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SPREAD SPECTRUM TECHNOLOGY STUDY

March 31, 1996

Project No. 599 - 439011

oject was completed by The Strategic Microelectronics
tium (SMC) in conjunction with Industry Canada.

FOREWARD

The ***"Spread Spectrum Technology Study"*** was written as a means to bring to the forefront the continous technological growth in the field of spread spectrum devices and to document the wide variety of applications and to estimate the wireless hardware products market. The purpose of the publication of this document is to investigate new possibilities that could result from a solid Canadian capability in Spread Spectrum Technology.

This study was a cooperative activity betweeen Industry Canada's Information Technology Industry Branch and the Strategic Microelectronics Consortium (SMC).

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1. EXECUTIVE SUMMARY

Spread Spectrum communications systems have been used by the military for roughly half a century due to their inherent robustness and security however, the use of Spread Spectrum in commercial communications systems has only recently become a reality. The increasing demand for wireless connectivity to communications networks has resulted in a demand for Spread Spectrum products. This document was prepared by the Strategic Microelectronics Consortium and provides an overview of Spread Spectrum technology and applications, in order to facilitate the commercialization of Spread Spectrum technology by the microelectronics industry in Canada.

Market forecasts predict that the total wireless products market will exceed $1.9 Billion US by the year 2000. The wireless LAN hardware products market has the most potential with estimated revenues in excess of $1.7 Billion US by the turn of the century. Technical advantages, the lack of licensing requirements and the emergence of the IEEE 802.11 standard for wireless LANs have made Spread Spectrum the most cost effective technology for wireless LAN communications systems.

Integrated circuits for Spread Spectrum radio design have only recently become available. Several companies are manufacturing Spread Spectrum ICs that operate at baseband frequencies and perform spreading, modulation, synchronization and despreading functions. Harris Semiconductor leads the pack with its Prism chipset for IEEE 802.11 wireless LANs; the only Spread Spectrum chipset for a complete baseband to RF radio.

Thick film and surface mount assemblies are both well-suited to modular radio design using chip-on-board technology. The GEC Plessey DE6003 Frequency Hopping Digital Radio was developed by Plessey Semiconductors to facilitate the design of wireless LAN systems by OEMs.

While the number of integrated products for Spread Spectrum radios has increased significantly over the past five years, there are still very few ICs and chipsets available to the RF systems designer. With such a new market and so few competitors, there is a window of opportunity for RF and signal processing IC manufacturers. With the proper strategy, a significant share of the emerging market for Spread Spectrum products can be gained.

2. SPREAD SPECTRUM FUNDAMENTALS

Spread Spectrum communications systems are distinctly different from narrowband systems in that a larger bandwidth than necessary is used to send an information signal, ie. $BW_{RF} >> BW_{INFO}$. Figure 2.1 illustrates how Spread Spectrum transmission differs from conventional narrowband transmission.

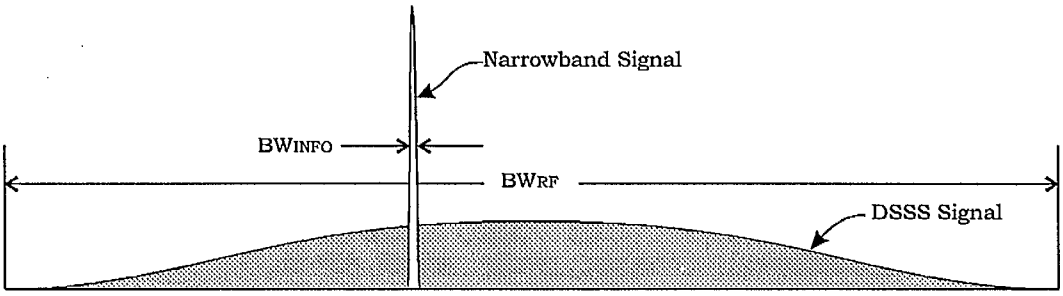


Figure 2.1
Spread Spectrum vs. narrowband transmission

Spread Spectrum communications systems are characterized by the following:

- The transmitted signal occupies a bandwidth which is much greater than the minimum bandwidth required to send the information.
- A spreading signal or code signal which is independent of the data is used to spread the bandwidth of the transmitted information.
- Data is recovered by the receiver by correlating the received spread signal with a synchronized replica of the spreading signal used by the transmitter.

There are three distinct forms of Spread Spectrum namely Direct Sequence, Frequency Hopping and Time Hopping. Hybrids of these types may also be used. This document will focus on Direct Sequence and Frequency Hopping since they are the most widely used techniques.

2.1.1 Direct Sequence

In Direct Sequence systems, the information signal is modulated by the spreading signal or code signal and the resulting wideband signal is

transmitted. Upon reception, the wideband signal is demodulated using a synchronized copy of the code signal and the information is recovered. Figure 2.1 is a representation of a Direct Sequence signal.

2.1.2 Frequency Hopping Systems

In Frequency Hopping systems, the information signal is modulated by a carrier whose frequency changes with time according to the spreading code i.e. the transmitter transmits on one frequency for a period of time and then 'hops' to another frequency and transmits again. The receiver must change frequencies in sync with the transmitter in order to be able to receive the information signal. Figure 2.2 illustrates the spectrum associated with Frequency Hoppers.

2.2 Spread Spectrum Advantages and Disadvantages

Spread Spectrum systems can offer substantial benefits over conventional communications systems. Some advantages of Spread Spectrum systems are:

- Interference suppression and resistance to jamming.
- Security of transmission.

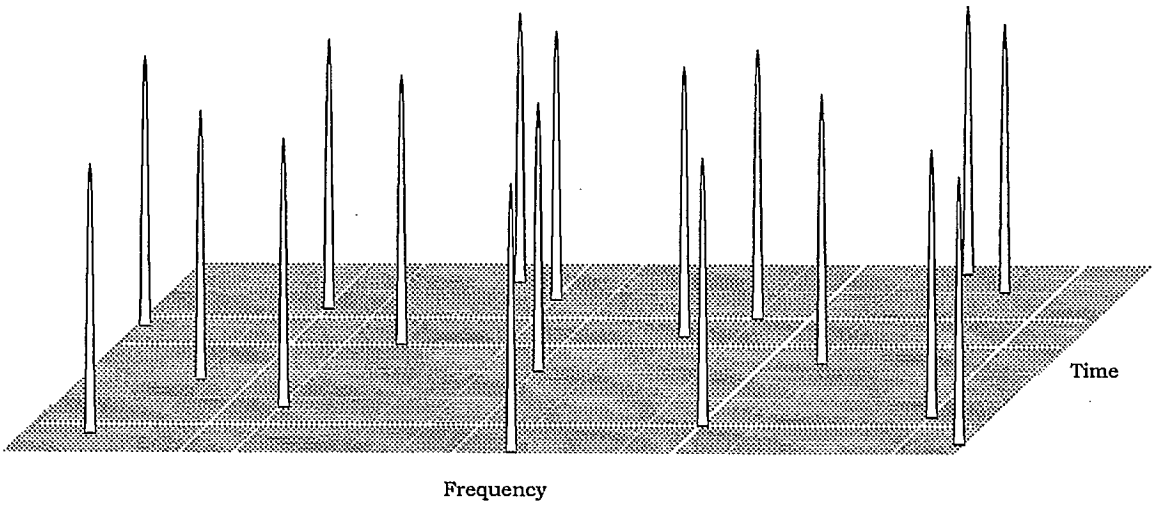


Figure 2.2
Spectrum of a Frequency Hopper

- Multiple access using Code-Division Multiple Access (CDMA)
- Reduced power spectral density of transmitted signals.

Disadvantages of Spread Spectrum systems may include:

- System complexity
- Difficulty of synchronization
- Wide spectrum required

The following sections look at Spread Spectrum technology in greater detail.

2.3 Interference Suppression

One important reason for using Spread Spectrum techniques is to reduce the effects of interference on a communications link and in turn reduce the likelihood of the signal being jammed intentionally. By using a wider bandwidth than necessary for signal transmission, a signal can still be recoverable even with a very low Signal to Noise Ratio (SNR). This is due to the fact that there is a processing gain associated with Spread Spectrum signals and that processing gain is proportional to the amount that the signal is spread. In other words:

$$Gp = \frac{BW}{Rd}$$

where Gp is the processing gain, BW is the bandwidth used to transmit the signal and Rd is the information signal data rate.

Most Spread Spectrum systems have a processing gain of at least 10. A Spread Spectrum receiver with a large processing gain can actually function with signal-to-noise ratios of less than unity[1] i.e. the noise power at the receiver is greater than the received signal. Although both Direct Sequence and Frequency Hopping systems have an associated processing gain, the mechanism that suppresses interference is different for each technique.

2.3.1 Resistance to Narrowband Interference

Figure 2.3 illustrates the effects of a narrowband interferer on a Direct Sequence signal. Because the correlation process at the receiver is

[1] This applies to Direct Sequence systems only

essentially a spreading process (the received signal is modulated with the spreading code), a narrowband interferer will be spread by the receiver's despreading process. The result is that the power of the interferer is spread out over a large bandwidth and only a small amount will affect the despread information signal.

In the case of Frequency Hopping, a narrowband interferer may wipe out one hop of the sequence but the other hopping channels will remain unaffected. An intelligent Frequency Hopper can avoid hopping to channels where there is interference and thus may only be effected once. Figure 2.4 illustrates the Frequency Hopping case.

2.3.2 Resistance to Multipath

One particularly insidious form of interference is caused by multiple reflections of a transmitted signal reaching the desired receiver. This phenomenon, known as 'multipath' can result in signal nulls and errors due to delay spread. Such multiple paths may be due to reflections from stationary or non-stationary objects as well as atmospheric reflection or refraction. In general, multipath becomes much worse as the frequency of operation and data rate increase. Most broadband wireless (>2Mbps) transmission systems require some form of anti-multipath measures. Mobile systems are particularly susceptible to multipath as receivers can move in and out of fades.

Spread Spectrum systems are inherently resistant to multipath. In the case of Direct Sequence systems, the code-correlation receiver effectively ignores reflected signals. Frequency Hoppers can get around multipath by hopping faster than the fade rate, thus avoiding signal nulls.

2.4 Spreading Codes

Both Direct Sequence and Frequency Hopping systems make use of spreading codes in their operation. In Direct Sequence systems, the carrier is modulated by the code sequence while Frequency Hopping systems use a code sequence to determine the hopping pattern. In either case, the receiving circuit must use a correlated copy of the code signal to recover the information signal.

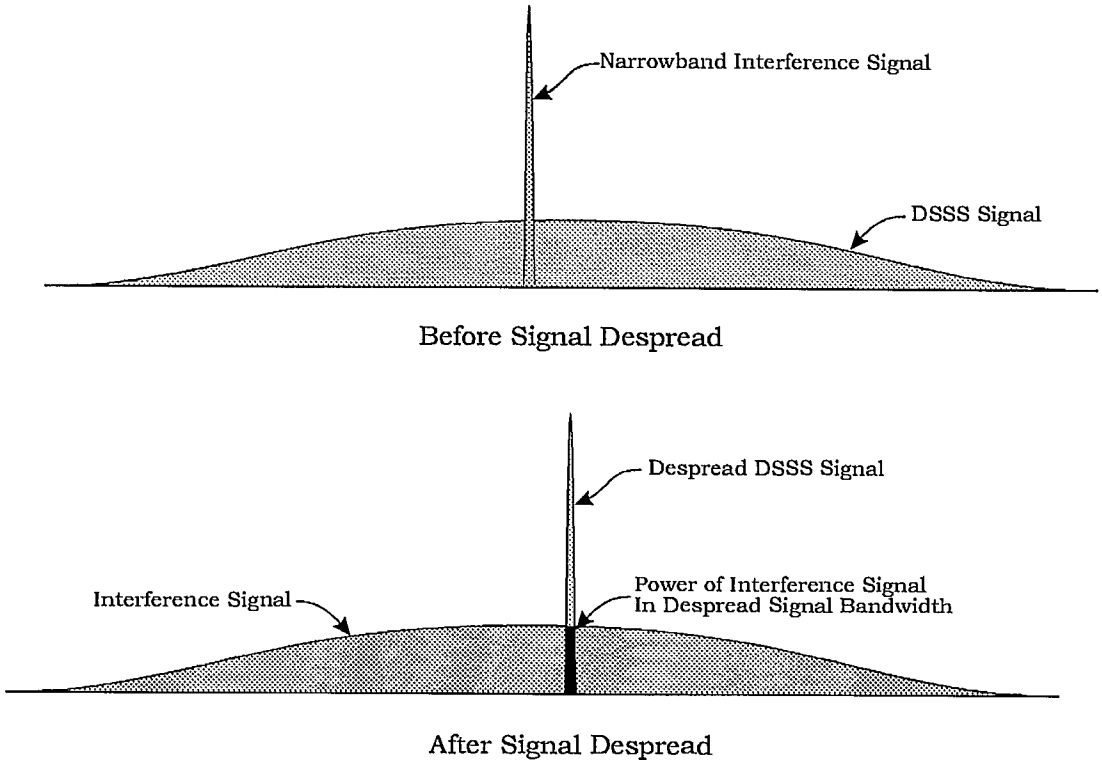


Figure 2.3
The effect of a narrowband interference on a Direct Sequence signal

Code signals that vary in a random manner are desirable due to their resemblance to wideband noise. Spread Spectrum systems that use truly random spreading sequences use a technique called Transmitter Reference. In a TR system two versions of the spreading sequence are transmitted simultaneously over separate channels. One signal is simply a replica of the spreading signal (the reference signal) while the other is the spreading signal modulated by the information signal. At the receiver, the reference signal is used to recover the information signal. Obviously there is a security issue with TR systems since the reference signal could either be intercepted or jammed by an unintended eavesdropper. Furthermore, TR systems require twice the bandwidth to operate and are subject to signal degradation at low signal amplitudes since noise affects both signals. For these reasons, a different technique known as Stored Reference is more commonly used.

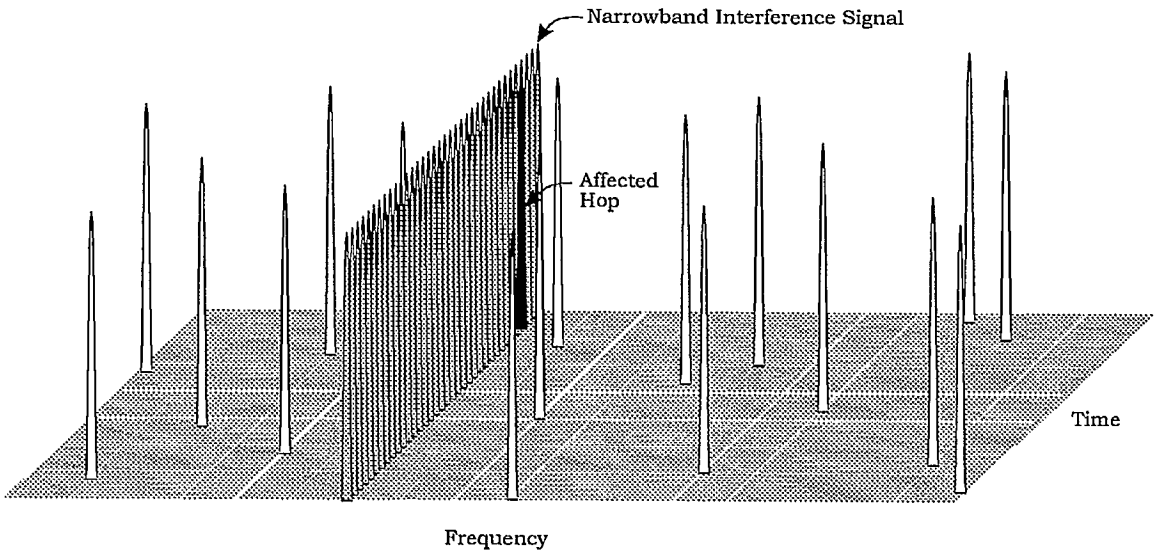


Figure 2.4
Effect of a narrowband interference signal on a Frequency Hopper

SR systems make use of a predetermined spreading signal known to both the transmitter and the receiver. The spreading signal cannot in this case be truly random for obvious reasons. SR systems make use of codes which are pseudo-random in nature.

In general, pseudo-random (PN) codes have the following properties:

- In each period of the sequence, the number of ones differs from the number of zeros by no more than one.
- The length of a run of consecutive bits of one type (i.e. all zeros or all ones) should vary such that about half of the runs are one bit in length, one quarter of the runs are two bits in length, one eighth of the runs are three bits in length and so on.
- The correlation of the spreading code with a shifted version of itself should be a maximum when the two sequences are aligned and a minimum for all other positions.

For recovery of the information signal in an SR system, it is absolutely essential that the receiver's code sequence be synchronized with the transmitter's sequence. In addition, the desired signal properties and multiple access requirements will dictate the nature of the PN codes that

will be employed by a Spread Spectrum system. The following sections deal with these issues.

2.4.1 Synchronization

Synchronization, the process by which a locally generated spreading signal is synchronized with a received Spread Spectrum signal is usually carried out in two stages; Acquisition and Tracking.

Acquisition refers to the initial synchronization of Spread Spectrum signals where uncertainties in time and frequency exist. Although the receiver is capable of generating an exact replica of the spread signal, before acquisition the receiver does not know at what point in the PN sequence the transmitter is operating. Most acquisition methods perform an initial correlation of the locally generated PN code with the received signal to generate a measure of the similarity between the two signals. If the measured correlation exceeds a certain threshold the signals are declared to be synchronized and a tracking loop takes over. If the measured value is below the threshold the receiver must perform some sort of a systematic search in order to determine the correct phase of the Spread Spectrum signal. This can be done by making a phase or frequency change to the locally generated code and re-measuring the correlation value.

The search can be done in a parallel or serial manner. In a parallel search, the received signal is simultaneously compared to a number of replicas of the PN code with varying amounts of delay. The replica which produces the highest degree of correlation is then chosen. While this method can greatly speed up acquisition of the signal, the number of correlators or matched filters required for such a system can be quite large. For this reason it is often more economical to use a serial search method.

Serial search methods use a single correlator or matched filter to measure the correlation between the received and locally generated signals. The phase of the locally generated signal is then varied after each correlation measurement until the threshold value is exceeded and synchronization is obtained. While serial search methods greatly reduce the complexity of the receiver, acquisition time can be much longer. A Sliding Correlator is most commonly used to obtain initial Acquisition of a Direct Sequence signal. A sliding correlator uses a chip rate clock which differs in frequency from the transmitted chip clock such that the two PN sequences continuously slide past each other. A correlator is used to detect the point of synchronization between the two codes.

After Acquisition, synchronization is maintained by a tracking circuit in the receiver. The two most common types of tracking circuits are the Delay Locked Loop (DLL) and the Tau-Dither Loop (TDL). Both types of circuits make use of one or more correlators and a feedback loop to synchronize the locally generated code for maximum correlation with the received signal.

2.4.2 Code Selection

In addition to the pseudo-randomness requirement, there are many considerations to be made when choosing a spreading code.

Chip Rate

The chip rate, defined as the clock rate of the modulating PN code can have an effect on the RF bandwidth and range resolution of a Spread Spectrum system.

In Direct Sequence systems the chip rate largely determines the RF spectrum occupied, therefore determining the processing gain of the system. Furthermore, in Direct Sequence ranging and direction finding systems the chip rate determines the range resolution capabilities.

The RF bandwidth utilized (and hence the processing gain) in Frequency Hopping systems is determined by the number of frequency channels used and is independent of the chip rate however, a faster chip (hop) rate may improve system performance in the presence of interference.

While faster chip rates may be beneficial in some instances, systems with chip rates over 100 Mchips/s may be difficult to implement. Such systems would require extremely fast processing capabilities to generate and synchronize the spreading codes.

Correlation Properties

Correlation refers to the degree of similarity between two waveforms. Autocorrelation is a measure of the similarity between a signal and a phase-shifted replica of itself while cross-correlation is a similar measure for two different signals. Figure 2.5 shows a pulse waveform and its corresponding autocorrelation function. Note that the autocorrelation

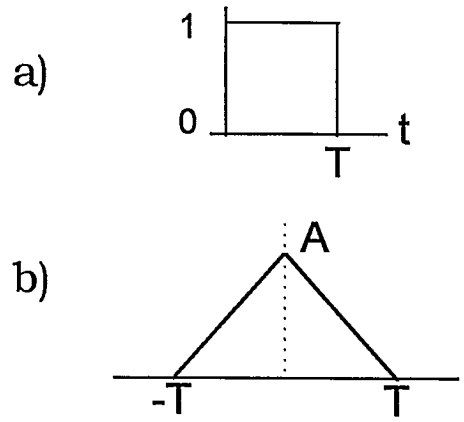


Figure 2.5
a) Binary pulse b) Autocorrelation function

function is a maximum when the shifted replica of the pulse is perfectly aligned with the original pulse (point A in Figure 2.5b).

It is important to select codes with a good autocorrelation function to reduce the chances of a false synchronization. In practice, the autocorrelation function may have a number of peaks which can cause some ambiguity in synchronization. A good code sequence will have one main peak and a minimum number of secondary peaks in its autocorrelation function. Maximal codes are a class of codes that have highly desirable autocorrelation properties.

Cross-correlation of codes is an important consideration when using Code Division Multiple Access (CDMA). It is important that the degree of correlation between different codes be minimized so that receivers can discriminate between signals.

In general, longer code sequences provide a greater number of independent code sequences which can meet the autocorrelation and cross-correlation requirements. This is an important consideration for CDMA systems in which a large number of users must share the same band of frequencies. Composite codes such as Gold codes are combinations of linear maximal codes which are not maximal but give a large number of individual codes with good cross-correlation properties.

2.5 Multiple Access Using Spread Spectrum

In any communications system where many users must share resources (bandwidth) a multiple access scheme must be adopted. There are three basic multiple access techniques, namely: Frequency Division Multiple

Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA).

In FDMA systems, each user operates in a unique frequency channel. Only those signals which fall into the desired channel are recepted, everything else is filtered out. FDMA is used in Television and Radio broadcasting and is the most widely used multiple access scheme for Radio-Frequency (RF) communications.

In TDMA systems individual users may share the same frequencies, however each user is only allowed to use the channel for a fraction of the time. Users are allotted time slots within a fixed-length frame. TDMA systems require precise timing coordination between users and may be difficult to implement in an RF system where propagation delays are highly variable. Many satellite communication systems use a form of TDMA.

CDMA systems are uniquely different from FDMA, and TDMA systems in that many users may transmit simultaneously at the same frequency. By using carefully chosen spreading codes, a single receiver can effectively ignore all but its intended signal, all other signals will appear as noise.

The mechanism for tuning out unwanted signals is different for Direct Sequence and Frequency Hopping systems. In Direct Sequence systems, the cross-correlation properties of the PN codes determine the amount of isolation between users whereas in Frequency Hopping systems, hop sequences (determined by the PN code) are chosen such that separate transmitters do not transmit on the same hop channel at the same time. In this respect, CDMA systems that use Frequency Hoppers can really be thought of as a hybrid of TDMA and FDMA systems.

2.5.1 Capacity of CDMA systems

The factor that determines the capacity of a CDMA system is the jamming margin of the individual receivers. The jamming margin is defined as the amount of interference a receiver can withstand while still producing a usable output signal. One unique property of CDMA systems is that as the number of users increases the level of interference seen by each user increases however, the users may still be able to operate subject to a degradation in performance. In TDMA and FDMA systems exceeding the capacity of the network may not be possible at all. In this respect CDMA systems degrade gracefully while FDMA and TDMA systems tend to be go-no go.

2.6 Direct Sequence vs. Frequency Hopping

Because Direct Sequence systems and Frequency Hopping systems are inherently different, the properties of each must be considered when choosing which technique to use. Table 2.1 gives some of the advantages and disadvantages of each method.

Table 2.1
Comparison of Direct Sequence and Frequency Hopping Modulation

DIRECT SEQUENCE	FREQUENCY HOPPING
Advantages	**Advantages**
• good range resolution • noise-like spectrum, low power spectral density, signal can be hidden in noise • can operate below ambient noise • can operate without error correction codes • more robust than FHSS • potentially lower cost • supports more equal-power users per unit of bandwidth • low interference to co-existing discrete frequency or Spread Spectrum systems within near-far constraints • Less susceptible to local TX WB noise including other DS units. • Initial synchronization more difficult by faster. For even faster synchronization, use short synchronization code, and a long spreading code. Care is needed to avoid false locks. Need tracking loop to maintain synchronization. • god voice quality with analog or digital modulation • more multipath resistant when delays exceed chip time. Inherent frequency diversity resists narrowband flat fading • high resolution in ranging • signal paths must be reasonably linear. The receiver circuits before the correlator should limit at least P.G. above largest desired signal. • more amenable to general purpose IC implementation than Frequency	• reduced RF power levels • low susceptibility to typical RF problems such as jamming and interception • operates in unlicensed bands • multiple access within frequency band is facilitated • signals can be difficult to detect by unauthorized listeners • higher permitted transmitting power (by FCC) • widely used in WLANs (2/3 of present companies including NCR, California Microwave, O'Neill Communications, Windata, Symbol Technologies, Proxim, Digital Ocean, Telesystems SLW, Xicom, and Dayna Communications.) • relatively large unused bandwidth (85 MHz) • best near-far performance. Can co-site multiple transceivers especially if T & R channel sets are separated and bandpassed • operates will with nonlinearity in signal path • easier to synchronize • high throughput speeds than DS • easier to implement than DS • fewer users per unit bandwidth • narrow instantaneous bandwidth, therefore signal presence easily detected • discrete frequencies or sub-bands can be deleted to circumvent interference • can withstand several narrowband

Hopping

in-band interferes much stronger than the desired signal. However, it is susceptible to local TX WB noise

- less critical code design. CDMA possible with codes of moderate orthogonality
- Code balance is not as important. The codes are typically slower, shorter (according to no. of channels) and output in parallel
- initial synchronization is easier but takes longer (SFH). It uses a short preamble for acquisition, time hops from there. Can track for longer intervals by means of local timer than in DS
- secure against casual eavesdroppers, especially if data modulate
- delay spreads may impact very fast data. Inherent frequency. diversity resists fading but whole hops may be lost in narrowband flat fades
- accommodates signal path non-linearities well at least up to compression level

Disadvantages

- near far performance worse than Frequency Hopping. Cannot co-site multiple transceivers unless T&R channels are separated and bandpassed. Power control can help. TDMA reduces near-far and cross-correlation problems of CDMA, but could introduce synchronization problems
- requires linear signal path
- synchronization more difficult
- harder to implement that FHSS
- lower throughput speed than FHSS
- employs contiguous spectrum and therefore must accept all signals in this spectral window
- susceptible to single in-band above jamming margin. This is a major weakness but can be offset by using FDMA or TDMA
- Code design more critical. Need good index of discrimination for

Disadvantages

- relatively complex systems as compared to system using standard modulation schemes - leading to increased cost
- SS chipsets (standard components) not widely available yet
- low data rate bandwidth limited - even with multiple frequencies, total bandwidth available to Spread Spectrum systems is inadequate to support more than about 1Mbps, only a tenth of the minimum 10 Mbps required to be compatible with current wired LAN data rates. It needs fast-switching synchronization, and data buffers for continuous data
- Boosting the data rate tends to reduce the range. Adding base stations solve problem but add cost and can cause interference problems with cellular phones, FM

reliable synchronization detection and good CDMA performance as well as to aid near-far performance. Code must be balanced to avoid discrete spectra. The codes are typically fast and long and are output serially.

- Less secure against casual eavesdropping, especially if analog modulated.

radio, and upper end of the UHF television band.

- higher power consumption
- requires error correction codes
- poor range resolution
- narrow instantaneous bandwidth
- must have positive S/N ration
- not as robust as DS
- must have a positive signal to noise ratio
- will interfere pathologically with co-sited DS systems sharing common spectrum
- susceptible to local TX WB noise including DS transmitters
- voice quality is poor unless digitized
- low resolution in ranging
- harder to design general purpose IC's because synthesizer designs are more application specific

To say that one method is better than the other would be meaningless without considering the intended application. In practice, the decision to use Direct Sequence or Frequency Hopping modulation is dependent on:

- what features the product must possess
- what physical and electromagnetic interference is anticipated (i.e. what other systems occupy the same frequency band)
- the technical expertise of the designer (Frequency Hopping is considered the more difficult of the two)
- the price point of the product

3. SPREAD SPECTRUM IN THE ISM BANDS

A major incentive for using Spread Spectrum techniques is that there are no licensing requirements for Spread Spectrum systems operating in the Industrial Scientific and Medical (ISM) frequency bands. Table 3.1 lists the three ISM bands and their respective bandwidths.

Table 3.1
ISM Band Allocations

Frequency Band	Available Spectrum
902 - 928 MHz	26 MHz
2400 - 2483.5 MHz	83.5 MHz
5725 - 5850 MHz	125 MHz

The ISM bands are multi-use bands and hence any systems operating in those bands must be able to tolerate interference from other users while limiting the amount of interference generated. Table 3.2 lists some of the occupants of the three ISM bands.

From Table 3.2, it is evident that the 900Mhz band is the most crowded of the three bands. It is also the smallest of the three. The 2.4 GHz (2400 MHz) band is attractive due to the absence of other interferers and its relatively low frequency (as compared to 5.7 GHz). The 2.4 GHz band is also the only one of the three which has been set aside for unlicensed use in Europe.

3.1 FCC Regulations for Spread Spectrum Systems

Spread Spectrum systems must meet certain criteria in order to qualify for unlicensed operation in the ISM bands. The spectrum allocation branch of Industry Canada is responsible for establishing guidelines for ISM operation in Canada while the Federal Communications Commission (FCC) covers US spectrum allocations. Due to the larger market potential in the US and the similarity of Canadian and US spectrum allocation policy this report will only consider the FCC guidelines[2].

[2] Information on Canadian regulations can be obtained from Industry Canada's Telecommunications Policy Branch.

Table 3.2
ISM Band Occupation

902-928 MHz	2400-2483.5 MHz	5725-5850 MHz
Vehicle location systems (licensed): up to 2000 W (fixed) up to 15 W (mobile) Old microwave ovens: up to 750 W Spread Spectrum users: Up to 1 W Industrial heaters: 50 000 - 100 000 W Military radars: up to 1 000 000 W	Microwave ovens: up to 900 W Spread Spectrum users: up to 1 W	Spread Spectrum users: up to 1 W Licensed users: up to 10 W

Regulations for unlicensed operation in the ISM bands are listed in Parts 15.247 and 15.249 of the FCC's Code of Federal Regulations. Unlicensed operation is limited to Direct Sequence and Frequency Hopping systems.

3.1.1 Direct Sequence Systems

Direct Sequence systems must satisfy the following requirements:

- Minimum 6 dB bandwidth of 500kHz
- Maximum peak output power of 1 Watt
- If directional antennas of gain greater than 6dBi are used, transmitter output power must be reduced by the amount in dB that the antenna gain exceeds 6dBi
- The transmitted power density averaged over any 1 second interval must be less than 8 dBm in any 3 KHz bandwidth within the ISM bands
- The processing gain must be at least 10 dB

In addition to the above criteria, there are guidelines for out of band emissions which are similar to guidelines for other frequency bands.

3.1.2 Frequency Hopping Systems

Frequency Hopping systems are subject to the following requirements:

- Hopping channel carrier frequency separation of at least 25kHz or the 20dB bandwidth of the hopping channel, whichever is greater
- Hopping channels must be selected from a pseudorandomly ordered list of hopping frequencies

- Frequency Hoppers operating in the 900MHz band must use at least 50 hopping channels with a maximum allowed 20dB bandwidth of 500kHz
- Frequency Hoppers operating in the 2.4 and 5.7GHz bands must use at least 75 hopping channels with a maximum allowed 20dB bandwidth of 1 MHz
- Maximum peak output power of 1 Watt
- If directional antennas of gain greater than 6dBi are used, transmitter output power must be reduced by the amount in dB that the antenna gain exceeds 6dBi

3.2 Obtaining FCC Approval

Spread Spectrum ICs or modules should be designed with regulatory considerations in mind so that Original Equipment Manufacturers (OEMs) that integrate them in their communications products do not have to do unnecessary design work in order to meet FCC specifications.

Proper testing of Part 15 compliant systems requires an appropriate test set up and in most cases is best left to a testing agency. Extremely stringent testing is performed for FCC Part15 approval and fines have increased tenfold over the last few years so it is important to choose a testing agency that has extensive experience in EMI testing.

For products defined as intentional radiators a filing fee of $800 US is required by the FCC. Certification can cost on the order of $6000 US for Part 15c compliant systems.

4. MARKET FORECASTS

The worldwide high technology sectors have been growing at an astonishing rate over the last twenty years. Computers have become the dominant means of data communications in all sectors of the economy. The advent of the Canadian Internet and National Test Network is bringing Canada to the world and the world to Canada. With the emergence of the virtual office and the increasing importance of customer relations, workers are spending an more and more time away from the office. Experts estimate that as many as fourty percent of workers are classified as roaming, meaning they are away from their desks for two or more hours a day. The need to maintain contact with a large number of roaming workers has led to the development of a strong market demand for wireless products. The Cellular Telecommunications Industry Association (CTIA) believes that over the next decade, "wireless devices and wireless networks will be the dominant mode of communications in the United States." Arthur D. Little, Inc., a Boston-based management and technology consultant has told his clients that half of all telecommunications traffic in North America will be wireless by the year 2000.[3]

The key to the rise and future stability of the wireless communications market is the ability to transmit information reliably, in tact and at a bandwidth high enough to transmit multimedia information. Wireless technology has only recently reached the point of commercial viability for high-speed data transmission. The emergence of Spread Spectrum modulation as a commercially available medium of transmission has allowed the development of wireless products with the performance necessary to become a viable alternative to wired systems. This has led to a sharp increase in wireless hardware product sales and the number of product manufacturers.

The wireless hardware products market is divisible into three categories. The first to be examined is wireless LAN systems that allow for the radio transmission of data. The wireless LAN market is further defined into LANs used to transmit data within a building (inter-building) and between two buildings (intra-building). The second category of wireless product examined in this study is the integrated products market. This comprises products that are able to transmit voice and data information between two points. Examples of wireless integrated products include wireless modems and personal digital assistants. The final category under examination is wireless voice hardware products market, which are Centrex, public branch exchange (PBX) and key telephone systems

[3] From: Wireless Personal Communications, page 3.

wireless units. These products create an in-building wireless telephone network that is person-to-person rather than station-to-station.

Note: The wide area wireless voice products market (e.g. cellular telephone networks) was not examined. A significant market exists in this field, but is a highly competitive, mature market.

The markets outlined above are currently being dominated by companies using Spread Spectrum modulation in their designs. The purpose of this market study is to assess these potential wireless markets, and to outline the barriers to entering these markets.

4.1 Total Wireless Hardware Products Market

The wireless hardware products markets including the wireless transmission of voice, video and data is expected to experience explosive growth in the 1990s. From a relatively small market with sales of 7.3 billion dollars in 1990, it is expected to grow at a compound annual growth rate of 52.4 percent to reach sales of 1.9 billion dollars by the year 2000. (see Figure 4.1 and Table 4.1)

Figure 4.1
Total Wireless Office Hardware Products Market
Revenue Forecasts (U.S.), 1990-2000

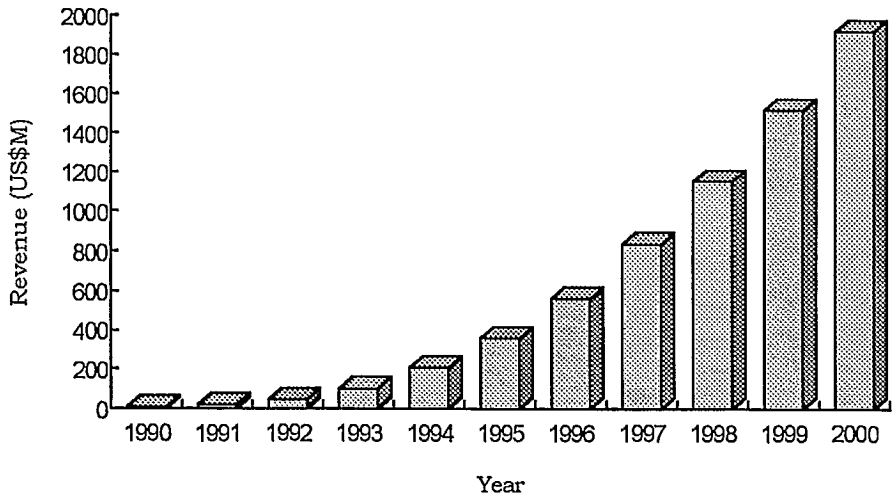


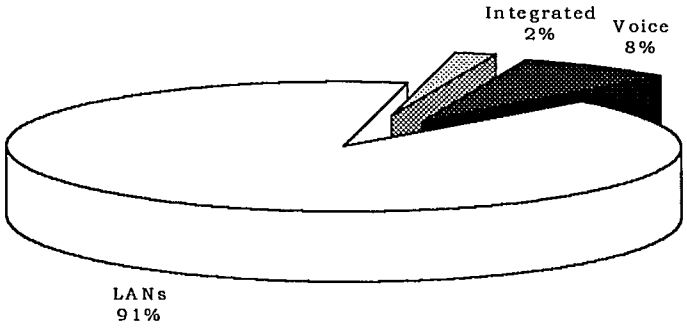
Table 4.1
Total Wireless Hardware Products Market
Revenue Forecasts (U.S.), 1990-2000

Year	Revenues ($ Million)	Revenue Growth Rate (%)
1990	7.3	---
1991	19.4	165.8
1992	44.2	127.8
1993	100.7	127.8
1994	206.1	104.7
1995	359.7	74.5
1996	565.3	57.2
1997	836.9	48.0
1998	1,155.9	38.1
1999	1,522.1	31.7
2000	1,923.1	26.3

Compound Annual Growth Rate (1993-2000): 52.4 %
Source: Frost & Sullivan: U.S. Wireless Office Hardware Product Markets

Wireless LANs are anticipated to account for the majority of this market segment by the year 2000.

Figure 4.2
Wireless Hardware Products Market
Year 2000



The explosive growth of the industry can be attributed to a number of factors.

The increasing use of computers has lead to a need for individuals to remain connected to their company networks at all times. The growth of Internet allows individuals to access their computer networks from virtually anywhere. CA*net, the Canadian arm of the Internet, has grown since it's inception in 1989 to include all ten provinces and two territories, and has three connections to the United States Internet. However there still remains a large area where access to the Internet is impossible. Wireless technology allows users to access the Internet from remote locations and to establish temporary facilities. Congressman Rick Boucher, chairman of Brown's Subcommittee on Science, when asking the Congressional Office of Technology Assessment (OTA) to study the role that wireless communication technology might play in the National Information Infrastructure stated; "If we're not careful, wireless technologies could well be the 'missing link' in the construction of a national information infrastructure that is capable of fully servicing all Americans."

Companies are putting a new emphasis on the virtual office. Executives want their sales forces to spend more time with the customers and less time at their desks. Consequently there is growing interest in wireless applications as a means of keeping "roaming" users in contact with their customers, office and computer information. This has led to an increasing interest in a number of wireless applications including personal digital assistants (PDAs), wireless in-building and wide area network telephone systems and wireless modems.

The largest single inhibitor to the acceptance of wireless technology has traditionally been the lack of performance. Wireless products have been plagued by low data rates, unreliable transmission, susceptibility to interference, security breaches and high costs. Technological advancements including the utilization of Spread Spectrum modulation have increased performance and reliability to a level acceptable to users. Data rates capable of multimedia applications (1.6Mbps) have been achieved with some vendors boasting data rates of 10 Mbps or more. As chipsets and integrated products become more commonly available, prices continue to drop and are now very competitive with wired LANs. While it is unlikely that wireless products will ever completely replace the wired voice or data LAN, they have demonstrated an advantage in a number of applications in which wired LANs are not feasible for either financial or logistical reasons.
Finally, a great deal of time and money has been spent by wireless vendors to educate potential users to the attributes of wireless products.

Users now rate acceptance of the technology and safety issues far below that of cost and performance.

4.2 Wireless LANs Hardware Products Market

Introduction

Wireless Local Area Networks (LANs) are used for the wireless transmission of data between two or more points. This includes portable computers, personal communication services (PCS) and personal digital assistants (PDA).

Wireless LANs can be classified into two categories:

Inter-building: transmit between two buildings.

Intra-building: is used within the walls of a building

Estimated Revenues to the Year 2000

Market analysts predict significant growth in the wireless LAN market through the year 2000. The wireless LAN market had sales of US$7.3M in 1990, this is anticipated to rise to US$1.7B by the year 2000. (see Figure 4.3 and Table 4.2)

Wireless intra-building LANs are expected to capture a large percentage of this market with sales of US$1.2B by the year 2000. Inter-building LANs are expected to achieve sales of US$525M by the year 2000. (see Figure 4.4 and Figure 4.5)

Of the total wireless LAN market, wireless LANs using radio frequency transmission are expected to comprise sixty five percent of the total market by the year 2000 with sales of approximately 1.7 million. All of the manufacturers of radio frequency wireless LAN products today are using Spread Spectrum techniques. There is considerable debate on the virtues of Direct Sequence compared with Frequency Hopping. The decision on which process to use will be determined by the intended use of the application, and the particular obstacles that must be overcome in that application.

Figure 4.3
Total Wireless LAN Hardware Products Market
Revenue Forecasts ($US), 1990-2000

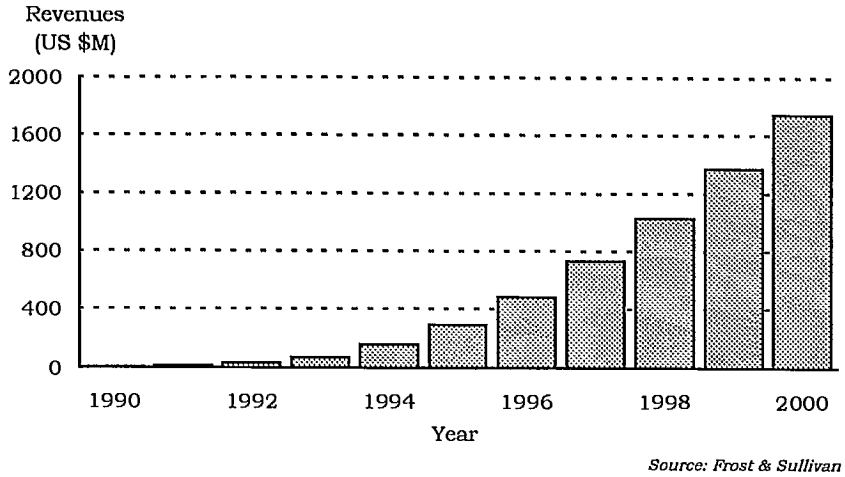


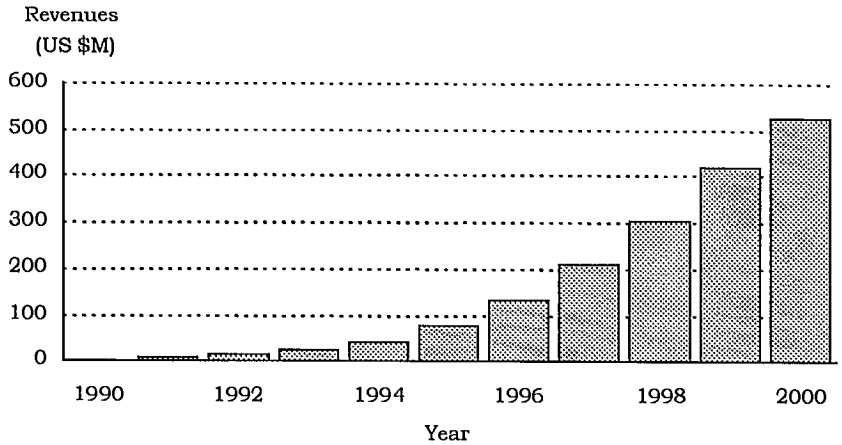
Table 4.2
Total Wireless LAN Hardware Products Market
Revenue Forecasts (U.S.),
1990-2000

Year	Revenues ($ Million)	Revenue Growth Rate (%)
1990	7.3	---
1991	15.4	111.0
1992	34.2	122.1
1993	68.0	98.8
1994	155.5	128.7
1995	292.6	88.2
1996	480.2	64.1
1997	731.1	52.2
1998	1,026.8	40.4
1999	1,367.4	33.2
2000	1,740.6	27.3

Compound Annual Growth Rate (1993-2000): 58.9 %
Source: Frost & Sullivan: U.S. Wireless Office Hardware Product Markets

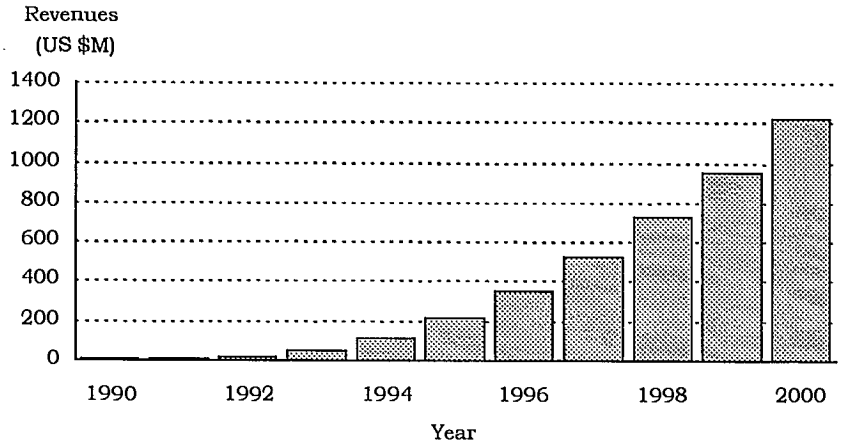
Figure 4.4

Wireless Inter-Building LAN Hardware Products Market
Revenue Forecasts ($US), 1990-2000



Source: Frost & Sullivan

Figure 4.5
Wireless Intra-Building LAN Hardware Products Market
Revenue Forecasts ($US), 1990-2000



Source: Frost & Sullivan

Target Market

The greatest market potential exists in applications where wired LANs are not feasible or are not cost effective. There are several applications in which a wireless LAN is better suited:

1. Facilities that are temporary (e.g. military camps and trade shows)

2. Where there is a high percentage of "roaming" workers, meaning they spend more than 2 hours per 8-hour day away from their desks. (e.g. university personnel and warehouse workers)
3. Where workstations are changed frequently (e.g. rapid expansion, banks)
4. Where the facility cannot be wired. (e.g. historic buildings or older building)
5. Where high speed and data rates are not essential

Best Market Prospects include:

- transportation and communications
- factories and warehouses
- retail stores
- higher education campuses
- trade shows
- hospitals
- military bases
- older historical buildings

Emerging Markets:

- banks
- commercial offices

Customer acceptance of the product or technology

Wireless LAN companies have expended a great deal of time and money educating prospective clients. The primary goals are to address concerns over health issues associated with using wireless products and to educate clients as to the features and benefits of wireless products. To this end, currently wireless producers have largely been able to accomplish this goal. This is reflected in the fact that the majority of systems managers see a lack of standards and security issues as more of a concern than health issues or functionality.

Spectrum Allocation

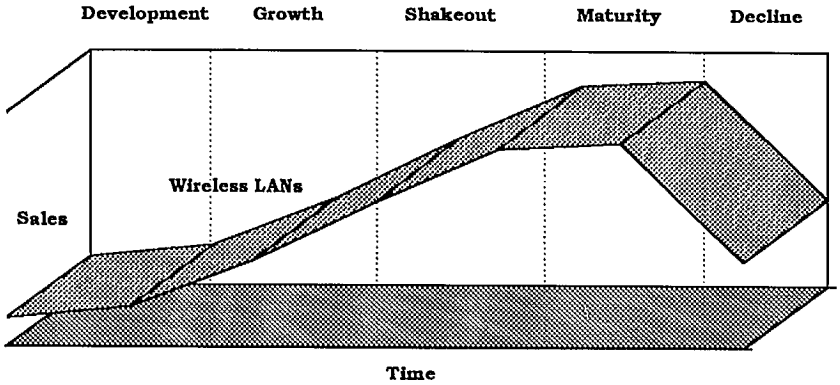
Wireless LAN products fall into 3 categories:

- unlicensed ISM (industrial, scientific and medical) frequency band comprised of:
  - ◊ 902-928 MHz
  - ◊ 2,400-2483.5 MHz
  - ◊ 5,725-5,875 MHz
- licensed narrowband (18MHz) band
- Unlicensed PCS frequency

Position on the growth curve

Wireless LANs are positioned to experience significant growth in the next five years (see Figure 4.6). Market knowledge and acceptance of the benefits of wireless LANs, increased performance, reduced costs, and the anticipated adoption of a common standard has positioned wireless LANs to make the move from a development to a growth period.

Figure 4.6
Product Growth Curve



Sources: Adapted from Collins & Doorley, Teaming up for the 90s, Speeding Toward the Interactive Multimedia Age, Deloitte & Touche, 1994

Industry Participants

The US wireless LAN market consists of approximately 19 companies. Only two of these companies are large multinationals or are subsidiaries of large multinationals. The remaining companies are small or medium sized companies.

Reasons to Enter

- young emerging market
- technological advancements are increasing functionality while reducing costs
- standards will likely be in place by the end of 1995
- high user knowledge and acceptance of the WLANs
- move to higher employee mobility and need for remote access
- ATM is emerging as a better LAN with no compatible Wireless products
- limited number of players in the market with a high majority of them being small or medium size
- Spread Spectrum technology can solve a number of the transmission, security and reliability issues.

Barriers to Entry

- standards have yet to be confirmed
- requires considerable technological expertise market of interest to a number of larger companies
- Ethernet, token ring and or ATM compatibility
- low cost transmission
- appropriate software to handle connections efficiently
- operating systems with built in communications features
- throughput data rate capable of multimedia transmission
- high reliability
- secure transmission

best to develop a hybrid unit that will work on both an inter and intra basis depending on the customer's choice.

Table 4.3
Wireless Office Hardware Products Market 1994

Company	Inter-building LANs	Intra-building LANs
AIRONET Wireless	X	X
Alps America		X
A.T. Schindler Communications	X	X
AT&T GIS	X	X
DATA RACE		X
Digital Ocean		X
IBM		X
Laser Communications	X	
Motorola	X	X
Noranda		X
O'Neill Connectivities		X
Persoft	X	X
Photonics		X
Proxim	X	X
Solectek	X	
Spectrix		X
Telxon		X
WiLAN		X
Windata	X	X
Xircom		X

4.3 Wireless Integrated Hardware Products Market

Introduction

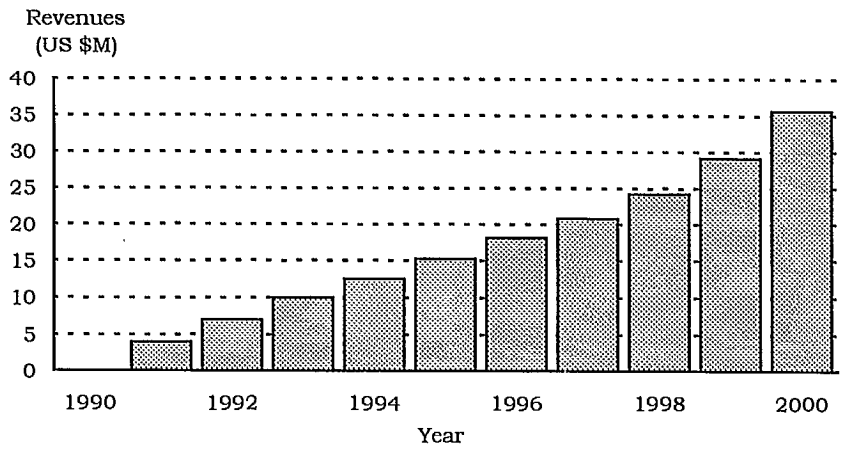
Integrated products are devices capable of transmitting voice and data between 2 points. Example of this are modems, personal digital

assistants and bridge-type "boxes". This market is in it's infancy in the United States. Currently the only wireless integrated products available are for inter-building units, intra-building units are still in development.

Estimated Revenues to the Year 2000

Figure 4.7 shows estimated revenues for wireless integrated products to the year 2000.

Figure 4.7
Wireless Integrated Hardware Products Market
Revenue Forecasts ($US), 1990-2000



Source: Frost & Sullivan

Estimated Target Market

Because of the early stage of development of these products, clear markets have not been established. However the need of many industries to be able to transmit voice and data will spawn many applications.

Best Market Prospects include:

- roaming workers
- transportation companies
- factories and warehouses
- hospitals
- universities, military bases and other "campus" environments
- remote detection and monitoring (i.e. trucks, planes, hazardous material, patients)

Table 4.4
Wireless Integrated Hardware Products Market

Revenue Forecasts (U.S.),
1990-2000

Year	Revenues ($ Million)	Revenue Growth Rate (%)
1990	---	---
1991	4.0	---
1992	7.0	75.0
1993	10.0	42.9
1994	12.5	25.0
1995	15.3	22.4
1996	18.1	18.3
1997	20.8	14.9
1998	24.2	16.3
1999	29.1	20.2
2000	35.6	22.3

Compound Annual Growth Rate (1993-2000): 19.9 %
Source: Frost & Sullivan: U.S. Wireless Office Hardware Product Markets

Customer acceptance of the product or technology
While there is growing customer interest in wireless integrated products, a lack of product knowledge and development has precluded any mass adoption of the technology. The inherent difference between how voice and data is transmitted (data being asynchronous and voice transmission being synchronous) is a significant barrier to developers. Current products are only able to transmit relatively low level information at slow speeds, limiting their functionality. Customer education remains low due to the lack of products and small number of vendors.

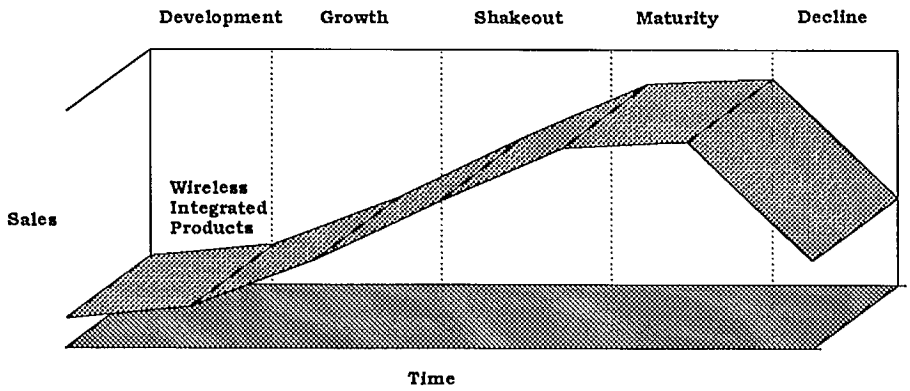
Spectrum Allocation
In the Federal Communication Commission (FCC) spectrum allocation plan tabled September 1993, it allocated 20 MHz for data transmission and 20 MHz for voice transmission applications in the unlicensed portion of the spectrum for the development of integrated products. Rumors persist that the FCC will modify this plan by reducing each of these allocations by 10 MHz. There is growing fear amoung industry watchers

that there may not be enough spectrum allocated for intra-building wireless transmission. The FCC recently presented a ruling which restricts the way in which manufacturers can package their wireless inter-building devices. This, coupled with a lack of standards development in this area has left a great deal of uncertainty in the integrated products market with regard to product development.

Position on the growth curve

The wireless integrated products development market is still in the early product development stage (see Figure 4.8).

Figure 4.8
Product Growth Curve



Sources: Adapted from Collins & Doorley, Teaming up for the 90s, Speeding Toward the Interactive Multimedia Age, Deloitte & Touche, 1994

Industry Participants

There are only two competitors in the wireless integrated voice and data market today. Cylink, which is becoming a large multinational has 94% market share and Transformation Techniques which has less than 10 employees hold the remaining 6% market share. Transformation Techniques is seen by industry analysts as an up and coming company with a good product line.

Table 4.5
Wireless Integrated Hardware Products Market
Company Market Share by Revenues (U.S.),
1993

Company Name	Market Share (%)
Cylink.....	94
Transformation Techniques.....	6

TOTAL.....	100

Source: Frost & Sullivan: U.S. Wireless Office Hardware Product Markets

Reasons to Enter

- very few competitors
- strong interest in wireless integrated products

Barriers to Entry

- lack of formal standards
- technological difference between the transmission of voice and data makes product development very difficult
- low customer knowledge and acceptance of products

4.4 Wireless Voice Hardware Products Market

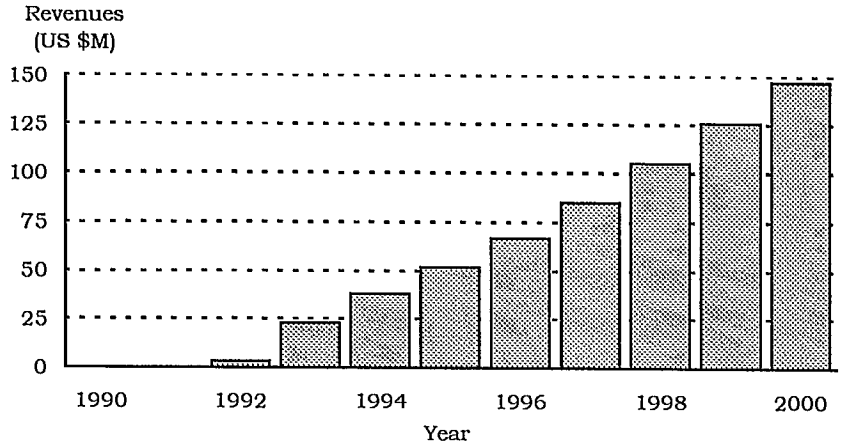
Introduction

The hardware products referred to in this market segment include public branch exchanges (PBX), and Centrex based wireless telephone systems for in-building use. The goal of the industry is to create an in-building wireless communication system that is person-to-person based rather than station-to-station based. This is not to be confused with the cellular telephone industry, which operates over wide area networks. A typical wireless adjunct or stand-alone system is comprised of portable telephone handsets, control units, and radio base stations. This will allow individuals to be contacted directly regardless of their location in the facility. One market organization estimates that there are 48 million workers in the United States alone that would be classified as mobile, meaning they are frequently away from their work areas but remain within the building.

Estimated Revenues to the Year 2000

Figure 4.9 shows estimated revenues for wireless integrated products to the year 2000.

Figure 4.9
Total Wireless Voice Hardware Products Market
Revenue Forecasts ($US), 1990-2000



Source: Frost & Sullivan

Table 6
Total Voice Hardware Products Market
Revenue Forecasts (U.S.),
1990-2000

Year	Revenues ($ Million)	Revenue Growth Rate (%)
1990	---	---
1991	-----	---
1992	3.0	---
1993	22.7	656.7
1994	38.1	67.8
1995	51.8	36.0
1996	67.0	29.3
1997	85.0	26.9
1998	104.9	23.4
1999	125.6	19.7
2000	146.9	17.0

Compound Annual Growth Rate (1993-2000): 30.6 %
Source: Frost & Sullivan: U.S. Wireless Office Hardware Product Markets

Estimated Target Market

Best Market Prospects include:
In-building (low power) cellular phone market:

- white collar companies
- healthcare facilities
- mines and other industries with sensitive equipment
- manufacturing
- warehousing
- higher education facilities
- retail
- military bases

Customer acceptance of the product or technology
Owing to the underdeveloped nature of the market, manufacturers are being forced to educate the market to the benefits and features of the products, in addition to selling their own product. While this is true, the widespread acceptance of WAN cordless phones will greatly reduce the education time.

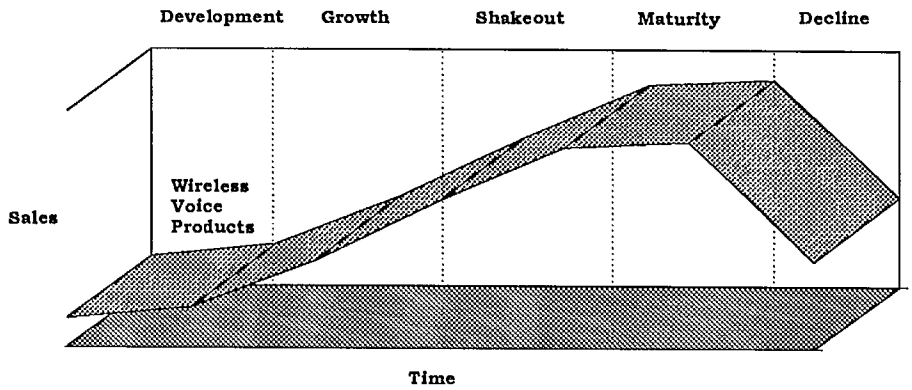
Spectrum Allocation
In September of 1993, the FCC released a plan to divide 160MHz of available frequency into many different-sized parts to be allocated under a number of different rules. This has raised a number of concerns by industry experts and potential users.

- The method of spectrum allocation is very complex which could lead to delays.
- The FCC plans to allocate spectrum in 10MHz channels, with only 1 20MHz channel being included in the initial round. While this spectrum allocation will put recipients in direct competition with existing cellular service providers, the 10MHz allocation is to small to allow them to effectively compete.
- There is a lack of standards, causing many of the products being developed to be stand alone systems. The expected acceptance of the 802.11 working group proposal in the fall of 1995 will eliminate this barrier.
- There is a fear that the auction process is too slow to keep up with new technologies.

Because of these industry concerns, the FCC is reconsidering the form in which spectrum will be allocated. Many potential entrants into this market are waiting to see what changes the FCC makes before deciding whether or not the enter the market.

Position on the growth curve

Figure 4.8
Product Growth Curve



Sources: Adapted from Collins & Doorley, Teaming up for the 90s, Speeding Toward the Interactive Multimedia Age, Deloitte & Touche, 1994

Industry Participants

Currently, there are only a small number of manufacturers in this market. The establishment of standard governing product development and the resolution of FCC spectrum allocation issues will result in a number of large companies entering the market.

Reasons to Enter

- only 10 major companies in the US wireless in-building voice products market. However most of the 10 are or are partnered with major companies (i.e. Panasonic and Southwestern Bell)
- Spread Spectrum provides greatly improved performance over analog systems
- large market

over fourty percent of workers are classified as roaming which means they spend more than 2 hours a day away from their desks, either in the building or outside

Table 7
ISM Wireless Voice Hardware Products Market:
List of Selected Companies by Product Type (U.S.),
1994

Company Name	902-928 MHz	2400-2483.5 MHz
AT&T GBC	X	
Cincinnati Microwave	X	
Ericsson Business Communications	X	
Panasonic Communications and Systems	X	
SpectraLink	X	
Rose Communications		X*
Uniden America	X	
VTECH Communications	X	

* Rose Communications has subsequently gone bankrupt

Barriers to Entry

- delays in spectrum allocation
- need to purchase bandwidth in most cases
- large players in the game (RBOCs, big telcos - NT, Mitel-lp, Bell South-lp, Panasonic Business Link-lp, Pacific Telesis-lp, GTE-lp)
- manufacturers view currently available spectra in the Part 15 ISM band as a congested, noisy, slapped-together base. Most are waiting the release from the FCC of 20 MHz of unlicensed spectrum for in-building product use before seriously considering entering the market.
- lack of rules regarding the sharing of airwaves. WINFORUM has been created to establish rules.
- there are still some health concerns by users
- lack of customer knowledge

5. APPLICATIONS

The unique properties of Spread Spectrum systems make them suitable for a wide variety of applications. This section describes the most common applications of Spread Spectrum technology.

5.1 Communications

Wireless communications systems are used to transmit voice and data between two or more points. Spread Spectrum systems offer some advantages over narrowband systems such as improved reception in the presence of interference, greater security from eavesdropping and in some cases, a more efficient use of available spectrum. Some applications where Spread Spectrum systems are already in use are in cellular networks (voice and data), cordless phones, wireless modems and wireless LANs and bridges. These subjects will be discussed in more detail in the following sections.

5.1.1 Cellular Telephone and Packet Data Networks

Spread Spectrum technology is applicable to both cellular telephone networks and Cellular Digital Packet Data (CDPD) or paging networks. The need for increased capacity in cellular telephone networks prompted a move towards digital wireless standards. A lot of the recent hype about Spread Spectrum is the direct result of the development of a new standard called IS95 which specifies the use of Spread Spectrum for increasing network capacity by as much as 20 times over existing analog standards. The major proponent of the IS95 standard is Qualcomm Inc. Qualcomm developed the standard and has made licensing agreements with several major service providers and equipment manufacturers for the use of their technology.

The IS95 standard may be applicable to packet data networks as well as cell phone networks since it uses digital technology. Should the IS95 standard be adopted as the new standard for cellular networks, the demand for IS95 compatible products will be enormous to say the least.

5.1.2 Personal Communications Systems

Several Canadian companies have recently been issued licenses to develop Personal Communications Services (PCS). The distinction between PCS and Digital Cellular is not clear and there are as yet no standards relating to PCS systems. What is clear is that PCS systems will operate at frequencies at or near 1.9 GHz, and will employ digital

technology which is capable of transmitting both voice and data. In order to compete with the already established Cellular service providers, PCS service providers will have to offer enhanced services such as higher data rates for wireless E-mail and Internet access. It is possible that an IS95-like standard will emerge for PCS systems. The need to minimize size, weight, cost and power consumption of PCS equipment will necessitate the development of PCS-specific ICs.

5.1.3 Cordless Phones

With the potential for improved range and signal quality using Spread Spectrum and the lack of licensing requirements, cordless phones are an ideal application. There are under half a dozen Spread Spectrum cordless phones on the market today and although they do offer increased performance, they are significantly more expensive than those using other technologies. At 900 MHz, a single-chip solution for cordless phones is feasible. A greater degree of integration will lower the cost of production of Spread Spectrum phones making them cost-competitive with other systems.

5.1.4 Wireless Modems

Wireless modems are used to transmit data between two terminals. Spread Spectrum modems can offer data rates that are higher than even the fastest conventional modems, without the need to be connected to a phone line. With permitted transmitter power levels of 1 Watt, wireless modems can have a range of tens of kilometers.[4] Wireless modems in general do not have any multiple access capabilities and are a niche application, however they are an economical, convenient way of connecting two remote terminals together.

5.1.5 Wireless Bridges

Wireless bridges perform a similar function to wireless Modems. Wireless bridges connect two or more separate networks together. High data rates are extremely important in connecting networks together to eliminate bottlenecks. There are several companies that manufacture wireless bridges and almost all of them use Spread Spectrum technology. It should be noted that narrowband technology is probably better suited to this application, however the use of Spread Spectrum eliminates the need for licensing which is a major motivating factor. With Direct Sequence systems, high data rates require extremely high chip rates

[4]range is dependent on frequency and data rate

hence there is a need for a very fast processor which can handle spreading and despreading at such rates.

5.1.6 Wireless LANs

Wireless LANs allow computers and peripheral equipment to be networked together with RF links. Some wireless LANs simply act as 'wire replacements' and do not perform any routing functions however most wireless LANs have routing capabilities similar to wired LANs. While some wireless LANs use Infrared (IR) transmitters, the majority of them use Spread Spectrum radio technology and operate in the ISM bands. The transmission protocol of choice is Ethernet using a technique known as CSMA-CA which stands for Carrier Sense Multiple Access with Collision Avoidance. The IEEE has developed a draft standard for wireless LANs known as IEEE 802.11. The standard deals primarily with the physical layer of the OSI model for interconnectivity and contains specifications for Direct Sequence systems only.

Traditionally, the lower data rates afforded by wireless LANs have hindered their widespread adoption. Wireless LANs that are currently on the market operate at aggregate data rates of up to 2 Mbits/s. Most wireless LANs make use of Frequency Hopping techniques. Due to the FCC rules for channel widths, Frequency Hoppers are limited in their maximum data rates. With a 1 MHz channel width, throughput is limited to about 1.6 Mbits/s using QPSK modulation. Higher order modulation schemes can improve on this number however, the Bit Error Rate (BER) will increase as well. For this reason, Direct Sequence may be preferable if data rates are to be increased. At 2.4 GHz with 80 MHz available, a Direct Sequence system could transmit up to 6 Mbits/s. As speeds for wired LANs increase and multimedia applications become the norm, Direct Sequence may be the only viable option for wireless LANs.

5.1.7 Communications in Sensitive Environments

There are several situations where ordinary communications systems are unusable due to the amount of Electromagnetic (EM) energy they emit. Two common examples are medical facilities which use sensitive diagnostic equipment and mining operations that use explosives. Because the output power is spread out over a large bandwidth in Direct Sequence systems[5], radiated EM energy is kept low enough for such systems to be used in EM-sensitive environments.

[5] Frequency Hopping systems radiate energy in a similar manner to narrowband systems and are not suitable for EM sensitive communications

5.2 Position Location and Other Applications

One extremely useful property of Direct Sequence[6] systems is their range resolution capabilities. By measuring the phase difference in PN codes between two transceivers, an estimate of the distance between the two can be made. The faster the chip rate, the better the resolution. For example, at a chip rate of 1 Mchips/s a phase difference of one chip corresponds to a 1ʃs propagation time. Since RF signals propagate at the speed of light (300 000 km/s), the range resolution for one chip is 300m. GPS systems use Spread Spectrum signals to compute ranges, and other systems such as Automatic Vehicle Monitoring (AVM) systems use similar techniques.

5.2.1 Global Positioning Systems

GPS receivers communicate with low-orbit satellites in order to establish a position (longitude, latitude and elevation). An accurate timing reference can also be determined using a GPS receiver. GPS receivers not only use Spread Spectrum for ranging, they also make use of a large processing gain to allow them to receive signals that may have negative signal to noise ratios (the received signal is weaker than the noise present at the receiver). In general, the bit rates are extremely low (50 bits/s) in GPS systems as are the code repetition rates (long GPS codes repeat themselves once a week). Synchronization is complicated with such long codes hence a shorter course acquisition code is used to facilitate synchronization. Receivers must synchronize to up to four satellites at once, making the task extremely processor intensive. Prices for GPS receivers will decrease rapidly as integrated receivers become more common.

5.2.2 Automatic Vehicle Monitoring Systems

AVM systems have priority over Part 15 systems operating in the 900 MHz ISM band. AVM systems use triangulation to pinpoint the location of a Spread Spectrum transmitter located in a vehicle. Such systems can be used to recover stolen cars or to facilitate fleet management for shipping and taxi companies. Current AVM systems use somewhat antiquated technology and require a license to operate due to the transmitter power levels. An implementation which could qualify for Part 15 unlicensed status would make the adoption of AVM systems more convenient and economical.

[6] Frequency Hoppers have chip rates which are generally too slow for ranging systems

5.2.3 RF Identification Devices

Because of the unique code-correlation properties of Spread Spectrum systems, such systems can be used for the purposes of identification. Such systems are usually referred to as RF ID systems and can be used in a wide variety of applications such as automatic toll collection, automatic inventory and security systems. The important consideration in RF ID applications is the cost and reliability of the ID tags. A one chip solution would be essential in reducing the cost of such a device to an acceptable level.

5.2.4 Point of Sale Devices

Wireless modems can be incorporated in point of sale devices to allow transactions to be processed by roaming salespersons. Spread Spectrum systems may be useful in such devices due to the inherent security of the transmission and their robustness in unpredictable environments. Data rates of less than 20 Kbits/s are sufficient for such devices but transmission must be error-free necessitating either a large processing gain or some form of error correction.

5.2.5 Summary of System Requirements

Many of the applications described have similar performance requirements. A chip set with suitable characteristics may be useful for many different applications. Table 5.1 lists the key parameters for the applications listed in the previous sections.

5.3 The IEEE802.11 Wireless LAN Standard

One of the most popular uses for commercial Spread Spectrum technology is in the implementation of wireless LANs. The IEEE has developed a draft standard which outlines the Physical Layer specifications for wireless LANs operating in the 2.4 GHz ISM band. The following sections give a summary of the pertinent specifications.

Table 5.1
Summary of System Requirements

Application	Data Rate	Level of Security	Cost	Code Length	Type of Spread Spectrum
Cellular phone/ packet data	<32 Kbits/s	medium	low	long	DS
PCS	32-256 Kbits/s	medium	low	long	DS or FH
Cordless Phones	<9.6 Kbits/s	medium	low	long	DS or FH
Modems	32 Kbits/s - 1 Mbit/s	medium	medium	long	DS or FH
Bridges	1-10 Mbits/s	high	high	long	DS or FH
LANs	256 Kbits/s - 6 Mbits/s	high	high		DS or FH
EM Sensitive Systems	<32 Kbits/s	medium	medium	medium	DS
GPS	<100 bits/s	low	low	long	DS
AVM	<100 bits/s	low	low	short	DS
RF ID	<100 bits/s	high	low	medium	DS or FH
Point of Sale	<32 Kbits/s	high	medium	medium	DS or FH

5.3.1 Physical Layer Specifications for Direct Sequence Wireless LANs

Physical Layer specifications cover data processing elements such as preamble and header generation as well as signal processing elements such as modulation methods and spectrum usage.

The Physical Layer Convergence Procedure (PLCP)
The PLCP bridges the gap between physical layer functions and MAC (Media Access Control) functions. Section 11.2 of the IEEE802.11 draft standard outlines the PLCP specifications.

PLCP Preamble
The PLCP preamble is transmitted using 1 Mbps DPSK modulation and consists of:

- 128 bits of scrambled 1 bits for synchronization
- A 16-bit unique word or start frame delimiter (05CF hex)

- An 8-bit 802.11 signal field which is used to indicate the type of modulation to be used for the transmission of data payload
- An 8-bit 802.11 reserved for future use
- A 16-bit PLCP length field which indicates the number of octets of data payload
- A 16-bit CRC16 field which implements the CCITT CRC16 Frame Check Sequence (FCS)

Figure 5.1 shows the PLCP frame format.

In addition to the frame format, the 802.11 standard specifies that data be scrambled before transmission using the polynomial:

$$1 + x^{-4} + x^{-7}$$

The standard also specifies that the PLCP preamble be transmitted using 1 Mbps DBPSK modulation and that the data payload be transmitted using either 1 Mbps DBPSK modulation or 2 Mbps DQPSK modulation as specified in the 802.11 signal field of the preamble.

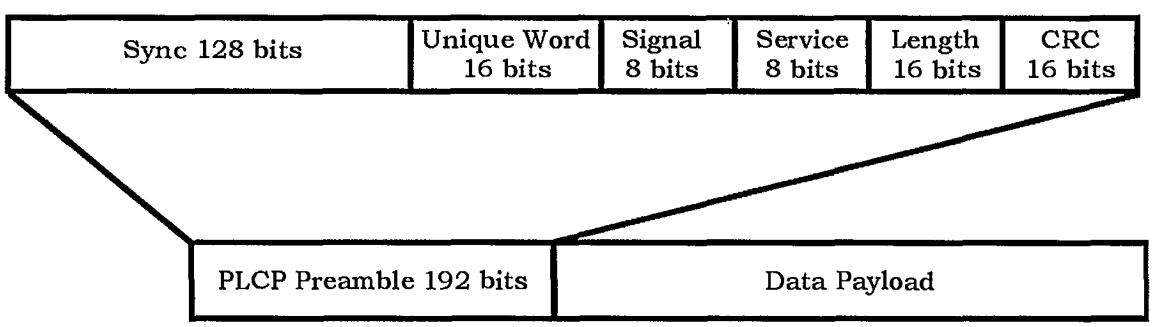


Figure 5.1
PLCP Frame Format

Signal Processing Specifications
In addition to data processing the 802.11 gives the following specifications for Direct Sequence wireless LANs operating in the 2.4 GHz ISM band:

- 7 channels which are divided into 4 groups are specified for the 2.4 to 2.483 GHz band
- The spreading sequence to be used is the 11-chip Barker sequence +1,-1,+1,+1,-1,+1,+1,+1,-1,-1,-1
- The spreading sequence should operate at a chip rate of 11 Mchips/s
- The chip rate clock should be accurate to +/- 25 ppm

- In-band and out-of-band spurious emissions should comply with FCC Parts 15.247, 15.205 and 15.209
- Transmit to receive turnaround time should be less than 10 gsec
- Receive to transmit turnaround time should be less than 10 gsec
- Operating temperature range should be 0 to +40tsC for type 1 devices (office environments) and -30 to +70tsC for type 2 devices (industrial environments)
- Power control should be incorporated into transmitters
- RSSI inputs should be used for CCA (Clear Channel Assessment)

5.3.2 Physical Layer Specifications for Frequency Hopping Wireless LANs

The IEEE802.11 draft standard does not include any specifications for wireless LANs that employ Frequency Hopping Spread Spectrum. It is expected that the standard will be modified to include specifications for Frequency Hoppers in the near future. It is interesting to note that approximately half of the Spread Spectrum wireless LANs in use today use Frequency Hopping. This is perhaps due to the fact that Frequency Hopping systems can be designed using an approach which is similar to narrowband design and hence manufacturers with expertise in narrowband design can easily adapt to design using Frequency Hopping techniques.

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