SYSTEM PLAN
WIRELESS LAN--BUS MODE, 2 MBS
SPREAD SPECTRUM, 1850-1990 MHZ, 3.2 MBS WITH BCH (31,21) FEC

OVERVIEW

This plan explores a possible wireless LAN operating with spread spectrum modulation under a proposeable extension of FCC Part 90 using frequencies authorized in Part 95 with a transmission capacity of 3.2 Mbs in the medium which, when allocated between data, forward error correcting coding and losses from propagation and processing time, yields a 2 Mbs channel. The system plan includes special measures for avoidance of excessive degradation from time dispersion and cochannel interference from frequency reuse.

The system concept is based on the use of low power transmitters, short distance propagation paths and multi-site "macro" diversity with fixed radio sites located on a continuous grid of square cells 70 meters/230 feet on a side. The indicated **transmitter power requirement is 50 microwatts with 20 dB margin.**

The LAN protocols served are limited to Bus mode and then to a 2 Mbs transmission capacity with a Token Passing Protocol. There may be non-optimum possibility for using CSMA/CD.

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SYSTEM PLAN

DERIVATION OF SYSTEM PLAN

The plan is built up from the primary limiting conditions such as spectrum allocation, information capacity and radio propagation. The frequencies chosen are now in use for private and governmental point-to-point microwave systems, and are allocated in Part 94.

Frequency Utilization and Spectrum Spreading Plan

Spread spectrum operation is selected using frequency space from 1850 to 1990 MHz. The parameters are chosen as follows:

The available space is divided into 80 channels separated by 1.75 MHz and starting at 1850.875 MHz, and then to use slow frequency hopping, but not in a random mode. Patterns are defined in which 1/5th of all frequencies are simultaneously in use at multiple sites, but no two transmitters use two frequencies at the same time. The patterns can be used to select one transmitter out of 16 for the same functions as channel selection is used in fixed frequency systems. The advantage obtained is that all users experience the same level of degradation from outside and cochannel interference. There is no advantage relative to time dispersion and other propagation effects. This also partially defines the burden for the forward error correcting code and diversity system.

The bit rate is 3.2 Mbs in the medium. The channel bandwidth could be slightly wider than the channel separation.

Data Modulation

It is necessary to assume a maximum symbol rate based on the time spreading effects that will be experienced. At the same time a high order of spectrum efficiency is desired, and this may be an incompatible requirement. **Quadrature Phase Shift Keyed modulation (QPSK) with phase coherent detection is the initial choice for the basic modulation.** For a carrier modulated in this way, there is 2 bits per symbol of data. Delimiting characters may be keyed as zero amplitude for intervals of 1 bit on each phase. The phase-shift keyed carrier is enclosed in a DSBSC (Double Sideband Suppressed Carrier) envelope. This results in an amplitude modulated waveform for which all phase shifts take place at zero amplitude.

With 4 subcarriers so modulated, the symbol rate is 1/8th of the overall bit rate--there is parallel transmission of each byte. Reducing the symbol rate to **400 kss (3.2 Mbs)**, is a major factor in reducing sensitivity to multi-path propagation. A further advantage is that the requirement for delay distortion in channel band filters is moderated by a factor of 4, and these filters are a large cost factor.

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It has been shown[1] that the minimum spacing between identically modulated carriers (format not data) is equal to the symbol rate. The channels are isolated at detection by orthagonality, not by band filters. Referred to a center frequency of 0, the subcarriers can be at +/- 200 and +/- 600 kHz. If a pilot carrier is used, it would be placed 400 kHz above the highest frequency subcarrier (or below the lowest).

One value in choosing this modulation is that it can be extended to data rates of 10 Mbs and 1.25 megasymbols/second. At the low rate chosen, the modulation should be adequate against time dispersion for much longer distances than needed for the proposed grid dimensions.

Radio System Layout

The fixed stations are assumed to be located at the intersections of a square grid about **70.7 meters (231 feet)** per side or 100 meters on the diagonal. It is assumed that a mobile at any location will be within range of 4 sites provided that there is no major obstruction.

Bernhardt[2] has shown that square cells with base station either at diagonal corners or at the centers of the sides is a good choice for an interference limited system, and particularly for the case where there is a 1% probability of signal-to-interference ratio poorer than 15 dB with a standard deviation of 10 dB (Table IV). The difference between the two plans affects only the definition of where the worst case mobile location is postioned for which the calculation is made.

Frequency Reuse Plan

An indefinitely large number of fixed radio stations may be necessary to cover large areas, and it is then inevitable that frequency reuse must occur at the closest spacings allowed by tolerable interference levels. This plan uses N=16. A pattern of 16 sites may be installed without frequency repetition or cochannel operation.

Cell Definition with Directional Antennas

The (approximately) square area defined by four sites at corners is one cell. A mobile within that square depends upon the availablility or existence of all four sites for reliability of operation. If the location of the mobile is known, no other transmitters need operate except those associated with the appropriate cell.

When the mobile transmits, the signal is received by the four fixed sites defining the cell. When the mobile receives, the signals, containing duplicate information, may be used from any or all of the four fixed sites.

The corner sites are defined to have directional antennas for transmitting and receiving on the inward facing quadrant from each corner. Each site then has four independent radio systems each covering one quadrant.

Frequency Hopping Plan

It is one object of the channel plan to avoid cochannel operation at adjacent sites, however the technical choices for the modulation and bandwidths do not rely on this arrangement. Another objective is avoidance of large jumps in channel frequency for any one step.

To better illustrate the system plan, a simple plan is described below which may be short of optimum. From the list of 80 channels, 80 sets of 16 frequencies are chosen. Each set is created as a rotation of the first channel of the first column to the last channel of the last column of the preceeding set. The sets begin with the channel numbers in the first row. The B set begins with 5, the C with 9. A new set may be generated by adding 4 to the preceding set until there is one unique set for each of 16 base sites. The root set A is as follows:

1. Collins Radio Company, "Kineplex" carrier data system, 1958
2. R. C. Bernhardt; "Macroscopic Diversity in Frequency Reuse Radio Systems;" IEEE Journal on Selected Areas in Communications, SAC-5 June 1987; p. 862

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1	5	9	13	17	21	25	29	33	37	41	45	49	53	57	61
65	69	77	73	80	76	72	68	64	60	56	52	48	44	40	36
32	28	24	20	16	12	4	8	3	7	11	15	19	23	27	31
35	39	43	47	51	55	59	63	67	71	75	79	74	78	70	66
62	58	54	50	46	42	38	34	30	26	22	18	14	10	2	6

Sites are labeled A . . . . P (16). The Table may be thought of as 80 columns and 16 rows where each row is the channel transmitting sequence for one fixed site and each column is the active channel at one moment for each of 16 sites. Each row contains all of the available channels, and each column contains the 16 which are or can be used simultaneously.

Time and Frequency Division Duplexing

A mobile transmission is made immediately following receipt of a token passing message received from a fixed station. The mobile uses the same channel on which the fixed station transmission was made to pass the token. There are now four possibilities (at least) for the channel on which the mobile will respond to receipt of the token. Each transmitting site must have the capability to receive on at least four channels though not necessarily simultaneously if selection is fast enough.

There is a possibility of full duplex operation where the mobile transmits on the received channel number plus two; and this is the reason for the channel jump size of 4 channels.

The token pass response out of a mobile is repeated identically from the fixed transmitters. If the next mobile were to receive this message, it could not not distinguish it from the same message transmitted at instant later from the fixed site. This does not happen because all unaddressed mobiles are switching to the next channel in the sequence at the end of the fixed station transmission.

Time division duplex eases the channel switching time requirement, because it can be done in a time interval not otherwise used.

Inclusion of Channel Numbers in Packets

Embedded tables in mobiles may be avoided if each fixed site transmitter includes the current and next two channel numbers to be used in the header extension for this physical medium.

Forward Error Correcting Code

Radio systems are more efficient and economical when power levels and antenna sites are defined to produce no better than .01 BER at the limits. It is necessary to provide an envelope for the 802.4 packets in which a second error-correcting code has been applied to all but the frame delimiters.

There is precedent for wrapping a second error-correction code around a message already containing error correction. Because of the radio system, there is significant value in determining error in the message as it goes along rather than waiting for a final CRC at the end of a long message.

There are many error detecting and correcting codes, from which a common choice has been made. **The BCH (31,21) block code uses a block of 31 bits to carry 21 bits of data. The code is capable of correcting two errors** anywhere in the block and detecting all 3-bit errors and many errors of larger value. For comparison, the coding gain for 1 and 2 error correcting forms of the BCH 31 bit block code are shown below[3]. The 5-check-bit code results in a loss until the channel error rate approaches 10^{-3} or better.

3. A. M. Michelson & A. H. Levesque; "Error Control Techniques for Digital Communication;" Wiley 1985; p. 250

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Output Error Rate vs. the Channel Error Rate

Channel B.E.R.	Error Out BCH (31,26)	Error Out BCH (31,21)
10^{-2}	3.5×10^{-2}	3.2×10^{-3}
10^{-3}	4.2×10^{-4}	4.2×10^{-6}
10^{-4}	4.5×10^{-6}	very small

The coding gain is greater the more bit errors that can be corrected. Indications from the work on the European digital telephone systems suggests that it is quite possible that Reed-Solomon codes are capable of providing correction of more errors per block than for comparably efficient BCH type.

The default selection for FEC uses 32.25% of the transmitted bits for error corection. With 1.6 Mbs in the medium, the data transfer capability is less than 1.083 Mbs. Since buffering is already inevitable from the FEC, the exact rate is not significant in altering the capability of the system.

The gains shown by Porter (see diversity[5]) are probably much more due to the diversity function than to forward error correction at threshhold signal levels. If the FEC detects errors and can control the selection of the diversity port, this may be sufficient for great improvement.

Macro Diversity and Combining Method

There is a choice of several techniques and combinations of techniques to give receivers more than one chance at receiving a message correctly. Space diversity has been eliminated from consideration because the widely separated antennas are mechanically awkward at mobiles. Frequency diversity, alone, is advantageous against multi-path fading, but not against shadows from large obstacles. These are both types of "Microscopic" diversity systems where all of the signals combined are all between the same two sites.

"Macroscopic Diversity"[2] has been used to describe a choice of path from multiple sites. If these sites surround the mobile, the chance of one of these sights being unshadowed or only slightly obstructed is greatly improved.

The most effective systems use both types of diversity or macro alone with additional ports to obtain an ultimate possibility better than 1×10^{-7} (3,2 or 4,1 macro,micro).

There are a number of combining methods which have been well analyzed.[4] The simplest is "selection" diversity in which the best antenna or one of N signal paths is chosen by switching. Methods of much greater complexity combine separate radio signals with random relative phase at RF. These methods place limitations on binary signal modulations which will work satisfactorily or the method will require a pilot carrier. Because the time of arrival of different signals from different sites could differ by a large fraction of a symbol time, there is risk in assuming the use of a phase-sensitive predetection combining method.

Some data[5] is shown below to which the following conditions apply: 1) Coherently detected QPSK modulation; 2) Error coding is BCH (31,21); 3) 2-ray fading; 4) d=0.1; 5) 900 MHz test frequency; 6) selection diversity.

4. W. C. Jakes; "Microwave Mobile Communications;" Wiley 1974; chapters 5, 6
5. This data was obtained from a Figure shown by P. T. Porter, Bellcore, during a workshop held in conjunction with CCIR IWP 8/13 on March 10, 1987.

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Average Reference SNR (dB) for Error Probability vs. (macro,micro) order of diversity

B.E.R.	1,1	2,1	3,1	4,1	1,2	2,2	3,2
10^{-1}	10.5				5		
10^{-2}	30	11	4		17	5	
10^{-3}		19	11	6	26	12	5
10^{-4}		31	16.5	10.5	37	17	10
10^{-5}			23	15		22	14
10^{-6}				19.5		27	17.5
10^{-7}				24			21

RADIO PROPAGATION AND LOSS BUDGET

At 1900 MHz, the free space loss, for 50 meters (164 feet) between isotropic antennas is 72 dB.[6] The distance is chosen as an approximation of the maximum distance the mobile can get from the nearest base site. This is the center of the square.

The conclusion has been drawn (under Diversity and FEC) that the total gain of these techniques leads to a required SNR of 20 dB for a 10^{-6} BER. Using this value (which takes into account large scale and fast fading), the contingency margin may be reduced to a smaller value.

An opening loss budget for the base to mobile direction may built up starting with receiver residual noise power and concluding with required transmitter power output. The adjustments are shown with the correct sign for addition to the previous power level value to obtain transmit power. For the base to mobile direction with quadrant antennas at the fixed site, the budget is as follows:

Receiver thermal noise power:		-112 dBm
N_0 (dBm) = -174 + 10 log B (Hz) B=1.6 MHz		
Receiver noise figure:	+ 4 dB	
Mobile receive net antenna gain:	- 5	
S/N for 10^{-6} BER in Rayleigh fading with FEC and 4,1 Diversity:	+ 20	
Margin for detector efficiency:	+ 6	
Required received level:		- 87 dBm
Path loss in free space:	+ 72 dB	
$L_{fs}=32.44 + 20 \log F_{MHz} + 20 \log D_{km}$		
Required transmit power (isotropic):		- 15 dBm
Net transmit antenna gain less cable loss:	- 18 dB	
Required transmitter power output--0 dB margin, FEC and Diversity, 10^{-6} BER, 1.0 MHz BW:		- 33 dBm
Margin for shadow and penetration loss:	+ 20 dB	
Required transmitter power output with margin, FEC and Diversity, 10^{-6} BER, 1.0 MHz BW:		- 13 dBm

If available tranmitter power may be increased by 6 dB, the choices are to increase the shadow loss margin, to use twice the distance or operating frequency or to use four times the bandwidth.

It is essential to use the improvements from diversity and FEC to improve the error expectancy to better than $1x10^{-6}$, not only for the power saving, but also it is impossible to get a low error rate with signal strength alone.

As shown above, the indication is that the required transmitter power output is about 50 microwatts. If the size of grid were increased 40% to about 460 feet on a side, the required power would be 100 microwatts. If decreased 40% to 230 feet, the required power would be 25 microwatts.

6. S. Shibuya; "A Basic Atlas or Radio-Wave Propagation;" Wiley 1987; Figure 1-8a p. 124

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BRIDGING AND BACKBONE LAN CONFIGURATION

If only the necessary transmitters operate for each transmission, the operation is like many small networks--one network per cell--and all networks are bridged to a common backbone. One cell is the extent of the bus definition.

If a mobile station joins the network, it must use the Response Window procedure (5.1.4) to become recognized in the token passing sequence. In this process, the bridge becomes informed of the presence of each mobile in its cell. There is an opportunity for a mobile to move to another cell with each circulation of the token.

DESCRIPTION OF THE PLAN IN REGULATORY TERMS

This proposal is described in summary terms which might be used in text for technical standards or requirements as follows:

Common to Mobile and Fixed	
Frequency range:	1850 to 1990 MHz
Number hopping frequencies:	80 Minimum
Maximum bandwidth of channel at -6 dB:	(1990-1850)/80
Minimum separation of hop frequencies:	Channel bandwidth
Occupancy of one frequency by one transmitter maximum:	100 millisec
Out-of-band radiation:	-30 dBc
Fixed Transmitters	
Peak output power:	200 microwatts (note 1.)
Transmit duty cycle--one frequency:	1/80th maximum
Maximum antenna power gain:	20 dB maximum
Mobile Transmitter	
Peak output power:	100 microwatts (note 1.)
Transmit duty cycle--one transmitter:	1/80th
Maximum length of one transmission:	100 milliseconds
Maximum antenna power gain:	7 dB

Note 1. Value for outdoor operation. Upon showing of special conditions, such as operation entirely within a building offering shielding loss to interference with other systems, power levels 10 or 20 dB greater may be authorized on a case-by-case basis.

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