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A novel solution to power problems in implanted biosensor networks

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Abstract— **Implanted biosensor networks are a special class of wireless sensor networks used in-vivo for various medical applications. One of major challenges of continuous implanted sensing is the power problems due to implanted sensors' communication cost. A deduction in theory has been made to prove the relationship between energy cost per bit and the data rate of one kind of signal. So choosing an appropriate kind of communication signals is one of the best ways to solve power problems in implanted biosensor networks. The great potential of impulse-based UWB signal, in particular low power consumption, low power spectral density, high data rate, and high immunity against interference makes itself an attractive option. This kind of communication system can probably break lots of limits in human body because of its simple architecture and carrier-free characteristic. Some successive works, which will unavoidably be met when impulse-based UWB signals are adopted in implanted biosensor network, are also discussed.**

Keywords—**Implanted biosensor networks, Power problems, Data rate, Impulse-based UWB**

I. INTRODUCTION

A biosensor is a device that detects records and transmits information regarding a physiological change in its environment. Data transfer for implanted biosensors must use wireless communication as it is impractical to distribute wires throughout the body [4].

The first problem of wireless sensor network is power restriction, whether they are biomedical implanted or others, for there are no wires connecting every sensor in one network. Battery supplies power for limited time, especially for those implanted biosensors. It is not practical to replace the battery of in-vivo smart biosensors as often as demand. There are two popular methods to provide power to biosensors, power coming from solar and vibration. But those could not provide sufficient power to continuous operation of implanted biosensor networks [3].

Furthermore, biosensors add additional constraints with regard to power, including the heat dissipated from using the power. We have done much research on causes of energy cost, and we discover that there are relationship between the energy cost per bit and the data rate of the communication signal.

So we concentrate on choosing a proper kind of communication signal in our research. Impulse-based UWB, Bluetooth, Wireless LAN (IEEE 802.11b), Zigbee (IEEE 802.15.4) and the other kinds of short distance wireless communication signals are all in consideration. Among those signals, Impulse-based UWB signal is a relatively best choice for practical use in implanted biosensor networks.

The Federal Communication Commission's (FCC) Report and Other (R&O), issued on Feb 2002, defines UWB as any signal that occupies more than 500MHz in the 3.1-10.6GHz band [11]. This is by far the largest spectrum allocation for unlicensed use the FCC has ever granted.

The major difference between impulse-based UWB and carrier-based narrowband or wideband system is that there is no sinusoidal carrier in an impulse-based UWB system. Frequency synthesizer and mixer are not needed. The design of the transceiver becomes simple [9]. The average power consumption and the average emission power of a UWB transmitter are very low though the peak power can be comparable to other wireless systems, see Fig.1.

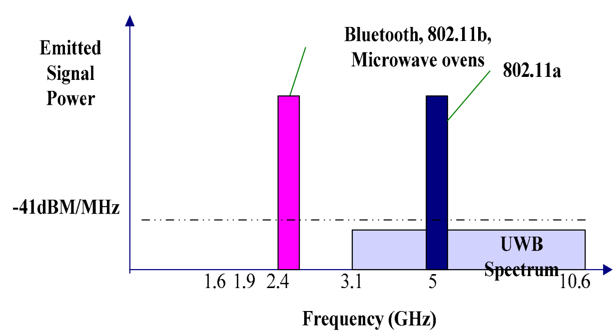

Fig.1. FCC Spectrum

Moreover, impulse-radio-based UWB technology has a number of inherent properties that could well suit implanted biosensor networks. Much higher power utilized rate makes it a more advanced technology to solve the problem, especially power problems of implanted biosensor networks [1].

In Section Ⅱ, we give an overview of related work. We describe our system model and simulation method we adopt in Section Ⅲ. We get our simulation results in Section Ⅳ and

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explore the meaning of our results. In Section Ⅴ, we make conclusion of our work and make research plans of our work in the future.

II. RELATED WORK

Little research has been done in the area of solving the power problems in implanted biosensor network through the field of selecting a signal with appropriate data rate. However, there has been considerable research going on the kinds of problems on implanted biosensor networks.

Q.Tang et al. [3] proposed a method that considering rotating the sensor cluster leadership to minimize the heating effects on human issues. The conclusion that a cluster-based protocol is better than tree-based protocol in minimizing the power consuming is proved by V. Shankar et al. [4]. A thermal-aware routing protocol that routes the data away from high temperature areas in human body has been proposed by Q. Tang et al .[5]. K.Hung et al. concerns on the telemedicine have done a lot of work to search an appropriate signal used in human tissue, like Bluetooth and IEEE 802.11b [6]. A simple introduction of using impulse-based Ultra Wideband communication system has been made by Chun Yi Lee et a.l [9].

III. SYSTEM MODEL

In the cluster system model in ref. [3], the frequencies used for RF powering and wireless communication are different. We consider the kind of wireless communication signal here to compare the power saving when using different signals.

One cluster within a specific small area is called the control volume: see Fig.2. We assume all sensors inside a control volume are members of one cluster. The cluster leader collects information from all the non-leader nodes and transmits it to the base station.

We examine the two signals through the link layer packet transmission between two common sensors during their communication period. The link layer data packet is the smallest communication entity between neighboring sensor nodes in a wireless biosensor network.

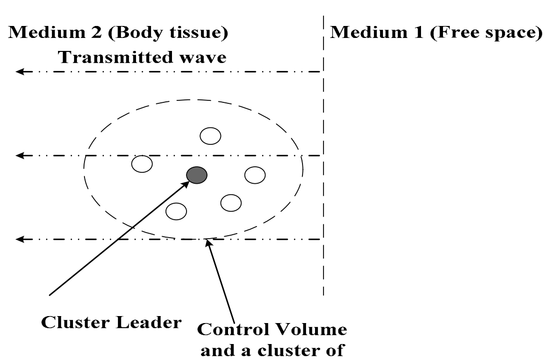

Fig.2. System Model: A cluster of implanted sensors

It consists of a header field α bits long, payload of size bits and a τ bit trailer, we define the link layer packet total length is $L = \alpha + l + \tau$,as shown in Fig.3.

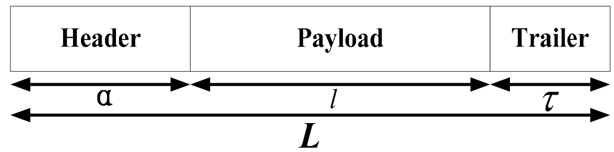

Fig. 3 The link layer packet format

Based on this packet format and the energy model outlined in ref. [7], we can express the energy required to communicate (transmit and receive) one bit of information (E_b) across a single hop as

$$E_b = E_t + E_r + \frac{E_{dec}}{l} \quad (1)$$

Where E_{dec} represents the decoding energy per packet, the encoding energy is assumed to be negligibly small. E_t, E_r are the transmitter and receiver energy consumptions, respectively, and are given by:

$$E_t = \frac{\left((P_{te} + P_0)\frac{(l + \alpha + \tau)}{R} + P_{tst}T_{tst} \right)}{l} = \frac{\left((P_{te} + P_0)\frac{L}{R} + P_{tst}T_{tst} \right)}{l} \quad (2)$$

$$E_r = \frac{\left(P_{re}\frac{l + \alpha + \tau}{R} + P_{rst}T_{rst} \right)}{l} = \frac{\left(P_{re}\frac{L}{R} + P_{rst}T_{rst} \right)}{l} \quad (3)$$

Where

$P_{te/re}$: Power consumed in the transmitter/receiver electronics

$P_{tst/rst}$: Start-up power consumed in the transmitter/receiver

$T_{tst/rst}$: Transmitter/receiver start-up time

P_0 : Output transmit power

L : Packet length

R : Data rate

For a given radio transceiver, $P_{te/re}, P_{tst/rst}, T_{tst/rst}, P_0$ are constants. We set L be a constant in our system. So there are only two parameters we have to consider.

So we get:

$$E_b = \left(\frac{(P_{te} + P_0)}{l} L + P_{re} L \right) \frac{1}{R} + P_{tst} T_{tst} + \frac{P_{rst} T_{rst}}{l} + \frac{E_{dec}}{l} \quad (4)$$

IV. SIMULATION AND DISCUSSION

As transceivers like RFM-TR3100, a typical low-power, short range wireless transceiver that has been incorporated into the MICA motes [8], we have calculated those parameters as:

$$\begin{aligned} & P_{te} \approx P_{re} = 10^{-13} W; \\ & P_0 = 0.5mW; \\ & P_{tst} \approx P_{rst} = 0.125 \times 10^{-6} W; \\ & T_{tst} \approx T_{rst} = 10ms \end{aligned} \quad (5)$$

We adopt those parameters in our research.

From (1)～(5), we could get the relationship between R and E_b.

In Fig.4, we could have a clear understanding of the relationship between the data rate and the energy cost per bit. The conclusion that the higher the Data rate is, the lower the energy consumed by a sensor node is could be got. The energy per bit while transmitting and receiving in 10 Mbps, which is the traditional data rate in implanted biosensor networks [2], is eight or nine times that using high data rate of about or above 100Mbps, which is the data rate of impulse-based UWB signal.

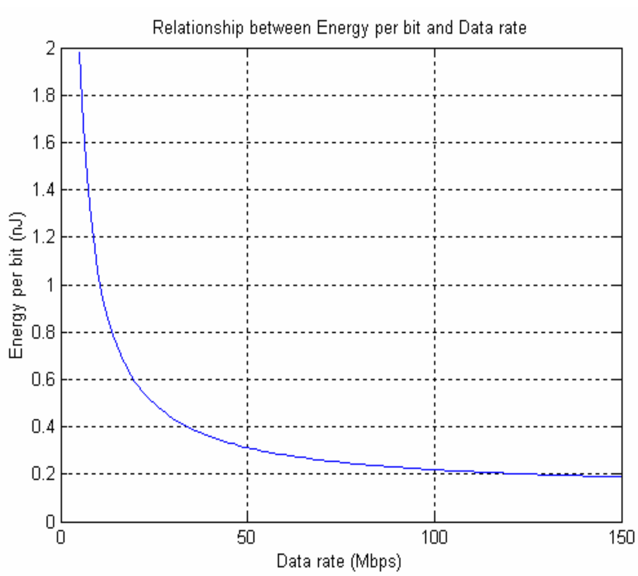

Fig. 4. Relationship between Energy per bit and Data rate

In our research work, we choose the impulse-based UWB signals as the best experiment signal for following reasons:

1) High data rate: Due to the FCC definition above, Impulse-based UWB has the capability to generate the high data rate signals, which are needed in power-saving system in implanted biosensor network.

2) Low power cost: Besides the reason of high data rate while low transceiver power cost [12], there are other aspects to save power cost of single biosensor node. A critical part of designing an impulse-based UWB implanted biosensor network that takes advantages of these features is to develop a suitable MAC that supports positioning, minimizes interference, and maximizes sleep periods and develops other counterparts of the very communication techniques.

3) Suitable implanted transceivers: Efficient antennas commonly are on the order of a half-wavelength long for a dipole or a quarter-wavelength long for a monopole. For medical applications, even smaller antennas may be required. A kind of "nanoantenna" is introduced by Hans Gregory Schantz [13].For 0-1GHz, Small is electrically small, antenna of those signals is inherently narrowband, inefficient radiation of those so-called small transceivers is not suitable to implant into human body.

4) Less interaction: Impulse-based UWB signal could provide high data rate (>100Mbps) with very low-power emission (less than -41 dBm/MHz) in a short range. When other narrow band signals exist in the same environment, it could nearly be seemed as the noise-like spectral characteristics and robustness. So it is less interaction than other narrowband signals and could be coexistence with others. Moreover, as with any medical information, the issue of confidentiality arises. It is not information that necessarily should be broadcast publicly. In addition, it is not desirable for an outsider to gain access to the sensors or the display. It could be dangerous, even fatal. Although it may seem attractive to encrypt all of the data, any meaningful, strong encryption would be too computationally intensive to be practical for these uses. Impulse-based UWB signals could be a strongly recommended candidate signals to solve security problems of implanted biosensor network.

5) Adapt to the electromagnetic environment in human body: The impulse-based UWB antenna radiation characteristic is much more suitable to electromagnetic environment in the human body. According to ref. [10], the absorption is largest for the lowest frequencies. According to the FCC definition [11], we could design a proper impulse-based UWB signals to fit this phenomenon.

V. CONCLUSION

From the discussion above, we could deduce that impulse-based UWB signal is the most suitable candidate signal using in implanted biosensor networks among those communication signals.

Impulse-based UWB could easily provide high burst data rates, show significant promise for low-power, low cost, wide-deployment sensor networks. Robust signal structure of impulse-based UWB means that sensor networks can extend battery life since devices are able to sleep for much of the time [9]. So it is of lots use to implanted sensors for which is impractical to change batteries of biosensors frequently.

Our ultimate goal is to develop practical impulse-based UWB biosensor networks system having least power consuming and the longest available time for using. More important, this equipment has to suit special biomedical use and the human body environment as well.

Our future work will concentrate on:

1) go into details of this research and search new discoveries on the basis of accurate parameter of one biosensor used for cluster-based communication ;

2) A new MAC protocol using Impulse-based UWB signals in transmitting this higher speed signal;

3) A novel network protocol using Impulse-based UWB signals in the wireless biosensor network;

4) Using Impulse-based UWB signals to calculate the temperature rise in the hot spot in one area where groups of sensor nodes are implanted.

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