Bluetooth-Based Wireless Personal Area Network for Multimedia Communication

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Abstract

This paper presents a Bluetoot-based Wireless Personal Area Network (WPAN) designed for multimedia communication among portable and distributed smart electronic devices within a short-range. The WPAN is a new standard under development, which will be part of the IEEE802.15 standard. The main objective of the WPAN is to replace wires between electronic and/or computing equipment in close proximity and provide connectivity to larger networks through a convenient transmission medium. The Paper presents hardware and software codesign based on the Bluetooth protocol stack as a vehicle for real-life performance studies for multimedia communication over WPAN and beyond. Some results based on tests performed in the laboratory environment are also presented in the paper.

1. Introduction

Wireless communication systems are evolving to support communication needs for wide range of applications [1]. Traditionally wireless communication systems have been used in outdoor communication environment such as cellular mobile radio, microwave radio, etc. In last decade there has been significant growth in wireless local area networking mainly driven by the IEEE802.11 standard. With the advancement of RF and semiconductor technologies researchers are now concentrating efforts in developing pico-networks where electronic devices within few meters to a maximum of 100 meters can communicate without requiring any fixed infrastructure [2]. Pico-networks are based on ad hoc networking technique, which is suitable for any electronic device to communicate with any other electronic device without prior set up. Recently emerged Bluetooth standard support short-range ad hoc wireless communication [3]. Bluetooth based short-range communication interface can be used in laboratory test equipment or industrial equipment or household equipment or security systems to exchange information [4]. HomeRF is another important and growing area where short-range radio communication will be used. Typical application in a home could be connecting various entertainment units using Bluetooth radio links[5].

With the arrival of Bluetooth standard and single chip hardware there is significant scope of developing short-range radio links for traditional communication purposes as well simply to provide connectivity between different electronics systems. In parallel to Bluetooth standardization group the IEEE802.15 working group is also working on developing a Wireless Personal Area Network (WPAN) standard [6]. Bluetooth is a low power radio interface operating the license free ISM (Industrial Scientific Medical) band which ranges from 2.400 GHz to 2.4835 GHz. Significant research effort is necessary to develop Bluetooth based system operating in different application environment. In this paper we present a Bluetooth based multimedia system design that can be extended to many other embedded system design.

The structure of this paper is as follows. Section 2 introduces the Bluetooth standard highlighting major design features. Section 3 describes multimedia signal coding techniques used in this work. Section 4 multimedia link design based on Bluetooth standard and Microsoft DirectShow® software. Section 5 presents some laboratory measurement data. Conclusions are made in the section 6.

2. Bluetooth Connectivity

The Bluetooth standard is developed around the ISM band using the frequency hopped Spread Spectrum (FHSS) technique as the medium access control protocol. The operating frequency band is divided into 1 MHz spaced channels, each supporting data rate of 1 Mbs.

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Frequency hopping is used cycling through 79 1 MHz hop channels at 1600 hops/sec. The current standard supports transmission rate of up to 1 Mbs for a half duplex link. Asymmetric and symmetric systems provide maximum half duplex user data rates of 725 kbs and 433 kbs respectively. The standard supports three power class devices: class 1 devices with transmission power of 100 mW can support transmission over 100 m while class 2 and 3 devices operate at 2.5 mw and 1 mw respectively.

The Bluetooth protocol stack is shown in figure 1. Because of operating mode, this protocol stack is slightly different from the conventional OSI seven layer model. The Bluetooth protocol stack supports the ad hoc connectivity between all participating terminals where no central controller is required. The lowest layer is the radio frequency (RF) layer that defines the operating characteristics of the radio link such as frequency bands, carrier arrangements, transmission power levels, etc. The base band layer is responsible for the physical (PHY) and medium access control (MAC) processing. The main tasks

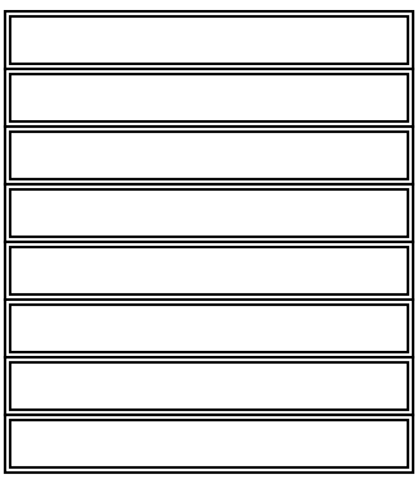

Figure 1: Bluetooth Protocol Stack.

performed by this layer are device discovery, link configuration, logical channel formation, timing and frequency hopping pattern. The link manager controls and configures links to other devices communicating with the host device. The HCI specification defines a standard interface independent method of communicating with the Bluetooth chip. The software stack on the host processor communicates with the Bluetooth hardware using HCI commands. A Bluetooth incorporates the three layers (RF, Baseband, Link) on a single chip as shown in figure 2.

Bluetooth devices operate in a master and slave configuration within a pico-network with a maximum radius of 100 m (class 1). Pico-networks operate in an ad

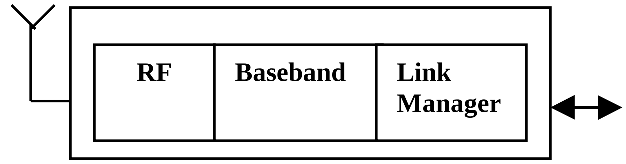

Figure 2: Bluetooth protocol stack on a chip.

hoc mode where each Bluetooth-enabled terminal/device identifies or discovers new terminals in a pico-network. A Bluetooth device could be either a master or a slave at any time. A master is a device that initiates an exchange of data whereas a slave responds to a master. Further during communication period a slave will utilize the timing its and hop its carrier frequency in synchronization. Each Bluetooth device has a 48 bit IEEE MAC address known as the Bluetooth device address (BD_ADDR).

For data transmission Time Division Multiplexed (TDM) technique is used with a slot size of 625 μs, a slot is the basic unit of transmission. To transmit longer data packets slot sizes of 1875 μs and 3125 μs can be used. For a standard slot payload of up to 2744 bits can be accommodated. Bluetooth standard specifies two types of physical links for data transmission. A physical link is established between a device acting as master and a device acting as slave. There are two types of link supported in a pico-network: Synchronous Connection Oriented (SCO) link and Asynchronous Connection Less (ACL) link. The SCO link is a symmetric circuit switched point-to-point link between a master and a single slave in a pico-net. The master maintains the SCO link by using reserved slots at regular intervals. The ACL link is a point to multipoint link between the master and all slaves in a pico-network. Master can set up ACL links on slots not reserved for SCO link. The master can exchange packets with any slave on a per-slot basis supporting a packet switched connection. Both asynchronous and isochronous services are supported on the ACL link. A slave is permitted to return an ACL packet in the slave-to-master slot if and only if it has been addressed in the preceding master-to-slave slot. ACL packets not addressed to a specific slave are considered as broadcast packets and are read by every slave. Standard Bluetooth packet format on SCO and ACL links is shown in figure 3. The access code

Access Code	**Header**	**Payload**
68 or 72 bits	54 bits	0–2745 bits

Figure 3: Bluetooth packet structure.

of the packet is used for synchronization, DC offset compensation and identification. The access code identifies all packets exchanged on the channel of the pico-network. Header contents of SCO and ACL packets are different. Payload size of SCO is fixed to 240 bits whereas for ACL payload size 0-2744 bits.

To ensure reliable transfer of ACL data both Forward Error Correction (FEC) and Automatic Repeat Request (ARQ) techniques are used for error free transmission. To protect payload either 1/3 or 2/3 rate FEC code is used. If errors cannot be corrected using the FEC bits then ARQ is initiated. Packet headers are always protected by 1/3 rate FEC. In a good transmission channel condition FEC bits can be dropped to increase number of information bits in the payload.

Quality of service is an important issue when designing any communication link. The Bluetooth specification provides Quality of Service (QoS) configuration to allow the properties of links to be configured according to the requirements of higher layer applications or protocols. The properties that can be configured depend on the application QoS requirements, data rate, buffer storage, peak bandwidth, delay requirements and delay variations. For example an application transferring compressed video streams may want a link that is not 'bursty', and may be able to miss a few packets as long as the delay on the link is not too high.

3. Multimedia Signal Coding

Multimedia signals need to be coded with appropriate source coding scheme to transmit in a wireless environment. Wireless environment is characterized by limited bandwidth and high bit error rate (BER). Selection of coding technique is also important for realtime audio and video transmission. In this work both SCO and ACL links have been used to transmit information signal. SCO link is only used to transmit Bluetooth audio, which is a circuit switched connection. Bluetooth audio is coded at a rate of 64 kbs using either an on-chip CVSD (Continuous Variable Slope Delta) coder or an A/μ law coder.

In this work we designed ACL links to transmit speech, MPEG-4 video and text data [7]. Speech signal was coded using a GSM full rate speech coder based on Linear Predictive coding with Regular Pulse Excitation (LPC-RPE). Speech is coded at a rate of 13 kbs by taking 20 ms speech samples. Each speech block contains 260 bits. An ACL packet can accommodate a number of speech blocks. For low delay link a number of speech blocks can be included in a single ACL packet.

The main challenge for realtime video communication is the enormous bandwidth requirement and delay restrictions. Even for low-resolution video, bandwidth requirements for transmission of raw video data are prohibitive. Equation 1 calculates the data rate of an uncompressed video frame that must be transferred every second in order satisfy the QoS requirements for video transmission.

$$I = H * W * F * C \tag{1}$$

where I is the video data rate expressed in bits/sec, H and W are the height and width of a video frame (both H & W are expressed in no. of pixels) respectively, F is the video frame rate in frames/sec and C is the colour depth in bits.

A video application with a QCIF of 176 x 144 and 30 fps using 24-bit colour will require a transmission data rate of 2.3 Mbs exceeding the maximum Bluetooth transmission rate. Hence the video data has to be compressed before it can be transmitted over a Bluetooth wireless link. To minimise the video transmission data rate the MPEG-4 video compression standard was chosen for this project as it provides error resilience tools for wireless applications. MPEG-4 is an ISO/IEC standard developed by the Moving Picture Experts Group.

MPEG uses motion vectors between frames to encode temporal redundancy, and the energy-compacting discrete cosine transform (DCT) to encode spatial redundancy, followed by entropy encoding. Predictive coding and variable-length code words are used to obtain a large amount of compression. However, a number of issues arise as a result of the digital compression and decompression. Because compression removes redundancy from the video data, compressed data is more sensitive to channel interference. Predictive coding causes errors in the reconstructed video to propagate in time to future frames of video, and the variable-length code words cause the decoder to easily loose synchronization with the encoder in the presence of bit errors. To make the compressed bit stream more robust to channel errors, the MPEG-4 video compression standard incorporates several error resilience tools to enable detection, containment, and concealment of errors. These are powerful source-coding techniques for combating bit errors when they occur at rates less than 10^{-3}; however, present-day wireless channels can have much higher bit error rates (BER). The harsh conditions on mobile wireless channels result from multi-path fading due to motion between the transmitter and the receiver, and changes in the surrounding terrain. Multi-path fading manifests itself in the form of long bursts of errors. Hence, some form of interleaving and channel coding is required to improve the channel conditions. Using a combination of source and channel coding, it is possible to achieve acceptable visual quality over error-prone wireless channels with MPEG-4 video compression.

4. Multimedia Link Design

In this section the ACL video link design is briefly described. The SCO link design is relatively simple with a limited capacity of 64 kbs and is not described here. For the multimedia system design we used Bluetooth prototype boards developed by Ericsson [7]. The maximum asymmetric data rate for a Bluetooth ACL link is 723.2 kbs using DH5 ACL packets with 57.6 kbs data rate on the reverse link. The MS DirectShow® is used as the application programming interface (API). MS DirectShow can capture and playback multimedia streams, supporting a wide variety of formats. MS DirectShow includes filters that support codecs written for audio compression manager (ACM) and video compression manager (VCM) interfaces. Filters are the basic building blocks of the DirectShow. Three categories of filters are used: source filters, transform filters and renderer filters. Source filters present the raw multimedia data for processing. They may get it from a file or from a 'live' source like camera or microphone. Transform filters process data before passing any data. Compression and decompression are the typical tasks performed by transform filters. Renderer filters generally accept fully processed data.

The Bluetooth video application is a win32 application developed using the Microsoft Visual C++ 6.0 development environment. It has been designed to allow video communication to occur in simplex or full-duplex mode, however greater video quality (faster frame rates) is achieved in simplex mode due to the use of an asymmetric link. The transmission of real-time video data over a Bluetooth ACL connection is facilitated through the use of Microsoft DirectShow®. Figure 4 shows the functional components in the system design.

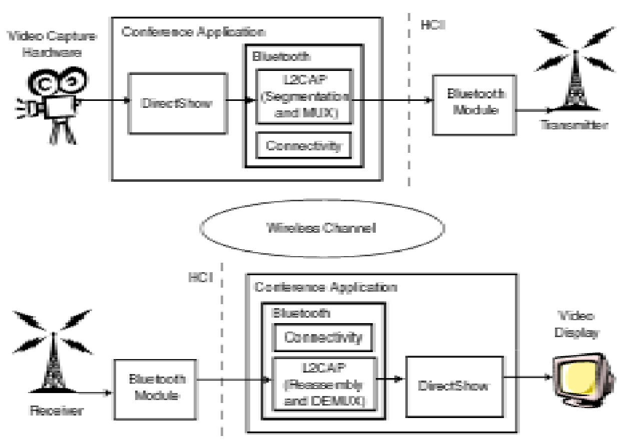

Figure 4: Realtime video transmission system.

On the transmitting side, DirectShow controls the capture of video data from capture hardware, and video compression using an MPEG-4 codec. It then sends the compressed data to the Bluetooth L2CAP layer for transmission over the HCI. On the receiving side, it receives video data of the Bluetooth network, decompresses it and sends it to be displayed. The application implements the Bluetooth L2CAP layer, which provides segmentation and reassembly so that the video packets can be sent and received using smaller HCI packets, and also protocol multiplexing which distinguishes higher layer protocols. All data is sent over the Bluetooth using byte arrays. The conference application supports point-to-point Bluetooth connectivity using the supplied test application code as a base. This code has been enhanced to include the discovery of multiple Bluetooth devices, and additional HCI commands including Inquiry_Cancel, Read_Buffer_Size, and HCI_Ericsson_AUX1. On initialisation, the application builds the DirectShow Tx (Transmitter) graph, and an Rx (Receiver) graph, but does not run them. In order for text, or video data transmission to commence, a Bluetooth ACL connection needs to be made.

5. Results

At this stage of the work we have done both subjective and objective measurements. Subjective measurements will be presented in the presentation. One of the objective measurements is the BER measurement. BER measurement is important because a radio link quality including the transmission delay is influenced by the BER. In the laboratory BER measurements were conducted using AUX1 baseband packets. The AUX1 packet (shown in Table 1) resembles a DH1 packet but has no CRC code. It can carry up to 30 information bytes (including the 1-byte payload header), and may cover up to a single time slot. Because the AUX1 packet supports no data integrity checks (no CRC), it is not subject to ARQ and therefore is not retransmitted in the presence of an error. This makes it suitable to perform BER measurements, as transmission errors can be determined from transferred data.

Table 1 AUX1 ACL Baseband packet

Type	Header (bytes)	Payload (bytes)	FEC	CRC
AUX1	1	0-29	No	No

AUX1 packets are sent using the *HCI_Ericsson_AUX1* command, which is a HCI command specific to the Ericsson module. This command sends AUX1 packets with known data in order to make BER measurements on the link that is identified by the *Connection_Handle* parameter. The *Connection_Handle* must be a connection handle for an ACL connection. If successful, the command results in that 100**AUX1_Number AUX1* packets will be automatically transmitted (if AUX1_Number is equal to zero, it means that an unlimited number of packets will be transmitted). The L_CH field = 10 in the header, and there are 29 bytes in the payload body. The data in the payload body is the same in all AUX1 packets and has L2CAP format. The first two bytes contain the L2CAP length and have the values (0x19, 0x00). The following two bytes contain the L2CAP CID and have the values (0x00, 0x00). The 25 bytes thereafter all contain the value 0x30. Only one out of *AUX1_Interval* frames is used to prevent overflow on the receiving side.

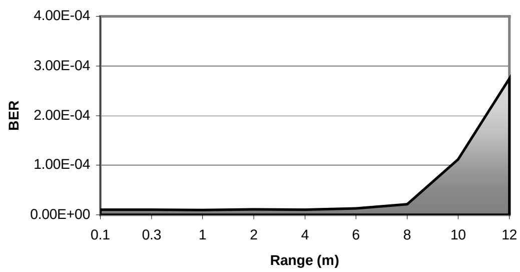

Figure 5: BER measurement with transmit and receive Bluetooth units placed on wooden desks.

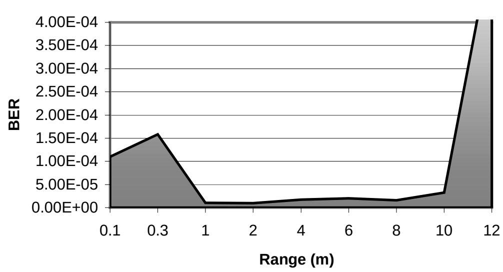

Figure 6: BER measurement for Bluetooth units placed on chairs.

The BER measurements were performed by first setting the distance between the Bluetooth Device antennas, and issuing several HCI_Ericsson_AUX1 commands from the Master to the Slave. A role switch (Master/Slave swap) was then performed, and several HCI_Ericsson_AUX1 commands were issued in the opposite direction to reduce bias towards a particular device. The average of the BER result was taken and recorded for that range, with the above procedure repeated for all ranges and environment configurations.

Figures 5-7 show the results of the BER measurements in the laboratory condition. Results suggest that BER can vary considerably depending on the surrounding of a pico-network. Figure 5 and 6 show that the BER in a close proximity is very high because of the reflections from the steel arm of the chair. In this experiment chairs consisted of a padded back support attached to an upright vertical steel arm. Figure 7 shows that the BER increases exponential as the range goes beyond 8 meters. The effect of BER on link quality will depend on the QoS requirement of the application.

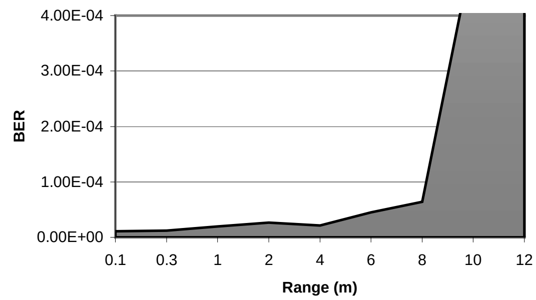

Figure 7: BER measurement in a typical office environment.

6. Conclusion

This paper presented a short-range multimedia radio link design for a wireless pico-network based on Bluetooth standard. Laboratory test results show that reliable radio links can be designed based on the Bluetooth standard to provide connectivity for various applications including multimedia communication.

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