A Bluetooth-based Telemedicine Model: Simulation Approach

Taskeen Nadkar and Srija Unnikrishnan

Abstract-- **This paper presents a simulation of a Bluetooth-based telemedicine network. However the operation of multi-hop ad hoc networks of Bluetooth devices, called scatternets, pose certain performance challenges- mainly mutual interference and interference from neighboring WiFi devices. In this work we study the performance implications of forming scatternets from piconets and then deploy a modified frequency-hopping scheme (FHS) in the model to avoid both problems. The enhanced model is more suited to provide the wireless links of telemedicine projects, which are gaining extensive popularity worldwide.**

Index Terms--**Bluetooth, Frequency-hopping, Piconet, Scatternet, Telemedicine, Wi-Fi**

I. INTRODUCTION

TELEMEDICINE is a generic term referring to all forms of medical information exchange, deploying a variety of telecommunication technologies [1]. The purpose of telemedicine is to provide medical expertise to places that due to their physical distance do not have access to this kind of competence. Examples of environments where these techniques could be of use are decision support for pre-hospital personnel working in ambulances or in patients' home. Telemedicine is also used to transfer important medical information from a remote location to a hospital or some other institution for diagnosis. Developments in telemedicine were from the beginning driven by the military, space research, naval and aviation industry and were mostly concentrated in remedy alarm situations were the geographical distances made it impossible to transfer injured persons to hospitals. Recent developments are increasingly focused on cost reduction and inconvenience of traveling. Clinicians, healthcare professionals and manufacturers of medical devices are realizing the advantages of wireless technology and are looking at wireless ad hoc networks to improve flexibility, connectivity, convenience and functionality of telemedicine projects. The key considerations of wireless telemedicine models are power consumption, data transfer rates, interference, reliability of links, interoperability with existing technologies, and expansion possibilities.

Originally introduced for short-range cable replacement, the Bluetooth specifications [2] define ways for which each device can set up multiple connections with neighboring devices so that communication can be established in a multi-hop fashion. In this sense, Bluetooth devices spread in a geographic area can provide the missing extension to the various heterogeneous network infrastructures of wireless access.

This paper aims at simulation analysis of a Bluetooth-based telemedicine network. The subsequent section provides an insight on Bluetooth scatternets. Sections III and IV describe the simulation model for a telemedicine network. In particular, this paper evaluates a performance metric Bit Error Rate (BER) in the presence of mutual interference and neighboring 802.11 interference. In sections V we propose and deploy a modified FHS for avoiding both the above problems, depicting performance improvement. Finally, Section VI concludes the paper.

II. SUITABILITY OF BLUETOOTH FOR WIRELESS TELEMEDICINE

Bluetooth technology is well suited for wireless medical networks and has the potential to enable and advance many applications. Bluetooth is a short-range radio technology operating in the unlicensed 2.4 GHz ISM (Industrial-Scientific-Medical) band, in which units are organized into piconets. The Bluetooth technology is expected to be one of the most promising technologies for enabling ad hoc networks allowing spontaneous deployment and self-management.

Bluetooth RF utilizes frequency hopping among 79 one-MHz wide frequencies bands at a rate of 1600 hops per second. Standard transmit power is 1 mW. Node separation is typically less than 10 m, but may be up to 100 m at optional higher transmit power settings. The signal is modulated by binary Gaussian Frequency Shift Keying (GFSK). The Bluetooth piconet consists of a master and anywhere from one to seven slaves. The master defines the piconet's pseudo-random frequency hopping sequence and transmission timing. A Bluetooth unit can participate in more than one piconet at any time but it can be a master in only one piconet. A unit that participates in multiple piconets can serve as a bridge thus allowing the piconets to form a larger network. A set of piconets that are all interconnected by such bridging units forms a multi-hop ad hoc network called a scatternet [8]. Using scatternets, higher throughput is available between devices in different piconets. Compared to other standards, Bluetooth is superior for medical applications based on properties summarized below (Figure 1) [3]:

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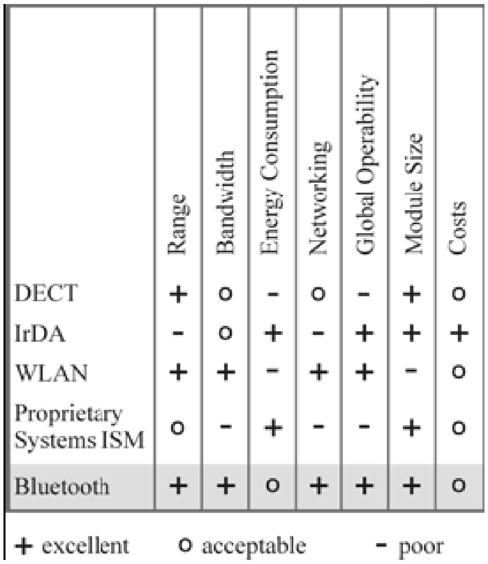

	Range	Bandwidth	Energy Consumption	Networking	Global Operability	Module Size	Costs
DECT	+	o	-	o	-	+	o
IrDA	-	o	+	-	+	+	+
WLAN	+	+	-	+	+	-	o
Proprietary Systems ISM	o	-	+	-	-	+	o
Bluetooth	+	+	o	+	+	+	o

+ excellent o acceptable - poor

Fig. 1. Properties of wireless transmission standards in comparison to Bluetooth

III. SIMULATION MODEL FOR TELEMEDICINE APPLICATION

To check the feasibility and performance of Bluetooth in a telemedicine project, a simulation approach is adopted. This work models the RF components of the Bluetooth transceiver in MATLAB Simulink. A single-hop transceiver comprises of the binary data generator, GFSK and a pseudo-random number generator to achieve frequency hopping among 79 one-MHz wide frequencies bands over an AWGN channel and the corresponding receiver. A piconet can be simulated with up to 7 slaves receiving on the same frequency hop pattern as that of the master.

Then in order to build a multi-hop ad hoc network for a telemedicine scenario, a scatternet is created. The received data is compared to the source data to estimate an important performance metric-Bit Error Rate (BER). For a three hop network, the scatternet model and the spectrum are as shown in Figure 2 and Figure 3 respectively.

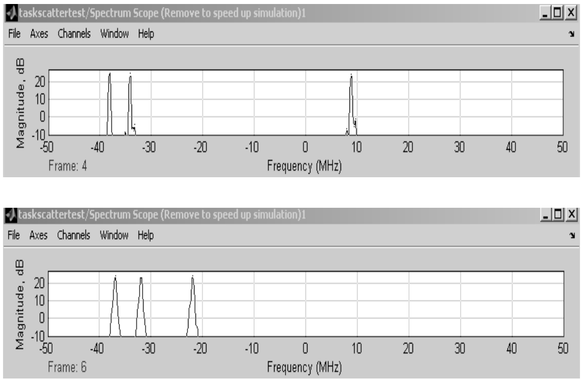

Fig. 3. Bluetooth Scatternet Spectrum

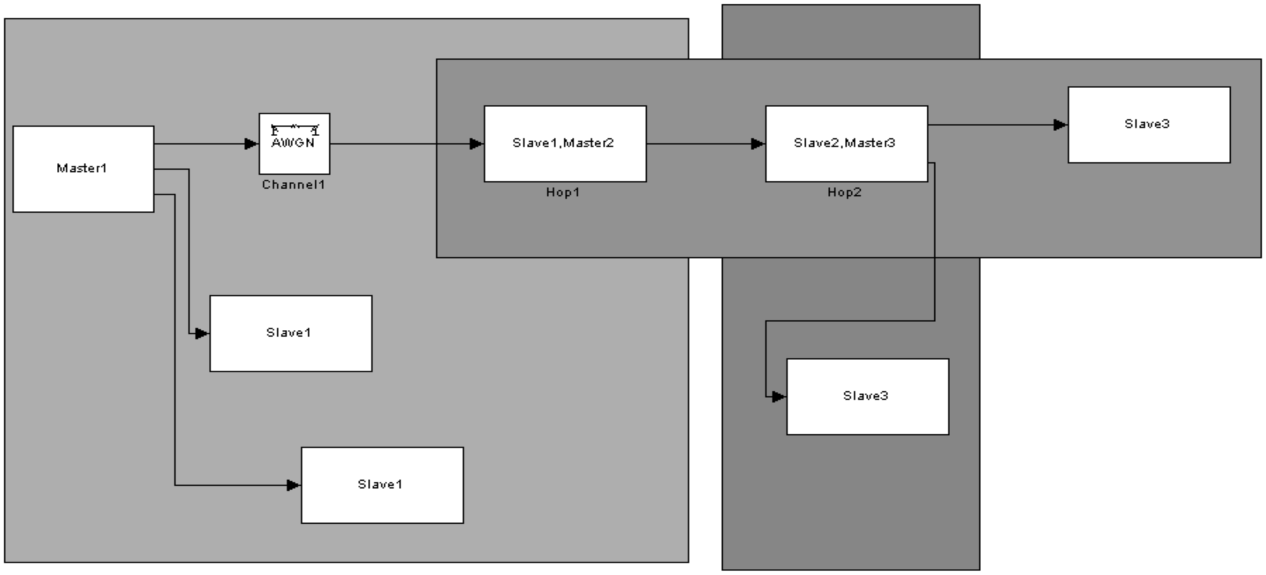

Fig. 2. Bluetooth Scatternet Model

IV. PERFORMANCE ISSUES IN A SCATTERNET

A. Mutual interference

If two piconets located in proximity of each other communicate at the same frequency at the same time it results in mutual interference [4]. Since all piconets share the same set of 79 channels, there will be more collisions when there are more piconets resulting in bit errors and degrading performance. The spectrum (Figure 4) indicates overlap between two frequencies of adjacent piconets for the three-hop model. Hence instead of three pulses, only two are seen.

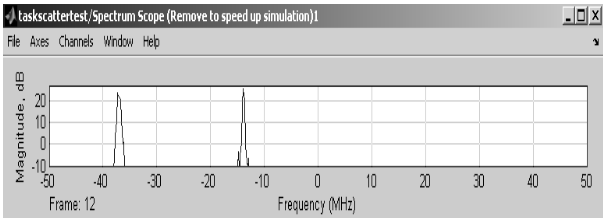

Fig. 4. Shared spectrum between three piconets

B. 802.11 Interference

Both Bluetooth and IEEE 802.11 or Wi-Fi and occupy a section of the 2.4 GHz ISM band. Bluetooth uses Frequency Hopping Spread Spectrum (FHSS) and is allowed to hop between 79 different 1 MHz-wide channels in this band. Wi-Fi uses Direct Sequence Spread Spectrum (DSSS). Its carrier does not hop or change frequency and remains centered on one channel that is 22 MHz-wide. When a Bluetooth radio and a Wi-Fi radio are operating in the same area, the single 22 MHz-wide Wi-Fi channel occupies the same frequency space as 22 of the 79 Bluetooth channels which are 1 MHz wide. When a Bluetooth transmission occurs on a frequency that lies within the frequency space occupied by a simultaneous Wi-Fi transmission, some level of interference can occur degrading the network performance of the scatternet [5][6].

In our simulation, a Wi-Fi interferer is modeled as in Figure 5 to demonstrate the performance degradation. The spectrum is as observed (Figure 6). As the distance of the interferer from the scatternet is increased the performance improves as observed in Figure 7.

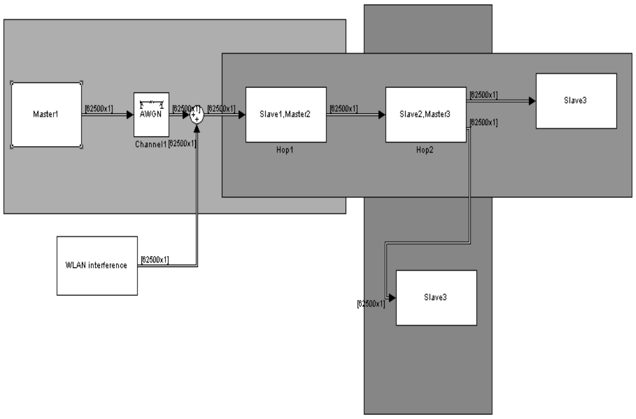

Fig.5. Wi-Fi interference on Bluetooth Scatternet

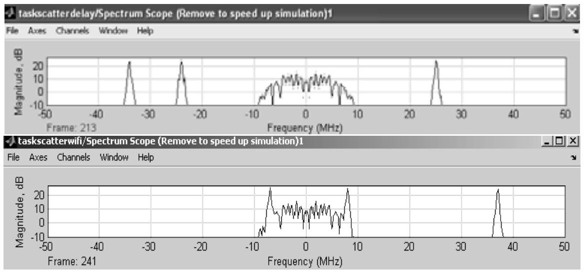

Fig. 6. Spectrum of Wi-Fi interference on the Bluetooth Scatternet

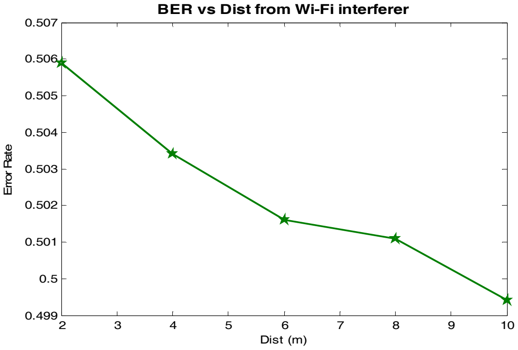

Fig. 7. Error Rate vs. Distance of interferer from Scatternet

V. MODIFIED FHS FOR AVOIDING MUTUAL INTERFERENCE AND THAT FROM WI-FI

Our effort however is to create a model which counters both these problems and appropriate algorithms are deployed in the model to overcome mutual interference and interference from Wi-Fi.

As proposed in [7] a unique FHS in the scatternet is used to avoid the network degradation due to mutual interference. A derived frequency from the main master is used in the piconets, as per the relationship - every hop frequency generated by the master will be decreased by a value, which is 10 times the address of the slave that creates a new piconet. With only seven different addresses possible inside a piconet and with the communication channel represented by a pseudo random sequence through the 79 (1-MHz) channels, decreasing each FHS by 10 times the slave address will avoid interference from any piconet with a minimum of 9 hops difference between piconets. In the presence of more devices or to have a better fluidity between piconets, another master hierarchy is performed. Slaves of masters that need to become master of the next hop will derive their hop frequency from the frequency of its Master, by decreasing it by 29 and adding its own address. (Figure 8)

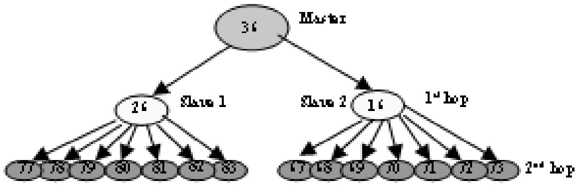

Fig.8. Derived FHS scheme

An interference mitigation algorithm is implemented in the model to avoid interference from neighboring Wi-Fi devices. It checks if the Bluetooth frequency encounters Wi-Fi interference, and if it does, the FHS is modified to be outside the interference range, thus ensuring improved performance.

Upon implementing both the modifications in the FHS scheme the frequencies for the three piconets simulated are as shown in Table I.

Table I
FHS for the three-hop scatternet

Master	**Pico 1**	**Pico 2**	**Pico 3**
0	**0**	**69**	**63**
1	**1**	**70**	**64**
2	**2**	**71**	**65**
3	**3**	**72**	**66**
4	**4**	**73**	**67**
5	**5**	**74**	**68**
6	**6**	**75**	**69**
7	**7**	**76**	**70**
8	**8**	**77**	**71**
9	**9**	**78**	**72**
10	**10**	**0**	**73**
11	**11**	**1**	**52**
12	**12**	**2**	**53**
13	**13**	**3**	**54**
14	**14**	**4**	**55**

It is observed that the frequencies of the three piconets are unique as well as outside the Wi-Fi spectrum. A performance improvement results, as observed in Figure 9. The Bluetooth scatternet is now rendered suitable for use in a telemedicine project.

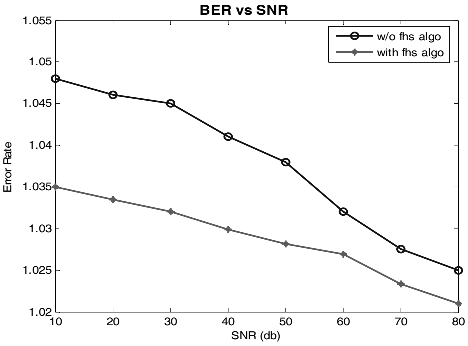

Fig.9. Performance improvement by deploying derived FHS scheme

VI. CONCLUSION

Telemedicine is poised to open up new frontiers for rural and long distance healthcare. The technology is extant and waits only creativity. Bluetooth is mature enough for telemedicine implementations with certain performance issues, which can be overcome with appropriate design. Bluetooth and Wi-Fi at the moment are the two prominent technologies in the ISM band and the interference problem between the two is being addressed by the task group 2 of IEEE 802.15. A scatternet model as proposed in the paper can be used to emulate telemedicine networks and can act as a basis for further research and motivate innovation and enhancement for improved performance.

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VIII. BIOGRAPHIES

Srija Unnikrishnan born on May 7,1960 has 23 years of teaching experience. She has done her Masters in Engineering and specializes in Telecommunication. She teaches DSP, Digital Communication, Data Communication and Networks, Wireless Communication at under-graduate and post-graduate level.. She has guided several B.Engg projects and a few M. Engg projects.

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