Wireless Ad-hoc Networking with Bluetooth

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ABSTRACT

During the last couple of years, much attention has been brought to research and development of mobile ad-hoc networks. These are the networks that are set up sometimes just for a short while where needed and we foresee that the communicating devices within the network could easily move around with their wireless connections. For the commercial sector, equipment for wireless mobile computing and communication has not been available at a prize affordable for any larger market. However, as capacity of common mobile computers is steadily increasing, the need for un-tethered networking is expected to do likewise. The next devices to reside on wireless networks are commodity devices such as stereo systems, cameras and other household and commercial appliances residing in "smart" offices and houses.

INTRODUCTION

The Ubiquitous Information and Communication Networks of tomorrow must provide mobility services to the users. Wireless access is one of the most important future technologies to provide this. Wireless systems will to a large extent be used by users who require to reach and be reached wherever in the world they might be for the moment. Within the next few years completely new demands will be put on the wireless systems. As individuals and companies change how and where they work, wireless end users will expect to have access to Internet or corporate intranets and LANs virtually anywhere. They will also expect the systems to handle video and other multimedia applications. The next devices to reside on wireless networks are commodity devices such as stereo systems, cameras and other household and commercial appliances residing in "smart" offices and houses. These terminals and the services they will utilize require much higher bit rates than that of todays mobile telephone systems. Third generation systems for public and global access should support a substantially wider and enhanced range of services with respect to those supported by second-generation systems. The enhancement includes interactive multimedia services. This naturally means that mobile telecom systems will be required to handle large amounts of high speed data.

During the last couple of years, much attention has been brought to research and development of mobile ad-hoc networks. These are the networks that are set up sometimes just for a short while where needed and we foresee that the communicating devices within the network could easily move around with their wireless connections. Traditionally, ad-hoc packet radio networks have mainly concerned military applications, where a decentralized network configuration is an advantage or even a necessity. Ad-hoc networks used by individuals are often referred to as a *Personal Area Network*, PAN. For the commercial sector, equipment for wireless mobile computing and communication has not been available at a prize affordable for any larger market. However, as capacity of common mobile computers is steadily increasing, the need for un-tethered networking is expected to do likewise. Moreover the daily use of various mobile devices like a cellular phone, a PDA (Personal Data Assistant), a laptop computer, etc. would be easily facilitated if the tedious work related with cables would be replaced by wireless links connecting the devices. When two or more devices within a short distance from each other need to communicate, an ad-hoc network is often much more effective than to communicate via public centralized networks. Ad-hoc networks could link to the wide area via many channels. The public networks may on the other hand serve as a link out to the world for the entire ad-hoc network. With the evolution of the second generation mobile phones into the *General Packet Radio Services*, GPRS, and a couple of years later into the third generation public mobile systems, i.e. *Universal Mobile Telecommunication Services*, UMTS, commu-

nication capacities at much higher rates than those of today's systems will be at hand. An ad-hoc network could also use a nearby wired LAN to reach the outer world.

This paper describes our ongoing work on a wireless ad-hoc network concept called Bluetooth which was presented in February 1998 by its five promoters - Ericsson, Nokia, IBM, Toshiba and Intel. These five companies have formed a special interest group, the Bluetooth SIG. The purpose of the consortium is to establish a de facto standard for the air interface and the software that controls it, thereby ensuring interoperability between devices of different manufacturers. Today, more than 400 companies have joined the SIG. The name Bluetooth was taken from Harald Blåtand, a Danish Viking king from the early Middle Age.

BLUETOOTH

The original intension of Bluetooth was to eliminate cables between phones, PC-cards, wireless headsets, etc. Today, Bluetooth is a true ad-hoc wireless network intended for both synchronous traffic, e.g. voice, and asynchronous traffic, e.g. IP-based data traffic. The aim is that any commodity device such as telephones, PDAs, laptop computers, digital cameras, video monitors, etc should be able to communicate over the radio interface, i.e. any of these devices should have the Bluetooth radio chip and its software.

System Description

Communication within a Bluetooth is organized by one of the communicating devices called the master. Any of the communicating devices could act as a master. The others are referred to as slaves. Two or more units sharing the same channel form a piconet. The communication channel is built up by using fast frequency-hop (FH) spread spectrum in the unlicensed ISM band (industrial-Scientific-Medical band) at 2.45GHz (bandwidth 80 MHz) with a nominal transmission power of 0 dBm. Frequency-hop systems divide the frequency band into several hop channels. During a session, radio transceivers hop from one channel to another in a pseudo-random fashion. Occasionally, interference jams a hop channel, causing faulty reception. When this occurs, error-correction schemes restore bit errors. The system offers a gross bit rate of almost 1 Mbps per piconet and allows a mix of voice and data communication channels. The system provides full-duplex transmission built on a slotted Time-Division Duplex (TDD), where each slot is 0.625 ms long. Time slots may carry both synchronous information (Synchronous Connection Oriented, SCO, voice links) dynamically allocated asynchronous information (Asynchronous Connection-less, ACL, data links). The SCO link is an 64 kbps channel mainly intended to carry voice traffic. The master allocates capacity for SCO links by reserving slots. The ACL links are handled by the master which polls the slaves. In this paper we focus on data transmission via ACL links. Two adjacent slots form a so called frame in which normally the first slot is used for transmitting from the master to one of the slaves and the next for transmission from the slave, that just received a transmission or at least a poll from the master. The slaves are polled one by one in a round robin fashion. Up to 8 active devices, but to that many inactive devices, may form a Bluetooth piconet. Several piconets can be established and linked together, forming a scatter-net in which each piconet is identified by a unique hopping sequence. Each active device in a piconet is given a unique 3-bit MAC address. A device that is leaving the active state looses its MAC address.

Normally one packet of fixed format is carried in each slot. The packet format is shown in figure 1. The packets have a payload size of 0-2745 bits and a header of 54 bits. The header contains control information such as the three bit MAC-address, flow control, a type field, an ARQ field and a HEC field. The header is proceeded by an access code of 72 bits. This access code is unique for each piconet and is derived from the master identity. A device that receives a packet with an access code that does not match the access code for the piconet that it belongs to, just discards that packet. The access code also contains information used for synchronization and compensation for offset. The access code is very robust and well protected against interference. In fact, there are two different ACL-link packets, one denoted DMx for which the payload is FEC-encoded and the DHx for which the payload is not protected. The subscript x stand for the number of slots that is required to transmit the packet.

In order to increase throughput under high data rates so called multi-slot packets may be used. These packets may cover three or five slots (thus x can take values 1, 3 or 5, see the paragraph above). A three slot packet may contain 6 times as much information as a single slot packet and a five slot packet 12 times as much.

Lost data packets are handled by an ARQ scheme and will immediately be retransmitted. This scheme works so that a lost packet is retransmitted in the next slot and thus the delay due to errors is just one

slot in duration. Voice traffic is protected by a robust voice encoding scheme and thus retransmission of voice never takes place. For a more detailed description of the system, the reader is referred to [7].

Bluetooth scenarios

Here we list some of the scenarios that one can see today. These scenarios are taken from the Bluetooth home page [8].

The three-in-one phone:

Use the same phone wherever you are. When you're at the office, your phone functions as an intercom (no telephony charge). At home, it functions as a portable phone (fixed line charge). And when you are on the move, the phone functions as a mobile phone (cellular charge).

The interactive conference:

Connect all participants for instant data exchange. In meetings and conferences, you can share information instantly with all participants, and without any wired connections. You can also cordlessly run and control, for instance, a projector.

The briefcase trick:

Use e-mail while your portable PC is still in the briefcase. When your portable PC receives an e-mail, you will get an alert on your mobile phone. You can also browse all incoming e-mails and read those you select in the mobile phone's display.

The forbidden message:

Compose e-mails on your portable PC while you are on an airplane. As soon as you have landed and switched on your mobile phone, all messages are immediately sent.

The automatic synchronizer:

Automatic background synchronization keeps you up-to-date. Automatic synchronization of your desktop, portable PC, notebook (PC-PDA and PC-HPC) and your mobile phone. For instance, as soon as you enter your office the address list and calendar in your notebook will automatically be updated to agree with the one in your desktop, or vice versa.

The instant postcard:

Send instant photos and video clips from any location. Cordlessly connect your camera to your mobile phone or any wire-bound connection. Add comments with your mobile phone, a notebook or your portable PC and send them instantly to a receiver anywhere in the world. Suitable for professional as well as personal use.

The portable speaker phone:

Use your portable PC as a speaker phone wherever you are. Connect cordless headsets to your portable PC and use the portable PC as a speaker-phone regardless of whether you are in your office, in your car or at home.

The cordless desktop:

Connect all peripheral tools to your PC or to the LAN. Cordless connection of your desktop or laptop to printers, scanners and to the LAN. Increase your sense of freedom in everyday work by cordless connection of your mouse and keyboard to your PC.

The ultimate headset:

A cordless connected headset keeps your hands free at all times. Connect your headset to your mobile PC or any wired connection to keep your hands free for more important tasks when you are at the office or in your car.

The internet bridge:

Surf the Internet regardless of the connection. Use your portable PC to surf the Internet whether you are wirelessly connected through a mobile phone (cellular) or through a wire-bound connection. (PSTN, ISDN, LAN, xDSL).

PUBLISHED AND SUBMITTED PAPERS

In [1] and [2] we analyzed a number of different situations under the scenario where slaves send web-like traffic to other slaves. There we analyzed symmetric as well as non symmetric load situations for both bursty and non bursty traffic characteristics. We also analyzed the transient behavior of the Bluetooth network when one of the slaves send a very dense burst for a short period.

In [3] and [4] the aim of the simulations was twofold. On one hand a case using only single slot packets (18 bytes of payload) was compared with one

that allows multi slot packets, i.e. 3 or 5 slot packets (corresponding to 122 and 226 bytes of payload for DM3 and DM5 packets respectively) as well. On the other hand, which is the main focus of these articles, the original Bluetooth media access principle, i.e. a strict round robin polling algorithm is challenged by a round robin exhaustive polling algorithm and also by a new polling algorithm proposed by the authors, and shows its applicability under various operating conditions.

In [5] we present a detailed simulation model of TCP/IP over Bluetooth. We used this model to examine the maximum throughput and packet delays for TCP/IP traffic under various conditions. We found that Bluetooth is well suited for TCP/IP traffic and that both high throughput and low delays can be achieved also when the radio channel has a high packet error probability.

In [6] we investigate larger piconets, i.e piconets with several nodes. In such networks the heavy load on the master node may cause long delays and packet losses for the slaves. The master node uses the Fair Exhaustive Polling (FEP) scheme, developed in [3], to control the traffic. We have compared the TCP Vegas congestion control with a new congestion control called TCP SACK. This control uses a selective acknowledgement algorithm to speed up the retransmissions. We also discuss feasible enhancements of the TCP congestion control that takes into account the short round trip times in Bluetooth.

FURTHER WORK

Future studies of the Bluetooth Technology will analyse functions this preliminary work did not cover. In particular

- piconet and scatternet formation principles,
- multicast performance, and
- support of different classes of service (QoS) through scheduling and priority mechanisms.

Further studies will also investigate how the Bluetooth technology will support a global IP networking for “thin” low-powered devices.

That activity may comprise topics such as

- IP addressing,
- ad-hoc routing protocols, and
- Mobile IP and scatternet interworking.

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