

The Cellular Concept System Design Fundamentals





Table of Contents

- ✿ Introduction
- ✿ Frequency Reuse
- ✿ Channel Assignment Strategies
- ✿ Handoff Strategies
 - ✿ Prioritizing Handoffs
 - ✿ Practical Handoff Considerations
- ✿ Interference and System Capacity
- ✿ Power Control
- ✿ Improving Coverage and Capacity in Cellular Systems

Introduction



ISM Band

- ✿ The industrial, scientific and medical (ISM) radio bands were originally reserved internationally for non-commercial use of RF electromagnetic fields for industrial, scientific and medical purposes.
- ✿ Free of license.
- ✿ The ISM bands are defined by the ITU-R in 5.138 and 5.150 of the Radio Regulations. Individual countries' use of the bands designated in these sections may differ due to variations in national radio regulations.
- ✿ 900 MHz, 1.8 GHz, 2.4 GHz, 5.8 GHz Bands.
- ✿ Most microwave ovens use 2.45 GHz.

Early Wireless Systems

- ✿ The first successful use of mobile radio dates from the late 1800s, when M. G. Marconi established a radio link between a land-based station and a boat sailing the English channel, over an 18-miles path.
- ✿ In 1934, 194 municipal police radio systems and 58 state police stations had adopted amplitude modulation (AM) mobile communication systems for public safety in the U.S.
- ✿ In 1935, Edwin Armstrong demonstrated frequency modulation (FM) for the first time. Since late 1930s, FM has been the primary modulation technique used for mobile communication systems throughout the world.

Early Wireless Systems

- ✿ The first public mobile phone service was the Mobile Telephone System (MTS) introduced in the United States in 1946, when FCC granted a licence to AT&T.
 - ✿ Operation was half duplex.
 - ✿ Call placement was manual operation.
 - ✿ Cover distances over 50Km.
 - ✿ Modulation was FM (frequency modulation).
 - ✿ 120KHz per channel.
- ✿ In 1950, the FCC doubled the number of mobile telephone channels, but with no new spectrum allocation.
 - ✿ 60 KHz per channel.
- ✿ By mid 1960s, the FM bandwidth of voice transmission was cut to 30 KHz.

Early Wireless Systems

- ✿ Improved Mobile Telephone System (IMTS) was introduced in 1969.
 - ✿ Full Duplex.
 - ✿ Automatic switching.
 - ✿ 450 MHz band.
- ✿ The cellular concept began to appear in Bell Laboratories proposals during the late 1940s.
 - ✿ Cellular concept is introduced because of limited spectrum.
 - ✿ Channels are reused when there is sufficient distance between the transmitters to prevent interference.
- ✿ AT&T proposed the concept of a cellular mobile system to the FCC in 1968.
- ✿ Cellular technology wasn't available to implement cellular telephony until the late 1970s.

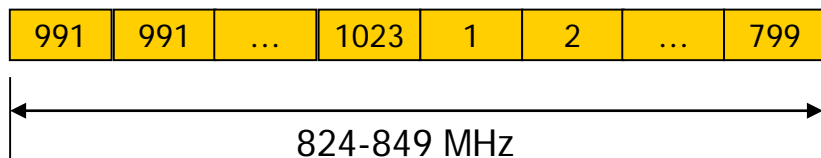


First Generation Cellular Systems

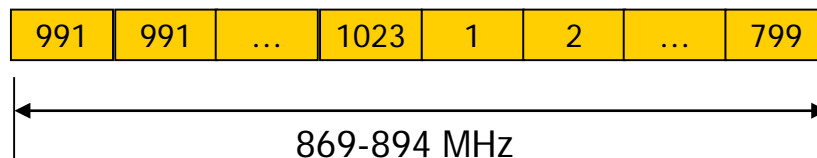
- ✿ Analog Voice Technology
- ✿ AMPS (advanced mobile phone service), introduced in 1983 in the USA.
 - ✿ 666 duplex channel.
 - ✿ 40 MHz of spectrum in the 800 MHz band.
 - ✿ 30 KHz for one way bandwidth.
 - ✿ In 1989, the FCC granted an additional 166 channels (10 MHz) to U.S. cellular service providers.
 - ✿ The forward and reverse channels in each pair are separated by 45 MHz.

AMPS Frequency Allocation

Reverse Channel



Forward Channel



	Channel Number	Center Frequency (MHz)
Reverse Channel	$1 \leq N \leq 799$	$0.03N + 825.0$
	$990 \leq N \leq 1023$	$0.03(N - 1023) + 825.0$
Forward Channel	$1 \leq N \leq 799$	$0.03N + 870.0$
	$990 \leq N \leq 1023$	$0.03(N - 1023) + 870.0$
Channels 800 - 990 are unused.		

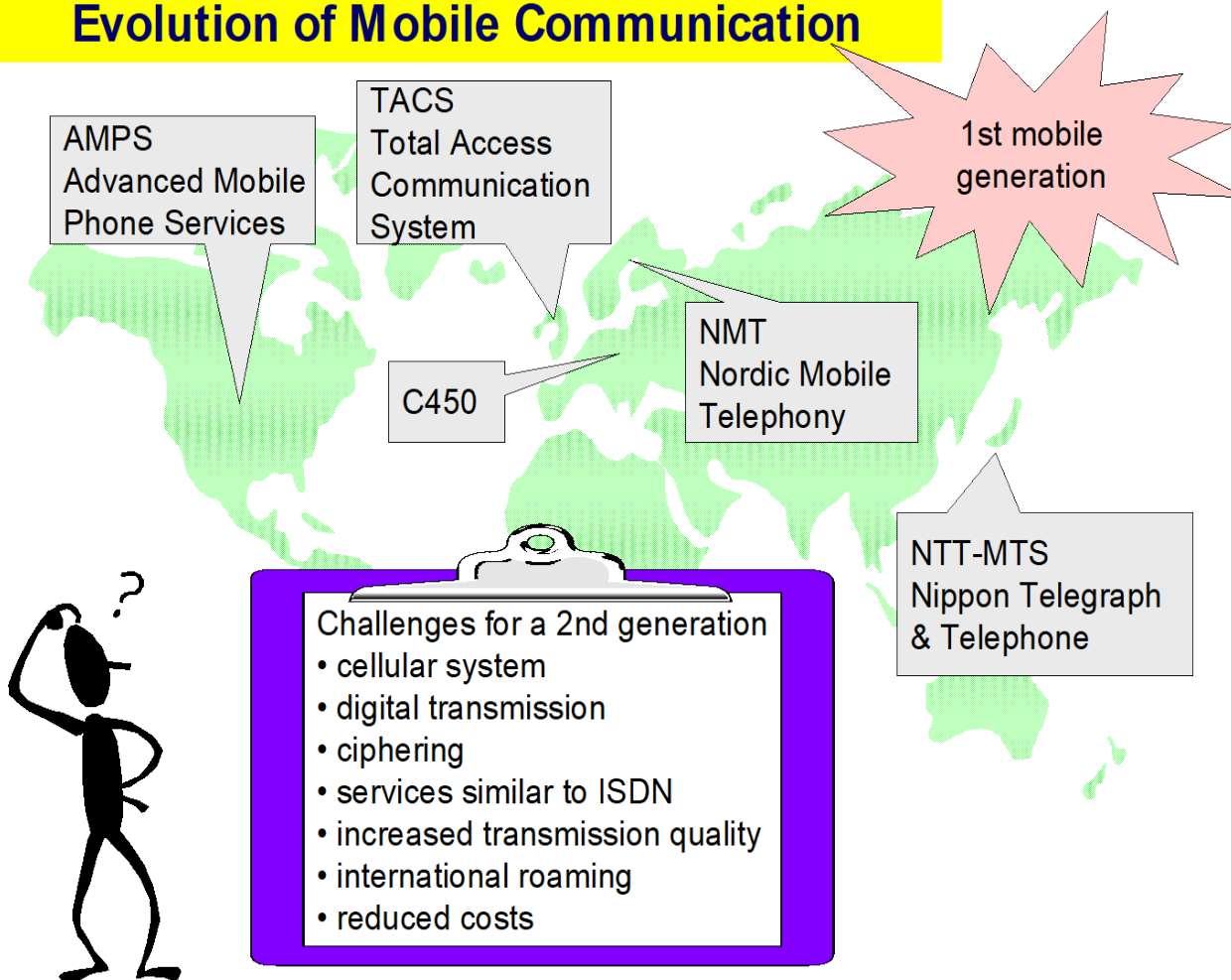


First Generation Cellular Systems

- ✿ NMT-450 (Nordic Mobile Telephone), introduced in 1981, was adopted by European states. (25KHz)
- ✿ TACS (Total Access Communication System) was a very successful system in Great Britain. (25KHz)
- ✿ NTT (Nippon Telephone and Telegraph) was introduced in 1979. (25KHz)

First Generation Cellular System

Evolution of Mobile Communication





Second Generation Cellular Systems

- ✿ Digital Technology
- ✿ US
 - ✿ A: USDC (IS-54/136), DCS1900, IS-95 (CDMA)
 - ✿ B: PACS
- ✿ Europe
 - ✿ A: GSM, DCS1800
 - ✿ B: CT2 (TDD), DECT(TDD)
- ✿ Japan
 - ✿ A: PDC
 - ✿ B: PHS (TDD)
- ✿ A: high speed, high BS power, low traffic density, few BSs.
- ✿ B: low speed, low BS power, high traffic density, many BSs.

Second Generation Cellular Systems

GSM - The Standard

Parameter	(E-)GSM-900	GSM-1800 (DCS, PCN)	GSM-1900 (PCS)	GSM-R
Frequency Range (Uplink)	890 - 915 MHz E-GSM: 880 - 890 Mhz	1710 - 1785 MHz	1850 - 1910 MHz	876 - 880 MHz
Carrier Spacing	200 kHz	200 kHz	200 kHz	200 kHz
Duplex Spacing	45 MHz	95 MHz	80 MHz	45 MHz



Third Generation Cellular Systems

- ✿ High Speed Data Service

- ✿ Three major standards:
 - ✿ UMTS (Universal Mobile Telecommunication Standard)
 - ✿ In Japan - WCDMA.
 - ✿ cdma2000 (IS-95 successor)
 - ✿ TD-SCDMA: Time-Division Synchronous CDMA

Third Generation Cellular Systems

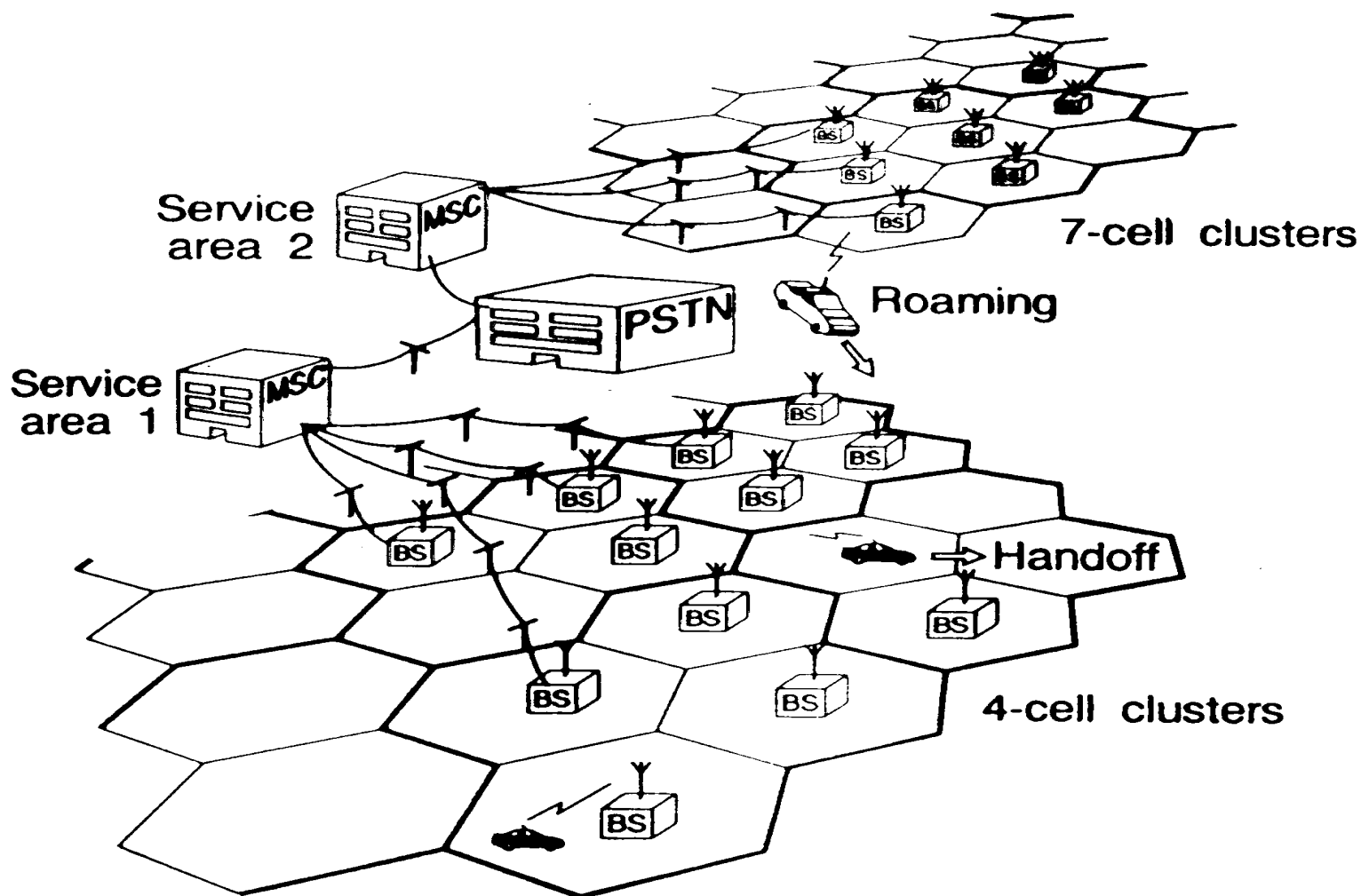
☀ IMT-2000 Services

- ☀ Indoor office: 2M bps
- ☀ Pedestrian: 384 kbps
- ☀ Vehicular: 144 kbps
- ☀ Satellite: 9.6 kbps

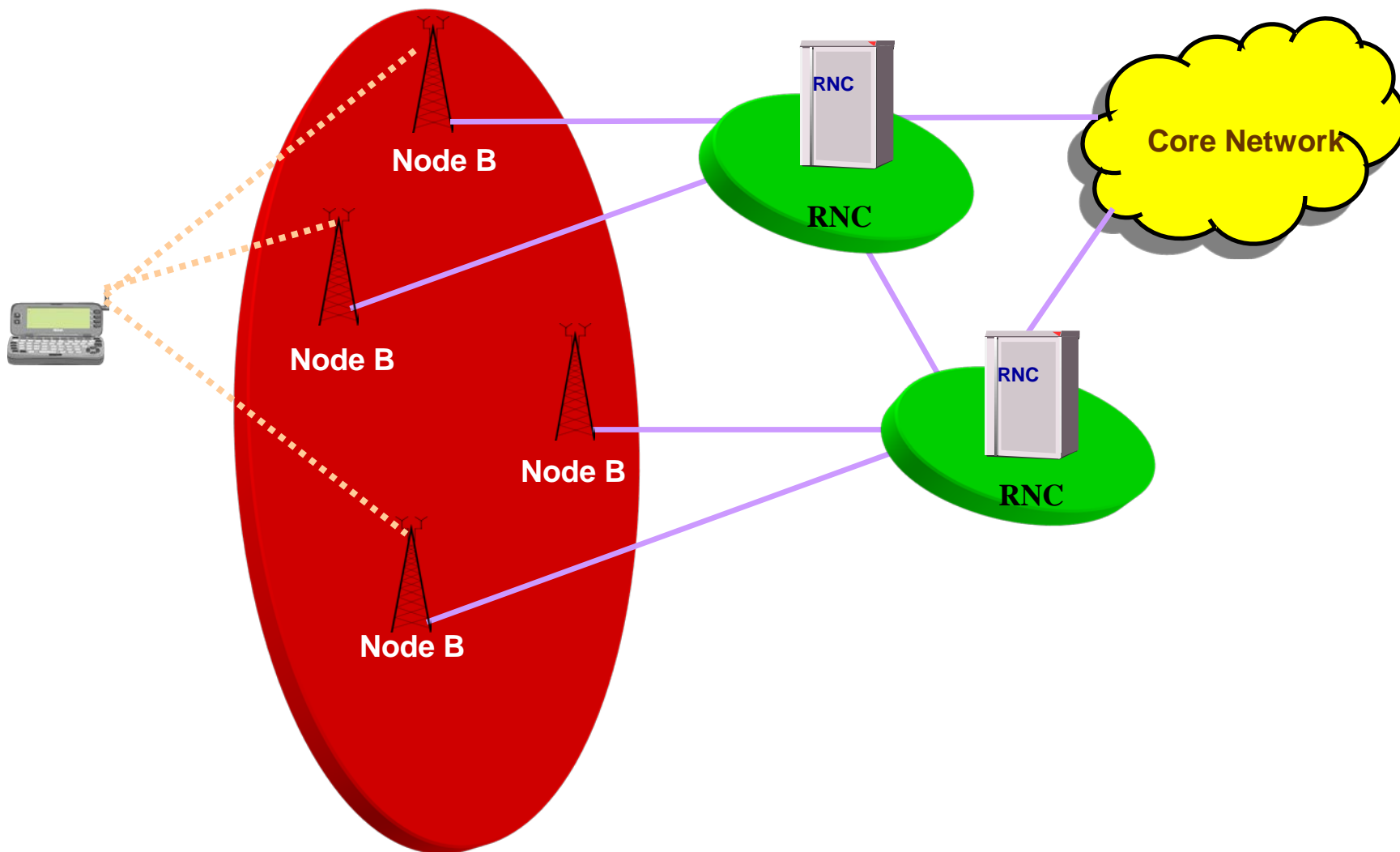
☀ Multi-environment operations

- ☀ Mega-cell (100-500 km)
- ☀ Macro-cell (≤ 35 km)
- ☀ Micro-cell (≤ 1 km)
- ☀ Pico-cell (≤ 50 m)

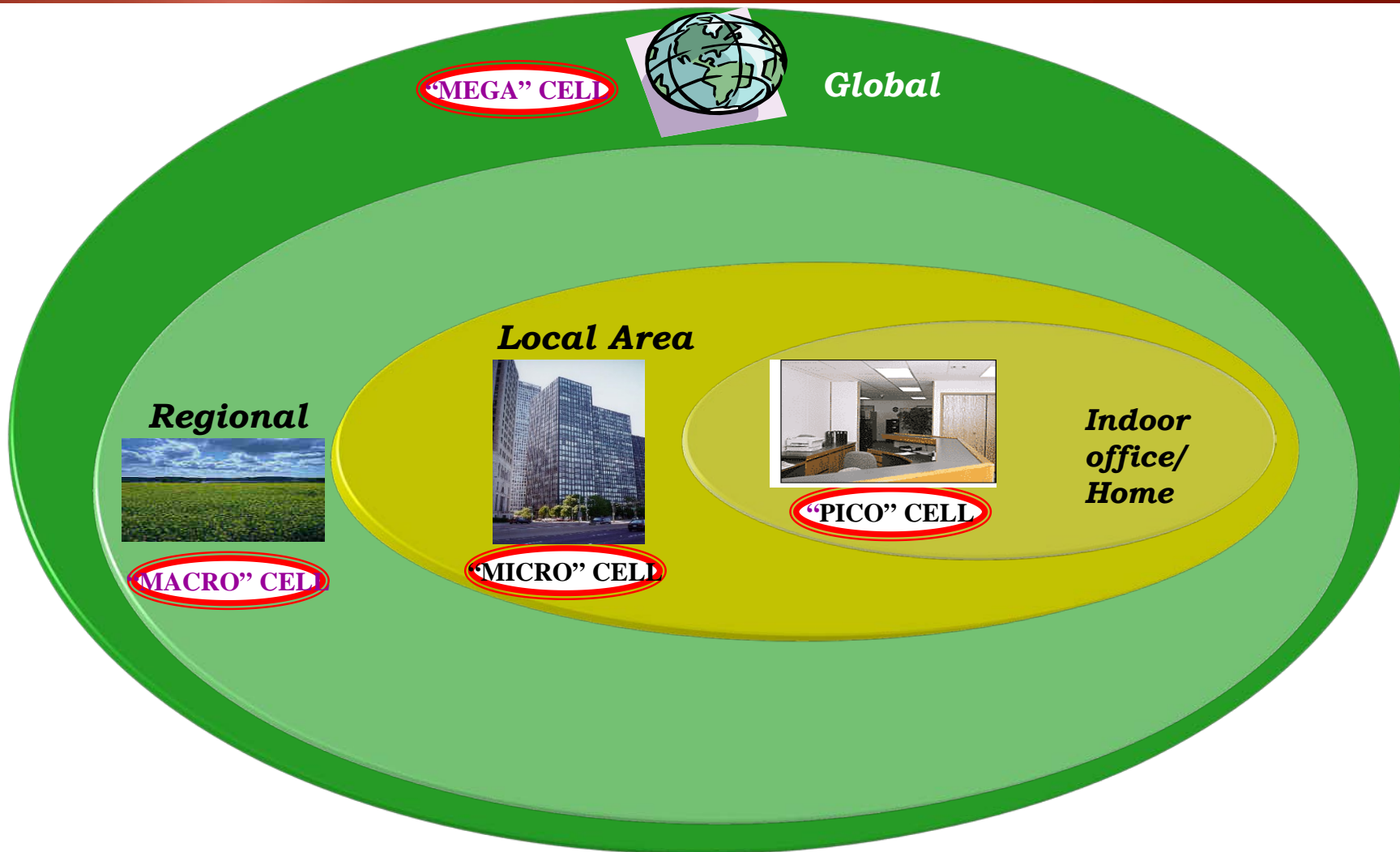
Traditional Cellular Networks



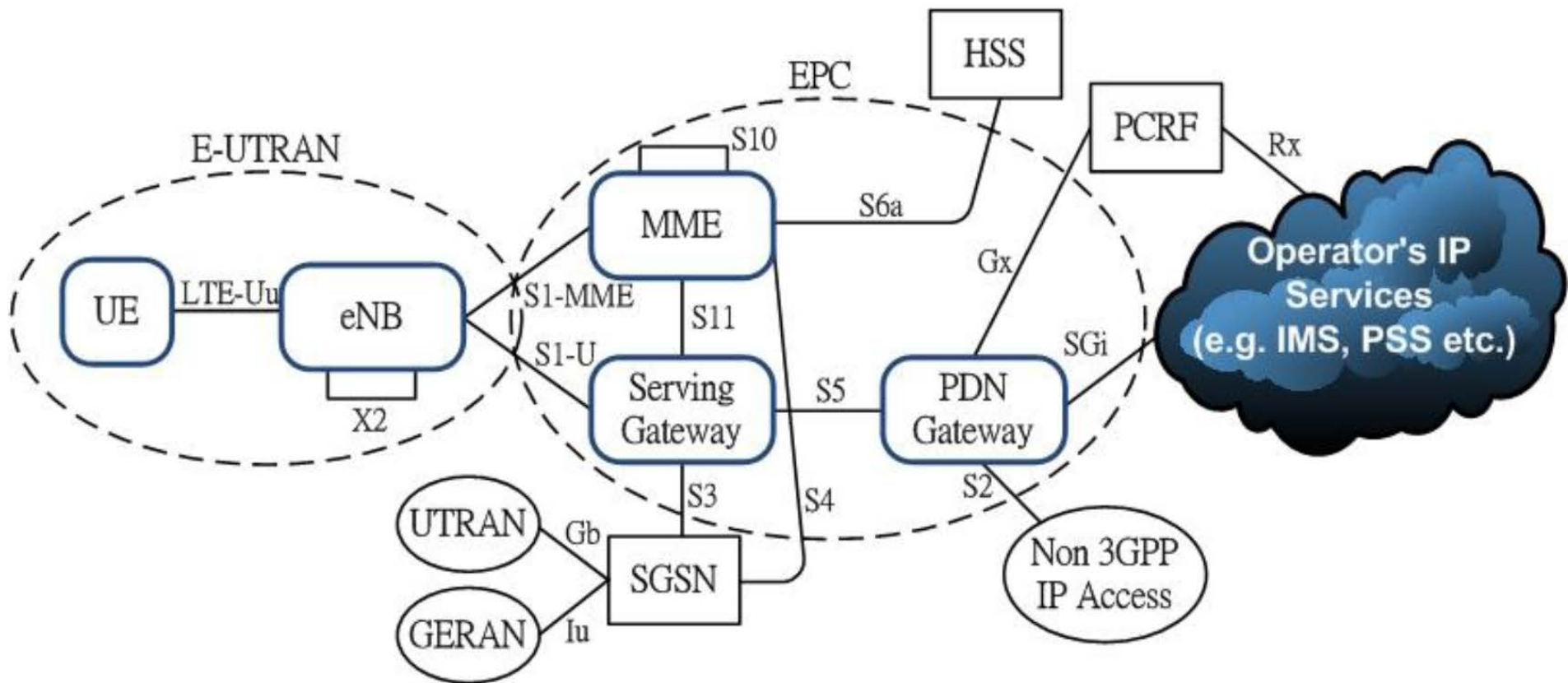
3G Cellular Network - WCDMA



Hierarchical Cellular Networks

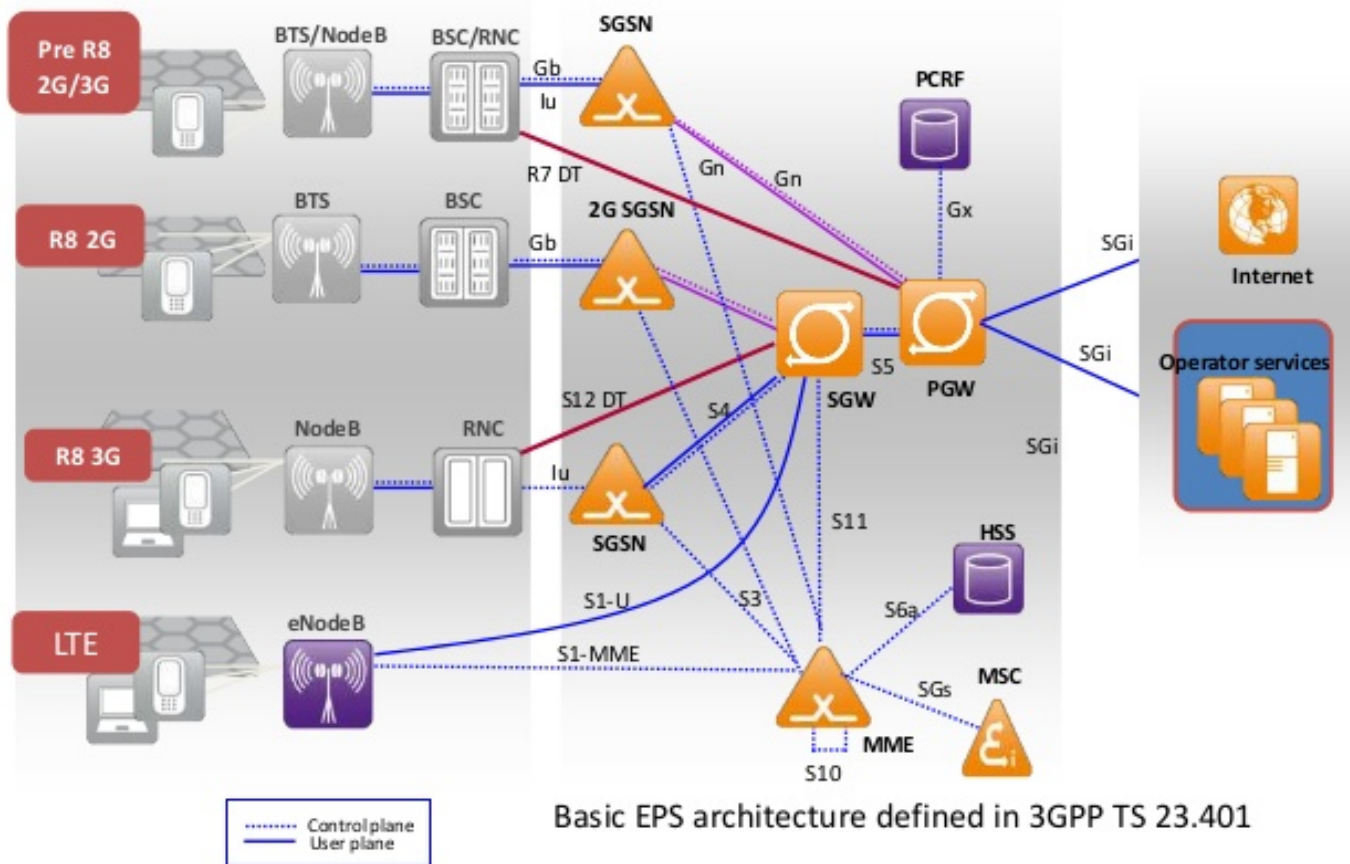


LTE Architecture



LTE Architecture

General LTE Architecture





Abbreviations

- ✱ GPRS: General Packet Radio Service (2.5G)
- ✱ EDGE: Enhanced Data Rates for GSM Evolution (2.75G)
- ✱ GGSN: Gateway GPRS Support Node
- ✱ SGSN: Serving GPRS Support Node
- ✱ MME: Mobility Management Entity
- ✱ PGW: Packet Data Network (PDN) Gateway
- ✱ SGW: Serving Gateway
- ✱ HSS: Home Subscriber Server
- ✱ PCRF: Policy and Charging Rules Function
- ✱ RNC: Radio Network Controller
- ✱ BTS: Base Transceiver Station
- ✱ BSC: Base Station Controller
- ✱ GERAN: GSM EDGE Radio Access Network
- ✱ RRC: Radio Resource Control

LTE & Mobile Internet

LTE and the Mobile Internet



LTE/Mobile Internet Highlights

LTE/RAN/MIMO

LTE Devices: Smartphones/Tablets/laptops
OFDM/MIMO Antennas in the 4G RAN
 Critical standards based components of 3GPP and LTE networks, multiple input multiple output (MIMO) is the use of more than one antenna for a single QoS. It enables for higher data rates through multiplexing and increased reliability (interference control). MIMO configurations can include up to 8 transmit and up to 4 receive antennas which can be set up in downlink and/or uplink.

- Most 3GPP standard features of 4G networks, multiple input multiple output (MIMO) is the use of more than one antenna for a single QoS. It enables for higher data rates through multiplexing and increased reliability (interference control). MIMO configurations can include up to 8 transmit and up to 4 receive antennas which can be set up in downlink and/or uplink.
- MIMO can be broken into three technology sub-categories
 - Space-time multiplexing
 - Spatial multiplexing
 - Diversity coding

LTE/Any-G Mobility

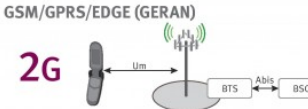
Anything, Anywhere, Anytime
 The mobile broadband environment is a mixture of legacy and LTE components, delivering:

- Seamless mobility of subscribers and services
- Minimum service disruption
- Fast signaling network (RPM) using R3 and R3 functionality to accelerate eUTRAN efficiency
- Guaranteed Quality of Service
- Efficient resource management
- Robust network assist

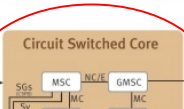
LTE Evolved Packet Core Interfaces

S1-MME - 3GPP 4.3: Control plane protocol between e-UTRAN and MME.
S1-M - 3GPP 4.4: Data path between e-UTRAN and Serving-GW for the peer bearer user plane for routing and inter-robust path switching during handover.
S2-M - 3GPP 4.29.27b: Provides the user plane with related control and mobility support between the user plane for peer bearer user plane for routing and inter-robust path switching during handover.
S2-U - 3GPP 4.29.27c: Provides the user plane with related control and mobility support between the evolved Packet Core (EPC) and the PDN GW. It is based on Proxy Mobile IPv6.
S3 - 3GPP 4.29.27d: Control plane for user and bearer information exchange for inter-SGW access network mobility in idle and active states.
S4 - 3GPP 4.29.27e: Control and mobility support between S-GW and the Iu-CS interface of Serving-GW. In addition, if direct tunnel is not established, it provides the user plane for routing and inter-robust path switching during handover.
S6 - 3GPP 4.29.27f: User plane for routing and inter-robust path switching during handover between Serving-GW and PDN GW. It is based on Proxy Mobile IPv6.
S6-M - 3GPP 4.29.27g: Handover S2-M and charging data from S-GW to Billing and Charging before handover in the PDN GW.
S6-U - 3GPP 4.29.27h: SIP related interface between S-GW and IMS.
S6a - 3GPP 4.29.27i: PDN GW to charging DCF for active credit request.
S6b - 3GPP 4.29.27j: PDN GW to charging DCF for offline credit request.
S6c - 3GPP 4.29.27k: PCRF interface between the PDN GW and the AAA.

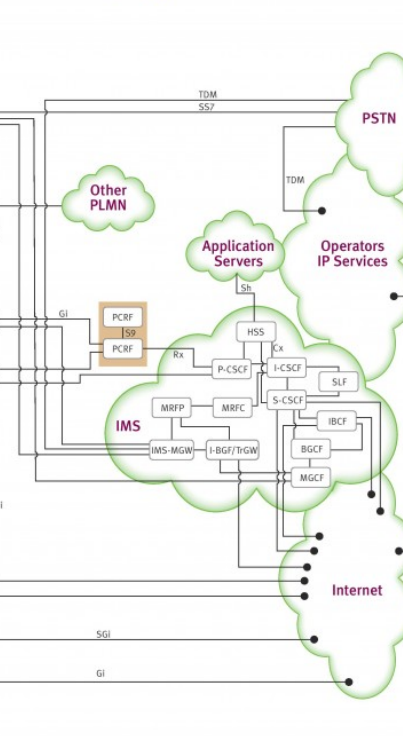
Radio Access Network



Core Network



Services/Applications Network



TESTING TOPICS

MIMO
 Multi Input Multi Output channeling is designed to boost LTE RAN performance without increasing Tx power requirements.
What to Test? Base station receivers, handset and device functionality and performance testing. BS/2 and BS/4 bidirectional MIMO performance, beam-forming and OTA with real-world channel models.

VoLTE
 Voice over LTE is the concept of carrier-grade voice service over the packet-switched 4G LTE/IMS network.
What to Test? SIP registration and negotiation procedures, supplementary services, call control, SMS, data performance with voice traffic, impacts of the UE on QoS, voice quality, interaction between media services (e.g., video) and voice service.

Timing Synchronization
 Two flavors of LTE timing: Precision Time Protocol (PTP) 1588v2 and Synchronous Ethernet (SyncE) G.8261.
What to Test? Time of Day accuracy, packet delay for downstream clocks, devices input and output wander and Backhaul performance.

Mobile Offload
 Femtocell/Wi-Fi technology impacting fixed/mobile convergence designed to free up RAN bandwidth. Solution are both unlicensed (Wi-Fi) and licensed (Femtocell).
What to Test? Handset automation, authentication, Wi-Fi offload key architecture, unique security for access and non-access functions and forward security limits exposure.

Security
 Network to device attacks. More unsecure access is driving ever-increasing security risks to users and operators. Hierarchical key architecture, unique security for access and non-access functions and forward security limits exposure.
What to Test? Simulate attacks on network elements and devices for functionality and performance with security levels and applications enabled.

DEVICES/RAN TESTING

SPiRENT VR5

Spirent VR5 HD Spatial Channel Emulator brings unprecedented ease of use to your MIMO, beamforming devices and base stations. BS MIMO, TD-LTE, LTE advanced, bidirectional and handset testing are just a few of the challenges that are easily handled with this benchmarking tool that engages the game with unparalleled integration and performance, while new hardware introduces order-of-magnitude improvements in bandwidth, output power and dynamic range.

SPiRENT CS8

Spirent CS8 provides a highly efficient solution for testing LTE, 4G LTE and 4G LTE devices in the RAN lab. CS8 is a single platform that delivers the most advanced and complete test capabilities for LTE, CS8 offers comprehensive support for multi-carrier, multi-MIMO capability and integrated MIMO.

NETWORK/APPS LAB TESTING

SPiRENT 8100

Spirent's 8100 is the leading solution for LTE device testing. 8100 is a multi-protocol test solution that is comprehensive, fully automated benchmarking tool and will decrease time required for device validation and approval. 8100 solutions are available in a range of scalable, cost-effective options, from bench top to fully integrated platforms covering application, location and data access test areas.

SPiRENT Landslide

Landslide provides a comprehensive end-to-end platform that emulates millions of mobile data subscribers, simultaneously accessing the wireless network using various access modes. Landslide emulates all of the key wireless core network elements including W-LAN, F-Offload gateway and end-to-end network elements.

SERVICE ASSURANCE TESTING

SPiRENT TestCenter

Spirent TestCenter provides unmatched performance with scale and reliability to test next-generation networks—from traditional performance testing to rigorous analysis of networks leveraging Virtualization, Cloud Computing, Mobile Backhaul and High speed Ethernet, emulating real network scenarios and traffic patterns to assess QoS and QoE.

SPiRENT TestCenter Live

Spirent TestCenter Live is used by telcos, MSSPs and MNOs around the world to support External service delivery. From mobile backhaul, to business services, to global IP networks—operator groups benefit from Spirent's architecture, performance monitoring and troubleshooting in a single deployed solution.



The Cellular Jargon

✿ *Roaming*

- ✿ A MS which operates in a service area (market) other than that from which service has been subscribed.

✿ HLR/VLR (*Home Location Register; Visitor Location Register*)

✿ *Handover* or *Handoff*

- ✿ The process of transferring a MS from a channel or a BS to another.
- ✿ *Hard handoff*: Assignment of different radio channel during hand off.
- ✿ *Soft handoff*: The ability to select between the instantaneous received signals from a variety of base stations.

The Cellular Jargon

- ✿ *Forward channel (Downlink channel):* BS \rightarrow MS
- ✿ *Reverse channel (Uplink channel):* MS \rightarrow BS

- ✿ *Full duplex*
 - ✿ TX & RX are allowed simultaneously
 - ✿ GSM, IS-95, CT2, DECT
 - ✿ Now full duplex has a new meaning: Single Channel Full-Duplex
- ✿ *Half duplex*
 - ✿ TX or RX is allowed at any given time
 - ✿ radio taxi, police radio
- ✿ *Simplex*
 - ✿ only one-way transmission
 - ✿ paging



The Cellular Jargon

- ✿ *Control Channel*: Radio channels used for transmission of call setup, call request, call initiation, and other beacon or control purposes.
- ✿ *Page*: A brief message which is broadcast over the entire service area, usually in a simulcast fashion by many base stations at the same time.
- ✿ *Transceiver*: A device capable of simultaneously transmitting and receiving radio signals.



Frequency Division Duplexing (FDD)

- ✿ Provides simultaneous radio transmission channels for the users and the base station.
- ✿ At the base station, separate transmit and receive antennas are used to accommodate the two separate channels.
- ✿ At the subscriber unit, a single antenna is used for both transmission to and reception from the base station, and a device called a *duplexer* is used to enable the same antenna to be used for simultaneous transmission and reception.
- ✿ It is necessary to separate the transmit and receive frequencies so that the duplexer can provide sufficient isolation while being inexpensively manufactured.
- ✿ FDD is used exclusively in analog mobile radio systems.



Time Division Duplexing (TDD)

- ✿ TDD uses the fact that it is possible to share a single radio channel in time so that a portion of the time is used to transmit from the base station to the mobile, and the remaining time is used to transmit from the mobile to the base station.
- ✿ If the data transmission rate of the channel is much greater than the end-user's data rate, it is possible to store information bursts and provide the appearance of full duplex operation to a user, even though there are not two simultaneous radio transmissions at any instant of time.
- ✿ TDD is only possible with digital transmission formats and digital modulation, and is very sensitive to timing.

Frequency Reuse

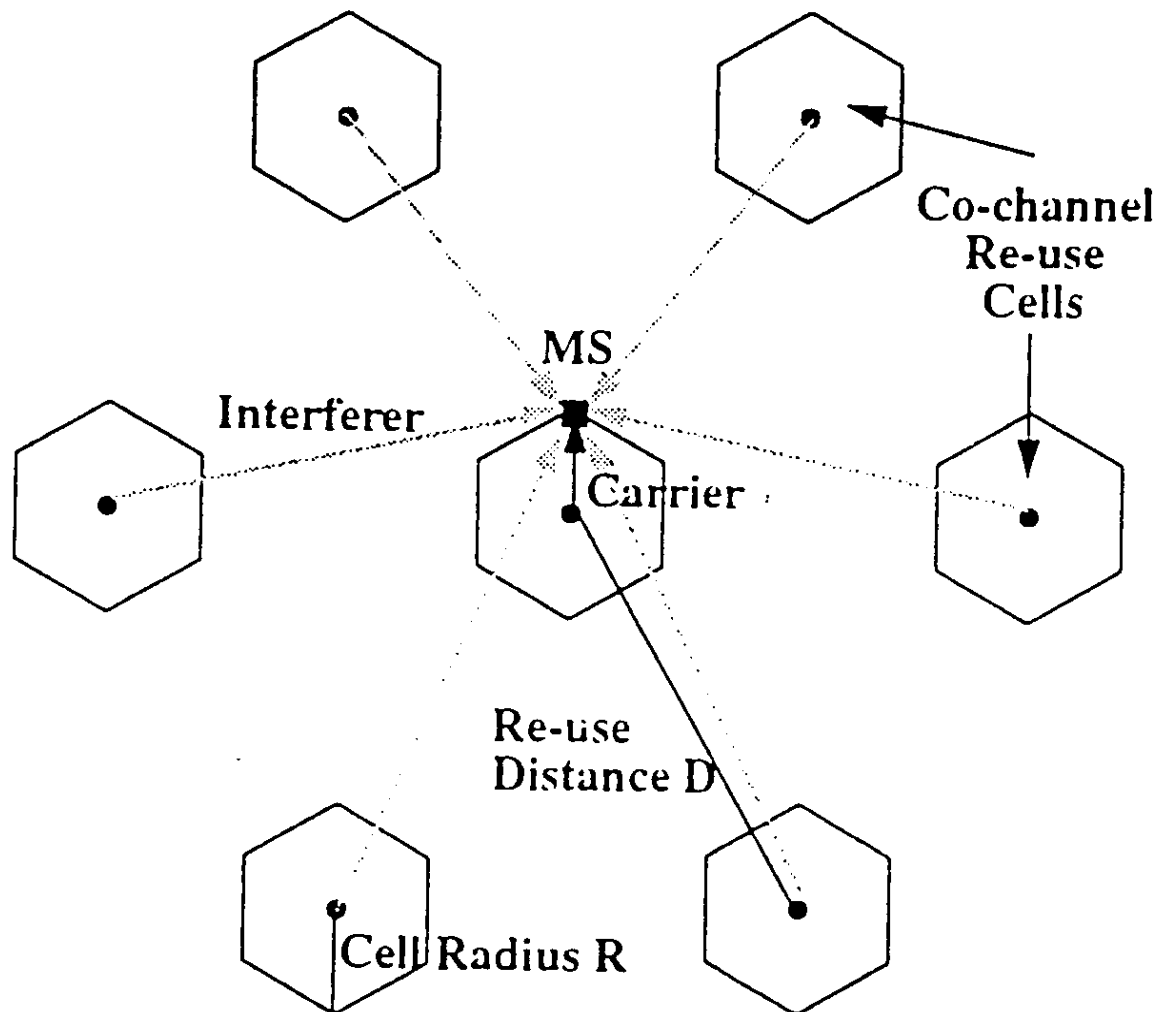




Cellular System Design Considerations

- ✿ To solve problems of spectral congestion and user capacity.
- ✿ Replacing a single, high power transmitter with many low power transmitters.
- ✿ Neighboring base stations are assigned different groups of channels so that the interference between base stations is minimized.
- ✿ Available Channels are distributed throughout the geographic region and may be reused as many times as necessary.
- ✿ With fixed number of channels to support an arbitrarily large number of subscribers.

Concepts of Frequency Reuse



Cellular Networks and Frequency Reuse

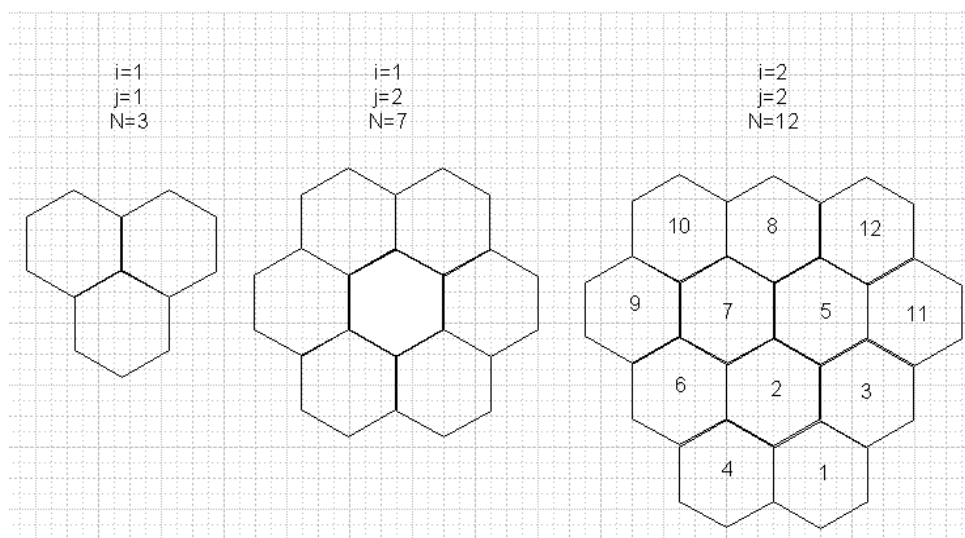
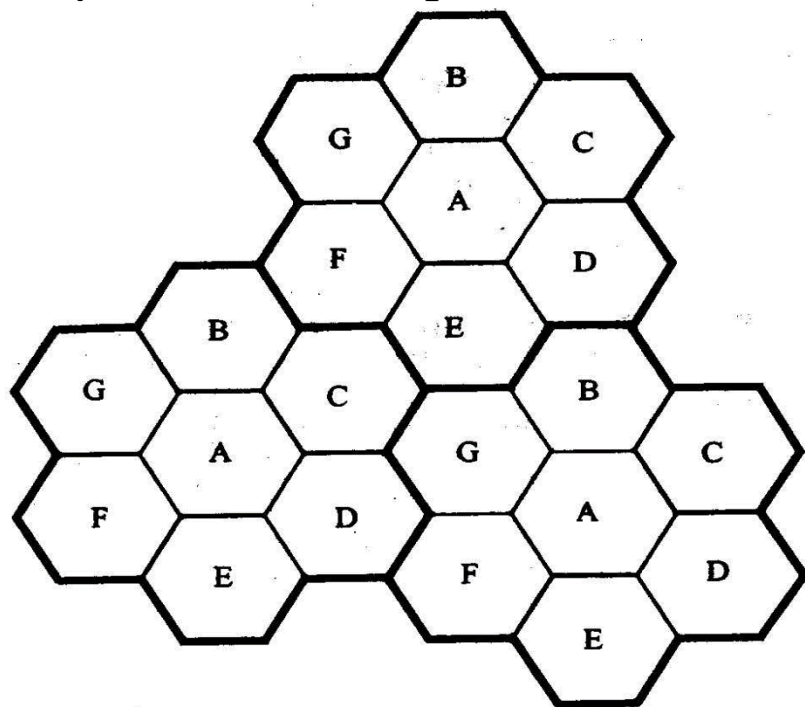
- ✿ One important characteristic of cellular networks is the *reuse of frequencies* in different cells.
- ✿ By reuse frequencies, a high capacity can be achieved.
- ✿ However, the reuse distance has to be high enough, so that the interference caused by subscribers using the same frequency (or an adjacent frequency) in another cells is sufficiently low.
- ✿ To guarantee an appropriate speech quality, the *carrier-to-interference-power-ratio (CIR)* has to exceed a certain threshold CIR_{\min} which is 9 dB for the GSM system.

Hexagons

- ✿ *Hexagonal cell* shape has been universally adopted.
- ✿ The actual radio coverage of a cell is known as the *footprint* and is determined from field measurements or propagation prediction models.
- ✿ Base stations can be placed at:
 - ✿ The cell center – center-excited cells – omni-directional antennas.
 - ✿ The cell vertices – edge-excited cells – sectored directional antennas.

Reuse Factor

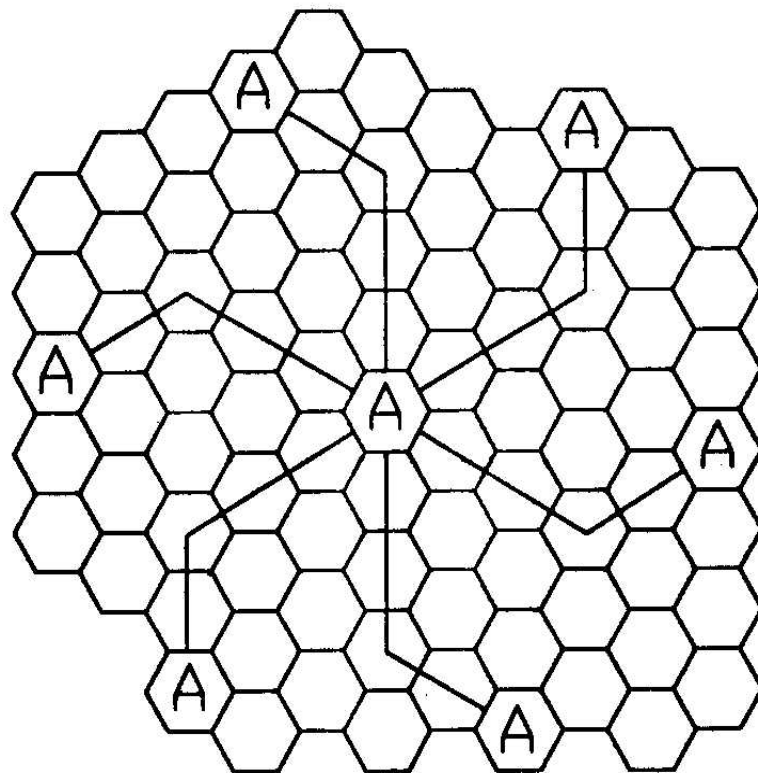
Due to the fact that the hexagonal geometry has exactly six equidistant neighbors and that the lines joining the centers of any cell and each of its neighbors are separated by multiples of 60 degrees, there are only certain cluster sizes and cell layouts which are possible.



Reuse Factor = $i^2 + ij + j^2$; i, j are non-negative integers.

Co-channel Neighbor Cells

- ✿ Move i cells along any chain of hexagons.
- ✿ Turn 60° counter-clockwise and move j cells
- ✿ For example:
 - ✿ $N=19: i=3, j=2;$
 - ✿ $N=12: i=2, j=2;$
 - ✿ $N=7; i=2, j=1;$



Channel Assignment Strategies





Channel Assignment Strategies

- ✿ Fixed Channel Allocation
- ✿ Dynamic Channel Allocation
- ✿ Hybrid Channel Allocation
- ✿ Borrowed Channel Allocation



Fixed Channel Assignment

- ✿ Each cell is allocated a predetermined set of voice channels.
- ✿ Any call attempt within the cell can only be served by the unused channels in that particular cell.
- ✿ *Probability of blocking* is high.

Dynamic Channel Assignment Strategy

- ✿ 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 MSC allocates a channel to the requested cell following an algorithm that takes into account the likelihood of future blocking within the cell, the frequency of use of the candidate channel, the reuse distance of the channel, and other cost functions.
- ✿ MSC only allocates a given frequency if that frequency is not presently in use in the cell or any other cell which falls within the minimum restricted distance of frequency reuse to avoid *co-channel interference*.



Dynamic Channel Assignment Strategy

- ✿ MSC has to collect real-time data on channel occupancy, traffic distribution, and *radio signal strength indications* (RSSI) of all channels on a continuous basis.
- ✿ Reduce the likelihood of blocking at the expense of increasing the storage and computational load.

Borrowing Strategy

- ✿ Modified from fixed channel assignment strategies.
- ✿ A cell is allowed to borrow channels from a neighboring cell if all of its own channels are already occupied.
- ✿ The MSC supervises such borrowing procedures and ensures that the borrowing of a channel does not disrupt or interfere with any of the calls in progress in the donor cell.

Handoff Strategies





Handoff / Handover

- ✿ In a cellular network, the process to transfer the ownership of a MS from a BS to another BS.
- ✿ Handoff not only involves identifying a new BS, but also requires that the notice and control signals be allocated to channels associated with the new base station.
- ✿ Usually, priority of handoff requests is higher than call initiation requests when allocating unused channels.
- ✿ Handoffs must be performed successfully and as infrequently as possible and be imperceptible to the users.

Handoff / Handover

✿ Handover Occasions

- ✿ Bad signal quality on current channel
 - ✿ noise or interference
- ✿ Traffic overload in current cell
 - ✿ load balancing

✿ Handover Indicator: The parameters to monitor to determine HO occasion

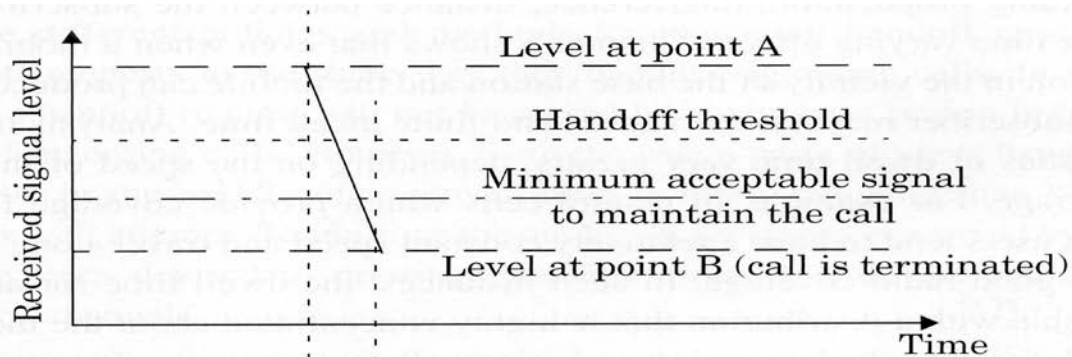
- ✿ RSSI, in ensemble average sense.
- ✿ Bit Error Rate (BER)/Packet Error Rate (PER), more accurate.

Handoff / Handover

- ✿ Need to specify an optimum signal level to initiate a handoff.
- ✿ Minimum useable signal for acceptable voice quality at the base station receiver is normally taken as between -90 dBm to -100 dBm.
- ✿ $\Delta = Pr_{\text{handoff}} - Pr_{\text{minimum-useable}}$
- ✿ If Δ is too large, unnecessary handoffs may occur.
- ✿ If Δ is too small, there may be insufficient time to complete a handoff.

Illustration of a handoff scenario at cell boundary

(a) Improper handoff situation



(b) Proper handoff situation

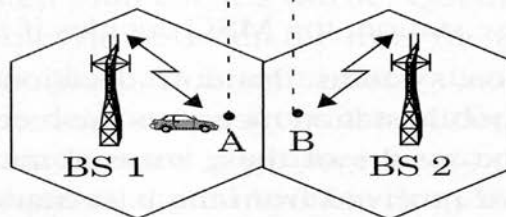
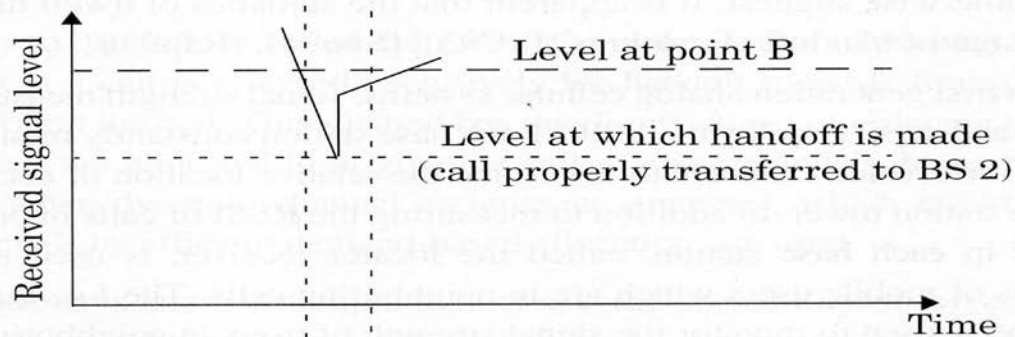


Illustration of a Handoff Scenario at Cell Boundary

- Figure (a) demonstrates the case where a handoff is not made and the signal drops below the minimum acceptable level to keep the channel active.
- The dropped call event in figure (a) can happen when there is an excessive delay by the MSC in assigning a handoff or when the threshold Δ is set too small for the handoff time the system.
- Excessive delays may occur during high traffic conditions due to computational loading at the MSC or due to the fact that no channels are available on any of the nearby base stations.

Handoff / Handover

- ✿ During handoff, it is important to ensure that the drop in the measured signal level is not due to momentary fading and that the mobile is actually moving away from the serving base station.
- ✿ The base station monitors the signal level for a certain period of time before a hand-off is initiated.
- ✿ The time over which a call may be maintained within a cell, without hand-off, is called the *dwel time*.

Handoff in 1st Generation Cellular Systems

- ✿ Signal strength measurements are made by the base stations and supervised by the MSC.
- ✿ Base station monitor the relative location of each user.
- ✿ *Locator receiver* is used to determine signal strengths of users in neighboring cells and is controlled by the MSC.
- ✿ Based on the information from locator receiver, MSC decides if a handoff is necessary or not.



Handoff in 2nd Generation TDMA Systems

- ✿ Handoff decisions are mobile assisted.
- ✿ In *mobile assisted handoff* (MAHO), every mobile measures the received power from surrounding base stations and reports the results to the serving base station.
- ✿ MAHO enables the call to be handed over at a much faster rate.



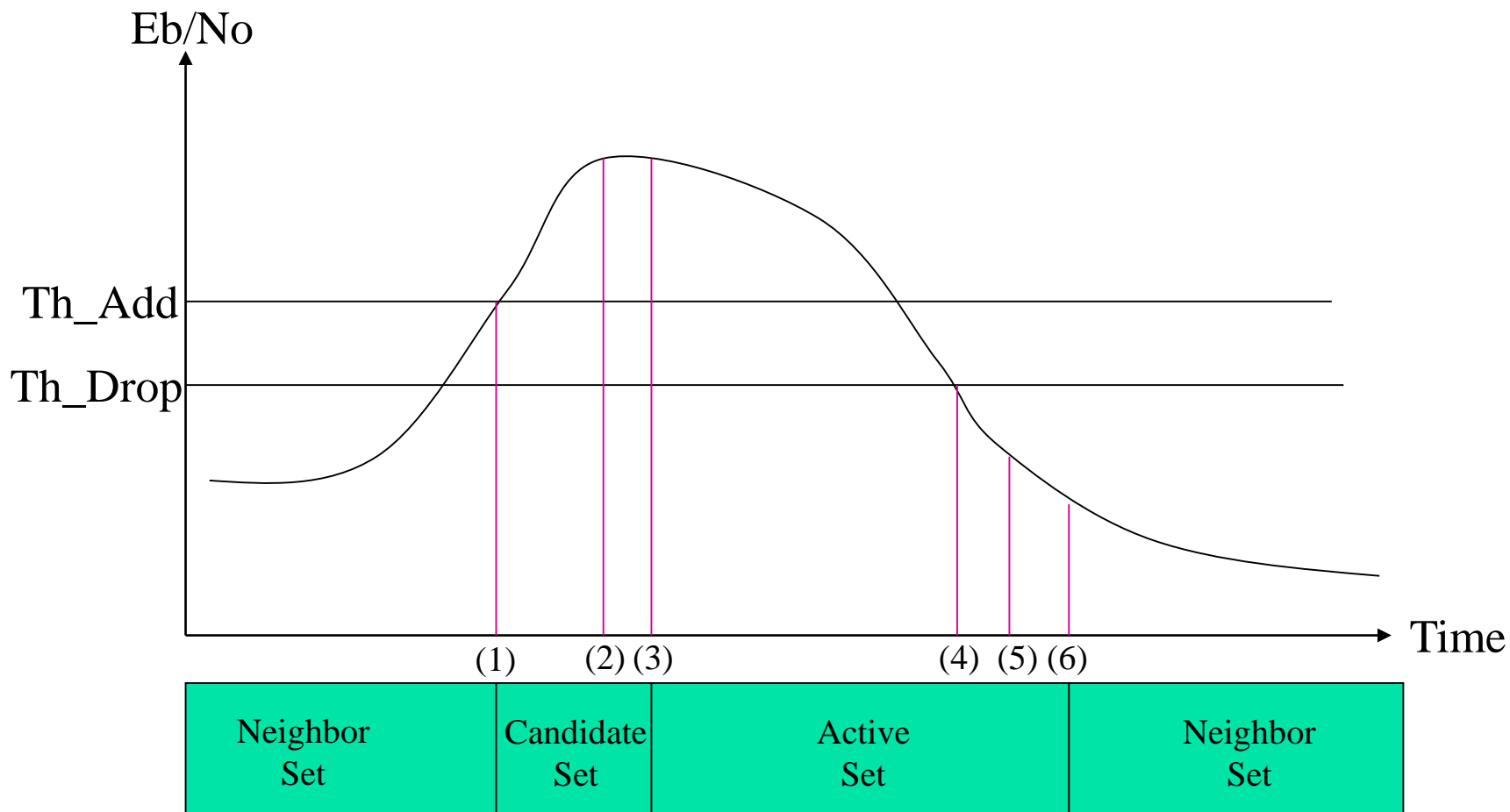
Handoff or Handover

- ✿ Mobile Assistant Handover – more efficient.
 - ✿ GSM:
 - ✿ MS monitors all BSs
 - ✿ MS reports the measurements to the BS
 - ✿ MSC makes decision
 - ✿ USDC (IS-54/136):
 - ✿ BSs monitor all MSs.
 - ✿ When a MS is leaving the cell, the BS sends it a measurement order
 - ✿ The MS begins its measurement and reports
 - ✿ MSC makes the Handover decision.

Handover Algorithms (IS-95 vs. WCDMA)

- ✿ Basic IS-95 handover algorithm uses **absolute threshold** algorithm.
- ✿ WCDMA handover algorithm users **relative threshold** algorithm.

Absolute Threshold Handover





Basic IS-95 HO Algorithm

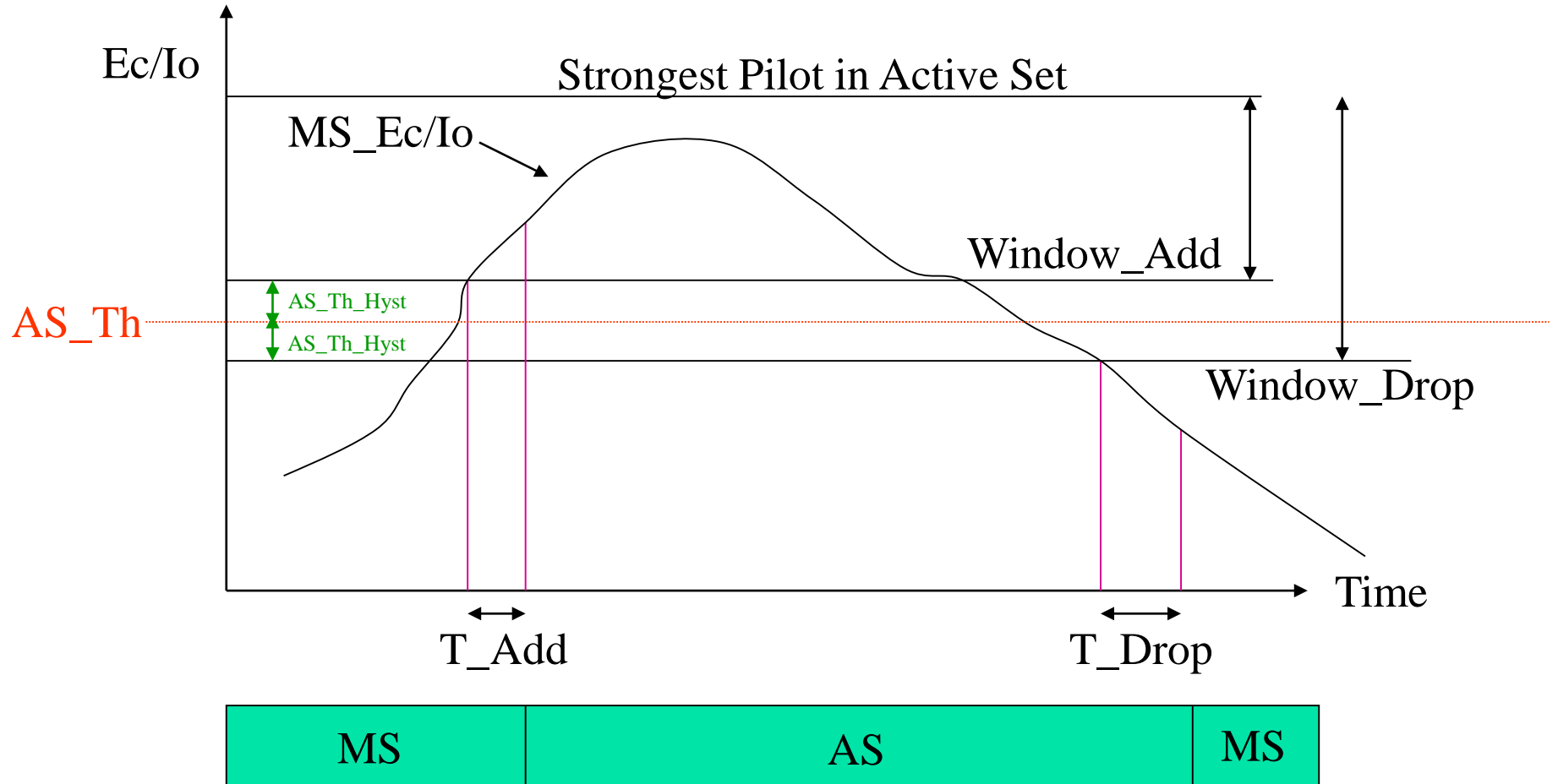
1. Pilot strength exceed T_Add . MS sends a **Pilot Strength Measurement Message** and transfers pilot to the Candidate Set.
2. BS sends a **Handover Direction Message**.
3. Mobile station transfers pilot to the Active Set and sends a **Handover Completion Message**.
4. Pilot strength drops below T_Drop . MS starts the handover drop timer.
5. Handover drop timer expires. MS sends a **Pilot Strength Measurement Message**.
6. BS sends a **Handover Direction Message**. MS moves pilot from the Active Set to the Neighbor Set and sends a **Handover Completion Message**.



Problems with Absolute Threshold Algorithm

- ✿ Some locations in the cell receive only weak pilots (requiring a lower handover threshold).
- ✿ Some locations in the cell receive a few strong and dominant pilots (requiring a higher handover threshold).

Relative Threshold HO

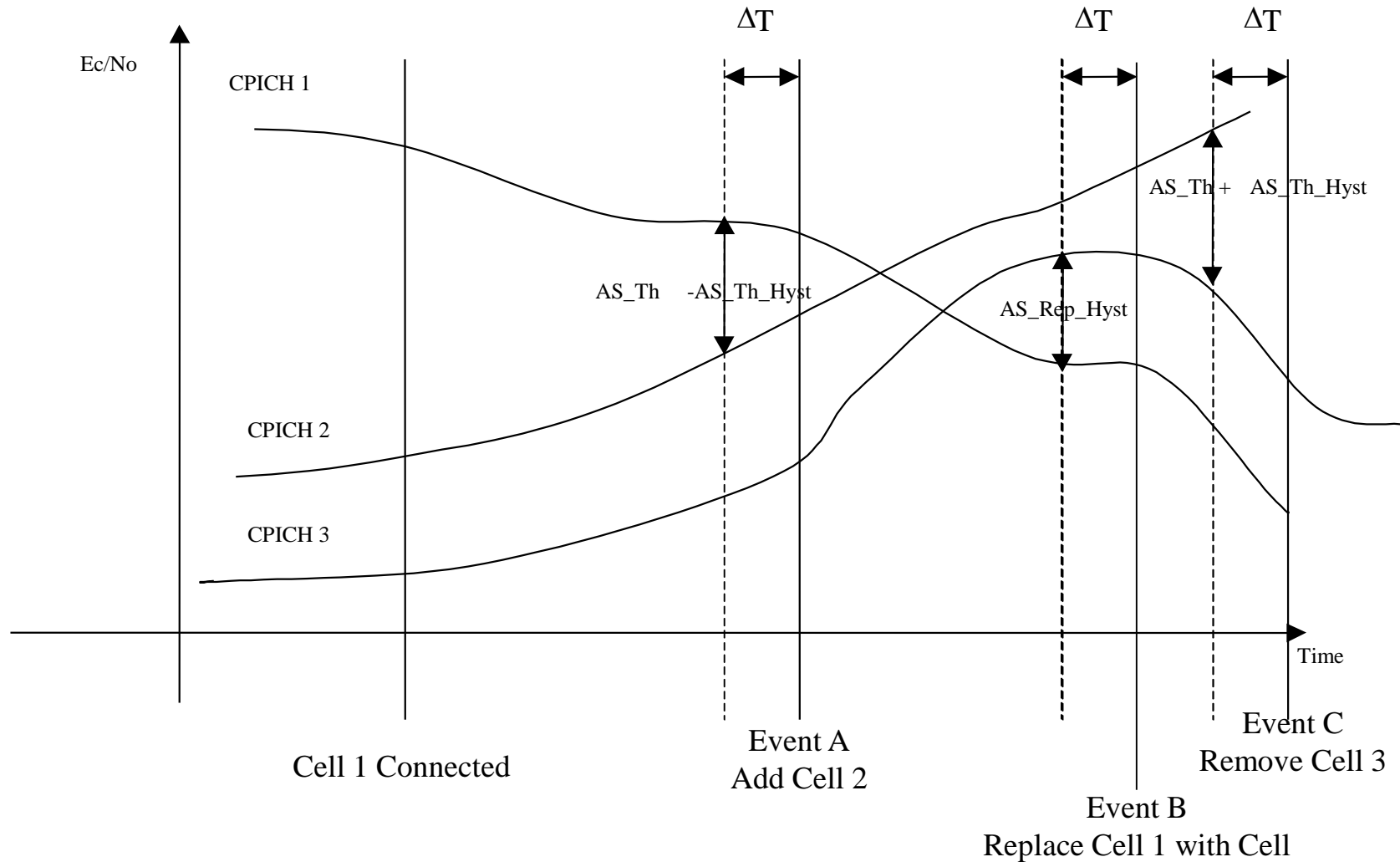




Active vs. Monitored Set

- ☀ Active Set (AS): User information is sent from all these cells and they are simultaneously demodulated and coherently combined.
- ☀ Monitored Set (MS): Cells, which are not included in the active set, but are monitored according to a neighboring list assigned by the UTRAN.

Soft Handover Algorithm (for Active Set limit = 2)





Intersystem Handoff

- ✿ Intersystem handoff happens when a mobile moves from one cellular system to a different cellular system.
- ✿ The MSCs involved in the two cellular systems are different.
- ✿ Compatibility between the two MSCs must be determined.

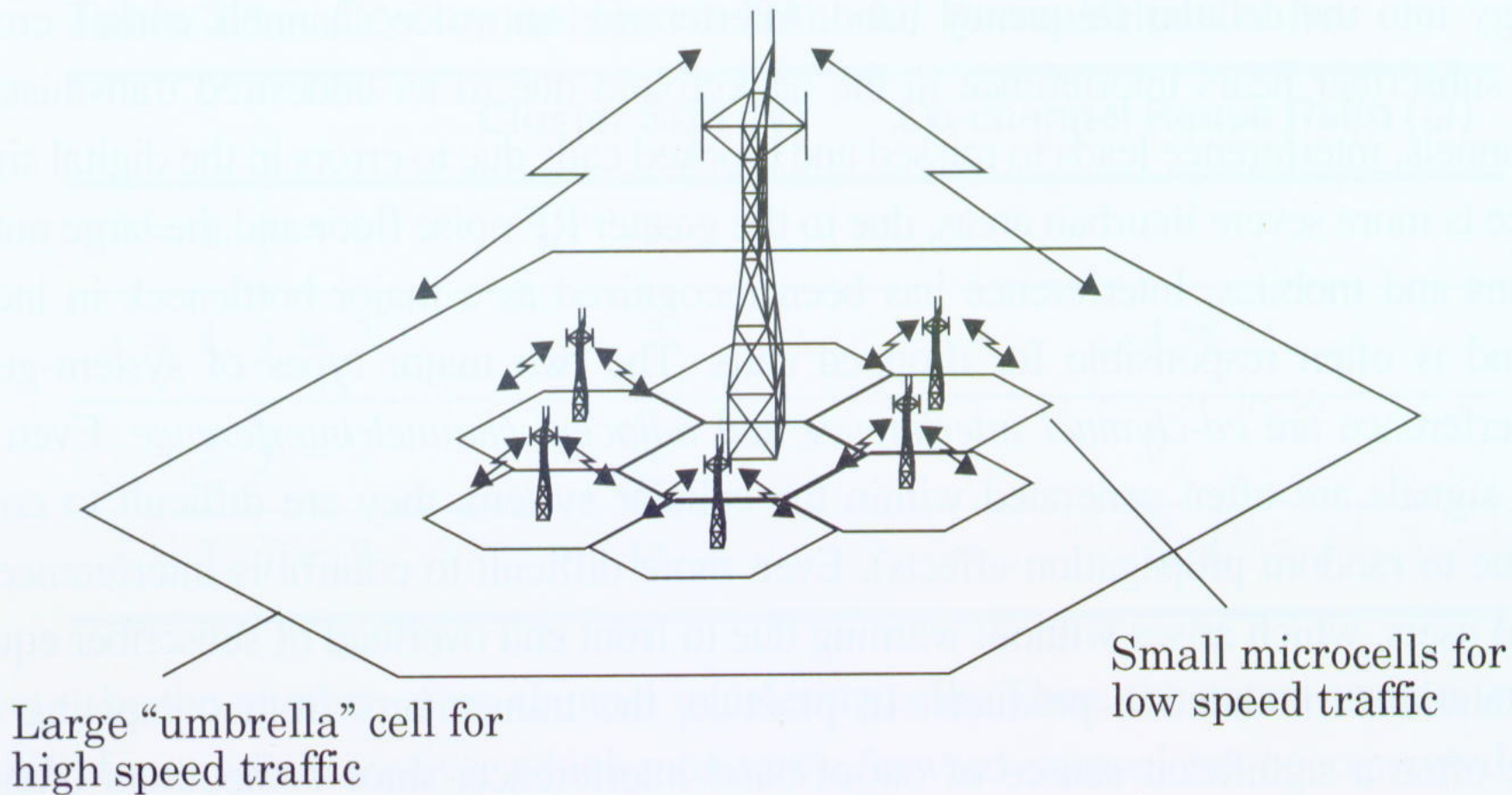
Prioritizing Handover

- ✿ *Guard Channel Concept* : Use reserved guard channel for handover.
 - ✿ Disadvantage: Reducing the total carrier traffic.
- ✿ *Queuing of Handover Requests*: To prevent forced termination by queuing the request.
 - ✿ 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 Handover Consideration

- ✿ **Problem 1:** Simultaneous traffic of high speed and low speed mobiles.
 - ✿ Small cell → high speed mobile → frequent handoff
 - ✿ large cell → Reduce capacity
- ✿ *Solution:* *Umbrella Cell - Cell Split* or *Hierarchical Cell Structure*
 - ✿ By using different antenna heights and different power levels, it is possible to provide large and small cells which are co-located at a single location.
 - ✿ Small cell for low speed mobile
 - ✿ Large cell for high speed mobile
 - ✿ Need Strength Detection and Handoff control.

The Umbrella Cell Approach



Practical Handover Consideration

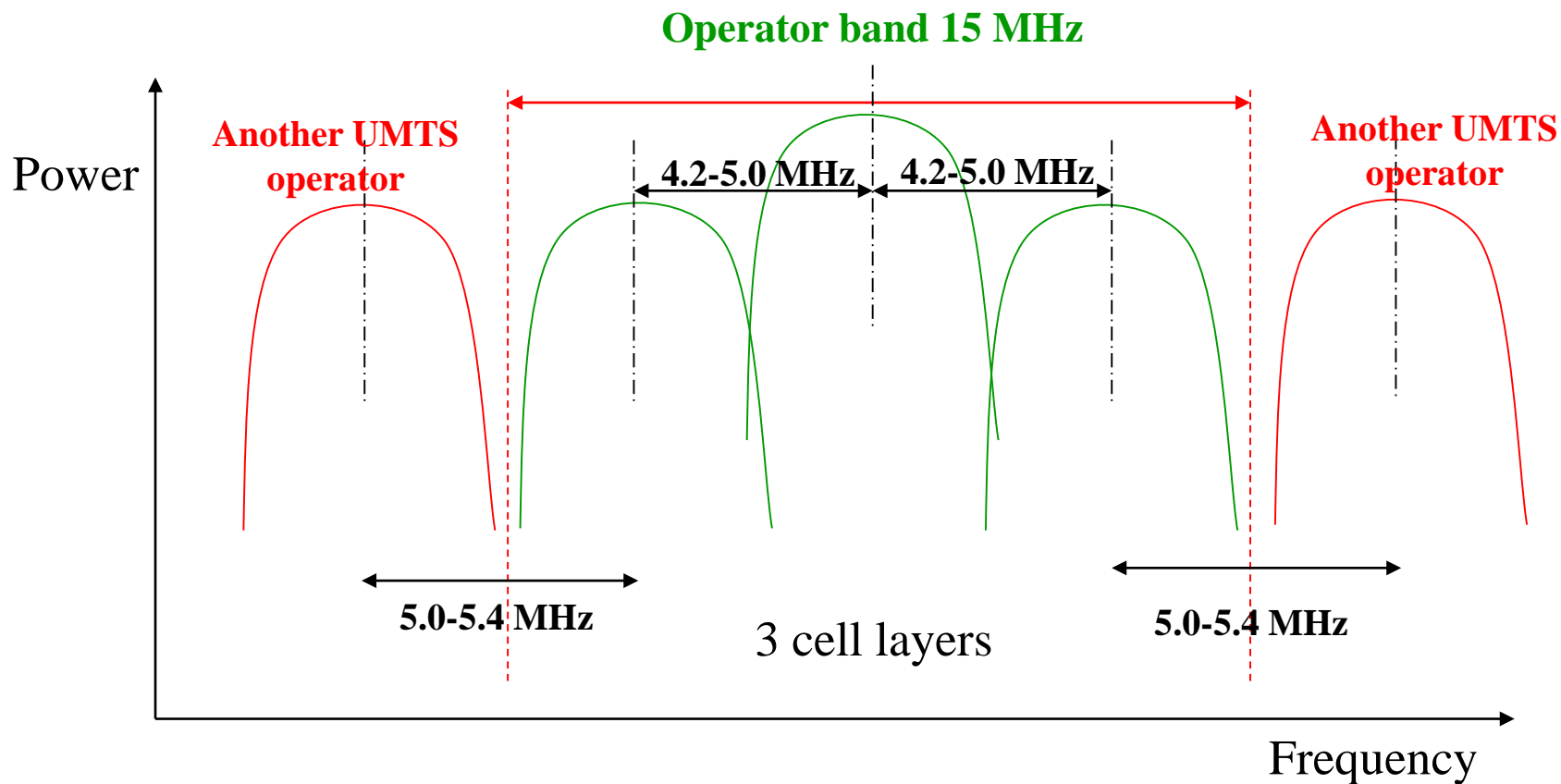
✿ Problem 2: *Cell Dragging*

- ✿ Caused by pedestrian users that provide a very strong signal to the base station.
- ✿ Often occurs in an urban environment when there is a line-of-sight (LOS) radio path between the subscriber and the base station.
- ✿ As the user travels away from the base station at a very low speed, the average signal strength does not decay rapidly and the received signal at the BS may be above the handoff threshold, thus a handoff may not be made.
- ✿ Creates a potential interference and traffic management problem.
- ✿ Solution: Careful arrangement of handoff threshold and radio coverage parameters.

Handoff Miscellaneous

- ✿ Intra-frequency Handoff: handoffs in the same system and carrier.
- ✿ Inter-frequency Handoff: handoffs between same systems and different carriers.
 - ✿ May be used for handoff between different cell layers of the multi-layered cellular network, when the cell layers use different carrier frequencies.
- ✿ Inter-system Handoffs: handoffs between different systems.
- ✿ Inter-frequency and inter-system handoffs may be used for coverage or load balancing reasons.

Frequency Utilization with WCDMA



Uplink: 1920-1980 MHz

Downlink: 2110-2170 MHz



Intra-Frequency Handoff

- ✿ *Hard Handoff*: assign different radio channels during a handoff.
- ✿ *Soft Handoff*: the ability to select between the instantaneous received signals from a variety of base stations.
 - ✿ Soft handoff exploits macroscopic space diversity provided by the different physical locations of the base stations.
- ✿ *Softer Handover*: A mobile station is in the overlapping cell coverage area of two adjacent sectors of a base station.

LTE Handover Overview



Basic Objective of Handover Procedures

- ✿ LTE became the first All-IP mobile network.
- ✿ Basic objective of handover procedures are:
 - ✿ QoS should be maintained all the time. Not after handover but during handover as well.
 - ✿ Handover should not drain UE battery.
 - ✿ UE should be able to continue its normal services before and after handover. For example a voice call before handover should be maintained after handover as well.
 - ✿ Seamless handoff between 2G/3G/CDMA/LTE technologies.

Types of Handover Approach

- ✿ Normally there are two types of handover approach available in mobile networks:
 - ✿ Network Controlled: In this case, network makes handover decision.
 - ✿ Mobile Evaluated: The UE will make handover decisions and inform network about it. But still network takes the final decision based on radio resource available in target cell.
- ✿ In LTE network a hybrid approach is used.
- ✿ UE sends measurement information to network and based on those measurements network asks UE to move to a target cell.

Types of Handover in LTE Network

- ✿ Intra-LTE Handover: In this case source and target cells are part of the same LTE network.
- ✿ Inter-LTE Handover: Handover happens towards other LTE nodes. (Inter-MME and Inter-SGW)
- ✿ Inter-RAT (Radio Access Technology):

Intra-LTE Handovers

- ✿ **Intra-MME/SGW: Handover using X2 Interface**
 - ✿ X2 is the interface between two eNodeBs, serving eNodeB and target eNodeB in this case. When X2 interface is present then handover is completed without EPC (Evolved Packet Core) involvement. The release of the resources at source eNodeB is triggered by target eNodeB.
- ✿ **Intra-MME/SGW: Handover using S1 Interface**
 - ✿ In case when X2 interface is not available and source eNodeB and target eNodeB are part of same MME/SGW then handover is carried out through S1 interface. The S-eNB initiates the handover by sending a Handover required message over the S1-MME reference point. The EPC does not change the decisions taken by the S-eNB.

Inter-LTE Handovers

✿ Inter-MME Handover

- ✿ In Inter-MME handover two MME are involved in handover, source MME and target MME. The source MME (S-MME) is in charge of the source eNodeB and target MME (T-MME) is in charge of target eNodeB.
- ✿ Inter-MME handover occurs when UE moves between two different MMEs but connected to same SGW.

✿ Inter-MME/SGW Handover

- ✿ This is same as Inter-MME but only difference is that here UE need to move from one MME/SGW to another MME/SGW. Source eNodeB is part of one MME/SGW and target eNodeB is in another MME/SGW.

Inter-RAT Handover

- ✿ **Handover from eUTRAN to UTRAN**
 - ✿ In case of handover between eUTRAN to UTRAN, the source eNodeB is connected to source MME and SGW and target RNC is connected to Target SGSN and Target SGW.
 - ✿ First the required resources are reserved in UTRAN system and the handover is carried out.

Interference and System Capacity



Interference

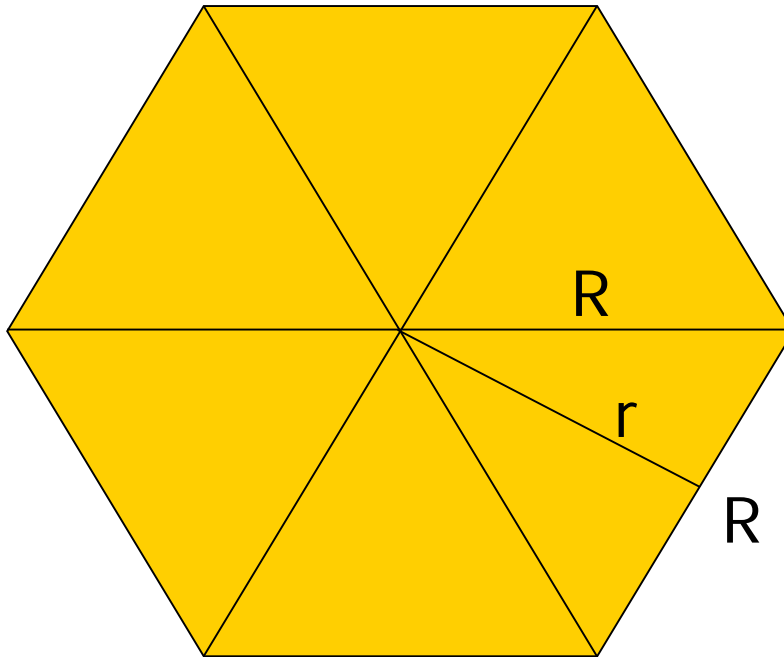
- ✿ The major source limiting cellular system capacity comes from interferences (as oppose to noise).
- ✿ Interference has been recognized as a major bottleneck in increasing capacity and is often responsible for dropped calls.

- ✿ Major Types of Interference:
 - ✿ Co-Channel Interference
 - ✿ Adjacent Channel Interference
 - ✿ Intra-Cell Type
 - ✿ Inter-Cell Type

Co-channel Cells and Interference

- ✿ In a given coverage area, there are several cells that use the same set of frequencies. These cells are called *co-channel cells*.
- ✿ The interference between signals from co-channel cells is called *co-channel interference*.
- ✿ Unlike thermal noise which can be overcome by increasing the signal-to-noise ratio (SNR), co-channel interference can't be overcome by simply increasing the carrier power because an increase in carrier 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.

Hexagon



$$r = \frac{\sqrt{3}}{2} \cdot R$$

$$\text{Cell Area} = \frac{(r \cdot R)}{2} \cdot 6 = \frac{3\sqrt{3}}{2} \cdot R^2 = 2\sqrt{3}r^2$$

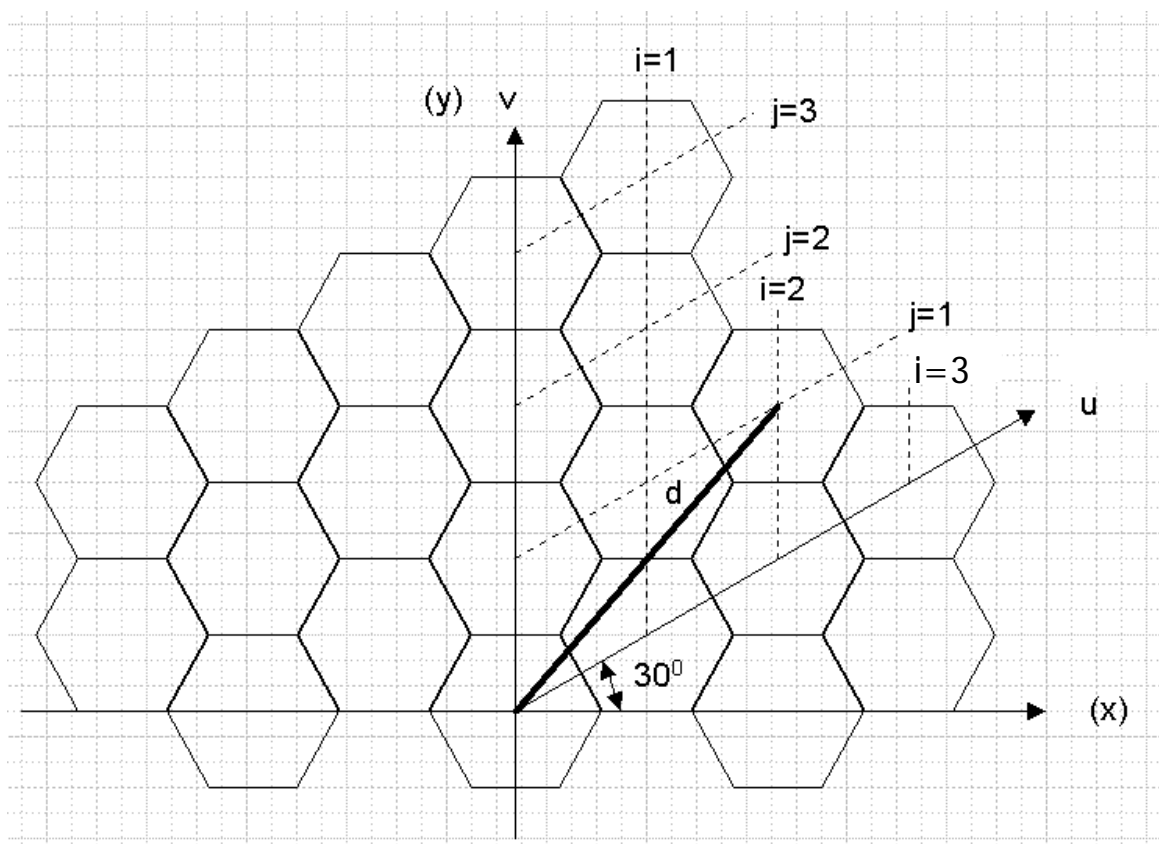
Hexagon

A cell centered at (u, v)

$$(u, v) = (2ri, 2rj)$$

$$x = u \cdot \cos(30^\circ) = \frac{\sqrt{3}}{2} \cdot u$$

$$y = u \cdot \sin(30^\circ) + v = \frac{u}{2} + v$$



Hexagon Distance

- Distance between (u_a, v_a) and (u_b, v_b)

$$\begin{aligned}
 D_{ab}^2 &= (x_a - x_b)^2 + (y_a - y_b)^2 \\
 &= \left(\frac{\sqrt{3}}{2} u_a - \frac{\sqrt{3}}{2} u_b \right)^2 + \left(\frac{u_a}{2} - \frac{u_b}{2} + v_a - v_b \right)^2 \\
 &= (u_a - u_b)^2 + (v_a - v_b)^2 + (u_a - u_b) \cdot (v_a - v_b) \\
 &= (2r)^2 \cdot \left[(i_a - i_b)^2 + (j_a - j_b)^2 + (i_a - i_b)(j_a - j_b) \right]
 \end{aligned}$$

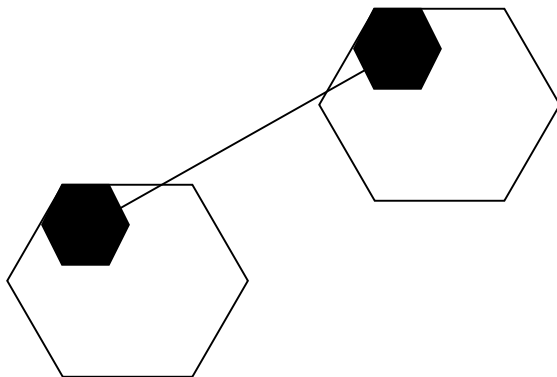
- For special case (distance from origin)

$$D = 2r \cdot \sqrt{i^2 + j^2 + ij}$$

Hexagonal Cluster

✿ Hexagonal Cluster

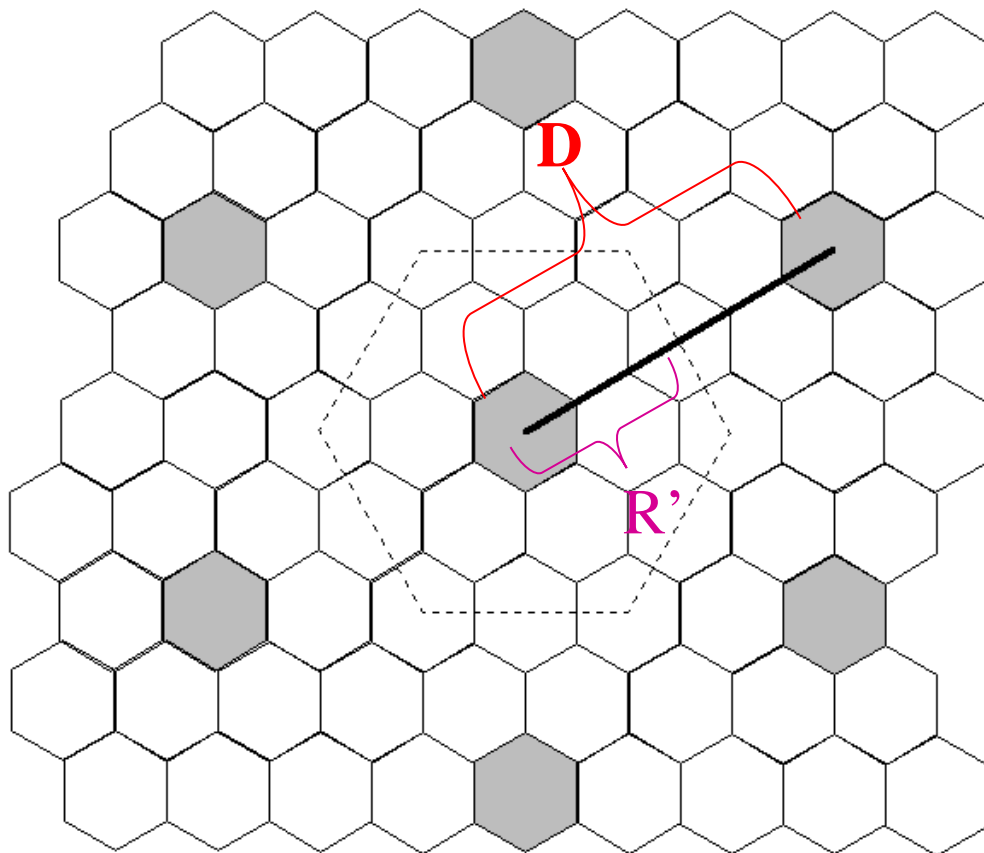
- ✿ Each cluster is surrounded by six similar clusters with the same orientation
- ✿ Each cluster has a total area equivalent to what can be called a “*super-hexagon*”
 - ✿ view a cluster as a “hexagon”



$$D = 2r \cdot \sqrt{i^2 + j^2 + ij}$$

Super-Hexagon Concept

D = Frequency Reuse Distance



$$\begin{aligned}
 R' &= \frac{D}{2} \\
 N &= \frac{A_{\text{Super-Hexagon}}}{A_{\text{Cell}}} \\
 &= \frac{(2\sqrt{3}R'^2)}{(2\sqrt{3}r^2)} \\
 &= i^2 + j^2 + i \cdot j \\
 &= \text{Cluster Size}
 \end{aligned}$$

Co-Channel Reuse Ratio

- The signal to co-channel interference ratio is independent of the transmitted power and becomes a function of the radius of the cell (R) and the distance between centers of the nearest co-channel cells (D).
- Co-channel Reuse Ratio Q* : The spatial separation between co-channel cells relative to the coverage distance of a cell.

$$\begin{aligned}
 D &= 2 \cdot r \cdot \sqrt{i^2 + j^2 + i \cdot j} \\
 &= 2 \cdot r \cdot \sqrt{N} \\
 &= R \cdot \sqrt{3N}
 \end{aligned}$$

$$r = \frac{\sqrt{3}}{2} \cdot R$$

$$Q = \frac{D}{R} = \sqrt{3N}$$

CO-Channel Reuse Ratio

Table 2.1 Co-channel Reuse Ratio for Some Values of N

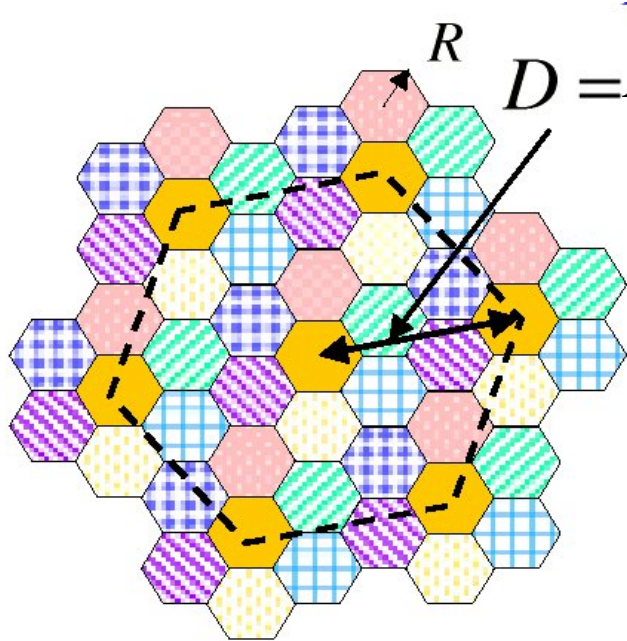
	Cluster Size (N)	Co-channel Reuse Ratio(Q)
$i = 1, j = 1$	3	3
$i = 1, j = 2$	7	4.58
$i = 2, j = 2$	12	6
$i = 1, j = 3$	13	6.24

Small $Q \rightarrow$ Small $N \rightarrow$ Large Capacity

Large $Q \rightarrow$ Large $N \rightarrow$ Small Level of Co-Channel Interference

Co-Channel Signal to Interference Ratio (SIR)

- ✿ SIR: Signal to Interference Ratio.
- ✿ Consider only first tier interference.
- ✿ Assuming all interfering BS' s are equal-distance.



$$D = R \cdot \sqrt{3N} \quad \frac{S}{I} = \frac{S}{\sum_{i=1}^{i_0} I_i} \quad P_r = P_0 \left(\frac{d}{d_0} \right)^{-n}$$

Worst Case (Mobile)

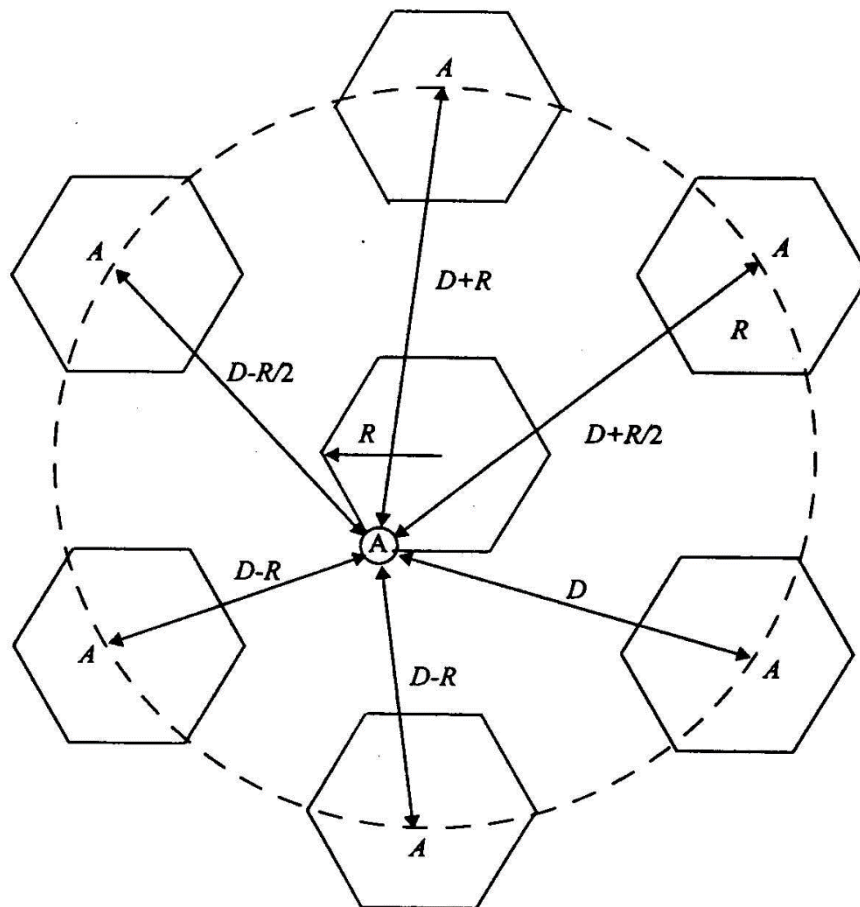
$$\text{SIR} = \frac{P_t R^{-n}}{\sum_{i=1}^{i_0} P_t d_i^{-n}} \approx \frac{R^{-n}}{i_0 D^{-n}} = \frac{(\sqrt{3N})^n}{i_0}$$

Example: $i_0=6, n=4$

$N=3 \Rightarrow \text{SIR}=11.3 \text{ dB}$

$N=7 \Rightarrow \text{SIR}=18.7 \text{ dB}$

7-Cell Co-channel Signal to Interference Ratio



An approximation of the exact geometry.



7-Cell Co-Channel Signal to Interference Ratio – An Approximation

$$\frac{S}{I} = \frac{R^{-n}}{2(D-R)^{-n} + 2(D+R)^{-n} + 2D^{-n}}$$

$$\frac{S}{I} = \frac{1}{2(Q-1)^{-4} + 2(Q+1)^{-4} + 2Q^{-4}}$$



Adjacent Channel Interference

- ✿ Adjacent channel interference results from imperfect receiver filters which allow nearby frequencies to leak into the passband.
- ✿ Adjacent channel interference can be minimized through careful filtering and channel assignments.
- ✿ Channels are allocated such that the frequency separation between channels in a given cell is maximized.

Near-Far Effect

- ✿ A nearby transmitter (which may or may not be of the same type as that used by the cellular system) captures the receiver of the subscriber.
- ✿ Alternatively, the near-far effect occurs when a mobile close to a base station transmits on a channel close to one being used by a weak mobile. The base station may have difficulty in discriminating the desired mobile user from the close adjacent channel mobile.

Power Control





Power Control for 2G Cellular Systems

- ✿ Power levels transmitted by subscriber unit are under control by the serving base stations.
- ✿ Power control is 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 reduces the reverse channel S/I in the system.

Power Control in 3G (WCDMA)

- ✿ Tight and fast power control is perhaps the most important aspect in WCDMA in particular on the uplink. Without it, a single overpowered mobile could block a whole cell.
- ✿ Near-Far problem of CDMA: A MS close to the base station may be overpowered and block a large part of the cell.
- ✿ Power control in WCDMA:
 - ✿ Open-loop power control
 - ✿ Close-loop power control
 - ✿ Inner-loop power control
 - ✿ Outer-loop power control

Open Loop Power Control in WCDMA

- ✿ Attempt to make a rough estimation of path loss by measuring downlink beacon signal.
- ✿ Disadvantage: Far too inaccurate, because fast fading is essentially uncorrelated between uplink and downlink, due to the large frequency separation of uplink and downlink band of the WCDMA FDD mode.
- ✿ Open-loop power control is used in WCDMA to provide a coarse initial power setting of the MS at the beginning of a connection.

Outer Loop Power Control in WCDMA

- ✱ To adjust the target SIR setpoint in the BS according to the individual radio link quality requirements, usually defined as BER or FER.
- ✱ The required SIR for FER depends on the mobile speed, multipath profile, and data rate.
- ✱ Should the transmission quality is decreasing, the Radio Network Controller (RNC) will command the Node B to increase the target SIR.
- ✱ Outer loop power control is implemented in RNC because there might be soft handover combining.

Inner-loop Power Control in WCDMA Uplink

- ✿ Base station performs frequent estimates of the received Signal-to-Interference Ratio (SIR) and compares it to a target SIR.
 - ✿ If the measured SIR is higher than the target SIR, the base station will command the MS to lower the power.
 - ✿ If SIR is too low, it will command the MS to increase its power.
- ✿ The power control is operated at a rate of 1500 times per second.

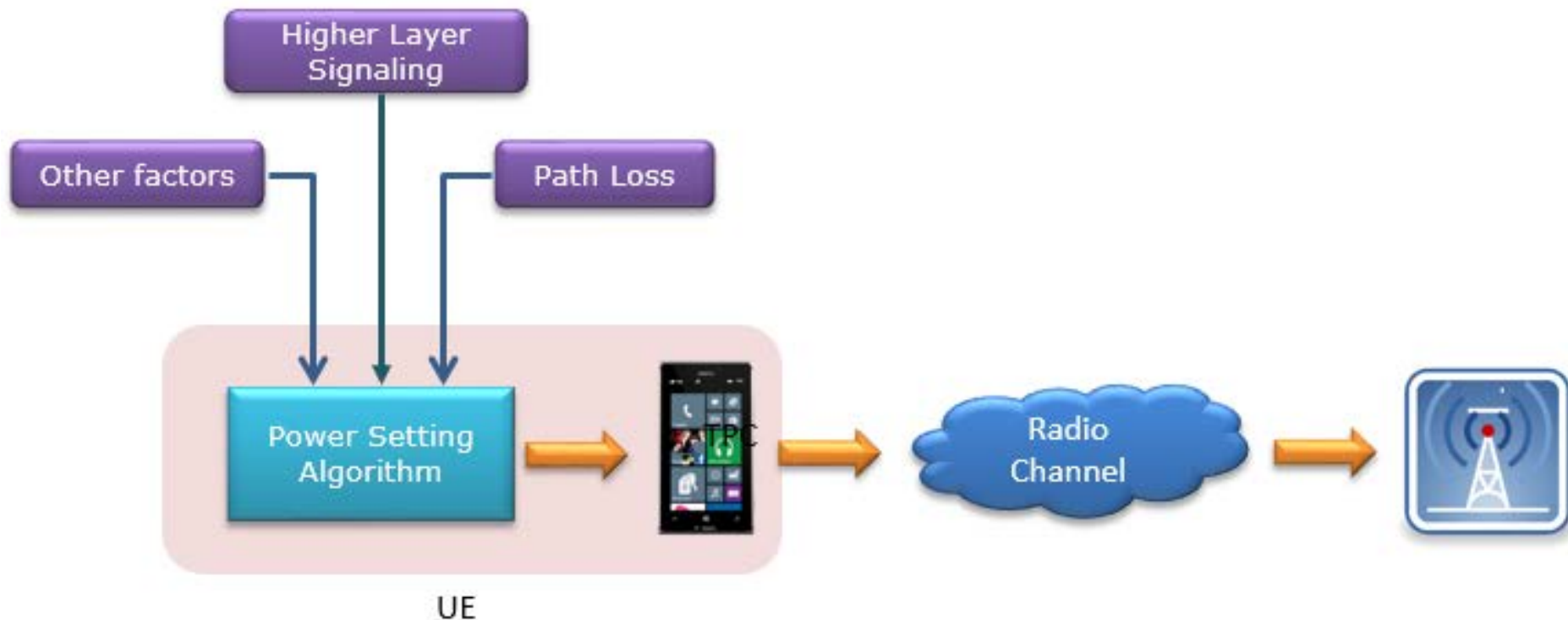


Inner-loop Power Control in WCDMA Downlink

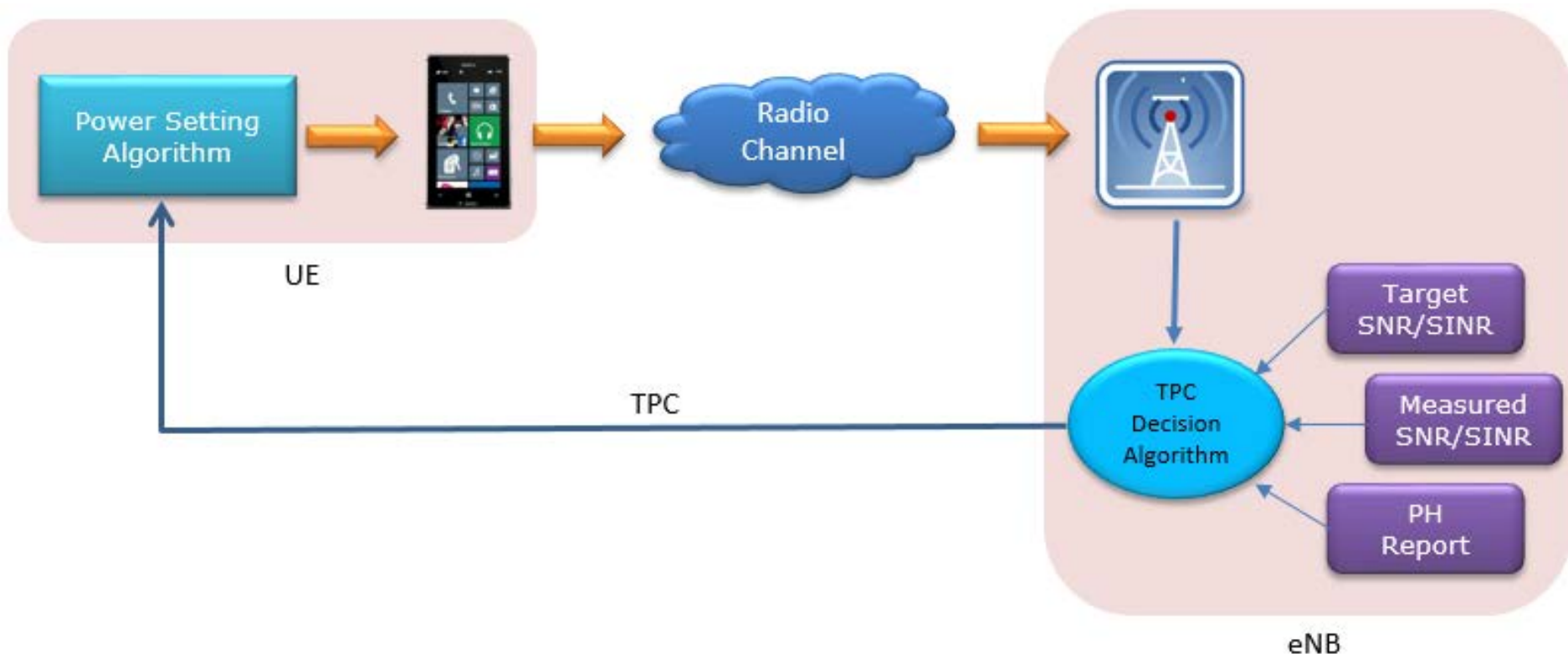
- ✿ Adopt same techniques as those used in uplink.
- ✿ Operate at a rate of 1500 times per second.
- ✿ There is no near-far problem in downlink.
- ✿ Purposes for downlink closed-loop power are:
 - ✿ Provide a marginal amount of additional power to MS at the cell edge as they suffer from increased other-cell interference.
 - ✿ Enhancing weak signals caused by Rayleigh fading at low speeds when other error-correcting methods (interleaving and error correcting codes) doesn't work effectively.

Overall Flow for Open Loop Power Control in LTE

< Overall Flow for Open Loop Power Control >



Overall Flow for Open Loop Power Control in LTE



Improving Capacity in Cellular Systems





System Expansion Techniques

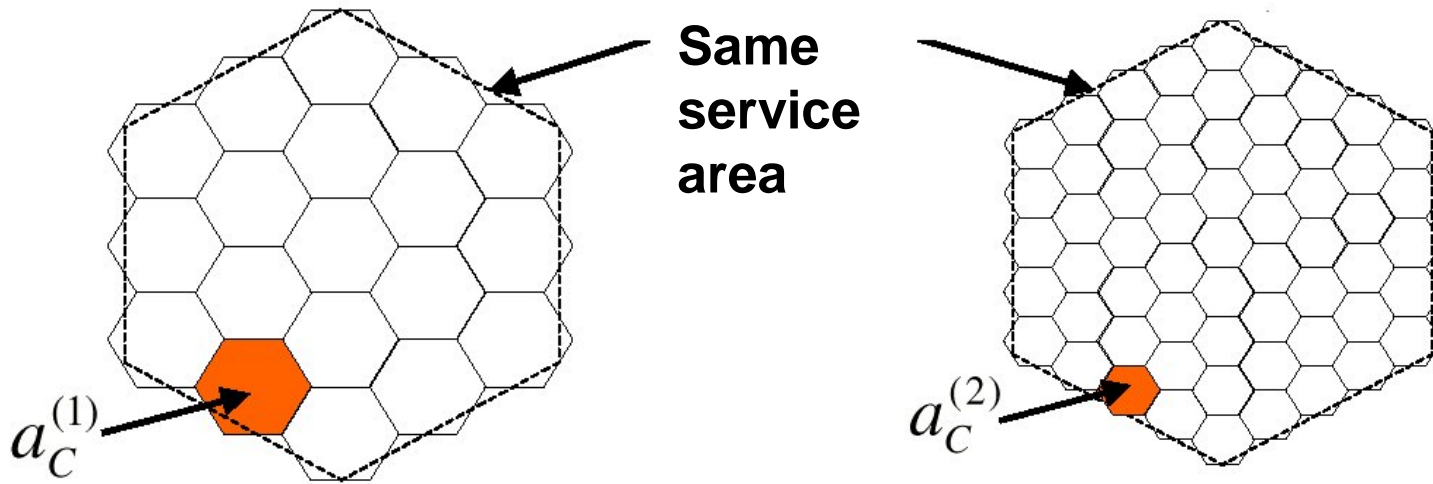
- ✿ Adding New Channels
- ✿ Frequency borrowing
- ✿ Cell Splitting
- ✿ Sectoring / Sectorization
- ✿ Change of Cell Pattern

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.

Cell Splitting

- Cell splitting \Rightarrow small cells (microcells)



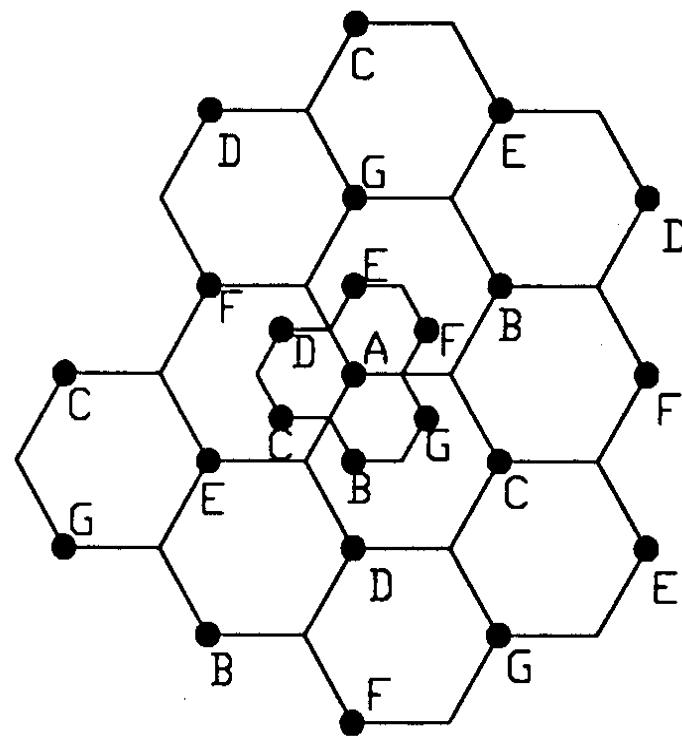
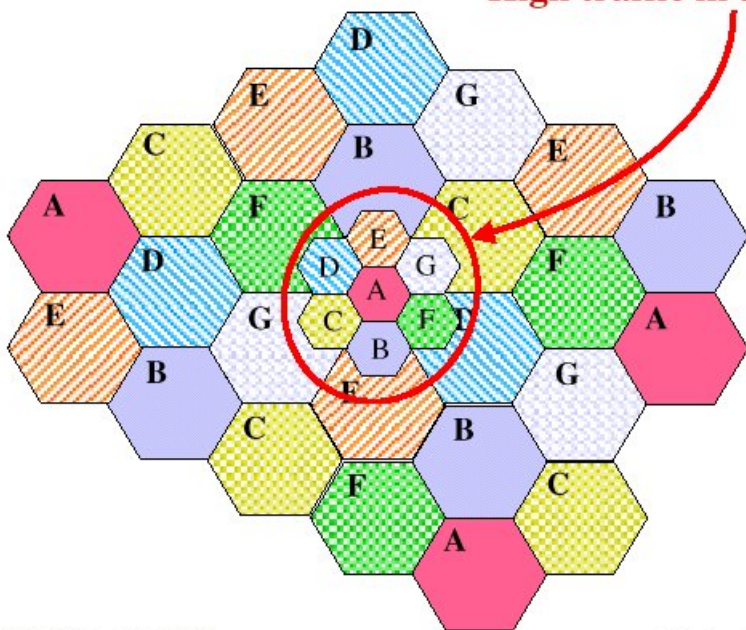
More cells in the service area, more capacity.

Cell Splitting

Cell Splitting

(Hot Spot)

High traffic in this area



Transmit Power for Split cell

- ✿ The transmit power of the split cell must be reduced.
- ✿ For example, if new cell radius is half of that of old cell and the path loss exponent $n = 4$:

$$P_r[\text{at old cell boundary}] \propto P_{t1} R^{-n}$$

$$P_r[\text{at new cell boundary}] \propto P_{t2} (R/2)^{-n}$$

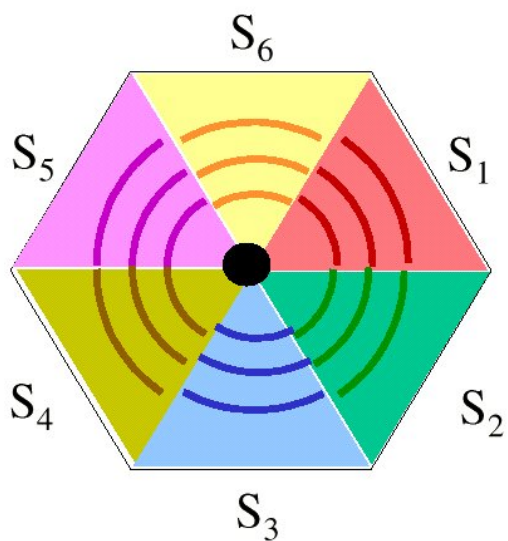
$$P_r[\text{at new cell boundary}] = P_r[\text{at old cell boundary}]$$

$$P_{t2} = \frac{P_{t1}}{16}$$

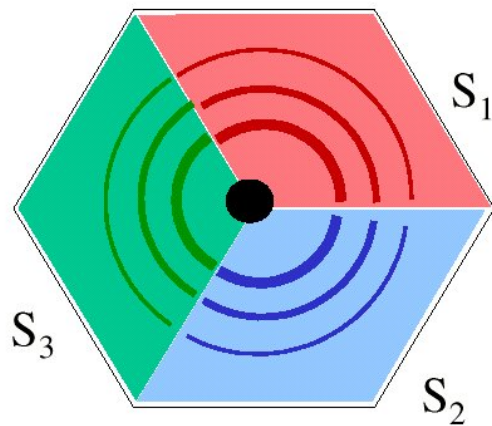
Sectoring

- ✿ 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.
- ✿ # of antenna \uparrow , # of handover \uparrow , trunking efficiency \downarrow

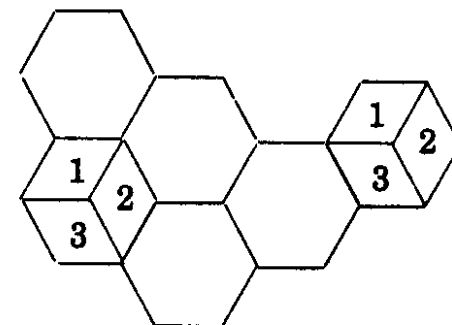
Sectoring



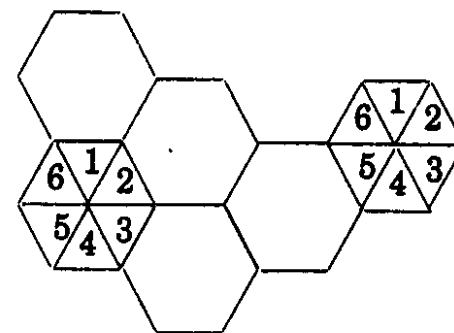
6 sectors, $BW = 60^\circ$



3 sectors, $BW = 120^\circ$

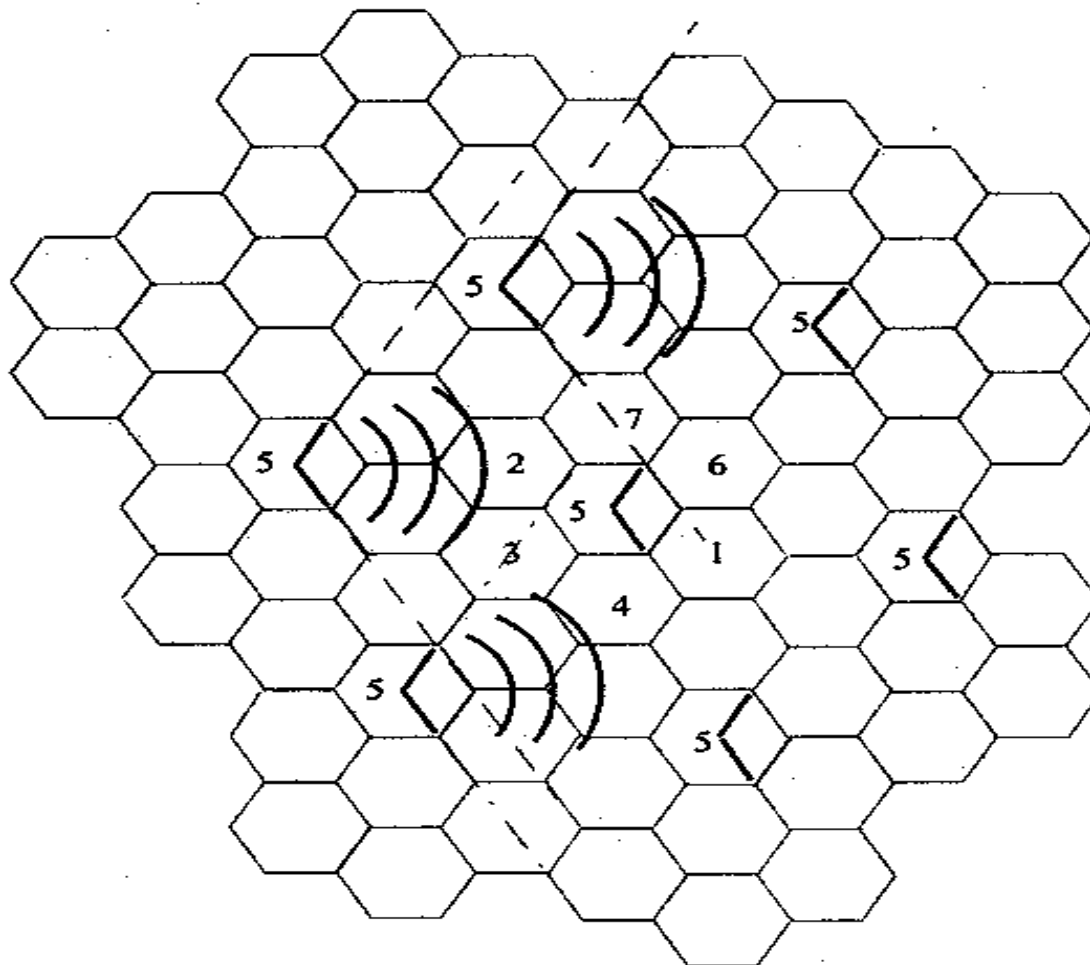


(a)

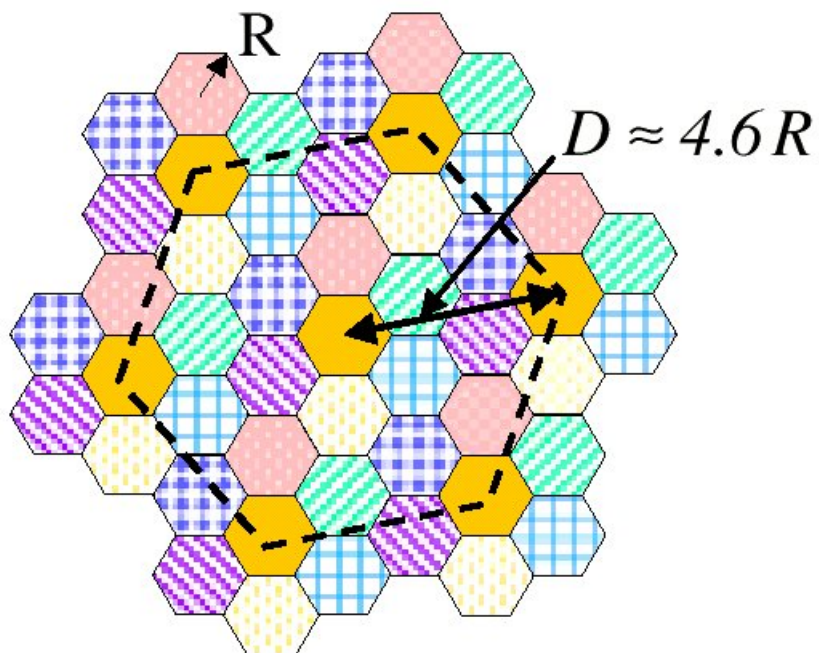


(b)

Sectoring

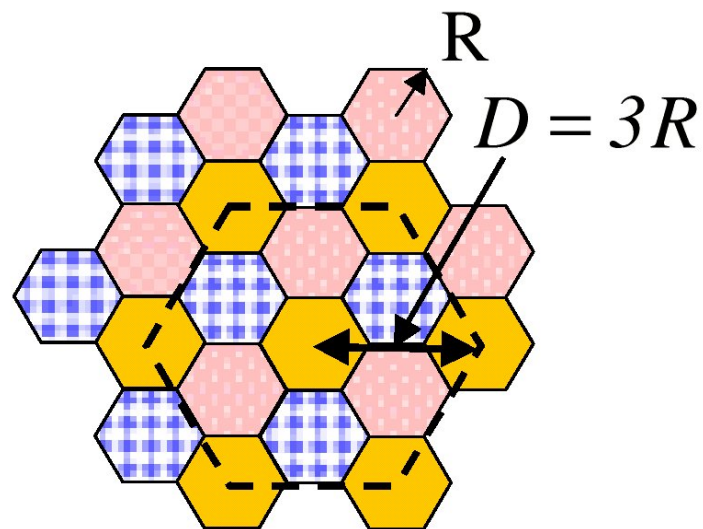


Chang of cell Pattern



$N=7, \Rightarrow C_T/7$ channels per cell

high SIR



$N=3, \Rightarrow C_T/3$ channels per cell

low SIR (\Leftarrow by-product)