Downlink Communication for Body-Centric Wearable Networks

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Abstract

Recent advances in wireless communication technology have made it possible to create a wearable network in and around the human body. Such a network can provide a wide range of services from monitoring human body activities to personal entertainments. Downlink traffic management is an important aspect of such a network. To save energy, devices in a wearable network turn off their radios when not in use. However, if the receiver is in a sleep state, waiting time increases for the downlink communication. This increases the communication delay. An on-demand scheme can reduce such delay. In this work, we present the performance analysis of downlink traffic of a typical body-centric wearable network using an on-demand mechanism.

1. Introduction

In recent times, the design and implementation of wearable systems are on the rise [1]. They are being actively used for both medical and non-medical applications. Some typical devices and applications are presented in Table 1.

Table 1. Typical application of wearable devices.

Medical	Non-medical
ECG	Music/Video player
EEG	Positioning device
Blood pressure monitor	Gaming device
Hear rate monitor	Motion sensor
Temperature monitor	Sports and Fitness

A network of such devices can be formed to monitor activities in and around the human body. However, these devices usually have limited processing, battery and memory capacity. Energy efficiency and low delay are among the major design issues. To save energy, when not in use, a device goes to sleep state. This means the main radio is turned off. It is turned on when there is a need for communication. Managing this sleep and wake up mechanism is a delicate affair. It can be managed through scheduling. Periodic scheduling of sleep/wake up is easier to implement. However, it is not desirable due to variable nature of the communication traffic. In an event based randomized environment, the downlink communication suffers from long delay due to an increase in the waiting time for the sender. To handle this, adaptive scheduling is proposed for sensor networks [2]. However, it still suffers from delay.

Downlink communication can be effectively used for activities such as network management and unscheduled event-based communication. An on-demand scheme can be used to successfully reduce the delay in such a scenario. A device does not need to periodically wake up to check the medium for messages. A sender can use an external mechanism to wake up a sleeping device to communicate. In this work, we present such a system to manage the wearable device communication in an efficient manner.

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

2. System Design

On demand radio triggered systems have been proposed for sensor networks [3,4]. The rationale behind it is that when communication is not required, a device usually goes to the sleep state to save energy. A neighbor device cannot communicate with a sleeping device unless it is awake. This introduces unnecessary delay. In this case, one way to wake up a device from the sleep state is to send an interrupt signal through the pins of the micro-controller unit. In the on-demand scheme, such an interrupt signal can be generated by the wake up radio circuitry [4]. This type of wake up mechanism is called out-of-band radio triggered wake up mechanism. A simplified working of the wake up radio system is shown in Fig. 1.

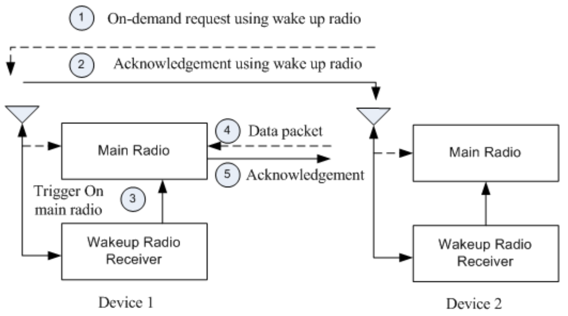

Fig 1. On-demand communication.

In the proposed system, we have used two channels for communication - one for the wake up packet and other for the data packet. At first, a device attempts to send a wake up packet. The receiver acknowledges it by sending a wake up acknowledgement (WACK) packet. It is followed by the data packet and ends with receiver sending an acknowledgement (ACK) using the main radio. The data communication process is shown in Fig.2.

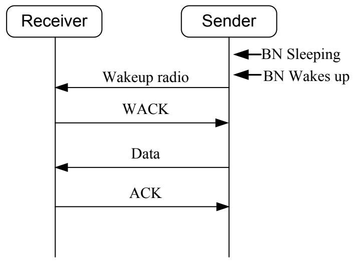

Fig 2. Data communication.

3. System Analysis

We have used a contention based single queue system with K buffer size. We have taken into consideration that in the event of a collision, a device uses back-off mechanism. We used a uniform distribution for back-off in the range [0, B-1]. A device, on average waits for $\overline{B}$ slots before attempting a transmission. Let packets arrive with rate λ and let σ be the utilization. We define τ as the steady state probability that a device transmits in a random time slot. The service time (μ) is given by,

$$\mu = \overline{B}T_s + T_{tx} \quad (1)$$

where T_{tx} is the transmission time and T_s is the average slot length. T_{tx} is given by,

$$T_{tx} = \frac{L_{pkt}}{R} \quad (2)$$

where L_{pkt} and L_{ack} are the length of the data and ACK packets, respectively. R is the transmission rate. Let N be the number of devices in the network. Let p_i, p_s, p_c be the probability of idle, success and collision states, respectively.

We calculate the average slot length as follows,

$$T_s = p_i T_i + p_s T_s + p_c T_c \quad (3)$$

where

$$p_i = (1-\tau)^{N-1} \quad (4)$$

$$p_s = (N-1)\tau(1-\tau)^{N-2} \quad (5)$$

$$p_c = 1 - p_i - p_s \quad (6)$$

The parameter τ is given by,

$$\tau = \frac{\sigma_q}{\overline{B}+1} \quad (7)$$

The average number of back-off slots that a device selects is given by,

$$\overline{B} = \frac{B-1}{2} \quad (8)$$

Thus, the energy consumption for transmitting a packet (E_{tx}) is given by,

$$E_{tx} = P_{tx}\frac{L_{pkt}}{R} + (\eta - 1)P_{tx}\frac{L_{pkt}}{R} \quad (9)$$

Where η is the number of retransmission attempt.

The energy consumption for receiving (E_{rx}) a packet is given by,

$$E_{rx} = P_{rx}\frac{L_{ack}}{R} \quad (10)$$

The overhead energy consumption is given by,

$$E_{ov} = P_{sl}T_{sl} + P_{tr}T_{tr} + P_{sw}T_{sw}(\eta+2) + P_{rx}\left(\left(\frac{L_{pkt}}{R} + \frac{L_{ack}}{R}\right)\left(\frac{N-1}{2}\right)(\eta-1)\right) \quad (11)$$

The first term on the right hand side in (11) is the energy consumption in the sleep state. The second term is the energy consumed to wake up from sleep state to ready state, and the third term is the energy consumed to switch the transceiver between transmit and receive states. The last term is the energy consumption due to overhearing.

The total energy consumption is calculated by summing up all the energy consumed in transmit, receive and overheads and given by,

$$E_{tot} = E_{tx} + E_{rx} + E_{ov} \quad (12)$$

Delay is affected by the number of packets in the queue denoted by $E[q_n]$. With a finite buffer size of K, $E[q_n]$ is given by,

$$E[q_n] = \frac{\rho\left[1 + K\rho^{K+1} - (K+1)\rho^{K}\right]}{(1-\rho)\left(1-\rho^{K+1}\right)} \quad (13)$$

Therefore, the packet delay (D_{pkt}) is given by,

$$D_{pkt} = \frac{E[q_n]}{\lambda(1-p_d)} \quad (14)$$

The average throughput can be expressed in terms of utilization (σ) and service rate as follows,

$$S = \sigma\frac{L_{data}}{\mu} \quad (15)$$

4. Results and Discussion

The performance evaluation in terms of energy consumption, delay and throughput is presented. The input parameters are presented in Table 2.

Table 2. Input Parameters.

Terms	Values	Terms	Values	Terms	Values
P_{tx}	27mW	T_{tr}	0.8ms	B	32
P_{rx}	1.8mW	T_{sw}	0.4ms	R	25kbps
P_{sw}	14.39mW	P_{id}	0.0035mW	λ	variable
P_{tr}	0.004mW	T_{ack}	3.2ms		

We can see from Fig. 3 that the energy consumption is fairly low along with low delay.

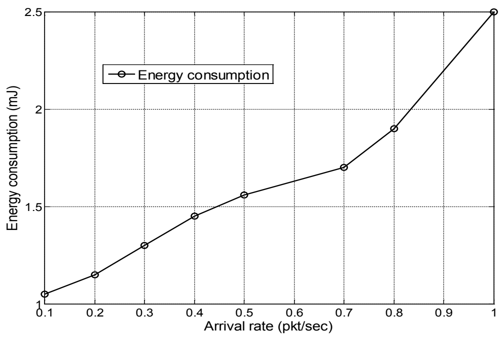

Fig 3. Energy consumption.

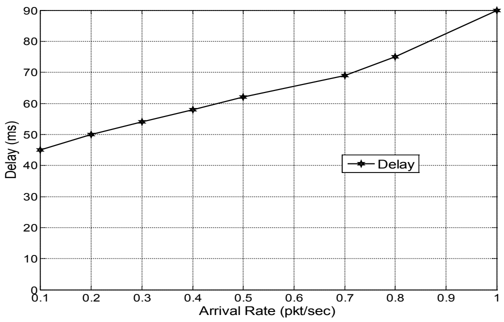

Fig 4. Delay.

Fig. 4 shows delay results. At arrival rate 0.1, the delay is under 50ms. This is reasonably low for such a network. The major reason is that in the proposed on-demand system, a device is able to avoid unnecessary wake ups. This reduced the time it spends on probing the channel for incoming packets. The throughput as shown in Fig.5 also shows encouraging trends.

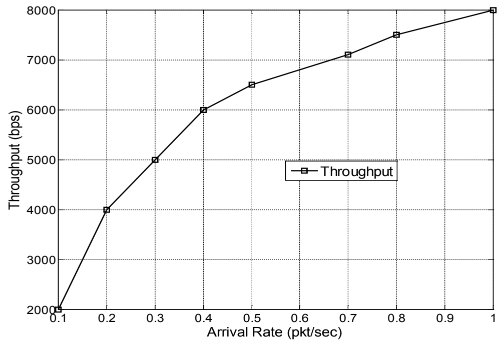

Fig 5. Throughput.

5. Conclusions

Body-centric wearable device network is emerging as a major research and application area. In this paper, we propose an on-demand scheme to communicate in a downlink environment using. The initial performance analysis shows improved energy consumption with low delay. The throughput also displays consistent improvements. Our future works involve comparing the proposed method with existing protocols.

Acknowledgement

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