WIRELESS COMMUNICATION NETWORKS

VI SEMISTER-IARE-R16

Prepared By

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WIRELESS COMMUNICATION NETWORKS

CO's	Course outcomes
CO1	Demonstrate their understanding on functioning of wireless communication system and evolution of different wireless communication systems and standards..
CO2	Compare different technologies used for wireless communication systems operations..
CO3	Explain the architecture, functioning, protocols capabilities and application of various wireless communication networks I/O device with different modules.
CO4	Demonstrate an ability explain multiple access techniques for Wireless Communication.
CO5	Demonstrate an ability to evaluate design challenges, constraints and security issues associated with Ad-hoc wireless networks.

UNIT-I

The Cellular Concept-system Design Fundamentals

CLOs	Course Learning Outcome
CLO1	Understand the principles and fundamentals of wireless communications.
CLO2	Demonstrate cellular system design concepts in wireless mobile communication networks.
CLO3	Understand the fundamental Radio Wave Propagation Mechanisms.

OUTLINE

- Introduction
- Frequency Reuse
- Channel Assignment Strategies
- Handoff Strategies
- Interference and System Capacity
- Improving Capacity In Cellular Systems

INTRODUCTION

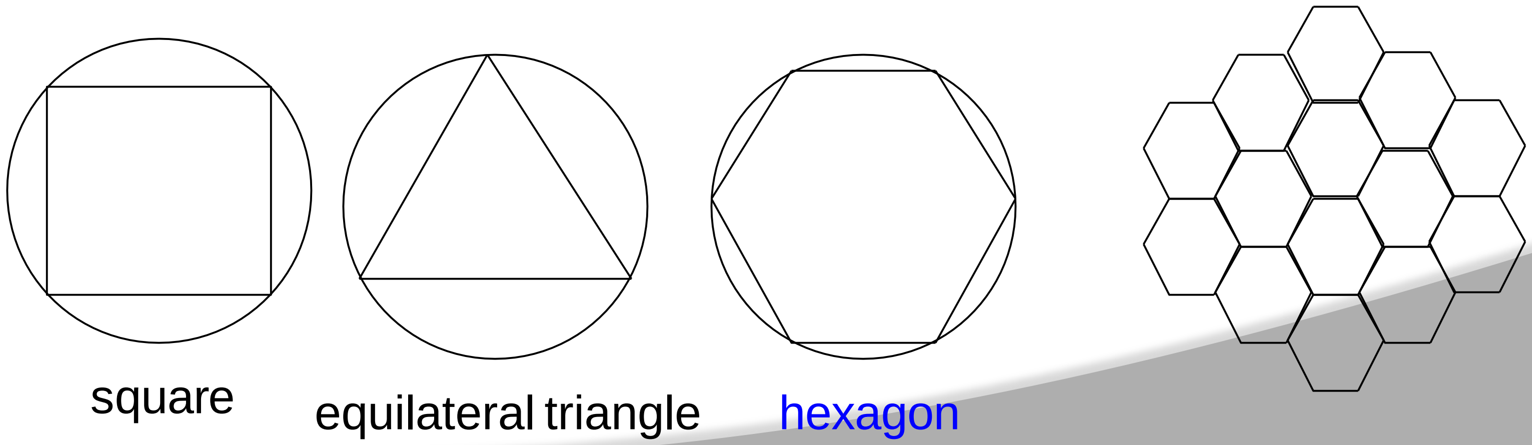
- Early mobile radio systems
  - A single high powered transmitter (single cell)
  - Large coverage area
  - Low frequency resource utility
  - Low user capacity
  - The cellular concept
  - A major breakthrough in solving the problem of spectral congestion and user capacity
  - Many low power transmitters (small cells)
  - Each cell covers only a small portion of the service area.
  - Each base station is allocated a portion of the total number of channels
  - Nearby base stations are assigned different groups of channels so that the interference between base stations is minimized

Frequency Reuse

- A service area is split into small geographic areas, called cells.
- Each cellular base station is allocated a group of radio channels.
- Base stations in adjacent cells are assigned different channel groups.
- By limiting the coverage area of a base station, the same group of channels may be reused by different cells far away.
- The design process of selecting and allocating channel groups for all of the cellular base stations within a system is called **frequency reuse** or frequency planning.

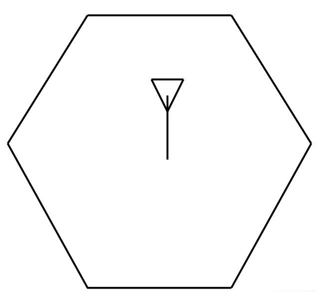
Frequency Reuse: Cell Shapes

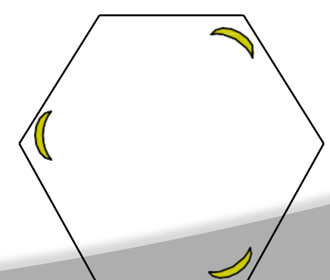
- Geometric shapes covering an entire region without overlap and with equal area.
- By using the hexagon, the fewest number of cells can cover a geographic region, and the hexagon closely approximates a circular radiation pattern which would occur for an omni-directional



Frequency Reuse: Excitation

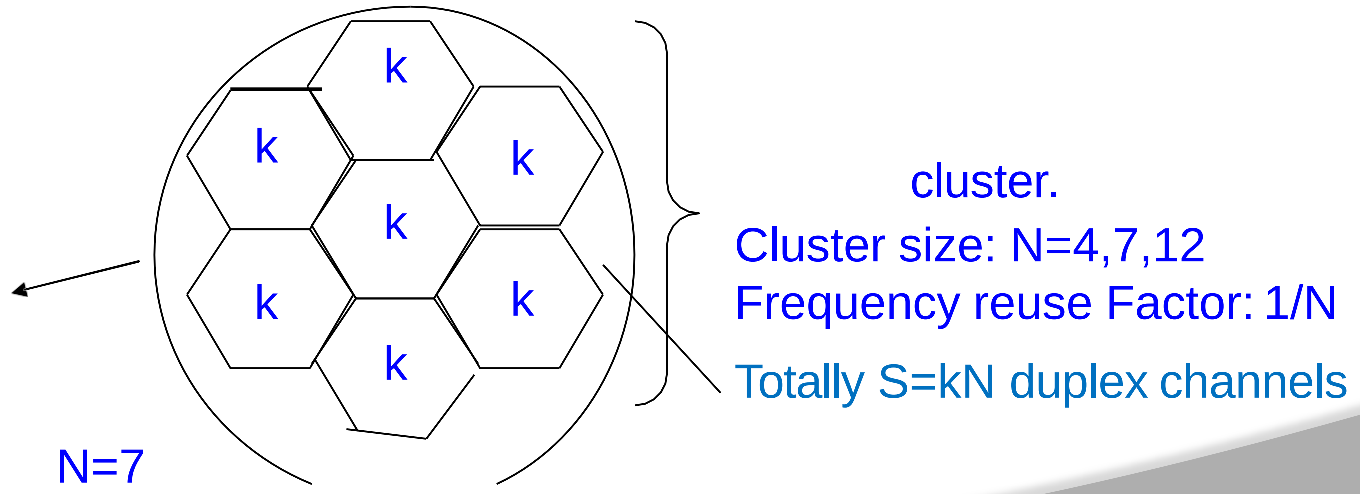
- Center-excited cell Base station transmitter is in the center of the cell.
- Omni-directional antennas are used.
- Edge-excited cell
- Base station transmitters are on three of the six cell vertices.
- Sectored directional





Frequency Reuse:The concept of Cluster

- Consider a cellular system which has a total of S duplex channels available for use.
- The S channels are divided among N cells (cluster).
- Each cell is allocated a group of k channels.
- The total number of available radio channels can be expressed as S=kN.

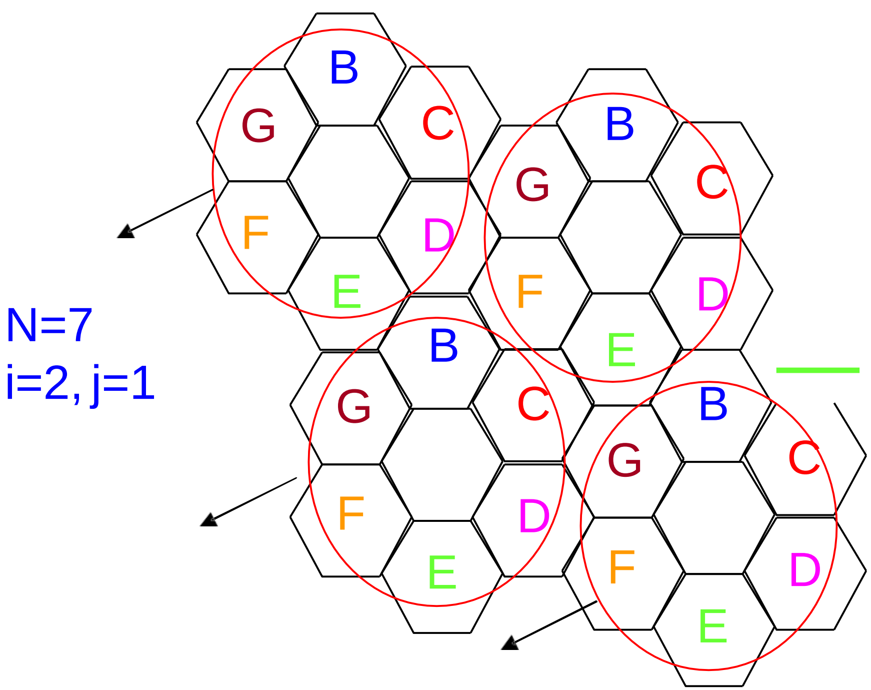


Frequency Reuse: Reuse Planning

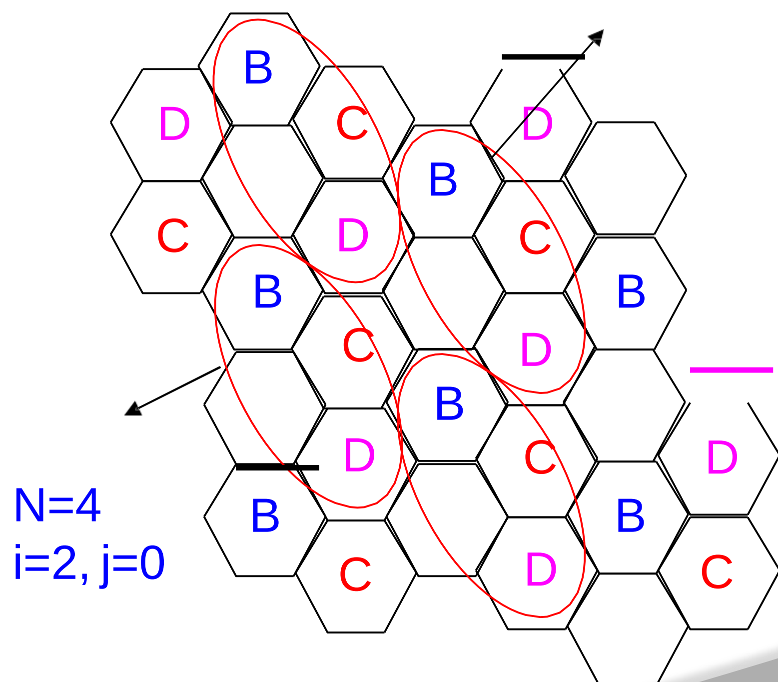
- If a cluster is replicated M times within the system, the total number of duplex channels, C, can be given as C = MkN = MS.
- Mathematically,N= i2 + ij + j2
- Where i and j are non-negative integers.
- The nearest co-channel neighbors of a particular cell can be found by doing what follows:
- move i cells along any chain of hexagons;
- turn 60 degrees counter-clockwise;
- move j cells.

Frequency Reuse: Reuse Planning

- Examples

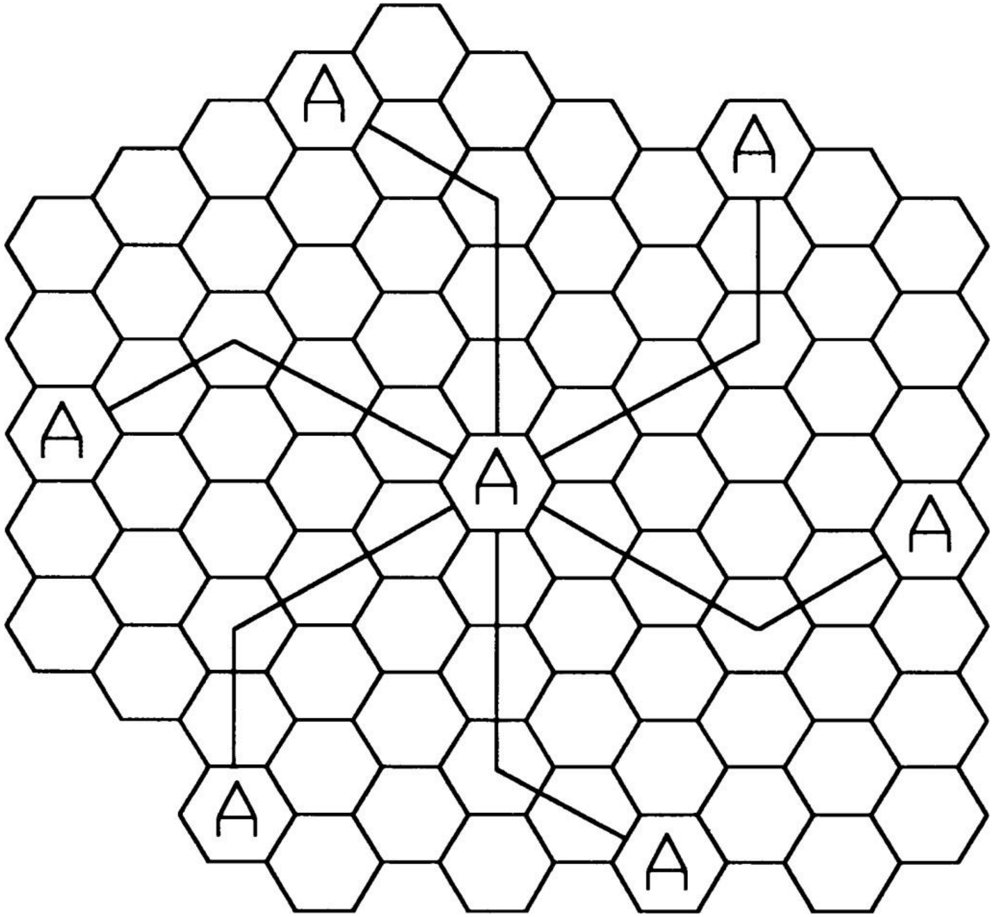


7-cell reuse



4-cell reuse

19-cell reuse example (N=19)



Method of locating co-channel cells in a cellular system.
In this example, N = 19 (i.e., I = 3, j = 2)

Channel Assignment Strategies

- Objectives:
- Increasing capacity
- Minimizing interference
- Classification:
- Fixed channel assignment strategies
- Dynamic channel assignment

Fixed channel assignment

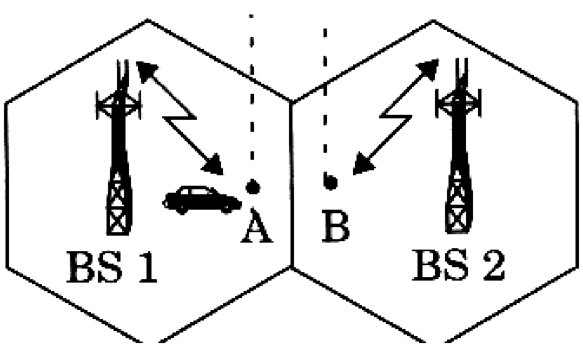
- Each cell is allocated a predetermined set of channels.
- Any call attempt within the cell can only be served by the unused channels in that particular cell.
- If all the channels in that cell are occupied, the call is blocked and the subscriber does not receive service.

Dynamic channel assignment strategies

- Channels are not allocated to different cells permanently.
- Each time a call request is made, the serving base station requests a channel from the MSC.
- The switch then allocates a channel to the requested cell following an algorithm that takes into account:
- The likelihood of fixture blocking within the cell
- The frequency of use of the candidate channel
- The reuse distance of the channel other cost functions.

Handoff Strategies

- Handoff:
  - When a mobile moves into a different cell while a conversation is in progress, the MSC automatically transfers the call to a new channel belonging to the new base station.
- Processing handoffs is an important task in any cellular radio system.



Handoff Strategies: Requirements

- Handoffs must be performed:
- Successfully;
- As infrequently as possible;
- Imperceptible to the users.
- How to meet these requirements
- Specify an optimum signal level to initiate a handoff;
- Decide optimally when to handoff;
- Consider the statistics of dwell time.

Handoff Strategies: Requirements

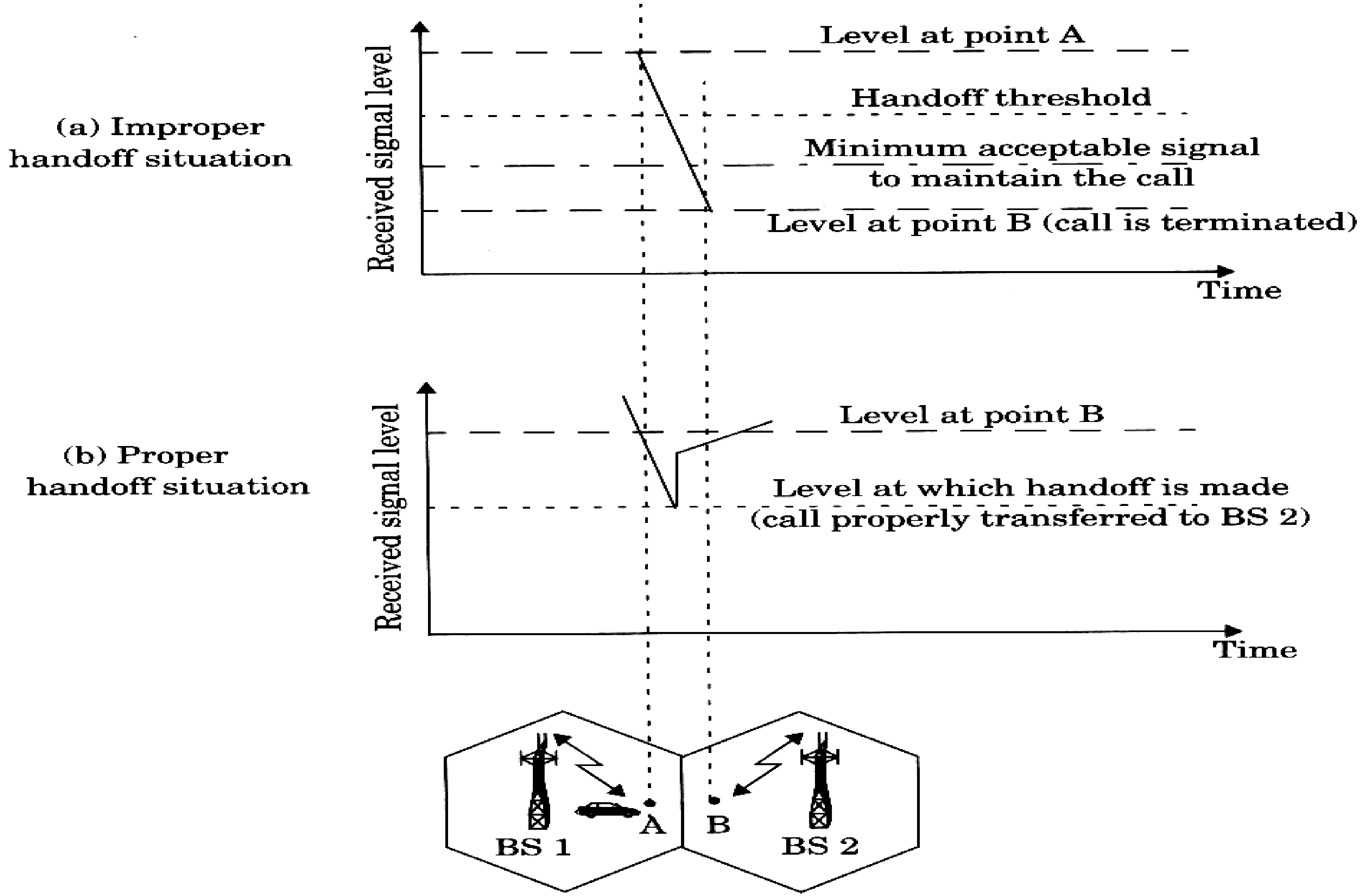


Figure 3.3 Illustration of a handoff scenario at cell boundary.

Handoff Strategies:
Signal strength measurements

- First generation analog cellular systems:
  - Signal strength measurements are made by the base stations and supervised by the MSC.
- Second generation systems:
  - Handoff decisions are mobile assisted;
  - The MSC no longer constantly monitors signal strengths.

Handoff Strategies: Managing of handoffs

Prioritizing Handoffs

- Guard channel: a fraction of the total available channels in a cell is reserved exclusively for handoff requests from ongoing calls which may be handed off into the cell.
- Queuing of handoff requests: to decrease the probability of forced termination of a call due to lack of available channels.
- Queuing of handoffs is possible due to the fact that there is a finite time interval between the time the received signal level drops below the handoff threshold and the time the call is terminated due to insufficient signal level.

Practical Handoff Considerations

- Observations
  - High speed vehicles pass through the coverage region of a cell within a
    matter of seconds.
  - Pedestrian users may never need a handoff during a call.
  - Particularly with the addition of microcells to provide capacity, the MSC can quickly become burdened if high speed users are constantly being passed between very small cells.
  - It is difficult for cellular service providers to obtain new physical cell site
    locations in urban areas.
  - Another practical handoff problem in microcell systems is known as cell dragging.

The umbrella cell approach

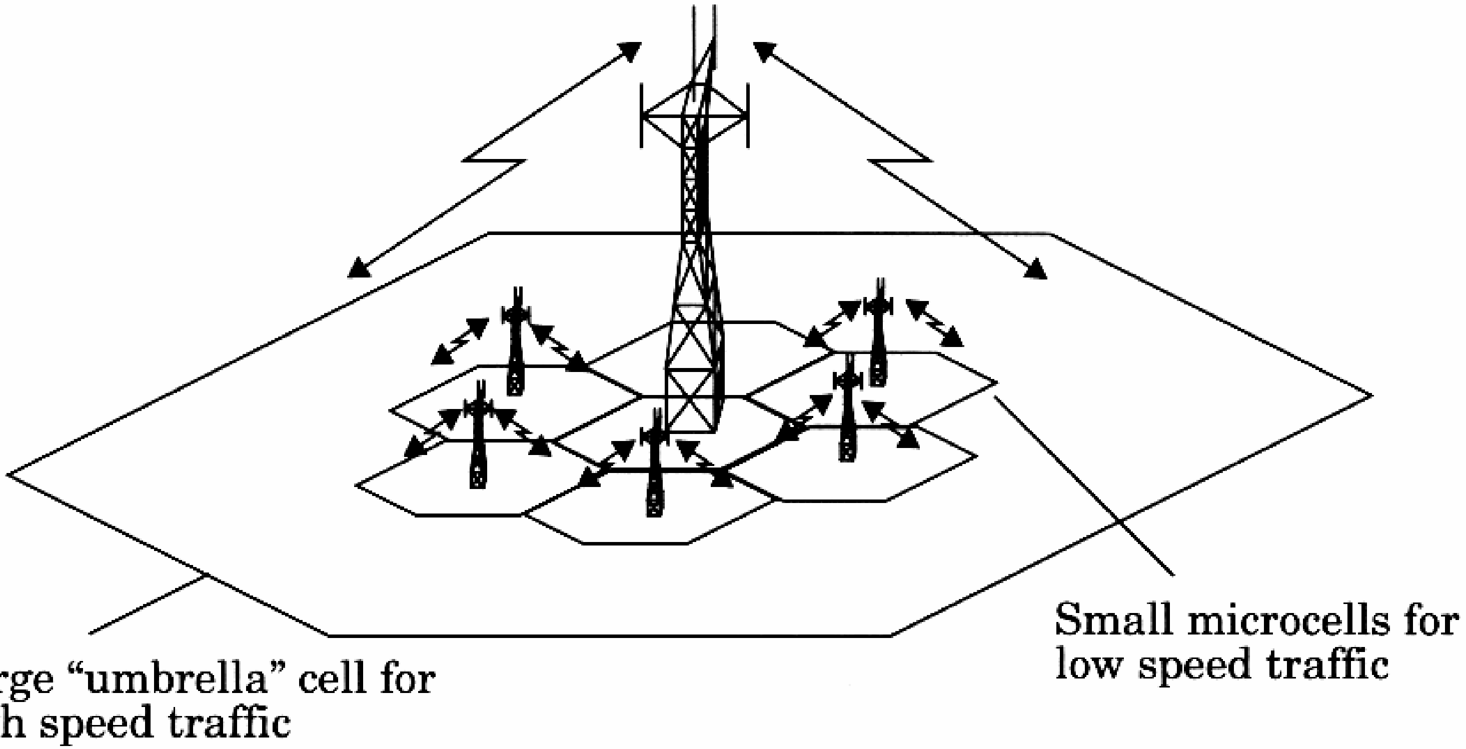


Figure 3.4 The umbrella cell approach.

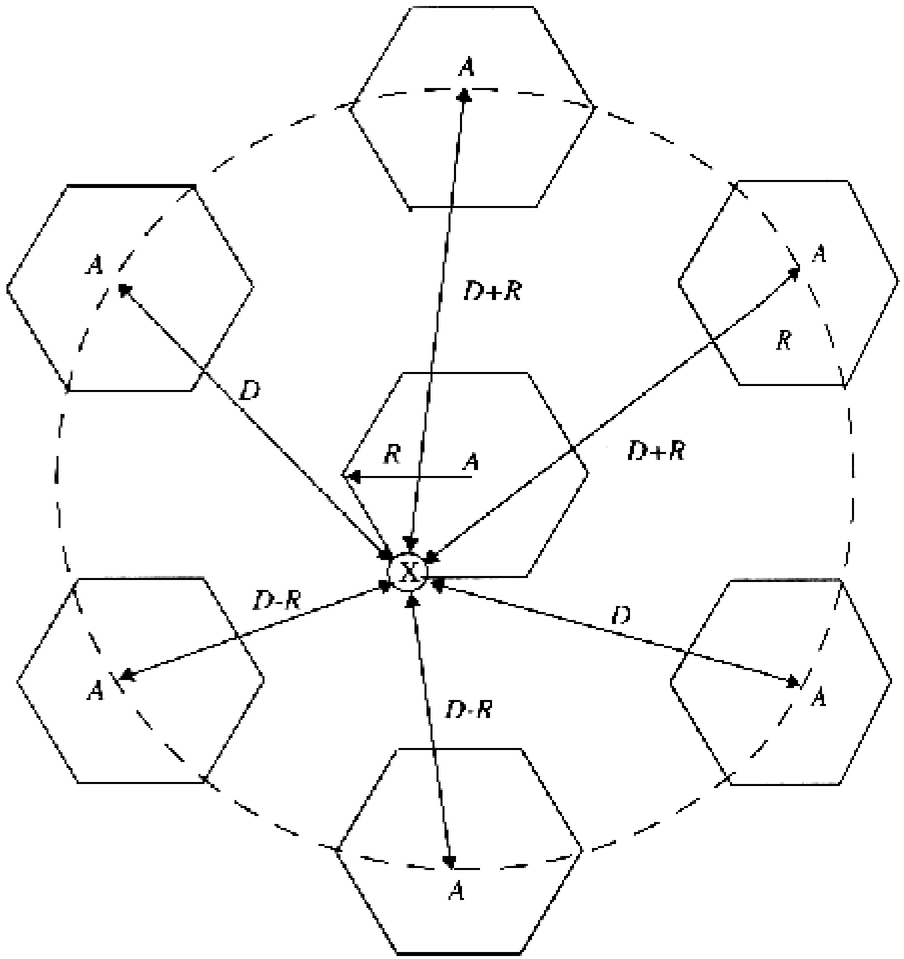
Interference and System Capacity

- Interference is the major limiting factor in the performance of cellular radio systems:
  - a major bottleneck in increasing capacity
  - often responsible for dropped calls
- The two major types of system-generated cellular interference are:
  - co-channel interference
  - adjacent channel interference
- Power Control for Reducing Interference

Co-channel Interference and System Capacity

- **Co-channel Interference**
  - Cells using the same set of frequencies are called co-channel cells, and the interference between signals from these cells is called co-channel interference.
  - Unlike thermal noise which can be overcome by increasing the signal-to-noise ration (SNR), co-channel interference cannot be combated by simply increasing the carrier power of a transmitter. This is because an increase in carrier transmit power increases the interference to neighboring co-channel cells.
  - To reduce co-channel interference, co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation.

Co-channel cells for 7-cell reuse



Co-channel Interference and System Capacity

- The co-channel interference ratio is a function of the radius of the cell (B) and the distance between centers of the nearest co- channel cells (D).
- By increasing the ratio of D/R, the spatial separation between co-channel cells relative to the coverage distance of a cell is increased. Thus interference is reduced.

Cochannel reuse ratio

- The parameter Q= D/R, called the cochannel reuse ratio, is related to the cluster size N.
  - When the size of each cell is approximately the same, and the base stations transmit the same power, we have

$$Q = D/R = (3N)^{1/3}$$

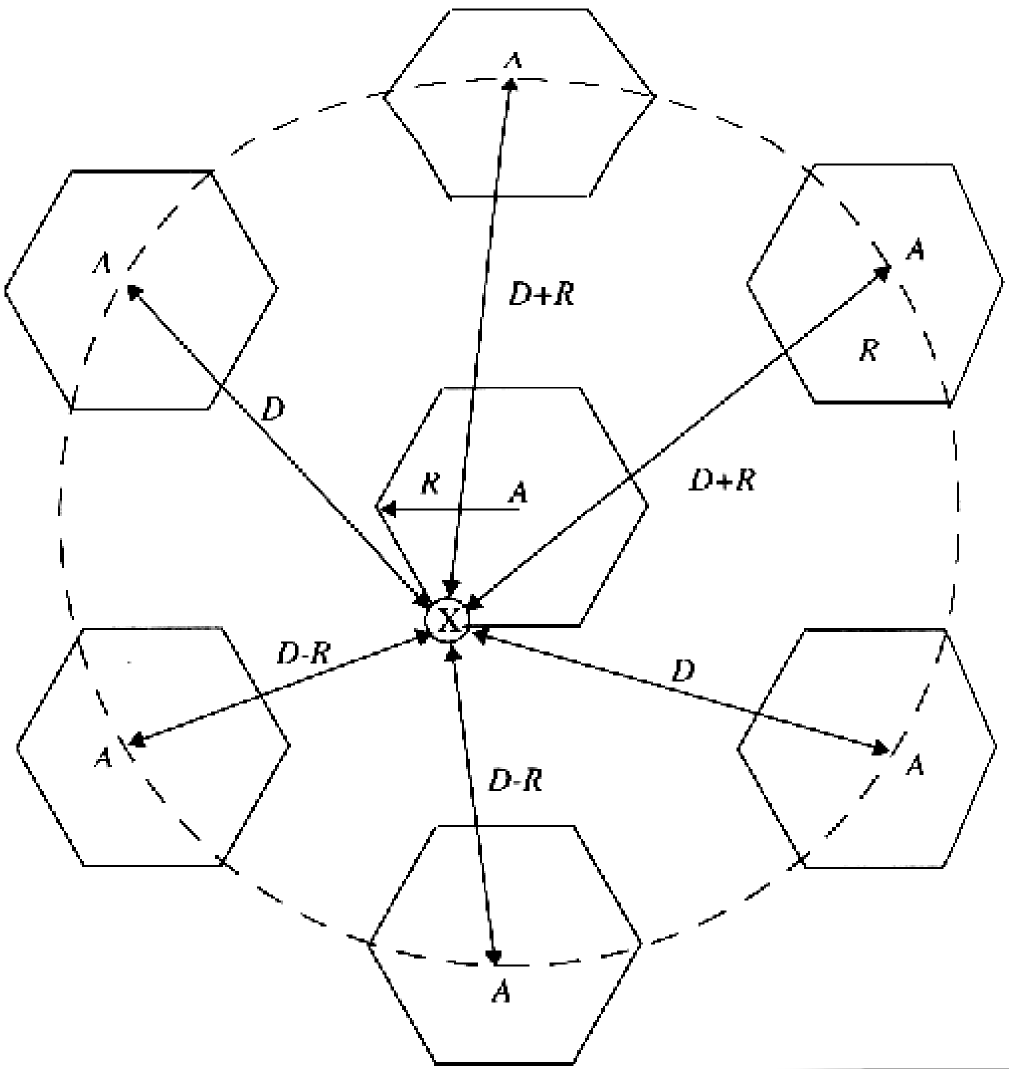
  - A small value of Q provides larger capacity since the cluster size N is small, whereas a large value of Q improves the transmission quality, due to a smaller level of co-channel interference.
  - A trade-off must be made between these two objectives in actual cellular design.

Smaller N is greater capacity

Table 3.1 Co-channel Reuse Ratio for Some Values of N

	Cluster Size (N)	Co-channel Reuse Ratio (Q)
$i = 1, j = 1$	3	3
$i = 1, j = 2$	7	4.58
$i = 2, j = 2$	12	6
$i = 1, j = 3$	13	6.24

Signal-to-interference ratio (SIR)



Signal-to-interference ratio (SIR)

- The average received power P at a distance *d* from the transmitting antenna is approximated by
- If all base stations transmit at the same power level, the SIR can be given as
- In practice, measures should be taken to keep the SIR on a acceptable level.

Adjacent Channel Interference

- Interference resulting from signals which are adjacent in frequency to the desired signal is called adjacent channel interference.
- Adjacent channel interference results from imperfect receiver filters which allow nearby frequencies to leak into the passband.
- Near-far effect:
  - If an adjacent channel user is transmitting in very close range to a subscriber's receiver, the problem can be particularly serious.

Adjacent Channel Interference

- Adjacent channel interference can be minimized through careful filtering and channel assignments:
  - By keeping the frequency separation between each channel in a given cell as large as possible, the adjacent channel interference may be reduced considerably.
  - Channel allocation schemes can also prevent a secondary source of adjacent channel interference by avoiding the use of adjacent channels in neighboring cell sites.
  - High Q cavity filters can be used in order to reject adjacent channel interference.

Adjacent Channel Interference

Table 3.2 AMPS Channel Allocation for A and B Side Carriers

1A	2A	3A	4A	5A	6A	7A	1B	2B	3B	4B	5B	6B	7B	1C	2C	3C	4C	5C	6C	7C
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126
127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147
148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168
169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189
190	191	192	193	194	195	196	197	198	199	20	201	202	203	204	205	206	207	208	209	210
211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231
232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252
253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273
274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294
295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	-	-	-
313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	667	668	669
670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690
691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711
712	713	714	715	716	-	-	-	-	991	992	993	994	995	996	997	998	999	1000	1001	1002

A SIDE

Power Control for Reducing Interference

- In practical cellular radio and personal communication systems the power levels transmitted by every subscriber unit are under constant control by the serving base stations.
- This is done to ensure that each mobile transmits the smallest power necessary to maintain a good quality link on the reverse channel.
- Power control not only helps prolong battery life for the subscriber unit, but also dramatically improves the reverse channel S/I in the system.
- Power control is especially important for emerging CDMA spread spectrum systems that allow every user in every cell to share the same radio channel.

Improving Capacity In Cellular Systems

- As the demand for wireless service increases, the number of channels assigned to a cell eventually becomes insufficient to support the required number of users.
- Techniques to expand the capacity of cellular systems :
  - Cell splitting: increases the number of base stations in order to increase capacity.
  - Sectoring: relies on base station antenna placements to improve capacity by reducing co-channel interference.
  - Coverage zone: distributes the coverage of a cell and extends the cell boundary to hard-to-reach places.

Cell Splitting

- Cell splitting is the process of subdividing a congested cell into smaller cells, each with its own base station and a corresponding reduction in antenna height and transmitter power.
- Cell splitting increases the capacity of a cellular system since it increases the number of times that channels are reused.

Cells are split to add channels with no new spectrum usage

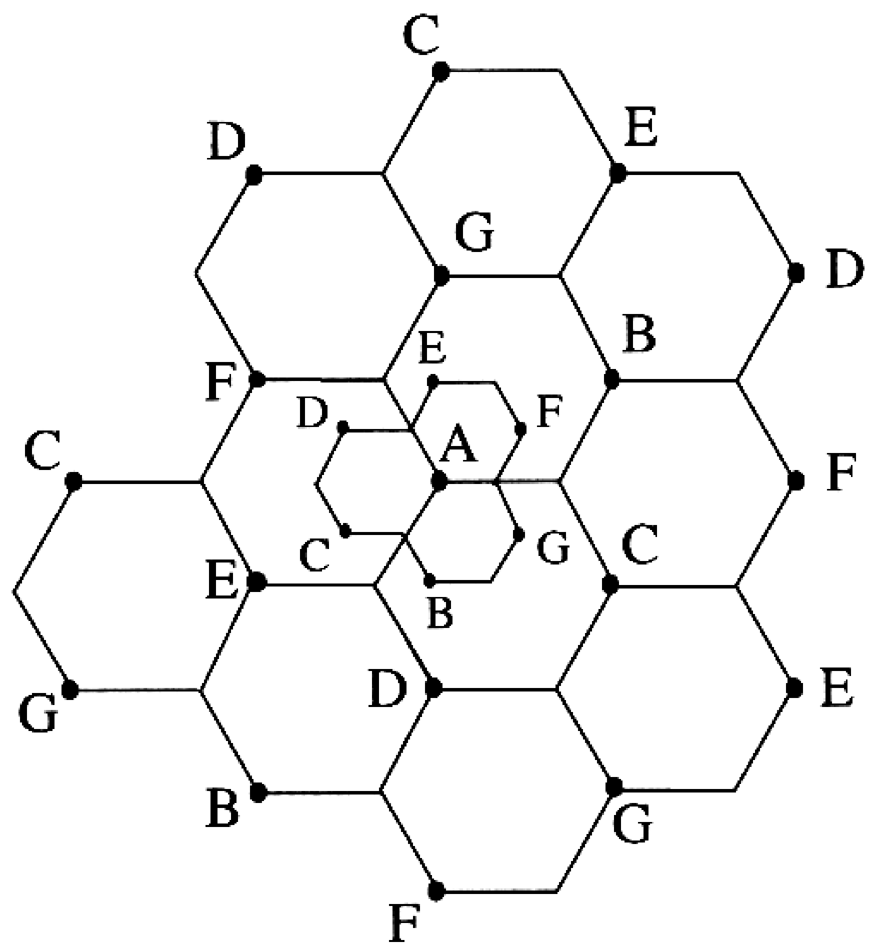


Figure 3.8 Illustration of cell splitting.

Cell Splitting increases capacity

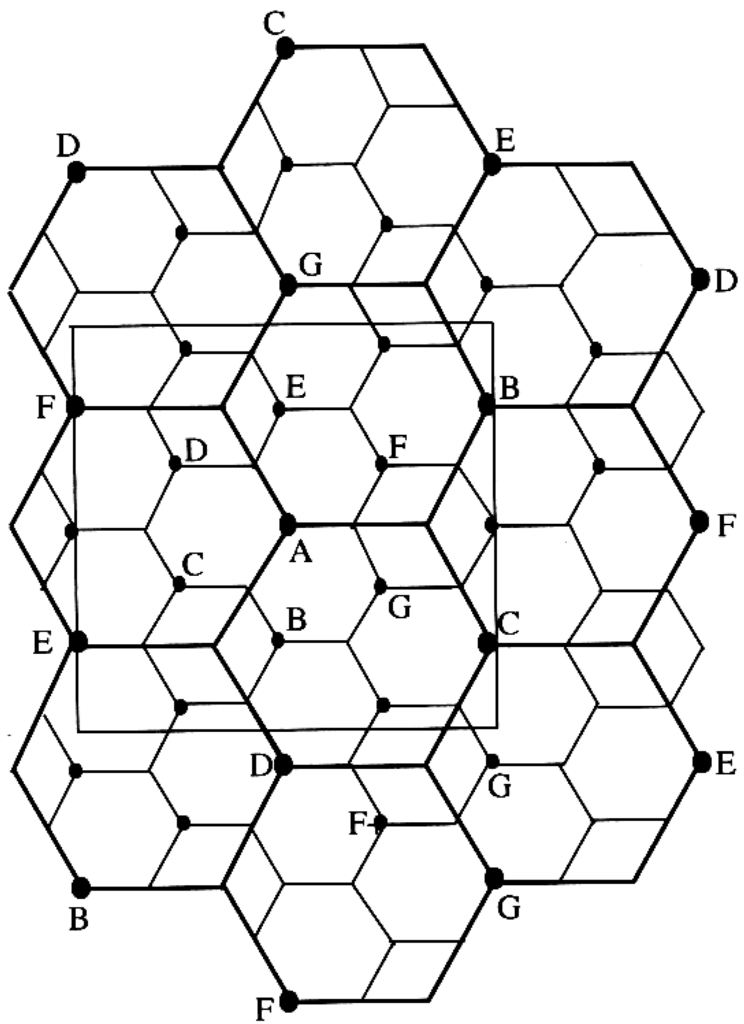


Figure 3.9 Illustration of cell splitting within a 3 km by 3 km square centered around base station A.

Sectoring

- The technique for decreasing co-channel interference and thus increasing system capacity by using directional antennas is called sectoring.
- The factor by which the co-channel interference is reduced depends on the amount of sectoring used.

Sectoring improves S/I

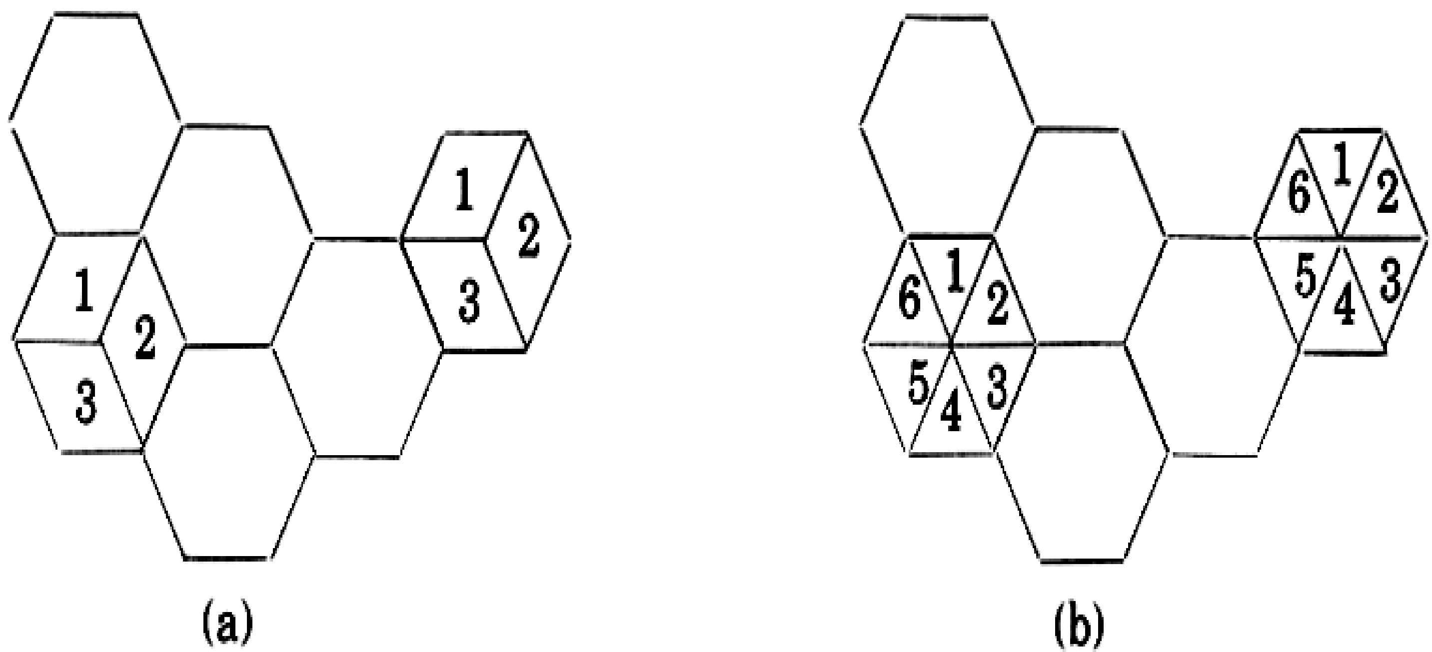


Figure 3.10 (a) 120° sectoring; (b) 60° sectoring.

Sectoring improves S/I

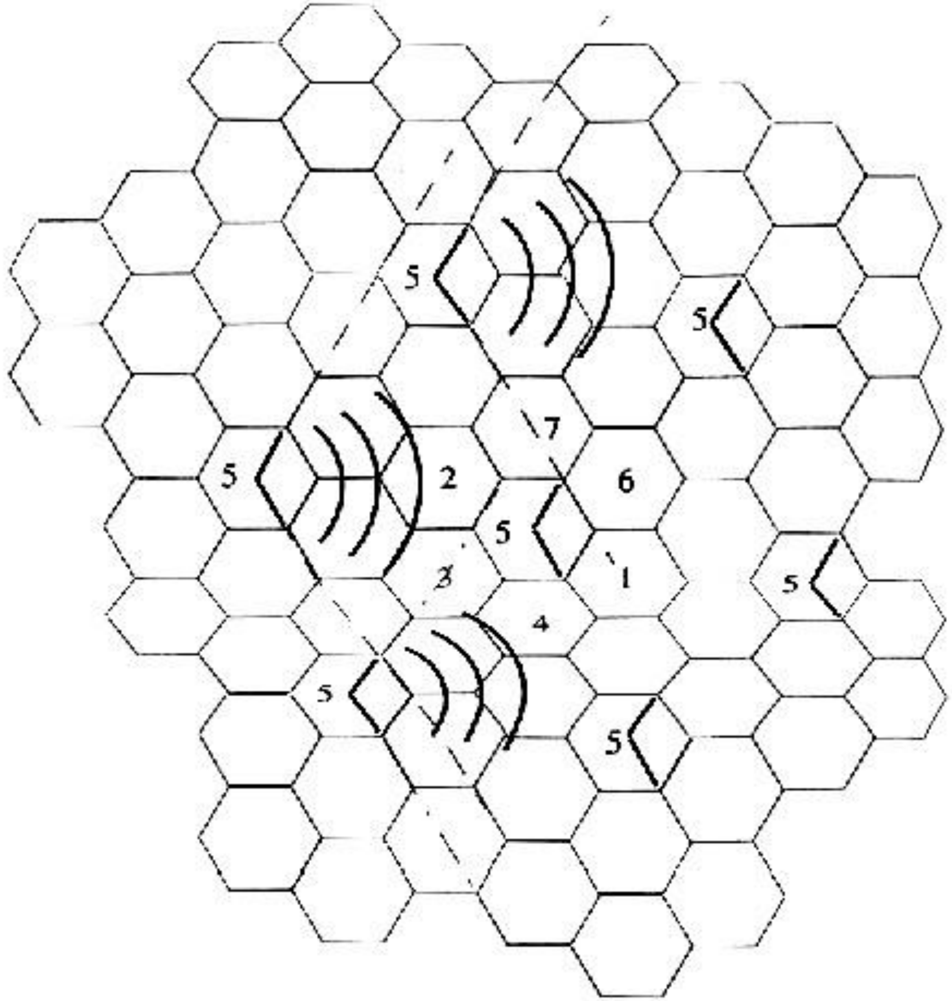


Figure 3.11 Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only two of them interfere with the center cell. If omnidirectional antennas were used at each base station, all six co-channel cells would interfere with the center cell.

A Novel Microcell Zone Concept

- **Zone Concept**
  - Zone sites are connected to a single base station and share the same radio equipment.
  - The zones are connected by coaxial cable, fiberoptic cable, or microwave link to the base station.
  - Multiple zones and a single base station make up a cell.
  - As a mobile travels within the cell, it is served by the zone with the strongest signal.
  - This technique is particularly useful along highways or along urban traffic corridors.

The Zone Cell Concept

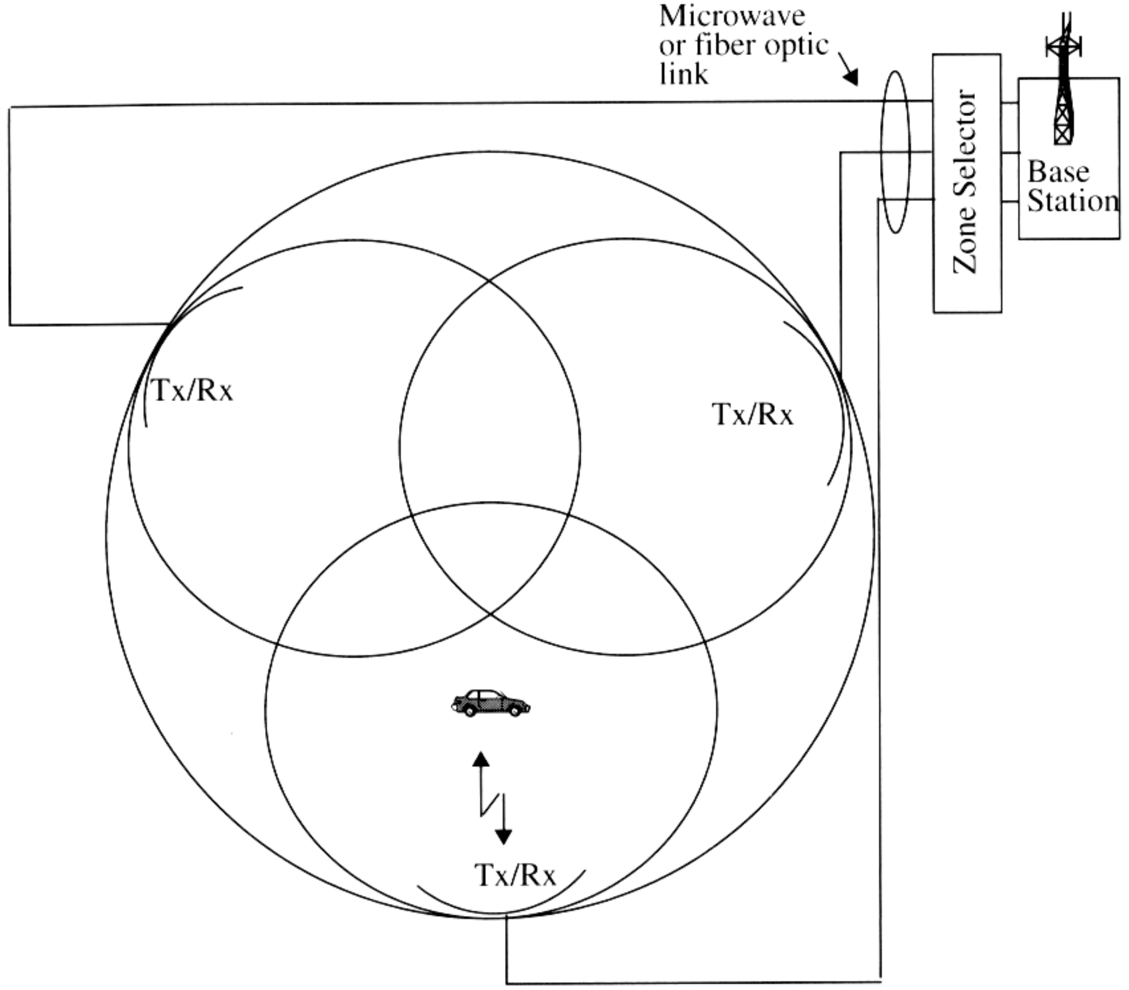


Figure 3.13 The microcell concept [adapted from [Lee91b] © IEEE].

UNIT- II

MOBILE RADIO PROPAGATION–
Large-Scale Path Loss

CLOs	Course Learning Outcome
CLO6	Analyze perspective on Fundamentals of Equalization and Mobile Radio Propagation Multipath Measurements
CLO7	Analyze various multiple access schemes and techniques used in wireless communication
CLO8	Discuss the Parameters of Mobile Multipath Channels and Types of Small-Scale Fading- Fading effects.

Outline

- Introduction to Radio Wave Propagation
- Three Basic Propagation Mechanisms
- Free Space Propagation Model
- Practical Link Budget Design using Path Loss Models
- Outdoor Propagation Models
- Indoor Propagation Models
- Signal Penetration into Buildings

Introduction to Radio Wave Propagation

- The mobile radio channel places fundamental limitations on the performance of wireless communication systems.
- Radio channels are extremely random and do not offer easy analysis.
- Modeling radio channel is important for:
  - Determining the coverage area of a transmitter
    - Determine the transmitter power requirement
    - Determine the battery lifetime
  - Finding modulation and coding schemes to improve the channel quality
    - Determine the maximum channel capacity

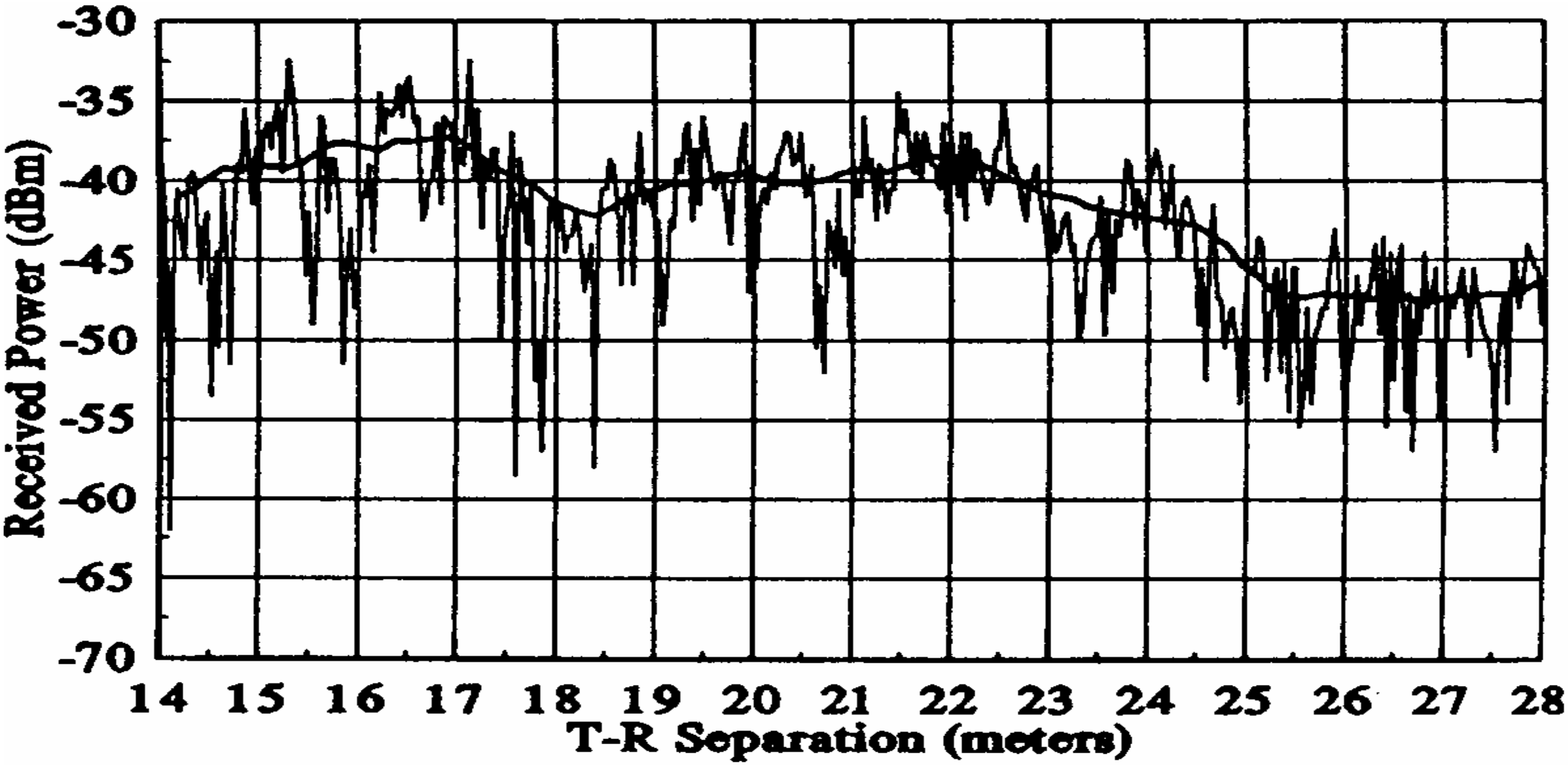
Introduction to Radio Wave Propagation

- The mechanisms behind electromagnetic wave propagation are diverse, but can generally be attributed to reflection, diffraction and scattering.
- Propagation models have traditionally focused on predicting the average received signal strength at a given distance from the transmitter, as well as the variability of the signal strength in close spatial proximity to a particular location.

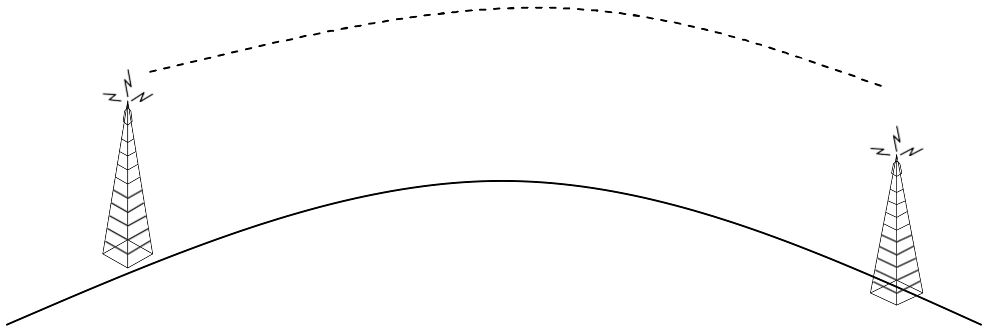
Introduction to Radio Wave Propagation

- Propagation models that predict the mean signal strength for an arbitrary transmitter-receiver (T-R) separation distance are useful in estimating the radio coverage area of a transmitter and are called large-scale propagation models.
- On the other hand, propagation models that characterize the rapid fluctuations of the received signal strength over very short travel distances (a few wavelengths) or short time durations (on the order of seconds) are called small-scale or fading models.

Introduction to Radio Wave Propagation

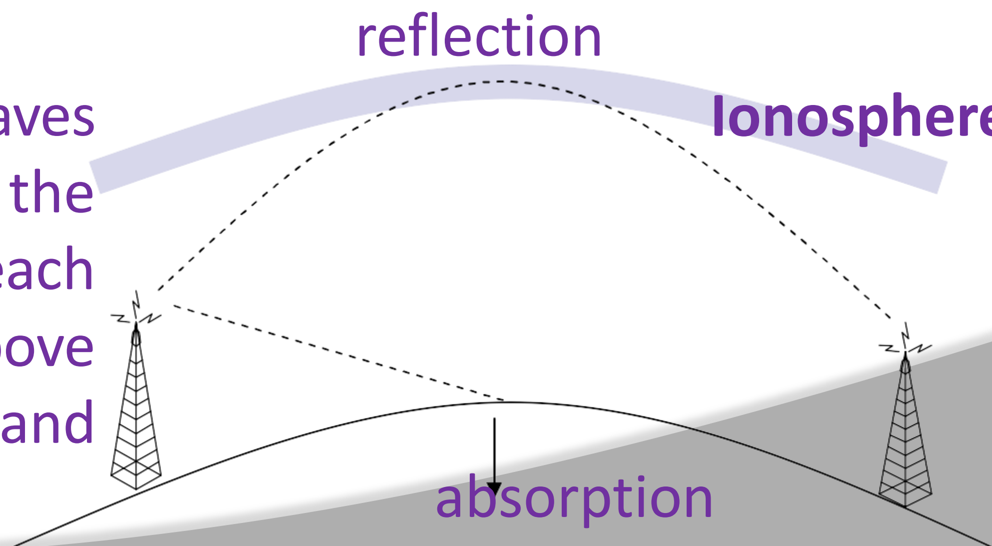


Basics - Propagation



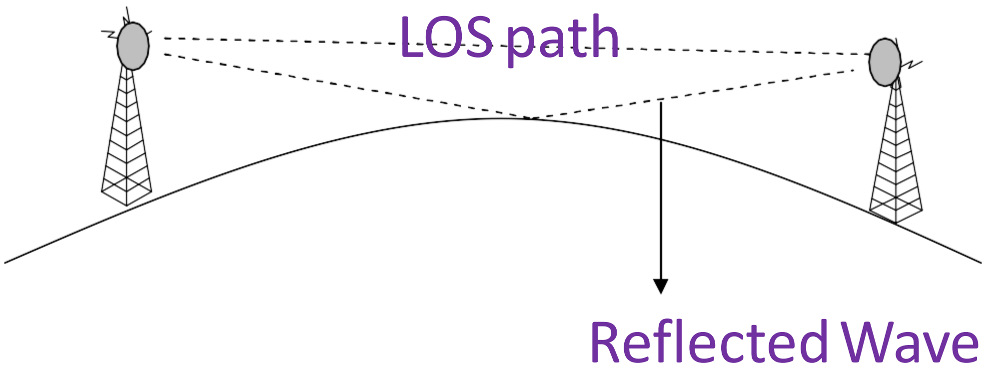
At **VLF, LF, and MF** bands, radio waves follow the ground.
AM radio broadcasting uses MF band

At **HF** bands, the ground waves tend to be absorbed by the earth. The waves that reach ionosphere (100-500km above earth surface), are refracted and sent back to earth.



Basics - Propagation

VHF Transmission



-Directional antennas are used
-Waves follow more direct paths
-LOS: Line-of-Sight Communication
-Reflected wave interfere with the original signal

Basics - Propagation

- Waves behave more like light at higher frequencies
  - Difficulty in passing obstacles
  - More direct paths
- They behave more like radio at lower frequencies
  - Can pass obstacles

Radio Propagation Models

- Transmission path between sender and receiver could be
  - Line-of-Sight (LOS)
  - Obstructed by buildings, mountains and foliage
- Even speed of motion effects the fading characteristics of the channel

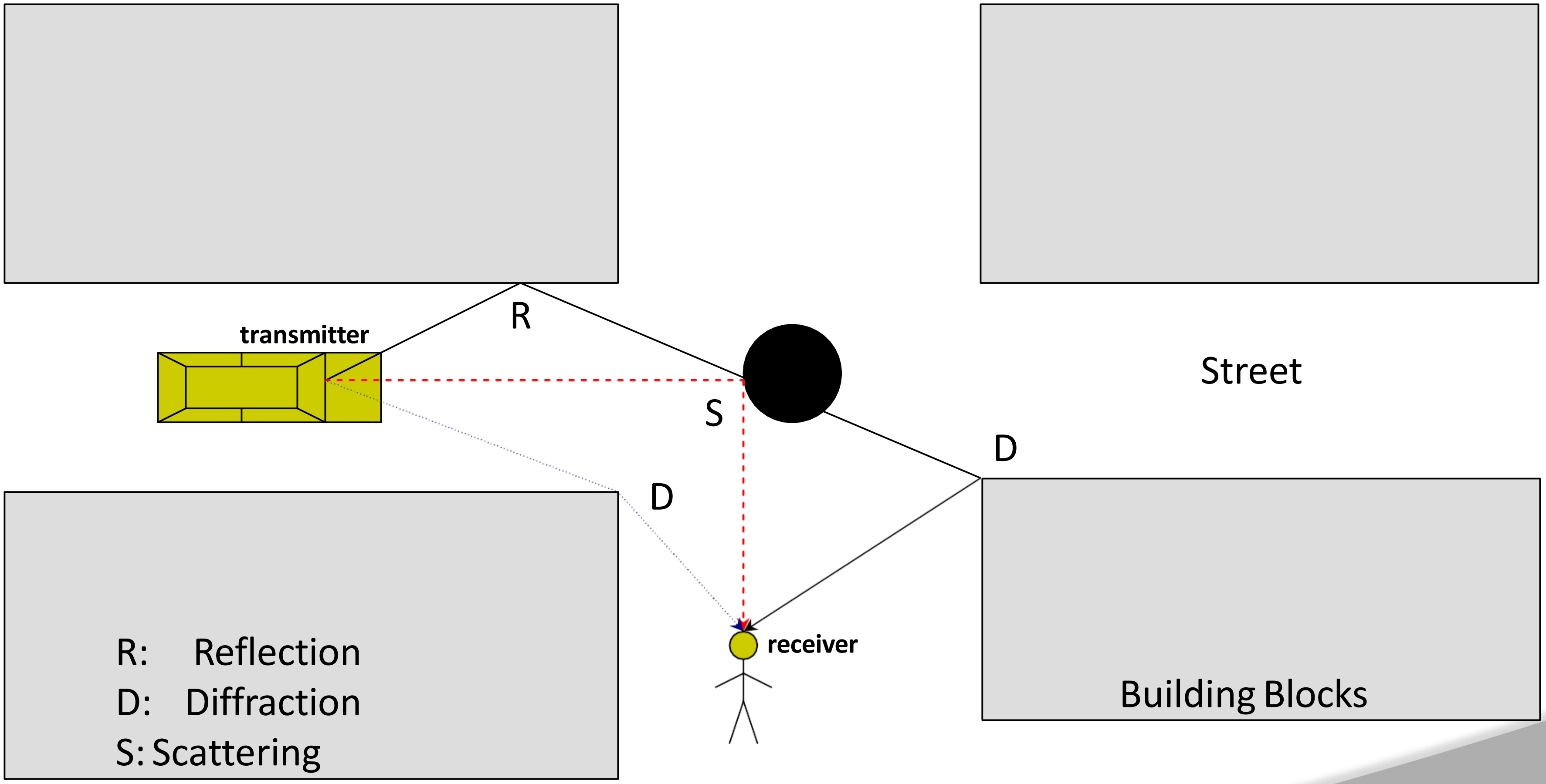
Three Radio Propagation Mechanisms

- The physical mechanisms that govern radio propagation are complex and diverse, but generally attributed to the following three factors
  1. Reflection
  2. Diffraction
  3. Scattering
- Reflection
  - Occurs when waves impinges upon an obstruction that is much larger in size compared to the wavelength of the signal
  - Example: reflections from earth and buildings
  - These reflections may interfere with the original signal constructively or destructively

Three Radio Propagation Mechanisms

- Diffraction
  - Occurs when the radio path between sender and receiver is obstructed by an impenetrable body and by a surface with sharp irregularities (edges)
  - Explains how radio signals can travel urban and rural environments without a line-of-sight path
- Scattering
  - Occurs when the radio channel contains objects whose sizes are on the order of the wavelength or less of the propagating wave and also when the number of obstacles are quite large.

Mechanisms


transmitter
R
S
D
D
Street
receiver
Building Blocks
R: Reflection
D: Diffraction
S: Scattering

Three Radio Propagation Mechanisms

- As a mobile moves through a coverage area, these 3 mechanisms have an impact on the instantaneous received signal strength.
  - If a mobile does have a clear line of sight path to the base-station, than diffraction and scattering will not dominate the propagation.
  - If a mobile is at a street level without LOS, then diffraction and scattering will probably dominate the propagation.

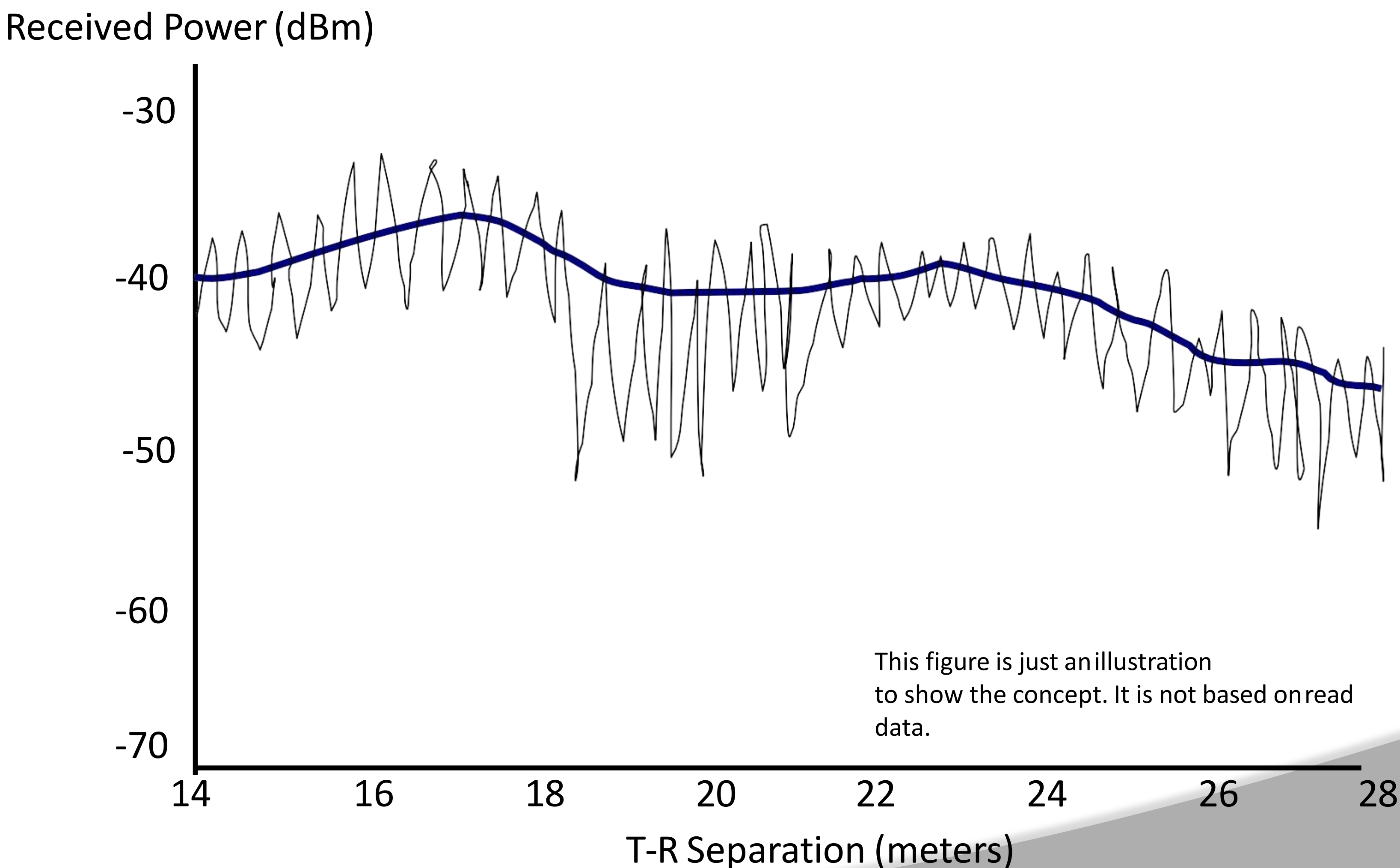
Radio Propagation Models

- As the mobile moves over small distances, the instantaneous received signal will fluctuate rapidly giving rise to small scale fading
  - The reason is that the signal is the sum of many contributors coming from different directions and since the phases of these signals are random, the sum behave like a noise (Rayleigh fading).
  - In small scale fading, the received signal power may change as much as 3 or 4 orders of magnitude (30dB or 40dB), when the receiver is only moved a fraction of the wavelength.

Radio Propagation Models

- As the mobile moves away from the transmitter over larger distances, the local average received signal will gradually decrease. This is called large-scale path loss.
  - Typically the local average received power is computed by averaging signal measurements over a measurement track of for PCS, this means 1m-10m track)
- The models that predict the mean signal strength for an arbitrary-receiver transmitter (T-R) separation distance are called large-scale propagation models
  - Useful for estimating the coverage area of transmitters

Small-Scale and Large-Scale Fading



This figure is just an illustration to show the concept. It is not based on read data.

Free-Space Propagation Model

- Used to predict the received signal strength when transmitter and receiver have clear, unobstructed LOS path between them.
- The received power decays as a function of T-R separation distance raised to some power.
- Path Loss: Signal attenuation as a positive quantity measured in dB and defined as the difference (in dB) between the effective transmitter power and received power.

Free-Space Propagation Model

- Free space power received by a receiver antenna separated from a radiating transmitter antenna by a distance d is given by Friis free space equation:
  - P_t is transmited power
  - $P_r(d)$ is the received power
  - G_t is the trasmitter antenna gain (dimensionless quantity)
  - G_r is the receiver antenna gain (dimensionless quantity)
  - d is T-R separation distance in meters
  - L is system loss factor not related to propagation ($L >= 1$)
    - L = 1 indicates no loss in system hardware (for our purposes we will take L = 1, so we will igonore it in our calculations)

Free-Space Propagation Model

- The gain of an antenna G is related to its affective aperture A_e by:
  - The effective aperture of A_e is related to the physical size of
    the antenna, is related to the carrier frequency by:

Free-Space Propagation Model

- An *isotropic* radiator is an ideal antenna that radiates power with unit gain uniformly in all directions.
- It is as the reference antenna in wireless systems.
- The *effective isotropic radiated power* (EIRP) is defined as:
  - $EIRP = P_t G_t$ [Equation 4]
- Antenna gains are given in units of dBi (dB gain with respect to an isotropic antenna) or units of dBd (dB gain with respect to a half-wave dipole antenna).
  - Unity gain means:
    - G is 1 or 0dBi

Free-Space Propagation Model

- For Friis equation to hold, distance *d* should be in the far-field of the transmitting antenna.
- The far-field, or Fraunhofer region, of a transmitting antenna is defined as the region beyond the far-field distance d_f given by:
  - $d_f = 2D^2$ [Equation 7]
    - D is the largest physical dimension of the antenna.
  - Additionally, $d_f >> D$

Free-Space Propagation Model – Reference Distance d0

- It is clear the Equation 1 does not hold for $d = 0$.
- For this reason, models use a close-in distance d_0 as the receiver power reference point.
  - d_0 should be $>= d_f$
  - d_0 should be smaller than any practical distance a mobile system uses
- Received power $P_r(d)$, at a distance $d > d_0$ from a transmitter, is related to P_r at d_0, which is expressed as $P_r(d_0)$.
- The power received in free space at a distance greater than d_0 is given by:

[Equation 8]

Free-Space Propagation Model

- Expressing the received power in dBm and dBW
  - $P_r(d)$ (dBm) = 10 log $[P_r(d_0)/0.001W]$ + 20log(d_0/d)
    where $d >= d_0 >= d_f$ and $P_r(d_0)$ is in units of watts [Equation 9]
  - $P_r(d)$ (dBW) = 10 log $[P_r(d_0)/1W]$ + 20log(d_0/d)
    where $d >= d_0 >= d_f$ and $P_r(d_0)$ is in units of watts [Equation 10]
- Reference distance d_0 for practical systems:
  - For frequncies in the range 1-2 GHz
    - 1 m in indoor environments
    - 100m-1km in outdoor environments

Two main channel design issues

Communication engineers are generally concerned with two main radio channel issues:

- Link Budged Design
  - Link budget design determines fundamental quantities such as transmit power requirements, coverage areas, and battery life
  - It is determined by the amount of received power that may be expected at a particular distance or location from a transmitter
- Time dispersion
  - It arises because of multi-path propagation where replicas of the transmitted signal reach the receiver with different propagation delays due to the propagation mechanisms that are described earlier.

Link Budged Design Using Path Loss Models

- Radio propagation models can be derived
  - By use of empirical methods: collect measurement, fit curves.
  - By use of analytical methods
    - Model the propagation mechanisms mathematically and derive equations for path loss
- Long distance path loss model
  - Empirical and analytical models show that received signal power decreases logarithmically with distance for both indoor and outdoor channels

Path Loss Exponent for Different Environments

Environment	Path Loss Exponent, *n*
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Selection of free space reference distance

- In large coverage cellular systems
  - 1km reference distances are commonly used
- In microcellular systems
  - Much smaller distances are used: such as 100m or 1m.
- The reference distance should always be in the far-field of the antenna so that near-field effects do not alter the reference path loss.

Log-normal Shadowing

- Equation 11 does not consider the fact the surrounding environment may be vastly different at two locations having the same T- R separation
- This leads to measurements that are different than the predicted values obtained using the above equation.
- Measurements show that for any value d, the path loss PL(d) in dBm at a particular location is random and distributed normally.

Log-normal Shadowing, n and

- The log-normal shadowing model indicates the received power at a distance d is normally distributed with a distance dependent mean and with a standard deviation .
- In practice the values of n and are computed from measured data using linear regression so that the difference between the measured data and estimated path losses are minimized in a mean square error sense.

Example of determining n

- Assume $P_r(d0)$ = 0dBm and d_0 is 100m
- Assume the receiver power P_r is measured at distances 100m, 500m, 1000m, and 3000m,
- The table gives the measured values of received power

Distance from Transmitter	Received Power
100m	0dBm
500m	-5dBm
1000m	-11dBm
3000m	-16dBm

Example of determining n

- We know the measured values.
- Lets compute the estimates for received power at different distances using long- distance path loss model. (Equation 11)
- $P_r(d_0)$ is given as 0dBm and measured value is also the same.
  - mean_P_r(d) = $P_r(d_0)$ – mean_PL(from_d_0_to_d)
  - Then mean_P_r(d) = 0 – 10log*n*(d/d0)
  - Use this equation to computer power levels at 500m, 1000m, and 3000m.

Example of determining n

- $Average\_P_r(500m) = 0 – 10\log n(500/100) = -6.99n$
- $Average\_P_r(1000m) = 0 – 10\log n(1000/100) = -10n$
- $Average\_P_r(3000m) = 0 – 10\log n(3000/100) = -14.77n$

- Now we know the estimates and also measured actual values of the received power at different distances
- In order approximate n, we have to choose a value for n such that the mean square error over the collected statistics is minimized.

Path loss and Received Power

- In log normal shadowing environment:
  - PL(d) (path loss) and Pr(d) (received power at a distance d) are random variables with a normal distribution in dB about a distance dependent mean.
- Sometime we are interested in answering following kind of questions:
  - What is mean received $P_r(d)$ power (mean_$P_r(d)$) at a distance d from a transmitter
  - What is the probability that the receiver power $P_r(d)$ (expressed in dB power units) at distance *d* is above (or below) some fixed value (again expressed in dB power units such as dBm or dBW).

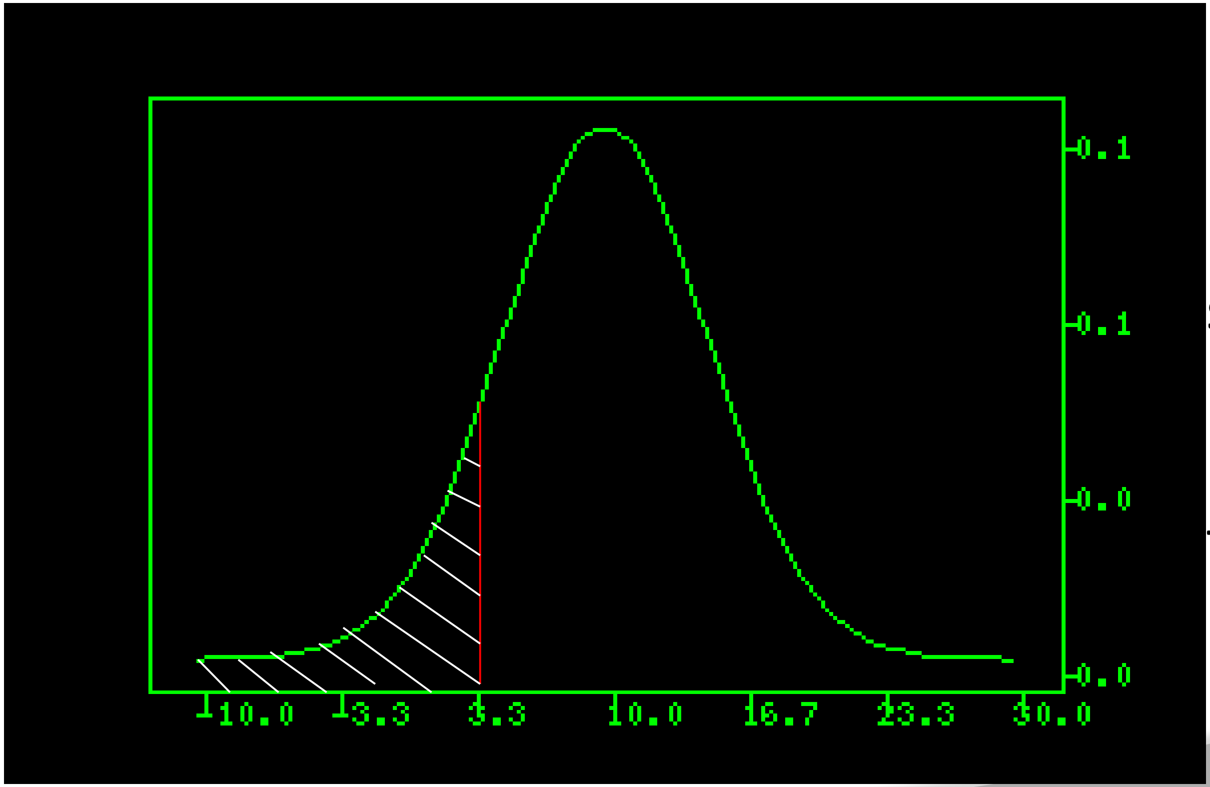
Received Power and Normal Distribution

- In answering these kind of question, we have to use the properties of normal (gaussian distribution).
- $P_r(d)$ is normally distributed that is characterized by:
  - a mean
  - a standard deviation

Received Power and Normal Distribution PDF

Figure shows the PDF of a normal distribution for the received power P_r at some fixed distance d

(x-axis is received power, y-axis probability)

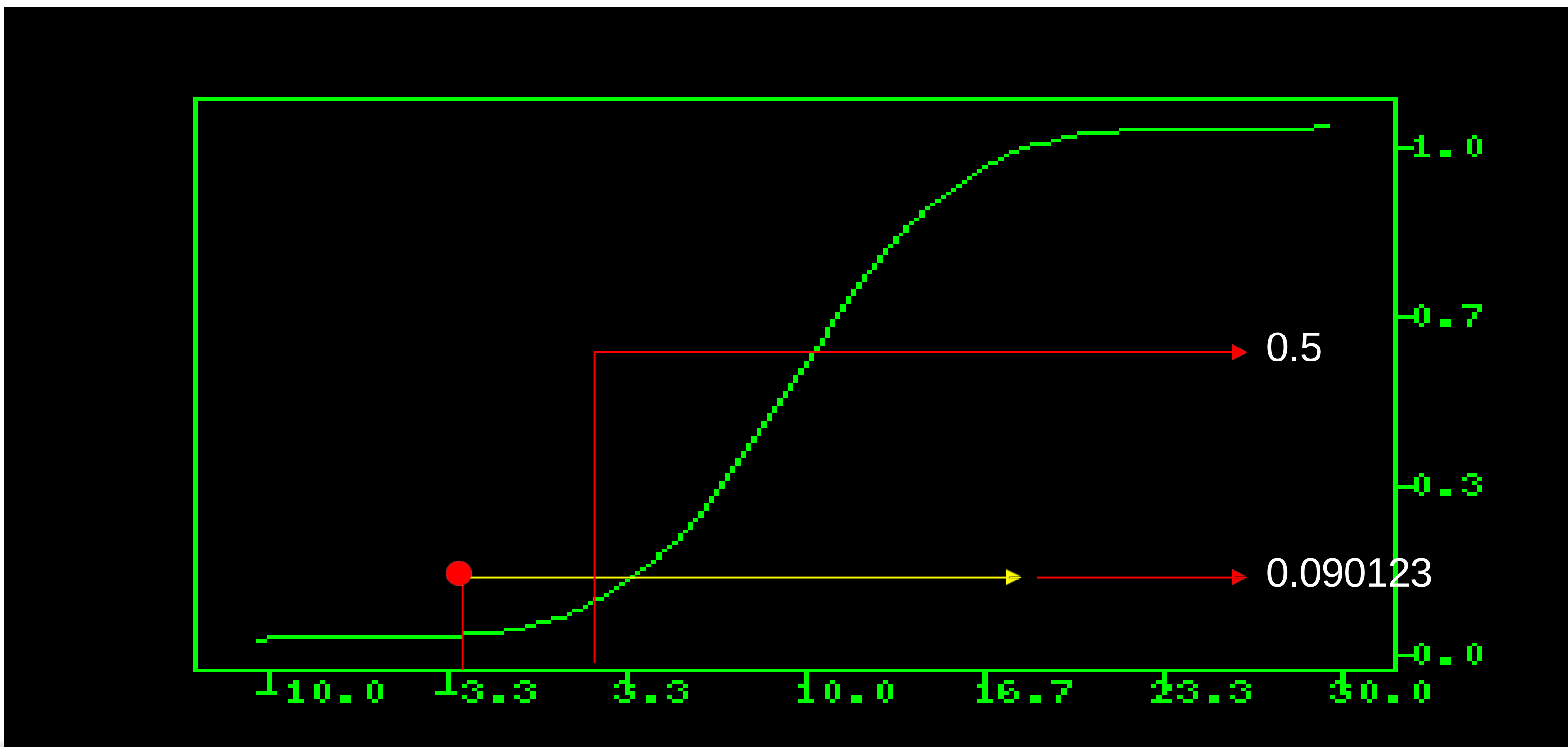


EXAMPLE:

Probability that P_r is smaller than 3.3 (Prob(Pr <= 3.3)) Is given with value of the stripped area under the curve.

Normal CDF

- The figure shows the CDF plot of the normal distribution described previously. Prob(Pr <= 3.3) can be found by finding first the point where vertical line from 3.3 intersects the curve and then by finding the corresponding point on the y-axis.
- This corresponds to a value of 0.09. Hence Prob(Pr <= 3.3) = 0.09



Percentage of Coverage Area

- We are interested in the following problem
  - Given a circular coverage area with radius *R* from a base station
  - Given a desired threshold power level .
- Find out
  - *U,* the percentage of useful service area
    - i.e the percentage of area with a received signal that is equal or greater than [illegible] given a known likelihood of coverage at the cell boundary

Outdoor Propagation

- We will look to the propagation from a transmitter in an outdoor environment
  - The coverage area around a tranmitter is called a cell.
  - Coverage area is defined as the area in which the path loss is at or below a given value.
  - The shape of the cell is modeled as hexagon, but in real life it has much more irregular shapes.
  - By playing with the antenna (tilting and changing the height), the size of the cell can be controlled.

Macrocells

- Base stations at high-points
- Coverage of several kilometers
- The average path loss in dB has normal distribution
  - Avg path loss is result of many forward scattering over a great many of obstacles
    - Each contributing a random multiplicative factor
    - Converted to dB, this gives a sum of random variable
  - Sum is normally distributed because of central limit theorem

Macro cells

- In early days, the models were based on empirical studies
- Okumura did comprehensive measurements in 1968 and came up with a model.
    - Discovered that a good model for path loss was a simple power law where the exponent n is a function of the frequency, antenna heights, etc.

Macrocells versus Microcells

Item	Macrocell	Microcell
Cell Radius	1 to 20km	0.1 to 1km
Tx Power	1 to 10W	0.1 to 1W
Fading	Rayleigh	Nakgami-Rice
RMS Delay Spread	0.1 to 10μs	10 to 100ns
Max. Bit Rate	0.3 Mbps	1 Mbps

Street Microcells

- Most of the signal power propagates along the street.
- The sigals may reach with LOS paths if the receiver is along the same street with the transmitter
- The signals may reach via indirect propagation mechanisms if the receiver turns to another street.

Indoor Propagation

- Indoor channels are different from traditional mobile radio channels in two different ways:
  - The distances covered are much smaller
  - The variablity of the environment is much greater for a much smaller range of T-R separation distances.
- The propagation inside a building is influenced by:
  - Layout of the building
  - Construction materials
  - Building type: sports arena, residential home, factory,...

Indoor Propagation

- Indoor propagation is domited by the same mechanisms as outdoor: reflection, scattering, diffraction.
  - However, conditions are much more variable
    - Doors/windows open or not
    - The mounting place of antenna: desk, ceiling, etc.
    - The level of floors
- Indoor channels are classified as
  - Line-of-sight (LOS)
  - Obstructed (OBS) with varying degrees of clutter.

Indoor Propagation

- Buiding types
  - Residential homes in suburban areas
  - Residential homes in urban areas
  - Traditional office buildings with fixed walls (hard partitions)
  - Open plan buildings with movable wall panels (soft partitions)
  - Factory buildings
  - Grocery stores
  - Retail stores
  - Sport arenas

Partition Losses

- There are two kind of partition at the same floor:
  - Hard partions: the walls of the rooms
  - Soft partitions: moveable partitions that does not span to the ceiling
  - The path loss depends on the type of the partitions

Partition Losses Average signal loss measurements reported

Material Type	Loss (dB)	Frequency (MHz)
All metal	26	815
Aluminim Siding	20.4	815
Concerete Block Wall	3.9	1300
Loss from one Floor	20-30	1300
Turning an Angle in a Corridor	10-15	1300
Concrete Floor	10	1300
Dry Plywood (3/4in) – 1 sheet	1	9600
Wet Plywood (3/4in) – 1 sheet	19	9600
Aluminum (1/8in) – 1 sheet	47	9600

Partition Losses between Floors

- The losses between floors of a building are determined by
  - External dimensions and materials of the building
  - Type of construction used to create floors
  - External surroundings
  - Number of windows
  - Presence of tinting on windows

Partition Losses between Floors

Building	FAF (dB)	? (dB)
Office Building 1		
Through 1 Floor	12.9	7.0
Through 2 Floors	18.7	2.8
Through 3 Floors	24.4	1.7
Through 4 Floors	27.0	1.5
Office Building 2		
Through 1 Floor	16.2	2.9
Through 2 Floors	27.5	5.4
Through 3 Floors	31.6	7.2

Signal Penetration Into Buildings

- RF signals can penetrate from outside transmitter to the inside of buildings
  - However the siganls are attenuated
- The path loss during penetration has been found to be a function of:
  - Frequency of the signal
  - The height of the building

Signal Penetration Into Buildings

- Effect of Frequency
  - Penetration loss decreases with increasing frequency

Frequency (MHz)	Loss (dB)
441	16.4
896.5	11.6
1400	7.6

- Effect of Height
  - Penetration loss decreases with the height of the building up- to some certain height
    - At lower heights, the urban clutter induces greater attenuation
  - and then it increases
    - Shadowing affects of adjascent buildings

Conclusion

- More work needs to be done to understand the characteristics of wireless channels
- 3D numerical modeling approaches exist
- To achieve PCS, new and novel ways of classifying wireless environments will be needed that are both widely encompassing and reasonably compact.

UNIT III

CELLULAR SYSTEM DESIGN FUNDAMENTALS

CLOs	Course Learning Outcome
CLO7	Examine the perspective on Fundamentals of Equalization, Linear Equalizers, Non-linear Equalization.
CLO8	Study and understand the Diversity Techniques and RAKE Receiver in Radio Propagation.
CLO9	Demonstrate wireless local area networks and their specifications in communication system.

Outline

- Small-Scale Multipath Propagation
- Impulse Response Model of a Multipath Channel
- Small-Scale Multipath Measurements
- Parameters of Mobile Multipath Channels
- Types of Small-Scale Fading
- Rayleigh and Ricean Distributions
- Statistical Models for Multipath Fading Channels

Small Scale Fading

- Describes *rapid fluctuations* of the amplitude, phase of multipath delays of a radio signal over short period of time or travel distance
- Caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times.
- These waves are called multipath waves and combine at the receiver antenna to give a resultant signal which can vary widely in amplitude and phase.

Small Scale Multipath Propagation

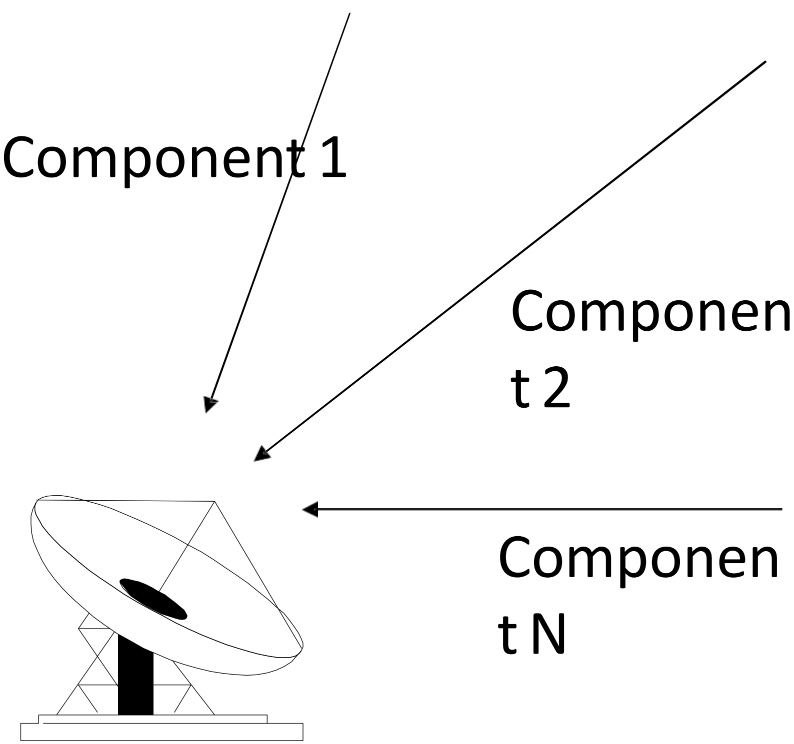
- Effects of multipath
  - Rapid changes in the signal strength
    - Over small travel distances, or
    - Over small time intervals
  - Random frequency modulation due to varying Doppler shifts on different multiples signals
  - Time dispersion (echoes) caused by multipath propagation delays
- Multipath occurs because of
  - Reflections
  - Scattering

Multipath

- At a receiver point
  - Radio waves generated from the same transmitted signal may come
    - from different directions
    - with different propagation delays
    - with (possibly) different amplitudes (random)
    - with (possibly) different phases (random)
    - with different angles of arrival (random).
  - These multipath components combine vectorially at the receiver antenna and cause the total signal
    - to fade
    - to distort

Multipath Components

Radio Signals Arriving from different directions to receiver



Receiver may be stationary or mobile.

Mobility

- Other Objects in the radio channels may be mobile or stationary
- If other objects are stationary
    - Motion is only due to mobile
    - Fading is purely a spatial phenomenon (occurs only when the mobile receiver moves)
    - The spatial variations as the mobile moves will be perceived as temporal variations
        - $\Delta t = \Delta d/v$
- Fading may cause disruptions in the communication

Factors Influencing Small Scale Fading

- Multipath propagation
  - Presence of reflecting objects and scatterers cause multiple versions of the signal to arrive at the receiver
    - With different amplitudes and time delays
    - Causes the total signal at receiver to fade or distort
- Speed of mobile
  - Cause Doppler shift at each multipath component
  - Causes random frequency modulation
- Speed of surrounding objects
  - Causes time-varying Doppler shift on the multipath components

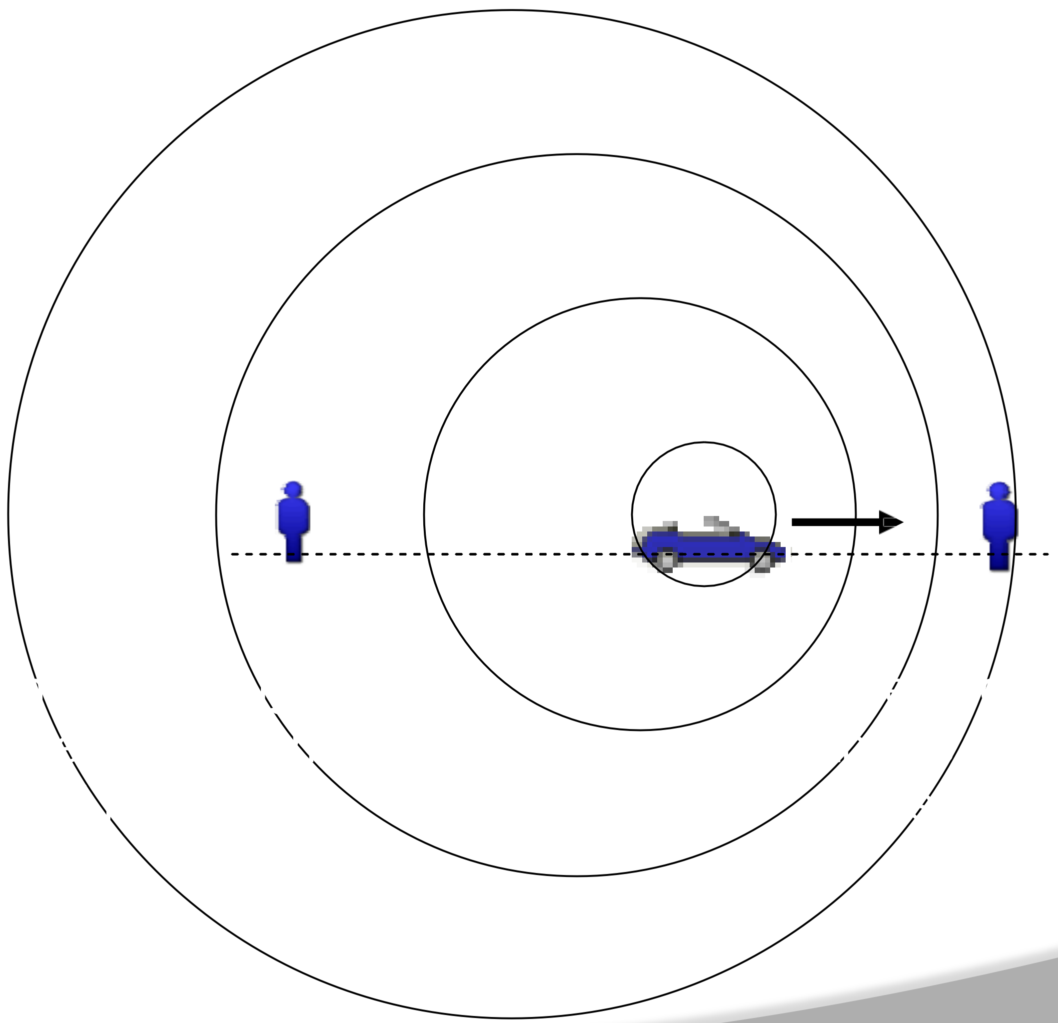
Factors Influencing Small Scale Fading

- Transmission bandwidth of the channel
- The transmitted radio signal bandwidth and bandwidth of the multipath channel affect the received signal properties:
  - If amplitude fluctuates or not
  - If the signal is distorted or not

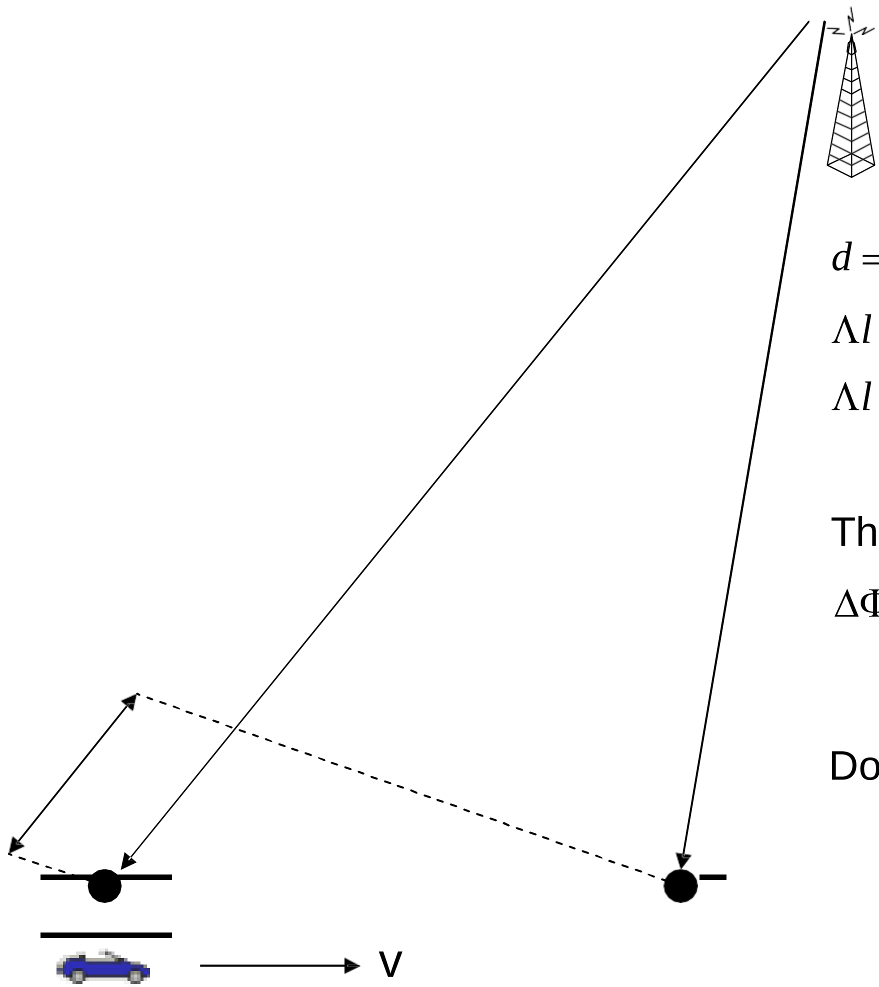
Doppler Effect

- Whe a transmitter or receiver is moving, the frequency of the received signal changes, i.e. İt is different than the frequency of transmissin. This is called Doppler Effect.
- The change in frequency is called Doppler Shift.
  - It depends on
    - The relative velocity of the receiver with respect to transmitter
    - The frequenct (or wavelenth) of transmission
    - The direction of traveling with respect to the direction of the arriving signal.

Doppler Shift – Transmitter is moving



Doppler Shift –Recever is moving



$$d = |XY|$$

$$\Lambda l = |SX| - |SY| = d \cos 0$$

$$\Lambda l = v\Lambda t \cos 0$$

The phase change in the received signal:

$$\Delta\Phi = \frac{\Lambda l}{Z} 2\nu = \frac{2\nu v\Lambda t}{Z} \cos 0$$

Doppler shift (The apparent change in frequency) :

$$\overline{2\nu \ \ \Delta t} \quad \overline{Z}$$

A mobile receiver is traveling from point X to point Y

Doppler Shift

- The Dopper shift is positive
  - If the mobile is moving toward the direction of arrival of the wave.
- The Doppler shift is negative
  - If the mobile is moving away from the direction of arrival of the wave.

Impulse Response Model of a Multipath Channel

- The wireless channel charcteristics can be expressed by impulse response function
- The channel is time varying channel when the receiver is moving.
- Lets assume first that time variation due strictly to the receiver motion ($t = d/v$)
- Since at any distance d = vt, the received power will be combination of different incoming signals, the channel charactesitics or the impulse response funcion depends on the distance d between trandmitter and receiver.

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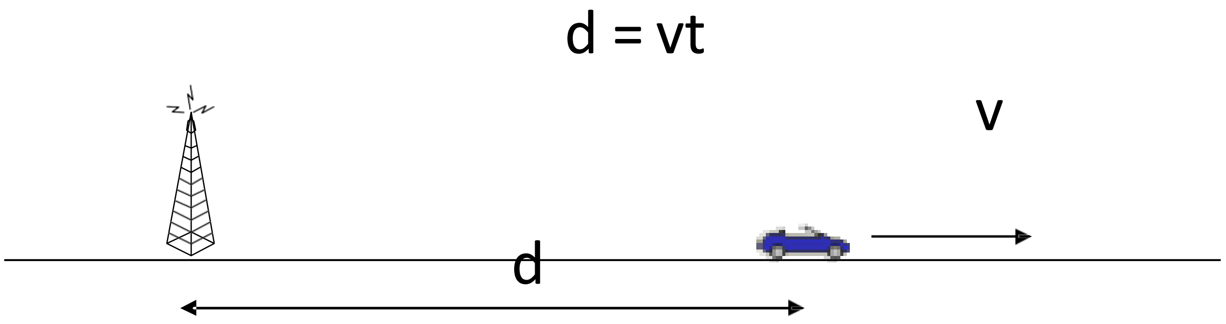
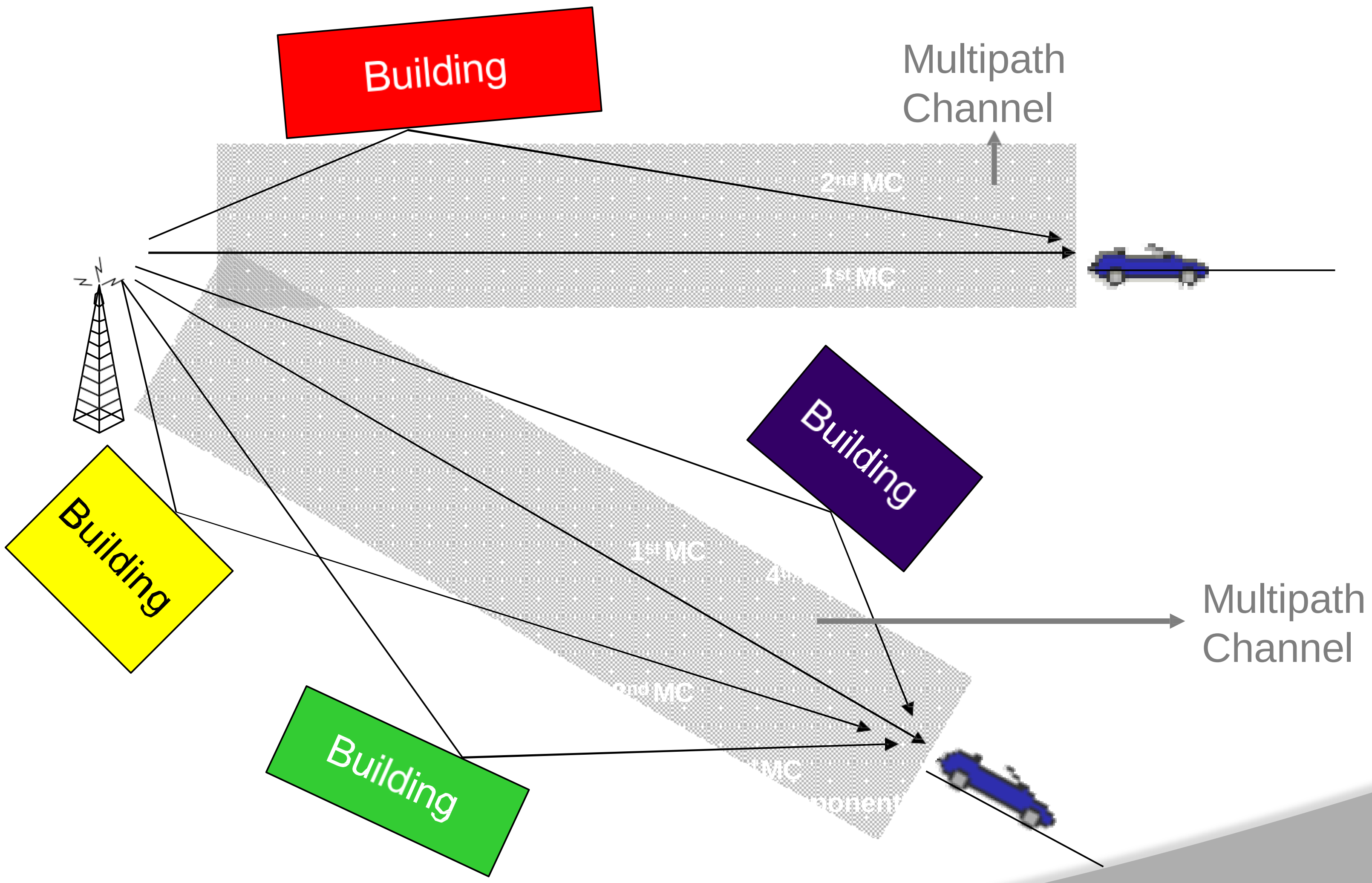
Impulse Response Model of a Multipath Channel

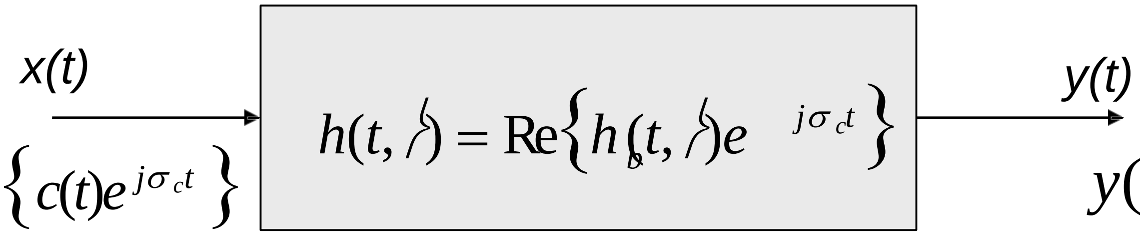


- A receiver is moving along the ground at some constant velocity v.
- The multipath components that are received at the receiver will have different propagation delays depending on d: distance between transmitter and receiver. Hence the channel impulse response depends on d.

Multipath Channel Model



Impulse Response Model

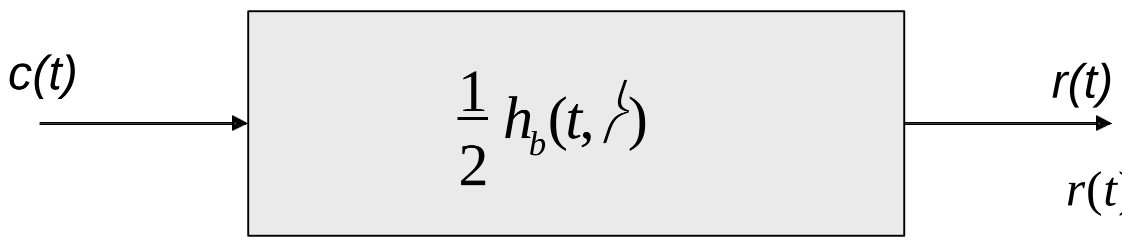


$$x(t) = \text{Re}\left\{c(t)e^{j\omega_c t}\right\}$$

$$y(t) = \text{Re}\left\{r(t)e^{j\omega_c t}\right\}$$

$$y(t) = x(t) \otimes h(t,\tau)$$

Bandpass Channel Impulse Response Model



$$r(t) = c(t) \otimes \frac{1}{2}h_b(t,\tau)$$

Baseband Equivalent Channel Impulse Response Model

Impulse Response Model

$$r(t) = c(t) \otimes \frac{1}{2} h_b(t,\tau)$$

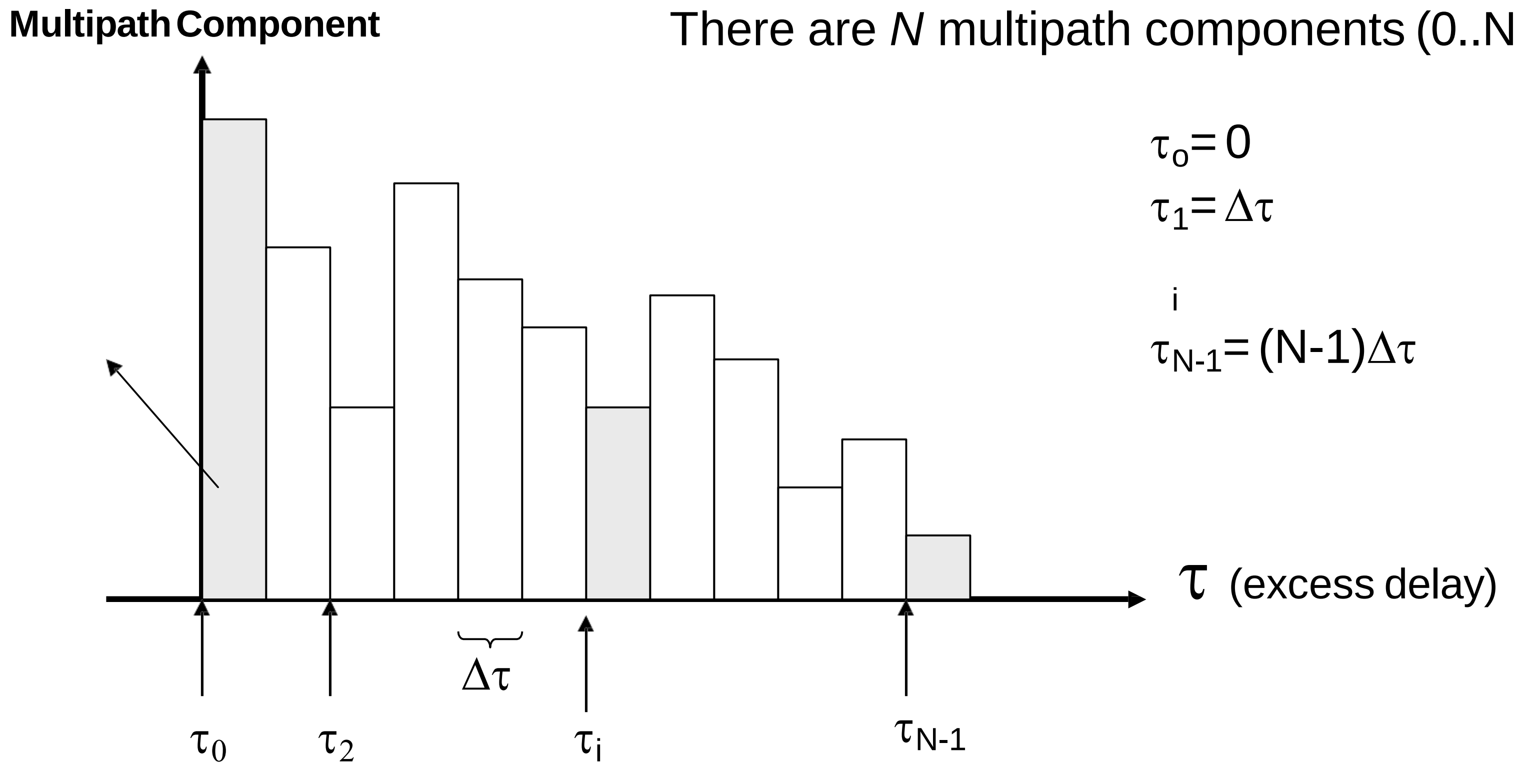
$$x(t) = \mathrm{Re}\left\{ c(t) e^{j 2 \pi f_c t} \right\} \qquad \sigma_c = 2 \pi f_c$$

$$y(t) = \mathrm{Re}\left\{ r(t) e^{j 2 \pi f_c t} \right\}$$

c(t) is the complex envelope representation of the transmitted signal
r(t) is the complex envelope representation of the received signal

$h_b(t,\tau)$ is the complex baseband impulse response

Discrete-time Impulse Response Model of Multipath Channel



There are *N* multipath components (0..N-1)

$\tau_o = 0$

$\tau_1 = \Delta\tau$

i

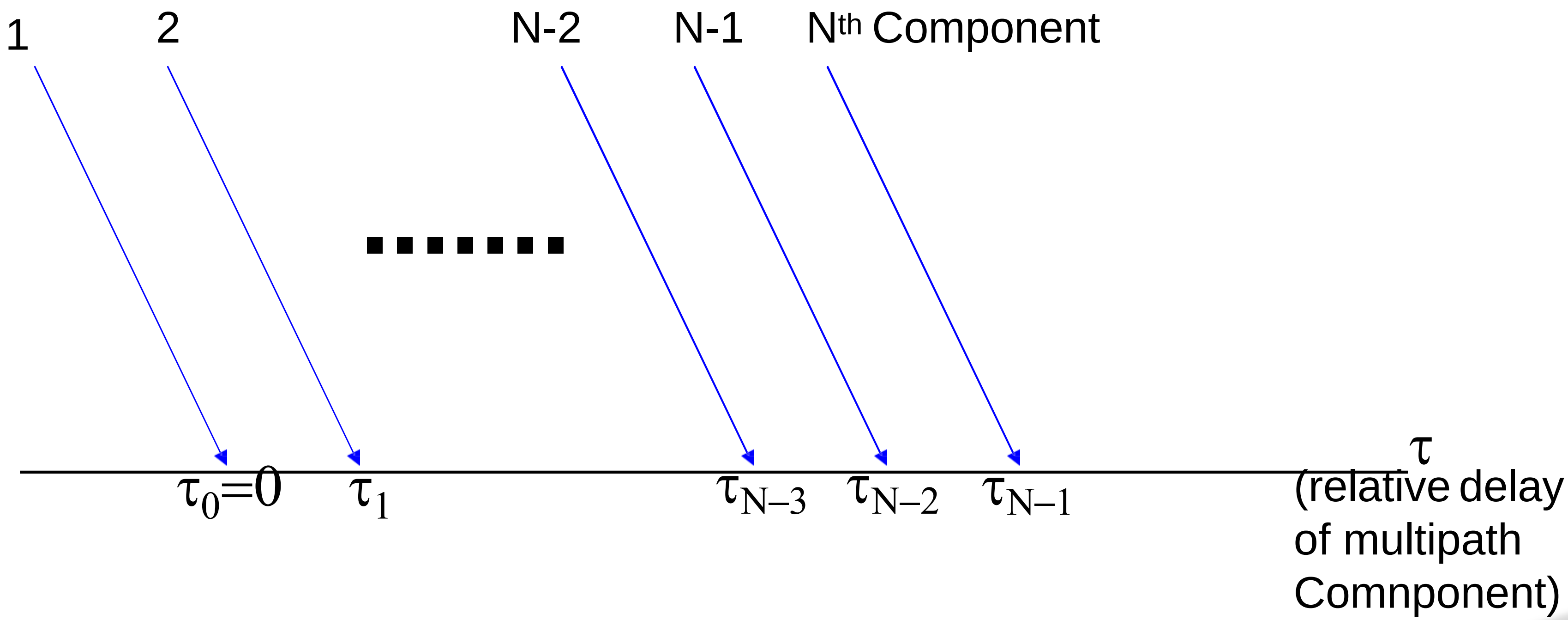
$\tau_{N-1} = (N-1)\Delta\tau$

Excess delay: relative delay of the ith multipath componentas compared to the first arriving component

τ_i : *Excesss delay* of i^th^ multipath component, **N6**}: *Maximum excess delay*

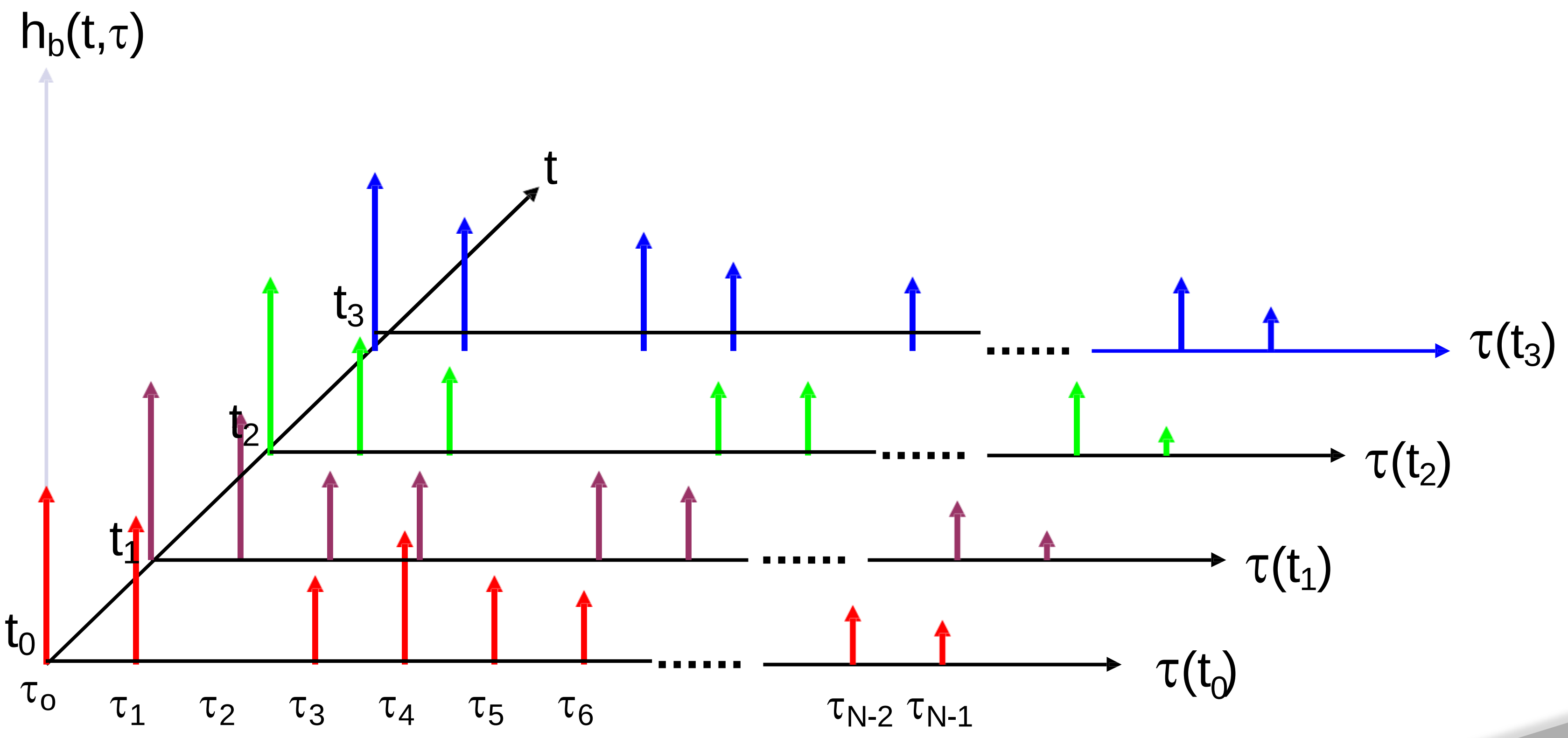
Multipath Components arriving to a Receiver

Ignore the fact that multipath components arrive with different angles, and assume that they arriving with the same angle in 3D.



Each component will have different Amplitude (a_i) and Phase (θ_i)

Discrete-Time Impulse Response Model for a Multipath Channel



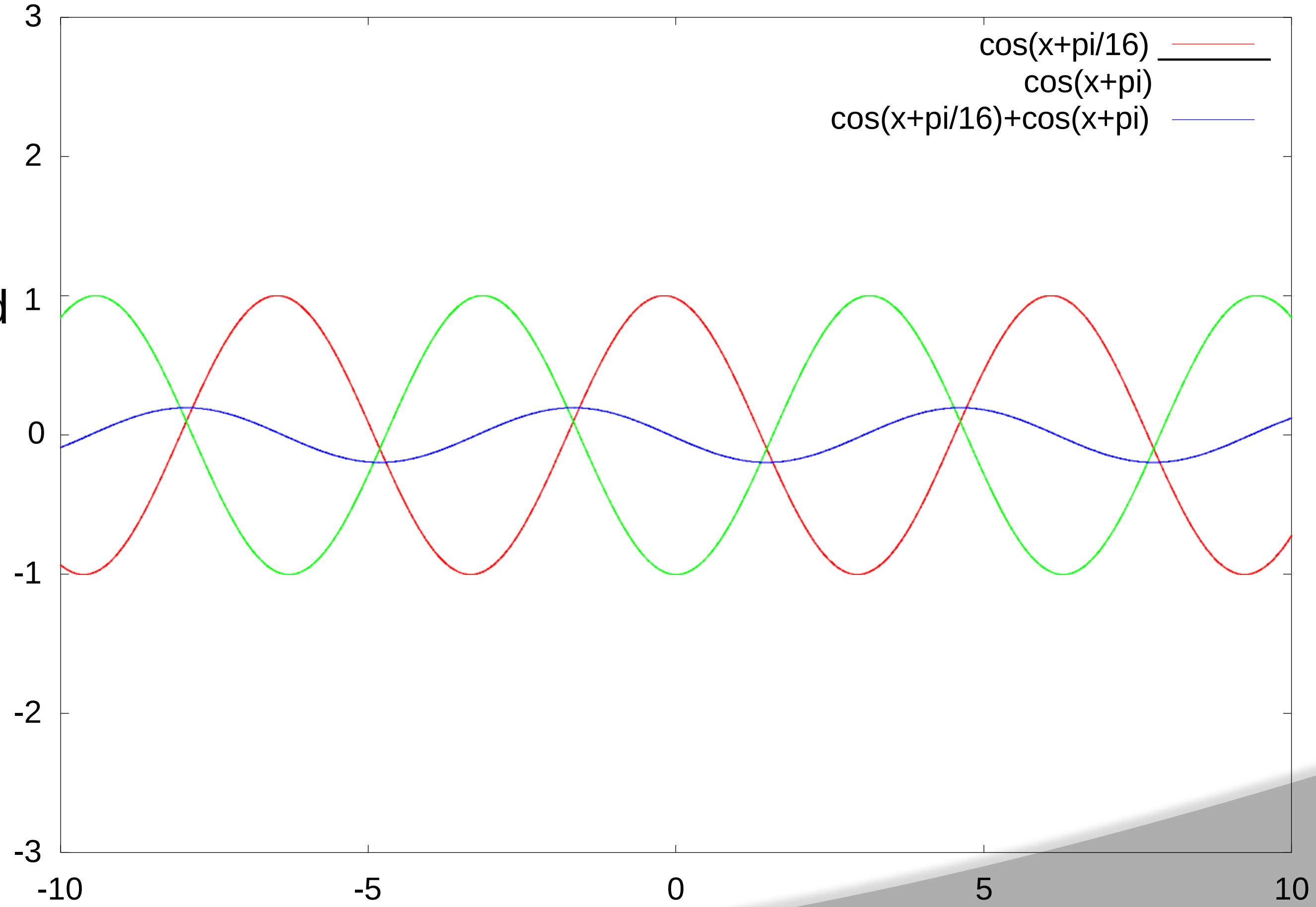
Example 1 – Addition of Two Signals

MC: Multipath Component

1st MC

2st MC

Combined Signal



$a_1/a_2=1$

$\theta_1=\pi/16$

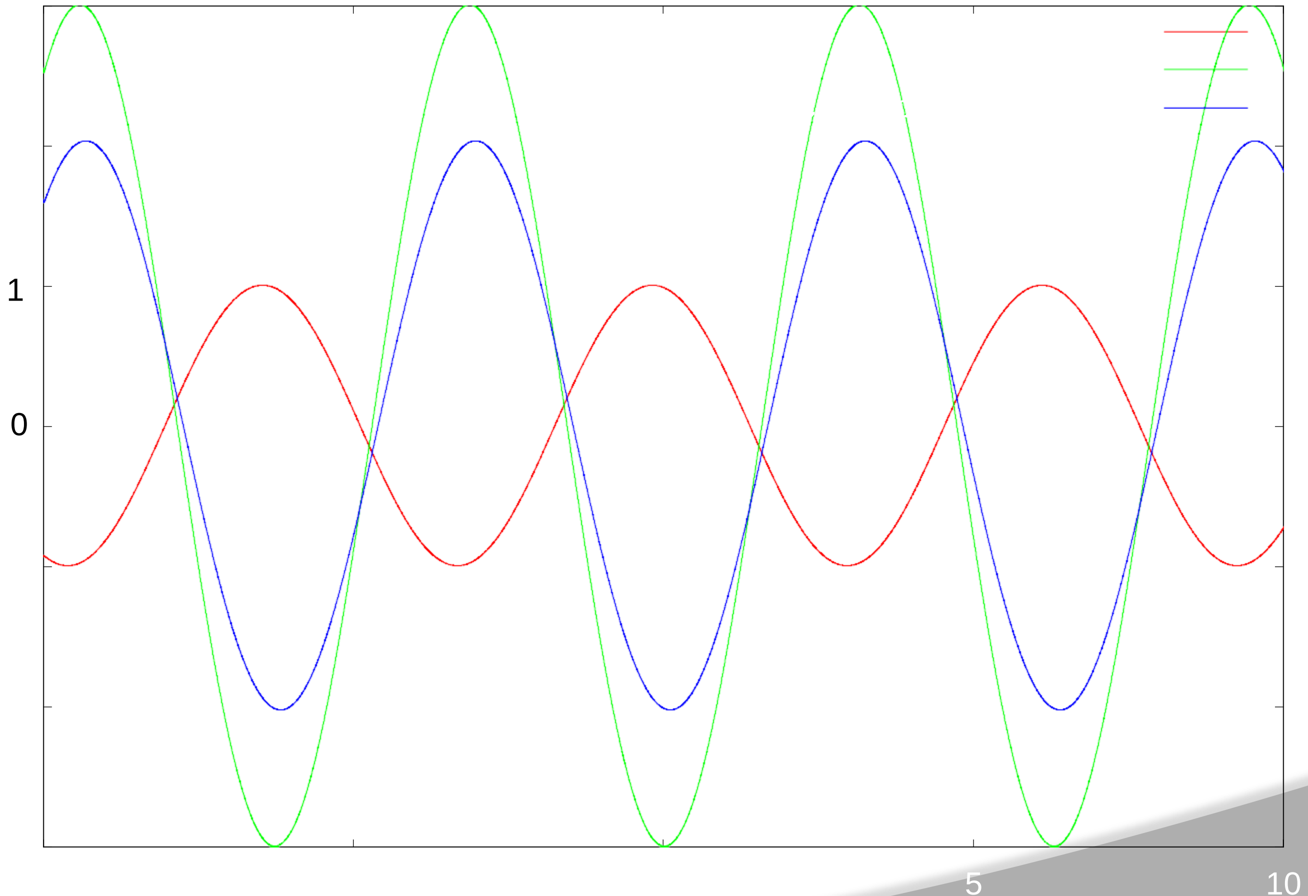
$\theta_2=\pi$

Example 2 – Addition of Two Signals

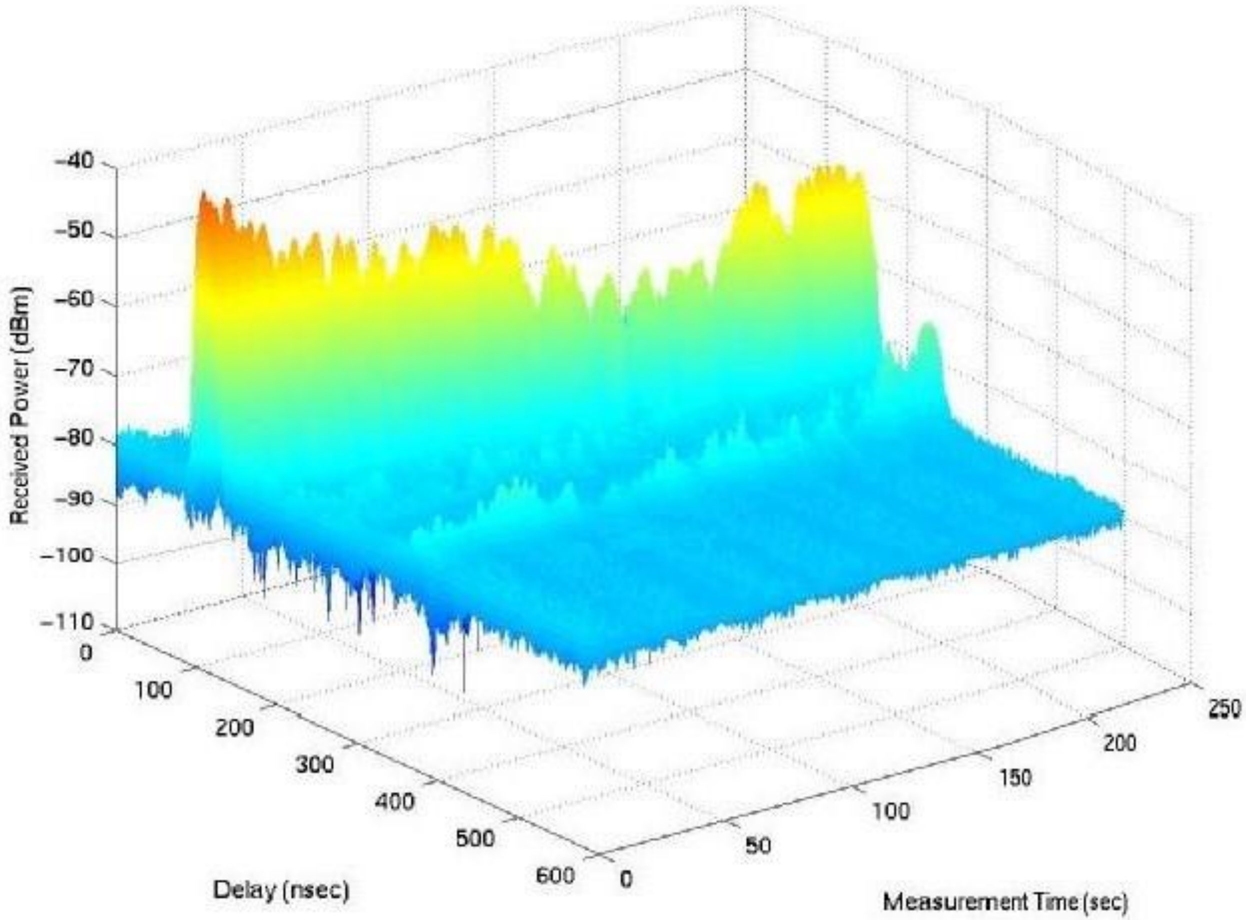
1st MC

2st MC

Combined Signal

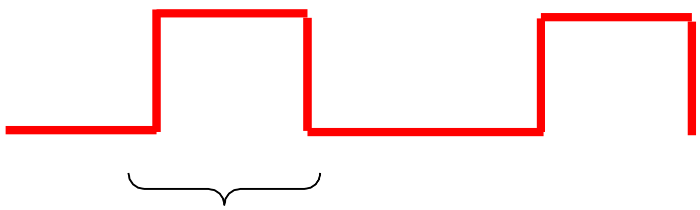


Example power delay profile

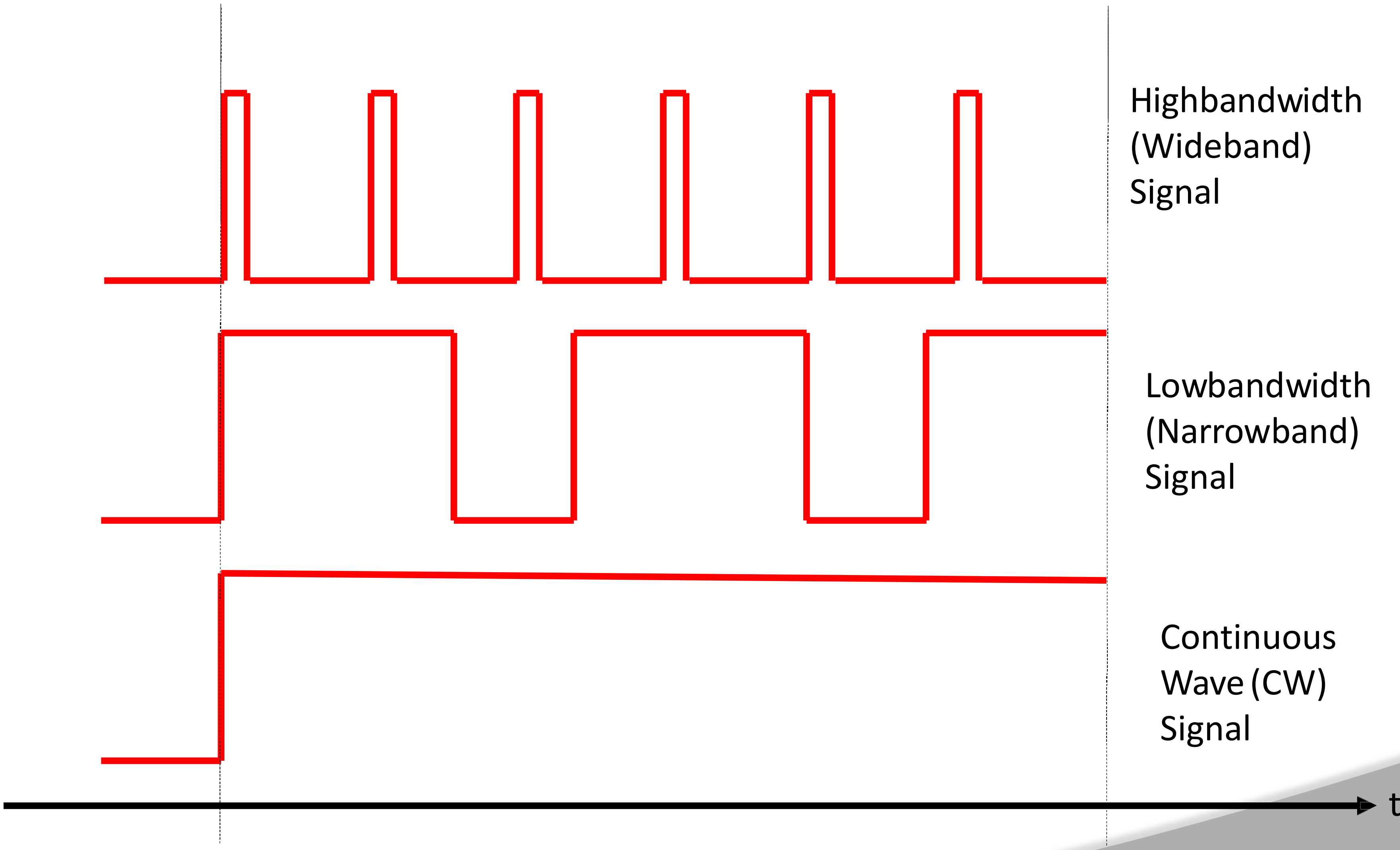


Power Relationship between Bandwidth and Receiver

- What happens when two different signals with different bandwidths are sent through the channel?
  - What is the receiver power characteristics for both signals?
- We mean the bandwith of the baseband signal
  - The bandwidth of the baseband is signal is inversely related with its symbol rate.



Bandwidth of Baseband Signals



Received Power of Wideband Signals

The output r(t) will approximate the channel impulse response since p(t) approximates unit impulses.

$$r(t) = \frac{1}{2}\sum_{i=0}^{N-1} a_i e^{j\theta_i} \cdot p(t - \tau_i)$$

Assume the multipath components have random amplitudes and phases at time t.

$$E_{a,\theta}[P_{WB}] = E_{a,\theta}\left[\sum_{i=0}^{N-1} \left| a_i e^{j\theta_i} \right|^2\right] = \sum_{i=0}^{N-1} \overline{a_i^{\,2}} = E[P_{WB}]$$

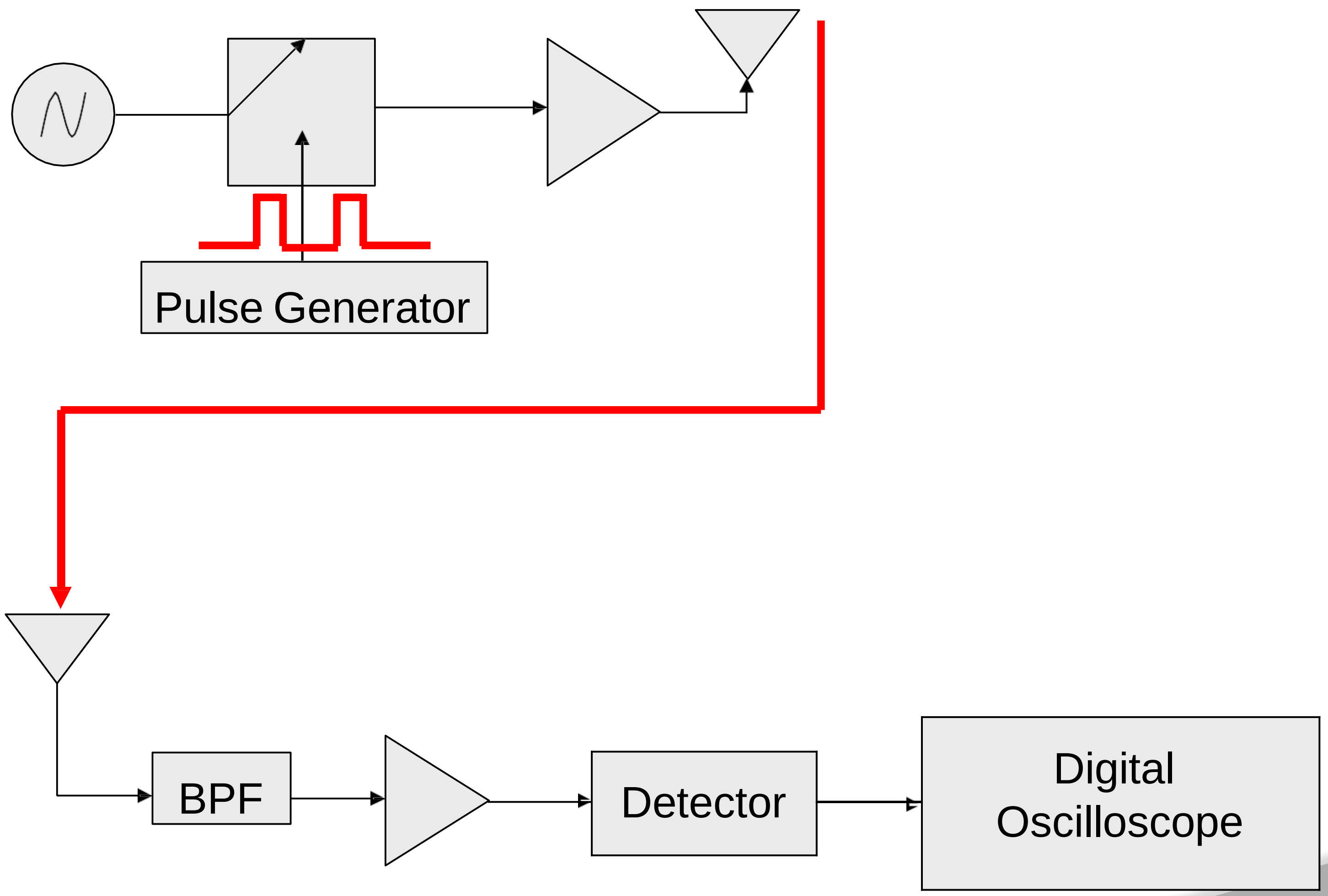
Received Power of Wideband Sİgnals

- This shows that if all the multipath components of a transmitted signal is resolved at the receiver then:
  - The average small scale received power is simply the sum of received powers in each multipath component.
- In practice, the amplitudes of individual multipath components do not fluctuate widely in a local area (for distance in the order of wavelength or fraction of wavelength).
- This means the average received power of a wideband signal do not fluctuate significantly when the receiver is moving in a local area.

Small-Scale Multipath Measurements

- Several Methods
  - Direct RF Pulse System
  - Spread Spectrum Sliding Correlator Channel Sounding
  - Frequency Domain Channel Sounding
- These techniques are also called channel sounding techniques

Direct RF Pulse System



Parameters of Mobile Multipath Channels

- Time Dispersion Parameters
  - Grossly quantifies the multipath channel
  - Determined from Power Delay Profile
  - Parameters include
    - Mean Access Delay
    - RMS Delay Spread
    - Excess Delay Spread (X dB)
- Coherence Bandwidth
- Doppler Spread and Coherence Time

Measuring PDPs

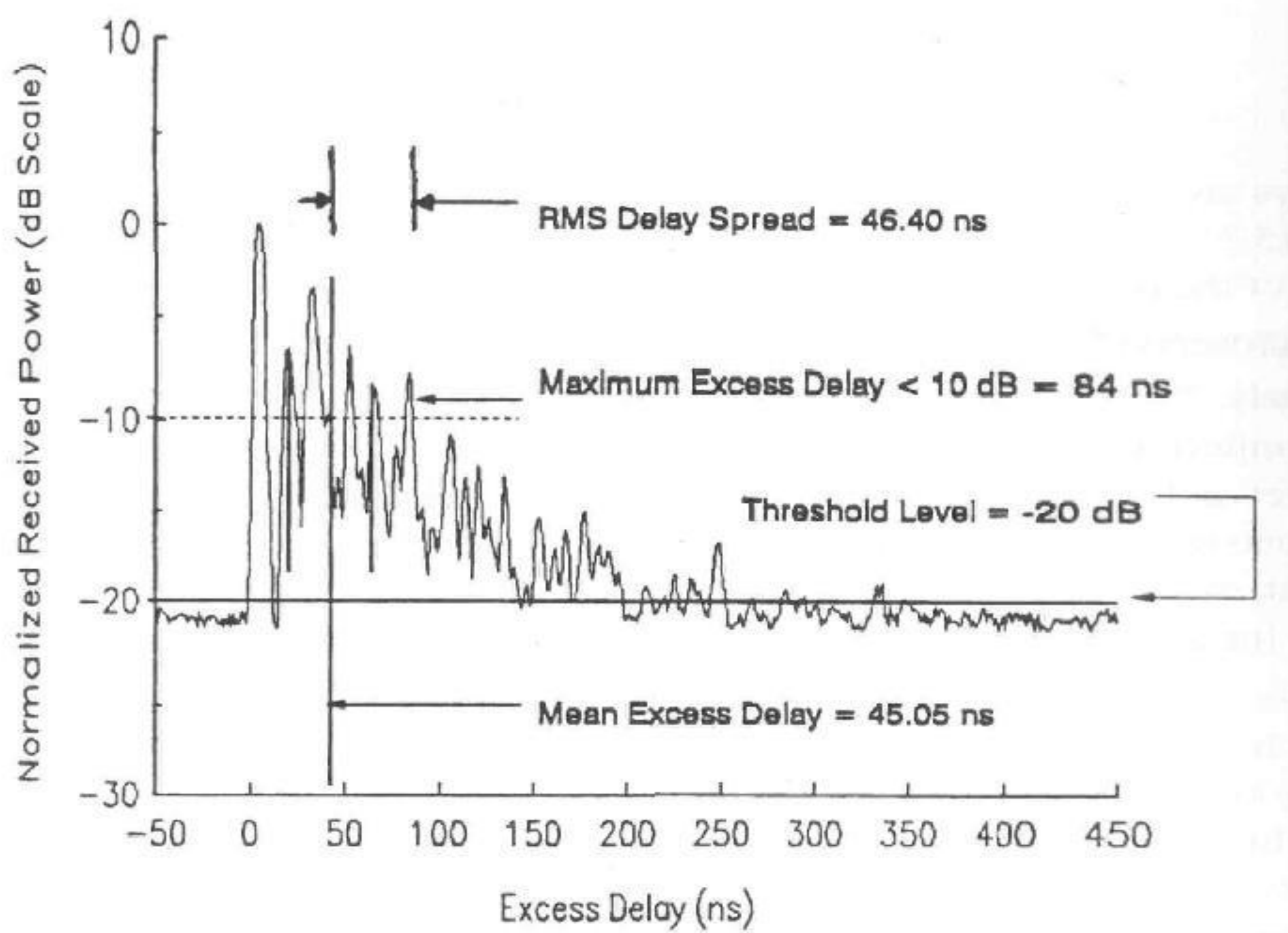
- Power Delay Profiles
  - Are measured by channel sounding techniques
  - Plots of relative received power as a function of excess delay
  - They are found by averaging *intantenous* power delay measurements over a local area
    - Local area: no greater than 6m outdoor
    - Local area: no greater than 2m indoor
      - For 450MHz – 6 GHz frequency range.

Timer Dispersion Parameters

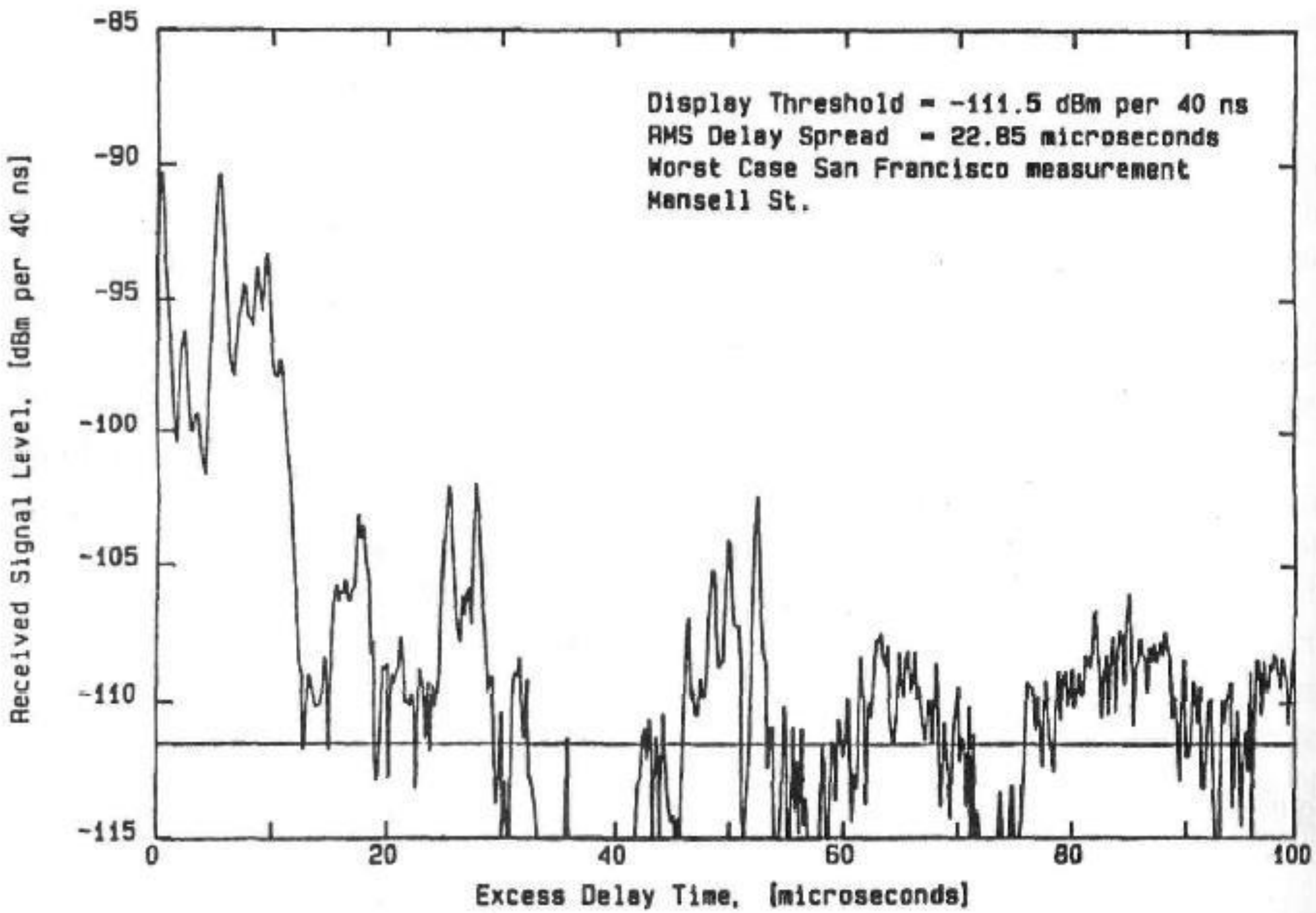
Maximum Excess Delay (X dB):

- Defined as the time delay value after which the multipath energy falls to X dB below the maximum multipath energy (not necesarily belonging to the first arriving component)
- It is also called excess delay spread.

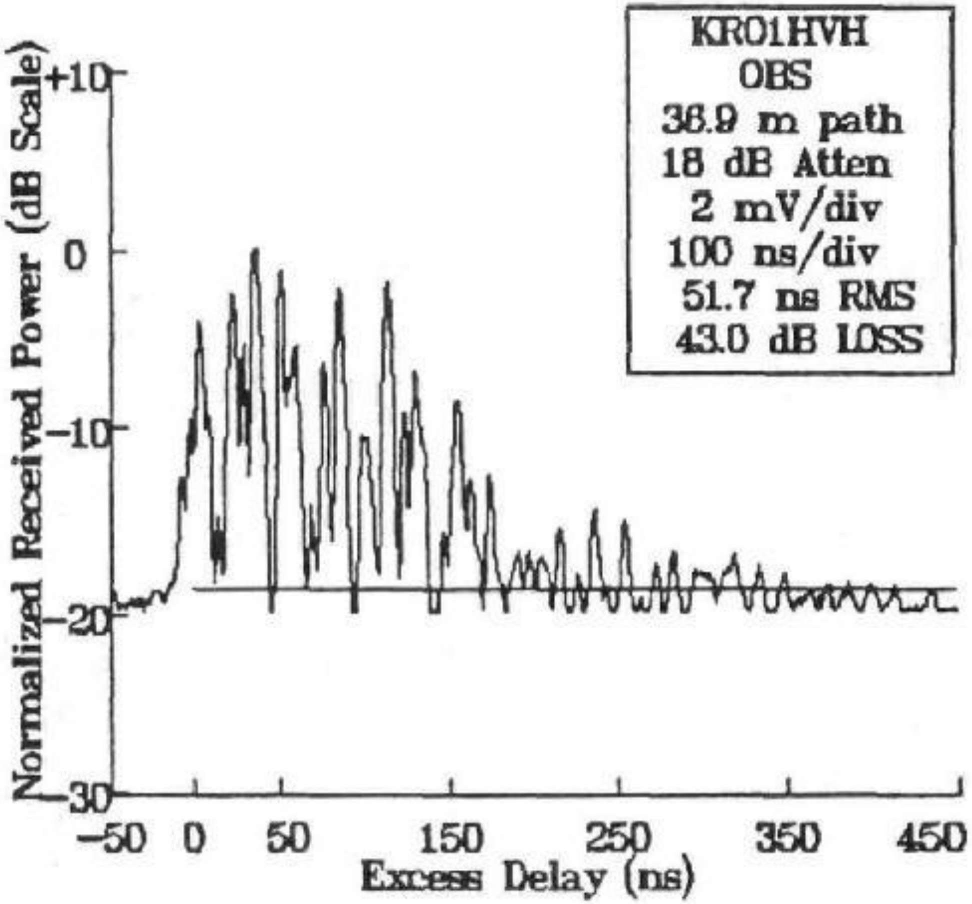
RMS Delay Spread



PDP Outdoor


Display Threshold = -111.5 dBm per 40 ns
RMS Delay Spread = 22.85 microseconds
Worst Case San Francisco measurement
Mansell St.
Received Signal Level, [dBm per 40 ns]
-85
-90
-95
-100
-105
-110
-115
0
20
40
60
80
100
Excess Delay Time, [microseconds]

PDP Indoor



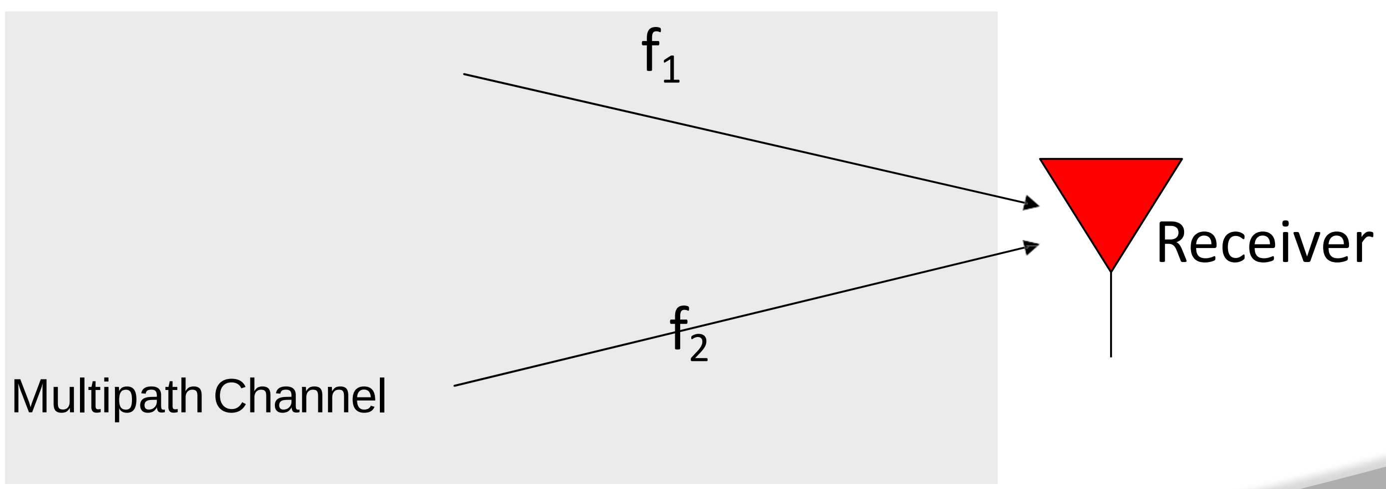
KR01HVH
OBS
38.9 m path
18 dB Atten
2 mV/div
100 ns/div
51.7 ns RMS
43.0 dB LOSS
Normalized Received Power (dB Scale)
+10
0
−10
−20
−30
−50
0
50
150
250
350
450
Excess Delay (ns)

Noise Threshold

- The values of time dispersion parameters also depend on the noise threshold (the level of power below which the signal is considered as noise).
- If noise threshold is set too low, then the noise will be processed as multipath and thus causing the parameters to be higher.

Coherence Bandwidth (BC)

- Range of frequencies over which the channel can be considered flat (i.e. channel passes all spectral components with equal gain and linear phase).
  - It is a definition that depends on RMS Delay Spread.
- Two sinusoids with frequency separation greater than B_c are affected quite differently by the channel.



Coherence Time

- Delay spread and Coherence bandwidth describe the time dispersive nature of the channel in a local area.
  - They don't offer information about the time varying nature of the channel caused by relative motion of transmitter and receiver.
- Doppler Spread and Coherence time are parameters which describe the time varying nature of the channel in a small-scale region.

Types of Small-scale Fading

Small-scale Fading
(Based on Multipath Time Delay Spread)

Flat Fading

1. BW Signal < BW of Channel
2. Delay Spread < Symbol Period

Frequency Selective Fading

1. BW Signal > Bw of Channel
2. Delay Spread > Symbol Period

Small-scale Fading
(Based on Doppler Spread)

Fast Fading

1. High Doppler Spread
2. Coherence Time < Symbol Period
3. Channel variations faster than baseband signal variations

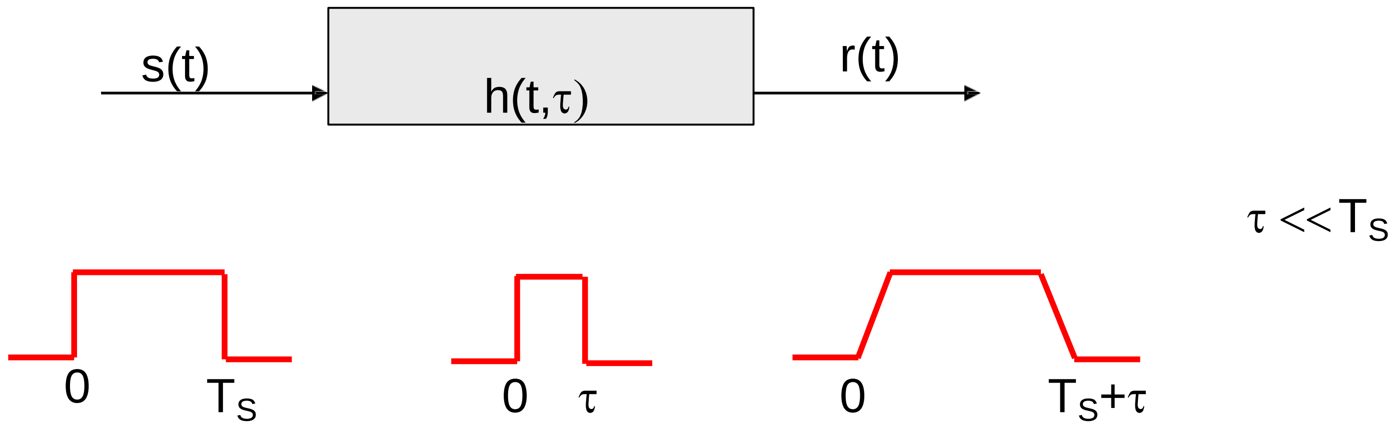
Slow Fading

1. Low Doppler Spread
2. Coherence Time > Symbol Period
3. Channel variations smaller than baseband signal variations

Flat Fading

- Occurs when the amplitude of the received signal changes with time
  - For example according to Rayleigh Distribution
- Occurs when symbol period of the transmitted signal is much larger than the Delay Spread of the channel
  - Bandwidth of the applied signal is narrow.
- May cause deep fades.
  - Increase the transmit power to combat this situation.

Flat Fading



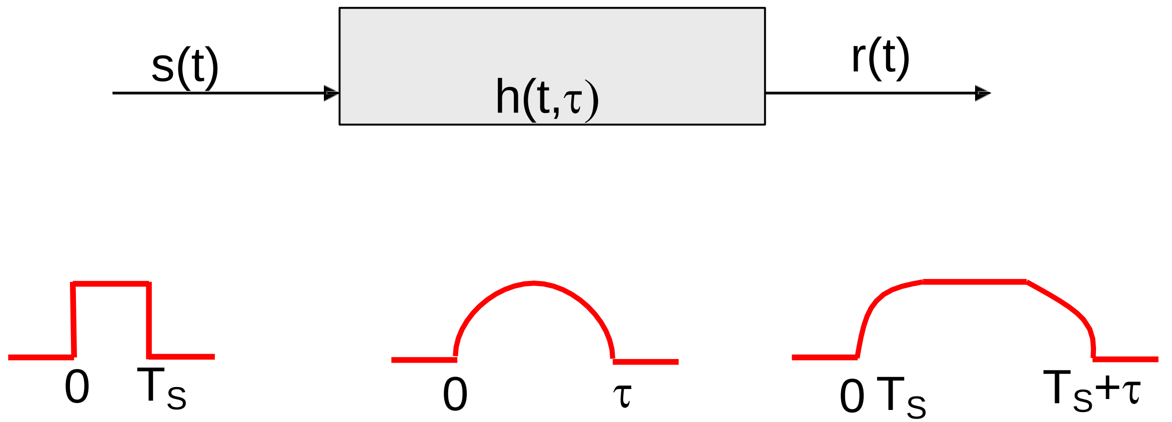
Occurs when:
$B_S << B_C$
and
$T_S >> \sigma_\tau$

B_C: Coherence bandwidth
B_S: Signal bandwidth
T_S: Symbol period
σ_τ: Delay Spread

Frequency Selective Fading

- Occurs when channel multipath delay spread is greater than the symbol period.
  - Symbols face time dispersion
  - Channel induces Intersymbol Interference (ISI)
- Bandwidth of the signal s(t) is wider than the channel impulse response.

Frequency Selective Fading



$\tau >> T_S$

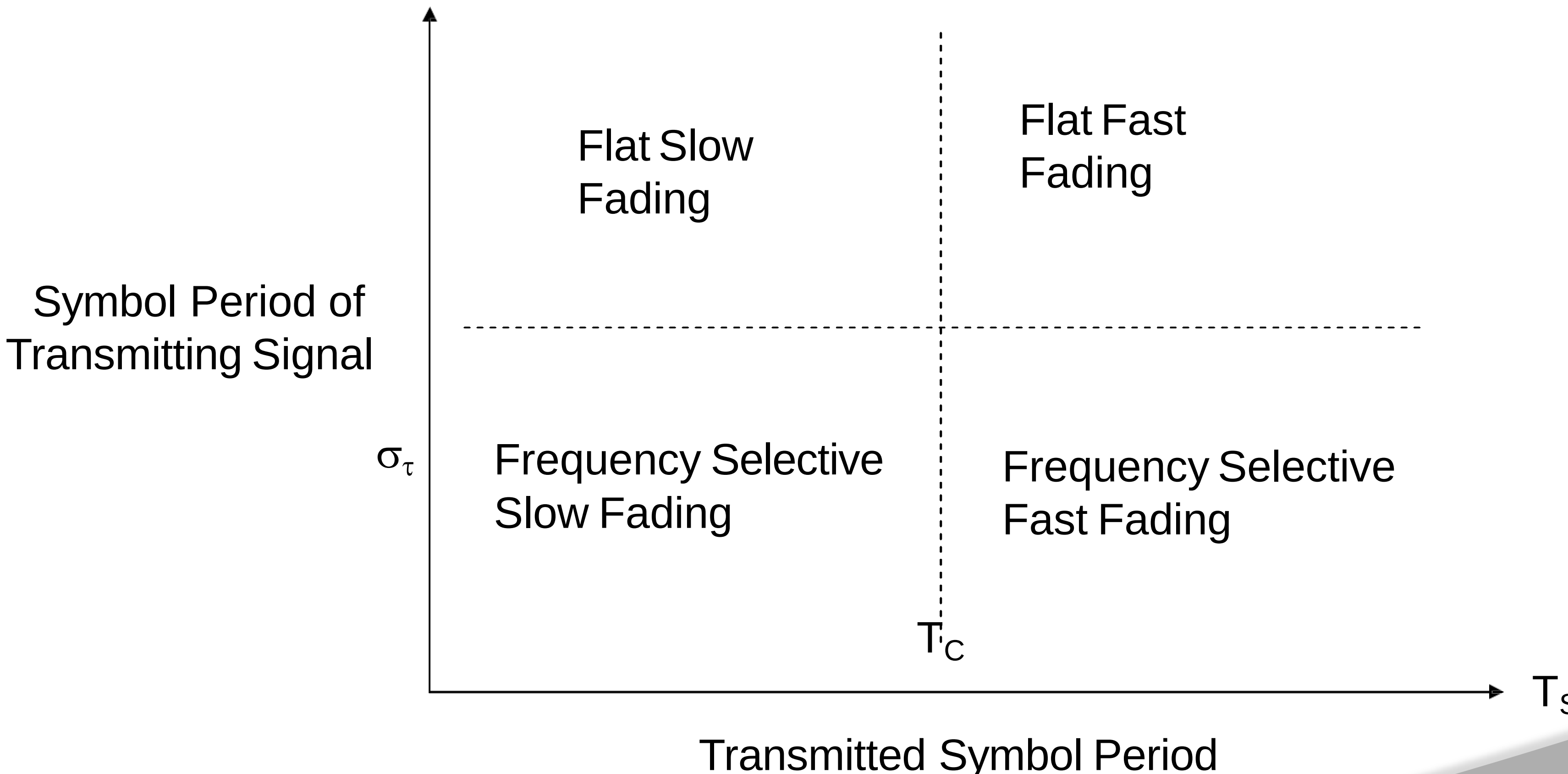
Causes distortion of the received baseband signal

Causes Inter-Symbol Interference (ISI)

Occurs when:
$B_S > B_C$
and
$T_S < \sigma_\tau$

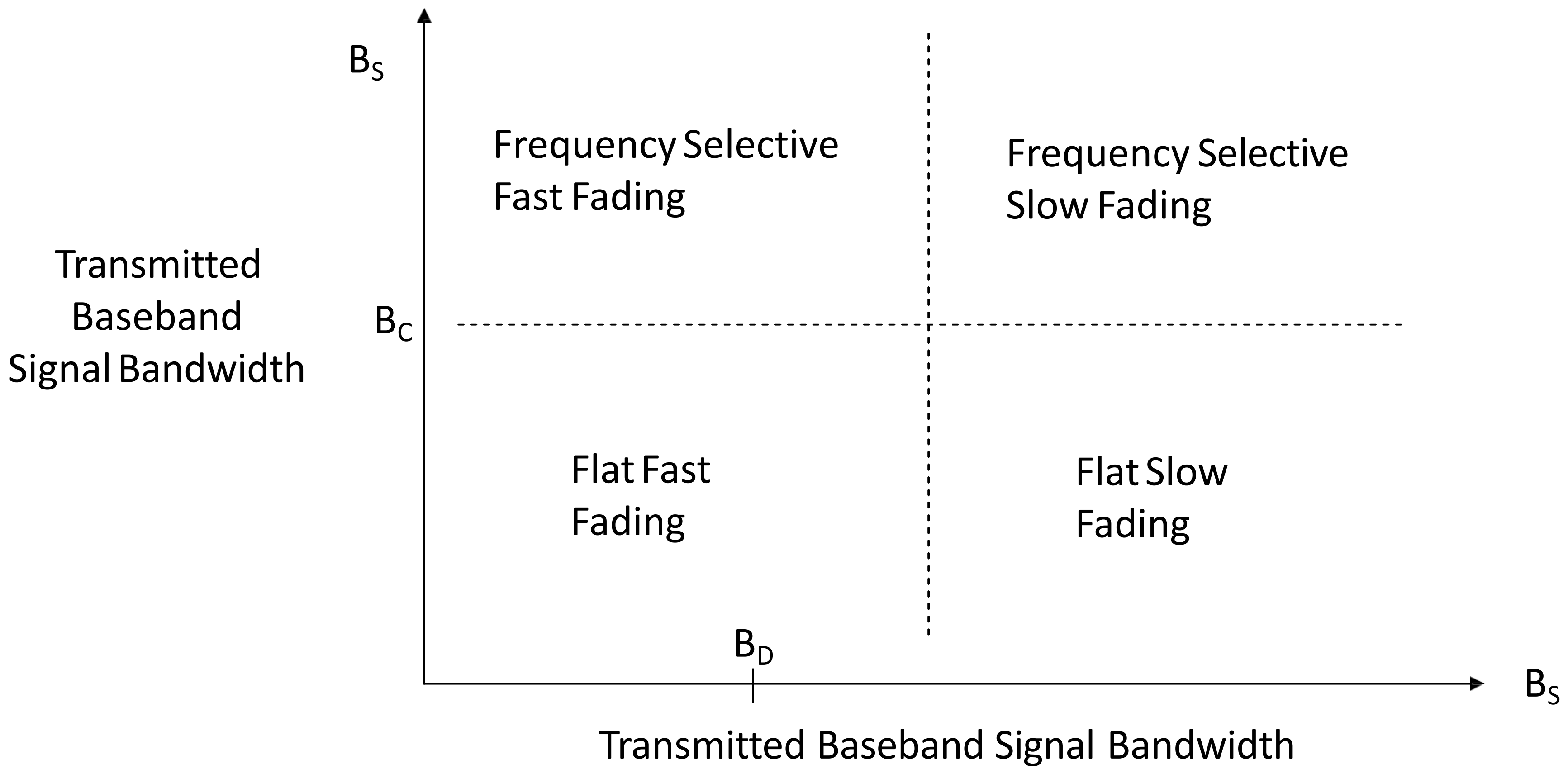
As a rule of thumb: $T_S < \sigma_\tau$

Different Types of Fading



With Respect To SYMBOL PERIOD

Different Types of Fading



With Respect To BASEBAND SIGNAL BANDWIDTH

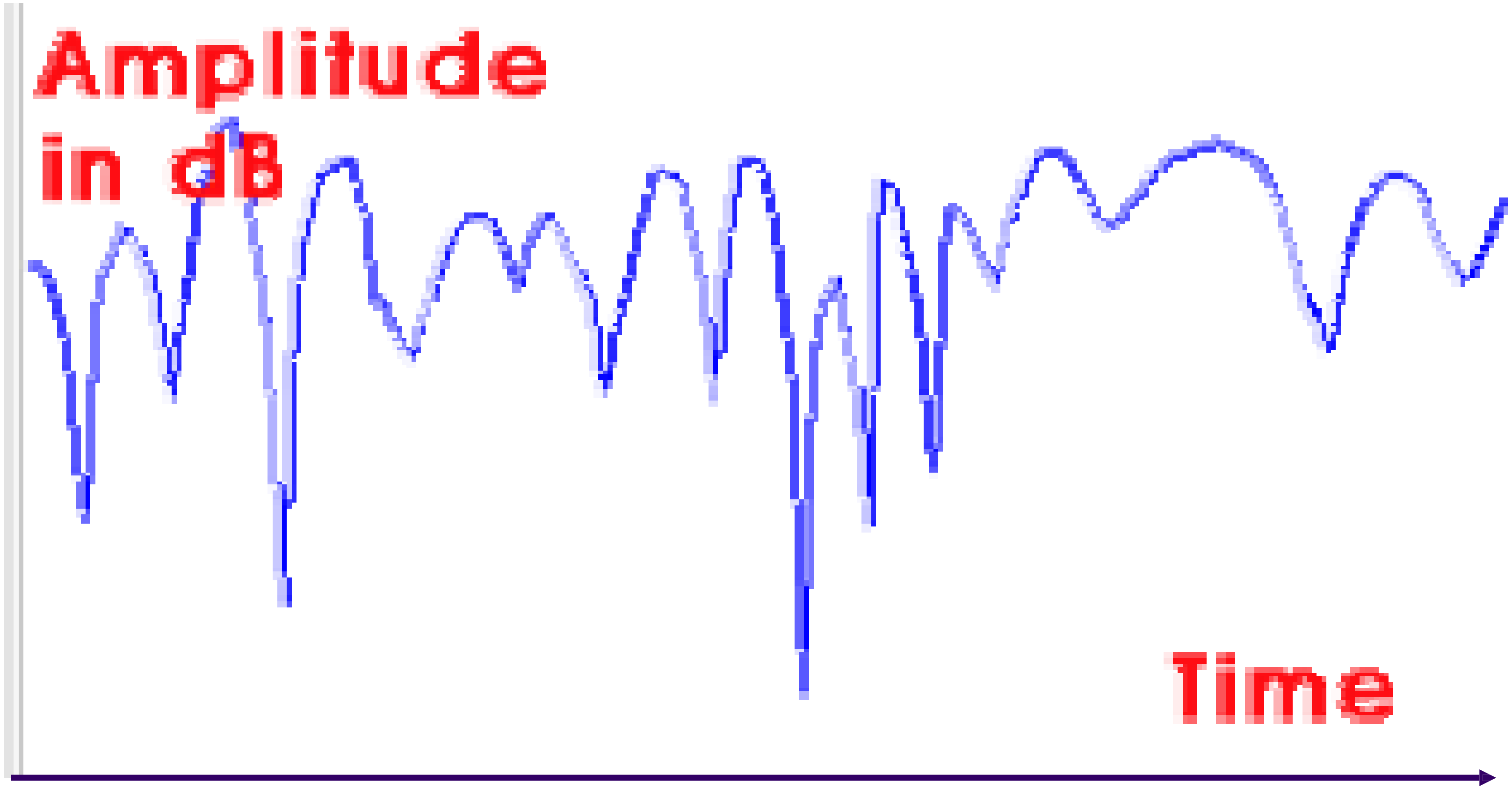
Fading Distributions

- Describes how the received signal amplitude changes with time.
  - Remember that the received signal is combination of multiple signals arriving from different directions, phases and amplitudes.
  - With the received signal we mean the baseband signal, namely the envelope of the received signal (i.e. r(t)).
- Its is a statistical characterization of the multipath fading.
- Two distributions
  - Rayleigh Fading
  - Ricean Fading

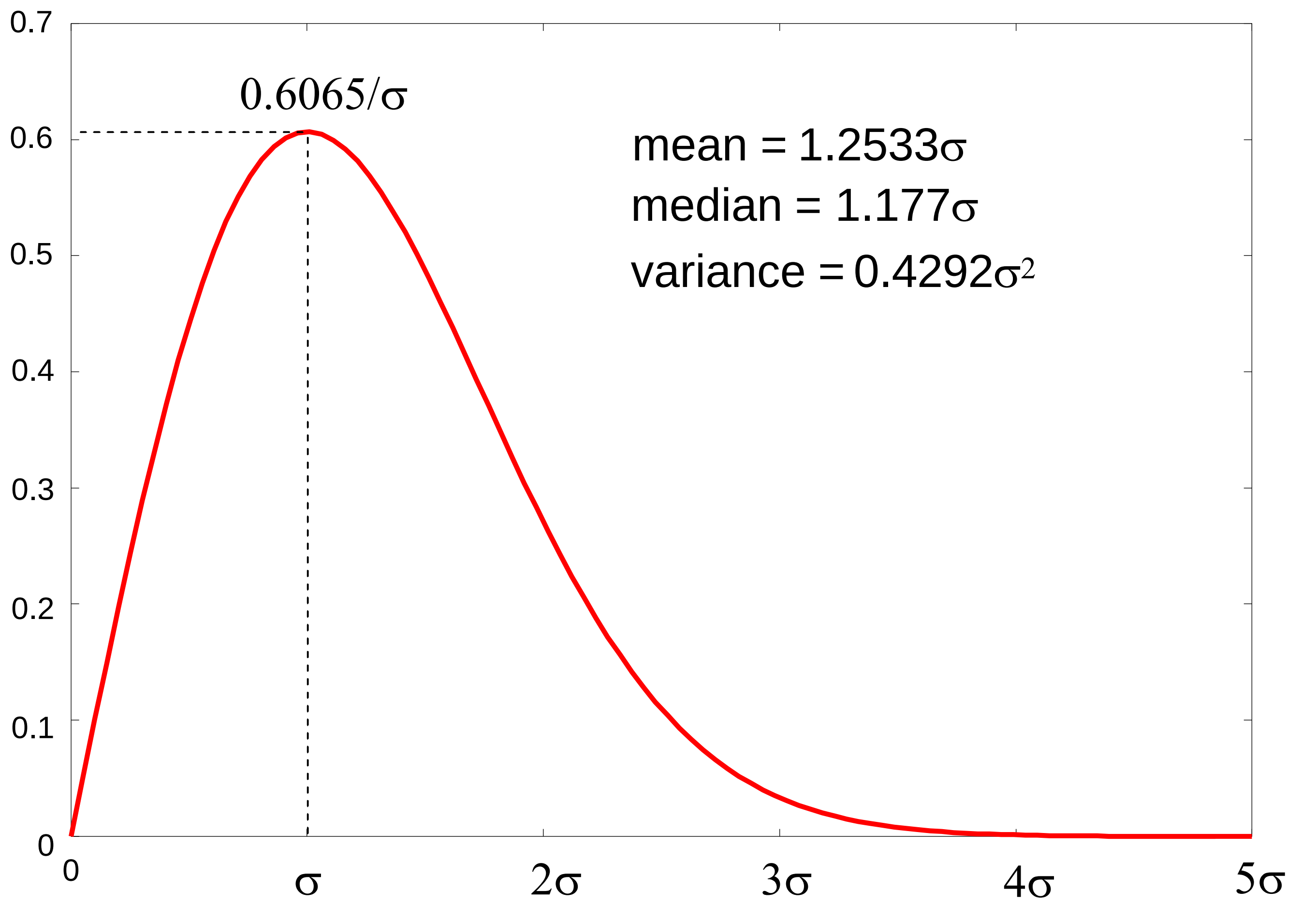
Rayleigh and Ricean Distributions

- Describes the received signal envelope distribution for channels, where all the components are non-LOS:
  - i.e. there is no line-of–sight (LOS) component.
- Describes the received signal envelope distribution for channels where one of the multipath components is LOS component.
  - i.e. there is one LOS component.

Rayleigh Fading



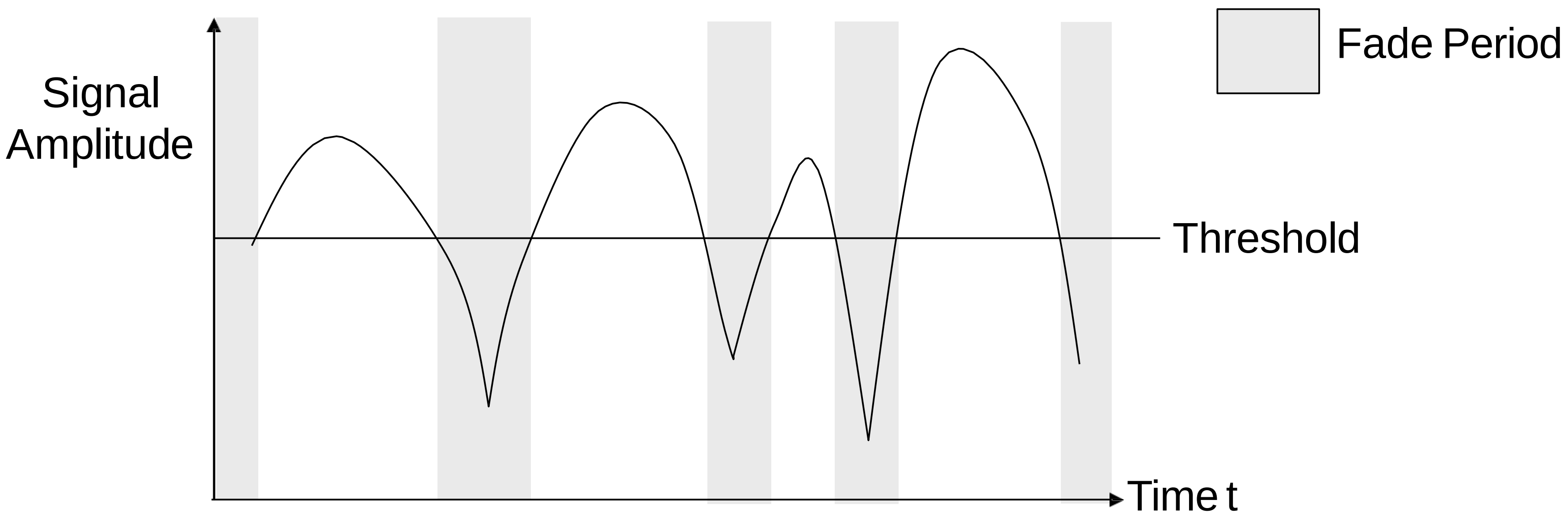
Rayleigh Fading

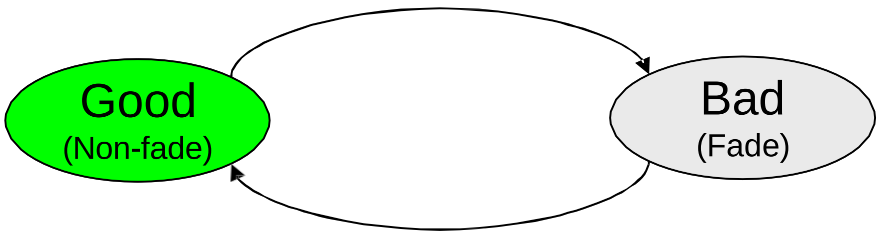


Ricean Distribution

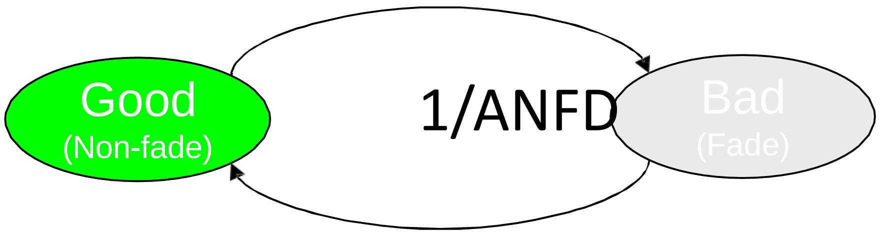
- When there is a stationary (non-fading) LOS signal present, then the envelope distribution is Ricean.
- The Ricean distribution degenerates to Rayleigh when the dominant component fades away.

Fading Model – Gilbert-Elliot Model





Gilbert-Elliot Model



- The channel is modeled as a Two-State Markov Chain.
- Each state duration is memory-less and exponentially distributed.

- The rate going from Good to Bad state is: 1/AFD(AFD: Avg Fade Duration)
- The rate going from Bad to Good state is: 1/ANFD (ANFD: Avg Non-Fade Duration)

UNIT-IV

Equalization and Diversity

CLOs	Course Learning Outcome
CLO10	Understand the analytical perspective on the design and analysis of the traditional and emerging wireless networks
CLO11	Discuss the nature of and solution methods to the fundamental problems in wireless networking.
CLO12	Discuss the architecture of the various wireless wide area networks such as GSM, IS-95, GPRS and SMS.

Outline

- Introduction
- Fundamentals of Equalization
- Survey of Equalization Techniques
  - Linear Equalizers
  - Nonlinear Equalization
  - Algorithms for Adaptive Equalization
- Fundamentals of diversity
- Survey of Diversity Techniques
  - Frequency/Time/Space/Polarization Diversity
  - Selection/MRC/EGC Combining
  - RAKE Receiver
  - Interleaving

Introduction

- The properties of mobile radio channels:
  - Multipath fading -> time dispersion, ISI
  - Doppler spread -> dynamical fluctuation

  These effects have a strong negative impact on the bit error rate of any modulation.
- Mobile communication systems require signal processing techniques that improve the link performance in hostile mobile radio environments.
- Three popular techniques:
  - Equalization: compensates for ISI
  - Diversity: compensates for channel fading
  - Channel coding: detects or corrects errors

  These techniques can be deployed independently or jointly.

Equalization

- If the modulation bandwidth exceeds the coherence bandwidth of the radio channel, ISI occurs and modulation pulses are spread in time.
- Equalization compensates for intersymbol interference (ISI) created by multipath within time dispersive channels.
- An equalizer within a receiver compensates for the average range of expected channel amplitude and delay characteristics.
- Equalizers must be adaptive since the channel is generally unknown and time varying.

Diversity

- Usually employed to reduce the depth and duration of the fades experienced by a receiver in a flat fading (narrowband) channel.
- Without increasing the transmitted power or bandwidth.
- Can be employed at both base station and mobile receivers.
- Types of diversity:

  .antenna polarization diversity

  .frequency diversity

  .time diversity.
- Spatial diversity is the most common one.
- While one antenna sees a signal null, one of the other antennas may see a signal peak.

Channel Coding

- Used to Improve mobile communication link performance by adding redundant data bits in the transmitted message.
  - At the baseband portion of the transmitter, a channel coder maps a digital message sequence into another specific code sequence containing a greater number of bits than originally contained in the message.
- The coded message is then modulated for transmission in the wireless channel.
- coding can be considered to be a post detection technique.
- Because decoding is performed after the demodulation portion
- two general types of channel codes:

  block codes

  convolutional codes.

Fundamentals of Equalization

- Intersymbol interference (ISI)
  - caused by multipath propagation (time dispersion) ;
  - cause bit errors at the receiver;
  - the major obstacle to high speed data transmission over mobile radio channels.
- Equalization
  - a technique used to combat ISI;
  - can be any signal processing operation that minimizes ISI;
  - usually track the varying channel adaptively.

Operating modes of an adaptive equalizer

- Training (first stage)
  - A known fixed-length training sequence is sent by the transmitter so that the receiver's equalizer may average to a proper setting.
  - The training sequence is designed to permit an equalizer at the receiver to acquire the proper filter coefficients in the worst possible channel conditions
  - The training sequence is typically a pseudorandom binary signal or a fixed, prescribed bit pattern.
  - Immediately following the training sequence, the user data is sent.

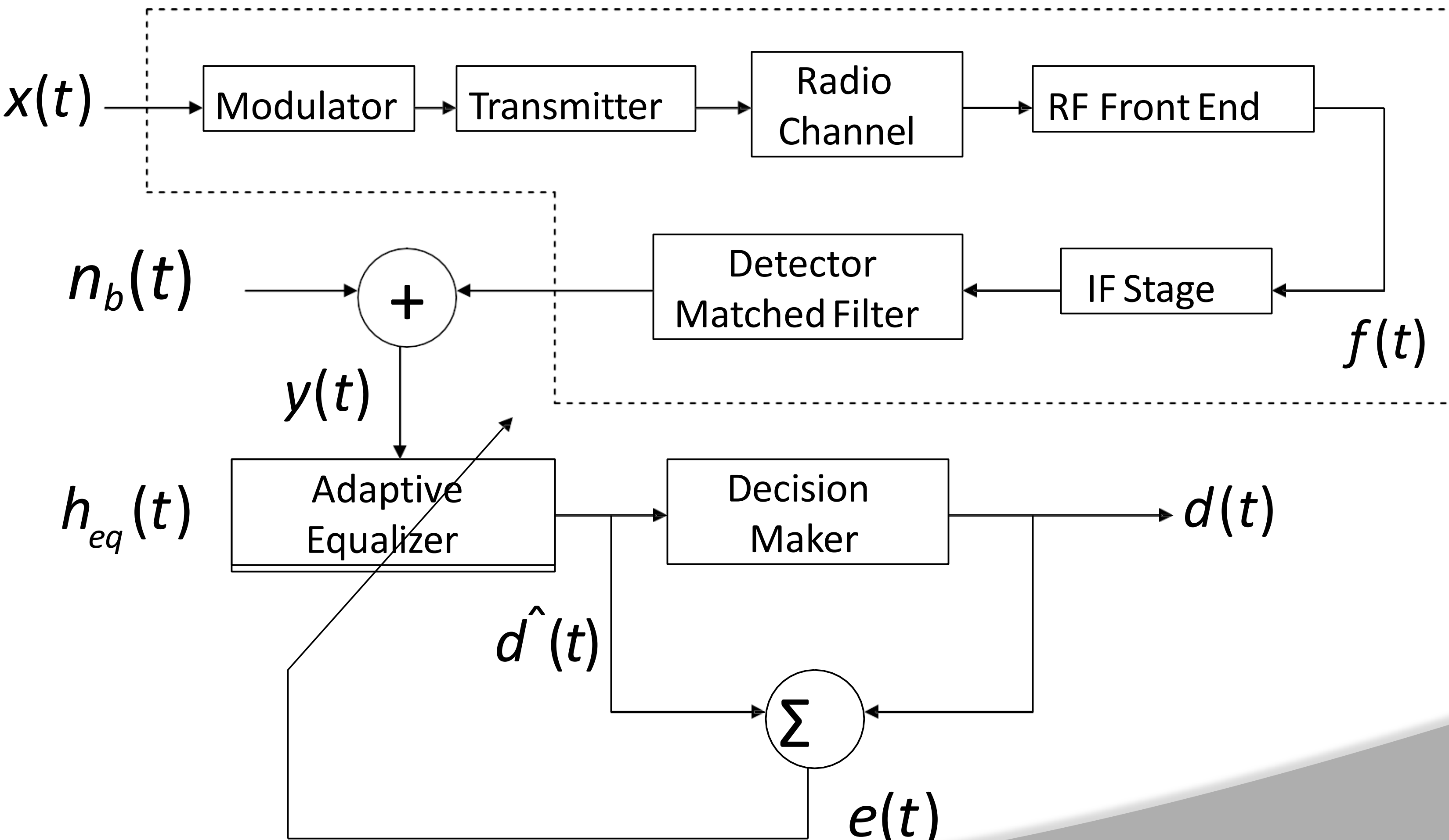
Operating modes of an adaptive equalizer

- Tracking (second stage)
- Immediately following the training sequence, the user data is sent.
- As user data are received, the adaptive algorithm of the equalizer tracks the changing channel and adjusts its filter characteristics over time commonly used in digital communication systems where user data is segmented into short time blocks.
- TDMA wireless systems are particularly well suited for equalizers data in fixed-length time blocks, training sequence usually sent at the beginning of a block

Communication system with an adaptive equalizer

- Equalizer can be implemented at baseband or at IF in a receiver.
- Since the baseband complex envelope expression can be used to represent bandpass waveforms and, thus, the channel response, demodulated signal, and adaptive equalizer algorithms are usually simulated and implemented at baseband
- Block diagram of a simplified communications system using an adaptive equalizer at the receiver is shown in next page

Communication system with an adaptive equalizer



Relevant equations

$$y(t) = x(t) * f(t) + n_b(t)$$

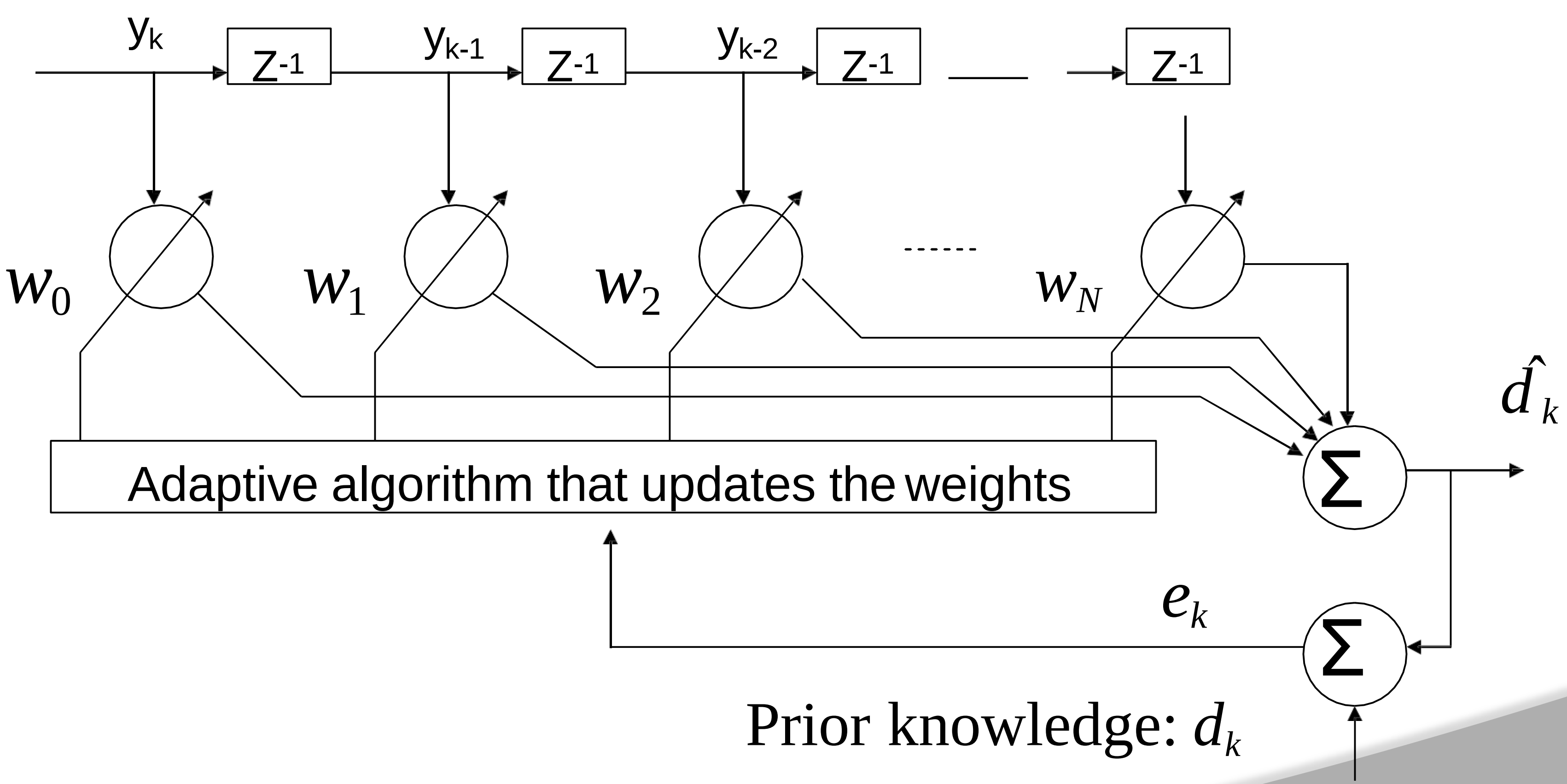
$$\hat{d}(t) = x(t) * f(t) * h_{eq}(t) + n_b(t) * h_{eq}(t)$$

$$h_{eq}(t) = \sum_k c_k \delta(t - nT_s)$$

To eliminate ISI, we must have

$$h_{eq}(t) * f(t) = \delta(t) \qquad H_{eq}(f) = \frac{1}{F(f)}$$

A Generic Adaptive Equalizer



A Generic Adaptive Equalizer

- A transversal filter with
  - N delay elements
  - N+1 taps
  - N+1 tunable complex multipliers
  - N+1 weights:
- These weights are updated continuously by the adaptive algorithm either on a sample by sample basis or on a block by block basis.
- The adaptive algorithm is controlled by the error signal e_k.
- e_k is derived by comparing the output of the equalizer with some signal which is either an exact scaled replica of the transmitted signal x_k or which represents a known property of the transmitted signal.

A Generic Adaptive Equalizer

- A cost function is used
  the cost function is minimized by using e_kThe, and the weights are updated iteratively.
- For example, The least mean squares (LMS) algorithm can serve as a cost function.
- Iterative operation based on LMS

  New weights = Previous weights + (constant) x (Previous error) x (Current input vector)

  Where

  Previous error = Previous desired output — Previous actual output

A Generic Adaptive Equalizer

- Techniques used to minimize the error
  - gradient
  - steepest decent algorithms
- Based on classical equalization theory, the most common cost function is MSE

  MSE----mean square error (MSE) between the desired signal and the output of the equalizer

A Generic Adaptive Equalizer

Blind algorithms

- More recent class of adaptive algorithms
- Able to exploit characteristics of the transmitted signal and do not require training sequences provide equalizer convergence without burdening the transmitter with training overhead able to acquire equalization through property restoral techniques of the transmitted signal,
- Two techniques:
  - The constant modulus algorithm (CMA) used for constant envelope modulation forces the equalizer weights to maintain a constant envelope on the received signal
  - Spectral coherence restoral algorithm (SCORE). exploits spectral redundancy or cyclostationarity in the transmitted signal

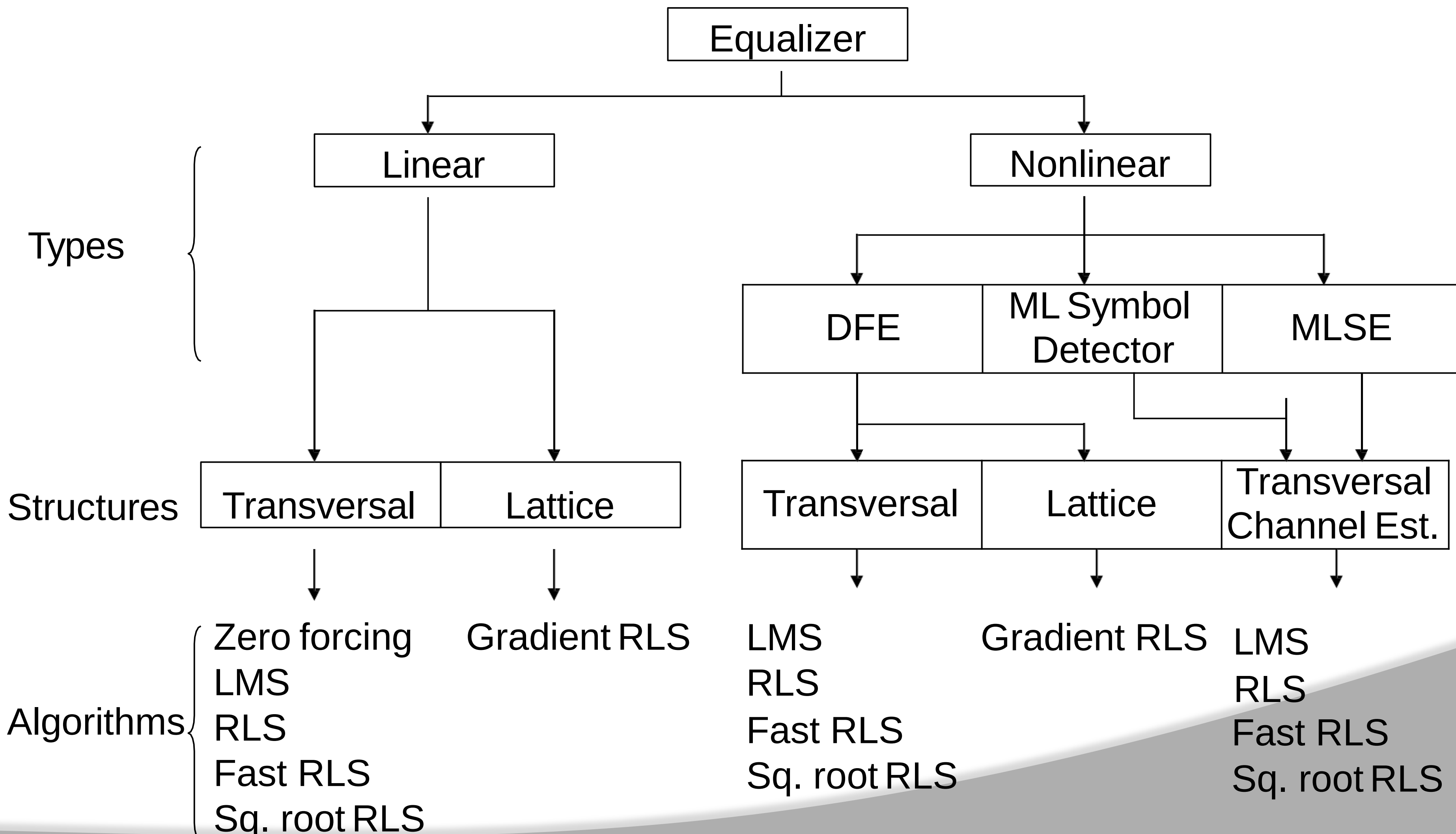
Survey of Equalization Techniques

- Equalization techniques can be subdivided into two general categories:
  - linear equalization
    - The output of the decision maker is not used in the feedback path to adapt the equalizer.
  - nonlinear equalization
    - The output of the decision maker is used in the feedback path to adapt the equalizer.

- Many filter structures are used to implement linear and nonlinear equalizers

- For each structure, there are numerous algorithms used to adapt the equalizer.

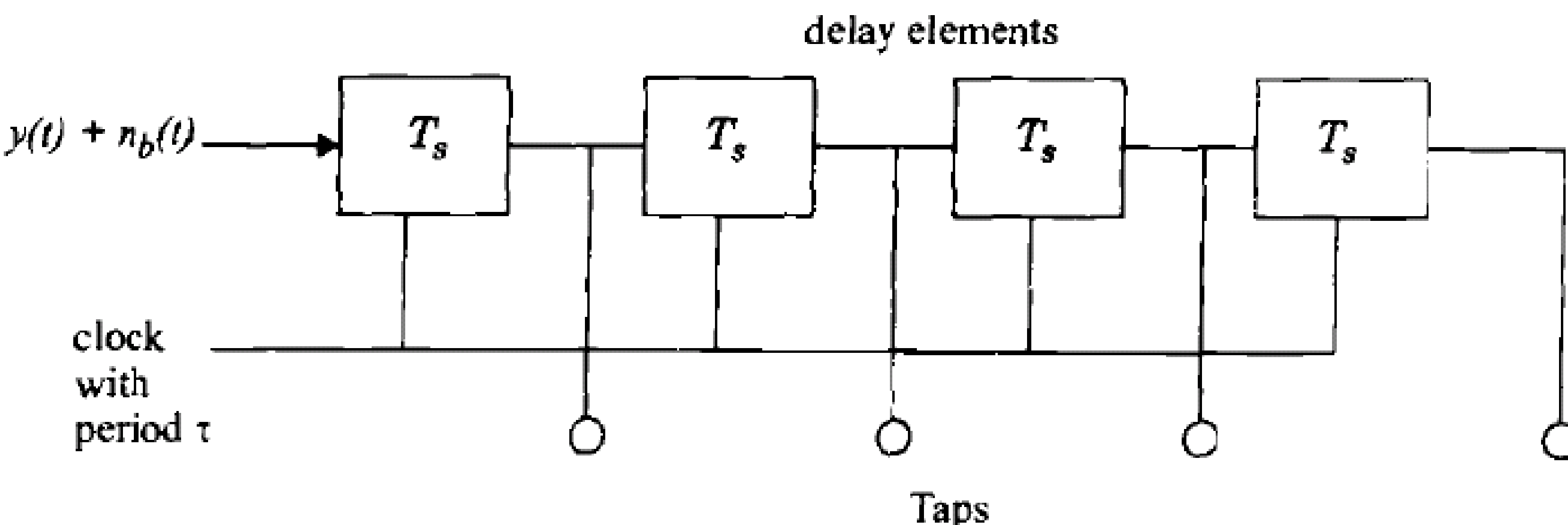
Classification of equalizers



Most common structure:
---- Linear transversal equalizer (LTE)

- **Made up of tapped delay lines, with the tappings spaced a symbol period (Ts) apart**
- **The transfer function can be written as a function of the delay operator** $-j\sigma T_s$ **or** Z^{-1}

Assuming that the delay elements have unity gain and delay Ts, of a linear



Basic linear transversal equalizer structure

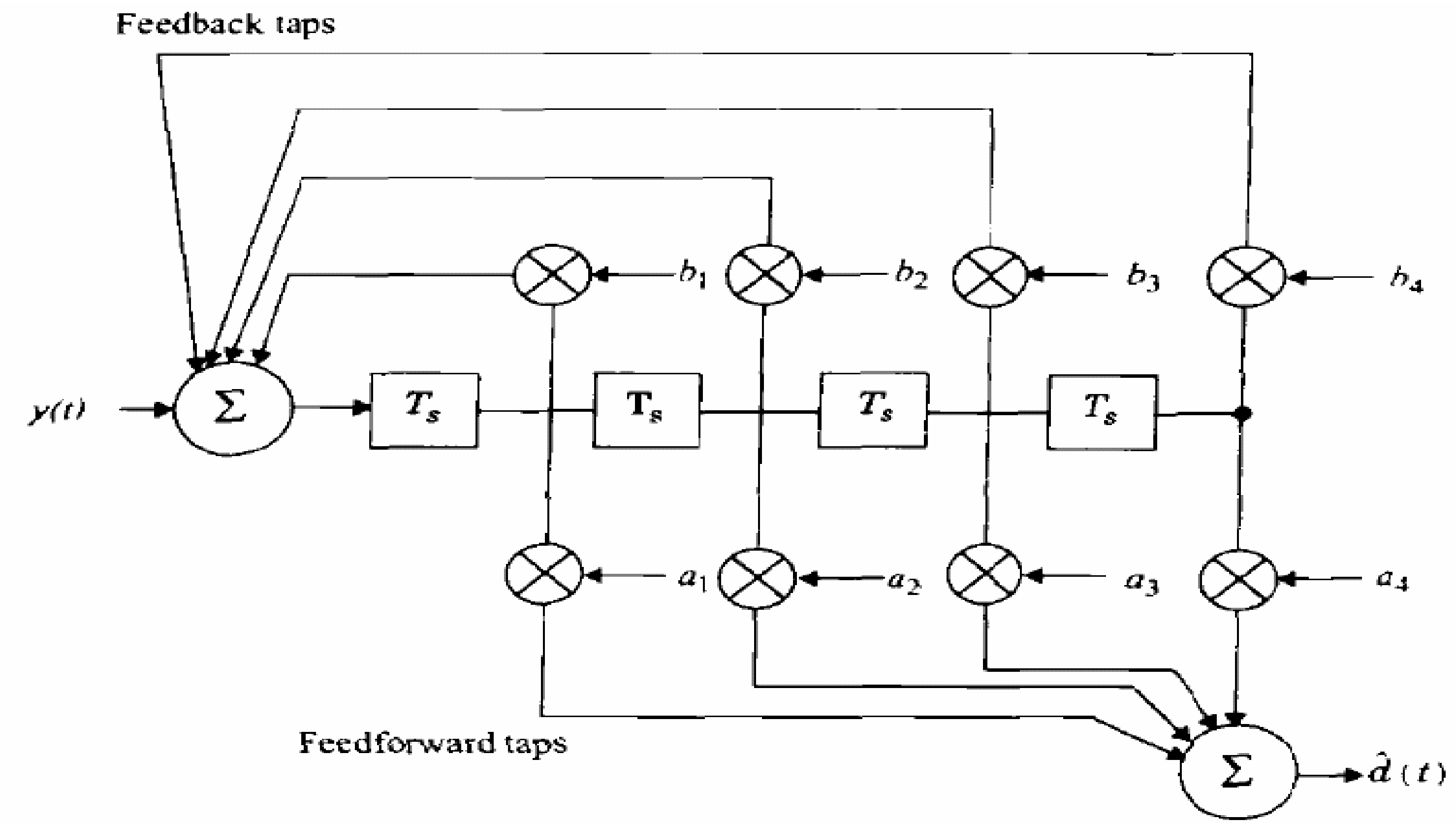
Most common structure:
---- Linear transversal equalizer (LTE)

Two types of LTE

- finite impulse response (FIR) filter
  - The simplest LTE uses only feed forward taps
  - Transfer function is a polynomial in has many zeroes but poles only at z = 0 Usually simply called a transversal filter

- Infinite impulse response (IIR) filter
  - Has both feed forward and feedback taps
  - Transfer function is a rational function of Z^{-1} with poles and zeros.
  - Tend to be unstable when used in channels where the strongest pulse arrives after an echo pulse (i.e., leading echoes) rarely used.

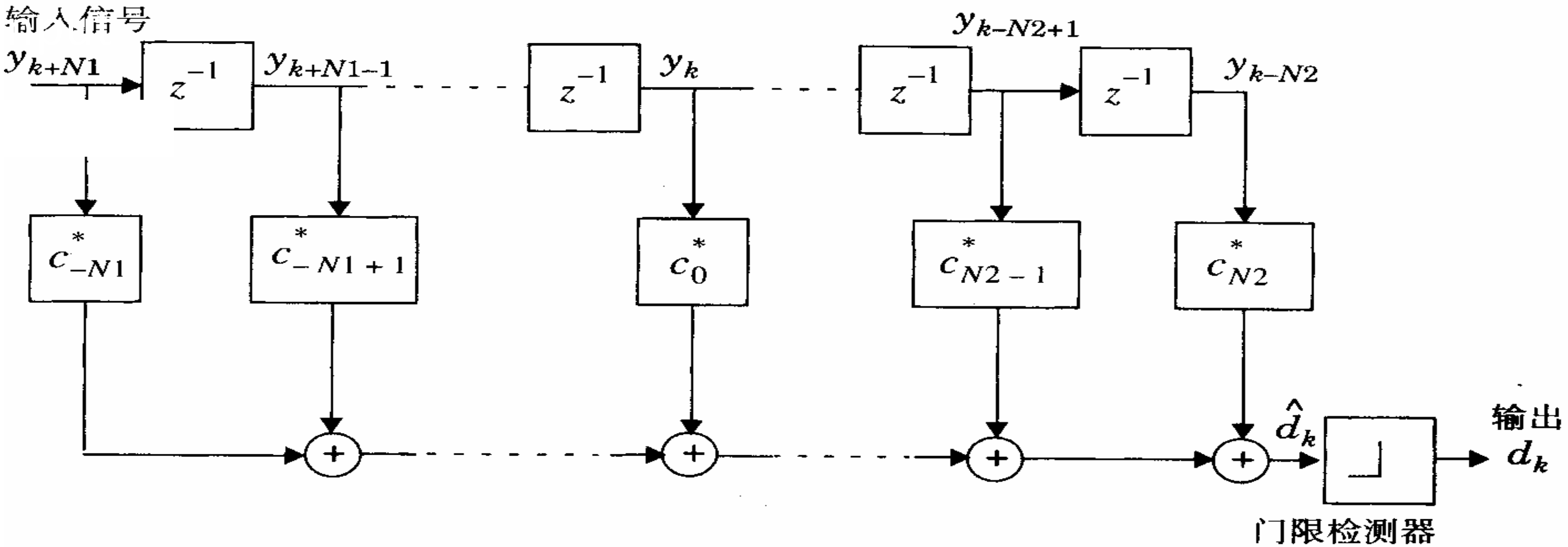
Rayleigh Fading



Tapped delay line filter with both feedforward and feedback taps (IIR)

Linear Equalizers

Transversal filter implementation (LTE)



This type of equalizer is the simplest.

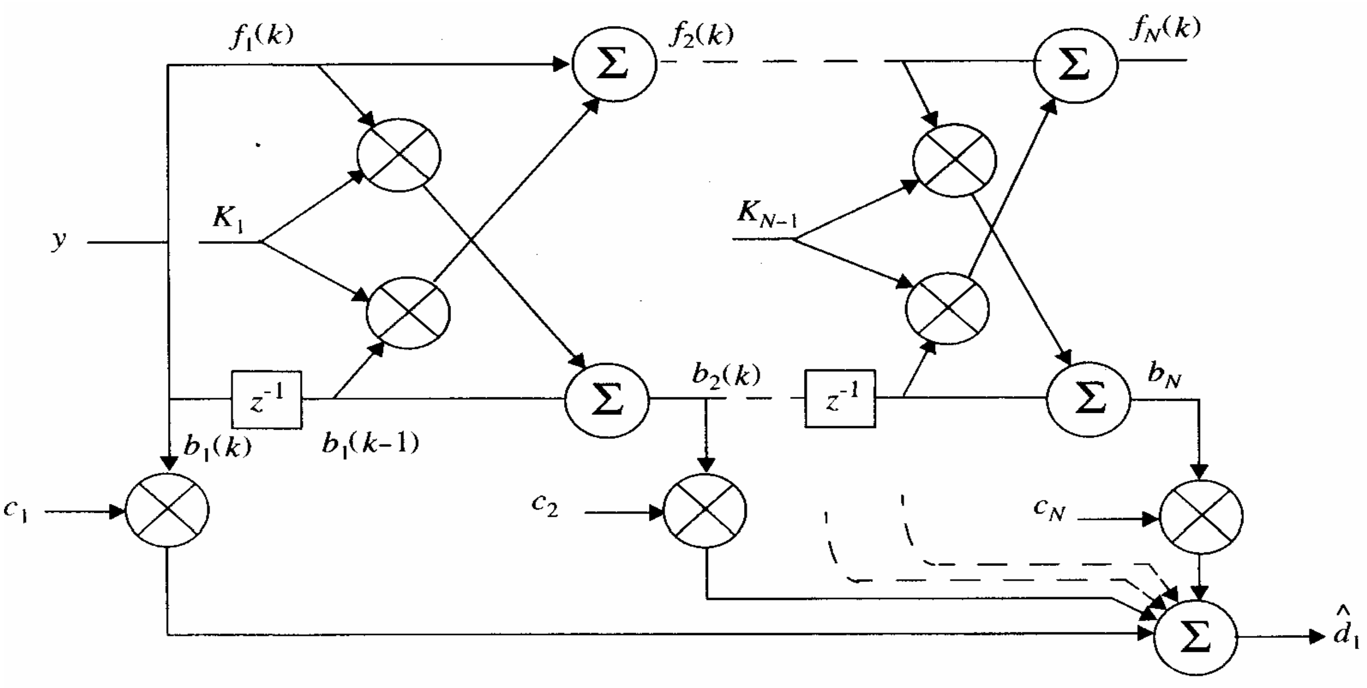
Linear Equalizers

- Current and past values of the received signal are linearly weighted by the filter coefficient and summed to produce the output,
  - If the delays and the tap gains are analog, the continuous output of the equalizer is sampled at the symbol rate and the samples are applied to the decision device.
  - Implementation is usually carried out in the digital domain where the samples of the received signal are stored in a shift register.
- The output before decision making (threshold detection)

- The minimum MSE it can achieve

$$E[|e(n)|^2] = \frac{T}{2\pi}\int_{-\pi/T}^{\pi/T} \frac{N_0}{|F(e^{j\omega T})|^2 + N_0} d\omega$$

Linear Equalizers



Numerical stable, faster convergence, Complicated

Nonlinear Equalization

- Linear equalizers do not perform well on channels which have deep spectral nulls in the pass band.
- In an attempt to compensate for the distortion, the linear equalizer places too much gain in the vicinity of the spectral null, thereby enhancing the noise present in those frequencies.
- Nonlinear equalizers are used in applications where the channel distortion is too severe for a linear equalizer to handle.
- Three very effective nonlinear equalizer
- Decision Feedback Equalization (DFE)
- Maximum Likelihood Symbol Detection
- Maximum Likelihood Sequence Estimation (MLSE)

Decision Feedback Equalization (DFE)

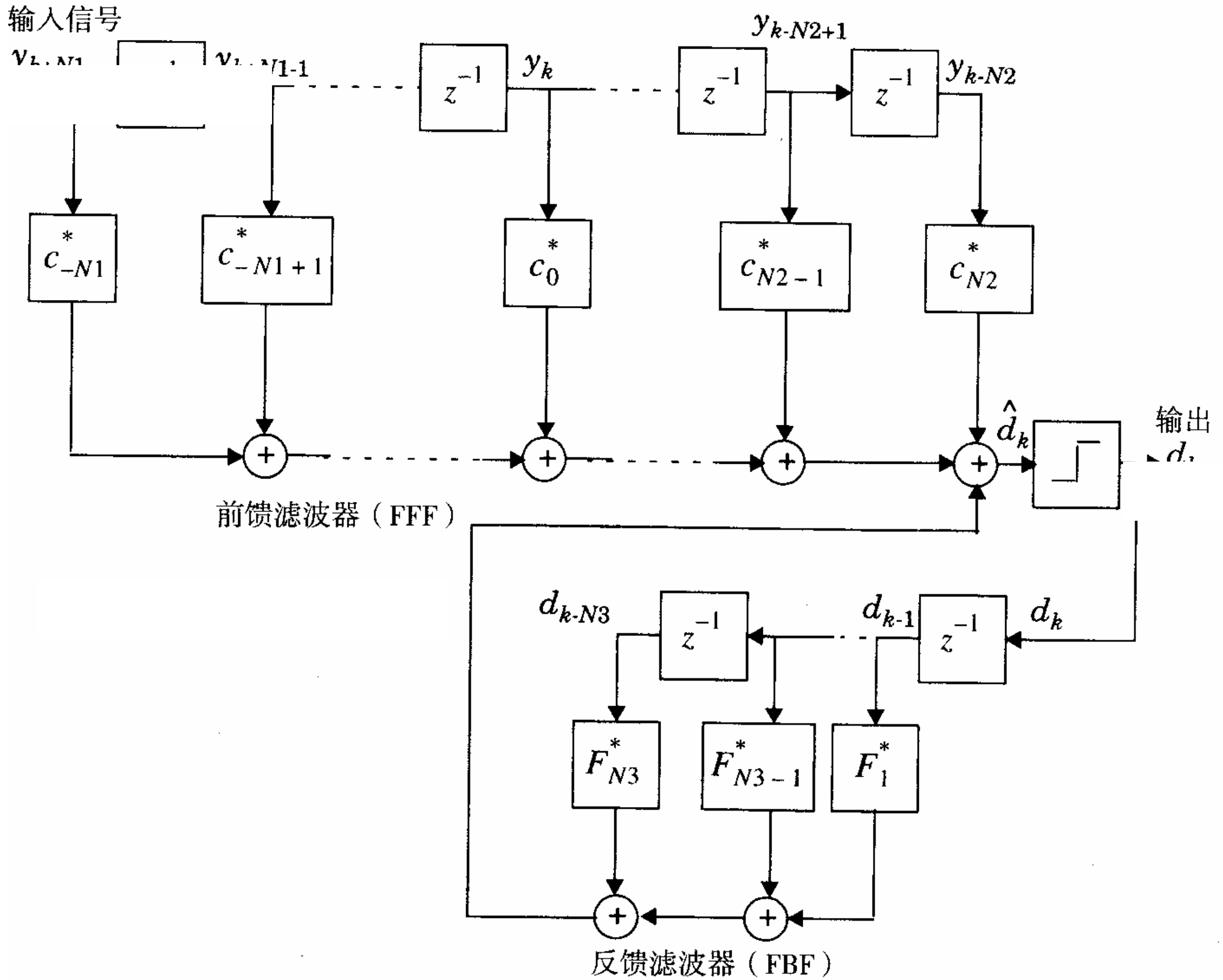
Basic idea:

once an information symbol has been detected, the ISI that it induces on future symbols can be estimated and subtracted out before detection of subsequent symbols.

- DFE Can be realized in either the direct transversal form or as a lattice filter.
- The LTE form consists of a feedforward filter (FFF) and a feedback filter (FBF).

  The FBF is driven by decisions on the output of the detector, and its coefficients can be adjusted to cancel the ISI on the current symbol from past detected symbols.
- The equalizer has N1 + N2 + I taps in FFF and N3 taps in FBF

Decision Feedback Equalization (DFE)



Decision Feedback Equalization (DFE)

The output of DFE $$\hat{d}_k = \sum_{n=-N_1}^{N_2} c_n^* y_{k-n} + \sum_{i=1}^{N_3} F_i d_{k-i}$$

The minimum mean square error of DFE

$$E[|e(n)|^2]_{min} = \exp\left\{\frac{T}{2\pi}\int_{-\pi/T}^{\pi/T} \ln\left[\frac{N_0}{|F(e^{j\omega T})|^2 + N_0}\right] d\omega\right\}$$

•It can be seen that the minimum MSE for a DFE is always smaller than that of an LTE

Unless $|F(e^{j\sigma T})|$ *is a constant, where adaptive equalization is not needed*

•If there are nulls in the $|F(e^{j\sigma T})|$ **, a DFE has significantly smaller minimum MSE than an LTE.**

Decision Feedback Equalization (DFE)

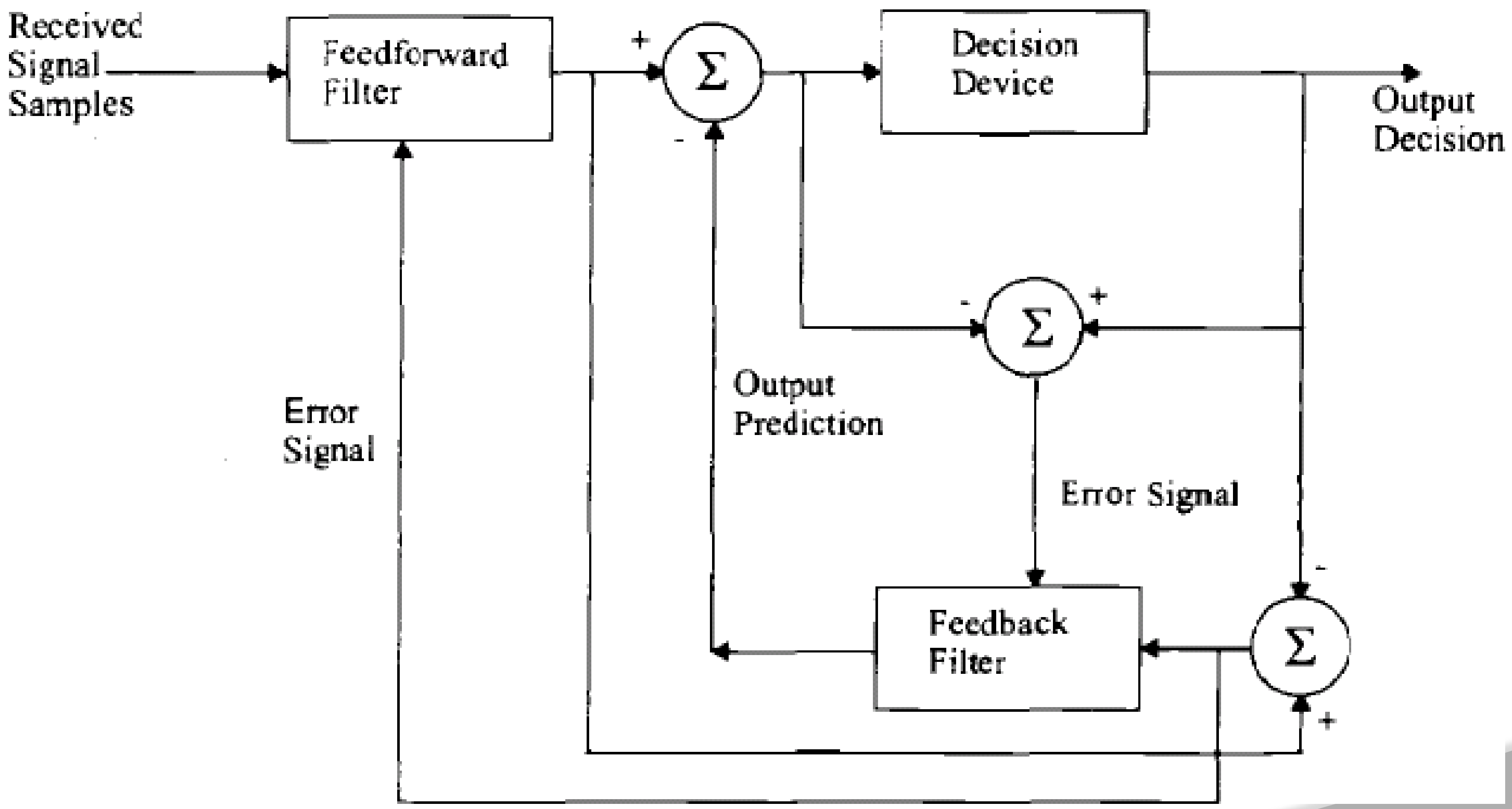
Conclusion

- An LTE is well behaved when the channel spectrum is comparatively flat
- A DFE is more appropriate for severely distorted wireless channels.
- If the channel is severely distorted or exhibits nulls in the spectrum
  - The performance of an LTE deteriorates and the mean squared error of a DFE is much better than a LTE.
  - Also, an LTE has difficulty equalizing a nonminimum phase channel where the strongest energy arrives after the first arriving signal component.

Another form of DFE----predictive DFE

- Also consists of a feed forward filter (FFF) as in the conventional DFE.
- Difference: the feedback filter (FBF) is driven by an input sequence formed by the difference of the output of the detector and the output of the feed forward filter.
- The FBF here is called a noise predictor because it predicts the noise and the residual ISI contained in the signal at the FFF output and subtracts from it
- The predictive DFE performs as well as the conventional DFE as the limit in the number of taps in the FFF and the FBF approach infinity.
- The FEF in the predictive DFE can also be realized as a lattice structure

Another form of DFE----predictive DFE



Maximum Likelihood Sequence Estimation (MLSE) equalizer

- The MSE-based linear equalizers are optimum with respect to the criterion of minimum probability of symbol error when the channel does not introduce any amplitude distortion.
- Yet this is precisely the condition in which an equalizer is needed for a mobile communications link.
- MLSE uses various forms of the classical maximum likelihood receiver structure.
- The MLSE tests all possible data sequences (rather than decoding each received symbol by itself), and chooses the data sequence with the maximum probability as the output.
- A channel impulse response simulator is used with in the algorithm.

Maximum Likelihood Sequence Estimation (MLSE) equalizer

NOTES:

- The MLSE requires knowledge of the channel characteristics in order to compute the metrics for making decisions.
- The MLSE also requires knowledge of the statisticall distribution of the noise corrupting the signall the probability distribution of the noise determines the form of the metric for optimum demodulation of the received signal.
- The matched filter operates on the continuous time signal, whereas the MLSE and channel estimator rely on discretized (nonlinear) samples.

Algorithms for Adaptive Equalization

- Equalizer requires a specific algorithm to update the coefficients and track the channel variations.
- Since it compensates for an unknown and time-varying channel
- This section outlines three of the basic algorithms for adaptive equalization.
- Though the algorithms detailed in this section are derived for the linear, transversal equalizer, they can be extended to other equalizer structures, including nonlinear equalizers.

Comparison of Various Algorithms for Adaptive Equalization [Pro9l]

Algorithm	Number of Multiply Operations	Advantages	Disadvantages
LMS Gradient DFE	$2N + 1$	Low computational complexity, simple program	Slow convergence, poor tracking
Kalman RLS	$2.5N^2 + 4.5N$	Fast convergence, good tracking ability	High computational complexity
FTF	$7N + 14$	Fast convergence, good tracking, low computational complexity	Complex programming, unstable (but can use rescue method)
Gradient Lattice	$13N - 8$	Stable, low computational complexity, flexible structure	Performance not as good as other RLS, complex programming
Gradient Lattice DFE	$13N_1 + 33N_2 - 36$	Low computational complexity	Complex programming
Fast Kalman DFE	$20N + 5$	Can be used for DFE, fast convergence and good tracking	Complex programming, computation not low, unstable
Square Root RLS DFE	$1.5N^2 + 6.5N$	Better numerical properties	High computational complexity

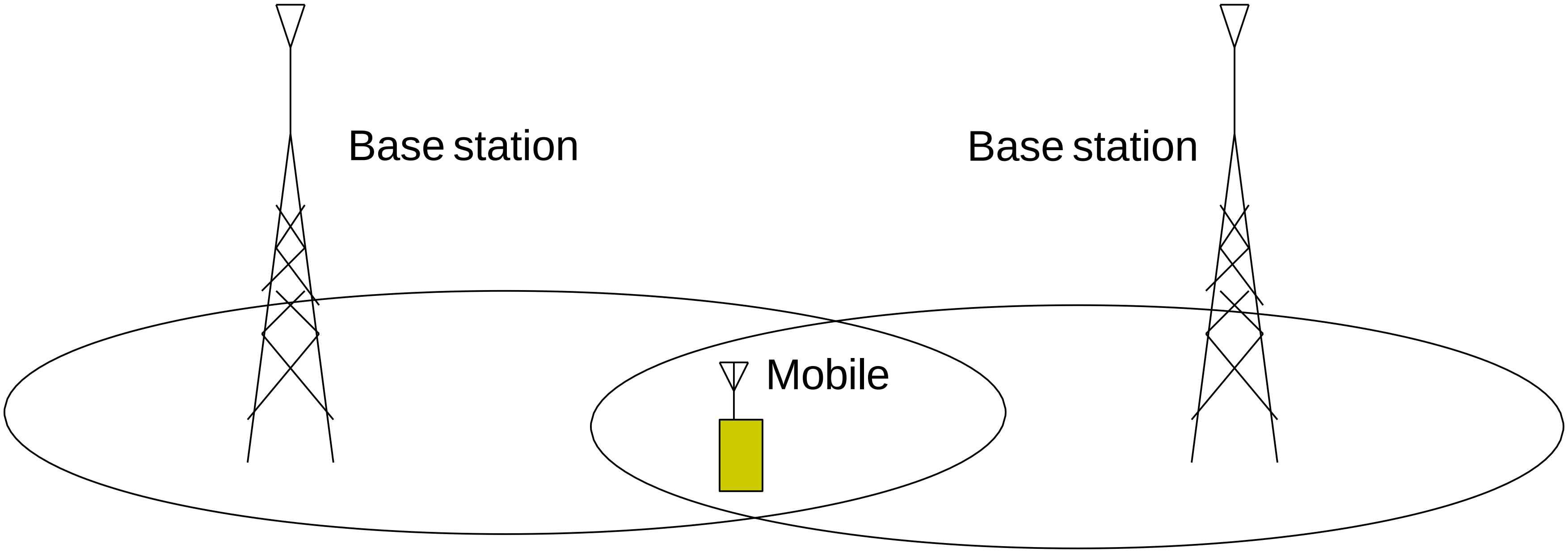
Fundamentals of Diversity Techniques

Macroscopic diversity

- Macroscopic diversity is also useful at the base station receiver.
- By using base station antennas that are sufficiently separated in space, the base station is able to improve the reverse link by selecting the antenna with the strongest signal from the mobile.
- Used to combat slow fading (shadowing)
- Samples: Base-station handoff in cellular networks

Fundamentals of Diversity Techniques

Macro-scope diversity



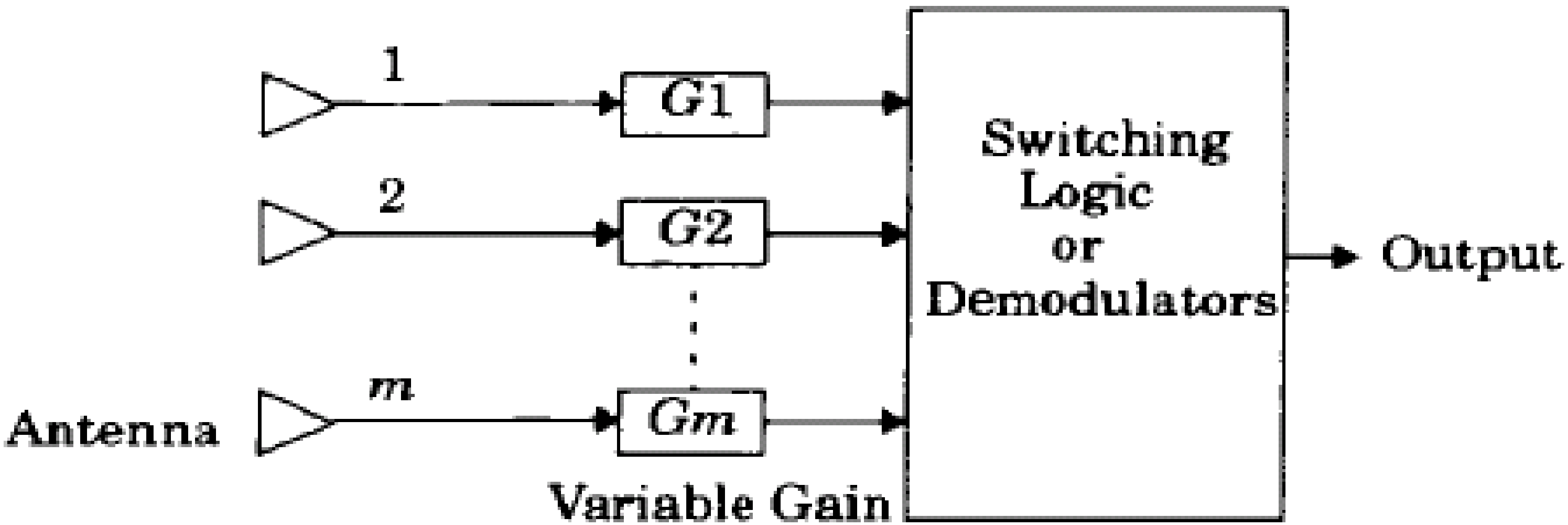
Fundamentals of Diversity Techniques

- Strategies used in diversity techniques
  - Selection diversity
  - Maximal ratio combining diversity
  - Equal-gain combining diversity
  - Hybrid schemes
- Practical considerations
  - effectiveness, complexity, cost, and etc.

Derivation of Selection Diversity improvement

- **Consider M independent Rayleigh fading channels available areceiver.**

  Each channel is called a diversity branch.



Derivation of Selection Diversity improvement

- Now, the probability that all M independent diversity branches receive signals which are simultaneously less than some specific SNR threshold μ **is**

$$Pr[\gamma_1, \ldots, \gamma_M \le \gamma] = (1 - e^{-\gamma/\Gamma})^M = P_M(\gamma)$$

This is the probability of all branches failing to achieve $SNR = \mu_i$.

- If a single branch achieves $SNR > \mu$, then the probability that $SNR > \mu$ for one or more branches is given by

$$Pr[\gamma_i > \gamma] = 1 - P_M(\gamma) = 1 - (1 - e^{-\gamma/\Gamma})^M$$

This is the probability of exceeding a threshold when selection diversity is used.

Derivation of Selection Diversity improvement

How to determine the average signal-to-noise ratio of the received signal when diversity is used?

- First of all, find the pdf of (the instantaneous SNR when M branches are used). Thus we compute the derivation of CDF

$$p_M(\gamma) = \frac{d}{d\gamma}P_M(\gamma) = \frac{M}{\Gamma}(1 - e^{-\gamma/\Gamma})^{M-1} e^{-\gamma/\Gamma}$$

- Then, we can compute the average SNR, $\bar{\mu}$,

$$\bar{\gamma} = \int_0^{\infty} \gamma p_M(\gamma) d\gamma = \Gamma \int_0^{\infty} Mx(1 - e^{-x})^{M-1} e^{-x} dx$$

where $x = \mu / \Gamma$**.**

The above equation can be evaluated to yield the average SNR improvement offered by selection diversity.

Derivation of Selection Diversity improvement

- Selection diversity offers an average improvement in the link margin without requiring additional transmitter power or sophisticated receiver circuitry.
- The diversity improvement can be directly related to the average bit error rate for various modulations.
- Selection diversity is easy to implement because all that is needed is a side monitoring station and an antenna switch at the receiver.
- However, it is not an optimal diversity technique because it does not use all of the possible branches simultaneously.
- Maximal ratio combining uses each of the M branches in a co- phased and weighted manner such that the highest achievable SNR is available at the receiver at all times.

Derivation of Selection Diversity improvement

Example

Assume four branch diversity is used, where each branch receives an independent Rayleigh fading signal. If the average SNR is 20 dB, determine the probability that the SNR will drop below 10 dB. Compare this with the case of a single receiver without diversity.

Solution

For this example the specified threshold $\gamma = 10$ dB, $\Gamma = 20$ dB, and there are four branches. Thus $\gamma / \Gamma = 0.1$ and using equation (6.58),

$$P_4(10 \text{ dB}) = (1 - e^{-0.1})^4 = 0.000082$$

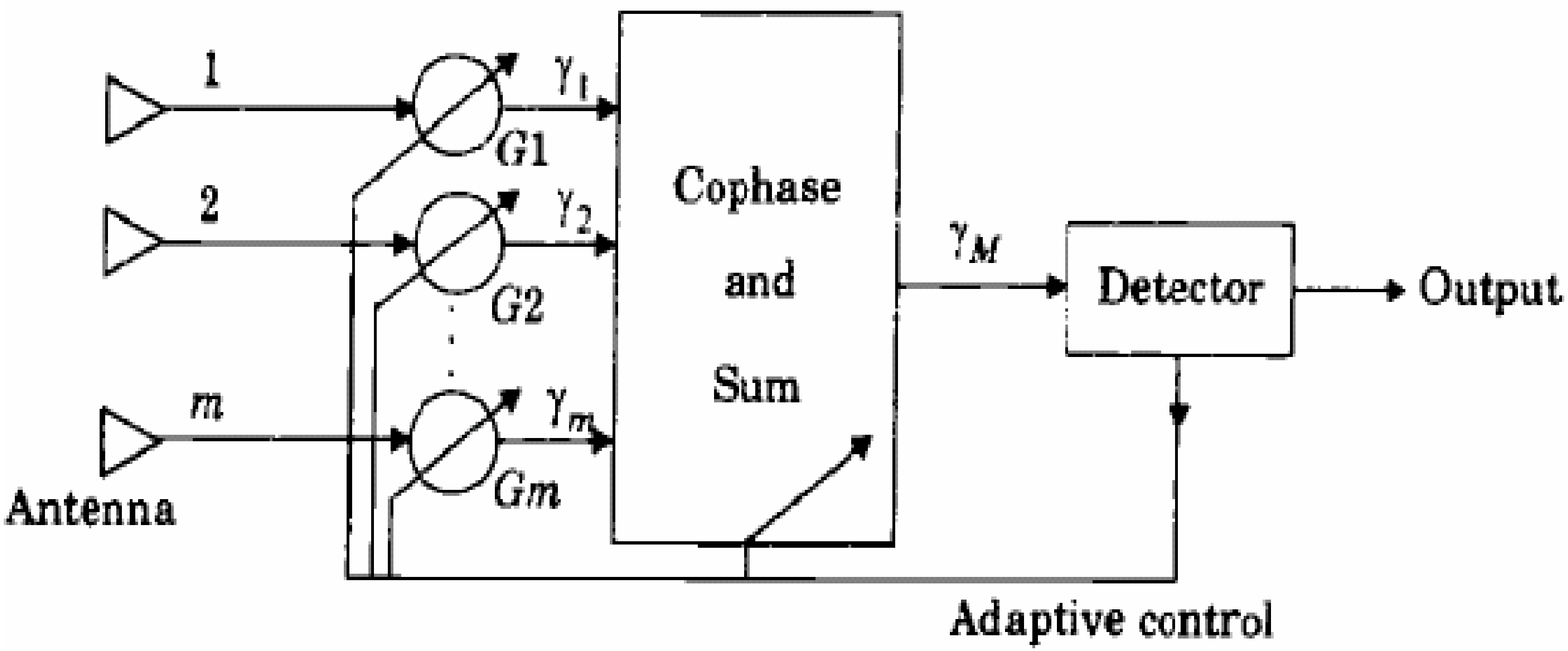
When diversity is not used, equation (6.58) may be evaluated using $M = 1$.

$$P_1(10 \text{ dB}) = (1 - e^{-0.1})^1 = 0.095$$

Notice that without diversity the *SNR* drops below the specified threshold with a probability that is three orders of magnitude greater than if four branch diversity is used!

Derivation of Maximal Ratio Combining Improvement

M diversity branches are co-phased to provide coherent voltage addition and are individually weighted to provide optimal SNR.



Derivation of Maximal Ratio Combining Improvement

1) The SNR out of the diversity combiner:

- If each branch has gain G_i , then the resulting signal envelope applied to the detector is

$$r_M = \sum_{i=1}^{M} G_i r_i$$

- Assuming that each branch has the same average noise power N, the total noise power N_T applied to the detector is simply the weighted sum of the noise in each branch. Thus

$$N_T = N \sum_{i=1}^{M} G_i^2$$

which results in an SNR applied to the detector, γ_M , given by

$$\gamma_M = \frac{r_M^2}{2N_T}$$

Derivation of Maximal Ratio Combining Improvement

- Using Chebychev's inequality, is maximized

$$\gamma_M = \frac{1}{2}\frac{\sum(r_i^2/N)^2}{N\sum(r_i^2/N^2)} = \frac{1}{2}\sum_{i=1}^{M}\frac{r_i^2}{N} = \sum_{i=1}^{M}\gamma_i \quad (7\text{-}66)$$

- **Conclusion:**

  The SNR out of the diversity combiner is simply the sum of the SNRs in each branch.

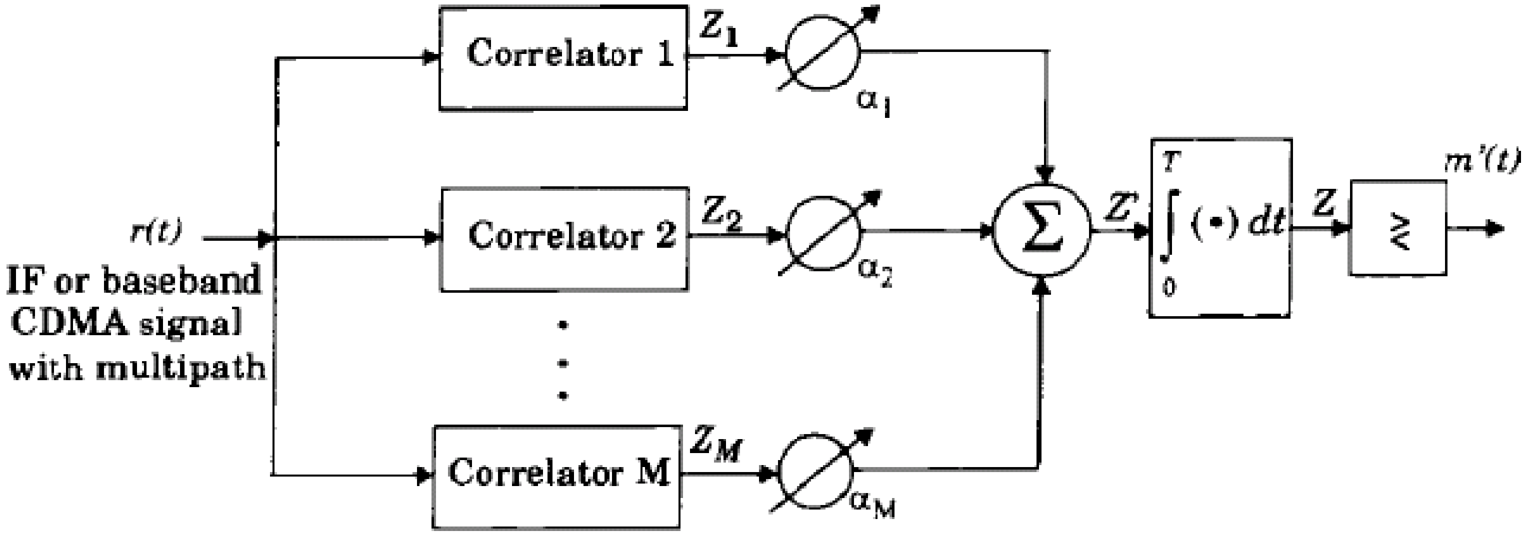
RAKE Receiver

- In CDMA spread spectrum systems, the spreading codes are designed to provide very low correlation between successive chips.
- If the multipath components are delayed in time by more than a chip duration, they appear like uncorrelated noise at a CDMA receiver, and equalization is not required.
- However, since there is useful information in the multipath components, CDMA receivers may combine the time delayed versions of the original signal transmission in order to improve the signal to noise ratio at the receiver
- A RAKE is employed to do this:

  It attempts to collect the time-shifted versions of the original signal by providing a separate correlation receiver for each of the multipath signals.

RAKE Receiver

The RAKE receiver is essentially a diversity receiver designed specifically for CDMA, where the diversity is provided by the fact that the multipath components are practically uncorrelated from one another when their relative propagation delays exceed a chip period.



An M branch (M-finger) RAKE receiver implementation. Each correlator detects a time shifted version of the original CDMA transmission, and each finger of the RAKE correlates to a portion of the signal which is delayed by at least one chip in time from the other fingers.

UNIT V

WIRELESS NETWOKS

CLOs	Course Learning Outcome
CLO13	Understand the operation of the various wireless wide area networks such as GSM, IS- 95, GPRS and SMS.
CLO14	Understand the existing and emerging wireless standards in wireless wide area networks
CLO15	Examine the emerging techniques OFDM and its importance in the wireless communications.

Wireless?

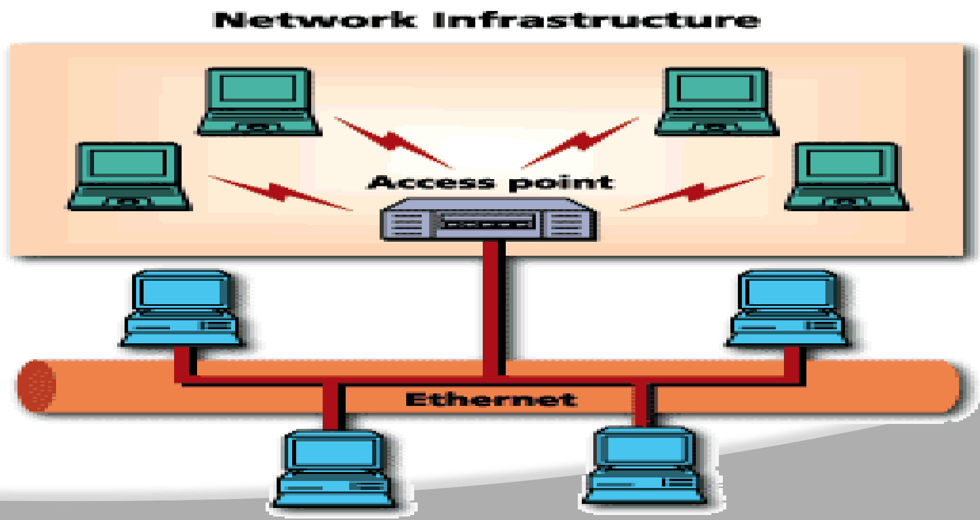
- A wireless LAN or WLAN is a wireless local area network that uses radio waves as its carrier.
- The last link with the users is wireless, to give a network connection to all users in a building or campus.
- The backbone network usually uses cables

Common Topologies

The wireless LAN connects to a wired LAN

- There is a need of an access point that bridges wireless LAN traffic into the wired LAN.
- The access point (AP) can also act as a repeater for wireless nodes,

  effectively doubling the maximum possible distance between nodes.



Common Topologies

Complete Wireless Networks

- The physical size of the network is determined by the maximum reliable propagation range of the radio signals.
- Referred to as **ad hoc** networks
- Are self-organizing networks without any centralized control
- Suited for temporary situations such as meetings and conferences.

How do wireless LANs work?

- Wireless LANs operate in almost the same way as wired LANs, using the same networking protocols and supporting the most of the same applications.

How are WLANs Different?

- They use specialized **physical and data link** protocols
- They integrate into existing networks through **access points** which provide a bridging function
- They let you stay connected as you **roam** from one coverage area to another
- They have unique **security** considerations
- They have specific **interoperability** requirements
- They require **different hardware**
- They offer **performance** that differs from wired LANs.

Physical and Data Link Layers

Physical Layer:

- The wireless **NIC** takes **frames** of data from the link layer, scrambles the data in a predetermined way, then uses the modified data stream to modulate a **radio carrier signal**.

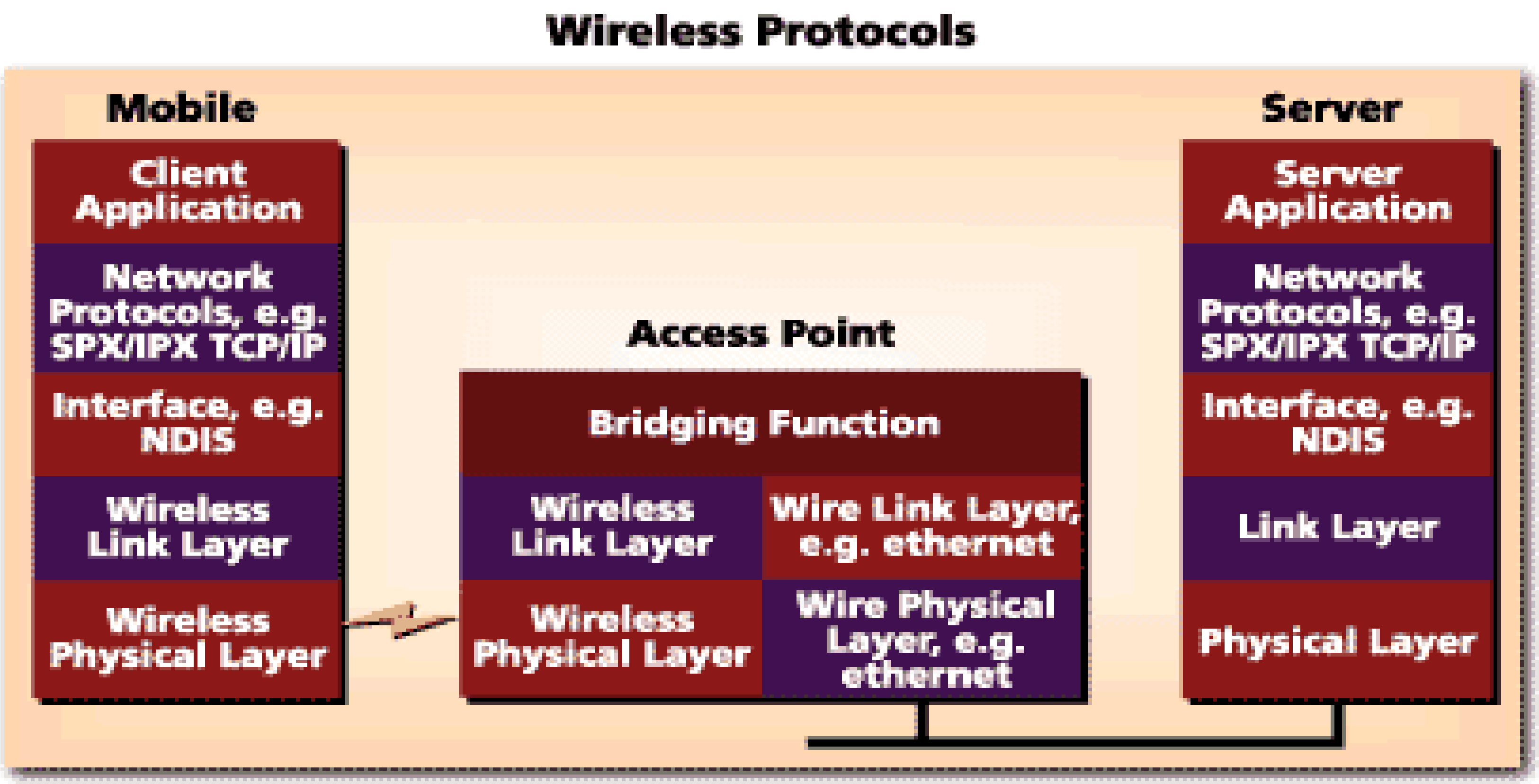
Data Link Layer:

- Uses **C**arriers-**S**ense-**M**ultiple-**A**ccess with **C**ollision **A**voidance (CSMA/CA).

Integration With Existing Networks

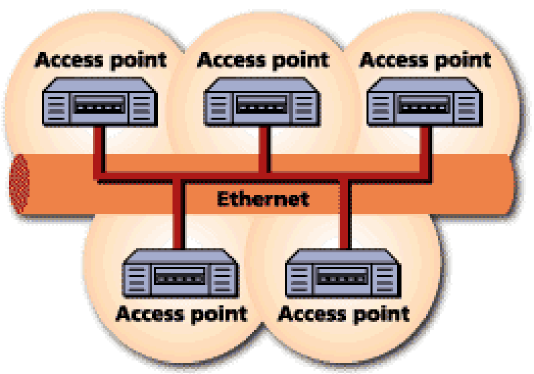
- Wireless Access Points (APs) - a small device that bridges wireless traffic to your network.
- Most access points bridge wireless LANs into Ethernet networks, but Token-Ring options are available as well.

Integration With Existing Networks



Roaming

- Users maintain a continuous connection as they roam from one physical area to another
- Mobile nodes automatically register with the new access point.
- Methods: DHCP, Mobile IP
- IEEE 802.11 standard does not address roaming, you may need to purchase equipment from one vendor if your users need to roam from one access point to another.



Security

- The IEEE 802.11 standard specifies optional security called "**W**ired **E**quivalent **P**rivacy" whose goal is that a wireless LAN offer privacy equivalent to that offered by a wired LAN. The standard also specifies optional authentication measures.
- In theory, spread spectrum radio signals are inherently difficult to decipher without knowing

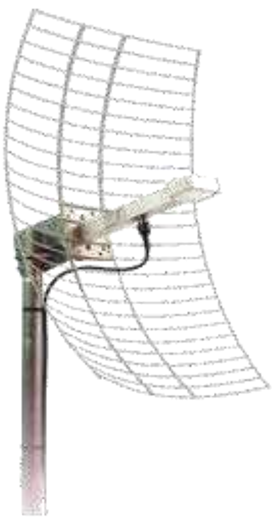
Interoperability

- **Before** the IEEE 802.11 interoperability was based on cooperation between vendors.
- **IEEE** 802.11 only standardizes the physical and medium access control layers.
- Vendors must still work with each other to ensure their IEEE 802.11 implementations interoperate
- Wireless Ethernet Compatibility Alliance (WECA) introduces the Wi-Fi Certification to ensure cross- vendor interoperability of 802.11b solutions

Hardware

- PC Card, either with integral antenna or with external antenna/RF module.
- ISA Card with external antenna connected by cable.
- Handheld terminals
- Access points

Hardware



Performance

- **802.11a** offers speeds with a theoretically maximum rate of 54Mbps in the 5 GHz band
- **802.11b** offers speeds with a theoretically maximum rate of 11Mbps at in the 2.4 GHz spectrum band
- **802.11g** is a new standard for data rates of up to a theoretical maximum of 54 Mbps at 2.4 GHz.

What is 802.11?

- A family of wireless LAN (WLAN) specifications developed by a working group at the Institute of Electrical and Electronic Engineers (IEEE)
- Defines standard for WLANs using the following four technologies
  - Frequency Hopping Spread Spectrum (FHSS)
  - Direct Sequence Spread Spectrum (DSSS)
  - Infrared (IR)
  - Orthogonal Frequency Division Multiplexing (OFDM)
- Versions: 802.11a, 802.11b, 802.11g, 802.11e,

Frequency Hopping Vs. Direct Sequence

- FH systems use a radio carrier that "hops" from frequency to frequency in a pattern known to both transmitter and receiver
  - Easy to implement
  - Resistance to noise
  - Limited throughput (2-3 Mbps @ 2.4 GHz)
- DS systems use a carrier that remains fixed to a specific frequency band.
- The data signal is spread onto a much larger range of frequencies (at a much lower power level) using a specific encoding scheme.
  - Much higher throughput than FH (11 Mbps)
  - Better range

802.11a

- Employs Orthogonal Frequency Division Multiplexing (OFDM)
- Offers higher bandwidth than that of 802.11b, DSSS(Direct Sequence Spread Spectrum)
- 802.11a MAC (Media Access Control) is same as 802.11b
- Operates in the 5 GHz range

802.11a

- 5 GHz band is 300 MHz (vs. 83.5 MHz @ 2.4 GHz)
- More data can travel over a smaller amount of bandwidth
- High speed
- Up to 54 Mbps
- Less interference
- Fewer products using the frequency
- 2.4 GHz band shared by cordless phones, microwave ovens, Bluetooth, and WLANs

802.11a Advantages

- 5 GHz band is 300 MHz (vs. 83.5 MHz @ 2.4 GHz)
- More data can travel over a smaller amount of bandwidth
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- 2.4 GHz band shared by cordless phones, microwave ovens, Bluetooth, and WLANs

802.11a Disadvantages

- Standards and Interoperability
  - Standard not accepted worldwide
  - No interoperability certification available for 802.11a products
  - Not compatible or interoperable with 802.11b
  - Legal issues
  - License-free spectrum in 5 GHz band not available worldwide Market beyond LAN-LAN bridging, there is limited interest for 5 GHz adoption

802.11a Disadvantages

- Building-to-building connections
- Video, audio conferencing/streaming video, and audio
- Large file transfers, such as engineering CAD drawings
- Faster Web access and browsing
- High worker density or high throughput scenarios
- Numerous PCs running graphics-intensive applications

802.11a Applications

- Building-to-building connections
- Video, audio conferencing/streaming video, and audio
- Large file transfers, such as engineering CAD drawings
- Faster Web access and browsing
- High worker density or high throughput scenarios
- Numerous PCs running graphics-intensive applications

802.11e Introduces Quality of Service

- Also know as P802.11 T
- To enhance the 802.11 Medium Access Control (MAC) to improve and manage Quality of Service (QOS)
- Cannot be supported in current chip design
- Requires new radio chips
- Can do basic QOS in MAC layer

802.11f – Inter Access Point Protocol

- Also know as P802.11

- Purpose:

  - To develop a set of requirements for Inter-Access Point Protocol (IAPP), including operational and management aspects Point Protocol (IAPP), including operational and management aspects.

802.11b Security Features

- Wired Equivalent Privacy (**WEP**) – A protocol to protect link-level data during wireless transmission between clients and access points.
- Services:
  - **Authentication**: provides access control to the network by denying access to client stations that fail to authenticate properly.
  - **Confidentiality**: intends to prevent information compromise from casual eavesdropping
  - **Integrity**: prevents messages from being modified while in transit between the wireless client and the access point.