SIMULATION BASED ANALYSIS OF BLUETOOTH NETWORKS

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Abstract

Many of the electronic devices currently in use, such as desktop computers, printers, and scanners, are connected by using cables. As the number of devices in a local environment increases, and the desire to remain connected in mobile communication environment becomes popular, wireless connectivity will be a natural choice. In such situations, Bluetooth technology is rapidly becoming a popular choice of connecting devices together. Bluetooth technology is essentially a cable replacement technology for communication within a small geographic area. The research presented in this paper deals with the performance analysis of Bluetooth networks using simulation. The primary focus of this simulation study is to observe the effects of network traffic and the network size on the packet transmission delay. The simulation results are presented in terms of packet delay versus network traffic.

Keywords: Bluetooth technology, performance analysis, simulation.

1 INTRODUCTION

The worldwide growth of wireless cellular phone subscription has demonstrated that wireless communication is a viable, robust multimedia communication mechanism. In addition, emerging technologies have made it possible to develop smaller, inexpensive yet powerful portable computers that allow people to conduct their business and personal activities while on the move. These mobile devices can interact with other devices. Participants with these mobile devices can share documents or presentations, business cards can automatically find their way into the address book on a laptop; as commuters exit a train, their laptops could remain online; likewise, incoming email could now be diverted to their PDAs; finally, as they enter the office, all communication could automatically be routed through the wireless corporate campus network.

Next generation cellular networks are being designed to facilitate high-speed data communication traffic in addition to voice traffic. New technologies and standards are being implemented to replace fiber optic or copper lines between fixed points several kilometers apart. Wireless networks have been used increasingly in homes, buildings and small office settings through deployment of wireless local area networks (WLANs). The evolving Bluetooth technology promises to replace troublesome appliance communication cords with invisible connections within an individual’s personal workplace. The Bluetooth and WLAN are used within buildings and the both systems use low power and do not require a license for spectrum use.

Most electronic devices these days, such as computers, printers and scanners etc., are literally connected through cables. One could get confused when there is a need to change or rewire the cables for some or the other reasons when there are lot of wires connecting computers, printers, scanners and PDAs etc. In these situations Bluetooth technology [1,2,3,4] comes to rescue. Bluetooth is a cable replacement technology, which will help the electronic devices to communicate without the help of cables.

Developed initially by Ericsson, before being adopted by many other companies, Bluetooth is a standard for a small, low power, in-expensive chip to be plugged into computers, printers, mobile phones, etc. A transmitter in a Bluetooth chip is designed to transmit information to a receiver in another Bluetooth chip using a special radio frequency, which is otherwise normally transmitted by cables.

Bluetooth is basically a short-range radio link intended to replace cables connecting portable and/or fixed electronic devices. The main features are robustness, low complexity and low cost. Bluetooth operates in the unlicensed ISM (Industrial Scientific Medicine) band of 2.4 GHz. In majority of countries around the world the range of this frequency band is 2400-2483.5 MHz. To combat interference and fading, a frequency hopping mechanism is applied. The frequency hopping mechanism hops 1600 times in a minute. One hop in this hopping mechanism consumes 625 µs and consists of one
frequency slot. Time division duplex scheme is used for duplex communication. A packet normally covers a single slot but can be extended to cover up to 3 or 5 slots. A piconet is formed when one master device and one or more slave devices (up to 7) agree to communicate between them. A master device starts sending its packets in the even numbered slot and the slave device starts its packets in the odd numbered slot. The master device is responsible for coordinating with other devices to form and allocate the channel slots between the piconet units. A scatternet is formed when more than one piconets are involved in communicating between each other.

This objective of this paper is to analyze the performance characteristics of Bluetooth Piconet and Scatternet systems under different link configurations based on the number of links, packet types and traffic patterns. To achieve the objective of analyzing the performance issues of Bluetooth systems in general using a simulation model, the Bluetooth system with its basic protocols need to be modeled.

Bluehoc, a simulation tool developed by IBM specifically to study Bluetooth related networking issues, modeled the very basic layers, which are needed to simulate the virtual Bluetooth system units. Bluehoc simulates the Baseband, LMP and L2CAP protocols. NS (network simulator) based tools such as Telnet and Exponential Traffic were used for the purpose of traffic generation. In this research work the Bluehoc layered on top of Network Simulator is used to build the basic Bluetooth systems and modifications are made to suit the requirements. For different variation of traffic patterns and with varying number of devices the Delay characteristics of data sent, number of packets sent and Piconet generation time delay are analyzed.

The next section describes a general overview of the communications systems with reference to Bluetooth system. Section 3 explains the simulation tool used and the also explains about a simulation script used with information regarding the simulation parameters etc. Simulation results are presented in section 4 and finally conclusions are presented in section 5.

2 BLUETOOTH COMMUNICATION SYSTEM

Bluetooth is an open specification for short-range communication through radio frequencies. A Bluetooth transceiver operates in the 2.4 GHz ISM (Industrial Scientific Medicine) band with a data rate of 1 MBPS. In most countries the range of the frequency bandwidth is 2.400-2.4835 GHz. Some countries have a limitation in this range. To comply with this situation, special frequency hopping algorithms have been developed. To comply with out-of-band regulations, a guard band is used at the lower and upper end of the range. For example, in USA, Europe and most other countries the lower guard band is 2 MHz and the upper guard band is 3.5 MHz. So the actual communication channel width for the Bluetooth systems is 2400-2480 MHz. With 1 MHz channel spacing this results in 79 unique frequencies for actual use by Bluetooth units.

A combination of circuit switching and packet switching is employed in Bluetooth communications. Bluetooth can support an asynchronous data channel, up to three simultaneous synchronous voice channels. It can also simultaneously support an asynchronous data and synchronous voice channel. Each voice channel supports 64 Kb/s synchronous (voice) channel in each direction. The asynchronous data channel can support maximum of 723.3 Kb/s asymmetric (and still up to 57.6 Kb/s in the return direction), or 433.9 Kb/s symmetric.

A Bluetooth system consists of a radio unit, link control unit and a support unit for link management and host terminal interface. The Bluetooth link controller unit carries out the Baseband protocol functionality and other low-level link routines. Point-to-point connection is established between two Bluetooth radios or a point-to-multipoint connection is established when a there are more than two Bluetooth systems involved wherein channel is shared among the several units. These multiple units form a Piconet, where one unit acts as a master and the other units (maximum up to 7) acts as slaves. A piconet as shown in Figure 1 can have up to seven slaves active any time, and other radios, if they exist, can stay in parked mode and become active when the active mode devices leaves the piconet or goes on to any state other than active state. The master device supervises channel allocation for both active mode and the parked mode are synchronized to the master any time.

A Scatternet is formed to assist in communication between more than one piconets. Each piconet master has its own unique frequency sequence based on the BD_ADDR of the master device. Data is transmitted to other piconet through a particular slave/master which acts as a bridge device between two piconets on a Time Division Multiplexing basis. A master in one piconet can also act as a slave in another piconet. Each piconet has only one master.

There is a unique frequency sequence for each piconet, which is controlled by the Bluetooth device address of the master device. The channel is represented by pseudo-random hopping sequence hopping through 79 or 23 unique frequencies. The channel is divided into time slots where each slot corresponds...
to a single radio frequency. Nominal slot length of 625 µs leads to 1600 slots per second.

The time slots are numbered according to the Bluetooth clock of the piconet master and the number ranges from 0 to $2^{27}$-1 and is cyclic with a cycle length of $2^{27}$. A TDD scheme is used where the master and the slave devices transmits alternatively. Figure 2 represents the schematic of a single slot packet and Figure 3 represents the schematic of multi-slot packets. The master device shall start its transmission in the even numbered slots only. And the slave device shall start its transmission in the odd numbered slot. Packets transmitted by the master or slave may extend up to 5 slots depending upon the packet data size.

The RF frequency shall remain fixed for the entire duration of the packet transmission. For a single slot packet, the RF hop frequency to be used is derived from the Bluetooth clock of the master device. And for a multi-slot packet the RF hop frequency to be used for the remaining slots is same as the one for the first slot. The RF frequency for the first slot after a multi-slot packet is based upon the current value of the Bluetooth clock of the piconet master.

Two types of links have been defined between the master and slave.
- **SCO** - Synchronous Connection Oriented and
- **ACL** - Synchronous Connectionless link.

SCO connection is between the master and a single slave and is point-to-point. Slots are reserved for an SCO connection by the master device. An ACL link is a point-to-multipoint link between the master and all the active slaves. On the slots not reserved for SCO connections the master can establish ACL links, even with the slaves already connected with an SCO link.

The SCO link is like a circuit-switched connection between master and the slave, since slots are reserved for the purpose of SCO links. SCO can support time-bounded information like voice. Master supports up to three SCO links to the same slave or different slaves. Slave can support up to three SCO links if the links are from the same master or two SCO links if the links are from different masters. An SCO link is established by the master through an SCO setup message in the Link Manager Protocol. The link setup message will contain parameters like $T_{SCO}$ (SCO interval) and $D_{SCO}$ (Offset) to identify the reserved slots. The SCO packets are sent at a regular interval, $T_{SCO}$ (slots) in the reserved SCO slots. SCO slots are never re-transmitted. SCO slave can always respond an SCO reception in the following slave-to-master slot even if the slave fails to receive the master-to-slave packet unless a
different slave was addressed in the previous master-to-slave slot.

An ACL connection can exist between master and a slave in the slots not reserved for SCO connection. An ACL link provides a connection similar to that of a packet switched connection. Only a single ACL connection can exist between a master and a slave. ACL packets are retransmitted to recover dropped/failed packets. An ACL slave can respond in the slot following the master-to-slave slot provided it has been addressed in the master-to-slave slot. If the slave fails to receive the packet or fails to decode the slave address in the packet, then it shall wait for the next turn. If a specific slave address is not mentioned in the ACL packet then it is considered as a broadcast message and is read by every device in the piconet. If there is no data to be sent and no polling required then no transmission shall take place.

A packet has three entities such as Access Code, header and Payload. As shown in the Figure 4, Access Code and Header have fixed sizes whereas payload ranges from 0-2745 bits. Different packet types have been defined. A Packet may consist of the Access code only or of the access code - header or access code - header - payload based on the type of packet being sent. In the receiving side Access Code is compared against a sliding correlator, which triggers if a threshold is reached. If there is a match the packet is received.

<table>
<thead>
<tr>
<th>LSB</th>
<th>72</th>
<th>54</th>
<th>0-2745</th>
<th>MSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCESS CODE</td>
<td>HEADER</td>
<td>PAYLOAD</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure: 4 General Packet Format [2]

3 SIMULATION

Bluetooth technology is a low cost, low power and low complexity cable replacement technology capable of connecting wide variety of devices like Personal Digital Assistants (PDA), mobile phones, cordless phones, headsets, laptops, home appliances, digital cameras etc. Since this is basically a cable replacement technology that’s it connects all the above-mentioned devices through 2.4 GHz ISM band of Radio Frequency waves. A Bluetooth enabled device is able to connect to another Bluetooth enabled device virtually without any knowledge about each other. As explained earlier the Bluetooth technology enables the devices to form a small-connected network what is known as Piconet with one unit being a master and up to seven units acting as slaves. A Scatternet scheme is proposed to connect devices in different piconets to communicate each other by this the extent of the communication range may be increased. In this present study the performance of the Bluetooth piconet communication and Scatternet communication is analyzed with reference to number of Bluetooth devices in the piconet and number of piconets in the scatternet arrangement with Exponential Traffic Pattern and FTP traffic pattern.

For the purpose of this research, at least, the following layers need to be implemented.

- Radio Layer
- Baseband Layer
- Link Manager Protocol Layer
- Logical Link Control and Adaptation Protocol layer.

Bluehoc simulator developed by IBM simulates the four basic layers. Bluehoc is an extension to the Network Simulator (NS) [5]. NS is object-oriented, discrete event driven network simulator developed at University of Berkeley written in C++ targeted at networking research. NS is primarily used for Local and Wide area networks. It implements network protocols such as TCP and UDP, traffic source behavior such as FTP, Telnet, Web, CBR and VBR, router queue management mechanism such as Drop Tail, RED and CBQ, routing algorithms such as Dijkstra, and more. NS also implements multicasting and some of the MAC layer protocols for LAN simulations. Bluehoc deals with frequency generation, frequency hopping, system clock management, frequency synchronization, piconet management, link configuration, QOS setup and scatternet management. Since it is paramount to have at least the above said layers simulated to study the performance of Bluetooth piconets and scatternets Bluehoc was chosen to be the right tool.

To achieve the objective of analyzing the performance issues of Bluetooth systems, the above said functionalities that form the part of the Bluetooth core protocols such as Baseband protocol, Link Manager Protocol (LMP), Logical Link Control and Adaptation protocol (L2CAP) are implemented in the Bluehoc tool.

A detailed set of parameters used for simulation for different studies have been defined. Various sets of data are applied in different circumstances to study the effects of congestion, mobility, data delivery rate, effect of queue size, data packet size, node range and slot size. A brief description of the parameters used in the simulation is as follows:

- Slot size - the size of slots can vary from 256 to 4096 bytes. In CDMA mode, the packets generated must be accommodated in a slot before transfer. This means that slot size must be consistent with the total size of data in all the packets to be packed in the slot.
Packet Generation Rate (PGR) - the program running at a node generates packets at the rate of 4 packets per second. Regardless of the size of the packet, these packets generate with a constant factor and are enqueued in the packet sending priority queue. If the queue is filled, the newly generated packets are dropped. If a packet stays in the queue for more than 30 seconds it is also expired and dropped.

Throughput - each node is fixed to have a 16kbps data transfer rate i.e. each node can transfer up to 16,384 bytes of data per second. A combination of varying packet sizes may be used to accommodate this transfer space. If the packet size is set to be 512 bytes then \((16384/512) = 32\) packets can be transferred at maximum. If packet size is 4096 bytes then only 4 packets can be sent per second.

Mobility-three levels of mobility are used; low, moderate, and high. In low mobility, only 20% of the nodes are allowed to move, in moderate mobility, 50% of the nodes are allowed, and in high mobility, 80% of the nodes are allowed to move.

Unit Range - can be 250 meters or 500 meters. Area of the field is set to be 10000 by 10000.

Queue Size - it is always set to be 50.

The simulation has a total of 30 nodes scattered around in the field by randomly determining individual’s x and y coordinates. Each node is given an address. Before initialization each node calls the find neighbor module to locate adjacent nodes if applicable. Once the adjacent nodes are located and their information is entered in the local node’s routing table, the simulation can be started. To determine the behavior, the simulation can be paused at intervals of pre-selected time.

4 SIMULATION RESULTS

This section presents analysis of a limited number of simulation results. The results mainly show the delay of piconet and scatternet formation under different traffic conditions.

The Figure 5 represents the graph of Time duration for piconet establishment and the number of devices involved in a piconet. As can be seen from the figure, maximum time duration for piconet establishment for a piconet with any number of devices (maximum up to 7) is around 10 seconds and this complies with the Bluetooth specification. This can be taken as a basis for further consideration of this simulation tool as a right tool for achieving the objectives specified in the introduction. A paper “Performance of a New Bluetooth Scatternet Formation Protocol”, [5] by students at MIT has also used Bluehoc as a simulation tool and obtained reasonable results.

Figure 5 Number of Devices versus Time Delay for Piconet Establishment

Figure 6 shows the graphical representation of relation between piconet data transfer delay and number of links in the piconet when the data packets created are using Exponential traffic. The relation is obtained for two different values of simulation timings, 20 sec and 40 sec. The time delay increases as the number of links in the piconet increase, though not very steep it has a linear relationship. The result is same even with duration of different simulation timings. This is due to the fact that as the number of links increases the master device distributes the available slots evenly to all the slaves participating in the piconet, hence resulting in less number of slots for a piconet that has more number of slave units. Figure 7 shows the graph of number of piconets and the data transfer time delay for FTP traffic pattern and Exponential traffic pattern. The FTP traffic pattern is encoded with the FEC while Exponential traffic pattern is not encoded with FEC.

5 CONCLUSIONS

The paper has presented a simulation study to observe the effects of network traffic and the network size on the packet transmission delay. The simulation results are presented in
terms of packet delay versus network traffic. The delay in packet transmission increases proportionally to number of devices in a piconet when the traffic pattern used is Exponential pattern. The delay in packet transmission increases proportionally when the traffic pattern used is of FTP pattern. It has been observed that that the packets with FEC (Forward Error Correction) offers more delay in transmission than the one without FEC. Suggesting use of packets without FEC where an error free Bluetooth environment exists. The data transmission delay in a Scatternet environment is proportional to the number of Piconets involved in the transmission, the result holds true for both FTP and Exponential pattern traffic. Suggesting that the data transmission delay can cause hindrance to quality of the information sent, the Bluetooth system user might feel awkward. To avoid deteriorating performance a Scatternet should always have lowest possible number of Piconets. While comparing a packet transmission delay for an FEC packet and a non-FEC packet, the delay is more for a packet with FEC than the one without FEC as is for a Piconet environment. Here also suggesting use of packet without FEC data in an error free environment, as is the case for a Piconet environment.

REFERENCES


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Figure: 6 Number of Links Vs Piconet Data Transfer Delay with FTP traffic
Figure 7  Number of Piconets Vs Data Transfer Delay in Seconds