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Performance analysis of low rate wireless technologies for medical applications

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Abstract

In this article, we discuss what wireless technologies can be used for medical applications and how well they perform in a healthcare/hospital environment. We consider the emerging low-rate Wireless Personal Area Network technology as specified in the Institute of Electrical and Electronics Engineers 802.15.4 standard and evaluate its suitability to the medical environment. We focus on scalability issues and the need to support tens of communicating devices in a patient's hospital room. We evaluate the effect of packet segmentation and backoff parameter tuning to improve the overall network performance that is measured in terms of packet loss, goodput, and access delay. We also evaluate the performance of 802.15.4 devices under interference conditions caused by other 802.15.4 devices and by wireless local area networks using IEEE 802.11b.
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Keywords: Medical applications; ECG; WLAN; WPAN; Healthcare systems; Performance analysis; Medium access control

1. Introduction

In medicine, providing timely access to complete patient information is key to saving lives and improving the overall safety of the patient's care. While better recording and reporting systems have been developed to provide a wealth of healthcare data, the information remains fragmented and largely inaccessible. Even within hospitals and large medical groups, when patients see multiple providers in different settings, no one seems to have access to complete information.

While many hospitals today are in the early stages of using data from all of the patient connected medical devices, connections are mainly based on the RS-232 port interfaces that are made permanently to stationary monitors. In addition to the wiring cost to plug more devices on the network, there are severe incompatibility issues where each device manufacturer defines its own data link communication method. Therefore, proprietary drivers have to be loaded every time a different device is plugged into the network, making it unrealistic to plug in mobile devices several times during the day. In this context, there is a need for a universal or even a wireless interface that provides connectivity, untethered access to information, and replaces the 'hard-wired' approach. Closing the gap on the network connectivity and scalability issues affecting the medical environment is poised to become a major effort in revamping the current healthcare system and making it more efficient.

The Institute of Electrical and Electronics Engineers (IEEE) 1073 working group is currently developing standard specifications for medical device communication focusing on wireless technologies that are adequate for the clinical domain and the patient's bedside. The main objective for this effort is to develop a universal and interoperable interface for medical equipments that is (1) transparent to the end user, (2) easy to use and (3) quickly (re)configured. The purpose of the group is not so much to develop new technologies, but to evaluate the suitability of current available technologies in the medical space.

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In this article, we consider the IEEE 802.15.4-2003 standard [1] that is a likely candidate for low bit rate wireless personal area network (WPAN) applications, given the low bandwidth, low power requirement of most patient bedside devices. We evaluate the performance of a network consisting of several communicating devices in a patient's hospital room and stress the scalability and performance trade-offs that exist. Our objectives are to answer a number of questions concerning the performance and operation of a WPAN in a medical environment, for example the following: How many devices can be plugged into a WPAN? What is the performance achieved? What protocol parameters can be tuned to improve performance? The remainder of this article is organized as follows. Section 2 discusses the medical environment application requirements. In Section 3, we give a brief overview of the IEEE 802.15.4 protocol specifications. In Section 4, we consider scenarios to discuss performance trends and trade-offs. In Section 5, we expand our understanding of the performance of 802.15.4 by considering interference scenarios caused by multiple WPANs and a wireless local area network (WLAN). In Section 6, we offer some concluding remarks.

2. Medical environment requirements

Medical environment requirements have life or death implications when data is lost, corrupted, or delayed. This is unlike most other environments where these types of requirements are mainly financial.

The medical environment itself can produce harmful effects when considering the numerous medical devices that are present. Examples of these critical applications are the delivery of the correct medicine in the correct dosage at the correct time; the delivery of critical monitoring information in real time for trend calculations in determining alarm situations; and the distribution of a patient's information.

Electrocardiogram (ECG) monitoring is a medical application that consists of attaching electrodes to a person's body and connecting these via cables to a recording device. The analog signal recorded can be digitized using different methods. The result is a digital stream, which may be sent to a personal computer (PC) or a personal data/digital assistant (PDA). Some ECG sampling rates, sample sizes, and numbers of leads are shown in Table 1.

Table 1
ECG data information

	Value
Number of leads	2–32
Samples per lead per second	200–500
Sample size (bit)	8, 16, 32
End to end delay (s)	2
Bit error rate (BER)	10^{-4}

Collecting, storing, and transmitting these samples may vary based on the facilities available. Other applications such as blood analysis samples and supervisory, alarms, and status messages have smaller and less frequent sampling.

3. Low rate WPAN for medical applications

The use of wireless technologies for medical applications already exists (e.g. WLAN for Internet access and file sharing). However, as time and technology progress, so does the infiltration of wireless into other areas and medical applications. Cable replacement for removing tethering devices or to avoid tripping hazards appears to be a good reason for applying wireless technologies to medical applications.

We examine the new low rate IEEE Std. 802.15.4-2003 and its application to some low rate medical applications. The IEEE Std. 802.15.4 describes a very low rate wireless technology that is designed for communication among wireless devices within a short range of each other, using very low power (most likely battery operated) and with low data rate requirements. The WPAN that is created when using this technology may be classified in one of two types: unslotted or slotted. For the unslotted WPAN, all devices are considered peers with respect to one another and all devices contend to access the wireless resource. For the slotted WPAN, a structure is imposed on the wireless resource. This structure is shown in Fig. 1.

Within the slotted structure there are potentially three time periods. The first is for the sending of the beacon frame. The two beacon frames bound this structure. The second is the period directly following the beacon frame. This second period may be considered the active portion of the structure because it is during this time period when transmission and receptions may occur. This second or active time period may be further divided into a contention period and a non-contention period. During the contention period all devices are considered peers and compete equally for the resource using a carrier sensed multiple access with collision avoidance (CSMA/CA) mechanism. During the non-contention period resources can be allocated for use on a per device basis. The third period, if it exists, is an idle

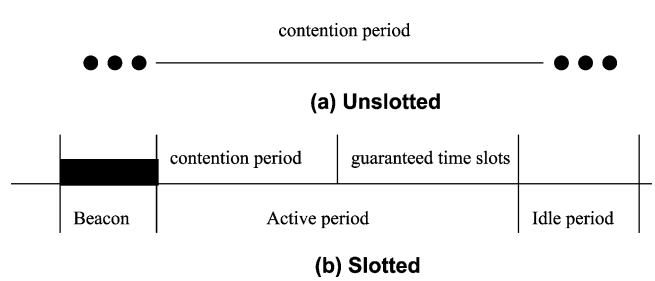

Fig. 1. WPAN structure of wireless resource.

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