Infrastructureless Packet Radio Networks - 9/98

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The Problem - Infrastructure

- Location - Location - Location!
  - Good (third-party) Sites imply commercial demand
  - Too Much time to install and maintain
  - Too Much cooperation needed
    - Requires top heavy political organizations
    - politicians compete, self-defeating

The Problem - Infrastructure

- Economics of Infrastructure Based Net
  - Two layers of radio designs
    - Cheap high production Access Radios
    - Low production Linking Radios
      - No Standards
      - Low Production - thus Expensive (time or money)
  - Catch 22.145.01
    - Cheap Access radios almost useless without expensive low production infrastructure

The Problem - Infrastructure

- Siting Problems - all the eggs
  - Noise level variation
  - Multipath - even at 9600 Baud!
    - flat fading (narrow bandwidth techniques)
    - delay spread (wide bandwidth, or long range)

The Problem - Infrastructure

- Hub'd access is System-wise inefficient
  - Omni-Antennas are cheap, but (fig.1)
    - no protection from multipath, noise or interference
    - inefficient use of BW/A/T resource - area of triangle Vs circle-low baud rate(delay spread)
  - Even sectored hubs are inefficient (fig.2)
    - entire triangle out to edge of cell

Figure 1

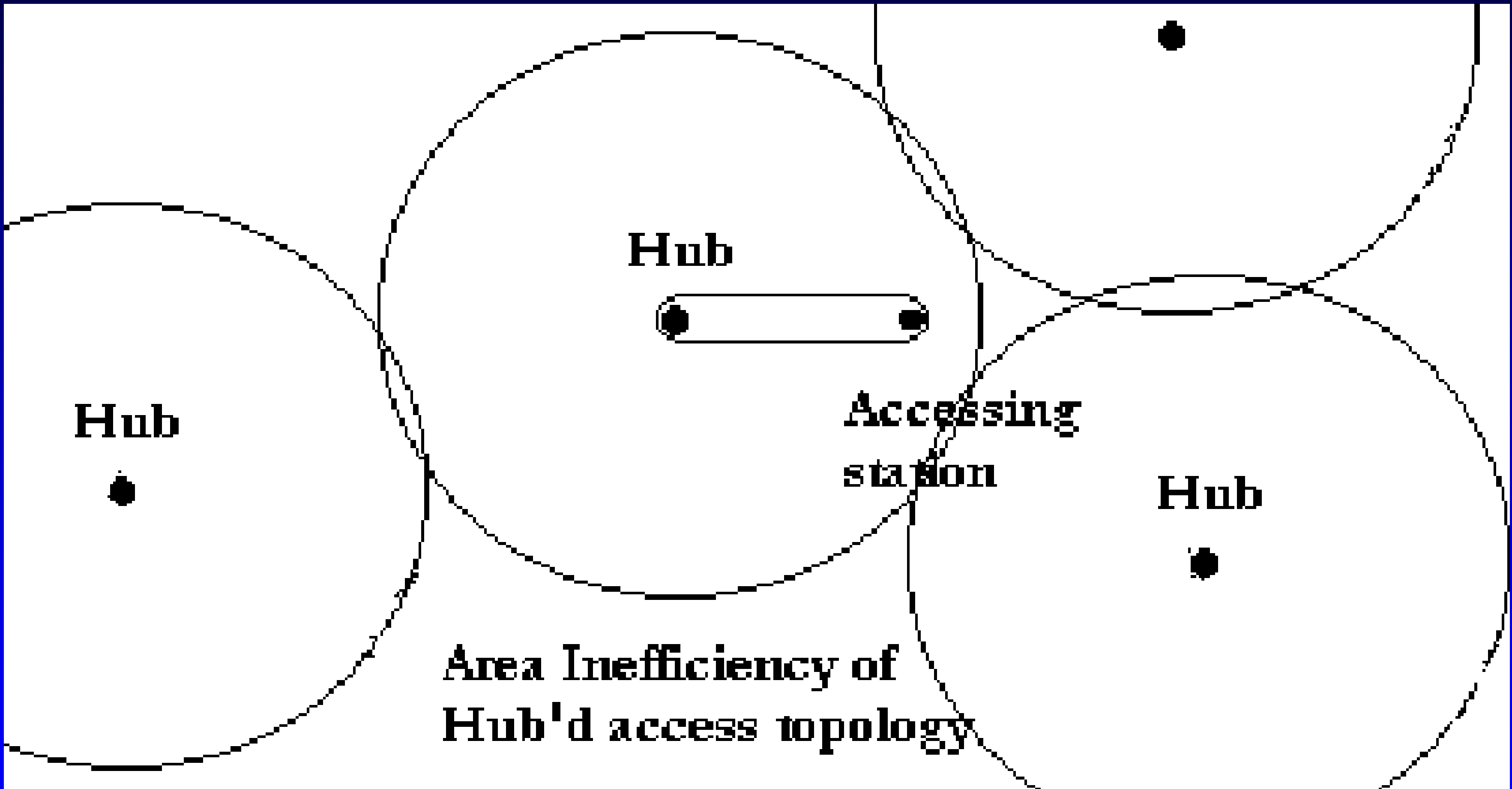
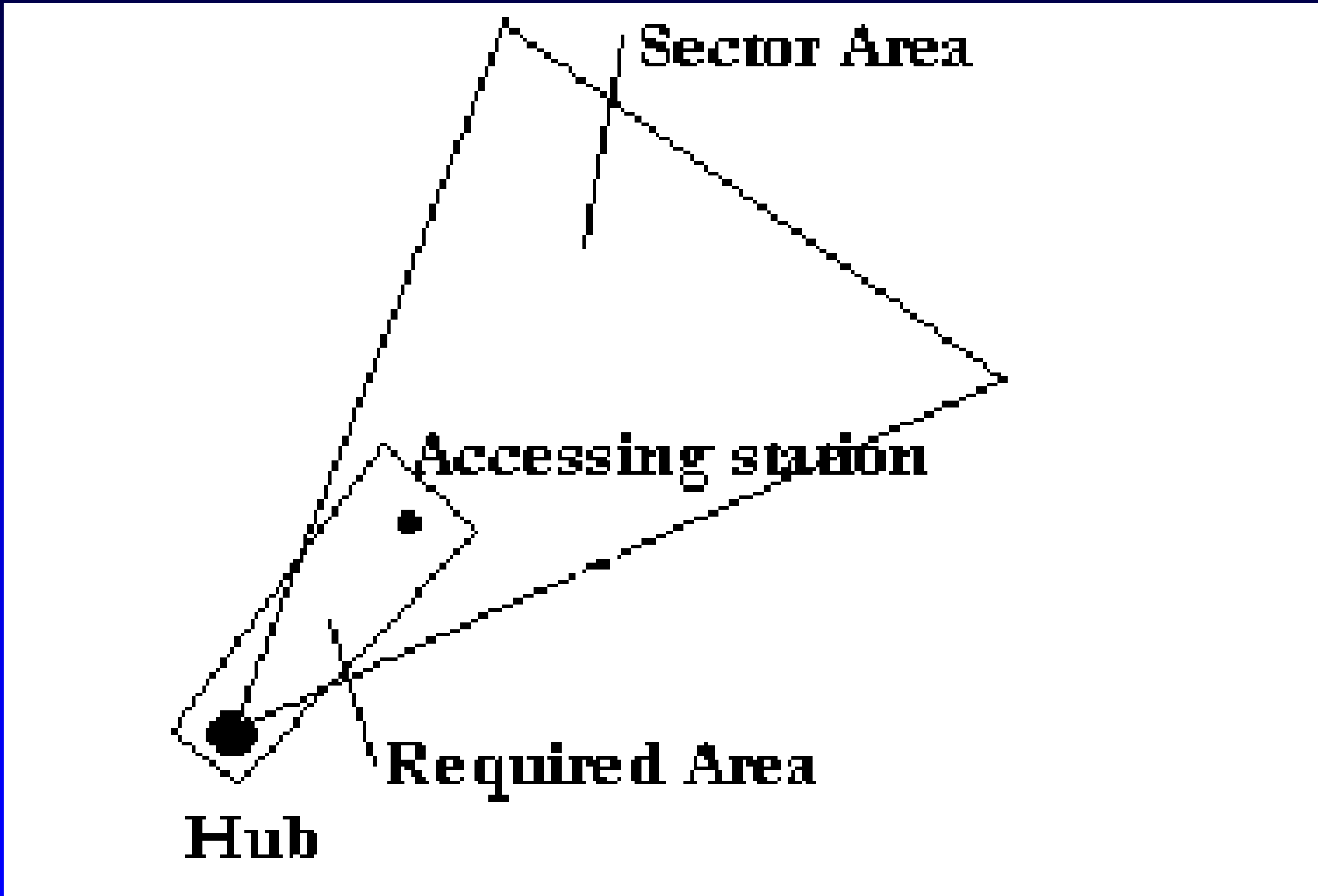


FIGURE 1

Figure 2



The Problem - Infrastructure

- packet times at megabaud Vs flight times
  - 3.34 us/km free space propagation time
  - Flight time creates a large uncertainty-time
    - time to reach all stations makes for inefficiency
      - At 1 MB , not too bad - 3 bits/km
      - At 10 MB - 33 bits/km
      - To a regenerator and back out could be 40 km!
    - MB access to channel can no longer be CSMA !
    - asynchronous RTS/CTS access techniques difficult in small cells, inefficient in large cells
    - synchronous access for Hubíd systems

Issues

- What Next? What are our goals now?
  - No longer long distance -> high data rate
  - No longer full coverage -> path to Internet
  - Applications Bonanza!
    - world wide web
    - voice over Internet - repeater linking
    - packet TV
    - remote/shared computing
    - whatever new happens - can t limit ourselves

Issues

- MAN ës
  - Internet now the overland network
  - Metro-area radio can be faster than phone line modems!
  - High speed into the Internet
- Getting Started?
  - typically 2 friends want to link
    - could buy commercial product - dead end !?!

Issues

- Can we overcome the Ham Radio Economics of Infrastructured MANís?
  - Network Station - hi production technical needs
    - One type of unit fits all
    - Share and access BW/A/T w/o infrastructure
      - political cooperation needed - little to none
    - Metro coverage capability with 100KB thruput
      - neighbor to neighbor much greater thruput
    - bought and sold with ìno worriesî - commodity
      - much like a HF radio equipment, now

System Issues

- Resources - BAT
  - (B)andwidth
    - wider bandwidth - less time?
  - geographical (A)rea
    - directive antennas permit simultaneous multiple communications
  - (T)ime
    - go fast, or slow?

System Issues

- Wireless MAN Performance Index
  - (MB*KM)/(MHz*KM^2*S)
    - 1 Costas
      - Paper on Interference Limited Networks
        - Used Ham Radio as the ultimate example thereof!

System Issues

- Full Vs Half Duplex in random networks
  - TCPIP is a bi-directional protocol
    - Returning level 3 acknowledgment packets
      - small - poor packet efficiency
      - traveling back from beyond range into range
      - create contention in network - death to thruput!
    - Full Duplex Radio is best
    - Half Duplex, Dual Radio second best
    - Half Duplex, Single Radio is the worst

System Issues

- Propagation (fig 3 + 4)
  - Ricean Regime
    - N=2, i.e. 20 log (distance) path loss slope.
    - slow fades
  - Do Not Want to use Rayleigh Regime
    - Larger BW pushes out the Ricean/Rayleigh transition range
    - N=4 for Rayleigh. The average multipath effected signal strength of a narrowband signal.

Figure 3

http://sss-mag.com/prop.html
Proffessor Randy H Katz

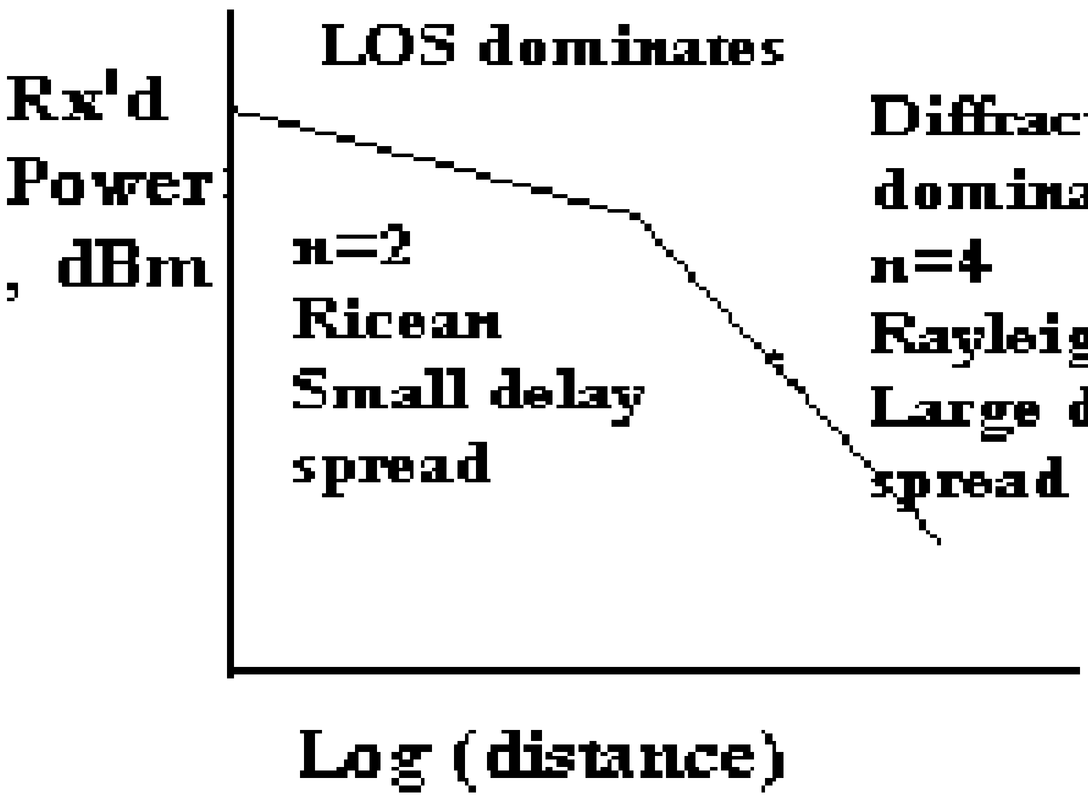


FIGURE 3

Figure 4

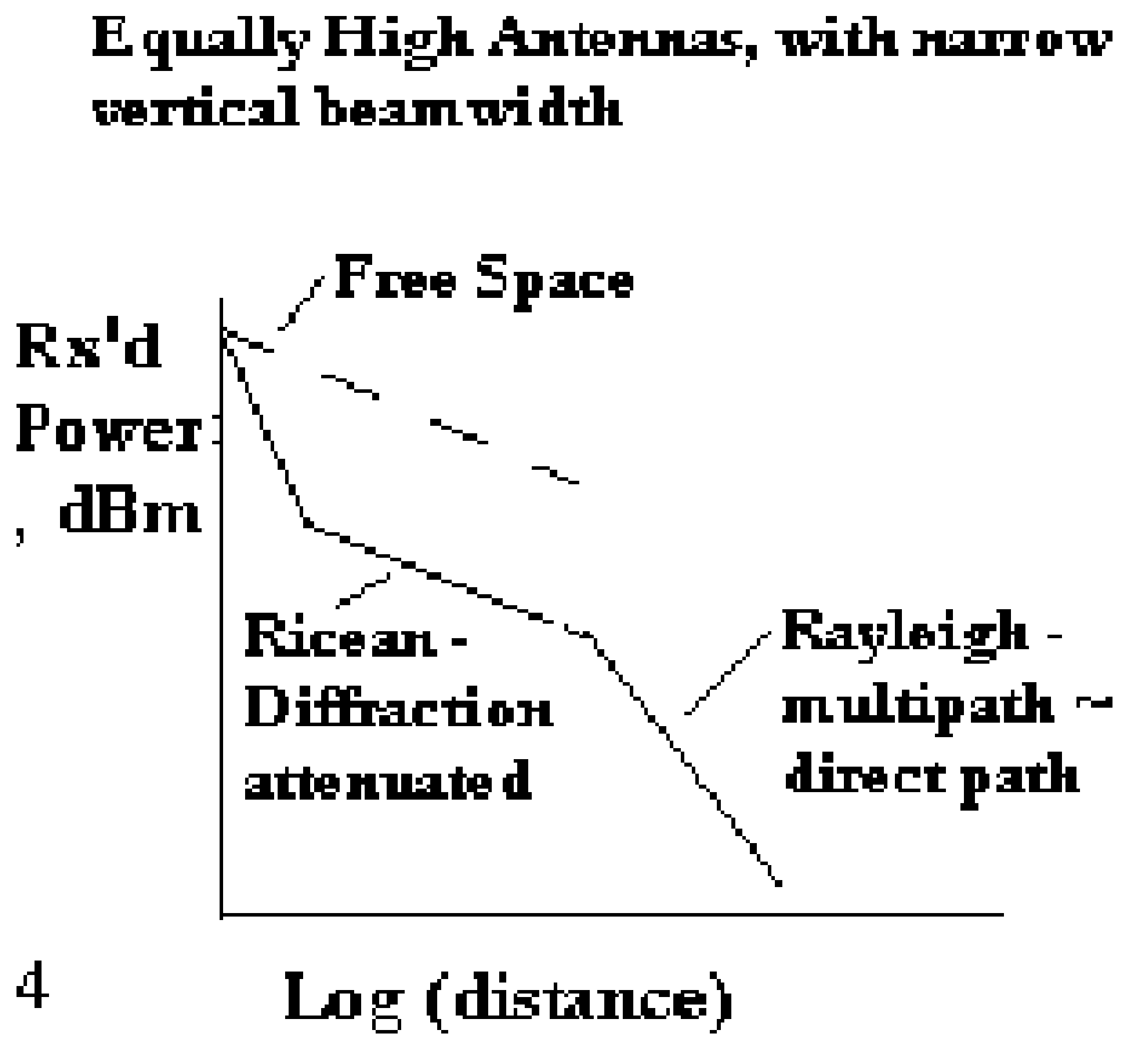


FIGURE 4

System Issues

- Propagation
  - Ricean Regime - How?
    - Rooftop to Rooftop paths.
    - Line of Sight, with obstructions in first fresnel zone worst case
    - Very short paths through tree tops.
    - Minimal multipath - directive antenna
    - Automatic detection of these paths is needed!
      - radio environment very random

System Issues

- Delay Spread (fig 5)
  - The Time Domain side of Multipath!
  - Longer Range, reflections even more time
  - The reflected paths can be long enough, with omniís in metro area to take out 9600 baud links, even! i.e. > 2 usec
  - For 1 MB, delay spread < .2 usec, and - 20 dBdp

Figure 5

Delay Spread,
the Time Domain side of Multipath!

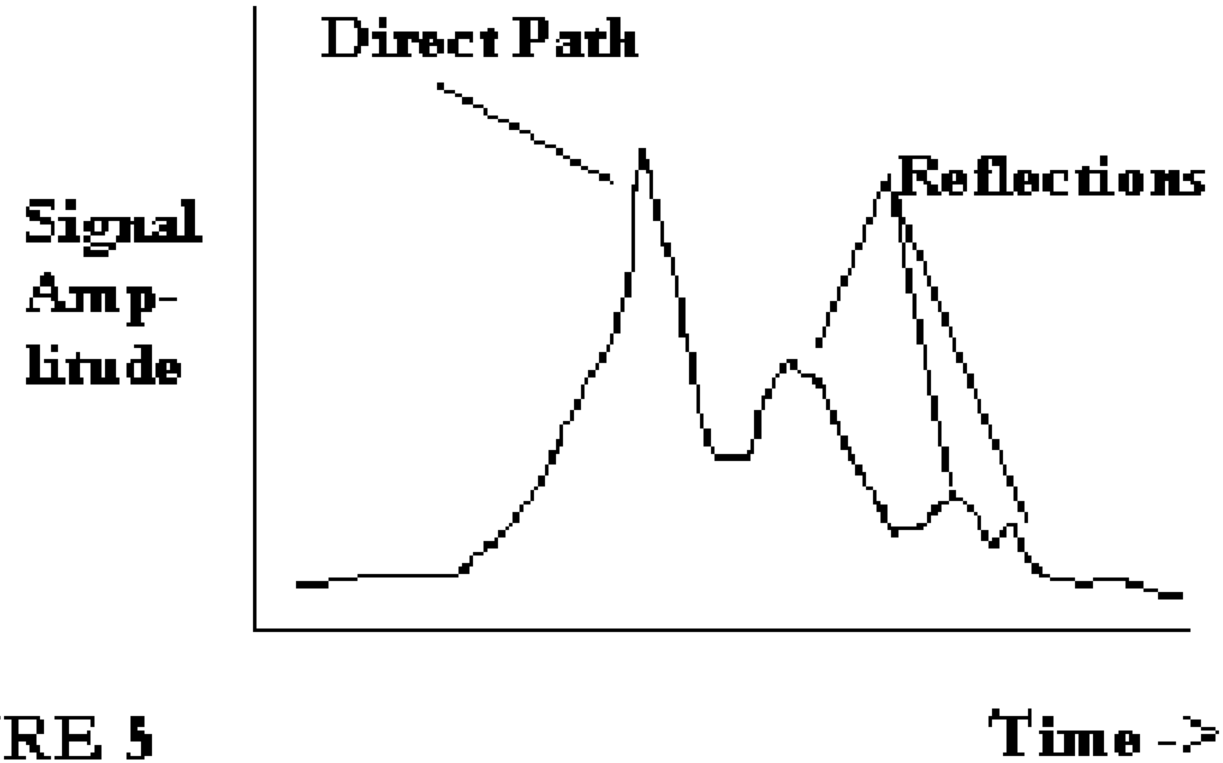


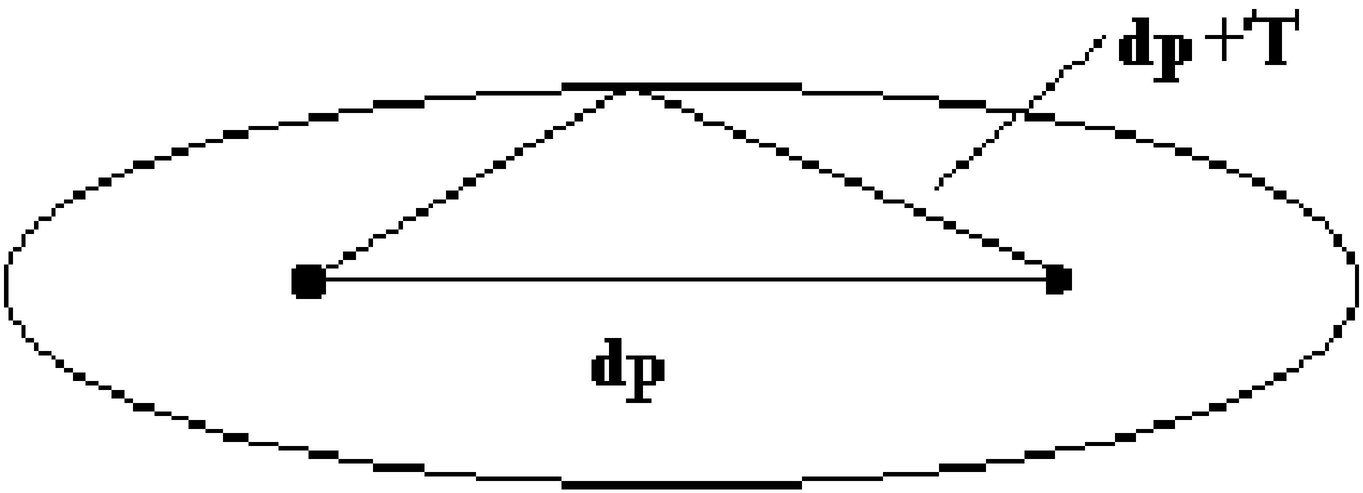
FIGURE 5

System Issues

- Delay Spread Vs Beamwidth (figure 6)
  - Omni Antennas - The confocal ellipse
    - Ellipse is at distance that is delay T in excess of the direct path.
      - near either end, reflectors can be relatively close! ìthe apartment problemî
    - Area outside ellipse must have reflectors below 20 dB.

Figure 6

Multipath Delay Spread with Omni Antennas - the Confocal Ellipse



Area inside the ellipse - reflections with delay spread < T
Reflectors outside ellipse will have delay spread times > T

System Issues

- Delay Spread Vs Beamwidth
  - Beam Antennas (figure 7)
    - Reflections within dual cone of -13 dB antenna pattern will reflect multipath @ -20 dBdp relative to a path within the -3 dB cone.
    - Width of intersection of coverage cones determines maximum reflection time wrt dp.
    - greater beamwidth, greater delay spread
    - greater the range, greater delay spread

Figure 7

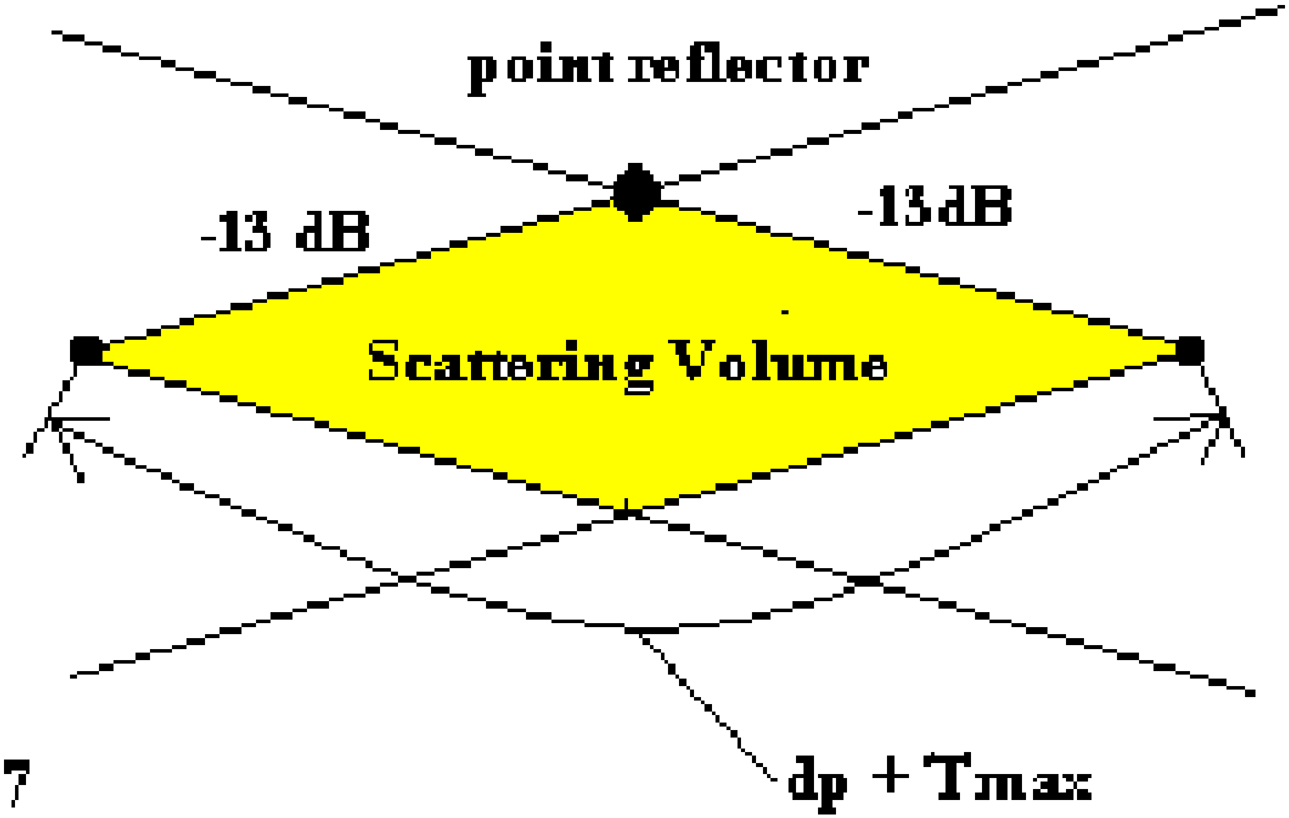


FIGURE 7

Beamwidth signal - point reflector

signal = -3 - 3 -(-13 - 13) = -20 dB

T delaymax = dp/cos(BWmax/2)

System Issues

- FHSS in Multipath Environment
  - In time domain, FH is too slow to avoid reflections (figure 5)
  - In frequency domain, FH will hop out of a multipath null (figure 8)
    - missed packet (assuming one packet/hop) every now and then
    - much better than narrowband in a null!

Figure 5

Delay Spread,
the Time Domain side of Multipath!

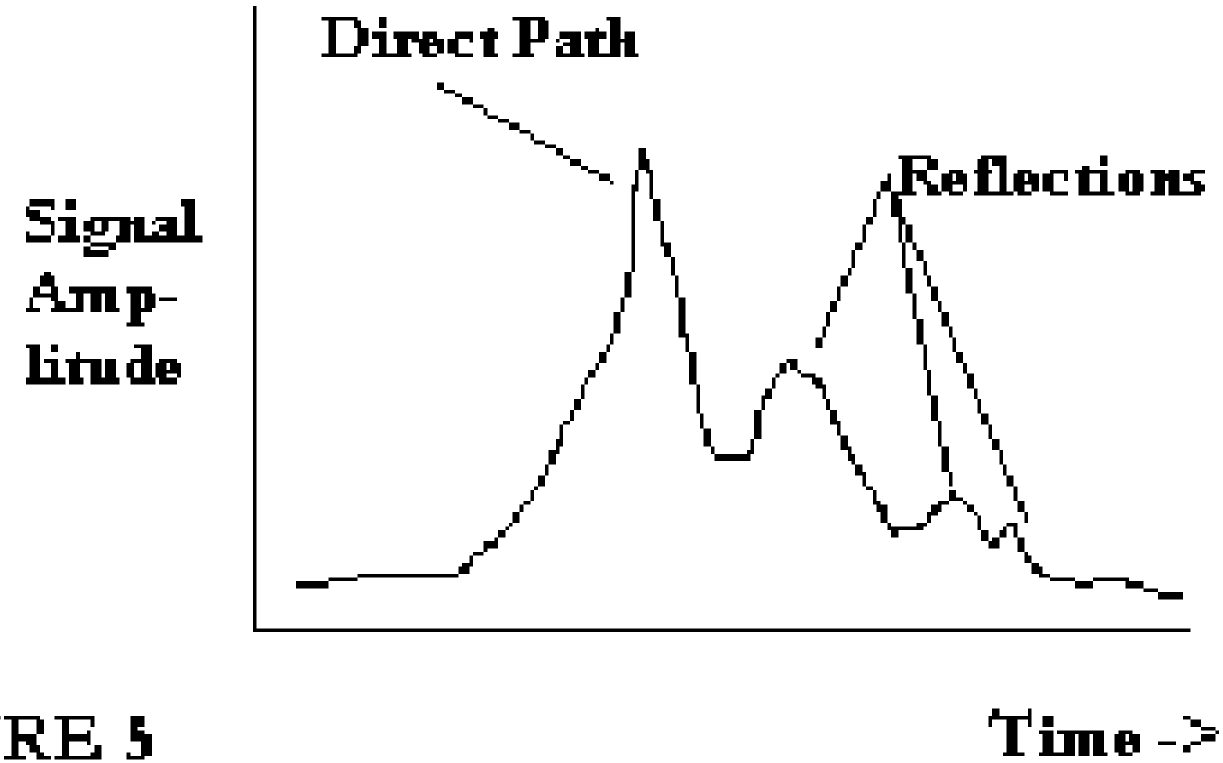


FIGURE 5

Figure 8

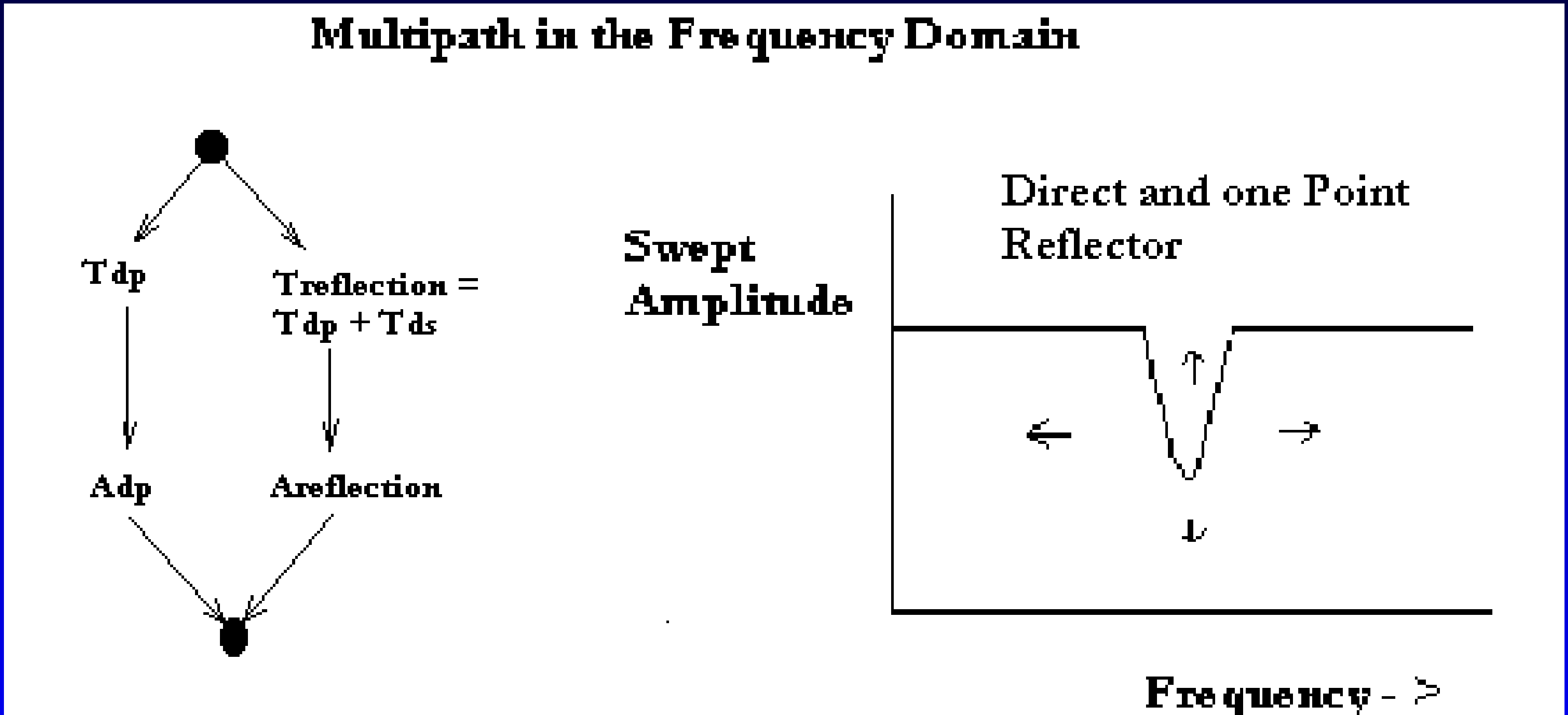


FIGURE 8

System Issues

- DSSS in Multipath Environment (fig5+8)
  - In time domain, reflections > 1 chip time can be attenuated by Gp (processing Gain)
  - In frequency domain, if signal is wider than null, the null represents a marginal decrease to entire signal strength.
  - DSSS has both time domain (delay spread) and frequency domain advantages over narrowbanded signals

Figure 5

Delay Spread,
the Time Domain side of Multipath!

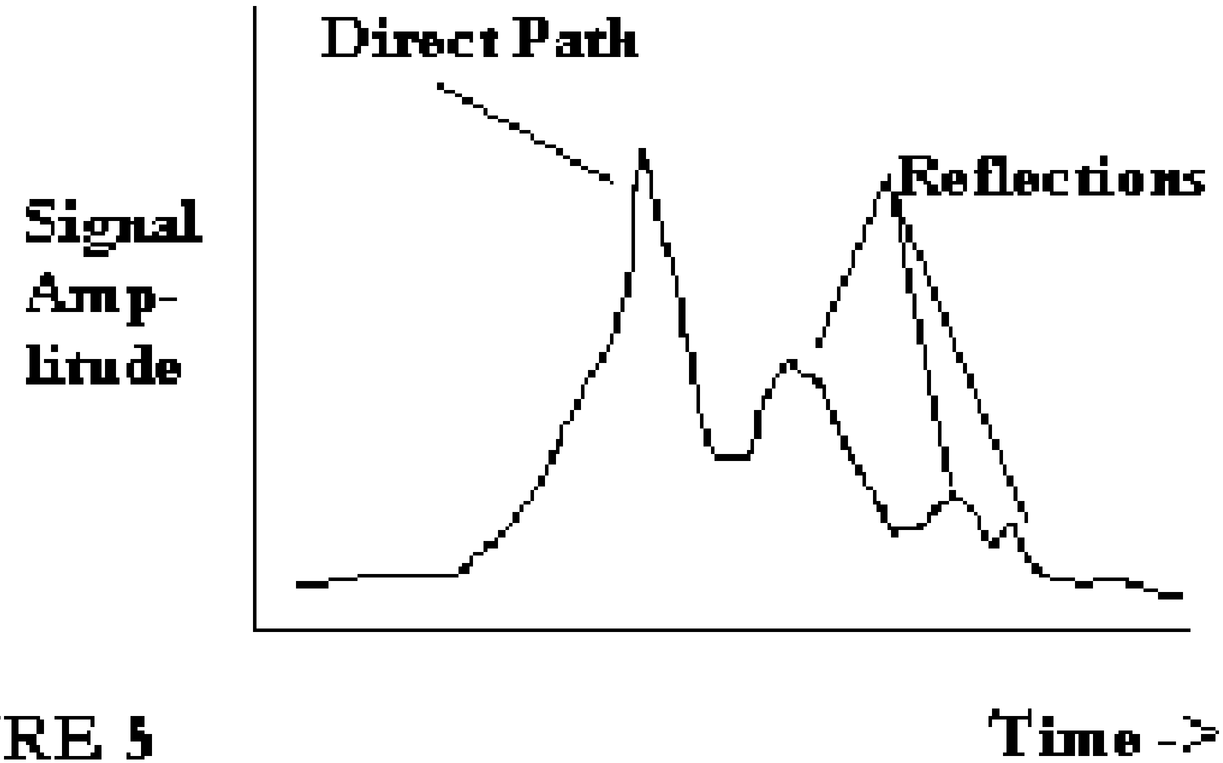


FIGURE 5

Figure 8

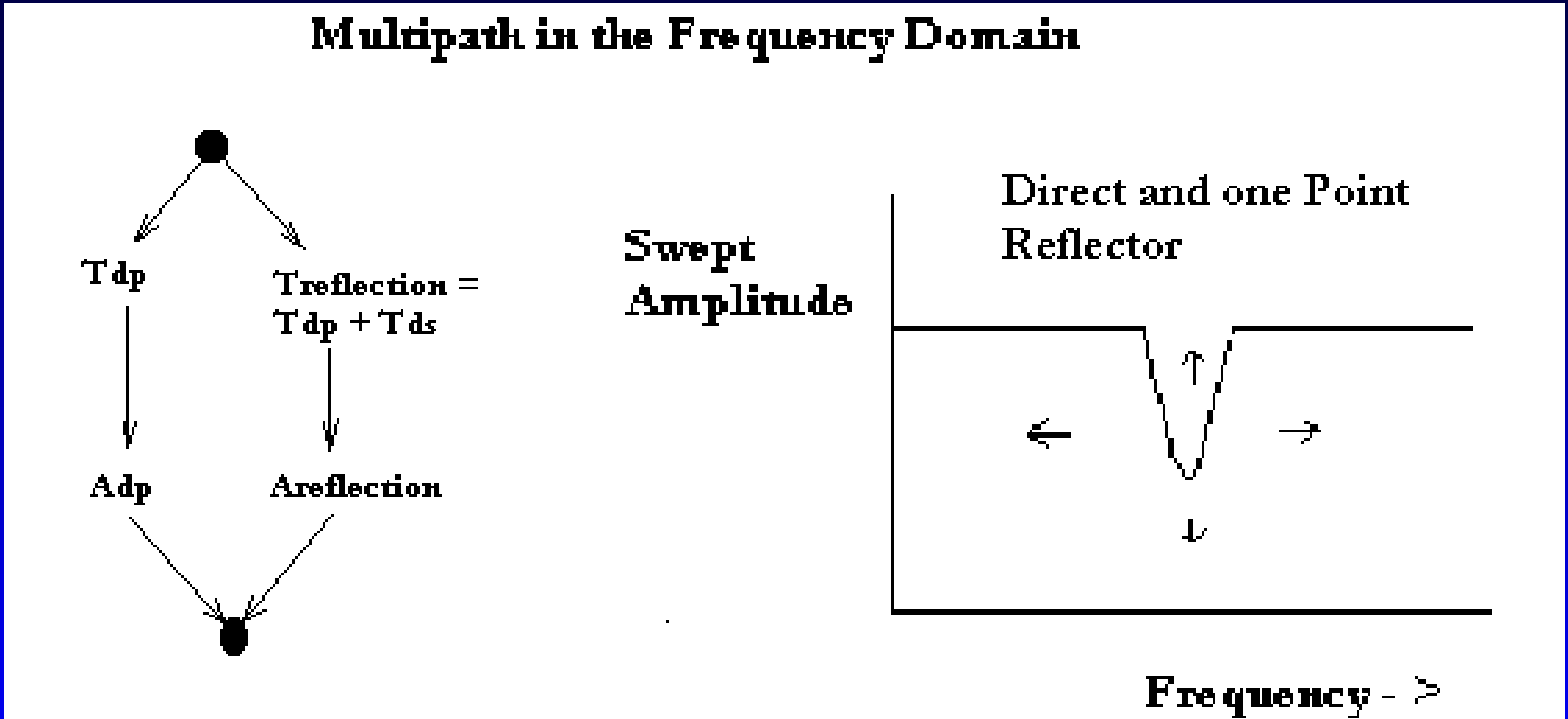


FIGURE 8

System Issues

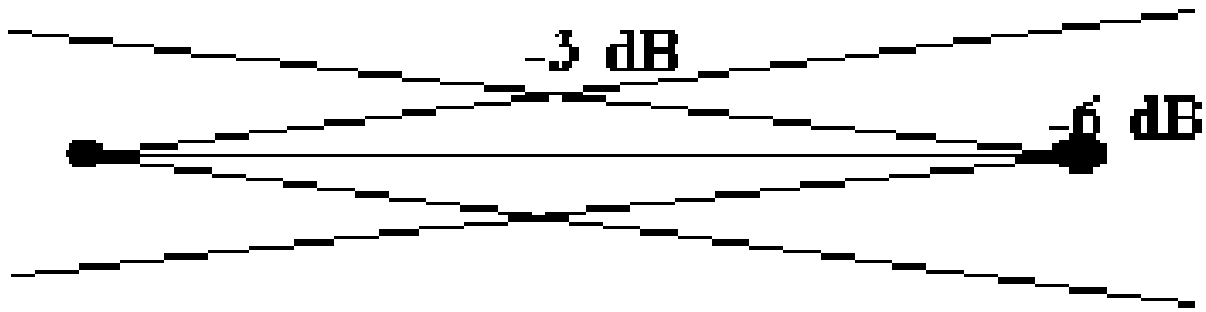
- Interference
  - Wavelan Vs Ricochetí
    - 1 MB Vs .05 MB, omni, .05 wins
    - 1 MB with 26 dB antenna gain and 13 dB rejection, against .05 MB omni
  - Weak Signal Contesting Vs Packet
    - interference should automatically cause directive packet stations to avoid W.S. qthís azimuth

System Issues

- DSSS, Multipath and Directivity
  - DSSS Gp and Antenna Directivity are complimentary (fig. 9)
    - 14 dB of Gp allows reflections at the antenna -3 dB beamwidth to be rejected at -20 dB
    - If beam directions not continuously variable, require up to 26 dB Gp to guarantee 20 dB reflection attenuation

Figure 9

DSSS Gp and Directivity are complimentary



Amax = -6 dBdp

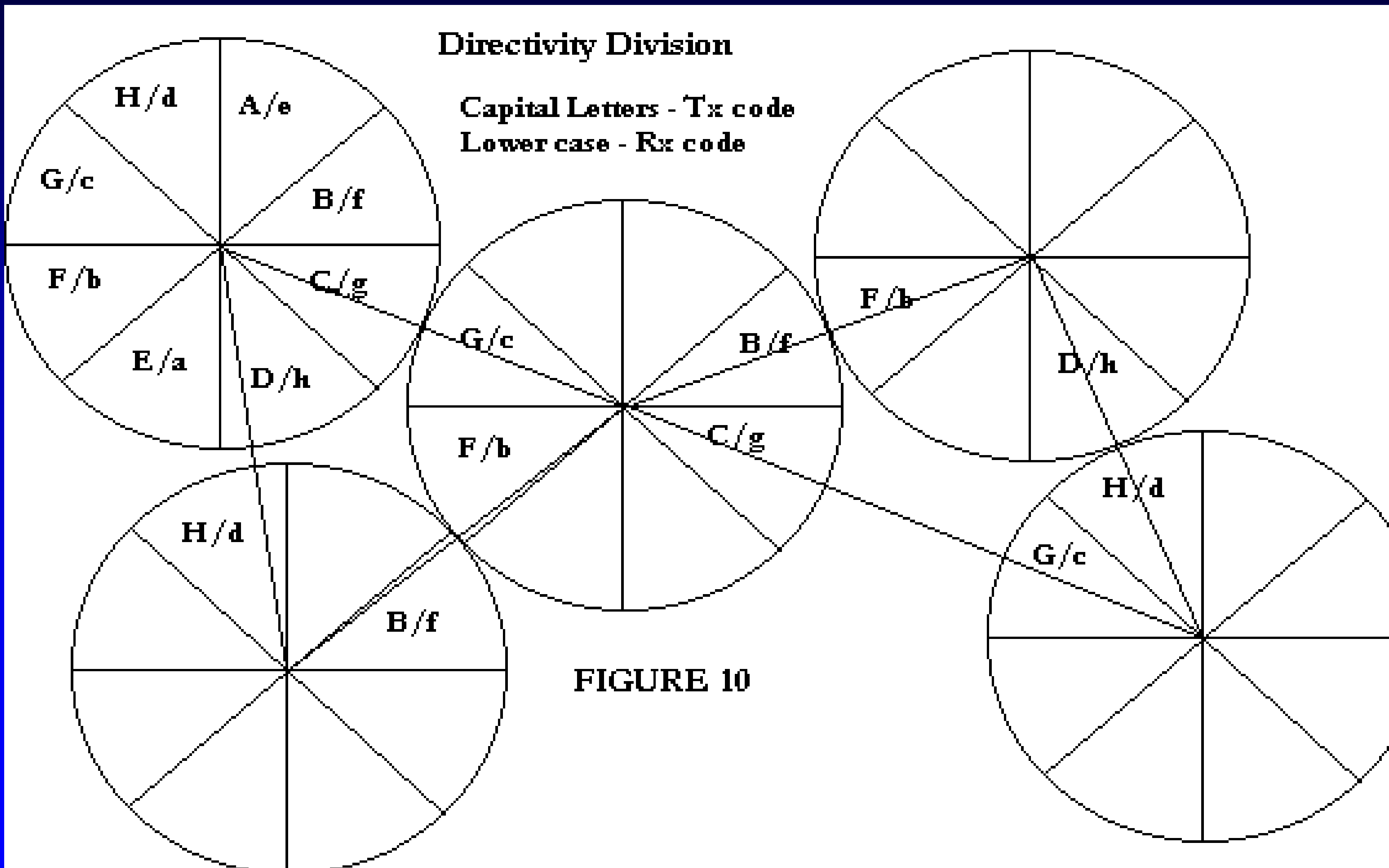
Amax with DSSS = -6 dBdp + -14 dB
= -20 dBdp

FIGURE 9

DDMA-WAN for MAN

- Directivity Division Multiple Access
  - Each direction a separate channel (fig. 10)
    - azimuthal rapidly scanning antenna <1ms r.a.
      - inline reverse direction paths isolated (fig.11)
    - spreading codes mapped to direction
      - crossing paths isolated - on different bearings(fig.12)
    - power control DSSS
      - in-line same direction paths isolated (fig.13)
    - reuse of same area resource over entire B.W.

Figure 10



Directivity Division
Capital Letters - Tx code
Lower case - Rx code
H/d
A/e
G/c
B/f
F/b
C/g
E/a
D/h
G/c
B/f
F/b
C/g
F/b
D/h
H/d
B/f
H/d
G/c
FIGURE 10

Figure 11

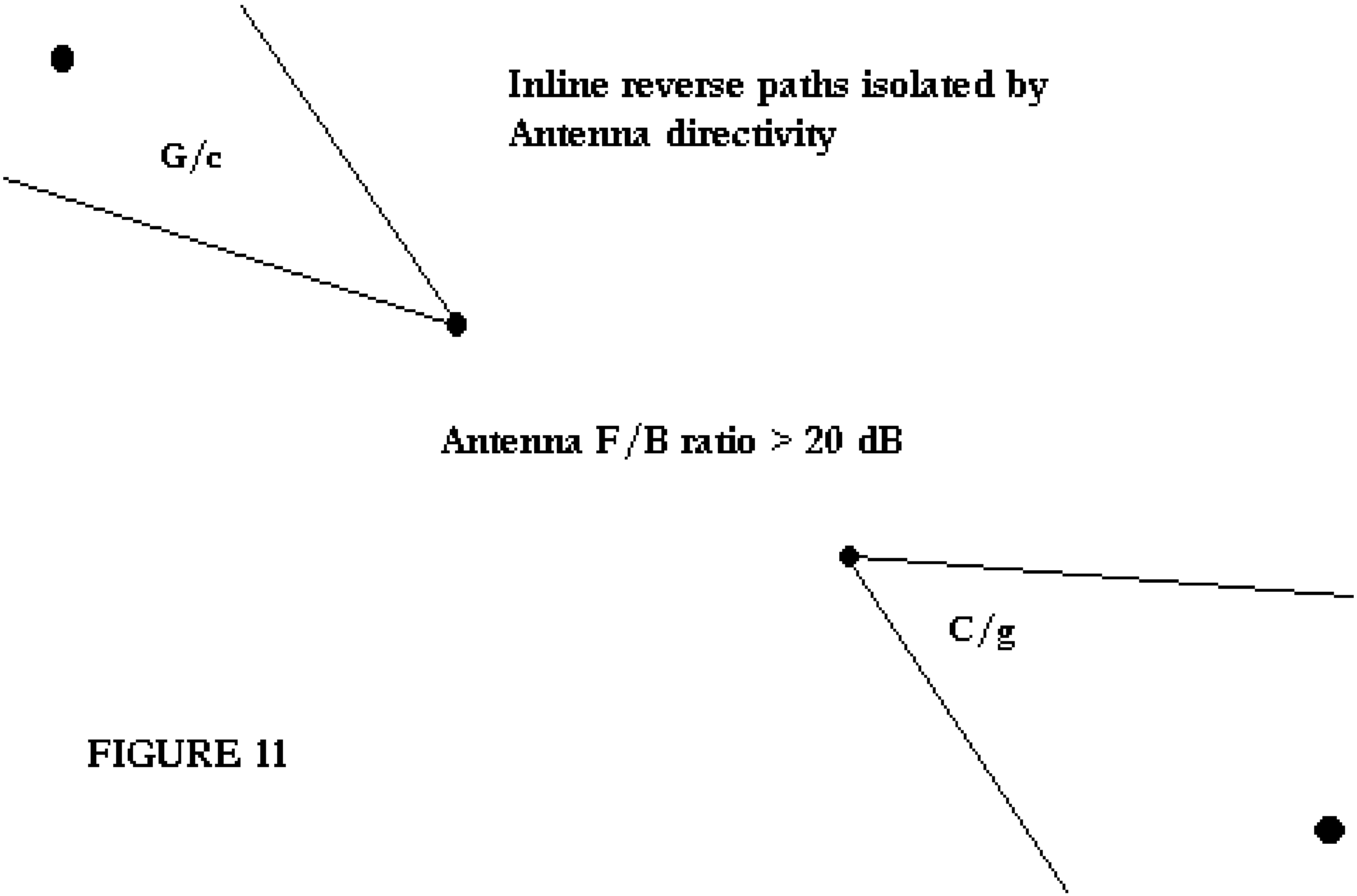


FIGURE 11

Figure 12

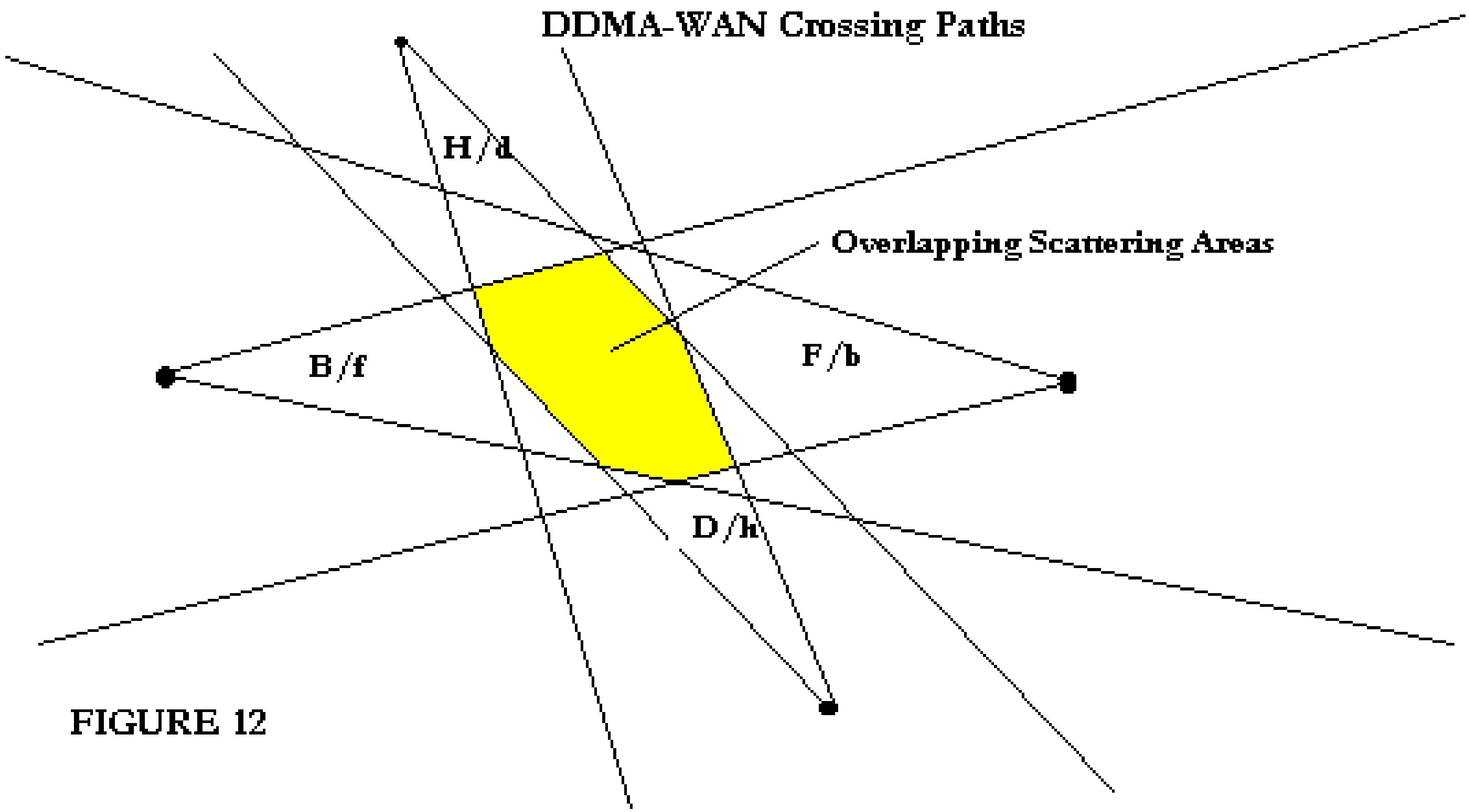
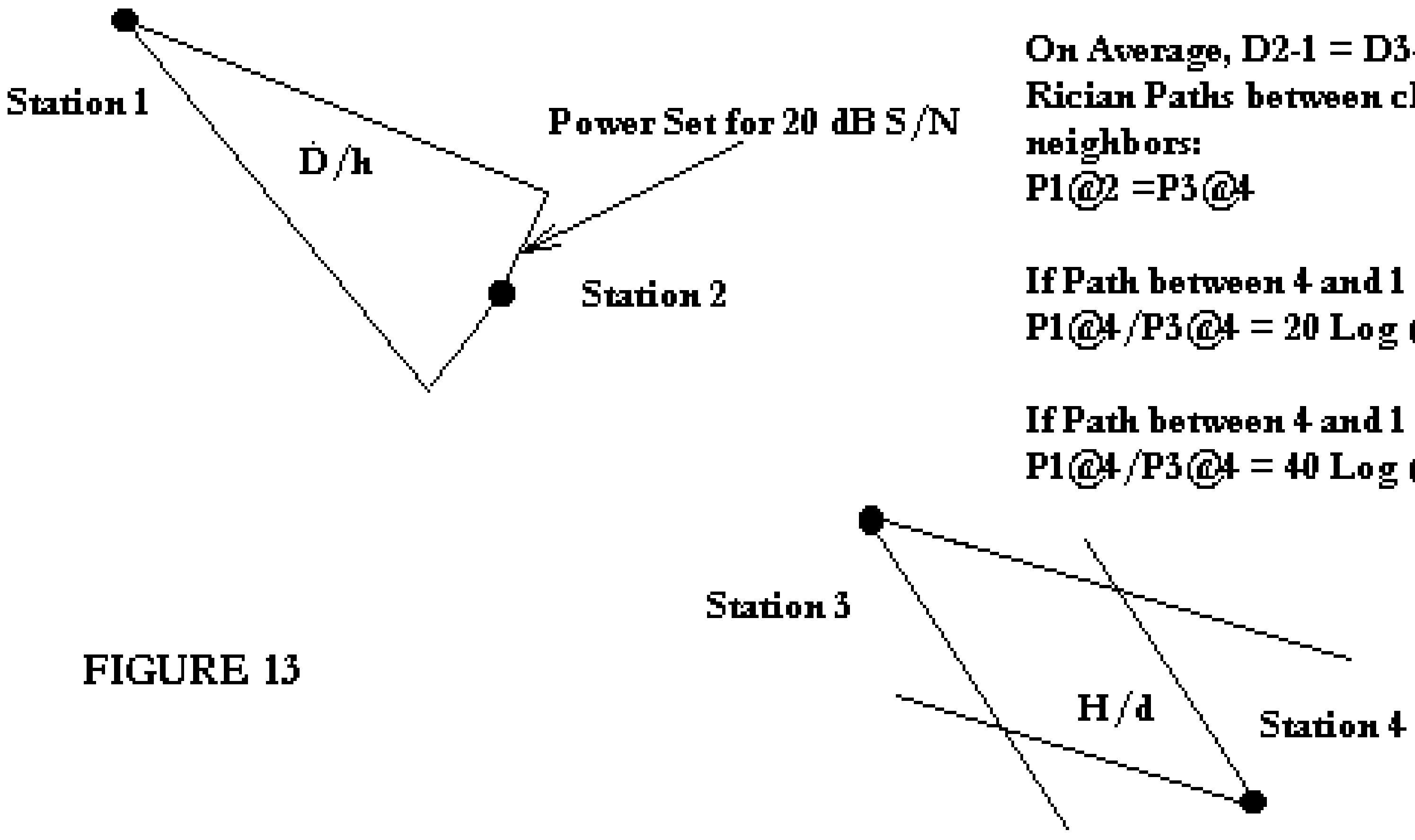


FIGURE 12

Figure 13

Inline Same Direction Isolation



On Average, D2-1 = D3-2=D4-3
Rician Paths between closest neighbors:
P1@2 =P3@4

If Path between 4 and 1 Rician
P1@4/P3@4 = 20 Log (1/3) = -9.5 dB

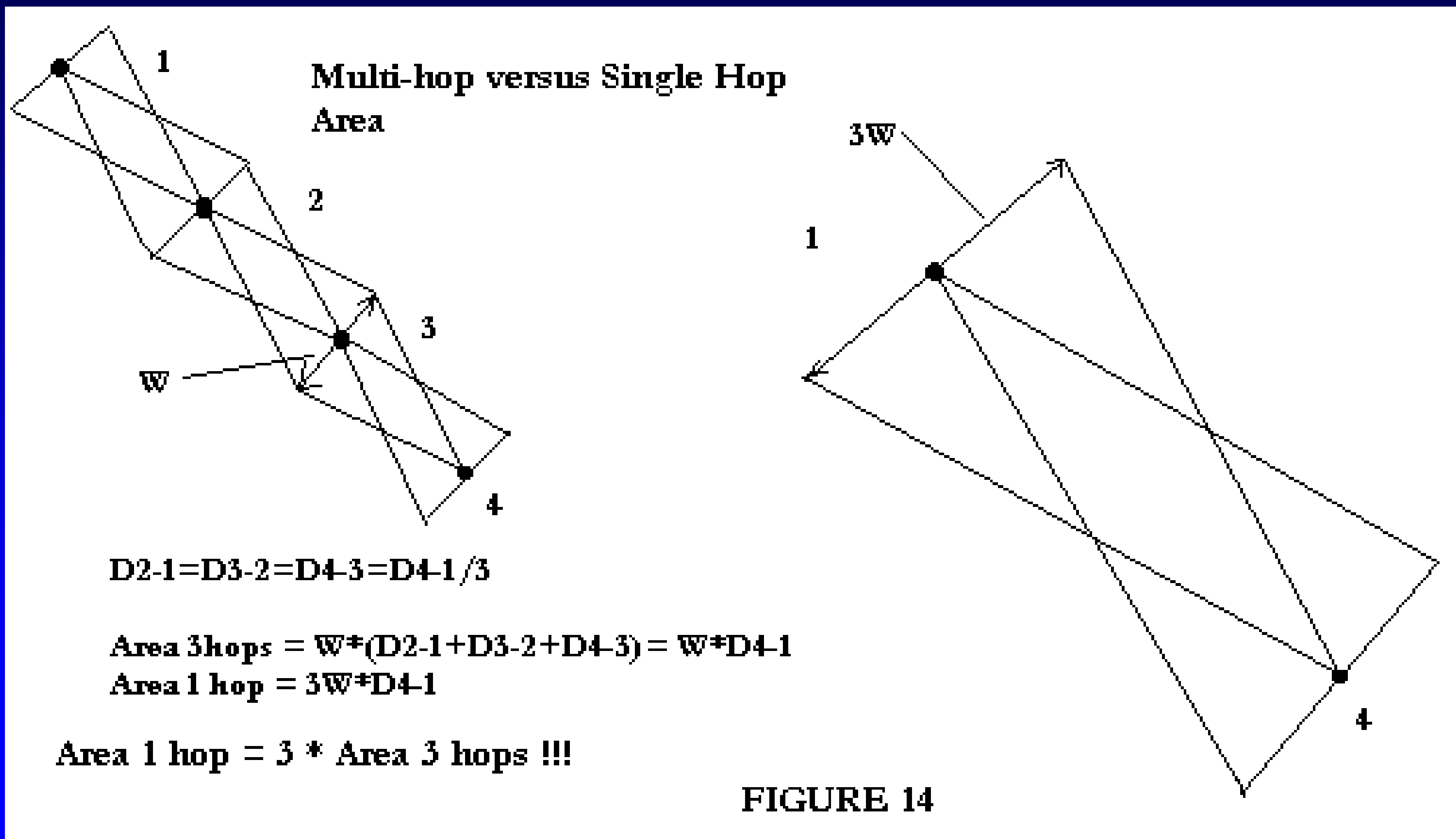
If Path between 4 and 1 Rayleigh
P1@4/P3@4 = 40 Log (1/3) = -19 dB

FIGURE 13

DDMA-WAN for MANís

- WAN structure
  - communicate to closest neighbor station - ìminimum energyî routing
    - minimizes area for communication between 2
      - multiple low power hops occupies cones of coverage with much less coverage than one hop with high power (fig14)
      - lowers contention for any particular unit area
        - graceful sharing of resource
    - shortest hop distance requires quickest transfer

Figure 14


Multi-hop versus Single Hop Area
1
2
3
4
W
3W
1
4
D2-1=D3-2=D4-3=D4-1/3
Area 3hops = W*(D2-1+D3-2+D4-3) = W*D4-1
Area 1 hop = 3W*D4-1
Area 1 hop = 3 * Area 3 hops !!!
FIGURE 14

DDMA-WAN for MANís

- WAN Structure - contíd
  - Using the entire BW allows for maximum baud rate - minimum time per packet.
  - Antenna directivity required to allow delay spread to be overcome reliably
    - circular requirements, directivity-> reuse band ->min energy routing -> highest baud rate -> directivity to get through the environment!

DDMA-WAN for MANís

- Delay Spread - 1 MB data rate
  - Fix completely by DSSS ?
    - requires 20 dB Gp, or 100 X Bandwidth!
  - Fix completely by Directivity?
    - 20 dB @ 1 mile for .2 nsec /-20 dBdp protection
      - 60 meter delta path length
      - 29 degree beamwidth for - 10 dB point!

DDMA-WAN for MANís

- Delay Spread - 1 MB data rate
  - Using 14 dB Gp DSSS and Directivity
    - 29 degree beamwidth @ - 3 dB
      - not that hard
    - 14 dB Gp
      - 25 times the bandwidth - reasonable

Technologies - Radios

- 1 MB DSSS Radios
  - digital matched filter
    - lockup time ~ 1 symbol time - STEL2000A
  - Gp 10 to 18 dB
- 100 KB FHSS Radios
  - Gp 10 to 30 dB
  - GFSK (ala K9NG)
    - lockup time ~ 100 symbols

Technologies - Radio

- 1 to 10 MB multi-tone modems
  - from ADSL - long training times

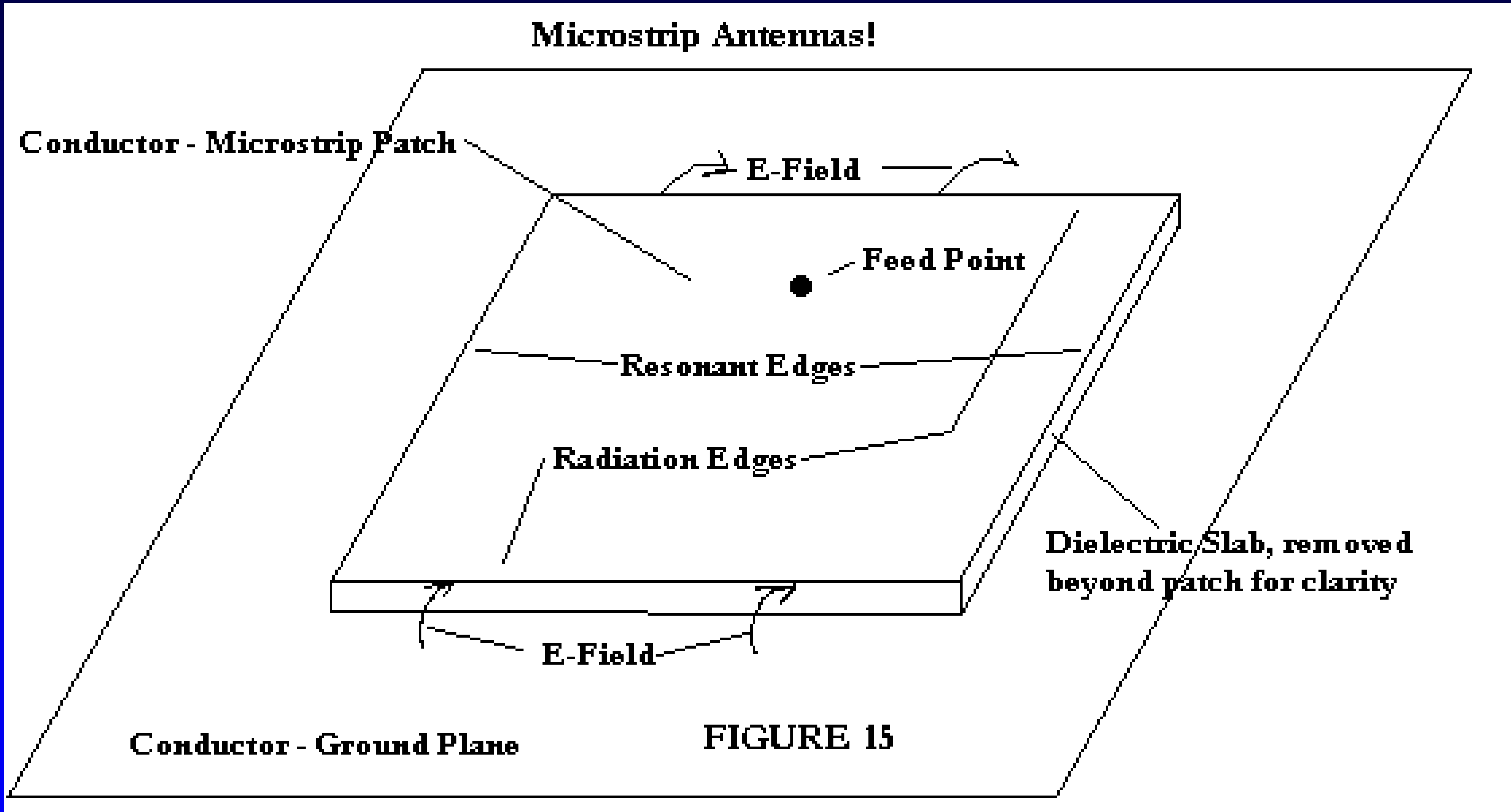
Technologies Antenna System

- Duplexors
  - cheap above 1 GHz
    - ceramic - lossy, but who cares at short range?
    - interdigital - wider duplex splits
    - waveguide - bulky at 2.5 GHz, but not at 10
    - LC - new ceramic materials for the Cís
- GaAs switches
    - 1 watt
    - < 1 ms switching!

Technologies Antenna System

- Microstrip Patch Antennas - Figure 15
  - Low element to element coupling
    - great for just-do-it array designs!
  - High F/B ratio
    - great for back mounted antennas
    - great for multipath out of apartments!
  - High Gain for a single element
    - Unidirectionality for free - 20 dB F/B ratio
    - Single 1/2 wave patch equivalent to 2 X 2 yagi

Figure 15



Microstrip Antennas!
Conductor - Microstrip Patch
E-Field
Feed Point
Resonant Edges
Radiation Edges
Dielectric Slab, removed beyond patch for clarity
E-Field
Conductor - Ground Plane
FIGURE 15

Technologies Antenna System

- Microstrip Patch Antennas - contíd
  - printable
  - large bandwidth single elements
    - backwards from yagiís
      - greater gain makes for greater bandwidth

Technologies - Misc.

- FEC in real time
- GPS 1 pulse per second outputs
  - Accuracy +/- .1 usec?

Direction(Channel) Acquisition

- How?
  - Stations do not hear each other unless antennas are pointed at each other!
  - How can one station detect another?

Direction(Channel) Acquisition

- Asynchronously
  - full duplex radios needed
  - Acquisition
    - all stations scan 360 degrees, unless busy
    - Accessing Station sends PRBS towards neighbor at minimum power, on RTS band
    - Known station detects and responds
      - on CTS band-echo prbs
      - packet in response has BER / Signal Strength / ID

Direction(Channel) Acquisition

- Synchronous
  - requires distributed timing standard - GPS?
  - simplex radios
  - Scheduled
    - For Example:
      - 1 talks to 2, 3 to 4, 5 to 6, 7 to 8 at top of cycle
      - second slot of cycle 2 to 3, 4 to 5, 6 to 7, 8 to 1
    - slots/cycle = max # of neighbors
      - = # of directions