DESIGN AND DEVELOPMENT OF A SECURE WIRELESS SYSTEM USING FREQUENCY HOPPING SPREAD SPECTRUM

by

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LIST OF ABBREVIATION

ADC	Analog to Digital Converter
BER	Bit Error Rate
CE	Chip Enable
CLK	Clock
CRC	Cyclic Redundancy Check
CS	Chip Select
DR	Data Ready
DSSS	Direct Sequence Spread Spectrum
FHSS	Frequency Hopping Spread Spectrum
FS	Full Scale
GFSK	Gaussian Frequency Shift Keying
GPIO	General Purpose In Out
GSM	Global System for Mobile Communications
ISM	Industrial-Scientific-Medical
kSPS	kilo Samples per Second
MCU	Microcontroller Unit
OD	Overdrive
PHY	Physical Layer
PN	Pseudo-Random (Spreading Code)
P0 (or P1)	(8051) In / Out Port 0 (or Port 1)
PWM	Pulse Width Modulation
PWR_DWN	Power Down

PWR_UP	Power Up
RF	Radio Frequency
RTC	Real Time Clock
RX	Receive
SFR	(8051) Special Function Register
SNR	Signal to Noise (power) Ratio
SPI	Serial Peripheral Interface
SPS	Samples per Second
SS	Spread Spectrum
ST_BY	Standby
TX	Transmit
UMTS	Universal Mobile Telephony System
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless LAN
XTAL	Crystal (oscillator)

REKABENTUK DAN PEMBANGUNAN SISTEM PENGAWSAN TANPA WAYAR MENGGUNAKAN LOMPATAN FREKUENSI SPEKTRUM TERSEBAR

ABSTRAK

Dalam penyelidikan ini, satu sistem tanpa wayar automasi untuk menghantar data yang bersertakan kod PN secara automatik kepada pihak berkuasa berkenaan telah dibangunkan. Gandaan pemprosesan yang dicapai oleh sistem ini ialah 18dB pada kadar lompatan 333.33 lompatan/saat di mana gandaan pemprosesan ini adalah 3dB lebih tinggi daripada gandaan pemprosesan piawaian (15dB) yang dimaklumkan oleh Federal Commissions for Communication (FCC). Penyelidikan ini dilaksanakan dengan menggunakan Spektrum Tersebar Lompatan Frekuensi (FHSS), di mana radio pemancar menghantar satu paket data pada satu frekuensi dan melompat ke frekuensi yang lain dengan cepat untuk penghantaran paket seterusnya. Sistem ini berkos efektif, bersaiz kecil dan mudah dibawa, sensitif kepada isyarat yang lemah, memerlukan ruang simpanan data yang minima dan mudah digunakan serta dikendalikan. Keputusan telah menunjukkan kesesakan kes paling teruk (ρ_{wc}) menurun apabila E_b/N_J meningkat. Keputusan ini turut menunjukkan bagi sasaran anggaran kuasa hinggar jenis ini, peningkatan susunan kepelbagaian secara cepat mengurangkan keberkesanan kesesakan hingar jalur-sebahagian. Penggunaan maklumat sampingan memperbaiki pelaksanaan sistem dalam semua kes. Atas sebab kod hingar-pseudo, data terselamat daripada interferens luaran dan boleh diterima secara berkesan. Penyelidikan ini telah menyediakan satu rangka analitikal untuk menilai keberkesanan operasi FHSS dalam kewujudan kesesakan hinggar jalur-sebahagian dengan pemodulatan dan penyahmodulatan tidak koheren *M*-ari FSK.

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ABSTRACT

In this research, an automated wireless system that sends the data accompanied with PN code automatically to the concerned authorities has been developed. The processing gain achieved by the system is 18dB at a hopping rate 333.33 hops/sec which is 3dB more than the standard processing gain (15dB) mentioned by the Federal Commissions for Communication (FCC). This work has employed frequency hopping spread spectrum (FHSS), where the transmitting radio transmits a data packet on one frequency and rapidly hops to another possible frequencies to transmit the next packet. The system is cost effective, is small and easy to transport, is sensitive to very weak signals, requires minimal data storage requirement and easy to use and operate. The results have indicated that worst case jamming (ρ_{wc}) decreases as E_b/N_J gets larger. It may be noted from the results that for this type of noise power estimation error, increasing the order of diversity rapidly reduces the effectiveness of partial-band noise jamming. The availability and use of side information improves the system performance in all cases. Because of pseudonoise code, data is saved from external interference and can be successfully received. This research has provided an analytical framework for evaluating the performance of FHSS operating in the presence of partial band noise jamming with *M*-ary FSK modulation and noncoherent demodulation.

CHAPTER 1

INTRODUCTION

1.1 Wireless Communication

Over the past decade, there has been unprecedented growth in wireless standards and services. The advancements in the field of wireless communications have led to more innovative consumer applications. These wireless applications have evolved to cater to the needs of the commercial industry, defense, private home users and educational institutions.

The birth of wireless communication is generally accepted to have occurred in 1897, when Marconi received credit with the patent for the radiotelegraph, from which the word radio was coined. Since that time, mobile radio communications has been used to navigate ships and airplanes, dispatch police cars and taxis, generate new businesses, and win wars. The use of radio telephones has evolved rapidly and grown explosively in the last few decades. This evolution of wireless systems can be viewed to have occurred in different stages. The main force driving the evolution is an increasing public demand for wireless services. To meet this ever increasing demand, better communication technologies are required to increase network capacity, to improve quality of service, and to introduce new service features.

Everybody is being exposed to a revolution in communications, a revolution that is taking us from a world where telephone subscribers were constrained to communicate over fixed telephone lines. In a digital network voice and data services have different and sometimes contradictory requirements. In order to understand the differences among service requirements, one must first examine the services from the user's point of view. At the outset, it is important to understand that users' expectations are based upon their experience with services provided in the public switched telephone network. Although digitized voice, imagery, and data are all "binary digits," there are different requirements for transmission of each service in a digital network. For example, because of the user's expectation of telephone-voice quality in the public wired network, voice service in a wireless network environment must be designed with careful attention to minimizing time delays.

The purpose of implementing information technologies is to reengineer processes, so that care is delivered more cost effectively and efficiently, not to reengineer people to do things differently as required by the information system.

Infrared waves cannot penetrate walls or structures, so direct line of sight is required between transmitter and receiver. Range is limited to approximately 30 feet per sensor, so multiple sensors are required. The infrared content of ambient light can interfere with IR radiation and, if extensive, can overload the receiver photodiode and drive it beyond its operating point. Three sources of ambient light are daylight, incandescent illumination, and fluorescent lamps, all of which potentially interfere with IR communications. Fluorescent light is the common method of lighting in office environments and poses the most serious problem for IR communications.

In spite of the improvement of the communication link improvement and despite all progress in advanced telecommunication technologies, there are still very few functioning commercial wireless mobile monitoring systems, which are most off-line, and there are still a number of issues to deal with.

Presently, the use of wireless devices such as cell phones, PDAs and walkie-talkies are restricted in hospitals due to fear of detrimental Electromagnetic Interference (EMI) (Silberberg, 1993). Healthcare providers therefore play it safe by restricting the use of any wireless devices. Unfortunately, there exist no quantified results to define the tolerable levels of emission in hospitals for various frequency bands. Knowledge of measured EMI caused by medical equipment and other sources in a hospital can help in determining the throughput of wireless devices operating in hospital or clinical environments. The benefits of wireless technology in healthcare could be far reaching if used in an appropriate manner. Doctors could store information in real time, access patient records and medical reference materials from the internet, send emails through handheld devices that are connected to server. This would lead to better and more efficient care. Doctors in remote areas can be equipped with a hand held device and be able to send details of their patients from their homes to a hospital's database receive the results of any investigations or procedures done. This could be especially useful when applied in medical disaster response where communications is frequently inadequate and medical responders need access to adequate, effective and reliable communication.

Short-range wireless devices and wireless local area networks (WLANs), which operate in the unlicensed 2.4GHz Industrial, Scientific and Medical (ISM) band, are potential wireless standards for medical applications. Bluetooth in particular is very promising due to its low cost, low power consumption and wide acceptance among manufacturers (www.bluetooth.com). Bluetooth chipsets can be readily integrated with the existing medical equipment to render them wireless. At higher frequencies, signal transmission through walls is more difficult. This feature is advantageous in wireless LAN applications where confinement of the signal within a room or building is a desirable privacy feature. Also, at higher frequencies the relationship between cell boundaries and the physical layout of the building is more easily determined, facilitating the planning of wireless LAN cell assignments within the building. Many wireless LAN's are specifically designated for spread spectrum technology because of its anti-multipath and anti-interference nature (Pahlavan, 1994).

1.2 Spread Spectrum

The spread spectrum technology was initially researched and developed with military applications in mind. This is because it offers a number of attractive advantages, such as a wireless communication means that is resilient to narrow-band jamming and difficult to intercept (Scholtz, 1994). Among the first applications of this technology was that of ranging in military radar systems, where it improved accuracy. Applications in wireless communications started to appear after Shannon's classic theory of statistical communication (Shannon, 1948). One of the most important conclusions of this theory is that the maximum possible theoretical capacity C_c of a communication channel is

$$C_c = B_s \log_2(1 + SNR) \text{ bits/sec} \tag{1.1}$$

where B_S is the bandwidth of the communication system that uses this channel Shannon also noted that when the channel is not known to the transmitter, the maximum capacity is achieved by a noise-like waveform with uniform power spectral density over B_S. The main characteristic of a spread spectrum system is that the transmitted signal has a bandwidth much larger than the bandwidth of the minimum signal-space representation of the corresponding baseband data stream. There are a number of methods to convert a baseband data stream in order to transmit signal with much larger bandwidth. One of them is Direct Sequence Spread Spectrum (DSSS).

Direct sequencing is the most common form of spread spectrum sequencing: it spreads its signal by expanding it over a broad portion of the radio band. This occurs when the information is divided into small blocks or data packets that are spread over the transmitting bandwidth, thus resulting in a low power density. The low power density comes across as white noise and lowers the possibility of interference. Once the packets are transmitted, the receiver must reassemble the packets. The content (data or voice) of a signal changes frequencies in the spectrum in accordance with the code. The rest of the frequencies in the spectrum that do not contain the signal are transmitted as noise. Each time another user is added, the noise level increases. Thus, users can be added using this technique until the signal to noise ratio becomes too small. Direct sequence is used in broadband bandwidths.

The other method for converting the baseband data stream into larger bandwidth signal is Frequency Hopping Spread Spectrum (FHSS).FHSS, as the name suggests, utilizes spread-spectrum method of transmitting signals. In frequency hopping (FH) spread spectrum, rather than transmitting information (data or voice) with the same carrier frequency, the carrier frequency is changed i.e. (hopped) periodically according to some pre-designated (but apparently random to a third party observer) code (a pseudo-random sequence).

The U.S patent for spread spectrum technology was held jointly by actress Hedy Lamarr and music composer George Antheil. Their patent for a "Secret Communication System," issued in 1942, was based on the frequency hopping concept, with the keys on a piano representing the different frequencies and frequency shifts used in music (Muller, 2001). In 1942, the technology did not exist for a practical implementation of spread spectrum. After the original patent had expired and Lemarr and Antheil obtained a patent for their idea, the U.S implemented frequency hopping spread spectrum for military communication systems onboard ships (Hoffman, 2002).The use of frequency-hopping systems has then increased dramatically since its inception in 1962.

The advantage of a frequency hopping signal is that it is relatively jam and intercept resistant. This feature is used widely in military communications where the risk of either enemy jamming or intercept is great. It is also used in the mobile communication industry as a multiple access technique where systems are required to handle high capacity data reliably in an urban setting (Hedylamarr, 2001). Frequency hopping (FH) communication systems have become an important component of military communications strategy. FH systems offer an improvement in performance when the communication system is attacked by hostile interference. FH systems also reduce the ability of a hostile observer to receive and demodulate the communications signal. FH systems are susceptible to a number of jamming threats, such as noise jammers and narrowband, single or multitone jammers.

If all frequency hops are to be jammed, the jammer has to divide its power over the entire hop band, thus lowering the amount of received jamming power at each hop frequency. Unfortunately, if the tone jamming signal has a significant power advantage, reliable communications will not be possible (Katsoulis and Robertson, 1997). Even when the jamming tones experience fading, reliable communications are not possible when the jamming signal has a significant power advantage (Robertson and Sheltry, 1996). If the FH signal has a sufficient hop range, received jamming power will be negligible. If a tone jammer is focused on a particular portion of the FH bandwidth, its power may adversely impact communications. A possible antijamming strategy is use a narrow bandstop filter to remove the tone from the received signal spectrum. Pérez et al. (2002) described a method for filtering tone jammers from a frequency hopping spread spectrum signal based on the undecimated wavelet transform. This technique isolates the jamming signal using frequency shifts to confine it to one transform subband. This method of removing a jamming signal is significantly more complicated than using a narrow bandstop filter.

1.3 Objectives

The objectives of the research are as follows:

(I). The main objective of the work is to design and develop a secure wireless system which combats to hostile jamming and interference at very weak signals.

(II). To develop PN code for the system to save it from external interference.

(III). To reduce the error rate of the system in Jamming environment.

In this research, a generic, secure and cost effective wireless system has been designed and developed for short and long range applications applying frequency hopping spread spectrum technology especially for remote patient-monitoring. The project focuses on a versatile, user-friendly and portable wireless system using nRF24E1 evolution board to characterize the RF spectrum over a wide range of frequencies. Particular emphasis is on interference rejection and reducing the latency of the entire system under 2.4GHz ISM band.

1.4 Thesis Overview

Chapter 2 consists of background and literature review which serves as a foundation for many of the concepts and issues presented in this thesis. It is divided into two sections which provide a brief description of telemedicine and frequency hopping spread spectrum, as well as reference to some previous works in this field.

Chapter 3 discusses the methodology of the system into three sections. Section 3.1 describes the design and development of the system using FHSS in order to set up the wireless modules, and to make them perform for communication. Section 3.2 describes the PN sequences in detail that help to determine how to minimize jammer effects and friendly interference on the system. This chapter discusses how the PN sequences are used to spread out frequency spectrum, reduce the power spectral density and minimize the jammer effects. In section 3.3, an anti-jam fast FH system in the presence of partial-band noise jamming is presented.

Chapter 4 describes the results and discussion of Software Implementation of Frequency Hopping Spread Spectrum, Performance of Pseudonoise Sequence in Frequency Hopping Spread Spectrum and Performance Analyses of Fast Frequency Hopping Spread Spectrum and Jamming Systems in sections 4.1, 4.2 and 4.3 respectively.

Finally Chapter 5 puts forth the conclusion, presents a summary of the results and lays direction for future work in this area.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Wireless networking is a rapidly emerging technology and security must be addressed as it is incorporated into new and existing local area networks (LANs). It is important to know what unique properties of wireless LANs might amplify existing LAN vulnerabilities or introduce new ones.

Wireless local area networks (WLANs) are a new alternative to traditional hard wired local area networks (LANs). They use radio frequency (RF) or infrared (IR) transmissions to communicate information from one point to another and do not rely on physical connections. A typical WLAN configuration includes an access point (AP) connected to the wired network using standard cabling. An access point antenna is mounted anywhere practical to obtain desired coverage. WLANs can provide continuous network access to users within their organization thus supporting productivity not possible with wired networks. People can physically move their node (computer) without breaking their virtual network connection. This will termed “roaming”.

GSM is a system currently in use, and is the second-generation (2G) of mobile-communication networks. When it is in the standard mode of operation, it provides data-transfer speeds of up to 9.6kbps, which is the current maximum rate of GSM (www.gsmworld.com).

The term wireless refers to telecommunication technology, in which the radio waves ,infrared waves and microwaves, instead of cables or wires, are used to carry a signal to connect communication devices (Rosen et al., 2002),. Wireless technology is rapidly evolving, and is playing an ever-increasing role in the lives of people throughout the world.

The greatest obstacle to achieving wireless multimegabit data communication rates is the lack of a suitable frequency band for reliable high-speed communication. The existing ISM bands as narrated by Marcus (1985) assigned for multiple-user applications are suitable for Wireless Local Area Network (wireless LAN), but they are restricted to spread-spectrum technology.

Current applications of spread spectrum technology include wireless LANs, bar-code scanners, and microphones. This technology improves the efficiency and effectiveness of business processes, many of which are finding that wireless communications are requisite for success. Frequency hopping is the easiest spread spectrum modulation to use. Any radio with a digitally controlled frequency synthesizer can, theoretically, be converted to a frequency hopping radio.

2.2 Wireless Technology

Wireless technology can be used in many applications especially in health industry and department of defense. This thesis discusses the telemedicine because in recent years, the health care industry has been anticipating the proliferation of medical wireless applications and other personal wireless devices in hospitals and clinics. The medical community recognizes the use of wireless technology as an excellent solution to improve manpower productivity, ease patient data storage, strengthen inventory control, and improve patient monitoring and patient care.

Telemedicine, as a concept, was introduced about 30 years ago, when telephone and fax machines were the first telecommunication means used. In recent years, several telemedicine applications have been successfully implemented over wired communication technologies like Plain Old Telephone System (POTS) and Integrated Services Digital Network (ISDN). However, nowadays, modem means of wireless telecommunication, such as the Global System for Mobile Communications (GSM), General Packet Radio Service (GPRS), and the forthcoming Universal Mobile Telecommunications Systems (UMTS) mobile telephony standards, as well as satellite communications, allow the operation of wireless telemedicine systems, freeing the medical personnel and/or the subject monitored from being bound to fixed locations (Lin, 1999; Lacovides et al. 1998; and Tachakra et al. 2003).

Graschew et al. (2005) analyzed the contributions to Computer Assisted Radiology and Surgery (CARS) in the areas of telemedicine, teleradiology, and telesurgery and compared the results to the number of publications cited in the Medline database (National Library of Medicine and Silver Platter International N.V.).

Adewale (2004) developed an Internet-based telemedicine environment for Nigeria, specifically to support consultations among remotely placed patients, rural health workers and specialists in the urban cities and provide a secure access to remote patient records. Author designed a system that allowed the rural healthcare workers to send the patients' demographic and clinical data, X-rays and ultrasound images through the IP-based wireless telemedicine network for consultation and diagnosis of any patient's illness. He proposed the referral of patient to appropriate specialists or hospitals through the IP-based telemedicine network where the physicians can compose a package of referral information from the patient record and submit the same to the appropriate server queue in order to select the appropriate specialists or hospital for the patient's condition based upon the information available.

Bigbee (1998) described that telehealth care opportunities that include expanded functions, such as case finding and referral through on-line networks of clients and providers, close observation of client status and concerns through electronic monitoring, enhanced client/provider communication systems, such as E-mail; specialty evaluation and consultation with distant providers through video conferencing; and broad-based evaluation of care through electronic data collection, storage, and analysis. The author mentioned that telehealth care should reduce caregiver burden, not increase it by requiring already stressed families and caregivers to cope with complex technical responsibilities for which they may not be prepared or interested and telehealth care system must pay particular attention to controlling access to clients' electronic records and protecting their privacy. It requires all healthcare professionals, individually and collectively, to engage in an ongoing process to determine how to achieve the most appropriate balance between access to electronic health information and the individual's right to privacy. Mohan and Yaacob (1998) discussed the Malaysian telehealth flagship and have proposed the challenges to security and privacy in providing access to an electronic Lifetime Health Record (LHR) at private and government health facilities and to the electronic Lifetime Health Plan (LHP). They mentioned that not only technical mechanisms but also national policies and practices addressing threats while facilitating access to health data during health encounters in different care settings. The authors proposed that ownership, custody and control of all the aggregated data of the Lifetime Health Records (LHR) will depend on the government of Malaysia should be in the custody and control of the government rather than privately held by commercial entities. They emphasized the need of a system which will ensure the security of data against data loss, tampering, unauthorised access and all data and information collected, stored and transmitted must be accurate, complete, reliable and valid in a common dataset with national and international standards.

Security and confidentiality of the sensitive medical data are of paramount importance to both patient and health care provider. Access to the data by the provider should only be granted with the patient's consent except in emergency cases. To implement this idea, Marschollek and Demirbilek (2006) designed a system which provides access to patient-related data in a distributed environment using a standard smart card. The card itself only holds basic information about the patient's identity and some emergency data that can be made available immediately. The patient holds the key to this information in the form of a smart card and the PIN without which the health care provider cannot gain access to the central data base. They used standard software components and technologies in order to facilitate interoperability with multiple system platforms. The aim of the project was to use a standard microprocessor card to provide a technical solution for recording the patient data.

Telemonitoring involves home monitoring of symptoms and vital signs using special devices linked to telephone lines or internet cables. This technology may be particularly valuable in heart failure, because close supervision may reduce hospital admissions and accelerate discharge. In this manner Louis et al. (2003) collated published studies on the effectiveness of telemedicine in the management of heart failure. The authors included 18 observational studies and six randomised controlled trials with between 20 and 218 participants (mean age in the different studies ranged between 53 and 74 years whilst mean follow-up age ranged between 3 and 18 months). They observed that patients readily accepted and adhered to telemonitoring.

Rapid advances of the Internet, multimedia technology and virtual reality have opened new opportunities for organizations to re-design their traditional functional units often are separated by vast distances into a virtually cohesive enterprise capable of responding quickly to market changes. Bui (2000) proposed an agent-based framework for supporting collaborative work among human and non-human teleworkers, namely, software agents. The author used taxonomy of agent characteristics to help identify different types of agents to support different types of decision tasks and developed a lifecycle that looks at agent- based decision support systems (DSS) as being a design of coordinated agents to optimally support a problem-solving process. In particular, author suggested a two-level development process. The micro-level seeks to identify and specify agents to handle specific decision support tasks, whereas the macro-level seeks to coordinate various agents to optimally support the entire decision-making process.

Another software agent was designed by Rialle et al. (2003) based on telemonitoring and alarm raising system. They designed a system keeping in mind the disabled and elderly people living alone, handicapped people, and patients with chronic diseases. Their system built with standard bricks based on object-oriented analysis, modeling and design, Internet and Java technologies. They distributed the system into three main kinds of agent, the central server, a data producer located in the patient's home, and several data consumers.

Kyriacou et al. (2001) presented multipurpose health care telemedicine system used in ambulances, Rural Health Centre (RHC) or other remote health location, Ships navigating in wide seas and airplanes in flight. They designed and implemented an integrated telemedicine system for different telemedicine needs. The system based on telemedicine unit and a base unit or doctor’s unit. The telemedicine unit used for collecting and transmitting biosignals and still images of the patients from the incident place to the doctor’s location while the doctor’s unit is responsible for receiving and displaying incoming data either in emergency case or when monitoring a patient from a remote place. The system used GSM mobile telephony links, satellite links or Plain Old Telephone Service (POTS) links and the software design was done using Borland Delphi 4 for windows 95/98/NT platform. They tested and demonstrated all the functions of the system at Athens Medical Center (Greece), the Malmo Ambulance Services (Sweden), the Azienda Ospedaliera Pisa (Italy) and Cyprus Ambulance Service (Cyprus). The demonstration was performed on 100 emergency cases for each hospital.

The utilization of distributed medical intelligence can contribute significantly to the continuous improvement of patient care and accelerates the qualification process of the medical staff. An efficient way of realization is the use of satellite networks for telemedical applications, as satellite communication has some distinct advantages over terrestrial communication channels. Graschew et al. (2003) described the use of satellite networks for telemedical applications. They emphasized the “Quality of service” and “Class of service” of telemedicine and experienced that the goals of telemedicine can only be achieved adequately when a high degree of interactivity, which is called telepresence is implemented. They described the improved proposal of Medical Assistance for

Ships (MEDEASHIP), which was set up on board-ships for telemedical consultations. They studied that during the pilot phase, the ships will be equipped with an ultrasound medical system and an electrocardiograph (12 channels), interfaced to Workstation for Telemedical Applications via Satellite (WoTeSa) / Wavelet-based interactive Video-communication system (WinVicos), as well as a satellite terminal (VSAT) on a special platform. They studied The Euro-Mediterranean Internet-Satellite Platform for Health, Medical Education and Research (EMISPHER) project which provides an integrated internet and satellite platform, dedicated to health applications and covering the whole Euro-Mediterranean area. Their study concluded that the use of teleteaching, telementoring as well as telepresence via the interactive networks contribute decisively to the qualification of the medical specialists.

Taking the advantage of wireless communication, Pavlopoulos et al. (1998) developed a novel emergency telemedicine AMBULANCE system based on wireless communication technology with telediagnosis, long distance support, and teleconsultation of mobile healthcare providers by experts located at an emergency coordination center or a specialized hospital. The system comprised of mobile unit (ambulance site) and the consultation unit (hospital unit). The mobile system was powerful (Pentium class) PC equipped with a frame grabber card, a CCD camera (SONY CCB-GC5/P) to capture still images, and a Siemens M1 GSM modem for communication with the server. The system stored information on the local hard disk displayed on the screen of the PC and transmitted through the GSM modem to the hospital station. They found that increased ECG transmission interruption enforced retransmissions for the packet lost. They recommended the integration of the system with a GIS/GPS system for ambulance vehicle control and management.

Yamamoto (1995) studied the feasibility of wireless portable teleradiology and facsimile (fax) transmission using a pocket cellular phone and a notebook computer to obtain immediate access to consultants at any location. The system designed using a desktop personal computer (PC) with a 80486DLC-33 microprocessor, 340-MB hard disk, 1-MB color super Video Graphics Array (VGA), and Windows 3.1, was used to send images to a portable wireless receiving unit. A 24,000-baud modem was used in this sending unit and a Gateway 2000 Handbook notebook computer was used as a test unit to receive image files. The system scanned and stored elbow X-rays and CT scans into the desktop PC and transmitted to the portable notebook via the cellular modem using a modification of the PC-teleradiology and faxing ECGs from a conventional fax machine to the cellular laptop unit was successfully tested. The author found that wireless teleradiology and fax transmission over cellular communication systems are feasible with current technology.

The feasibility of wireless pocket teleradiology had been further implemented by Yamamoto and Williams (2000). They demonstrated how brain computed tomography (CT) scan images of five neurosurgical emergency cases were received on a pocket computer via a wireless modem link. They selected two pocket computers for trial; (1) The Hewlett Packard 620LX, a pocket computer with a 256 color 640 by 240 pixel screen, measuring 19.5 by 10.0 by 3.2 cm, weighing 603 grams and (2) The Sharp Mobilon 4500, a pocket computer with a

256 color 640 by 240 pixel screen, measuring 18.5 by 9.7 by 3.0 cm, weighing 483 grams. The Sierra Wireless Air Card 300 was selected for use as a wireless modem. They obtained five sets of test CT scan images (each set consisted of 1, 3, or 4 CT cuts totaling 11 CT cuts) were uploaded into a web server. Those five sets of CT scan images, totaling 188.7 Kbytes in the JPEG compressed image file format (averaging 17 Kbytes per CT cut), were accessed wirelessly and viewed using the pocket computer's built in web browser in five different locations within the range of the wireless network, both indoors and outdoors. No wire connections, additional software or special computer commands were required to view the images. They experienced a poor wireless communication network. However, they experienced that wireless pocket computer access eliminates the limitation of requiring a consultant specialist to be physically present at a telemedicine center or telemedicine PC unit.

2.3 Frequency Hopping Spread Spectrum (FHSS)

The primary advantage of a spread spectrum communication system is its ability to reject interference whether it be an intentional or unintentional interference by another user simultaneously attempting to transmit through a channel or the intentional interference by a hostile transmitter attempting to jam the transmission (Schmidt, 1975).

Frequency hopping is the periodic changing of the carrier frequency of a transmitted signal (Muller, 2001). The sequence of carrier frequencies is called the frequency hopping pattern. The set of M possible carrier frequencies is called the hopset. The rate at which the carrier frequency changes is called the hop rate. Hopping occurs over a frequency band called the hopping band that includes *M* frequency channels. Each frequency channel is defined as a spectral region that includes a single carrier frequency of the hop set as its center frequency and has a bandwidth B large enough to include most of the power in a signal pulse with a specific carrier frequency.

In FHSS, the transmitter moves around a nominal centre frequency in a specific “hopping sequence”. This is accomplished using a pseudo random “spreading code” to control a frequency agile local oscillator (Viterbi, 1975). A replica of the spreading code is applied at the receiver to recover the wanted information signal. Other FHSS transmissions with different hopping sequences are rejected by the narrow band intermediate frequency (IF) filter, along with any wide band signal or noise content.

2.3.1 Pseudorandom Sequence Generators (PN Code)

In a frequency hopping spread spectrum technique, the spectrum of a data-modulated carrier is widened by changing the carrier frequency in a pseudo-random manner.

A spread spectrum system employs two identical pseudorandom sequence generators, one which interfaces with the modulator at the transmitting end and the second which interfaces with the demodulator at the receiving end. These two generators produce a pseudorandom or pseudonoise (PN) binary-valued sequence that is used to spread the transmitted signal in frequency at the modulator and to despread the received signal at the demodulator.

Time synchronization of the PN sequence generated at the receiver with the PN sequence contained in the received signal is required to properly despread the received spread spectrum signal. In a practical system, synchronization is established prior to the transmission of information by transmitting a fixed PN bit pattern that is designed in such away that receiver detects it with high probability in the presence of interference.

After time synchronization of the PN sequence generators is established, the transmission of information commences. In the data mode, the communication system usually tracks the timing of the incoming signal and keeps the PN sequence generator in synchronism.

It was reported that Radio Frequency Interference (RFI) interrupts the Tracking Data Relay Satellite (TDRS) S-band PN code spread spectrum forward communication link with the Space Shuttle Orbiter, and RFI causes the PN code lock system to be out-of-lock frequently (Schmaltz, 1990; Shack, 1990; Settapong and Apiruck 2004).

For a liner transponder, the PN system has an inherent capability (to certain point) to reject narrow-band continuous wave (CW) RFI signals (whose bandwidths are small compared to that of the spread signal) because the narrowband interfering signals are spread after the multiplication of the received signals with the PN sequence (Simon et al., 1985). However, in-band pulse RFI, e.g., a radar signal whose frequency is in the desired signal data band, can seriously degrade the PN system which is operating in a linear channel, because peak power of the pulse RFI is much stronger than the PN spread signal power. Hence, a soft-limiter at the front end of the receiver has been used for second generation transponder, which is also recommended for the design of the Space Station Freedom (SSF) S-band PN system.

Several methods have been proposed for the calculation of the effect of memoryless non-linearties on the sum of input signals. Of these, the transform method (Davenport and Root, 1958; Blachman, 1971) is widely applicable. For PN spread-spectrum signals, this method cannot give a complete analysis because it does not supply phase information about the output signals (Baer, 1992). A modified transform method which use the transfer characteristic of the nonlinear device as suggested by Davenport and Root (1958) and apply a time-domain approach has been used to study interference effects of hard-limiting in PN spread-spectrum systems (Baer,1992).

2.3.2 Fast Frequency Hopping Spread Spectrum and Jamming Systems

Spasojevic and Burns (2000) presented the report analyses of two main spread spectrum (SS) technologies used by wireless devices in the 2.4GHz ISM band. The authors compared the technical characteristics of frequency hope spread spectrum (FHSS) and direct sequence spread spectrum (DSSS). They used indoor and outdoor radio local area network (RLAN) densities of 100 and 1 per

km^2 respectively for illustration purposes and observed that FHSS systems will provide greater resilience to interference and will therefore be preferable for applications such as RLANs where it is necessary to deliver a specific grade of service.

Cardoso et al. (1997) described the implementation of a communication system that uses the power lines as the channel. The system consisted of an emitter/receiver operating with FHSS, and allowed data transmission at low rates. They built 2 prototypes to communicate between them. The system processing has been performed by a FPGA and an EPROM. The system designed by the authors worked up to 30m distance in the same electric phase in a very noisy environment. They proposed on an automatic gain control and an error correction code, in order to improve its performance in full-duplex transmission and also to achieve longer distances.

There have been many previous studies on phase noise of the frequency synthesizer over the past few decades. Hussain and Barton (1993) analyzed the communication performance of a noncoherent frequency shift keying (FSK) system with the phase noise of oscillator in the additive white Gaussian noise (AWGN) channel by the phase noise analysis method. Tsao et al. (1999) analyzed the performance of the optical heterodyne FSK satellite communication system with phase noise. Teh et al. (1998) addressed the multitone jamming rejection of fast frequency hopping (FFH) / binary phase-shift keying (BFSK) linear-combining receiver over Rayleigh-fading channels. Shin and Lee (2001) analyzed the performance of an FFH system with diversity