IEEE 802.11
802 LAN Access Method for Wireless Physical Medium

DATE: December 27, 1990

TITLE: **RADIO SYSTEM MULTIPATH PROPAGATION ANALYSIS LEADING TO POSSIBILITIES FOR MITIGATION**

AUTHOR: Chandos A. Rypinski,
Chief Technical Officer
LACE, Inc.
921 Transport Way
Petaluma, California 94954 USA
Telephone: 707 765 9627
Facsimile: 707 762 5328

BACKGROUND

The main limitation on data rate in the wireless medium is created by multipath propagation which causes fading and intersymbol interference. Many impulse response tests on representative in-building environments have shown:

1) the first pulse to arrive is not necessarily the highest amplitude.
2) sometimes the highest amplitude corresponds to less than free space loss (Rician fading).
3) the ringing of the medium persists for up to a few hundred nanoseconds after the first pulse arrives.
4) the degree of multipath time dispersion is weakly or not at all influenced by the length of the transmission path.

As the first step at synthesizing and evaluating proposed measures to mitigate the degradation from these phenomena, effort will be spent on describing the mechanisms involved.

CONCLUSIONS

Using antenna directivity, diversity, suitable modulation and a studied site, a great deal can be done to improve system resistance to multipath propagation at data rates in the 1 to 16 Mb/s range. There is a reach-rate tradeoff, and greater reach can be attained with selection of lower rates, higher access-points and more complex RF equipment.

RADIO SYSTEM MULTIPATH PROPAGATION ANALYSIS LEADING TO POSSIBILITIES FOR MITIGATION

Table of Contents **Page**

Figures

RADIO SYSTEM MULTIPATH PROPAGATION ANALYSIS LEADING TO POSSIBILITIES FOR MITIGATION

BACKGROUND

The main limitation on data rate in the wireless medium is created by multipath propagation which causes fading and intersymbol interference. Many impulse response tests on representative in-building environments have shown:

1) the first pulse to arrive is not necessarily the highest amplitude.
2) sometimes the highest amplitude corresponds to less than free space loss (Rician fading).
3) the ringing of the medium persists for up to a few hundred nanoseconds after the first pulse arrives.
4) the degree of multipath time dispersion is weakly or not at all influenced by the length of the transmission path.

As the first step at synthesizing and evaluating proposed measures to mitigate the degradation from these phenomena, effort will be spent on describing the mechanisms involved.

Types of Multipath

Multipath reflection may come from the floor or other flat surfaces close to the propagation path, or from more distant walls and obstacles.

Fading is the symptom of multipath where the difference in path length is smaller than the period of one transmitted symbol having a value of one bit. When the difference in path lengths are greater than a fraction of the symbol period, delayed intersymbol interference is caused.

Reference Constants

Free space propagation velocity is 300 meters/μsecond. At a data rate of 10 Mb/s, the length of a bit is 30 meters and proportionally longer for slower rates.

Path differences of 3 meters or less at 10 Mb/s can only cause fading, down and up, on the signal arriving by the direct optical path.

Path differences of more than 30 meters at 10 Mb/s, only cause interference to subsequently arriving pulses. In between, both fading and intersymbol interference occur.

Free space loss is 6 dB/octave or 20 dB/decade. Commonly measured average distance attenuation is about 12 dB/octave or 40 dB/decade, but this average applies to cluttered or statistically obstructed paths only.

Models

The first model for an office or store assumes:

1) a flat, smooth concrete floor
2) a 2.5 meter high suspended ceiling with acoustic tile in a metal framework
3) walls are assumed but with no specific characteristics
4) the interior arrangement is open plan with barriers up to 1.5 meters in height
5) a fixed antenna at the ceiling height
6) a station antenna at 1.5 meters height
7) a distance between antennas of up to 12 meters.

A second model for warehouses and factories assumes:

1) a large metal-walled building with sloped metal roof 8-12 meters above the floor
2) a flat, smooth concrete floor
3) vertical, steel I-beam columns on a 14 meter grid
4) antenna arrangements as further described
5) a distance between antennas of up to 20 meters
6) numerous metal obstacles, some stacked to heights near the roof, however so arranged that cartesian plan aisles are still present.

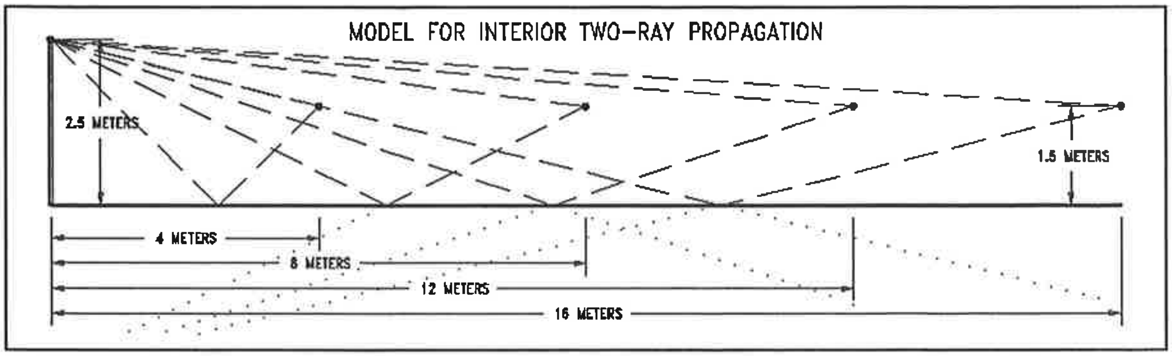

FIGURE 1 Scale Diagram Showing Two-ray Propagation Paths for Office Interior Environment

SMALL DELAY MULTIPATH

Shown above is the obvious case for floor reflection in a typical interior set-up. Figure I shows the path difference as a function of distance. It is interesting that the difference decreases as the station gets further from the access-point becoming less than 1 meter at a distance of 12 meters. (1 meter is 1/30th of a bit interval at 10 Mb/s)

Circumstances for Low Loss Reflection

Note that "Brewster Angle" is a consideration. Reflection at a dielectric interface becomes total as the incident angle approaches that of the plane. The power loss from reflection is probably much less (for smooth concrete) at the greater distances. For near perpendicular incidence, there might be large reflection loss, because concrete is not a good mirror. The same principle might apply to vinyl-covered sheet rock or other dielectric materials used in walls.

The cancellation possibilities for a two-ray model are much greater at distances of 6-height-differences or more where the path difference is a small fraction of a bit interval.

Frequency Sweep to Avoid Nulls

The loci of a null in the two-ray model are concentric circles around the source antenna. The spacing between the circles is much greater than a wavelength at the operating frequency. The radii of the null circles are a function of the operating frequency. It is therefore possible to think of a system design where the energy is distributed over a broad enough frequency band so that only a small portion of the energy is lost as a result of two-ray fading.

Figure 2, below, shows the phase difference between the two arriving rays in the model above for a frequency sweep of 235 MHz.

The slope is slightly less than 1° per MHz. A null would be about ±15° wide at least. A 30-MHz bandwidth would be the width of a null.

For the above assumptions at 10 meters and 1800 MHz, it is clear that the bandwidths necessary to make the floor bounce null negligible are above 60 MHz and probably unthinkable in practical systems.

Spacing of Anti-fade Diversity Antennas

A further deduction can be made from this model by exploring the effect of moving an antenna on the range or height axis. The rate of change of path difference as a function of distance movement is smaller for range difference than height difference. Suppose that an antenna is located at a point where there is cancellation, the closest alternative location where the signal is a maximum could be from a vertical translation. A horizontal translation might be ineffective, because the locus of the cancellation point is a circle around the fixed antenna (and vice versa).

The phase difference in the two-rays was calculated for variation of range and height as shown in the Figures 3 and 4 below. The slope of range variation is 0.75°/cm, and for height variation it is 10°/cm.

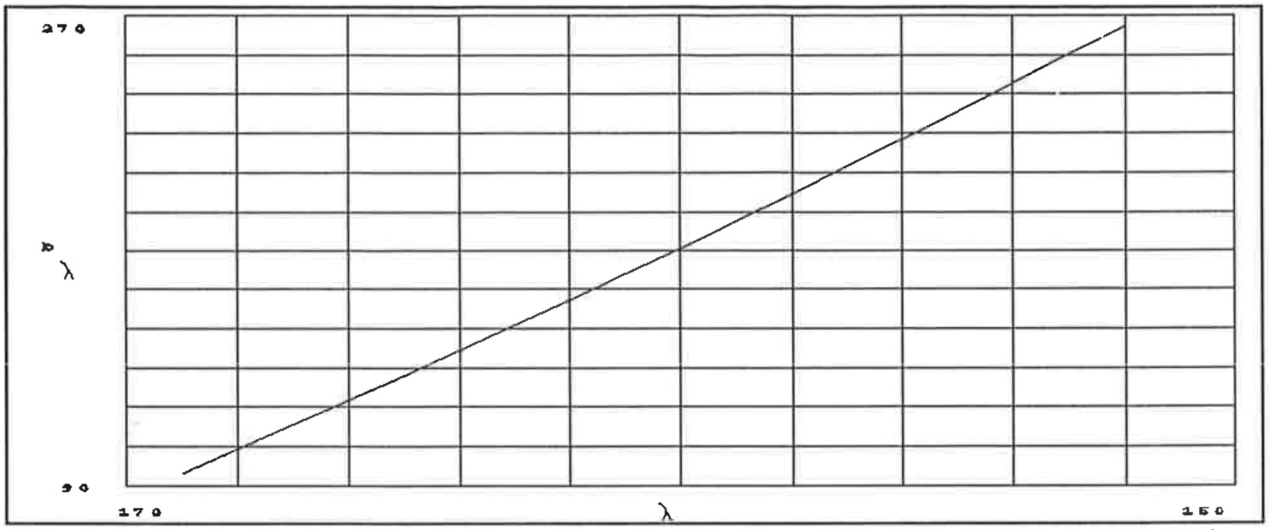

FIGURE 2 Wavelength Sensitivity of Phase Difference (150 MM = 2000 MHZ, 170 MM = 1765 MHZ)

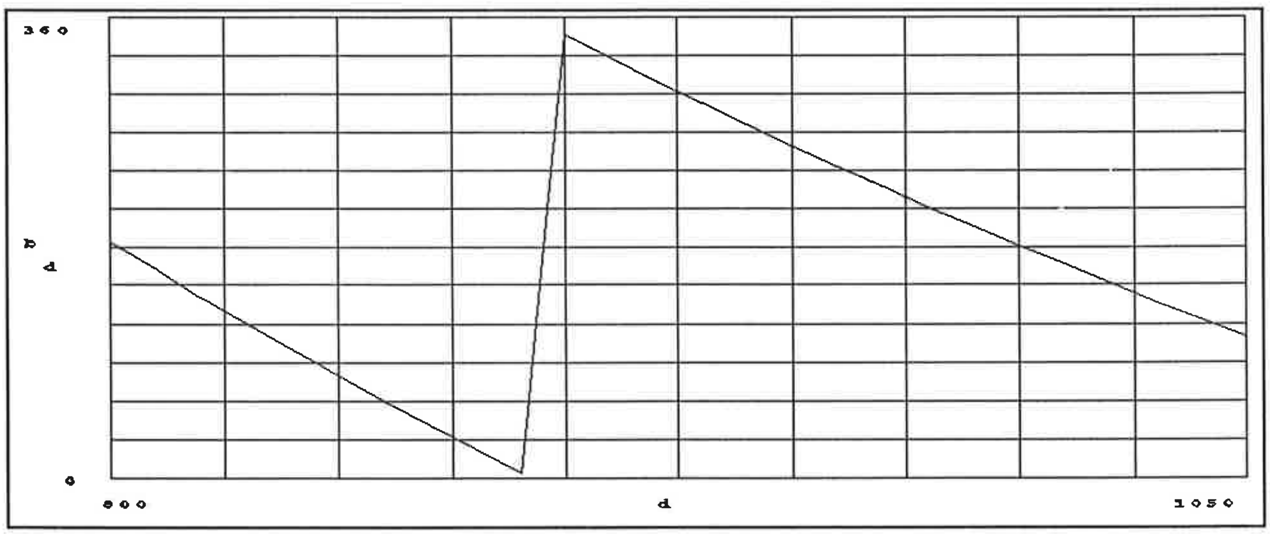

FIGURE 3 Distance Separation Sensitivity to Phase Difference

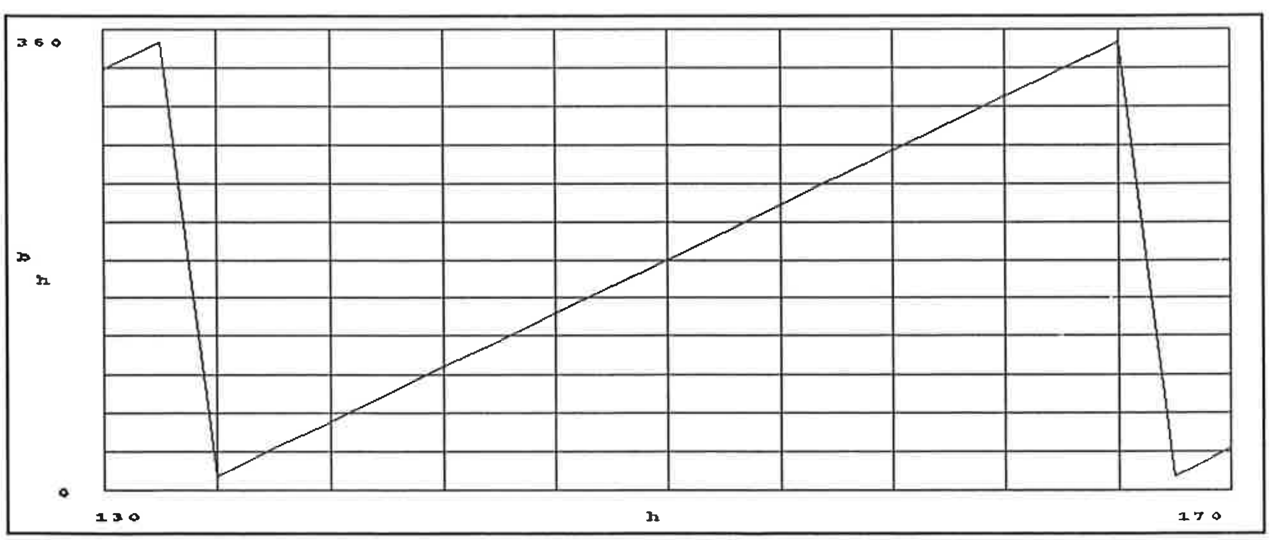

FIGURE 4 Lower Antenna Height Sensitivity to Phase Difference

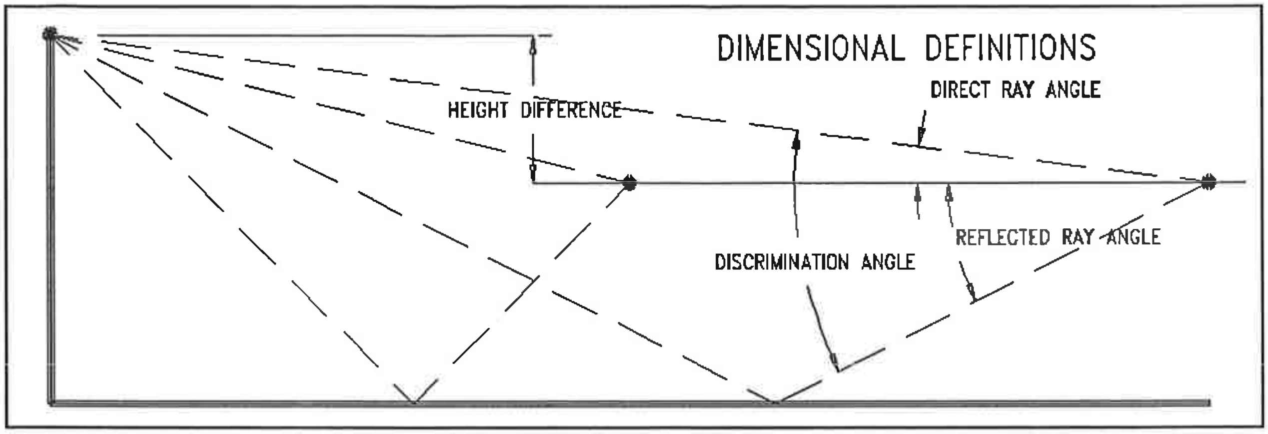

FIGURE 5 Definition of Angles

Two-antenna diversity with equal height antennas will be ineffective when both antennas are the same distance from the access-point and when they are spaced less than 0.4 meters in distance.

Two-antenna diversity with vertical separation of more than 3 cm will produce 30° or more phase difference in this context.

Vertical Angle Discrimination in Antenna Patterns

The lower of the two antennas looks up for the direct ray and down for the reflected ray. The higher antenna looks down for both of them. A lesser vertical directivity will attenuate the floor reflection for the lower antenna (at the station) than for the access-point. With directive antennas only at the station, a large improvement in fading from floor and other close reflectors would be obtained.

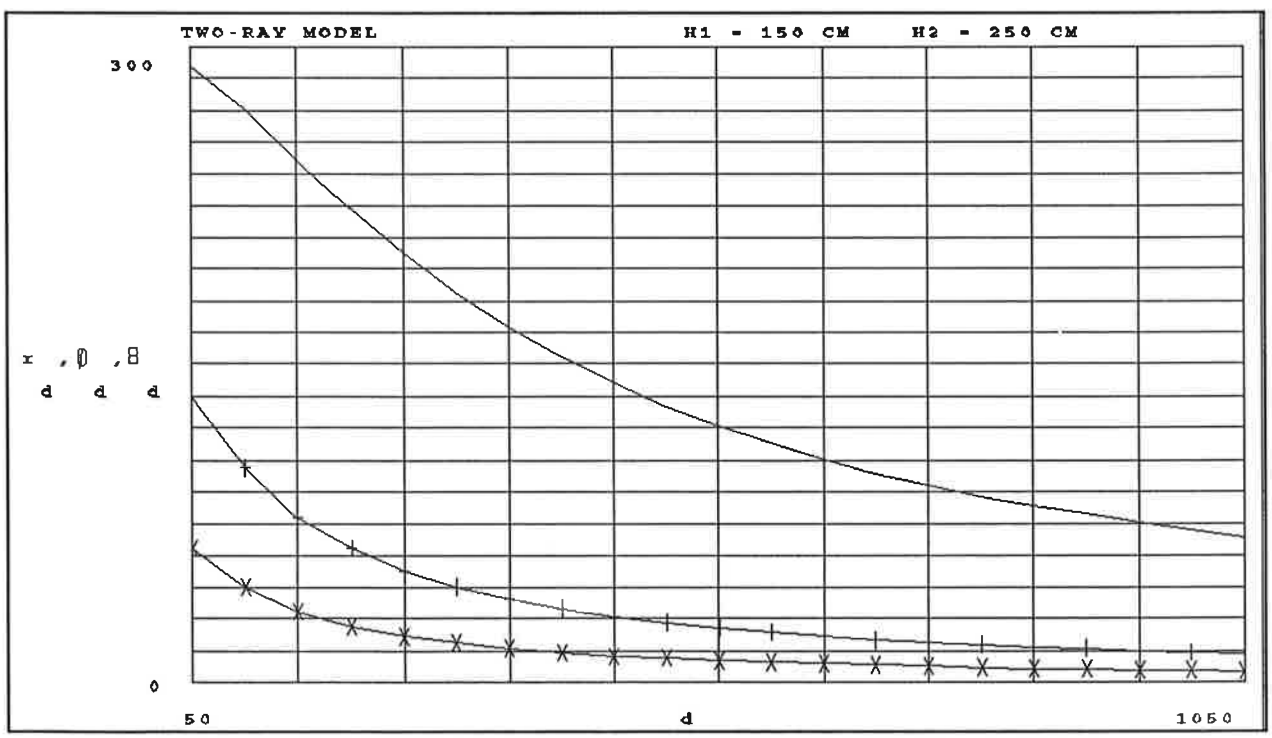

FIGURE 6 Path Difference Length (Line), Direct Ray Angle (x) and Discrimination Angle (+) vs. Horizontal Distance Between Antennas. X = 100 cm/div, Y = 15° or cm/div

Simple antennas can produce discrimination of more than 12 dB in 22.5° in a vertical pattern, and some possible patterns are shown in a later section. Recognition of the improvements possible should be made in the course of both access-point and station antenna design.

For this reason and others, it could be a design criteria that the angle of departure not be less than 22.5°. The immediate consequence of this relation is a firm requirement that the access-point antenna be higher than those in the service area, and that for any assumed height difference, there is a range limit.

LONG DELAY MULTIPATH

The model chosen for long delay multipath is a rectangular building with metal walls which are reflectors for RF energy. Dielectric walls will produce reflection only at near glancing angles which are associated with the small delays described above.

A right-angle corner is a "two-bounce" retro-reflector which will return energy in the direction from which it came. This case is frequently present.

The situation is different for illumination from the center or spaced from the wall, than for an access-point located in a corner.

A large set of locus points from which reflection can come is an ellipse with the station and access-point antennas at the opposed focal points. An inscribed triangle with a corner traveling the locus line is the ray path. The reflector must be a tangent to the ellipse. In the special case where the focal points fall on diametrically opposed points, the locus becomes a circle.

To the degree that random metal furniture and machines contain wavelength surfaces that meet the tangential requirement, they can be reflectors. The possibilities are greater (at microwave) for a corrugated rather than a sheet wall.

Example

It is necessary to understand the order of magnitudes involved. Assume the following example cases:

Path length:	10 meters
Wall orientation:	Parallel to path
Wall spacing:	5 meters
Bounce path length:	14 meters
Difference-	
Distance:	4 meters
Time:	13.3 nanosec
Bits @ 10 mb/s:	1/7th
Azimuth:	45°

Path length:	10 meters
Wall orientation:	Corner behind station
Spacing from station:	5 meters
Bounce path length:	20 meters
Difference-	
Distance:	10 meters
Time:	33.3 nanosec
Bits @ 10 mb/s:	1/3rd
Azimuth:	0°

The obvious is that the difference in path length required at 10 Mb/s to throw the longer path signal totally into the following symbol is 30 meters (10 meters will shift enough energy into the following symbol for degradation). To get 30 meters of difference when the maximum used path length is 10 meters requires significant distance to the reflector -- over 10 meters behind or 18 meters to the side. If the reflectors are stationary, and the path length is decreased, there is not much difference in the delay of the long delay multipath because it depends more on the geometry of the room than on the position of the observation point.

Relative Attenuation of Reflected Paths

The relative level of a reflected path relative to the unfaded and unreinforced optical path is nominally attenuated by 6 dB/octave of distance ratio. Reflection paths which are more than four times longer than the direct path should be down at least 12 dB, and for paths that long much of the energy is arriving in a later symbol interval.

All of this assumes that the reflectors are lossless which is not the case. What may happen is that the sum of the energy from many reflectors can add up to more significant amounts.

The multipath energy received at any point is more dependent on the location of the reflection points due to furniture, walls and other objects; and in this case, the shorter the path between the stations, the better the ratio of optical path to indirect path.

For the multipath to cause intersymbol interference rather than fading requires a bit period which is much shorter than the transit time for the optical path.

Possible Rule: The transit time for the maximum optical path length should be half the period of one bit (for unenhanced systems).

Example: The transit time for 10 meters is 33 nanoseconds. The period of one bit should be at least 66 nanoseconds or 16 Mb/s maximum.

REDUCTION OF MULTIPATH EFFECTS

There are several areas where improvements can be made:

1) antenna directivity
2) selection diversity
3) phase insensitive and low signal-to-noise modulation and demodulation technique
4) artful position placement of access-points

Directive Antennas

Narrowing of beamwidth of the antennas discriminates against paths materially different in azimuth or elevation from the optical path. It is likely that considerable improvement will result from access-point antennas that are down at least 6 db in the horizontal plane and 12 db at angles within 30° of straight down. Station antennas which have inverted properties will discriminate against floor bounce and some of the local reflectors. Two perpendicular dipoles fed 90° out-of-phase might be used to get a horizontally omni-directional pattern.

Vertically Directive Patterns

Figure 7, below is an example of a pattern approximating what is desired for a downward pointing access-point in one plane end-on to a dipole. The inner circle is the field level for a dipole without reflector. The departure angle alignment with the pattern is shown by the angular dimensions. The ground plane shown is 15"/side at 1800 MHz, and should be larger.

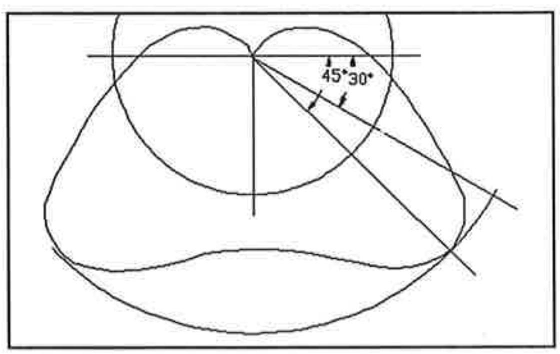

FIGURE 7 End-on Pattern for Dipole .375λ Below Horizontal Sheet Reflector 2.25λ Square

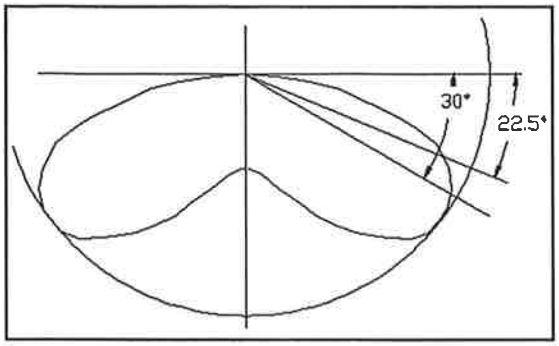

FIGURE 8 Pattern for Wider Spaced Dipole on Large Ground Plane

Figure 8 is a similar antenna except that the antenna is spaced .4λ from a larger reflector. The larger the reflector, the better the nulls in the plane of the reflector. If the spacing were increased to 0.5λ, the minimum straight down would become a null. The degree to which the main lobes can be brought closer to horizontal is limited by reflector size. As shown, the reduced downward field strength is about equal to the increased distance loss at the departure angle of the maximums.

With respect to angle of elevation considerations, the proportions are geometrically scalable in proportion to the relative height between access-point and station height.

Horizontally Directive Antennas

An advantage of corner mounted antenna is that the necessary beamwidth is 90° at 3 to 6 dB down. The maximum is aligned with the diagonal where greater reach is required. Two such antennas in diagonally opposite corners have good possibilities for path diversity operation.

Diversity Arrangements

When it is accepted that multipath fading is a dominant consideration on the optical path, then it is possible to consider diversity arrangements

Two antennas spaced vertically by more than a few inches will show a good decorrelation of fade minimums against floor bounce, but not against near wall bounce.

The simplest useful diversity would be selection type which would choose the best input port during the packet preamble.

It is also possible to select from among a set of horizontally directive antennas with similar circuits.

Fade and Interference Resistant Modulation

It has been shown impractical to escape from a floor bounce type null by wide frequency deviation. For greater path length differences it is different. Assuming a large number of simultaneous paths with similar signal magnitude, there will not be a null. The composite signal will be closer to a power sum, the desired consequence of CD spread spectrum.

This contributor believes that wide deviation FM may work better than many modulations for the inevitable non-coherent, multisignal conditions. The detail of the implementation must avoid a need for high RF signal-to-noise ratios to the greatest extent possible, because much of the multipath will look like noise that cannot be overcome by more transmitter power.

Site Selection

The first criteria for location of access-points is an optical path to the most common user locations. A limitation of dependence on bounced non-optical paths is that one path is not sufficiently differentiated in amplitude, direction or time from others for successful demodulation.

The use of corners and properly chosen height in connection with the antenna type and with some notice of major obstructions and reflection sources will be of great value. The use of illumination from corners is a possibility that should be considered.

Taking the GM Oshawa plant as an example, there is choice of implementing access-points on a 45' grid with sites in the center of a square of columns or on the column. On the column is likely to give a better multipath result.