAs, which also increases its back-off exponent creating a higher delay. However, the major cause for higher delay comes from the fact that the IEEE802.15.4 has no mechanism for sleeping device communication. It spends time in waiting for the device to wakeup for communication, which causes the extra use of energy.

The proposed scheme reduces causes of energy wastage.

5. Conclusion

In this paper, we present a simple out-of-band wakeup radio based protocol for wearable device communication. We compared it with the existing IEEE802.15.4 MAC. We have used only one CCA as opposed to the two CCA used in IEEE802.15.4 MAC. It is observed that at low arrival rate the proposed scheme has better energy conservation with an added advantage of the ability to communicate with a sleeping device without waiting for it to wakeup on its own time. The delay is also observed to be lower. The major advantage of the proposed scheme is that it can be used to wakeup a sleeping device to communicate as and whenever it is necessary.

Acknowledgement

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