Analysis of Bluetooth-Based Ad-Hoc Network for Voice Transmission over Local Area Network

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Abstract: In this paper, the analysis of Bluetooth-based ad-hoc network for voice transmission over Local Area Network is presented. The aim is to analyze the performance of Bluetooth technology when applied to communication between Bluetooth-enabled devices such as smart phones and personal computers connected over Local Area Network (LAN) in order to communicate with other users or devices which are out of the immediate Bluetooth range. Wireless communication helps you to control electricity cost and time consumption so that we can save without compromising on comfort. The methodology employed in this work is Matlab/Simulink –based. This includes the use of the following communication blocks : CPM Modulator Baseband , M-FSK Modulator Baseband block, General CRC Generator block, M-FSK Demodulator block, CRC Syndrome Detector block. The State flow charts were used to implement the transmitter and Receiver Controller respectively. Results obtained after simulation proved satisfactory. The use of Bluetooth in voice and data transmission could produce high data and audio rates while not producing a corresponding rise in error rates. Error rates has been found to be in the order of < 0.01.

KeyWords: Bluetooth, LAN, Ad-Hoc Network, Transmission, Communication

1.0 Introduction

Wireless communication is one of the most active areas of technology development and has become an ever-more important and prominent part of everyday life[1]. “Bluetooth is a short-range wireless networking technology that allows easy interconnection of mobile computers, mobile phones, headsets, PDAs and computer peripherals such as printers, without the need for cables. It is designed to be low-cost and low form-factor, so much design work is required to optimize resource usage. Promoted by a number of wireless communications equipment manufacturers, the technology is named after Harald Bluetooth, a Scandinavian king, famous for uniting the two countries of Denmark and Norway during the 10th century” [2]

Bluetooth “uses the unlicensed Instrumentation, Scientific, and Medical (ISM) band around 2.4GHz. It shares this channel with devices used for other applications including cordless phones, garage door openers, highway toll transponders, and outside broadcasting equipment. It is also susceptible to interference from microwave ovens, which emit radiation in this bandwidth”[2] . “There are two other wireless networking standards that use this frequency band, namely: 802.11b or "WiFi" and Home RF. 802.11b uses direct sequence spread spectrum(DSSS) and Home RF uses the frequency hopping spread spectrum(FHSS) of 802.11 (a precursor to 802.11b) for data and the DECT cordless phone standard for voice[2]. DECT stands for Digital Enhanced Cordless Telecommunication, a standard used in Europe to create cordless phone system. “Many networking products based on these technologies are currently available” [2].

2.0 Theoretical Background

“Bluetooth is managed by the Bluetooth Special Interest Group (SIG), which has more than 25,000 member companies in the areas of telecommunication, computing, networking, and consumer electronics [3]. Newton’s telecom dictionary. New York: Flatiron Publishing”[4][13]

The name "Bluetooth" “is an Anglicised version of the Scandinavian Blåtand/Blåtann, (Old Norse blátǫnn) the epithet of the tenth-century king Harald Bluetooth who united dissonant Danish tribes into a single kingdom and, according to legend, introduced Christianity as well. The idea of this name was proposed in 1997 by Jim Kardach who developed a system that would allow mobile phones to communicate with computers. At the time of this proposal he was reading Frans G. Bengtsson's historical novel The Long Ships about Vikings and King Harald Bluetooth[5] .The implication is that Bluetooth does the same with communications protocols, uniting them into one universal standard" [4], [6-7][13].

The quest "for true, seamless, mobile data and voice communications that enables constant connectivity anywhere is quickly becoming a reality. Wireless and computer industries are clearly leading the way with high-tech components that will shape our lives in the next century.
The technology operates in a globally available frequency band ensuring communication compatibility worldwide.
One of the primary advantages of the Bluetooth system is ease of computer vendor product integration[8]. Other key benefits of this technology are low power, long battery life, low cost, low complexity, and wireless connectivity for personal space, peer-to-peer, cable replacement, and seamless and ubiquitous connectivity. To achieve the Bluetooth goal, tiny, inexpensive, short-range transceivers are integrated into devices either directly or through an adapter device such as a PC Card. Add on devices such as a USB or Parallel port connections are also available for legacy systems. By establishing links in a more convenient manner this technology will add tremendous benefits to the ease of sharing data between devices.
One universal short-range radio link can replace many proprietary cables that connect one device to another. Laptop and cellular users will no longer require cumbersome cables to connect the two devices to send and receive email. Possible health risks from radiated RF energy of cellular handsets are mitigated with lower transmission power of the Bluetooth enabled ear set. (The ear set solution does not require the handset to be close to the head.) Moreover, unlike the traditional headset, the wireless ear set frees the user from any unnecessary wiring [9].
As Bluetooth offers the ability to provide seamless voice and data connections to virtually all sorts of personal devices the human imagination is the only limit to application options. Beyond un-tethering devices by replacing the cables, this technology provides a universal bridge to existing data networks, allows users to form a small private ad hoc wireless network outside of fixed network infrastructures, enables users to connect to a wide range of computing and telecommunications devices easily and simply, without the need to buy, carry, or connect cables. The Bluetooth technology allows users to think about what they are working on, rather than how to make their technology work.
Bluetooth is based on a critical technology known as Frequency-Hopping Spread Spectrum (FHSS), applied to combat interference, fading, and to facilitate optional operation at power levels up to 100 mW. The Spread spectrum technique spreads the narrowband data signal over the radio frequency band of 2.400 – 2.4835 GHz, 79 hops displaced by 1 MHz. FHSS spreads the signal by transmitting a short burst on one frequency and then hops to another frequency for another short burst and so on. In the FHSS system the carrier frequency of the transmitter hops in accordance with a pseudo-random hopping sequence, unique to each piconet. The frequency-hopping rate is 1600 hops/s for a single slot packet and slightly diminishes for multi-slot packets. The hopping rate will increase to 3200 hops/s when a link is being established (e.g. paging mode and inquiry mode). The transmitter and receiver synchronize to the hop sequence to ensure communication. The average signal strength on any given frequency is relatively low. The data signal is spread out over several MHz in the frequency spectrum, thus the resulting power spectrum also spreads out" scholar.
"Any time a Bluetooth wireless link forms, it is within the context of a piconet. A piconet consists of two or more devices occupying the same physical channel (synchronized to a common clock and hopping sequence). The common (piconet) clock is identical to the Bluetooth clock of one of the devices in the piconet, known as the master, and the hopping sequence is derived from the master's clock and the master's Bluetooth device address. All other synchronized devices are slaves in the piconet. The terms master and slave are used only when describing these roles in a piconet. Within a common location, a number of independent piconets may exist. Each piconet has a different physical channel (that is a different master device and an independent piconet clock and hopping sequence).

A Bluetooth enabled device may participate concurrently in two or more piconets. It does this on a time-division multiplexing basis. A Bluetooth enabled device can never be a master of more than one piconet (since the piconet is defined by synchronization to the master's Bluetooth clock it is impossible to be the master of two or more piconets). A Bluetooth enabled device may be a slave in many independent piconets.

A Bluetooth enabled device that is a member of two or more piconets is said to be involved in a scatternet. Involvement in a scatternet does not necessarily imply any network routing capability or function in the Bluetooth enabled device. The Bluetooth core protocols do not, and are not intended to offer such functionality" [10]. Logical transports, logical links and L2CAP channels provide capabilities for the transport of data.

"The implementation of Bluetooth can be defined in terms of sender and receiver units operating at deferent layers of the Bluetooth protocol stack"[11] "The sender and receiver's side consists of four functional units namely :User interface, Multimedia, Hardware, Bluetooth communication layer.

The sender side service provider consists of two functional units, namely: Bluetooth communication layer and Network communication layer.

The multimedia module is responsible for reading the voice data at the sender's end and then playing the voice data at the receiver's end. The microphone in the mobile cellular phone device is used in order to record the data. A speaker at the receiver mobile cellular phone is used to play the recorded data" [12]

"Bluetooth is the transmission medium for communication between mobile phone and the service provider. In this design, Bluetooth Module consists of four different as has been explained in the preceding sections.

The network module is responsible for sending the digital voice packets from the service provider at sender's side to the service provider at the receiver's side. This is also responsible for sending control packets from either of the sides and delivering it to the other side. This module is implemented at the sender's and receiver's side service provider"[10].

3.0 Design Methodology

In this paper, "the design of the physical layer was done in Matlab/Simulink environment. Operations such as link manager protocol and logical link control, which are better modeled as state machines in State flow are not considered here.

- Bluetooth transmits at a low power (1mW) and is therefore designed for short-range use of less than 10 meters.
- The modulation scheme used in Bluetooth is Gaussian Frequency Shift Keying (GFSK).
- Frequency hopping is also employed to avoid interfering with other devices transmitting in the band.

Even although Bluetooth transmissions will occasionally collide with those from another device, this can be tolerated or recovered from with appropriate coding schemes. Transmission time is divided into 625 µs slots, with a new hop frequency being used for each slot. Although the data rate is only a 1Mbps, a much larger bandwidth of 79MHz needs to be simulated to accurately model the frequency hopping effects.

Here we will look at the transmission of voice, for example between a mobile phone and headset. During communication, Bluetooth devices can be masters or slaves. The master is the device that initiates the connection to one or more slave devices. Figure 10.1 shows the communications link between the master transmitter and the slave receiver for voice transmissions"[2][13]

Matlab/Simulink Model

This model demonstrates the use of the following Communications blocks:

- The CPM Modulator Baseband block is used to implement the GFSK (Gaussian frequency shift keying).
- The Bluetooth radio module uses GFSK, where a binary one is represented by a positive frequency deviation and a binary zero by a negative frequency deviation.
- The M-FSK Modulator Baseband block is used to implement the frequency hopping in Bluetooth Radio.
- The Bluetooth radio accomplishes spectrum spreading by using 79 frequency hops, each displaced by 1 MHz, starting at 2.402GHz and finishing at 2.480GHz.
- The Free Space Path Loss block, together with the AWGN block and the 802.11b interference subsystem, shows the construction of a transmission channel.
- The General CRC Generator block is used for transmitted data CRC calculation.
- The use of the M-FSK Demodulator block, the General CRC Syndrome Detector block, and the implementation of rate 1/3 and rate 2/3 payload FEC are also included.

The model also uses Stateflow charts to implement:

- The Transmitter Controller
- The Receiver Controller, which decides on the successful reception of a packet by looking at the status of the access code, HEC and CRC

4.0 Results and Discussion

Various test conducted are shown in this section.

Table 1 shows the simulation -effect of various values of AWGN (Additive White Gaussian Noise) on the Bit Error Rate and Frame Error rate of the received signal, while the hop frequency assumes random values. The AWGN is gradually reduced from 5 to -2.

Table 1: Effects of AWGN on BER and FER

Test	802.11b	AWGN	Hop Frequency	BER	FER
i	Off	Eb/No= 5	Random	4.3 e-4	0
ii	Off	Eb/No= 0	Random	2.7 e-2	9.7e-3
iii	Off	Eb/No= -2	Random	6.4 e-2	0.18

4.1 BER versus E_b/N_o

A common test to perform on any communication system is to measure how the BER varies with the ratio of bit energy (E_b) or symbol energy (E_s) to noise energy (N_o), denoted E_b/N_oor E_s/N_o . Here $E_b = E_s$ as there is one symbol for every bit. The BER meter is contained in the error meter subsystem, which can be opened for viewing during the simulation. The final values of the meters are saved to workspace variables for later collection and analysis.

Figure 1 shows the plot of the E_b/N_o against the BER when the value of the E_b/N_o is gradually adjusted .

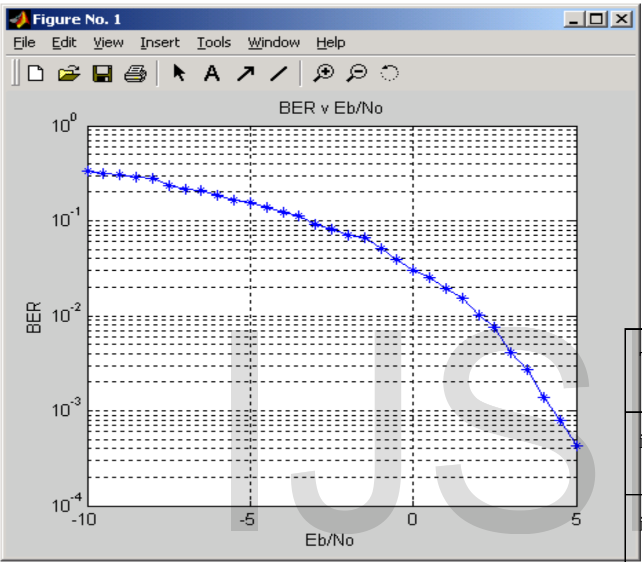

Figure 1: BER versus E_b/N_o

4.2 BER versus hop frequency with 802.11b

Another interesting test was to look at the BER as a function of hop frequency when the 802.11b transmitter is permanently on. It would be expected that performance of the Bluetooth system would degrade as it entered the 802 transmitter's bandwidth. See table 2 and Figure 2.

Table 2: BER versus hop frequency with 802.11b

802.11b	AWGN	Hop Frequency	BER
Packet Rate = 999 (Fixed On)	Off	0:78	Figure

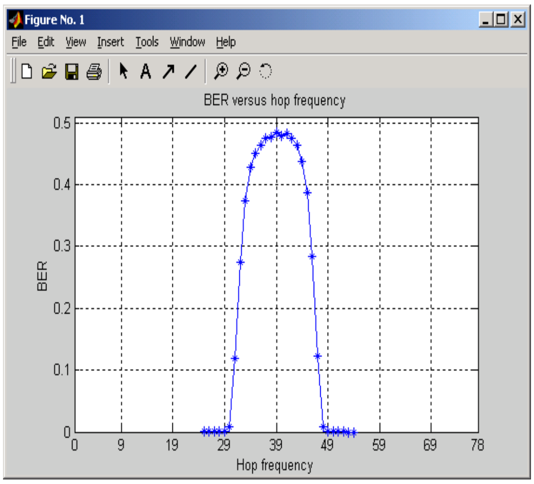

Figure 2: BER versus hop frequency with 802.11b on.

4.3 802.11b effect on voice quality

The effect of 802.11b interference on voice quality and the adjusted parameters used is shown in table 3, with the 802.11b transmitter set to two different packets rates while the timing diagram is shown in Figure3.

Table 3: Effect of 802.11b

Test	802.11b	AWGN	Hop Frequency	BER	FER
i)	Packet Rate = 200	Off	Random	1.6e-2	3.8e-2
ii)	Packet Rate = 500	Off	Random	4.6e-2	0.12
iii)	Packet Rate = 999 (Always On)	Off	Random	9.2e-2	0.21

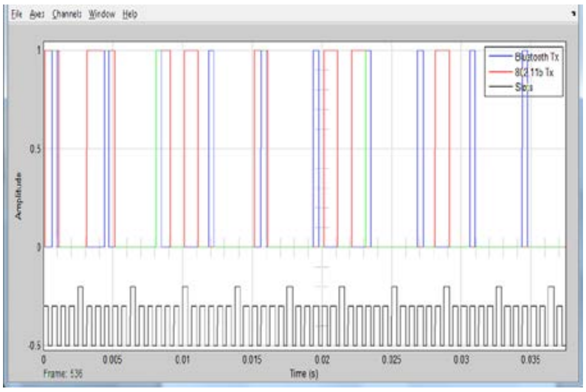

Figure 3: Timing diagram

The timing diagram gives a plot of the amplitude of the three signal(the Bluetooth transmitted signal, the 802.11b interferer signal and the time slot) to time for the transmitted signal.

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4.4 ISM Band Spectrum

Figure 4 shows the dynamic plot of the frequency of the transmitted signal against time which is another indicator of the performance of the Bluetooth signal .

The “raw bit error rate displays the inconsistencies between the bits in the transmitted signal and the received signal. Frame error rate refers to the ratio of frame failure to the total number of frames. Frame failure, caused by noise and interference, is determined if the HEC fails to match the header info or if less than 57 bits are correct in the access code. If the frame fails, this is captured by a zero-valued Frame OK signal, which is used in the FER calculation as well as to exclude bad frames from the residual BER calculation”.

The Scope’s icon opens a display of the spectrum of the transmitted Bluetooth signal (narrowband) with IEEE 802.11b interference.

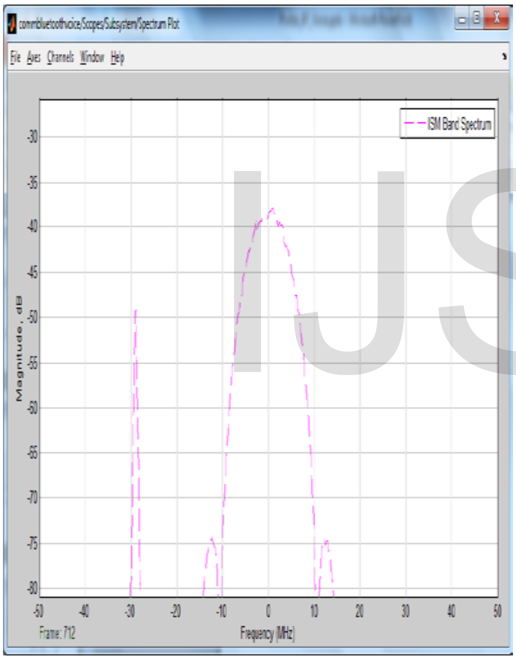

Figure 4: ISM Band Spectrum Plot

4.5 Spectrogram of the Channel

The spectrogram shows the variation in the quality of the audio signal between the transmitter and the receiver. “The thin lines are the Bluetooth transmissions, while the larger, more colorful blocks are the interferer slots. Most of the time, due to frequency hopping, there is not much overlap of these slots. In a few cases, the signals do collide, as the Spectrogram plot clearly shows”[2] Figure 5.

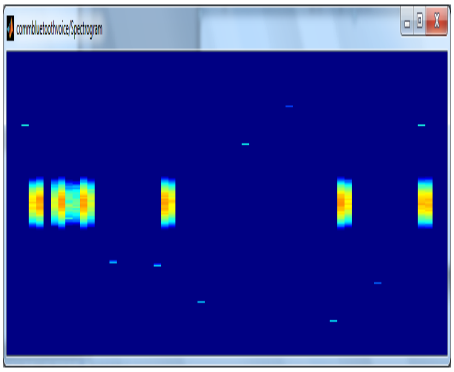

Figure 5: Spectrogram of the Channel

4.6 Analysis of Transmitted Data Rates

In this section, the signal generated by the master transmitter at the transmitting end was examined, and the changes in the signal through the AWGN channel without the interference from the IEEE 802.11 channel was observed.

Figure 6 shows the variation of the Bit Error Rate, the Bit Error and the Total Number of Bits with time without interference from the IEEE 802.11 signal. So it was observed that the bit error varies between 0.002 and 0.003 which is quite insignificant. Similar results were obtained with the presence of interference with just slight increase in errors.

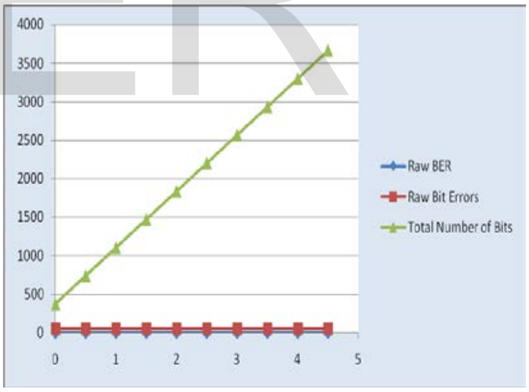

Figure 6: Error Rate performance

Table 4: Table of Error Rate Performance

SN	Time(sec)	Raw BER	Raw Bit Errors	Total Number of Bits
1	0	0.00325	50	366
2	0.5	0.003177	50	732
3	1	0.003105	50	1098
4	1.5	0.003036	50	1464
5	2	0.002907	50	1830
6	2.5	0.002846	50	2196
7	3	0.002739667	50	2562
8	3.5	0.002644667	50	2928
9	4	0.002549667	50	3294
10	4.5	0.002454667	50	3660

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4.7 Interference Analysis of 802.11a Signals

Figure 7 shows the variation of the Bit Error Rate, the Bit Error and the Total Number of Bits with time in the presence of interference from the IEEE 802.11 signal.

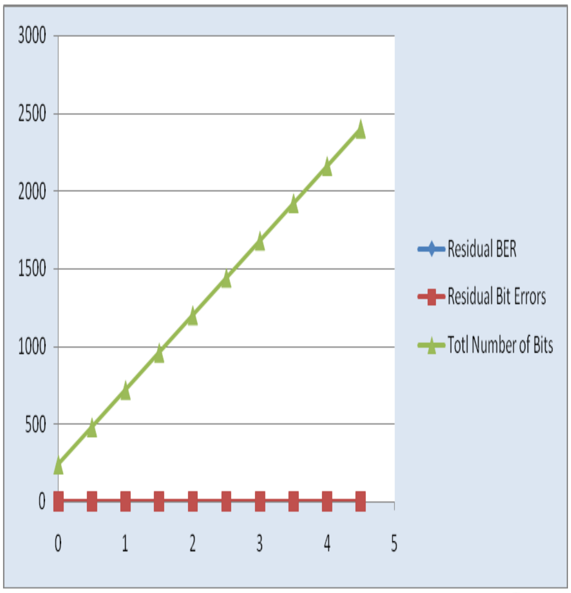

Figure 7: Effect of Residual BER

Table 5: Changes in Residual BER

SN	Time (secs)	Residual BER	Residual Bit Errors	Total Number of Bits
1	0	0	0	240
2	0.5	0	0	480
3	1	0	0	720
4	1.5	0	0	960
5	2	0	0	1200
6	2.5	0	0	1440
7	3	0	0	1680
8	3.5	0	0	1920
9	4	0	0	2160
10	4.5	0	0	2400

Receive Signal Analysis

Since audio signals are samples in frames, in this paper, the signal output at the receiver block and plot the variation of the Frame Error Rate, Frame Errors as well as the Total Number of Frame at different intervals of time was considered. The graph on Figure 7 shows the variation.

It was also observed that with the various parameters set at the appropriate values, the error rate also remains insignificant.

Table 6: Frame Error Rate Performance

SN	Time (secs)	Frame Error Rate	Frame Errors	Total number of Frames
1.00	0.00	0.00	0.00	1.00
2.00	0.50	0.00	0.00	2.00
3.00	1.00	0.01	0.00	3.00
4.00	1.50	0.01	0.00	4.00
5.00	2.00	0.02	0.00	5.00
6.00	2.50	0.02	0.00	6.00
7.00	3.00	0.02	0.00	7.00
8.00	3.50	0.03	0.00	8.00
9.00	4.00	0.03	0.00	9.00
10.00	4.50	0.04	0.00	10.00

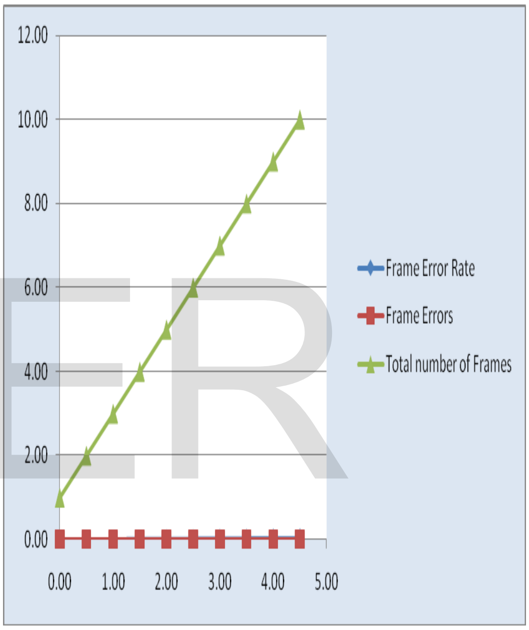

Figure 8: Effect of Frame Error Rate

From Figure 8 and other the various analysis, it is strongly observed that, the plot generated from the Simulink environment, that the use of Bluetooth in voice and data transmission could produce high data and audio rates while not producing a corresponding rise in error rates. Error rates has been found to be in the order of < 0.01.

It was importantly observed that the presence of interference from 802.11 signal produces a negligible effect on the voice/data transmission.

5.0 Conclusion

This results of the simulation contained in this work shows that Voice Communication can be made possible by combining existing Local Area

Network(LAN),wireless systems and Bluetooth technologies.

Although, Bluetooth devices operate at 2.4 GHz in the globally available, license-free ISM band which is the same band used by many other small-size devices which are supposedly prone to interference, the distortions can be reduced to a negligible minimum. Additionally, by employing Frequency Hopping Spread Spectrum in the channel assignment, it as observed that the effect of interference can further be mitigated against . The use of this band by many other systems including the operation of microwave ovens makes this a hostile environment. Bluetooth technology can be used as a viable alternative to existing wireless technologies for voice and data transmission.

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