TDM & FDM Overlays on Bluetooth

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Abstract- This work aims at providing a proof of concept for multiplexing in Bluetooth by using traditional (TDM and FDM) multiplexing overlays upon frequency hopping spread spectrum (Bluetooth Modulation) by means of a functional simulation. This overlaid multiplexing technique can simplify the point to multi-point connections, especially when there are multiple Bluetooth devices in the vicinity and using the limited ISM spectrum. The available narrow bandwidth can be better utilized in point to multipoint connections using the proposed method.

I. INTRODUCTION

Named after the Scandinavian King Harald Bluetooth, famous for uniting the countries Denmark and Norway during the 10th Century, Bluetooth was developed as a cheap short range communication protocol. This project was supported by a conglomeration of companies: Ericsson, IBM, Intel, Nokia, and Toshiba and rigorously promoted by many other wireless communication and portable devices companies. [1,2]

Bluetooth uses the unlicensed Industrial, Scientific, and Medical (ISM) band around the 2.4 GHz frequency range. A variety of other home appliances and public devices operate in this unlicensed frequency band, such as, cordless phones, microwave ovens, garage door openers, broadcasting devices, etc. This causes a lot of interference and the disturbance in the small band. There are also other wireless communication technologies using the same Industrial, Medical & Scientific (ISM) band. The two protocols that operate in this band are the 802.11 also known as WiFi and Home RF.

Though initially Bluetooth was caught in a catch twenty two – there were very few companies to accept the technology as Bluetooth devices need other Bluetooth enabled devices to connect to, which very few. Bluetooth has really become popular with cost of Bluetooth chips falling due to great advancements in semiconductor and VLSI fields.

II. CURRENT BLUETOOTH STANDARD

The Bluetooth Version 1 standard gives specifications for voice and data communication over a radio channel with a maximum capacity of 1Mbps, though Version 2 enhanced Bluetooth claims to have attained an impressive data rate of 2.1 Mbps.

Bluetooth devices use the complete ISM band, while never transmitting from a fixed frequency for more than a very short time. This ensures that Bluetooth conforms to the ISM restrictions on transmission quantity per frequency. The available frequency spectrum is divided into 79 channels 1 MHz apart.

Bluetooth transmits at a low power (1mW) and is therefore designed for short-range use of less than 10 meters. Bluetooth can support an asymmetric link with up to 723.2 kb/s in one direction and 57.6 kb/s in the return direction, or a symmetric link with 433.9 kb/s in both directions at once. Bluetooth devices switch frequencies 1600 times per seconds (frequency hopping) making it almost immune to security risks and external interference even though the devices share the ISM band with many other wireless technologies.
Bluetooth devices are capable of both point-to-point and point-to-multipoint communications. Due to power limitations Bluetooth operates in three power classes depending on distance separation between the communicating devices.

There have been many versions of Bluetooth, the latest being Version 2.0. There have been significant improvements with every new version. Bluetooth 2.0 has been designed to complement existing Bluetooth devices (backward compatible) and offers data transmission rates up to 2.1 Mbps [2].

Although Bluetooth is getting increasing popular one of the major limitations is a small bandwidth of 1 MHz. And this limited bandwidth has to be shared in case simultaneous of point-to-multipoint connections involving data transfer. This work proposes techniques to enable simultaneous transmissions from Master to multiple slaves in case of point to multipoint connections in a Piconet by effectively utilizing the available narrow bandwidth.

Before we proceed to the proposed method a clear understanding of Frequency Hopping Spread Spectrum (FHSS) and the Bluetooth architecture is necessary.

III. FREQUENCY HOPPING SPREAD SPECTRUM (FHSS)

Frequency hopping is employed to avoid interfering with other devices transmitting in the already crowded ISM band. The frequency spectrum is divided up into 79 channels spaced 1 MHz apart starting at the low end of the 2.4 GHz ISM band. The transmitter switches channels 1 MHz wide 1600 times per second. Figure 1 shows the frequency hopping spectrogram.

A shared Hopping code (a pseudo-random seed number) keeps the transmitter and the receiver tied, hoping to the same frequency channels simultaneously. [5]

Although the data rate is only a 1Mbps, a much larger bandwidth of 79MHz is needed. Transmission time is divided into 375 micro-second slots, with a new hop frequency being used for each transmission slot. Even although
Bluetooth transmissions will occasionally collide with those from another device, this can be tolerated or recovered from with appropriate coding schemes. [3]

The frequency hopping spread spectrum makes Bluetooth inherently advantageous over other wireless techniques in terms of security and channel interference.

Frequency hopping makes eavesdropping impossible, as the next hop is extremely difficult to guess. Even if the hop frequency channels can be known their dynamically changing hopping sequence is very hard to predict unless the Hopping code is known. This makes Bluetooth ideally suited in military applications, as Bluetooth transmission bursts change channels and also the dwell time is very short in duration (625 ms), therefore hard to detect and even harder to jam.

Any channel interference will be short lived as the transmitter shifts to another frequency band in the next transmission slot and any packet lost can be re-transmitted [4, 5]. Please refer to Figure 3.

![Figure 3: Hoping with background noise][4]

It also offers good resistance to multi-path path fading because the direct signal always arrives at the receiver first. Reflected signals follow a longer path and arrive later. By then the receiver may have changed frequency and no longer accepts signals on the previous frequency, thus eliminating interference between the direct and reflected signals. [3]

**IV. BLUETOOTH CONNECTIONS**

Whenever two or more Bluetooth devices are paired together one of them assumes the role of a Master and the rest are referred to as Slaves. A network of ad-hoc connections between a Master Bluetooth device and one or more Slave is called a Piconet. The current Bluetooth standard allows for up to seven active slaves to be paired with a Master device and up to 255 devices can be parked (connected but inactive) with the Master at any instant [6, 7, 8].

Devices alternately assume the role of Master in a Piconet in a cyclic manner. At any given instant of time, data transfer occurs between a Master and a Slave device.
Sometimes two Piconets can come together to form a Scatternet, where in a Master from one of the Piconets becomes the Master of the Scatternet and act like a bridge between the two Piconets [7].

V. SIMULINK MODEL FOR OVERLAYS ON BLUETOOTH

As discussed above even though Bluetooth supports point-to-multipoint connects simultaneous data transfer with one then one device is seldom used. This is mainly due to the small bandwidth of 1 MHz available to the device. However, using the two suggested methods devices can seamlessly connect and have simultaneous data transmissions with more than one device.

When designing Bluetooth systems (as with any semiconductor devices), it is crucial to simulate and test them in the presence of interference from these other devices. System-level design tools like Simulink give engineers the capability to simulate the behavior of their devices and carryout such tests before commencing costly hardware and embedded software design. This allows the discovery of design flaws early in the development process while they are inexpensive to correct.

The suggested approach is a software overlay over the existing Bluetooth protocol and necessitates no change in the device hardware. The Simulink Model for the Bluetooth protocol has been designed using the MATLAB communications blockset and signal processing tool box. The suggested overlay is modular in nature and is easily modifiable.

Simulink has been used to simulate the different scenarios. All the simulations consider a sample Piconet where a Master is connected with two Slaves. The intent of the simulation enables simultaneous data transfer between the Master and the two Slaves. Master acts as the transmitter the Slaves act as receivers. Both Master and Slave are the same (having a receiver and transmitter modules) but only differ by the roles they play within the Piconet.

A few simplifying assumptions have been made to enable faster simulation. Every Bluetooth has the same functional capabilities, consisting of the transmitter and receiver modules. The simulation takes into consideration atmospheric effects such as path loss in the medium and interference is implemented using Gaussian white noise model.

The above Figure 5 shows a Piconet consisting of a Master device and two Slave devices. The simulation aims to transmit data simultaneously to both the slave devices using Bluetooth. The Master device acts as the transmitter and the Slave acts as the receiver, neglecting the acknowledgements it transmits.
The transmitted data packets can be viewed using the spectrogram graph and also the device timing diagram. The Master shares a different set of Hopping codes with each of the two Slave devices, therefore each of the two Master-Slave connections are independent and the files transferred are also different.

The generation of the hopping code and the process of establishing and maintaining a Bluetooth connection is out of the scope of the work presented in this paper. The hopping code for an overlaid Bluetooth connection will be different from that of a regular Bluetooth connection, since additional parameters need to be conveyed in case of the overlaid connection.

VI. TDM OVERLAY ON BLUETOOTH

This overlay module implement the Time Division Multiplexing (TDM) module on the Bluetooth connections. Bluetooth protocols have six slots to transmit data. The transmitter and receiver are synchronized by means of the shared hopping code.

In this case the Master device is synchronized with two devices with the same hopping code. But Master transmits data to each of the Slave at different slots. This is because using only one transmitter module the Master can not jump to two frequencies at the same time. Hence, while it is at the one frequency it transmits data to both the devices but at different time slots. The dwell time at hopping frequency can be accordingly adjusted so as to provide for sufficient guard time between the two data transmission. More importantly the two receivers need to be properly synchronized with the transmitter. The encoding and modulation of data is the same as that used with the Bluetooth standard protocol.

From the receiver’s point of view it is no different from a simple Bluetooth connection. The receiver has to hop to the frequencies as dictated by the hopping code. Master needs to communicate this to the receiver, as to which time slot it should expect to receive the data.
As seen in Figure 6 and 7 the hopping sequence for both the channels, channel 1 (Master – Slave 1) and channel 2 (Master – Slave 2) is the same. But, the data is transmitted at different time slots. This can be clearly seen in the timing diagrams. The Master device transmits data to Slave 1 at every 4th time slot (Figure 8) and it transmits data to Slave 2 at every 1st time slot (Figure 9), within each hop. The two transmissions have a time difference of 3 slots between them. Therefore, there can be 6 simultaneous connections with the master each using a time slot, provided the dwell time at each frequency is long enough and there is appropriate guard time between transmissions for the receivers to know the difference.

Figures 8 and 9 again confirm the fact that both the connections shared the same hopping sequence. The figure show a Bluetooth transmission burst from the Master device in the frequency domain.
In special cases and additional facility can be incorporated in the TDM which will shared the hops between the two links in proportion to the size of the data transfer needed. For example, out of the 79 hops per second say 30 hops are dedicated to the connection with Slave 1 and the rest 49 are dedicated to the connection with Slave 2. This has to be negotiated while setting up the connection and the hopping sequence has to be then adequately generated. This new hopping code will tell the receiver which slots to listen to and which not.

**VII. FDM Overlay on Bluetooth**

In the case of an FDM overlay, let us assume that the ISM band is equally split into two equal bands ISM1 (lower half) and ISM2 (upper half). The Master can communicate with the two Slave devices independently with same hopping code by using these two half bands.

The hopping sequence for both the connections is the same. The only difference is that they operate in different halves of the same band, hence do not interfere.
Having the same hopping sequence eliminates the need for additional resources for generating second hopping frequencies. Assuming the hop generator generates frequencies for the lower band, the upper band frequency will be a constant higher than the lower band frequency. Hence, in this case the dwell time in each frequency is reduced to half the original. Consequently the in terms of hardware the frequency oscillator will have to switch frequencies twice as fast. Also, the hopping sequence’s random seed should be chosen such that the consecutive frequencies generated are not to close, as the available total available bandwidth is half of the ISM band. Though the bandwidth at any available hop is still the same at 1 MHz.

Depending on the necessity of the connections the dwell time can be altered to there by reducing the number of hops per second. Otherwise the number of hops per second can be reduced if the dwell time needs to be kept constant.

Figure 15: Connection 1 FHSS

Figure 16: Connection 2 FHSS

Figure 17: Data transmission bursts in the ISM Band
Figure 16 shows two Bluetooth transmission bursts in 100 MHz ISM band separated by 50MHz. This overlay helps the Master device maintain two data connections simultaneously with two slaves by splitting the available band into two. Both the files transmitted to the Slaves were received successfully at the end of the simulation.

For specialized applications where one connection dictates faster data transfer rate than the other, the ISM band can be unequally divided. Allocating the larger band to the connection demanding the higher data transfer rate, this in turn supports more hops per second.

VIII. CONCLUSION

In this paper we have presented a novel approach to implement TDM and FDM overlays on the Bluetooth protocol. These overlays help the Master maintain more than one data connection with the Slaves simultaneously.

IX. FUTURE WORK

Bluetooth technology is a very promising field of research and development, especially considering the fact that it is an evolving technology currently in its nascent stages. In the near future we will be concentrating our efforts mainly on the following tasks:

1. Developing algorithm for generating the hopping code for an overlaid connection.
2. Protocol for establishing an overlaid connection between the Master and Slave device.
3. Implement a working model in hardware.

REFERENCES