Wireless and Mobile Communication

by
Sunandita Debnath

Assistant Professor, Department of ECE

Introduction to wireless and mobile communication

Wireless communication is basically transmitting and receiving voice and data using electromagnetic waves in open space. A wireless communication network consists of a large number users in the region of interest or cells connecting to a base station or transceiver system.

Why Wireless communication ?

- Free from wires
- Easy installation
- Low installation cost
- Communication can reach where wiring is infeasible or costly
- Stay connected, flexibility to connect multiple devices

Types of Wireless communication:

- Mobile (Cellular Phones)
- Portable (Wi Fi)
- Fixed (WirelessMAN)

Application includes:

- Voice and data communication (GSM 900)
- Emergency services e.g. Military surveillance (GSM 1800)

GSM (Global system for mobile communication)

GSM uses digital technology and TDMA (Time Division Multiple Access). It uses 2.4 GHz ISM (Industrial, scientific and medical radio bands) band. It is not a only frequency, it is a band of frequencies.

Challenges:

- Network support for user mobility e.g. location identification, handover
- Maintaining QoS (quality of service) over unreliable links.
- Connectivity and Coverage
- Cost efficiency

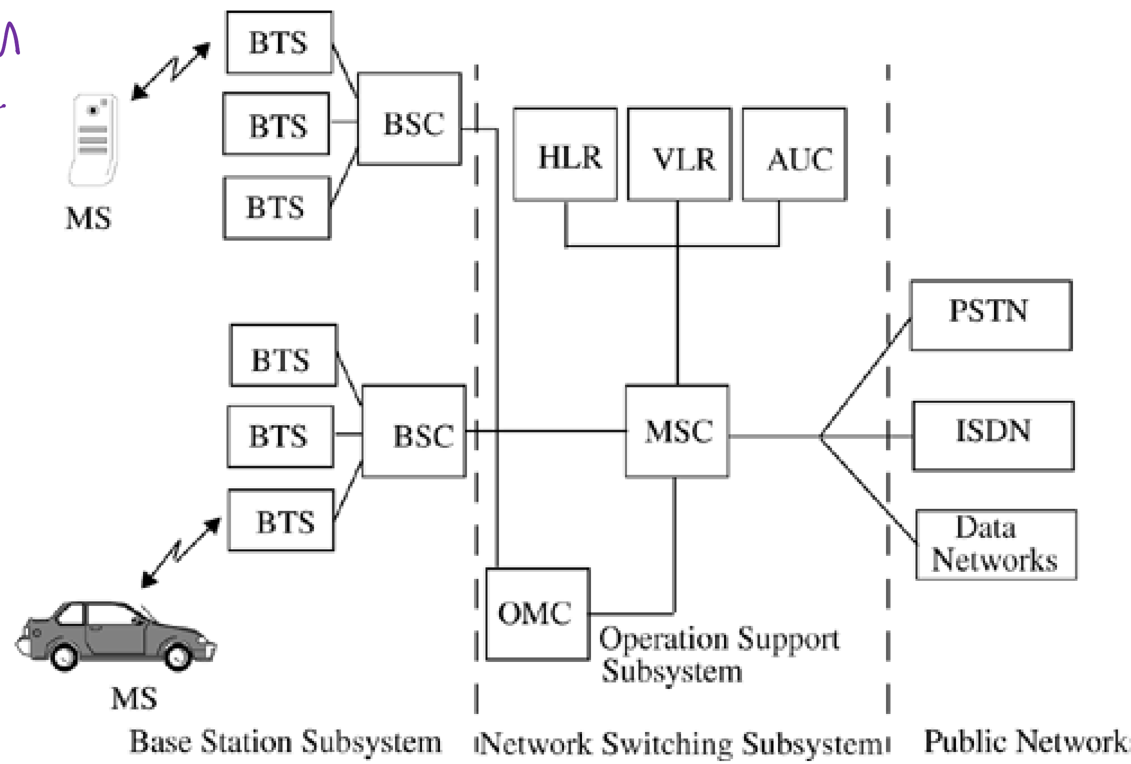
Frequency Reuse:

Need of frequency reuse?

How frequencies are reused?

GSM Architecture (Global System For Mobile Communication)

2G
900-GSM
1800-GSM



MS = Mobile Station

BTS = Base Transceiver System

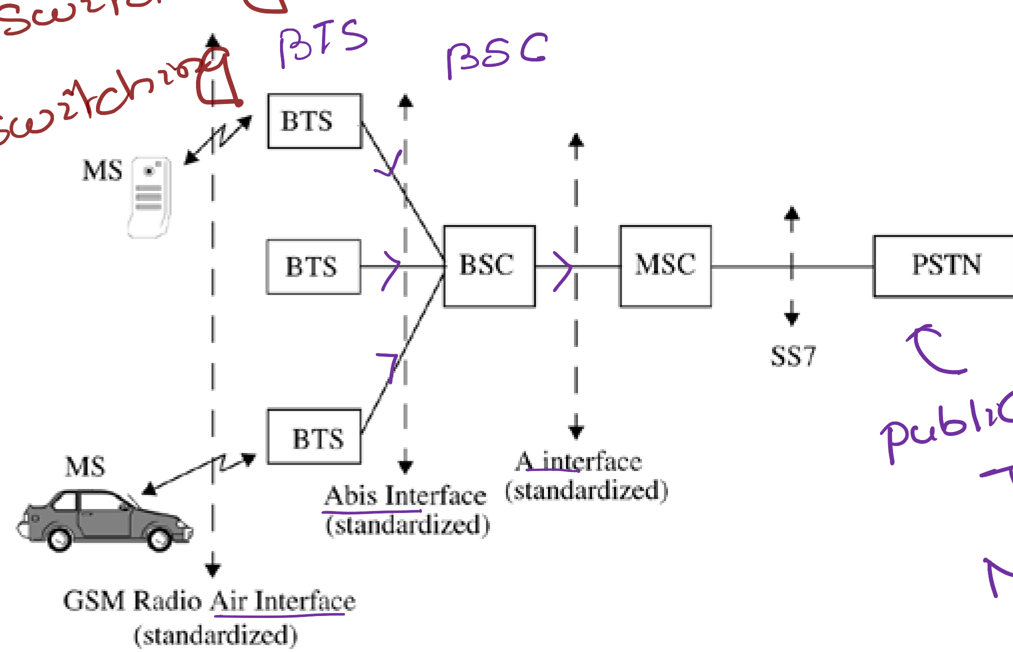
BSC = Base Station Controller

MSC =Mobile Switching Center

PSTN = Public Switched Telephone Network

→ Circuit Switching →

→ Packet Switching



Public Switched Telephone Network

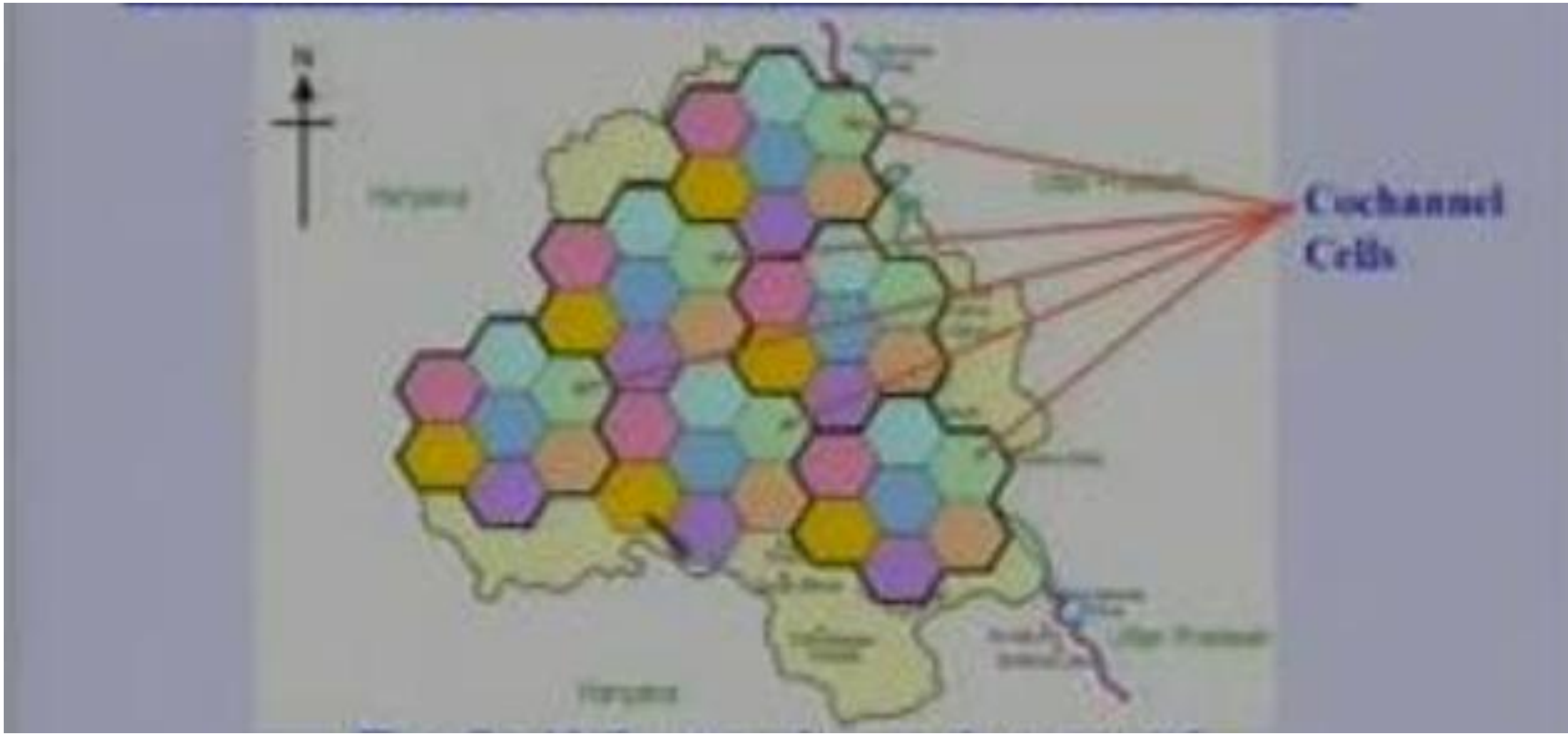
The A interface uses an SS7 protocol called the Signaling Correction Control Part (SCCP) which supports communication between the MSC and the BSS.

GSM originally used two 25 MHz cellular bands set aside for all member countries, but now it is used globally in many bands.

The 890–915 MHz band was for subscriber-to-base transmissions (reverse link), and the 935–960 MHz band was for base-to-subscriber transmissions (forward link).

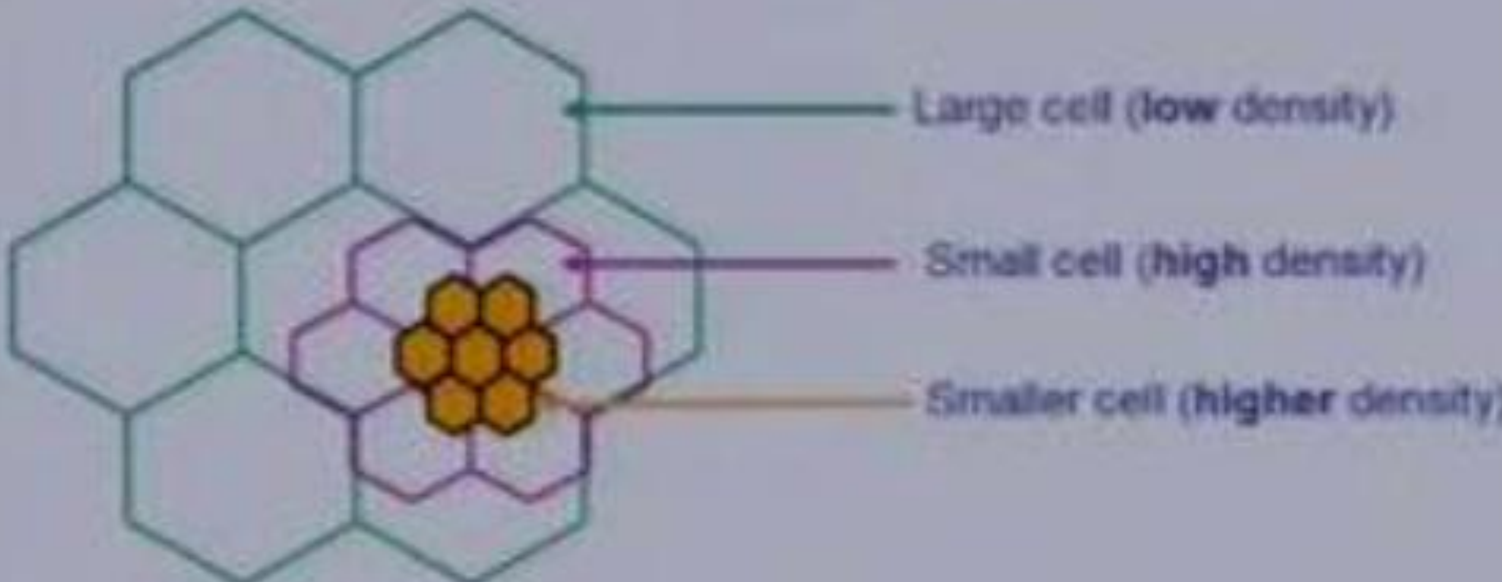
➢

Frequency Reuse



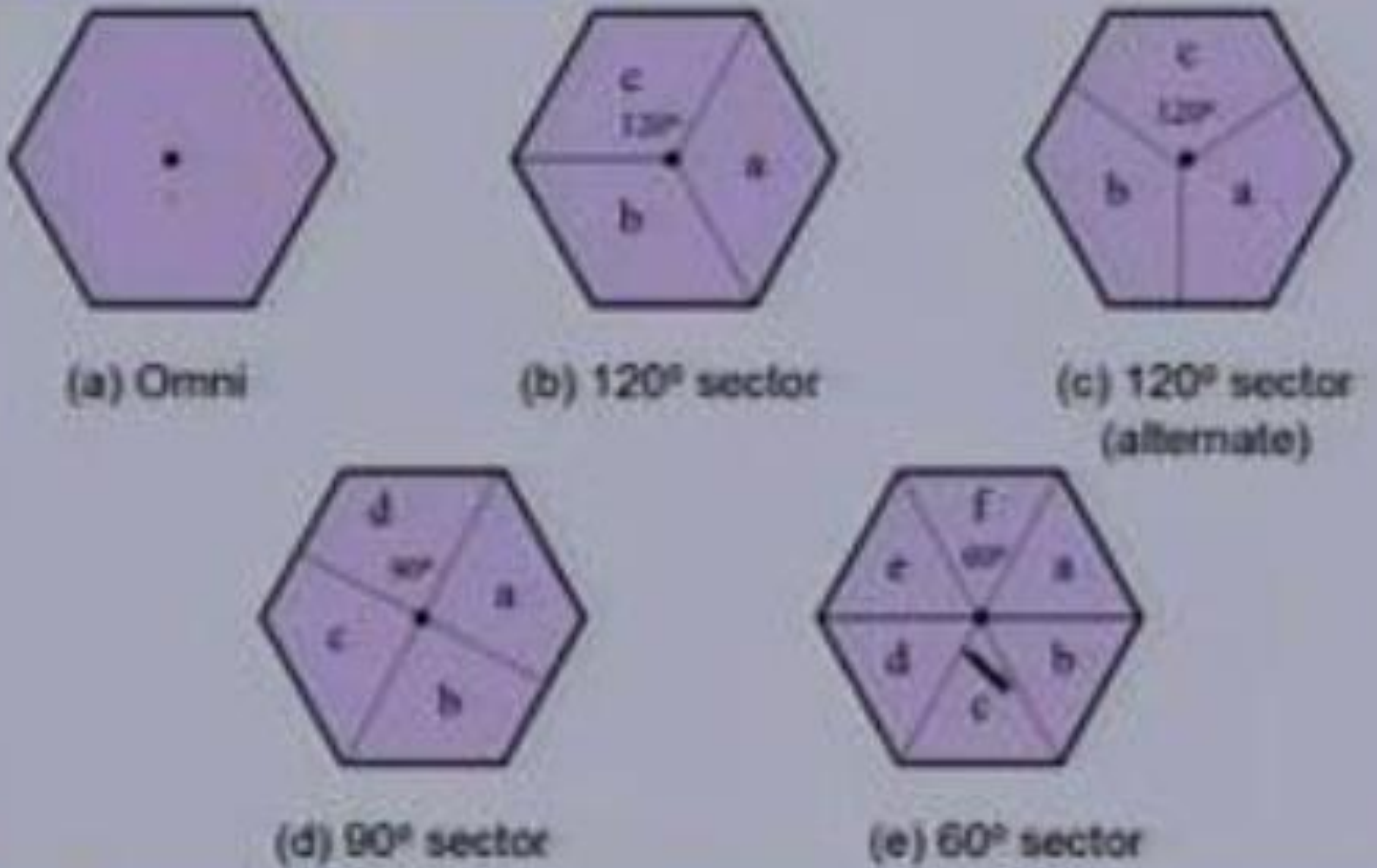
The cells with same colour use the same set of frequencies. The cell cluster is outlined in bold lines. Here the cluster size N =7.

Cell Splitting (2)

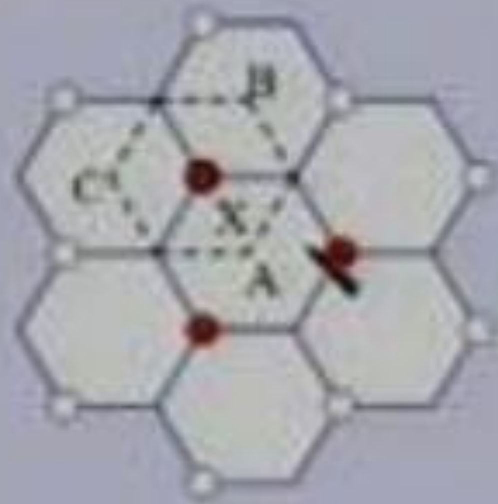


- Cells are split to add channels with **no new** spectrum usage.
- Depending on traffic patterns the smaller cells may be **activated/deactivated** in order to efficiently use cell resources.

Cell Sectoring (3)



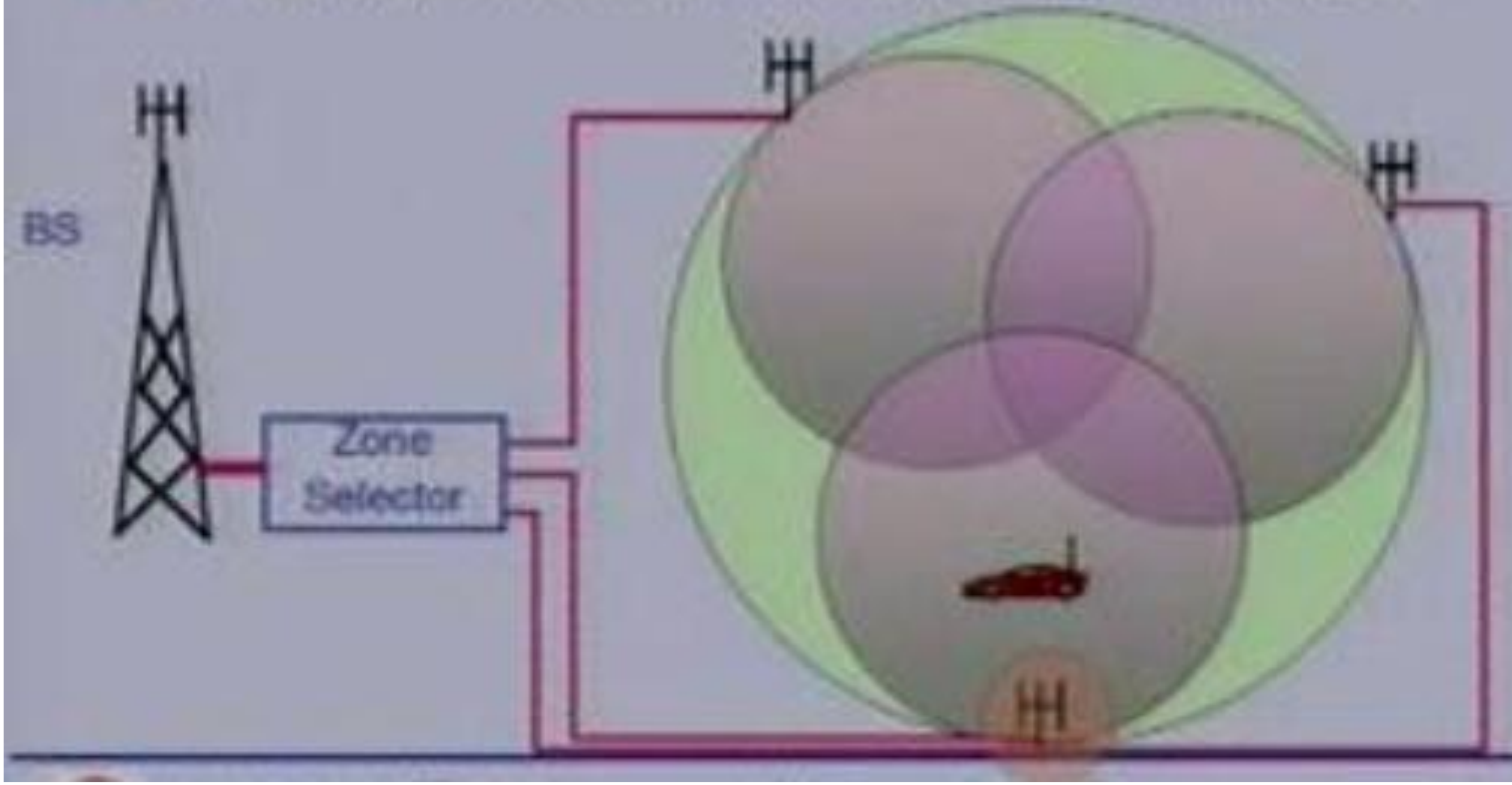
- Placing directional transmitters at corners where three adjacent cells meet



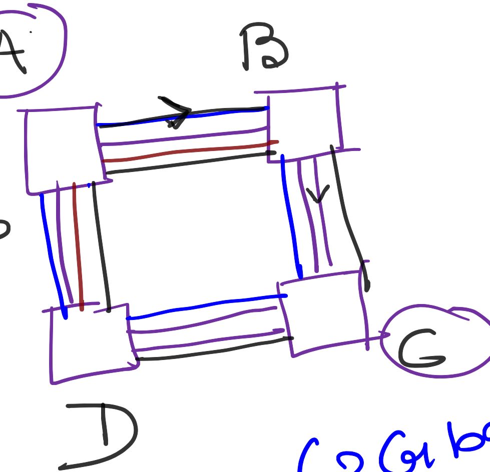
Sectoring improves *S/I*

Microcell Zone Concept (2)

- Let each cell be divided into three zones.



Circuit Switching and Packet Switching



- **Circuit Switching (FDM and TDM)** landline phones

GSM

Circuit Establishment

Data Transfer

Circuit Disconnect/termination

Limitations:

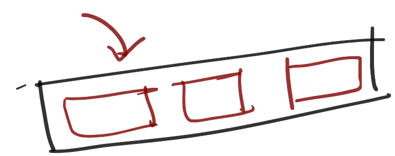
Circuiting Switching → GSM (2G band)

GPRS (2.5 G)

Dedicated paths

Line utilization is very low

Provide facility for data transmissions at a constant rate (data transmission pattern may not ensure this, Limits the utility of the method)



Internet acess

- **Packet Switching** → GPRS

Data are transmitted in short packets

A longer message is broken up into a series of packets

Every packet contains some control information (Header, Source address, Destination address, Sequence Number)

Three basic propagation mechanism

- Reflection

Occurs when a propagation EM wave impinges upon an object which has very large dimension compared when compared to the wavelength of the propagating wave. Reflection occurs from the surface of the earth and from buildings and walls.

- Diffraction

Occurs when the radio path between the Tx and Rx is obstructed by a surface that has sharp edges. At high frequencies, diffraction, like reflection depends on the geometry of the objects, as well as the amplitude, phase & polarization of the incident wave at the point of diffraction.

- Scattering

Three Occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength, and where the numbers of obstacles per unit volume is large. Scattered waves are produced by large, small objects or by other irregularities in the channel.

Fading

Fading: rapid fluctuations of received signal strength over short period of time /or travel distances. The rapid fluctuation is in essence of

- Amplitudes
- Phases
- Multipath delays

Three most important effects:

1. Rapid changes in signal strengths over small travel distances or short time periods.
2. Changes in the frequency of signals.
3. Multiple signals arriving at different times. When added together at the antenna, signals are spread out in time. This can causes spreading of the signal and interference between bits that are received.

- Even when a mobile receiver is static, the received signal may fade due to movement of surrounding objects in the radio channel.

Physical Factors Influencing Fading in Mobile Radio Channel

1) **Multipath Propagation**

- time delay of signal arrival
  - large path length differences → large differences in delay between signals
- urban area where many buildings distributed over large spatial scale
  - large number of strong multipath signals with only a few having a large time delay
- suburb with nearby office park or shopping mall
  - moderate number of strong multipath signals with small to moderate delay times
- rural → few multipath signals (LOS + ground reflection)

2) Speed of Mobile

- relative motion between base station & mobile causes random frequency modulation due to Doppler shift (f_d)
- Different multipath components may have different frequency shifts.

3) **Speed of Surrounding Objects**

- also influence Doppler shifts on multipath signals
- dominates small-scale fading if speed of objects > mobile speed

  otherwise ignored

4) **Transmission bandwidth of the signal:**

- relative motion between base station & mobile causes random frequency modulation due to Doppler shift (f_d)
- Different multipath components may have different frequency shifts.

Doppler Shift

- motion causes frequency modulation due to Doppler shift (f_d)

$$\Delta\phi = \frac{2\pi\Delta l}{\lambda} = \frac{2\pi v\Delta t}{\lambda}\cos\theta$$

$$f_d = \frac{1}{2\pi}\cdot\frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda}\cdot\cos\theta$$

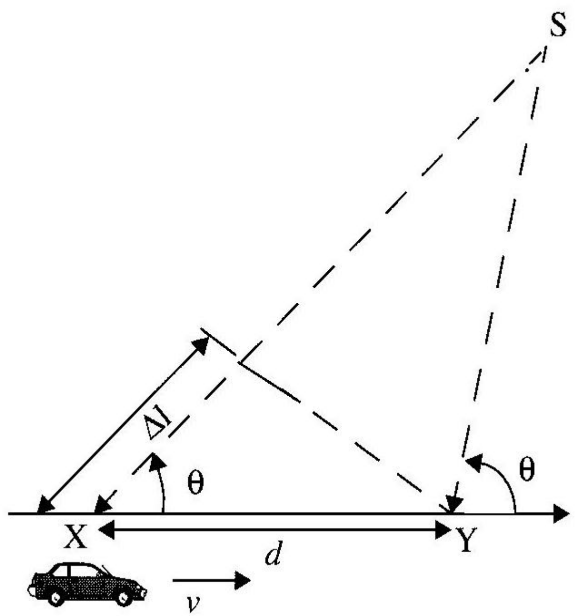


Figure 5.1 Illustration of Doppler effect.

- v : velocity (m/s)
- λ : wavelength (m)
- θ : angle between

  mobile direction

  and arrival direction of RF energy
  - + shift → mobile moving toward S
  - − shift → mobile moving away from S

Coherence Bandwidth (BW)

Coherence bandwidth is a statistical measure of the range of frequencies over which the channel passes all spectral component with approximately equal gain and linear phase.

- BW : statistical measure of frequency range where mobile radio channel response is flat
  - Channel response is flat = passes all frequencies with ≈ equal gain & linear phase
  - amplitudes of different frequency components are correlated
  - if two sinusoids have frequency separation greater than *B*W, they are affected quite differently by the channel

Small-Scale Fading
(Based on multipath time delay spread)

Flat Fading
1. BW of signal < BW of channel
2. Delay spread < Symbol period

Frequency Selective Fading
1. BW of 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 slower than baseband signal variations

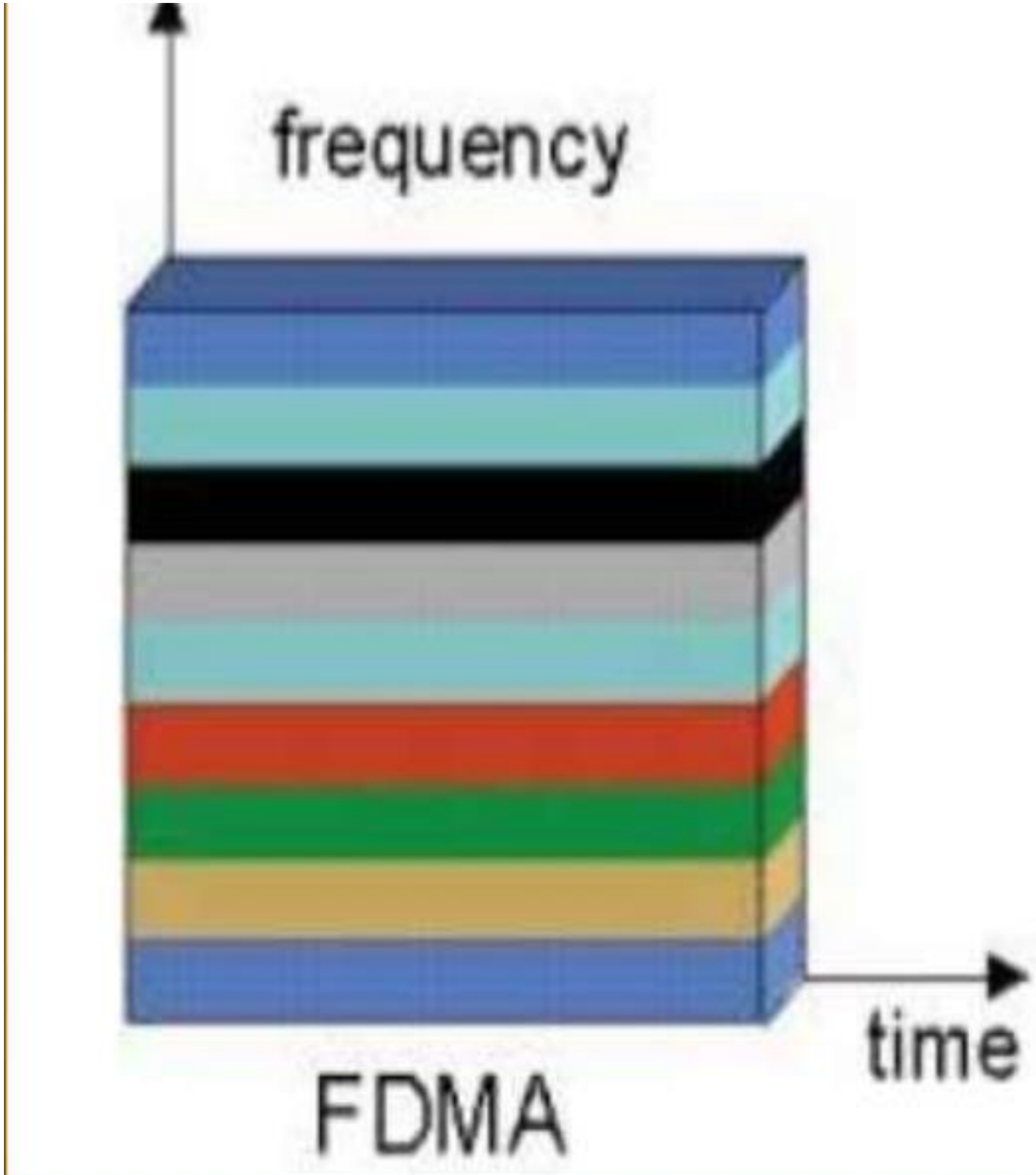
Figure 5.11 Types of small-scale fading.

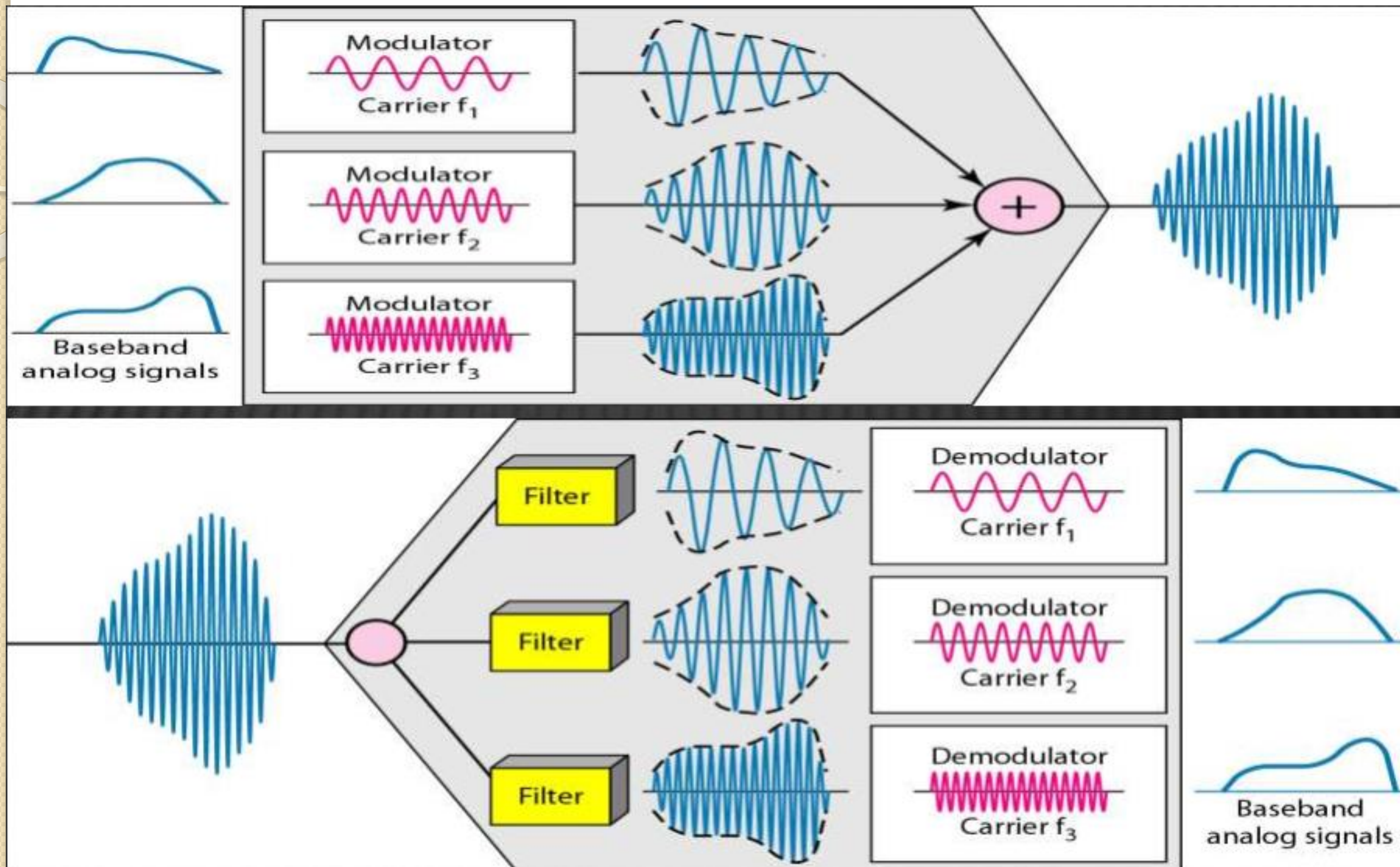
Multiple Access Techniques

Multiple access techniques are used to allow a large number of mobile users to share the allocated spectrum in the most efficient manner. As the spectrum is limited, so the sharing is required to increase the capacity of cell or over a geographical area by allowing the available bandwidth to be used at the same time by different users.

1) Frequency division multiple-access (FDMA)
2) Time division multiple-access (TDMA)
3) Code division multiple-access (CDMA)

FDMA enables multiple users to share the same physical channel for concurrent communication. It gives users an individual allocation of one or several frequency bands, or channels. If an FDMA channel is not in use, then it sits idle and it cannot be used by other users to increase share capacity.


frequency
time
FDMA


Modulator
Carrier f_1
Modulator
Carrier f_2
Modulator
Carrier f_3
Baseband analog signals
Filter
Filter
Filter
Demodulator
Carrier f_1
Demodulator
Carrier f_2
Demodulator
Carrier f_3
Baseband analog signals

Application of FDMA

Mobile communication systems and Satellite communication

Disadvantage

Crosstalk may cause interference among frequencies and disrupt the transmission.

Guard bands lead to a waste of capacity.

Difference between FDMA and FDM (Frequency division multiplexing)

1. FDM is a physical layer multiplexing technique, while FDMA is a data link layer access method.
2. Using FDM to allow multiple users to utilize the same bandwidth is called FDMA.
3. FDM uses a physical multiplexer, while FDMA does not.

TDMA

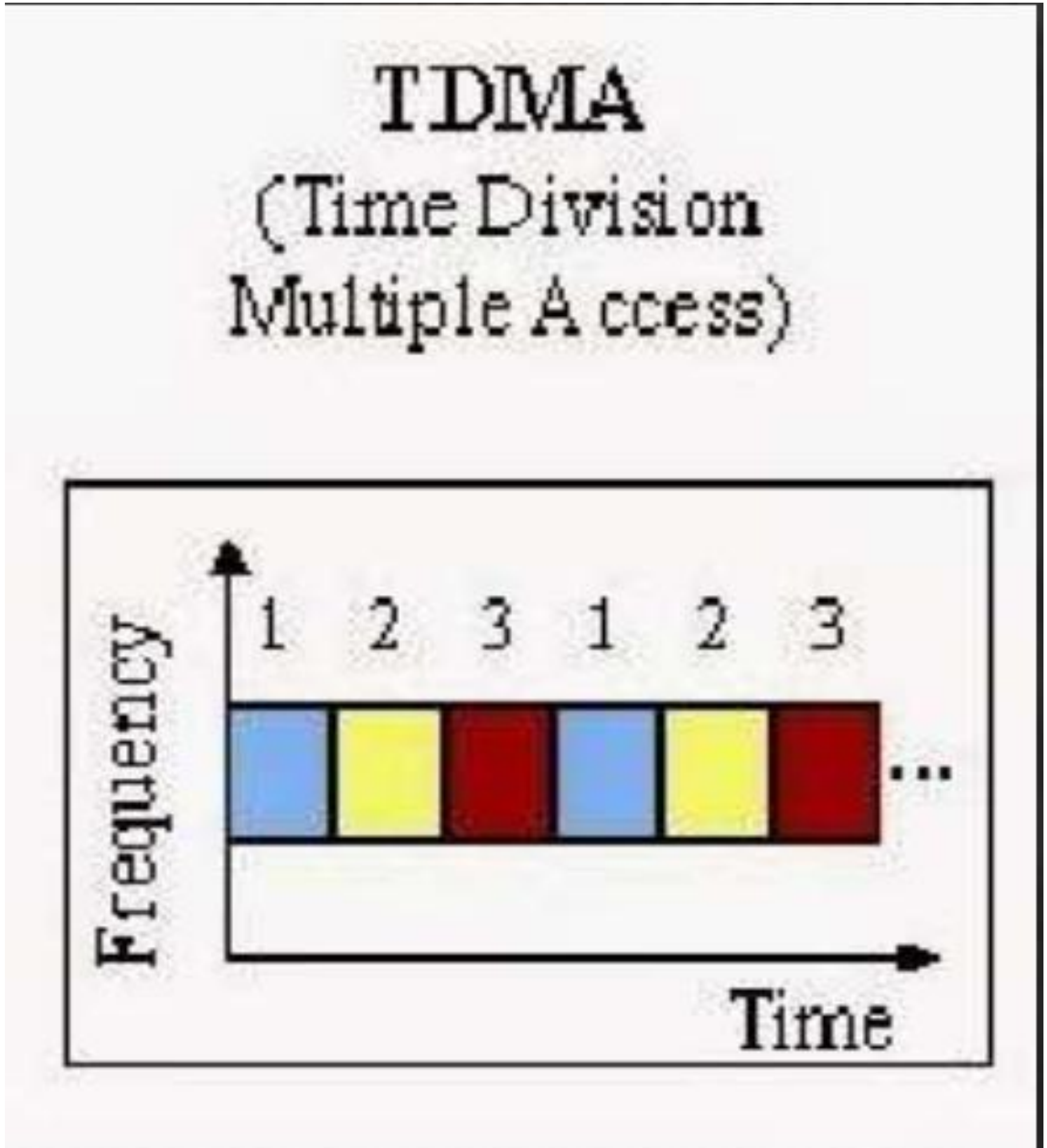
In digital systems, continuous transmission is not required because users do not use the allotted bandwidth all the time. In such cases, TDMA is a complimentary access technique to FDMA. Global Systems for Mobile communications (GSM) uses the TDMA technique. In TDMA, the entire bandwidth is available to the user but only for a finite period of time. TDMA requires careful time synchronization since users share the bandwidth in the frequency domain. The number of channels are less, inter channel interference is almost negligible. TDMA uses different time slots for transmission and reception. This type of duplexing is referred to as Time division duplexing (TDD).

Application of TDMA

GSM, passive optical networks and Satellite systems

Disadvantage

- The high data rates of broadband systems require complex equalization.
- Due to the burst mode, a large number of additional bits for synchronization and supervision are needed.
- Complex signal processing is required to synchronize within short slot.


TDMA
(Time Division
Multiple Access)
Frequency
1 2 3 1 2 3
...
Time

CDMA

In CDMA, the same bandwidth is occupied by all the users, however they are all assigned separate codes, which differentiates them from each other CDMA utilize a spread spectrum technique in which a spreading signal (which is uncorrelated to the signal and has a large bandwidth) is used to spread the narrow band message signal. The principle of Spread Spectrum is used to work with CDMA. Spread signal is below the noise level and noise has no effect on the signal. CDMA is not a frequency specific to each user, instead, every channel uses the full available spectrum.

Types of CDMA

DS-CDMA (Direct sequence)

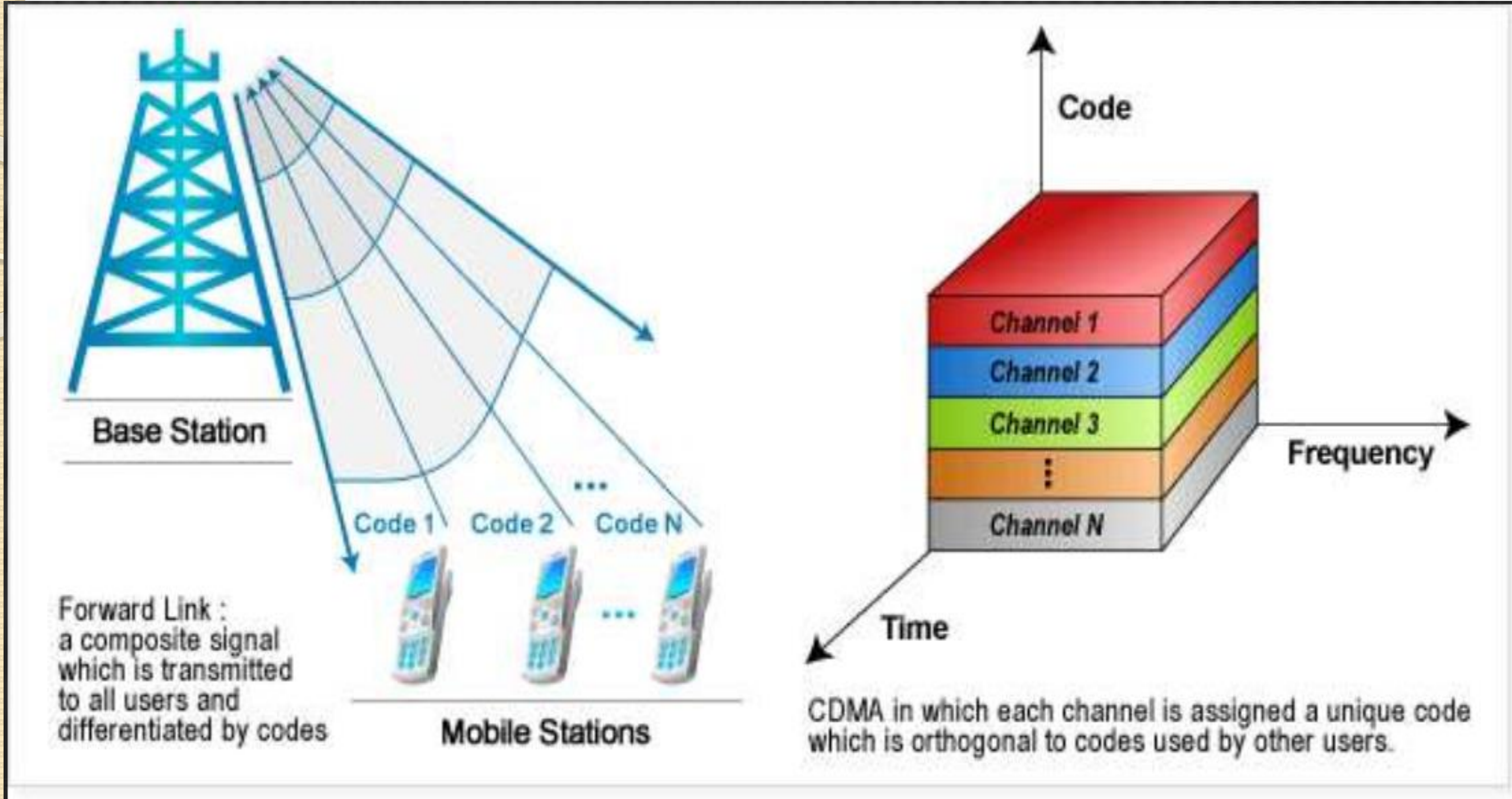
FH-CDMA (Frequency Hoping)

Application of CDMA

GSM, passive optical networks and Satellite systems

Disadvantage

Near Far problem: The near-far problem is a serious one in CDMA. This problem arises from the fact that signals closer to the receiver of interest are received with smaller attenuation than are signals located further away. Therefore the strong signal from the nearby transmitter will mask the weak signal from the remote transmitter.



Base Station
Code 1
Code 2
Code N
Forward Link :
a composite signal
which is transmitted
to all users and
differentiated by codes
Mobile Stations
Code
Channel 1
Channel 2
Channel 3
Channel N
Frequency
Time
CDMA in which each channel is assigned a unique code
which is orthogonal to codes used by other users.

Disadvantage

Self interference problem: In CDMA, self-interference arises from the presence of delayed replicas of signal due to multipath. The delays cause the spreading sequences of the different users to lose their orthogonality, as by design they are orthogonal only at zero phase offset. Hence in despreading a given user's waveform, nonzero contributions to that user's signal arise from the transmissions of the other users in the network.

PN Sequence

The pseudorandom number (PN) sequence, which spreads the signal, is the key element to get these good properties of the SS system. PN generator produces periodic sequence that appears to be random.

PN Sequence

- PN generator produces periodic sequence that appears to be random
- PN Sequences
  - Generated by an algorithm using initial seed
  - The algorithm is deterministic
  - Sequence isn't statistically random but will pass many test of randomness
  - Sequences referred to as pseudorandom numbers or pseudonoise sequences
  - Unless algorithm and seed are known, the sequence is impractical to predict

Important Properties of PN Sequence

Randomness

Uniform distribution

Independence

Correlation property

Unpredictability

Two basic techniques to compensate fading

Equalization

Diversity: It is a technique to compensate for fading channel impairments.

Micro diversity: provides a method to mitigate the effects of multi-path fading as in case of small scale fading.

Macro diversity: provides a method to mitigate the effects of shadowing, as in case of large scale fading.

Type of diversity techniques:

Antenna/ Space Diversity

Frequency Diversity

Time Diversity

Polarization Diversity

Angle Diversity

Code Diversity

The most common diversity technique is called spatial diversity technique, where multiple antennas are strategically spaced and connected to a common receiving system. The receiver is able to select the antenna with the best signal at any time.

- **Space Diversity:** Using antennas spaced enough (at Tx or Rx).
- **Polarization Diversity:** Using antennas with different polarizations.
- **Frequency Diversity:** Using frequency channels separated in frequency more than the channel coherence bandwidth.
- **Time Diversity:** Using time slots separated in time more than the channel coherence time.

Types of space Diversity reception methods

Selection Diversity

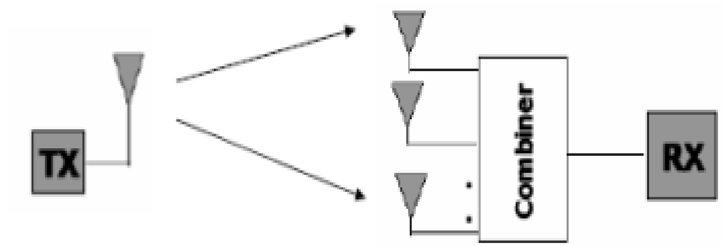
Feedback / Scanning Diversity

Maximal Ratio Combining (MRC)

Equal gain Diversity

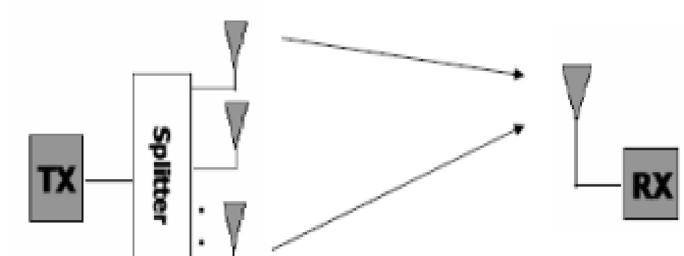
None Diversity

Single Input Single Output (SISO)



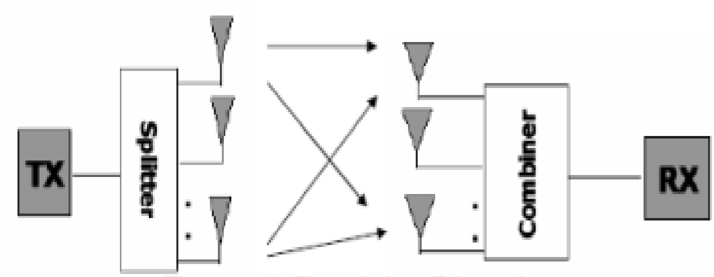
Receiving Diversity

Single Input Multi Output (SIMO)



Transmit Diversity

Multi Input Single Output (MISO)



Transmit/Receiving Diversity

Multi Input Multi Output (MIMO)

Use more than one antenna at the receiver

Need for Equalization

- It is used for compensating Inter symbol interference (ISI)
- An equalizer within a receiver compensates for the average range of expected channel amplitude and delay characteristics.
- A equalizer must be adaptive as the channel is generally unknown and time varying.

Why adaptive Equalizer

Linear equalizer: The output of the decision maker is not used in the feedback path to adapt the equalizer.

Nonlinear equalizer: The output of the decision maker is used in the feedback path to adapt the equalizer.

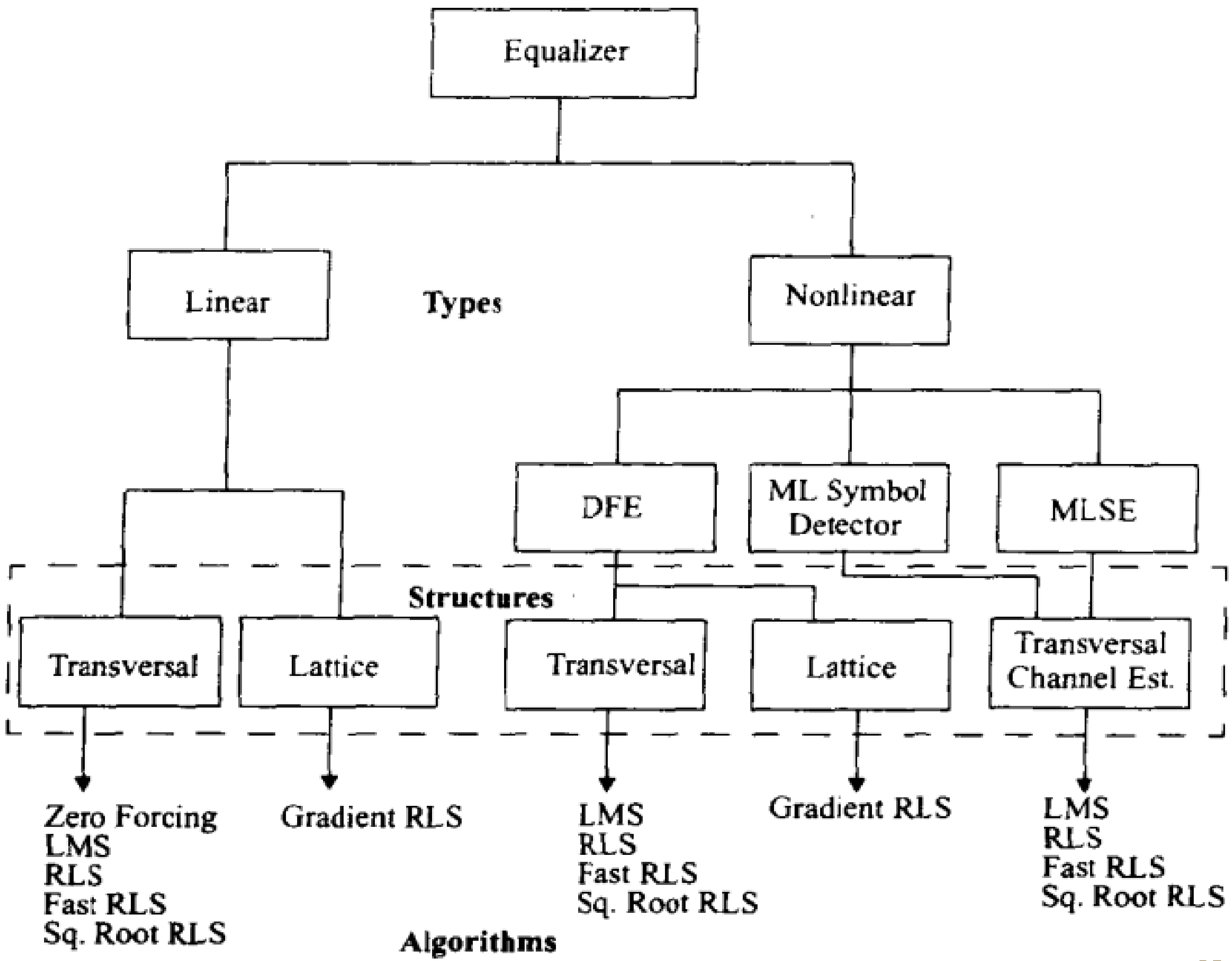
Types of Nonlinear equalizer:

Decision feedback equalization (DFE)

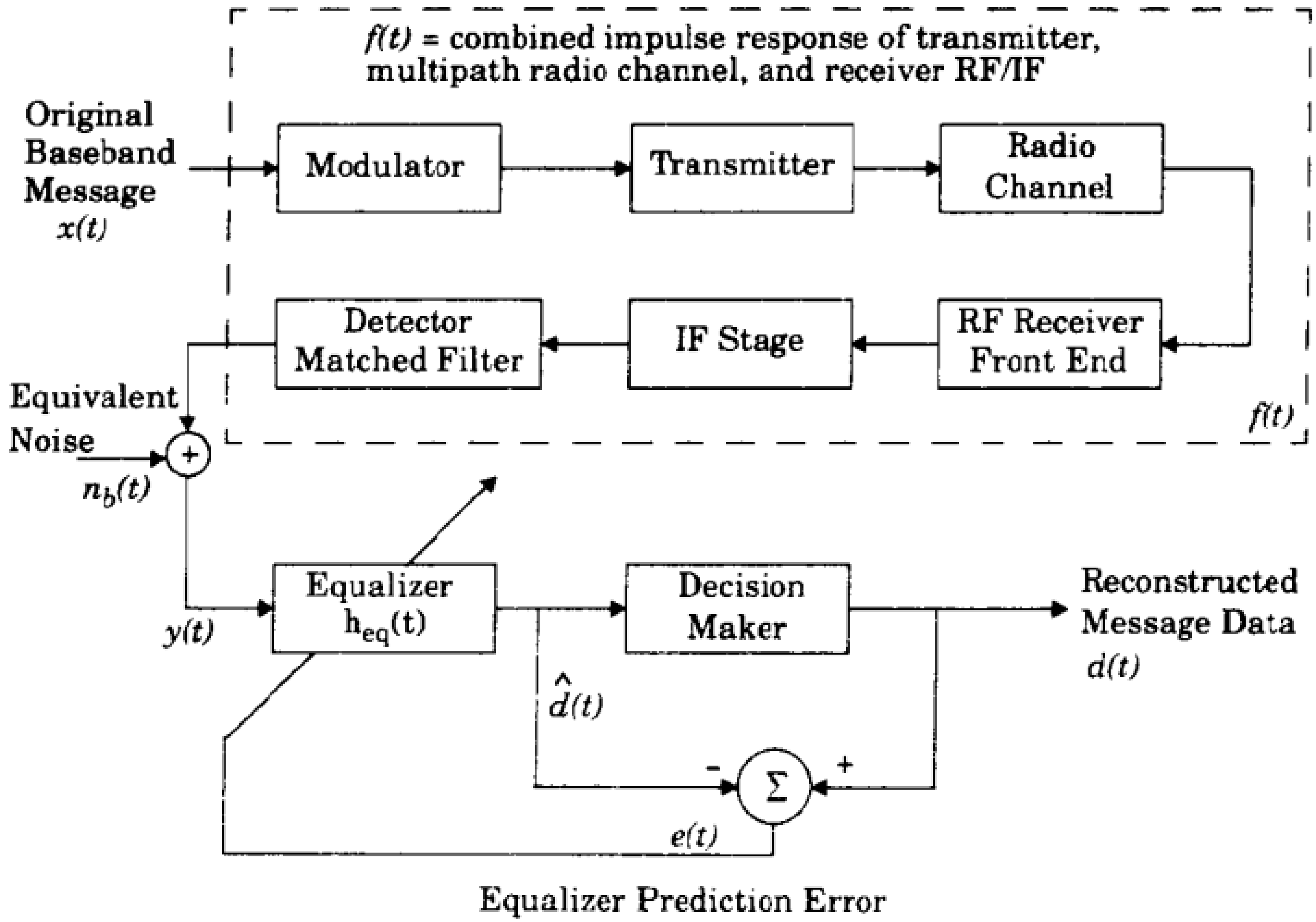
Maximal Likelihood Symbol Detection

Maximal Likelihood Sequence Estimation

Survey of Equalization Techniques



Block diagram of Adaptive Equalizer



Adaptive Equalization

The two operating modes of an adaptive equalizers are

- **training mode**
- **tracking mode**

Training Mode: In the training mode we have to send a known sequence or a PN sequence in order to understand how the channel is, it's basically a method to measure the frequency response and then fix a weights accordingly in order to overcome the effects of channel and then is a tracking mode. If a channel changes fast then we have to resort to training mode again and then when we are happy with the estimate of the channel we you go back into the tracking mode and we keep switching between the training and the tracking mode.

- **Tracking mode:** When data of the users are received, the adaptive algorithm of the equalizer tracks the changing channel. As a result of this, the adaptive equalizer continuously changes the filter characteristics over time. Equalizers are widely used in TDMA systems.

Algorithm for Adaptive Equalization

Zero forcing (ZF) Algorithm

Least mean square (LMS) Algorithm

Recursive least square (RLS) Algorithm

Zero forcing (ZF) Algorithm

Equalizer coefficients Cn are selected so as to force the samples of the combined channel and the equalizer response to zero at all but one of NT spaced sample points in a tapped delay line. It means it is trying to stimulate the Nyquist's condition where in other than its own sampling instance for all other instances it is forcing the value of the symbols to be zero.

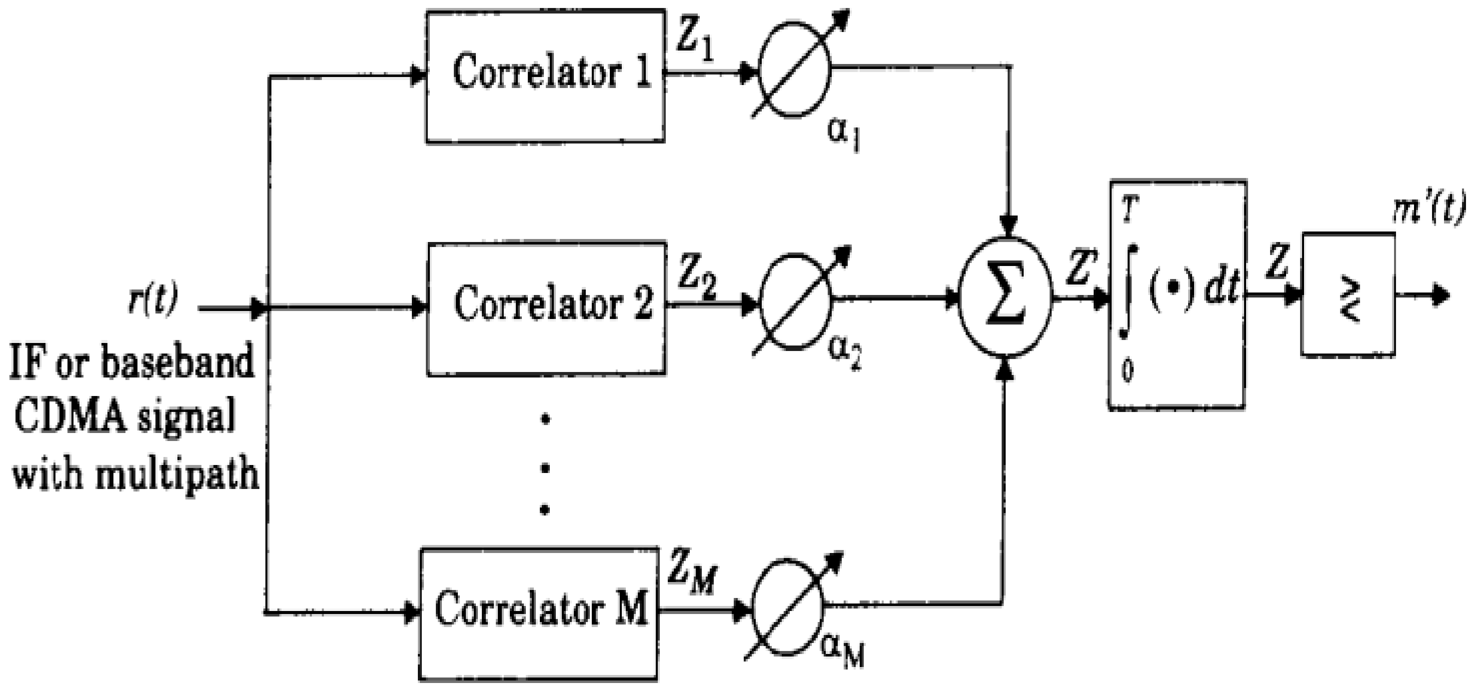
$$H_{ch}(f) H_{eq}(f) = 1, \; |f| < 1/2T$$

Disadvantage:

The H_{ch} channel is inverse to H_{eq} equalizer, the inverse filter may excessively amplify noise at frequencies where folded channel spectrum has high attenuation. The zero forcing algorithm is not used for wireless links except for static cases. It was originally invented for wire line applications so it is normally not used in wireless communication receivers.

Rake Receiver

Modern implementation of time diversity involves the use of RAKE receiver for spread spectrum CDMA.



GPRS (General Packet Radio Service)

General Packet Radio Service (**GPRS**) is a packet oriented mobile data standard on the 2G and 3G cellular communication network's global system for mobile communications (GSM). GPRS was established by European Telecommunications Standards Institute (ETSI). It is now maintained by the 3rd Generation Partnership Project (3GPP).

24x7 10 mins GSM → dialup → connecting (Paybill) 9.6 kbps

Key Features: Following three key features describe wireless packet data:

The always online feature - Removes the dial-up process, making applications only one click away.

An upgrade to existing systems - Operators do not have to replace their equipment; rather, GPRS is added on top of the existing infrastructure.

An integral part of future 3G systems - GPRS is the packet data core network for 3G systems EDGE and WCDMA.

Goals of GPRS: (Packet data transmission)

GPRS is the first step toward an end-to-end wireless infrastructure and has the following goals:

- Open architecture ✓
- Consistent IP services ✓
- Same infrastructure for different air interfaces ✓
- Integrated telephony and Internet infrastructure
- Leverage industry investment in IP
- Service innovation independent of infrastructure

Nokia -

MMS -

Services offered :

- SMS messaging and broadcasting
- Always on Internet access
- MMS (Multi media messaging Service)
- Push to talk over cellular

GSM ⇒ Voice comm + Data Transfer
Dial up connection

Benefits of GPRS:

Higher Data Rate: GPRS benefits the users in many ways, one of which is higher data rates in turn of shorter access times. In the typical GSM mobile, setup alone is a lengthy process and equally, rates for data permission are restrained to 9.6 kbit/s. The session establishment time offered while GPRS is in practice is lower than one second and ISDN-line data rates are up to many 10 kbit/s.

Easy Billing: GPRS packet transmission offers a more user-friendly billing than that offered by circuit switched services. In circuit switched services, billing is based on the duration of the connection. This is unsuitable for applications with bursty traffic. In contrast to this, with packet switched services, billing can be based on the amount of transmitted data. The advantage for the user is that he or she can be "online" over a long period of time but will be billed based on the transmitted data volume.

GSM

GPRS Architecture:

GPRS architecture works on the same procedure like GSM network, but, has additional entities that allow packet data transmission. This data network overlaps a 2G GSM network providing packet data transport at the rates from 9.6 to 171 kbps. Along with the packet data transport the GSM network accommodates multiple users to share the same air interface resources concurrently.

GPRS

GSM

MS

Mobile

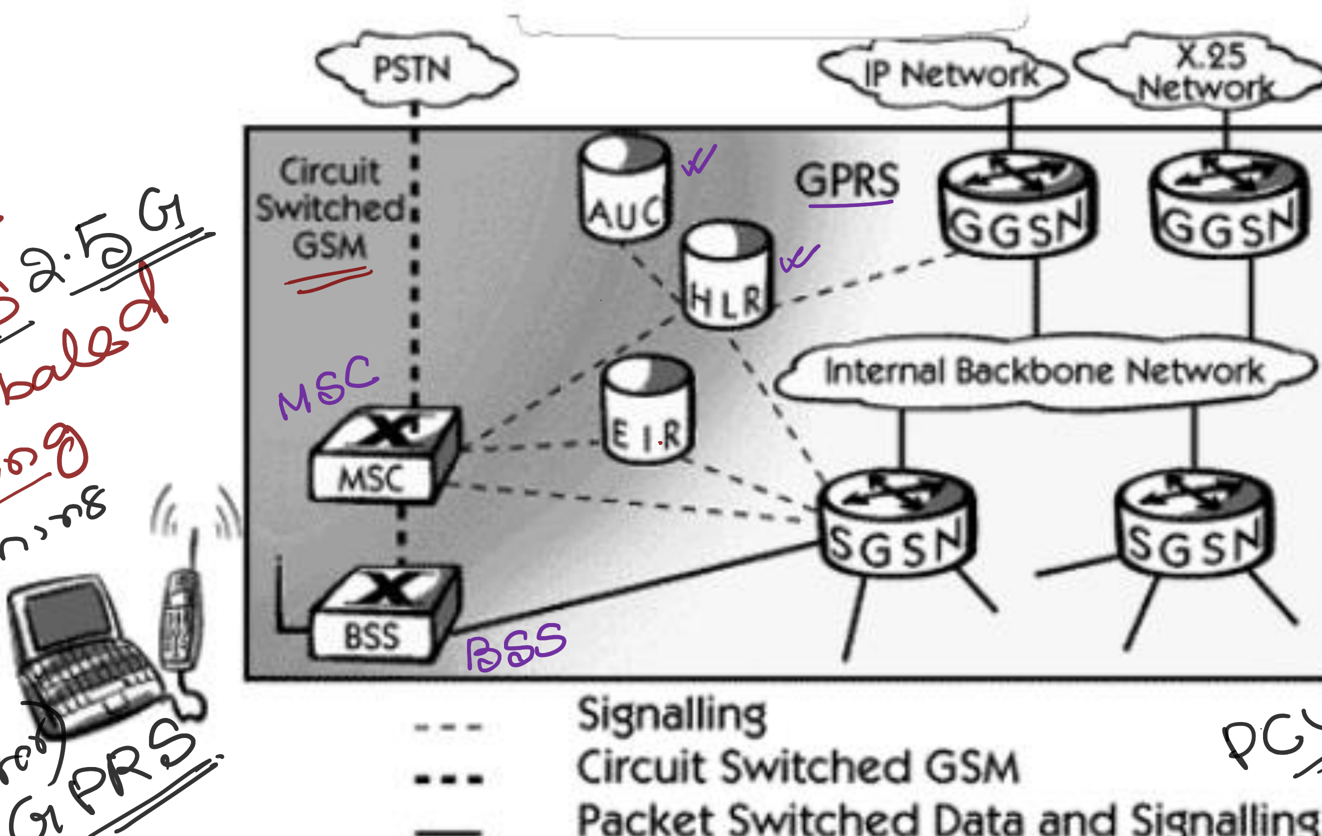
GPRS 2.5G

enbaled

Circuit switching

Packet switching (bursty data transfer)

GPRS



PCU

GPRS attempts to reuse the existing GSM network elements as much as possible, but to effectively build a packet-based mobile cellular network, some new network elements, interfaces, and protocols for handling packet traffic are required. Therefore, GPRS requires modifications to numerous GSM network elements.

SGSN = Serving GPRS Support Node

GGSN = Gateway GPRS Support Node

EIR = Equipment Identity Register

Mobile

GSM + GPRS

2G → 2.5G →

3G →

4G → 5G

- New Mobile Station is required to access GPRS services that is backward compatible with GSM for voice calls.
- Software upgrade is required at BTS and BSC. At BSC the installation of new hardware called PCU (Packet Control Unit). PCU directs the data traffic to the GPRS network and can be a separate hardware element associated with the BSC.
- All databases of HLR and VLR require software upgrades to handle the new call models and functions introduced by GPRS.

- **Internal Backbone:** The internal backbone is an IP based network used to carry packets between different GSNs (GPRS support nodes). Tunnelling is used between SGSNs and GGSNs, so the internal backbone does not need any information about domains outside the GPRS network. Signalling from a GSN to a MSC, HLR or EIR is done using SS7.
- **Routing Area:** GPRS introduces the concept of a Routing Area. This concept is similar to Location Area in GSM, except that it generally contains fewer cells. Because routing areas are smaller than location areas, less radio resources are used while broadcasting a page message.

GPRS (General Packet Radio services).

900GSM

1800GSM

Dual-band

Tri-band

2.5G

3G

UTMS (Universal Mobile Telecommunication System): UMTS

- UMTS is a 3rd generation wireless system. It is developed by 3GPP (3 Gen Partnership Project) a joint venture of several organization.
- It uses wideband code division multiple access (W-CDMA) radio access technology to offer greater spectral efficiency and bandwidth to mobile network operators.

Purpose of UTMS :

• The Dream was that 2G and 2.5G systems are incompatible around the world.

-Worldwide devices need to have multiple technologies inside of them, i.e. tri-band phones, dual-mode phones

• To develop a single standard that would be accepted around the world.

-One device should be able to work anywhere.

• Increased data rate.

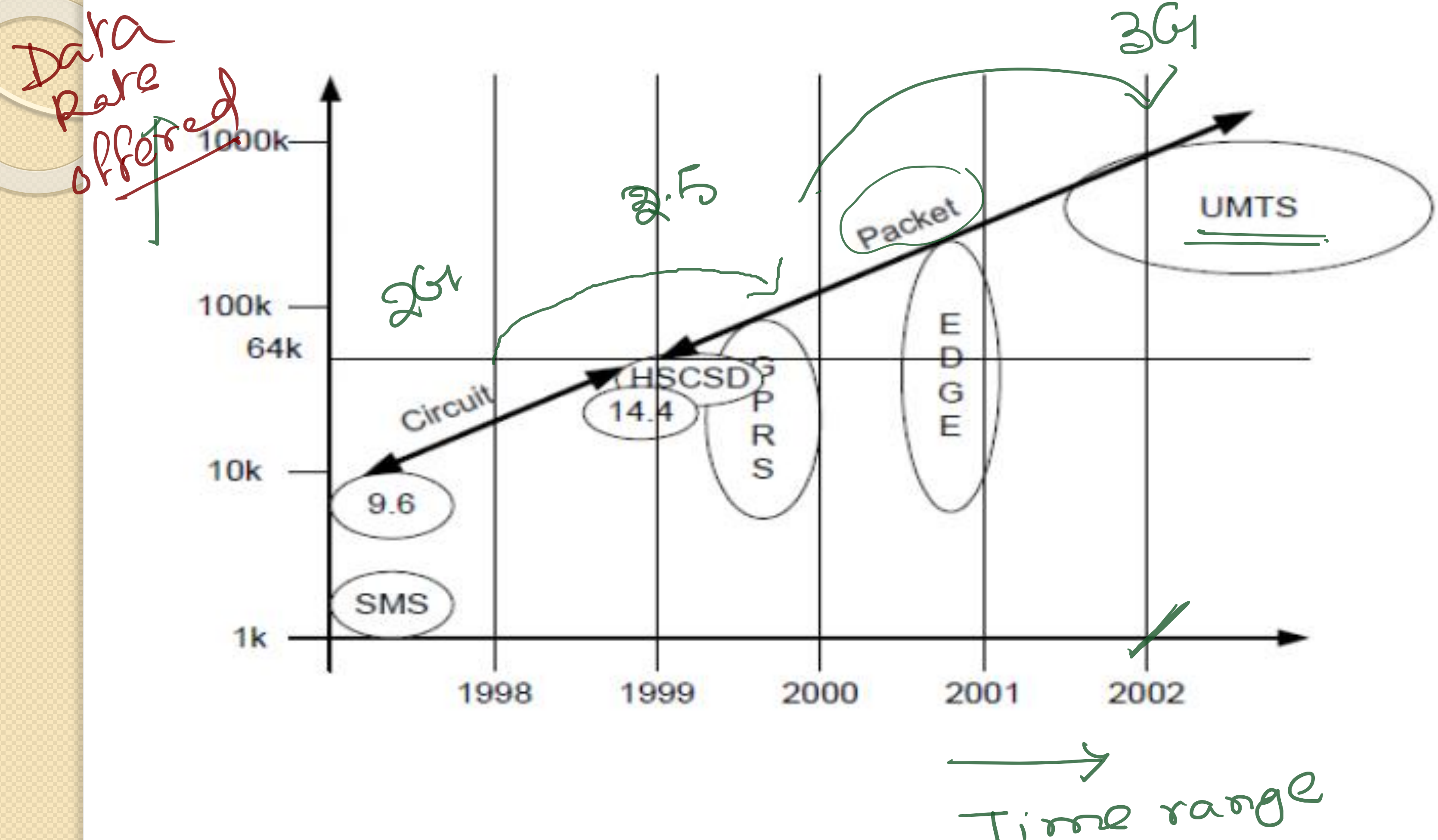
- Maximum 2048Kbps

- UMTS are intended to provide a global mobility with wide range of services including telephony, paging, messaging, Internet and broadband data
- Unlike EDGE and CDMA2000, UMTS requires new base stations and new frequency allocations.

Disadvantage:

The major disadvantage of the overlaid architecture is the reduced spectrum efficiency.

Evolution of the wireless networks



Features:

UMTS

MS → BS (uplink)

MS ← BS (downlink)

Data Rates

–Up to 100 Mbps Downlink

– Up to 50 Mbps Uplink

Packet Data

– Low Latency (real time services)

Flexible Frequency – FDD/TDD

Self Configuration and Optimisation

Multiple Access Scheme – CDMA

BPSK → uplink datarate

2 symbols

QPSK → Downlink

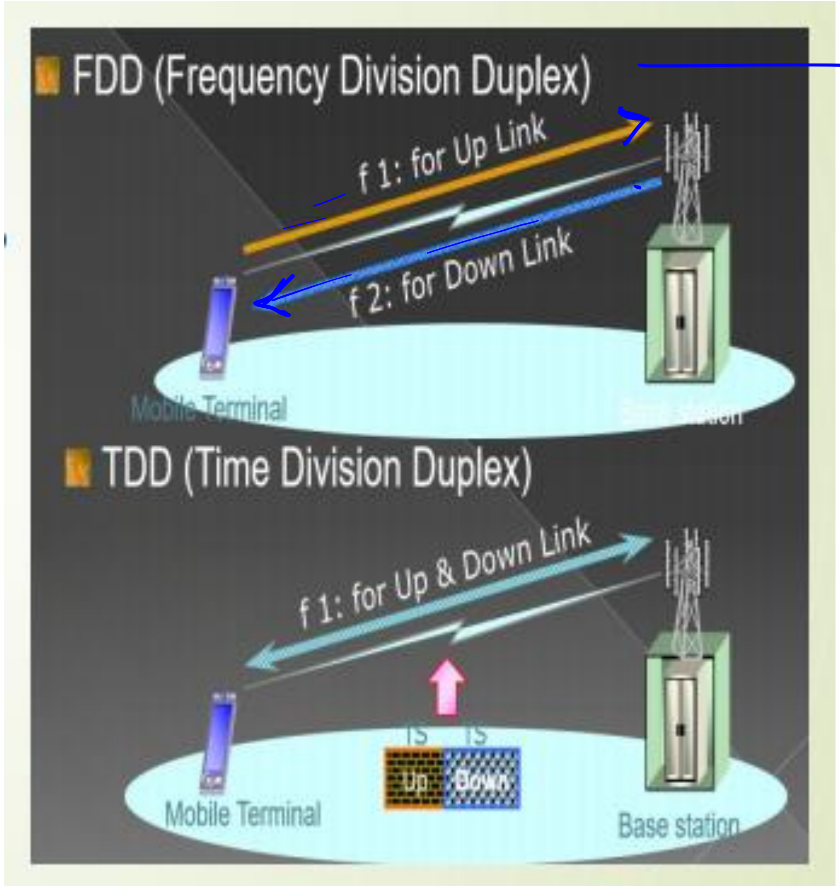
Higher modulation

4 symbols

- All IP Backbone
- Multibeam Transmission
- 5 MHz channel bandwidth
- It is very much flexible with 100/200 kHz carrier spacing.
- The Frame length unit is 10 ms.
- It uses BPSK for uplink and QPSK for downlink.
- It has variable spreading factor.
- The channel coding is convolution coding, turbo code for high data rate

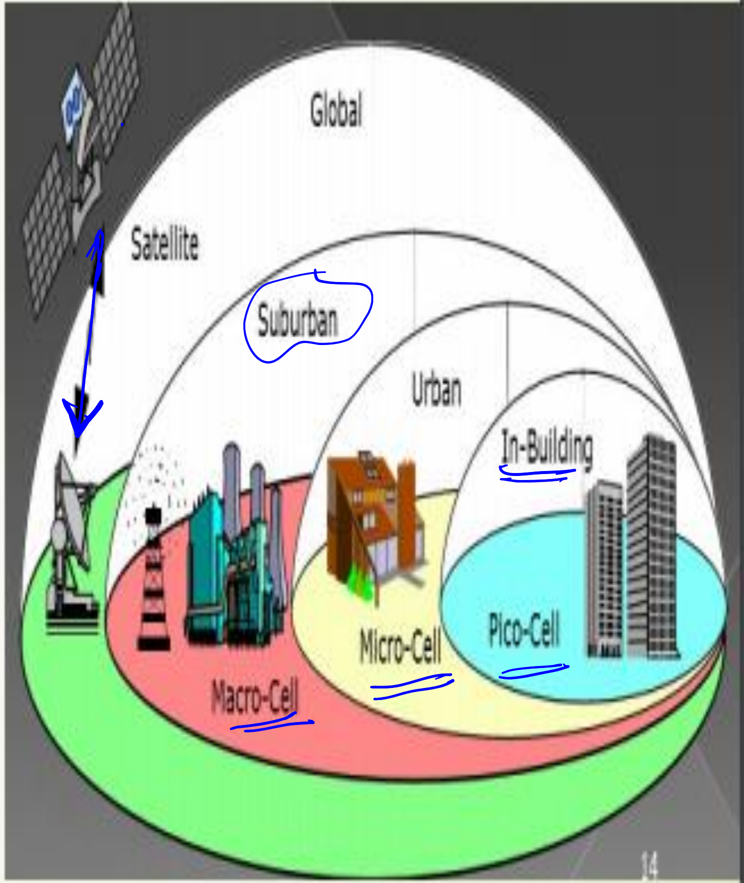
It has two modes. I) **UMTS-FDD** ii) **UMTS-TDD**

- In frequency division duplex mode there are two frequencies used one for the uplink and the other for the downlink.
- In Time division duplex mode only one frequency is used for both uplink and downlink, but the frequency is divided into time slots for uplink and downlink communication.



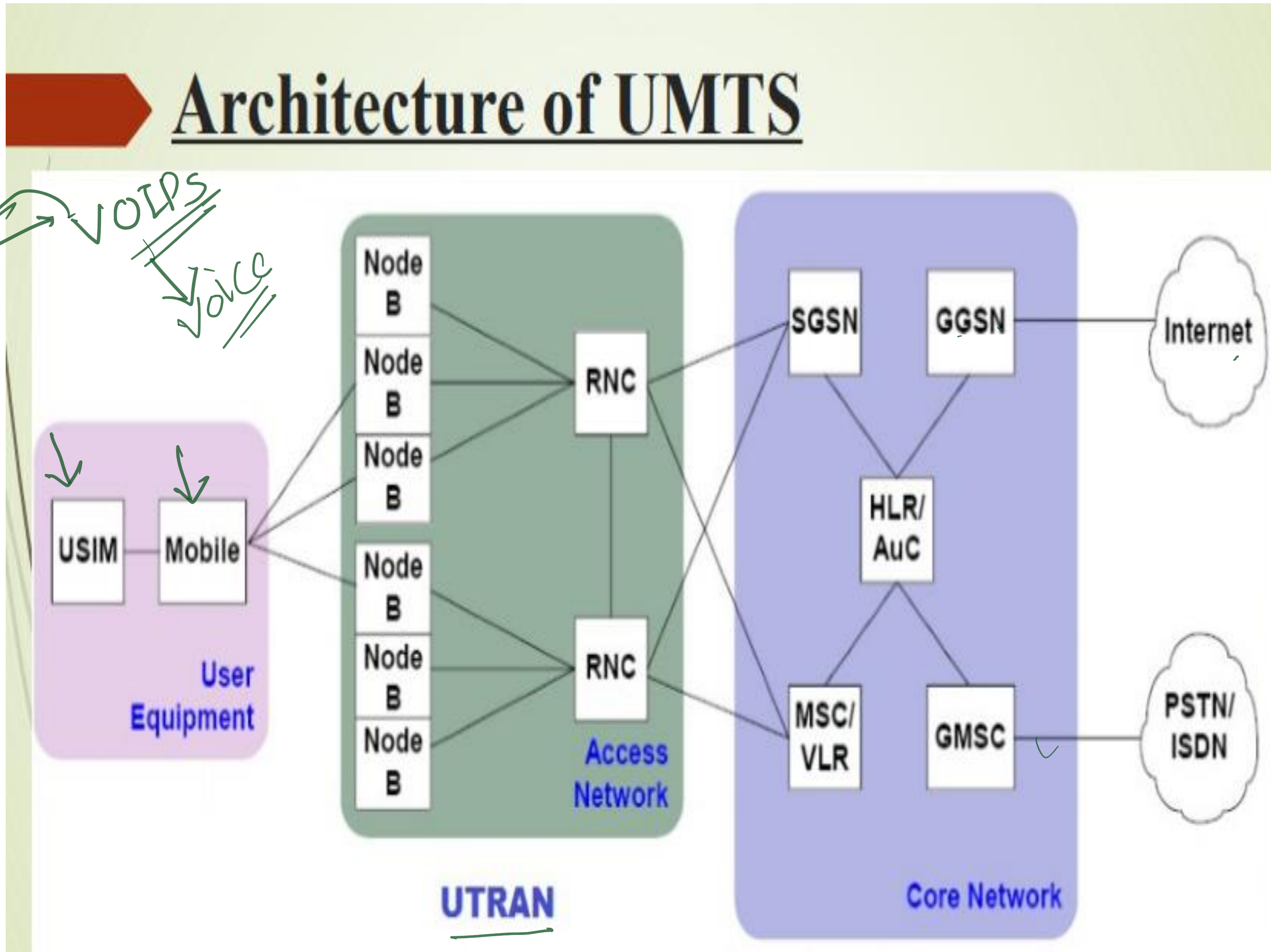
Types of Cells and its Data Rates

- **› Macro Cell**
- These cover a large area and will give slow access.
- 144 Kbps – max speed of 500 Km/h. Low data rate.
- **› Micro Cell**
- These should cover a medium area.
- 384 Kbps max speed 120 Km/h. Medium data rate.
-
- **› Pico Cell**
- Less than 100 metres.
- 2 Mbps – max speed of 10 Km/h. High data rat



- **USIM** = Universal Subscriber Identity Module (USIM)
- **RNC** = Radio Network Controller
- **GMSC =** Gateway Mobile Switching Centre

4G LTE VOIPS Voice



Introduction to 5G Wireless Communication:

1G

2G (GSM Systems)

3G (UMTS)

4G (LTE/WiMax)

5G

Mobile communication standards. Uses Millimeter waves (10 mm to 1 mm).

Features:

High data rate

Reduced latency

Energy saving

Cost reduction

Higher system capacity

Massive device connectivity

Multiple Access techniques: OFDM

Maximum achievable data rate 20 Gbits/sec