CDMA & UTRAN Specific Aspects

Dr. Hicham Aroudaki

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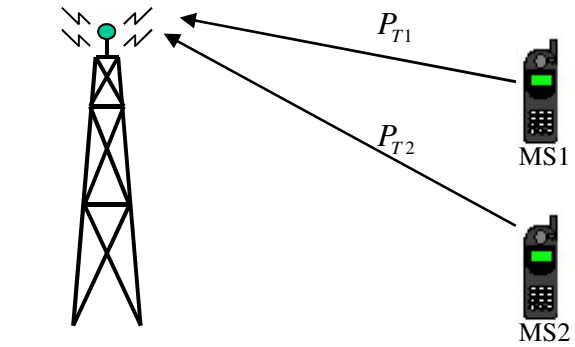
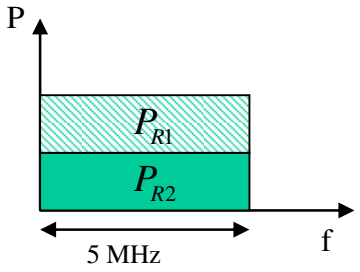
Power Control

Near Far Effect

Ideal CDMA System

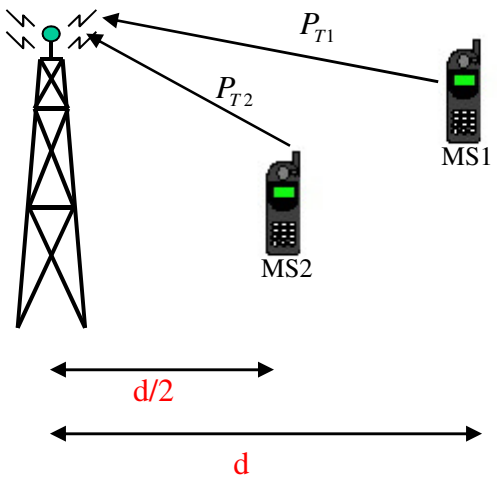


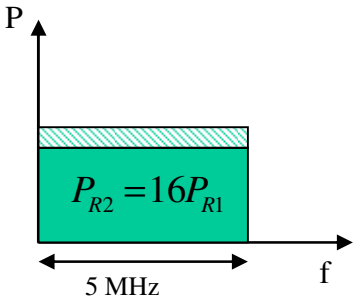


$$P_{R1} = P_{R2}$$

$$\frac{C}{I} = \frac{P_{R1}}{P_{R2}} = 1$$

Near-Far Effect





$$P_{R2} = \frac{1}{(d/2)^4} \cdot P_{R1}$$

$$P_{R1} \approx \frac{1}{16} \cdot P_{R2}$$

$$\frac{C}{I} = \frac{P_{R1}}{P_{R2}} = \frac{1}{16}$$

Background on Near Far Effect

- The near-far effect occurs in mobile radio systems that use single detection.
- The near-far effect is a problem in the uplink.
- The value of the autocorrelation function of the code sequence and the sum of the cross-correlation functions are sampled with all other code sequences at the input to the correlation filter receiver.
- In ideal circumstances (orthogonal codes and synchronous transmission), this part, the multiple-access interference equals zero.
- When mobile stations have the same transmitter power, the signal of one of the users close to the base station is received considerably stronger than the signal of a user who is further away. Hence, the bit error ratio of the remote user is much greater than that of the closer user. This is called the **near-far effect**.
- It only occurs if channel talkover also exists between code channels-for example, through a lack of synchronization or only quasi-orthogonal codes.
- This problem calls for uplink power control. The mobile stations far away from the base station should transmit with considerably higher power than mobiles close to the base station.

What is Power Control?

Power control refers to the strategies or techniques required in order to adjust, correct and manage the power from the BS/MS in both directions (i.e. uplink and downlink) in an efficient manner.

- ***Uplink***: Because of different attenuation signals to/from users nearer to BS are stronger than signals to/from further located users.
- ***Downlink***: Because of the nature of attenuation at the cell border the users experience higher interference that near to the BS. They have high level of interfering signals from own BS and from other BS..

Why Power Control - Uplink

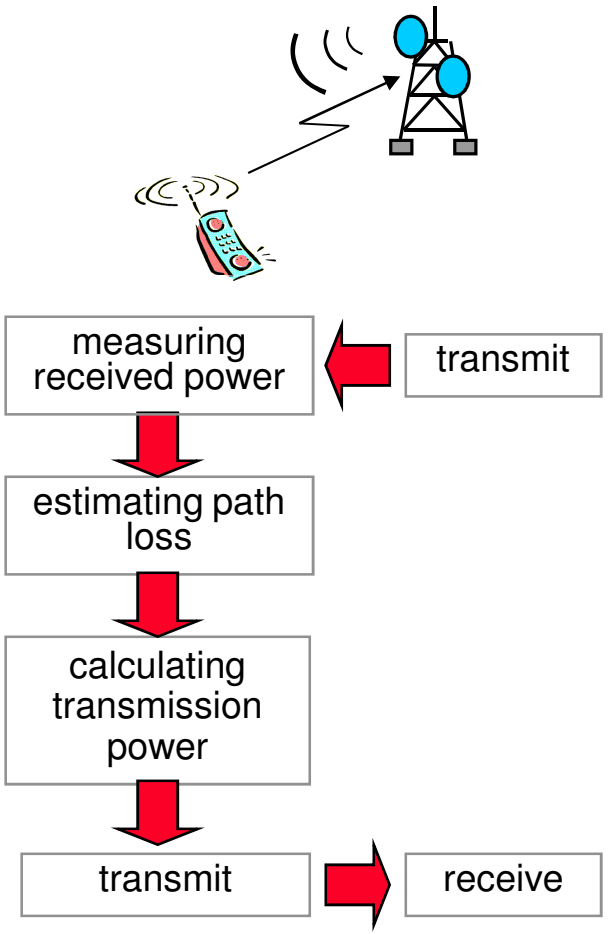
- In the uplink direction, all signals should arrive at the base station's receiver with the same signal power.
- The mobile stations cannot transmit using fixed power levels, because the cells would be dominated by users closest to the base station and faraway users couldn't get their signals heard in the base station.
- The phenomenon is called the near-far effect.
- This problem calls for uplink power control.
- ***The mobile stations far away from the base station should transmit with considerably higher power than mobiles close to the base station.***

Why Power Control - Downlink

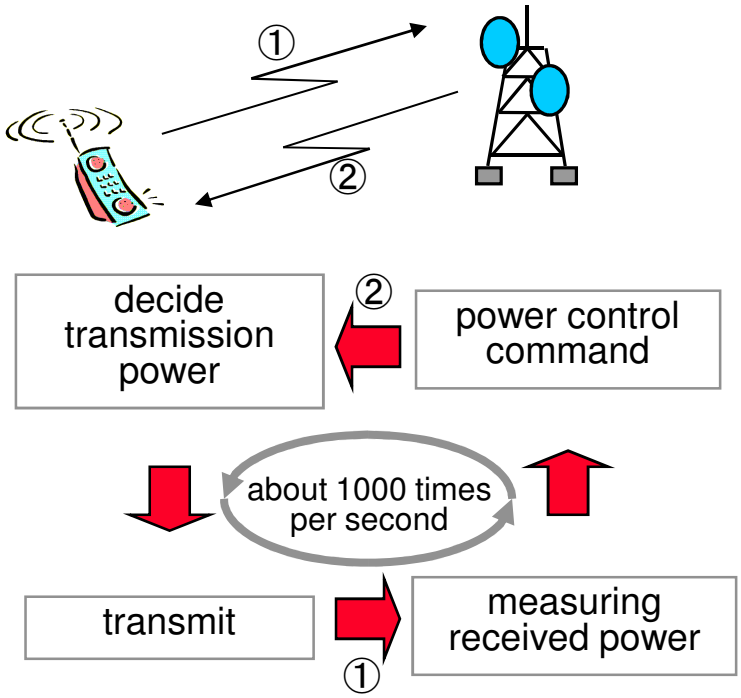
- The downlink signals transmitted by one base station are orthogonal.
- However, it is impossible to achieve full orthogonality in typical usage environments.
- Moreover, signals sent from other base stations are, of course, nonorthogonal and thus they increase the interference level.
- Therefore, power control is also needed in the downlink.
- ***The signals should be transmitted with the lowest possible power level, which maintains the required signal quality.***
- A mobile station close to the base station would not suffer if the signals it receives have been sent using too much power. But other users, especially those in other cells, could receive this signal as non-orthogonal noise, and therefore unnecessary high power levels should be avoided.

Types of Power Control

Open Loop Power Control

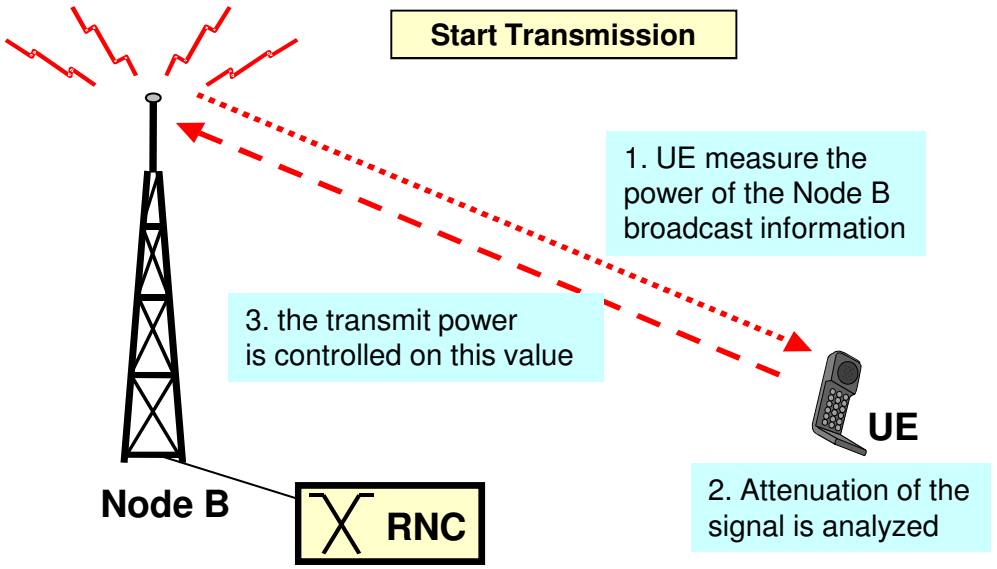


Closed Loop Power Control



Open Loop Power Control

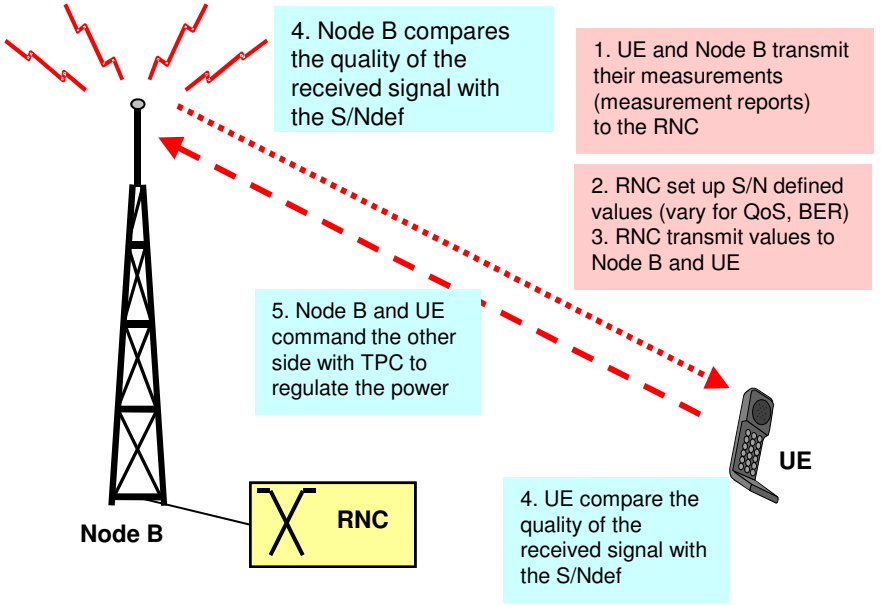
- Transmitting entity estimates the required power level by itself from the received signal.
- Used for UL transmission to control the initial transmission power (e.g. for random access) of the UE.
- Attenuation of the BTS power is analyzed by the UE.
- The UE power is initially controlled on the basis of the analyzed attenuation.
- As uplink and downlink fast fading (on different frequency carriers) do not correlate, this method gives the right power values only on average.



Closed Loop Power Control

"Inner Loop PC"

- BTS & UE compare the quality of the received signal with a specific target SNR value.
- UL:
  - The BS performs frequent estimations of the received SNR and compares it to SNR_{target}.
  - If the measured SNR is higher than SNR_{target}, the BS commands the UE to reduce the power (in case of lower, the command will be to increase the power).
- DL:
  - Same as for UL, however, motivation is different (no near far problem; one-to-many scenario).
  - It is desirable to provide a marginal additional power for the UEs at the cell edge, as they suffer from increased other cell interference.

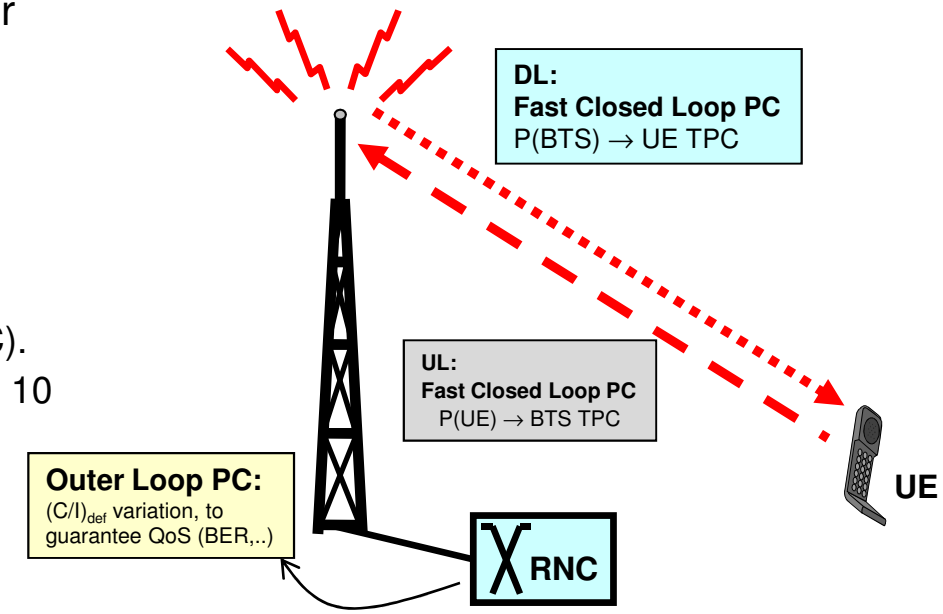


- The inner loop controls on the basis of time slots.
- The power adjustment is done with transmit power control (TPC) commands. TPC bit is set to 0 (reduce power) or 1 (increase power).

Closed Loop Power Control (cont'd)

"Inner Loop & Outer Loop"

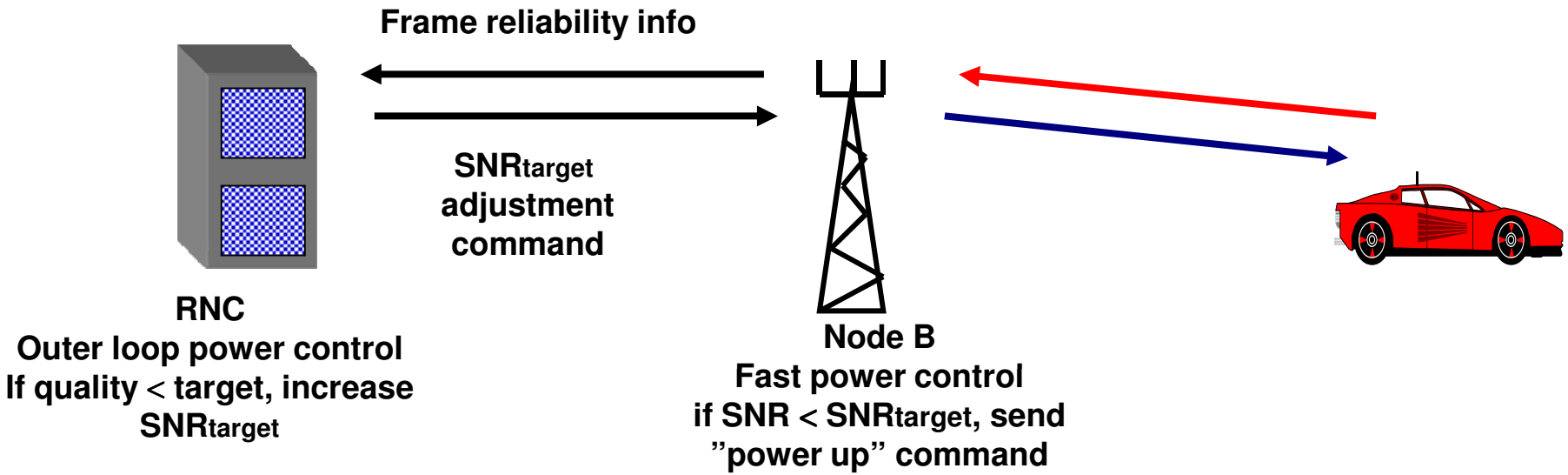
- The closed-loop power control can be further divided into two processes: inner-loop and outer-loop power control.

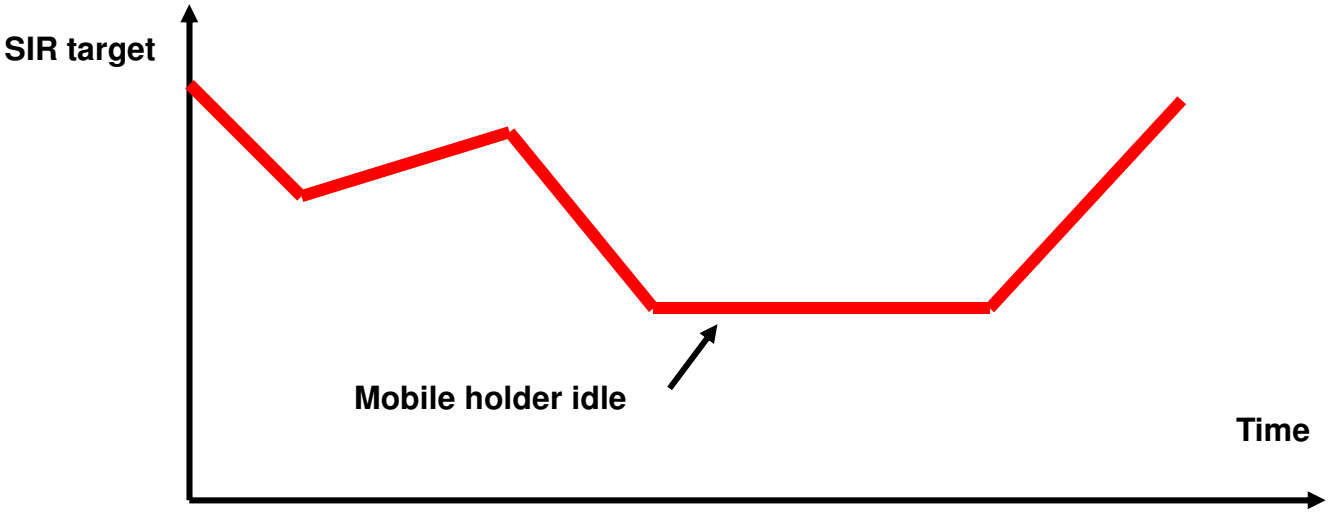


- Outer-loop power control
  - Process: estimate received signal quality and sets target for fast power control (SNR_{target}).
  - Is handled by the RRC in layer 3 (by the RNC).
  - Works on the time basis of frame length, thus 10 ms intervals.
  - Called "Slow Closed loop" if it is based on Frame Error Rate (FER) results. FER measurements are more reliable than SNR.
- Inner-loop power control (fast closed loop):
  - Process: adjusts the peer entity transmit power so that the measured SIR fulfills the SNR_{target} requirement.
  - The inner loop controls on the basis of time slots.
  - This adjustment is done with transmit power control (TPC) commands.
  - There is no neutral TPC command; it is always either an increase or a decrease command.
  - As there are 1,500 time slots in one second, the inner loop power control is a very fast method to adjust transmission power. Therefore known as as fast power control.
  - It is performed entirely in layer 1.

$S/N > (S/N)_{def}$
$\Rightarrow$ TPC = Down
Else
TPC = Up

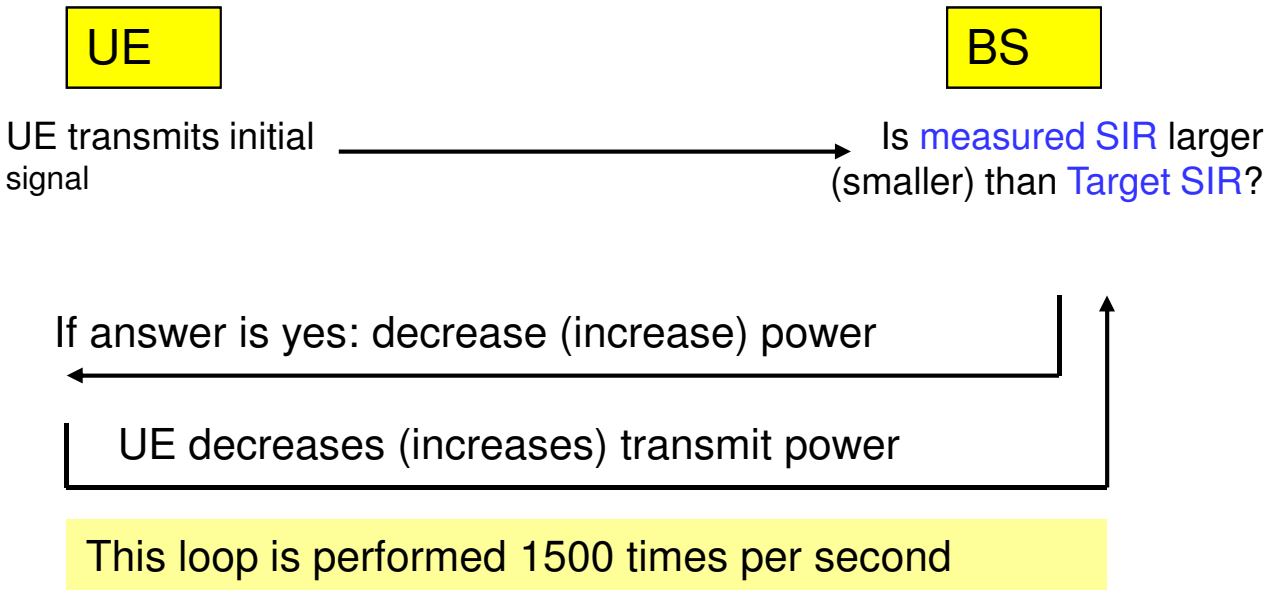
Outer Loop Power Control





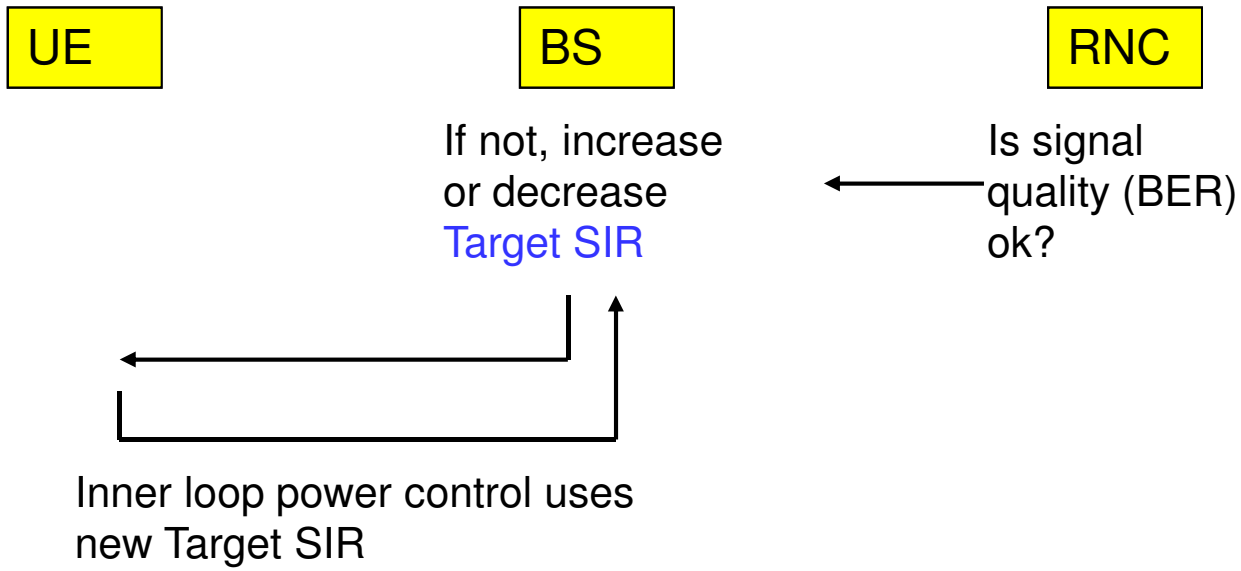
Inner Loop Power Control

Inner loop power control (also called fast power control) is used both in uplink (shown in this figure) and downlink.

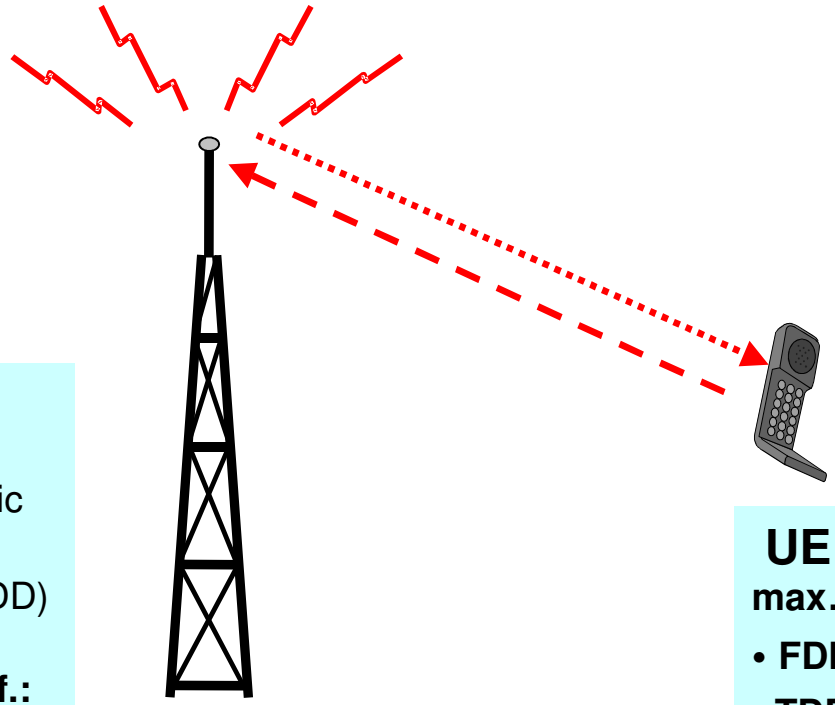


Outer loop power control

Outer loop power control is used both in uplink (shown in this figure) and downlink.



Power Classes and Dynamic Performance



- **FDD: 1500 PC cycles/s**
  (1 TPC per TS)
- **TDD: 100 - 800 cycles/s**

(100/s: per frame; >100/s: depends on frame config.)

Node B

max. power:
vendor-specific

PC stages:
1, 2, 3 dB (TDD)
1 (0.5) (FDD)

Dynamic perf.:
30 dB (TDD)
> 18 dB (FDD)

UE

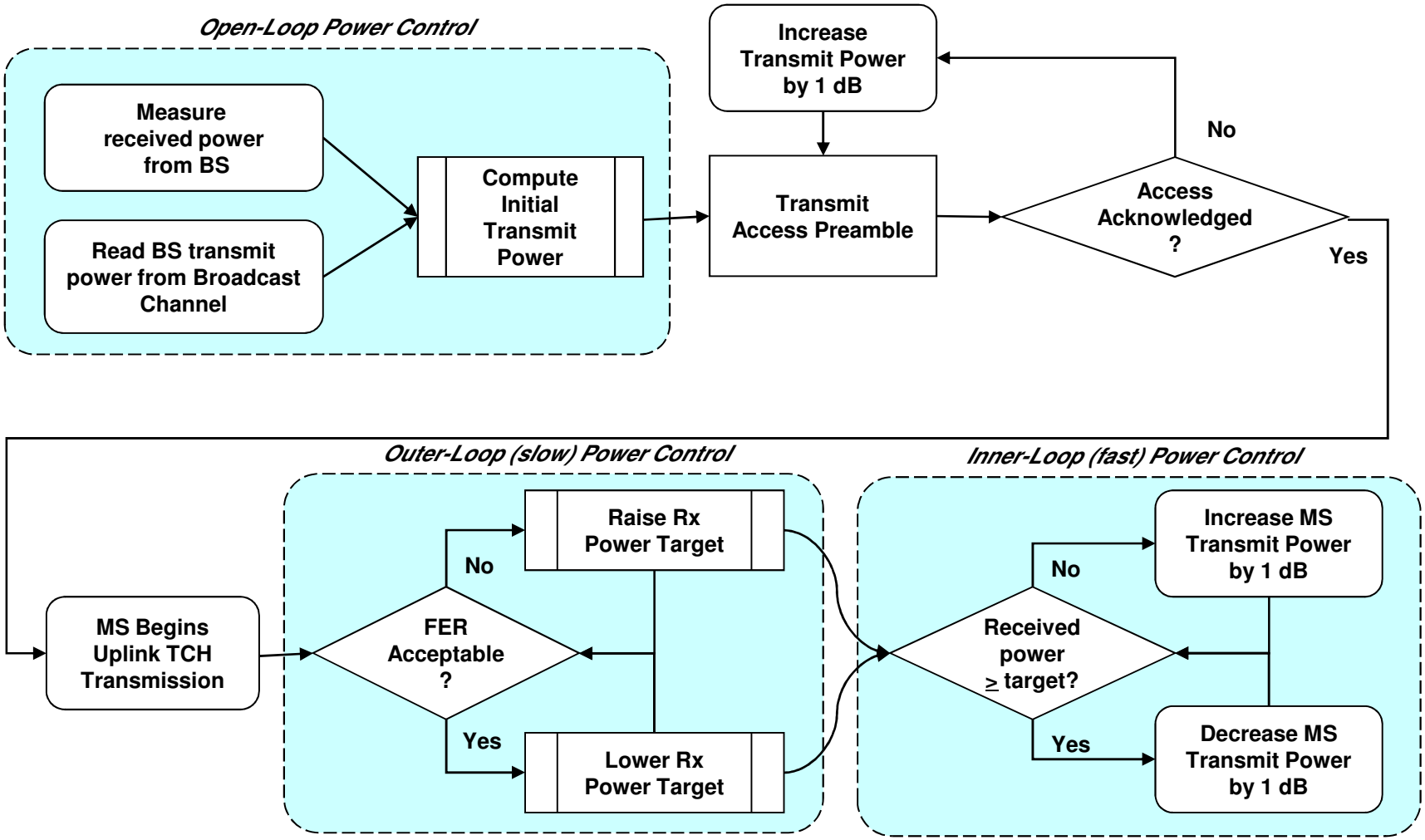
max. power (4 classes) **:**

- **FDD:** 2000 / 500 / 250 / 125 mW
- **TDD:** 1000 / 250 / 125 / 10* mW

PC stages: 1, 2, 3 dB

min. power : 0.04 µW

Power Control



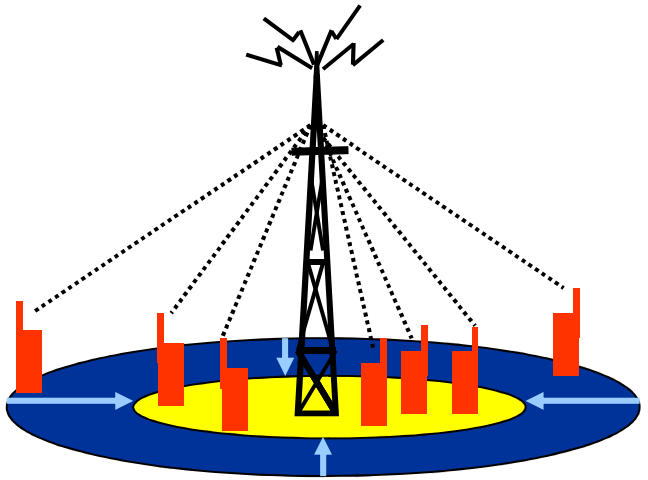
Cell Breathing

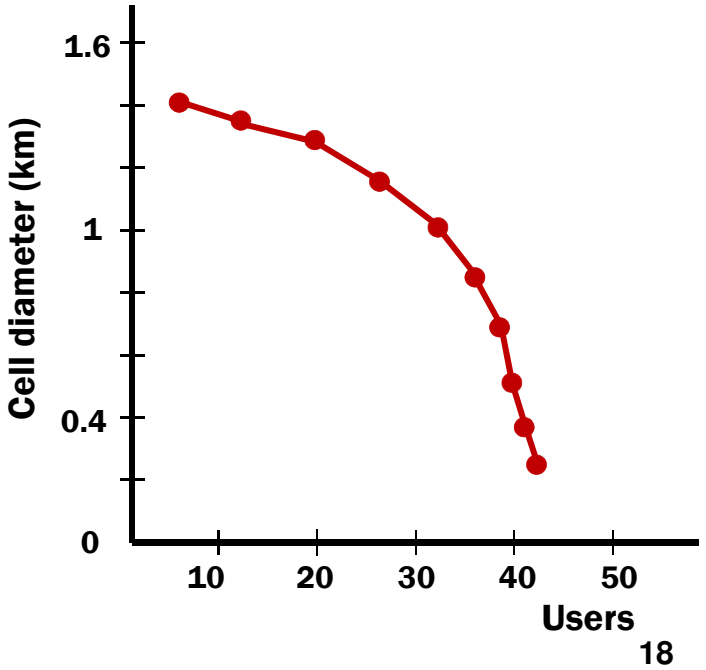
Cell breathing

- Cell breathing is used to describe the way in which the coverage of a Node B changes (***or breathes***) in response to changes in the network load (***number of users accessing the network***).
- In CDMA systems, there is a trade-off between capacity and coverage.
- Cell size depends on both maximum Tx power and number of active users (in the same and other cells).

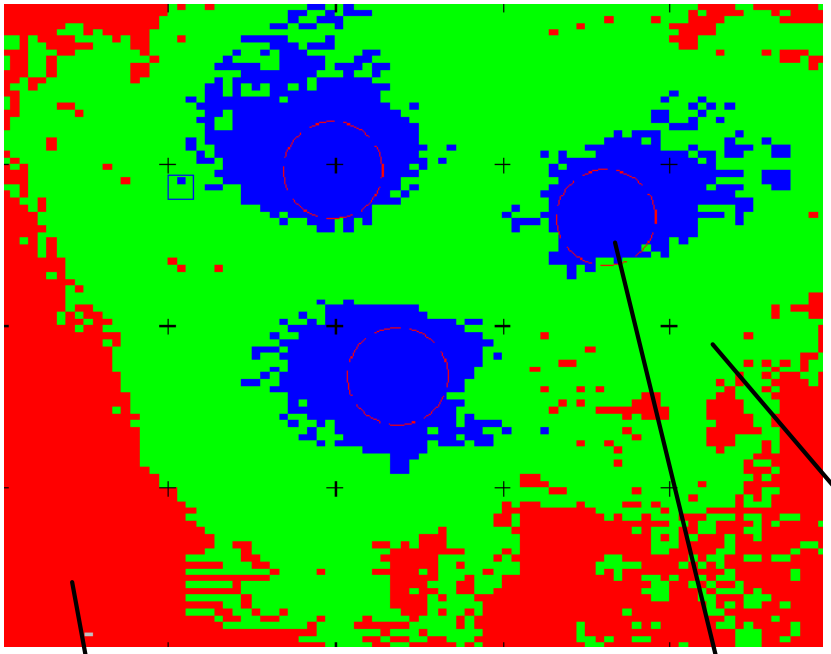
Cell Breathing Effect

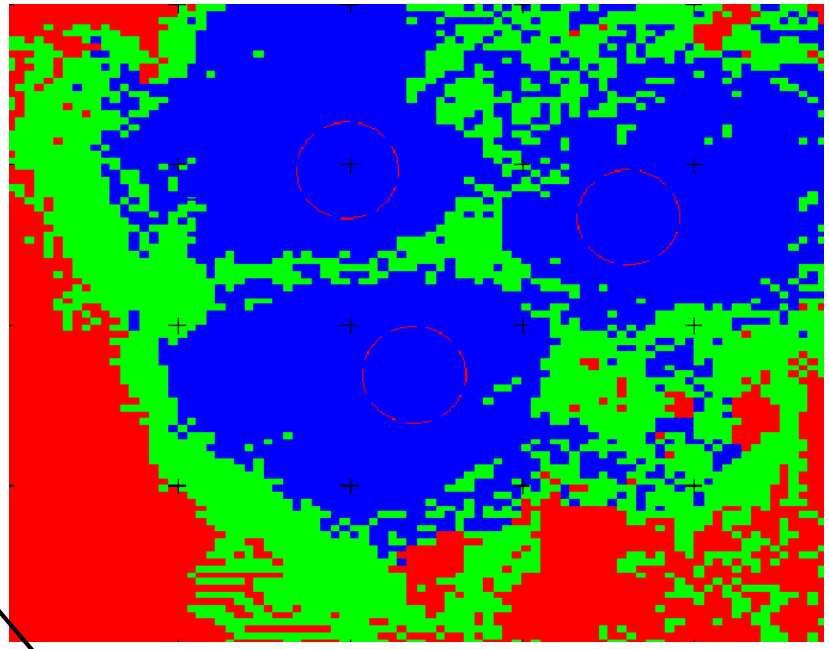
- Specified service specific C/I needs to be maintained at receiver to guarantee QoS.
- Growth of traffic leads to an increase of interference power (intra-cell as well as inter-cell)
- If transmitter power cannot be further increased (max. link power), maximum cell size decreases since specific C/I at far receiver is required.
- Load-dependent maximum cell size is referred to as „cell breathing“.
- As network load changes over the day, also the maximum cell size changes over the day. Especially during busy hours the interference rises and the signal will need to rise, extremely reducing range.
- Breathing is determined by intra-cell interference, which itself depends on orthogonality of codes and quality of receiver.
- ⇒ **Active Control of Load needed!!**





Cell Breathing





Case 1: 20 users

Case 2: 10 users

-10 < C/I < -5 dB

-15 < C/I < -10 dB

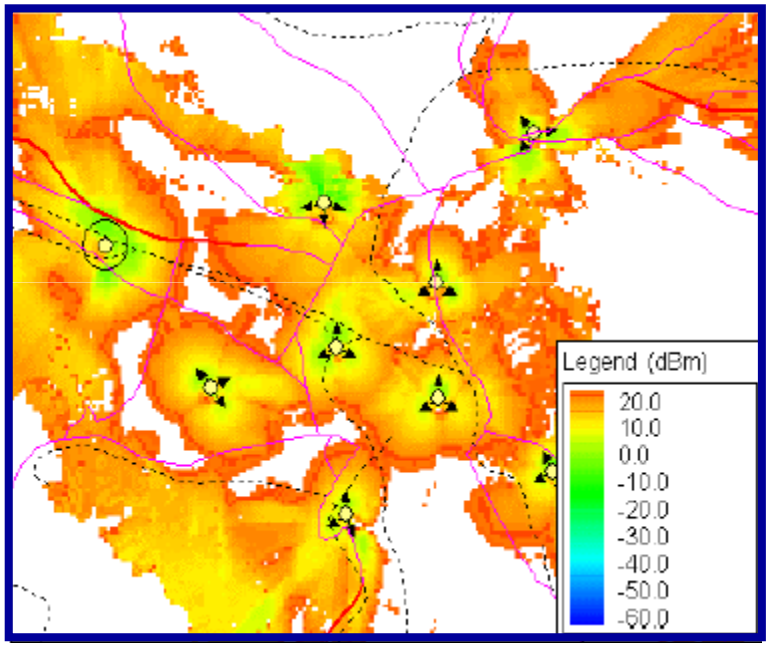
-15 < C/I < -50 dB

Dynamic cell range: f(# users)

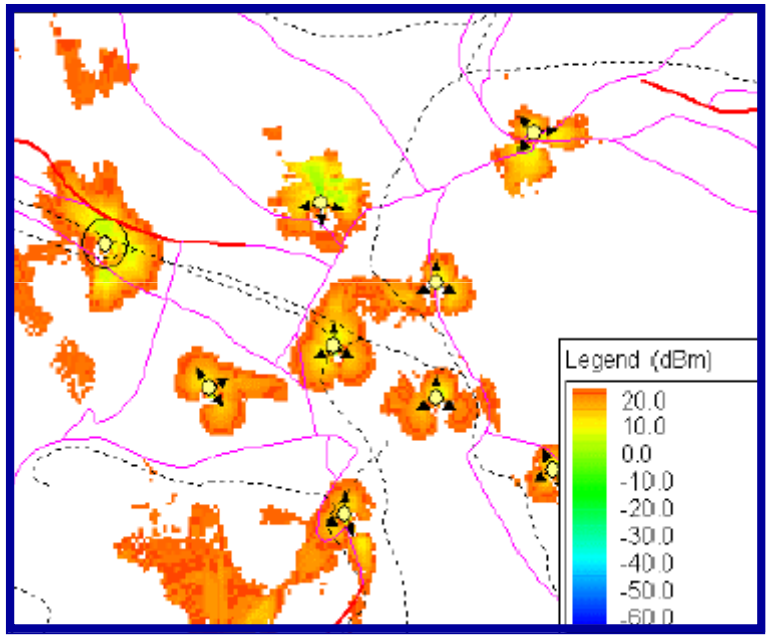
○ cells

Comparison:
Uplink Coverage Speech vs. 64 kBit/s

Uplink coverage
for speech service

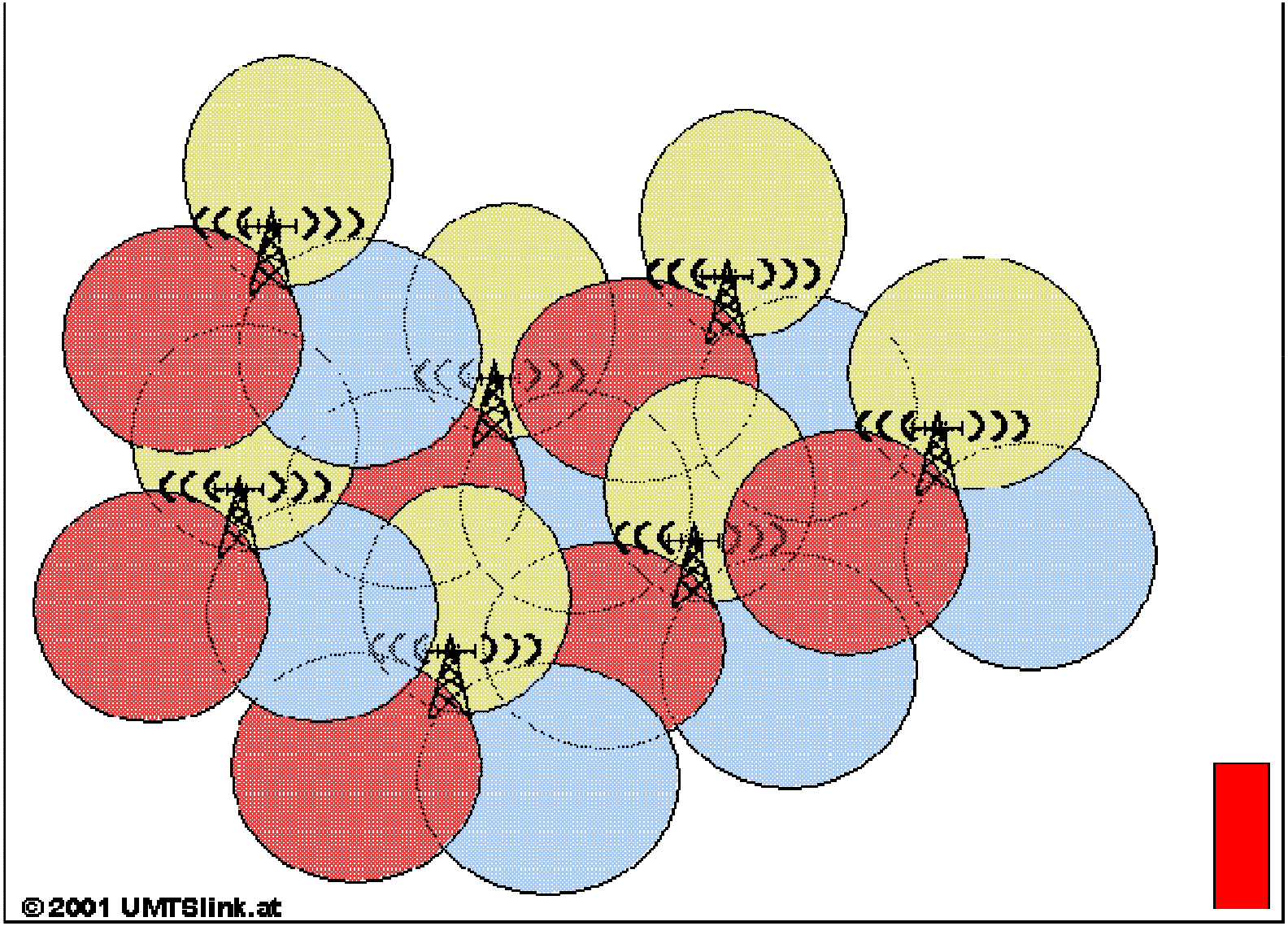


Uplink coverage
for 64 kBit/s data



- Services with a high data rate use a lower spreading factor.
- Therefore they operate with a small processing gain, and need in general a higher transmit power to achieve the required Eb/No.
- This will lead to smaller service areas compared to speech service

Cell Breathing Effect – System view



Hard and Soft Capacities

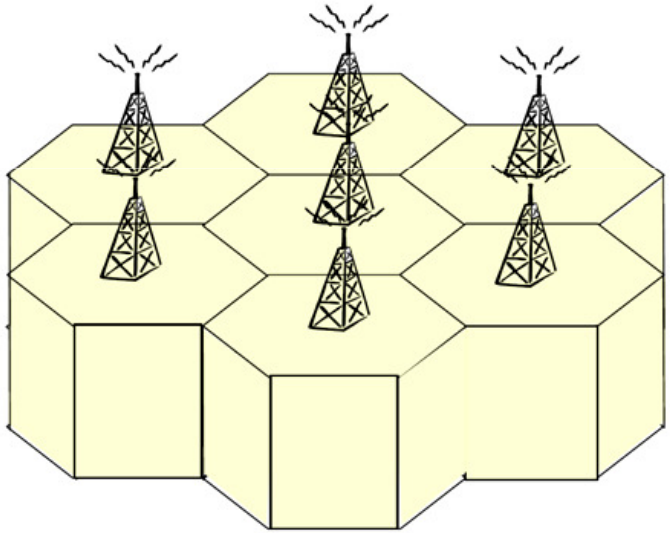
- **Hard capacity:**
  - capacity is limited by the given hardware
  - Capacity hard blocked
  - Capacity calculated from Erlang B formula

- **Soft capacity: (no fixed maximum value)**
  - Capacity is limited by interference on air interface due to frequency re-use 1
  - Neighbor cells share same interference
  - More traffic can be served with same blocking probability than for hard blocked system

Hard and Soft Capacities

Equal Load in neighbor cells

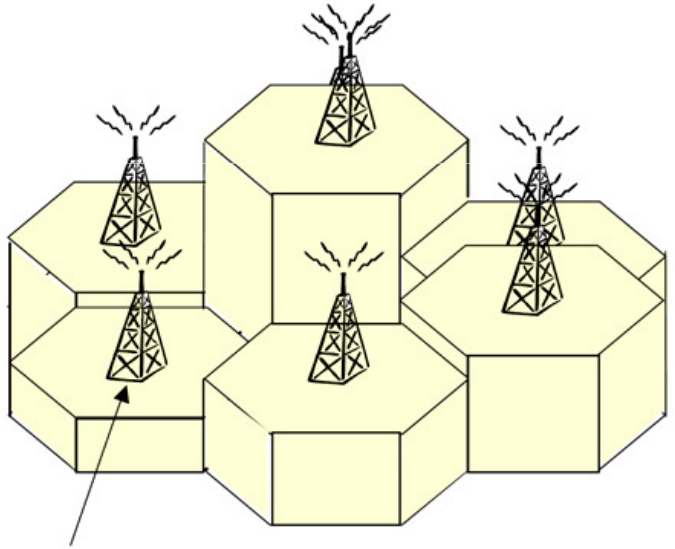
⇒ Equal capacity



Low load in neighbor cells

⇒ Low interference to share

⇒ High capacity possible for center cell

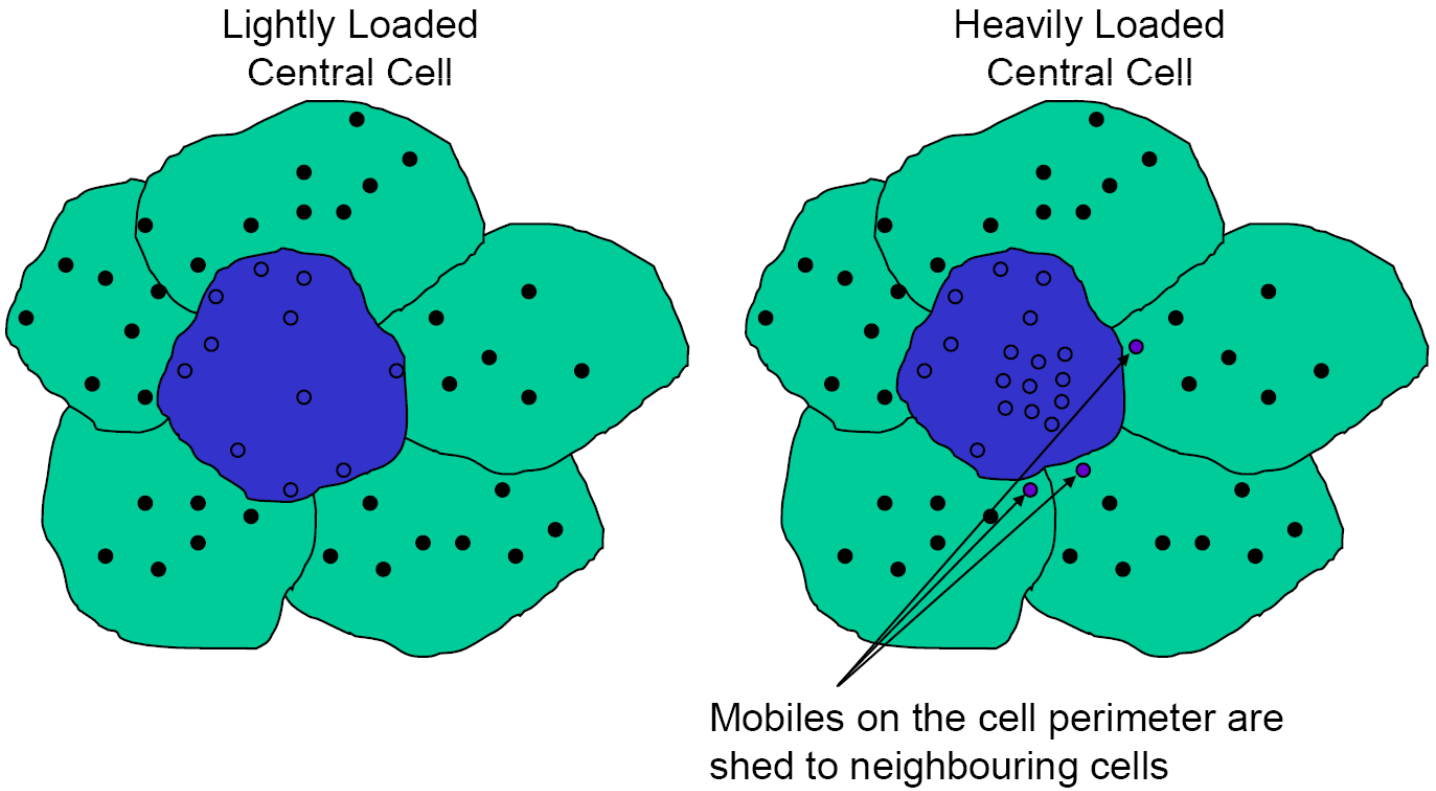


e.g. Low load allowed in cell

with mainly real-time data users

Load balancing

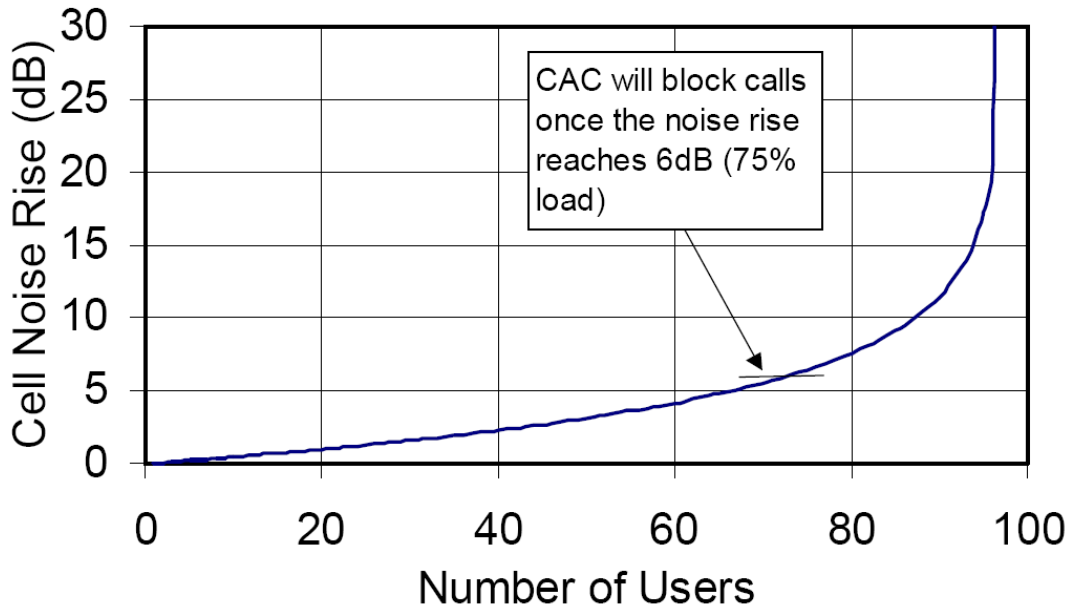
- Cell breathing provides a degree of load balancing.
- As a cell becomes more heavily loaded it becomes smaller.
- This has the effect of shedding users around the cell boundary to more lightly loaded neighboring cells.



Call Admission Control

- The extent of cell breathing can be limited through the use of call admission control.
- The CAC mechanism is used to decide when a new call can be accepted.
- Schemes that are based on the measured noise rise can be used to set the minimum cell size.

Any new calls will be blocked once the interference reaches a certain level.



CDMA system capacity

- WCDMA capacity limited by
  - Amount of interference that can be tolerated
  - Amount of interference generated by each user
  - Amount of downlink orthogonal codes
- Any reduction in generated interference directly improves capacity
  - Voice activity
  - Bursty transmission (packet-like services)
  - Narrow-beam antennas

Reducing interference (by any means)
⇒ direct increase of capacity

Resource Planning versus Power Planning

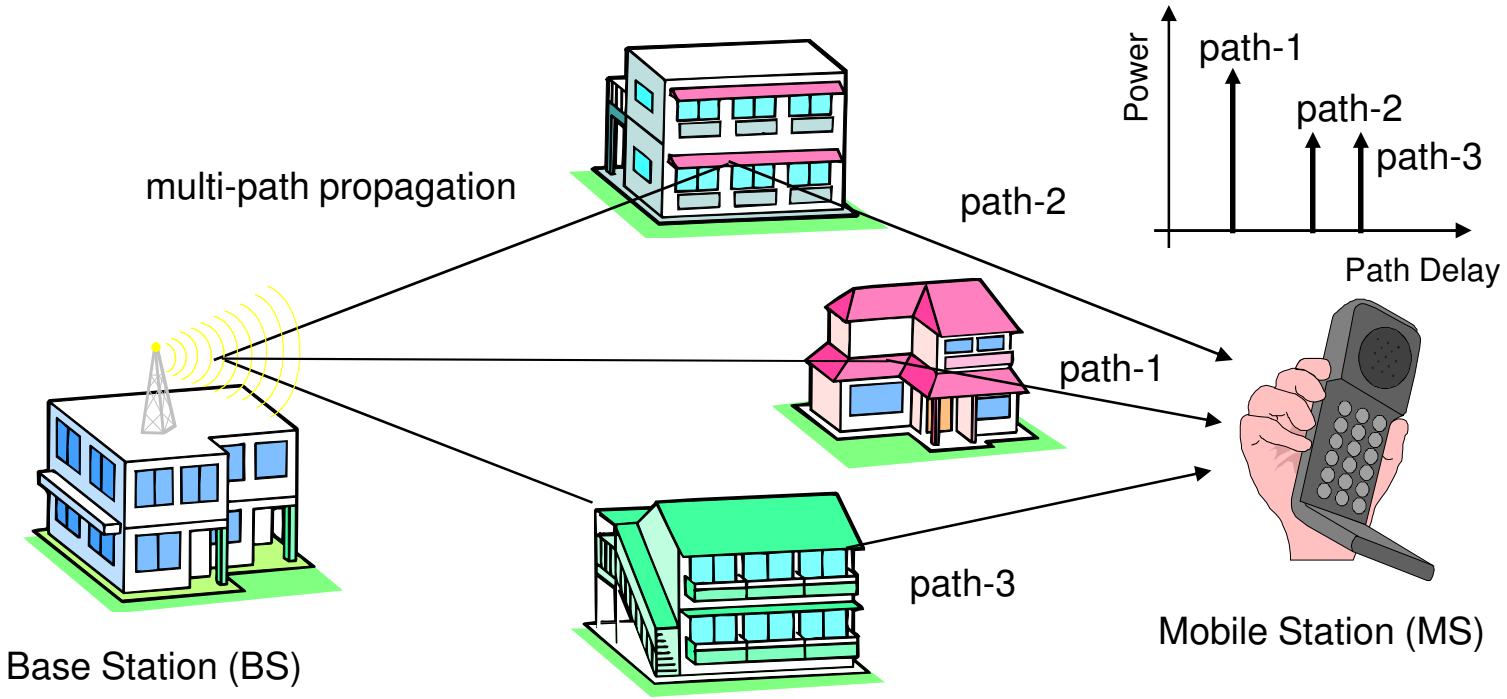
GSMA: Frequency Planning & Slot assignment

CDMA: Increased output power
⇒ increased interference
⇒ lower capacity
Power planning !

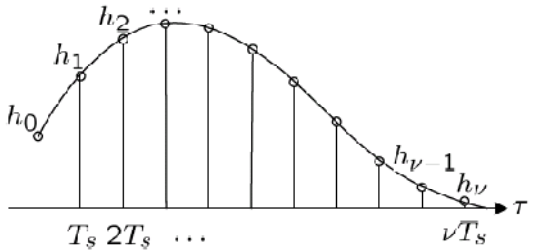
RAKE Receiver

A rake receiver for Direct Sequence SS optimally combines energy from signals over various delayed propagation paths.

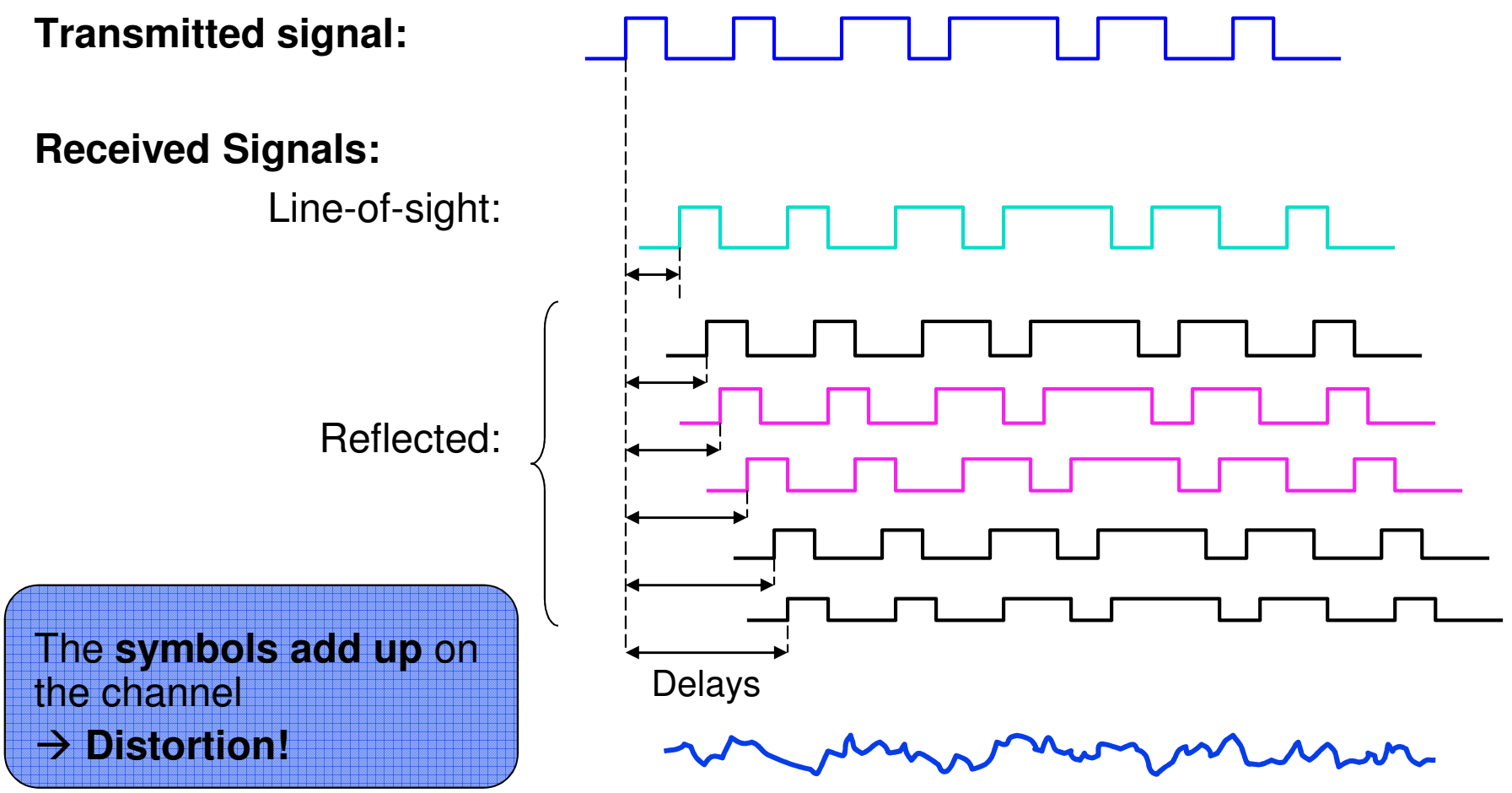
Multi paths: Power-Delay Profile



Channel Impulse Response:
Channel amplitude |h| correlated at delays τ.
Each "tap" value @ kTs Rayleigh distributed
(actually the sum of several sub-paths)



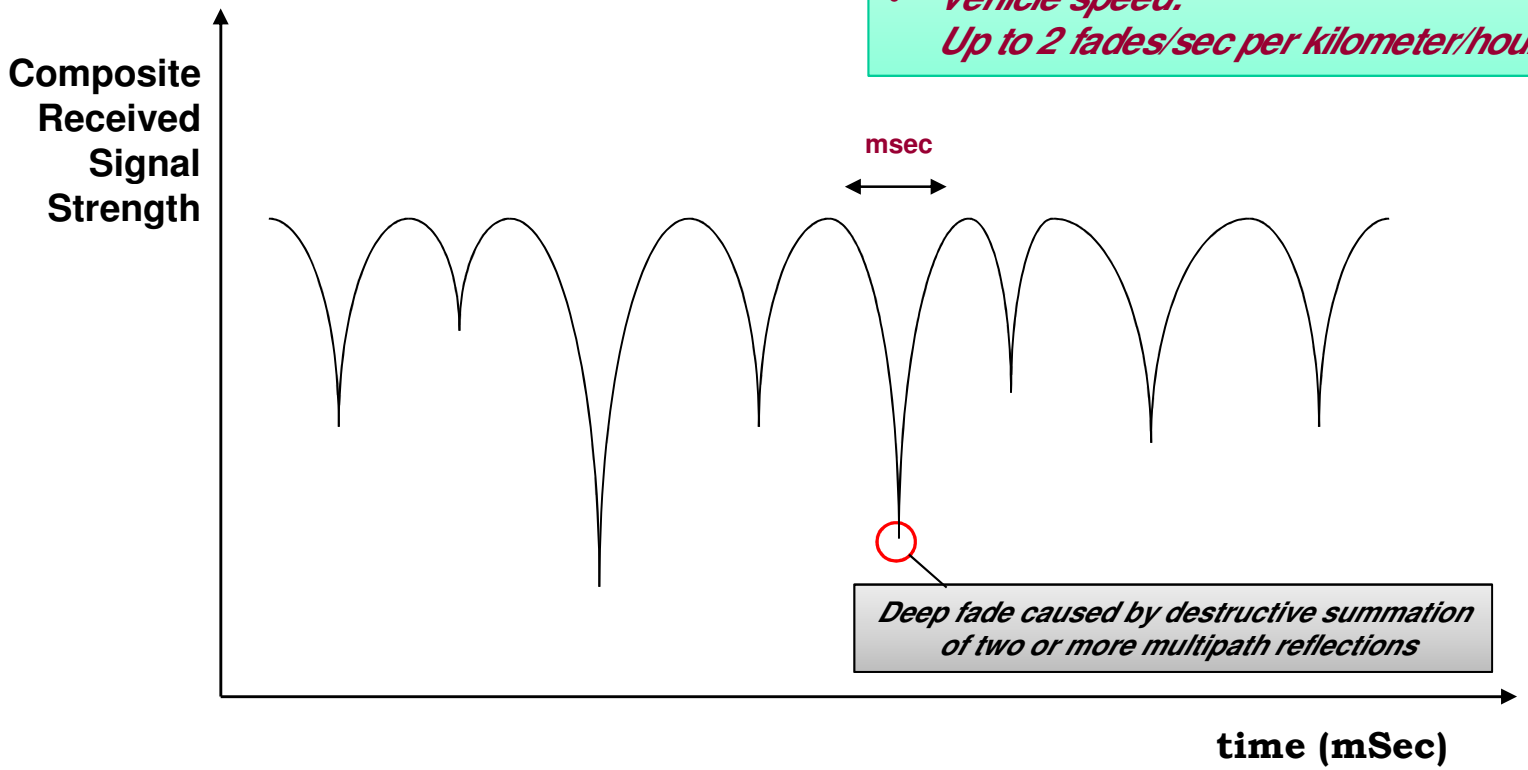
Inter-Symbol-Interference (ISI) due to Multi-Path Fading



Multipath fading
Fast (Rayleigh) Fading

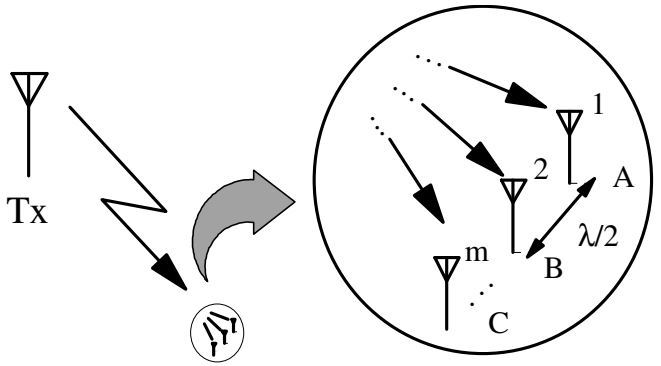
Time between fades is related to

- *RF frequency*
- *Geometry of multipath vectors*
- *Vehicle speed:*
  Up to 2 fades/sec per kilometer/hour

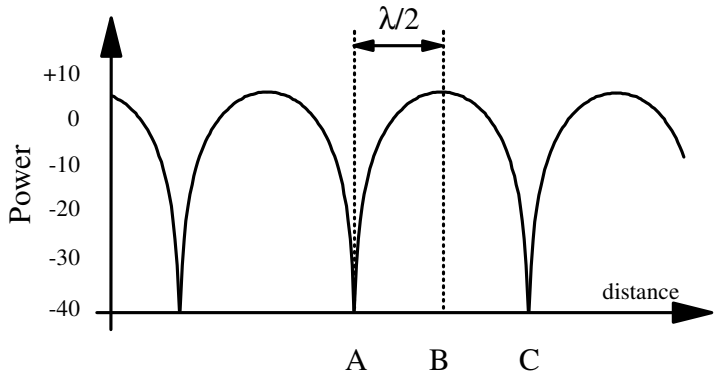


Diversity Techniques

- Diversity: the provision of two or more uncorrelated (independent) fading paths between transmitter and receiver.
- Unlike equalization, diversity requires no training overhead.
- Diversity exploits the random nature of radio propagation by finding independent (or at least highly uncorrelated) signal paths for communication. In virtually all applications, diversity decisions are made by the receiver, and are unknown to the transmitter.
- The concept: “If one radio path undergoes a deep fade, another independent path may have a strong signal. By having more than one path to select from, both the instantaneous and average SNRs at the receiver may be improved”.
- Methods for generating uncorrelated paths for diversity combining include time, frequency, polarization, angle, and space diversity.

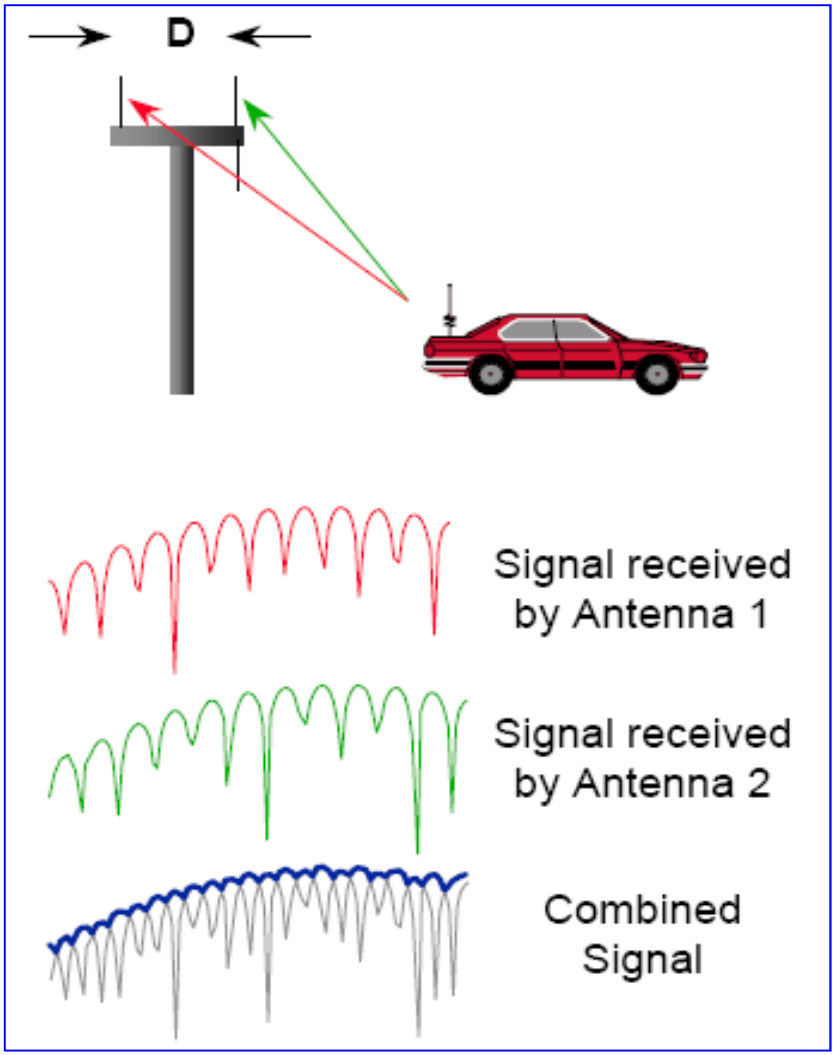


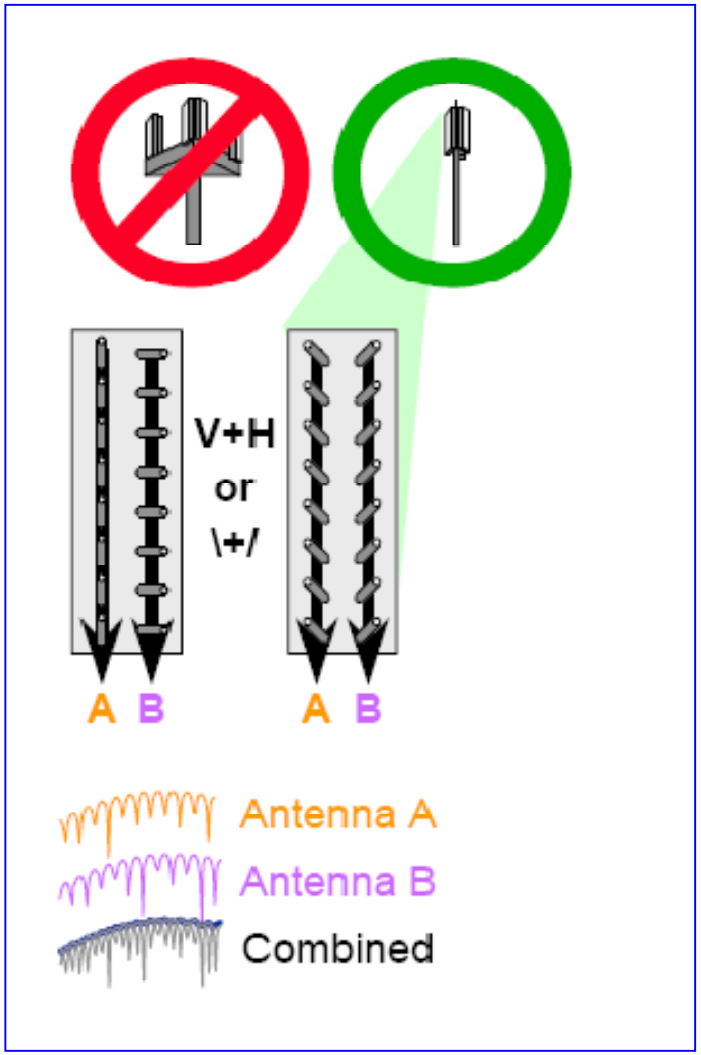
(i) Space Diversity



(ii) Power Variation with Distance

Examples:
Space Diversity & Polarization Diversity

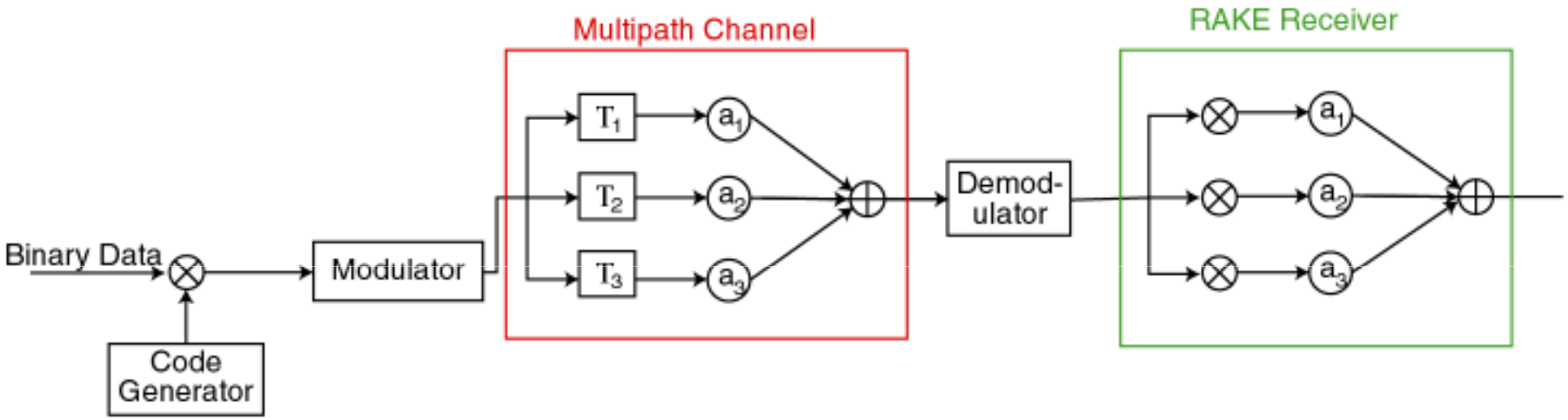




Diversity combining

- **Switched combining:** the current branch is used until a metric fails a certain threshold (e.g. Received Signal Strength Indicator)
  - Cheap and simple, but not ideal
- **Selection combining:** the most appropriate branch is always selected. Slight performance advantage over switch diversity.
  - All diversity branches must be analysed
  - RSSI is not ideal – unduly affected by interference
- **Equal Gain Combining:** simply co-phase and sum all branches
  - Multiple receive chains are required
- **Maximal Ratio Combining:** each branch is co-by its signal-to-noise ratio.
  - Optimal performance
  - Requires multiple receive chains and S/N calculation

The wireless channel



- Unknown Amplitudes (a_i)
- Unknown Delays (T_i)

Estimating the Channel
Basic Idea

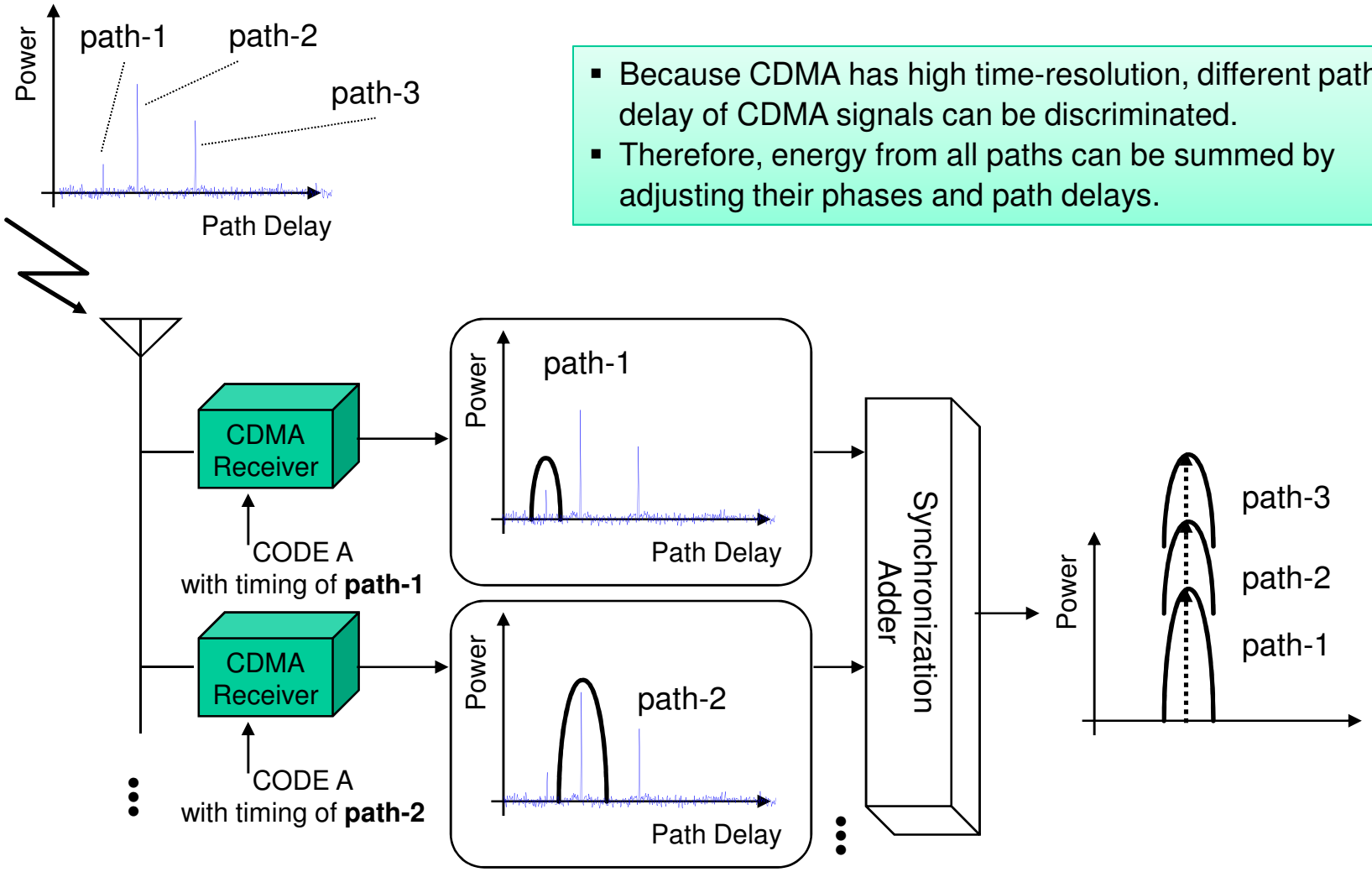
r contains the received bits
b contains the transmitted bits
v is the noise
U contains the user spreading codes
Z contains the channel parameters

$$\mathbf{r}_i = \mathbf{A}\mathbf{b}_i + \mathbf{v}_i$$

$$\mathbf{A} = \mathbf{U}\mathbf{Z}$$

Send a known signal **b**, and observe **r**.
Knowing **r** and **b**, we can estimate **A**.

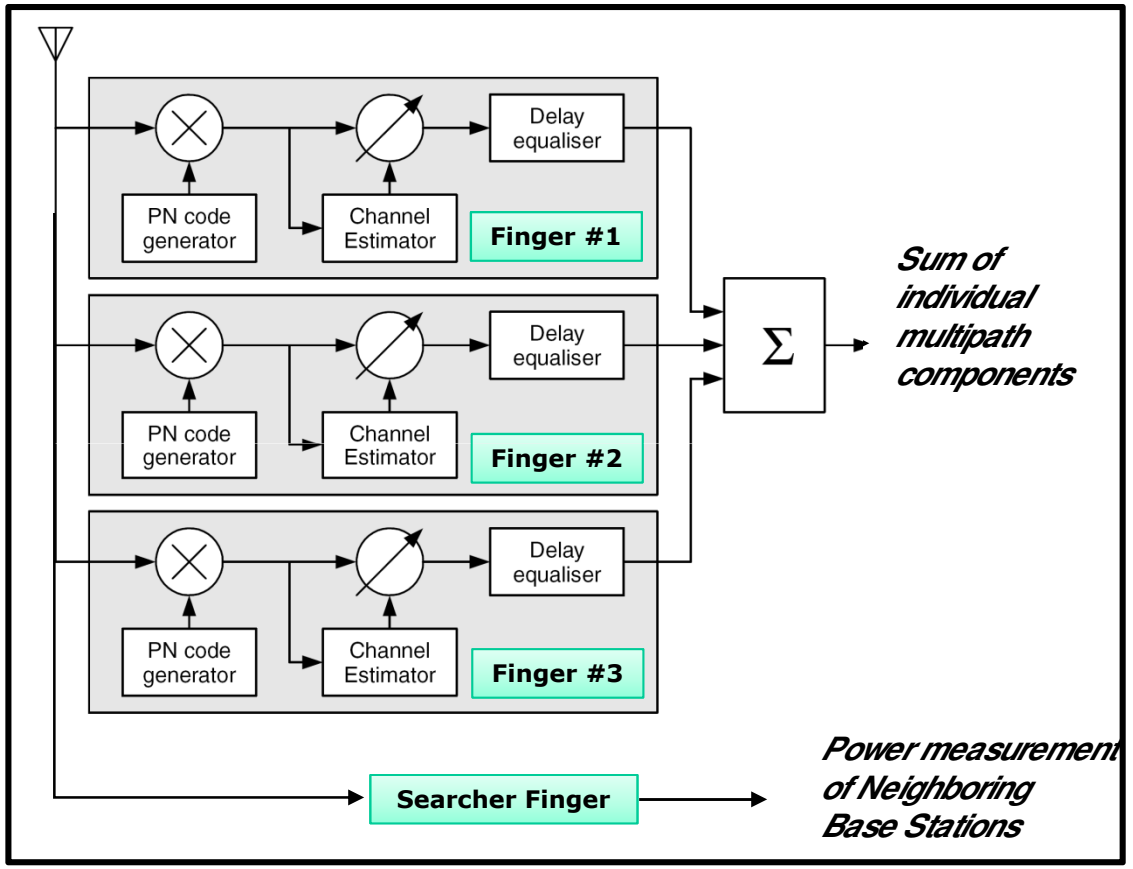
Fading in CDMA System
Rake Principle



- Because CDMA has high time-resolution, different path delay of CDMA signals can be discriminated.
- Therefore, energy from all paths can be summed by adjusting their phases and path delays.

The RAKE receiver
Basic Principle

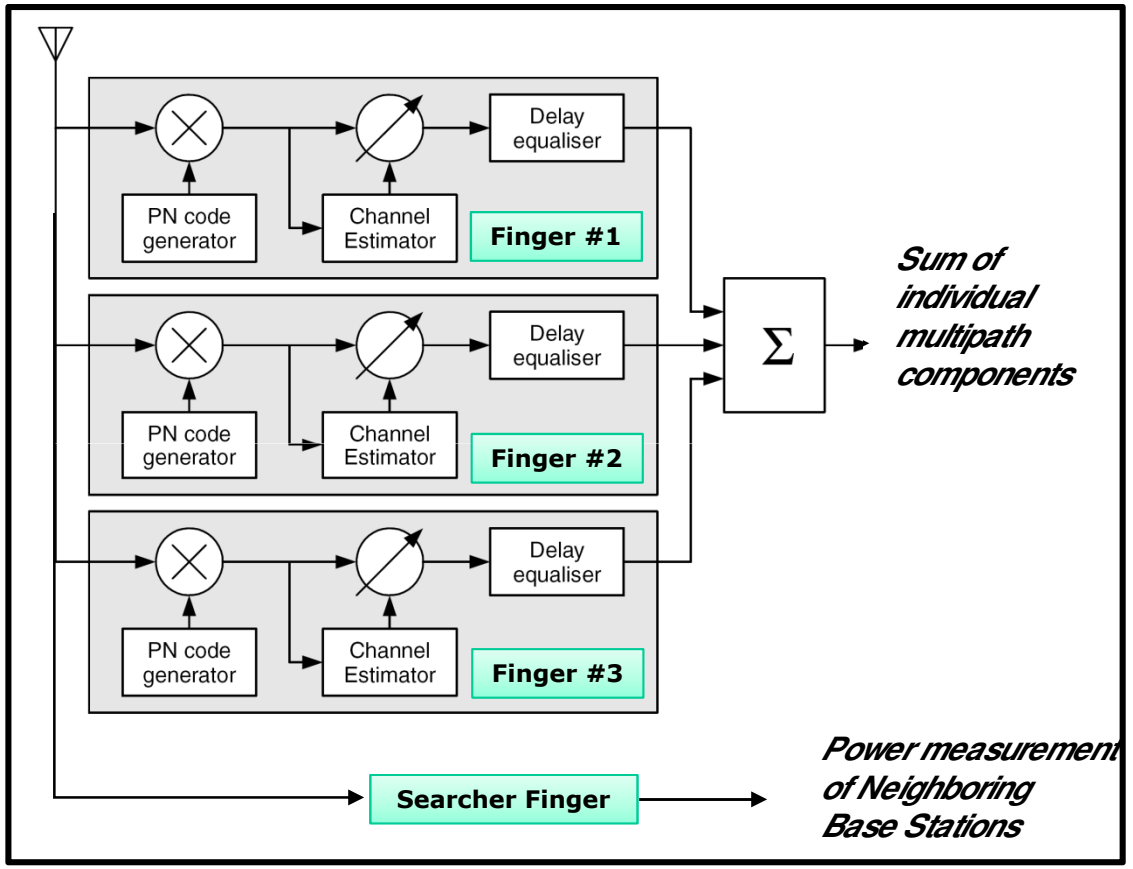
- Each of these RAKE fingers changes (by de-spreading) broadband signals with different delays from the same source (i.e., with the same spreading code) back into user information (correlation against the expected code to give an auto-correlated peak).
- The different RAKE fingers apply the spreading code with delays.
- The Channel estimator (Matched Filter) compares incoming information with predefined data sequences (shifted in time). If the incoming chip sequences match the predefined sequences, a power peak is registered.
- One finger used as a “Searcher” to identify other base stations.



- The MF returns information on the delays & amplitudes of the different user signals.
- Each finger has a delay equalizer so that the resolved peaks can be time aligned before passing to a summing unit where they are combined.
- Depending on the signal strength (MF information), the information components are summed (Maximum Ratio Combining)

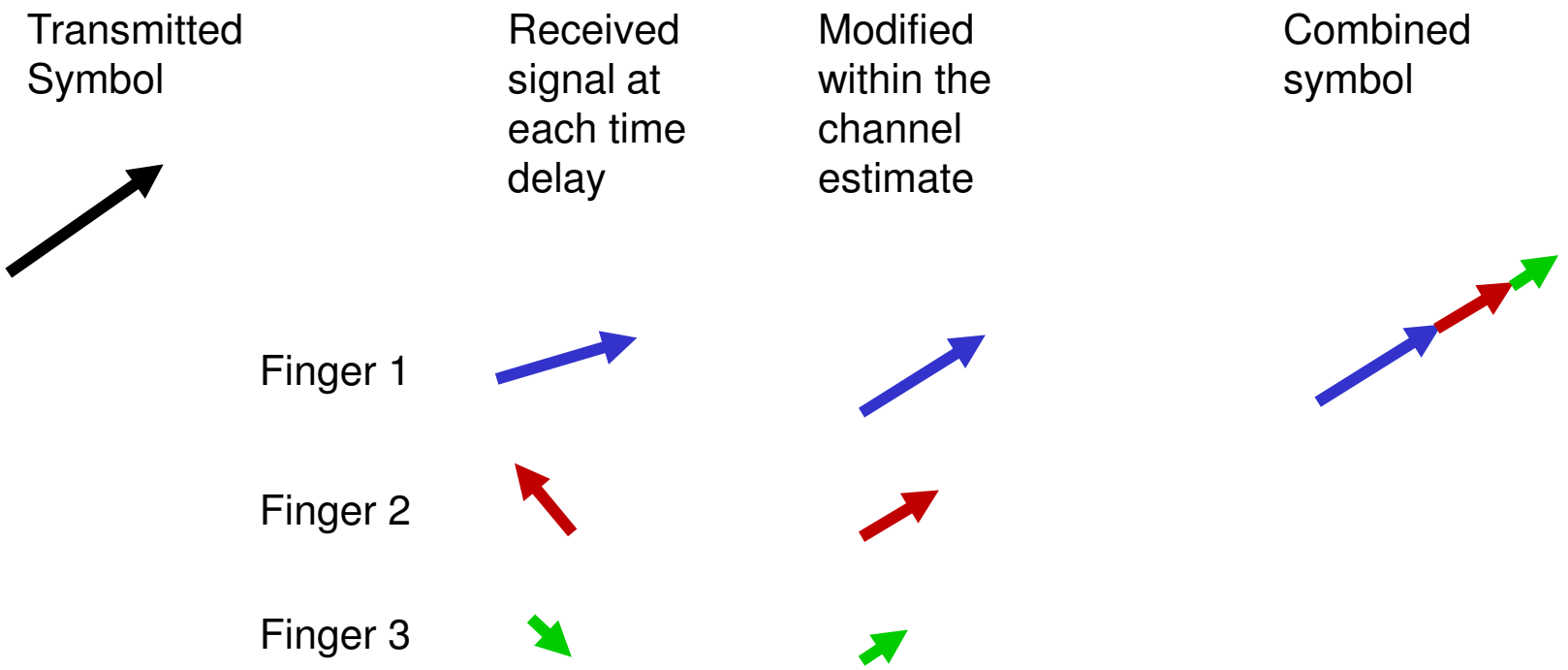
The RAKE receiver
Basic Principle

- The number of paths that can be successfully resolved is related to the ratio of chip width to multipath profile.
- For WCDMA, the chip rate is constant at 3.84 Mchips/s, giving a constant chip time of approximately 0.26 μs.
- Typically for an urban area, a multipath profile is of the order of 1–2 μs over which there are signals arriving with sufficient power to be successfully resolved.
- Over this period, this means there is adequate time to resolve about three or four signals.



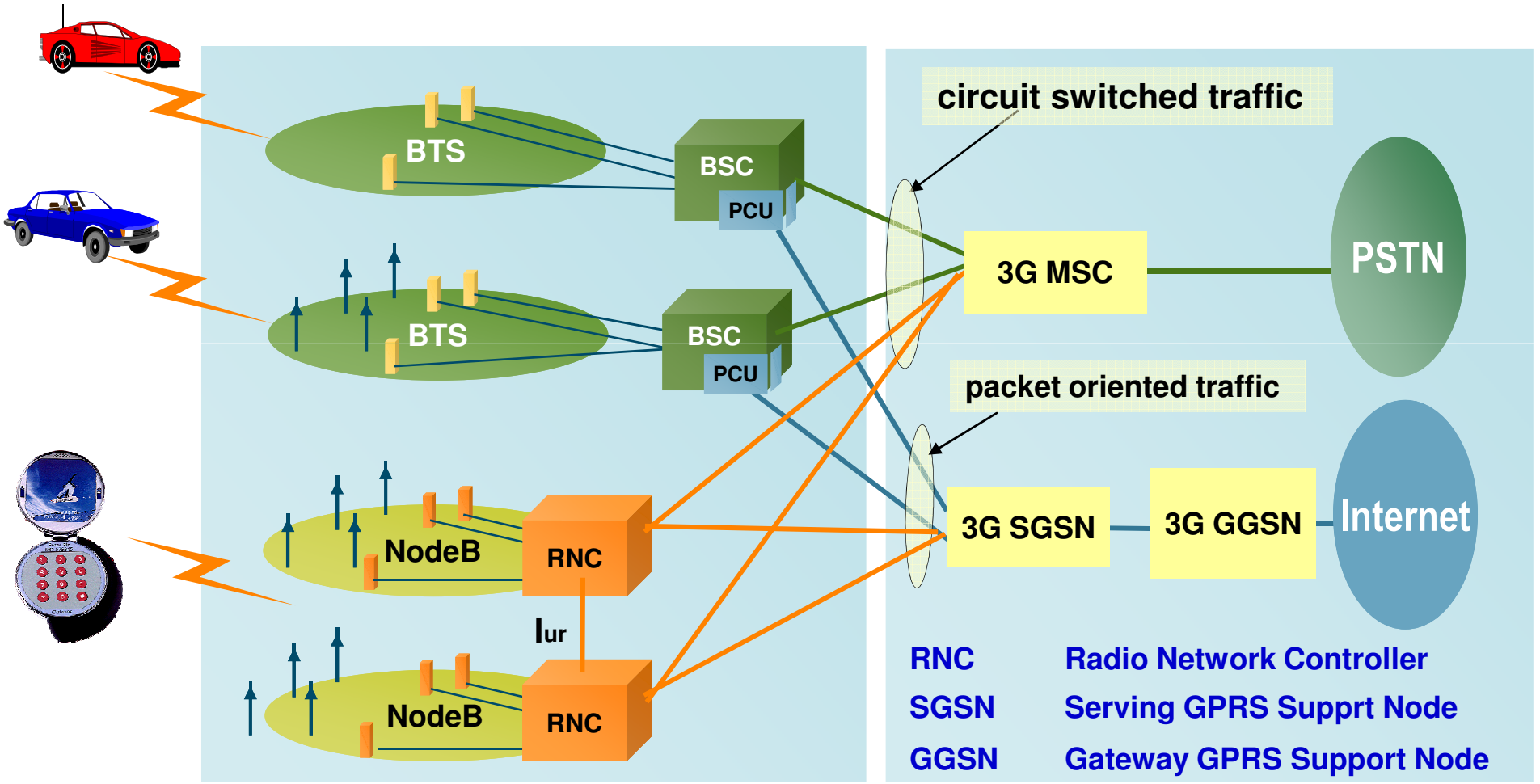
- In terms of distance, a time difference of 0.26 μs equates to 78 m, which means that to be resolved, a multipath must have a path length of at least 78 m greater than the direct signal.

The RAKE receiver
Basic Principle

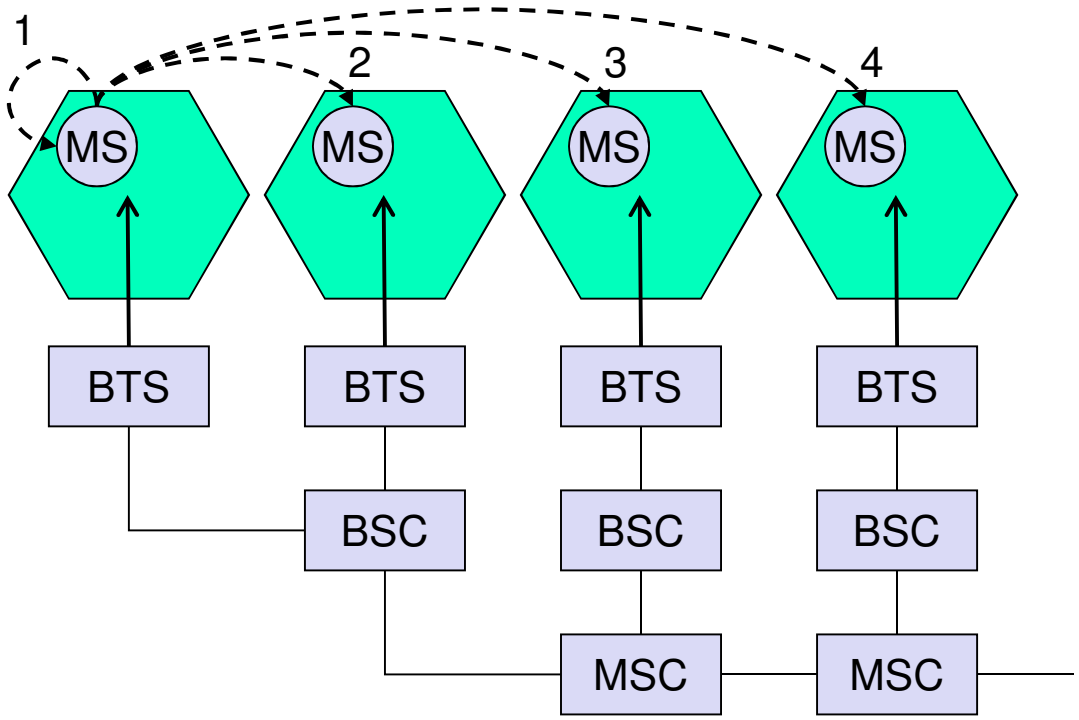


Handover

Network Overview



Handover Types in GSM



1. **Intra-cell: due to narrowband interference need to switch to another frequency**
2. **Inter-cell, intra-BSC: MS moves from one cell to another, but stays within the control of the same BSC**
3. **Inter-BSC, intra-MSC: between cells controlled by different BSCs (handover controlled by the MSC)**
4. **Inter MSC: between cells belonging to different MSCs**

Handover in UMTS (1/2)

10 fundamentally different Handover Types (type 1 to 6)

- INTRA-RNC
  - Intra-Node B (Hard)
  - Intra-Node B (Softer HO)
  - Inter-Node B (Hard)
  - Inter-Node B (Soft-HO)
- Internal INTER-RNC
  - Soft-Handover (S-RNC, D-RNC via Iur)
- External INTER-RNC
  - S-RNC-Relocation with new Iu-Supply-point

Inside one 3G-MSC

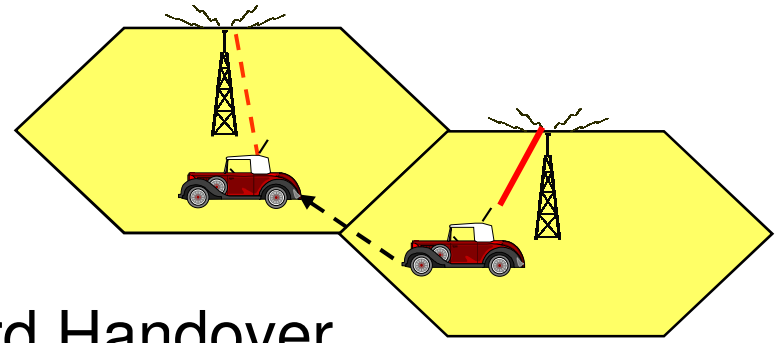
Handover in UMTS (2/2)

10 fundamentally different Handover Types (type 7 to 10)

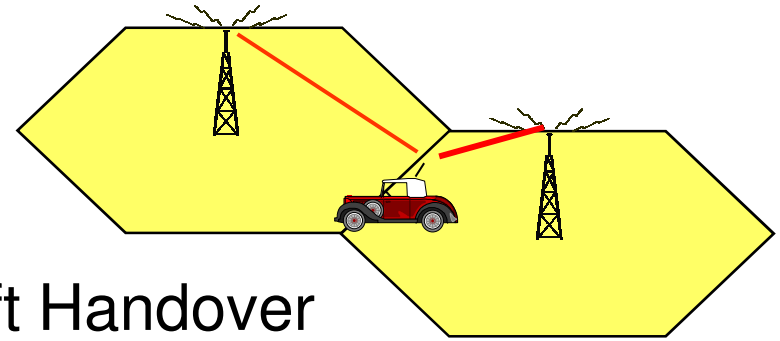
- INTER-MSC
  - New SRNS
- INTER-System
  - UMTS ⇔ GSM
  - UMTS ⇔ IMT-2000
- INTER-Segment
  - UMTS ⇔ SAT

Between two 3G-MSCs or between one 3G-MSC and one GSM-MSC

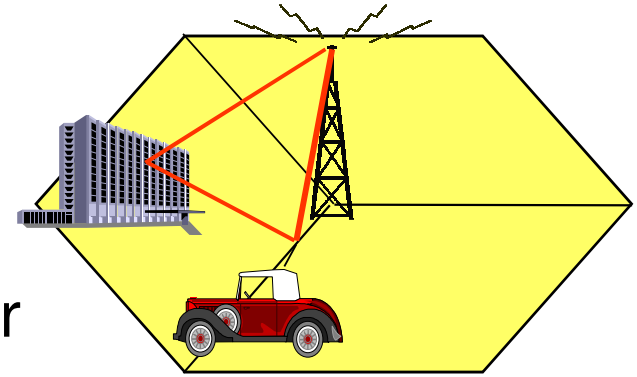
Handover Examples



Hard Handover
(GSM, UTRA TDD)

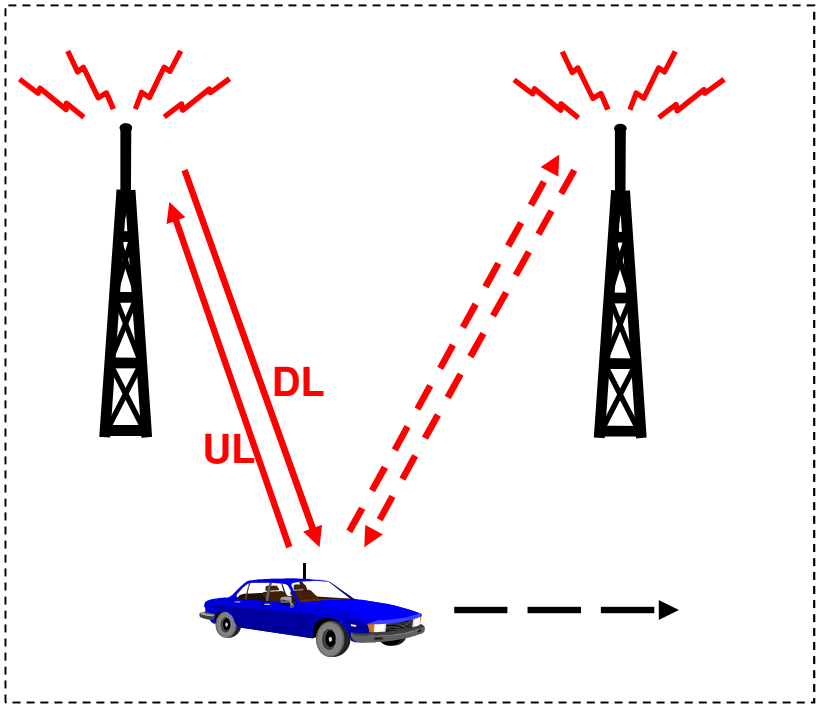


Soft Handover
(UTRA FDD)



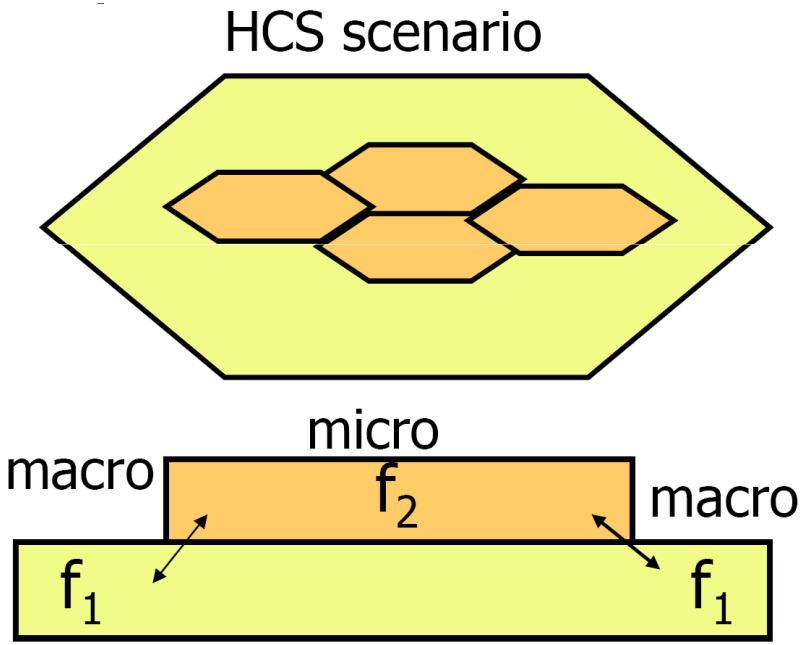
Softer Handover
(UTRA FDD)

UTRA - Hard Handover

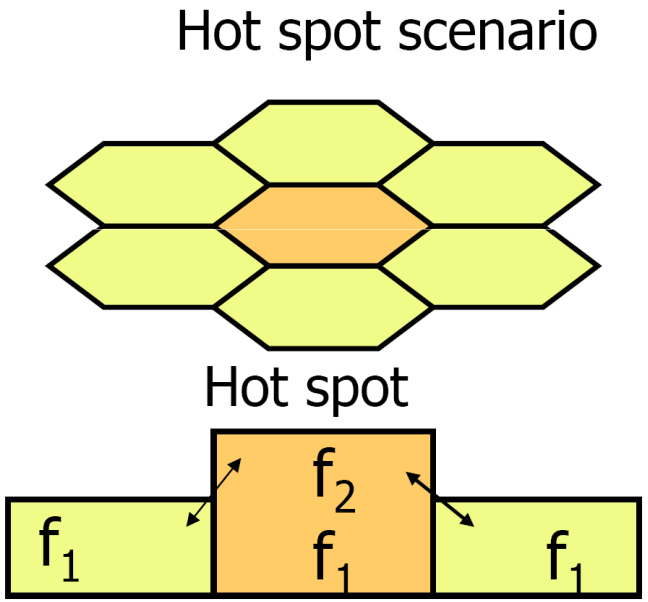


- Hard handovers refer to handovers in which a mobile station (MS) transmits its user information only via one base station at any one time.
- Up until the time of the handover command, the MS communicates with the old base station over a specific physical channel.
- After the handover command, Traffic and Control Channels are Disconnected and must be Reconnected with the new base station.
- Hard handovers are used in GSM and in the following cases in UMTS:
  - During TDD / TDD handovers
  - During FDD handovers if the frequency (inter-frequency handover) or the Core Network is changed.
  - During inter-system handovers – for example, when changing from FDD to TDD or from UMTS to GSM.

Inter-frequency Handover

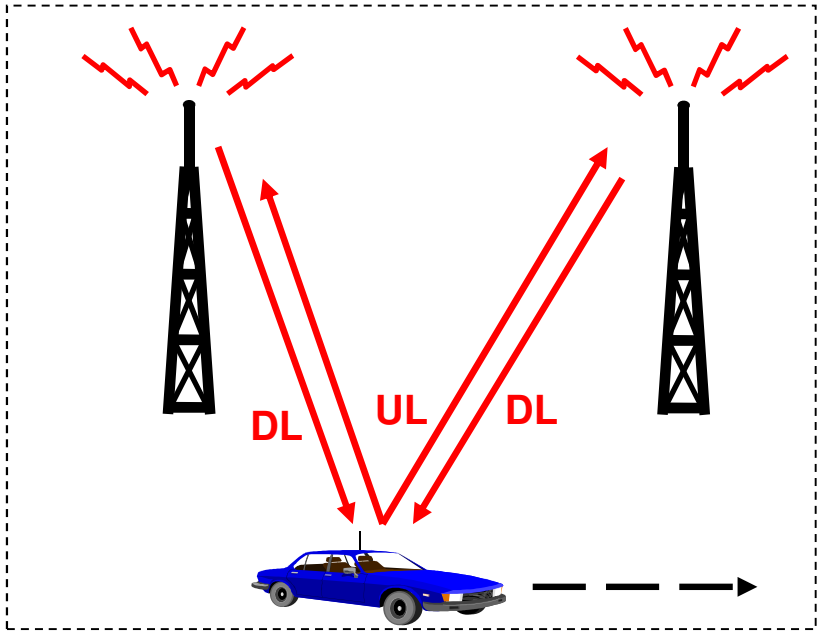


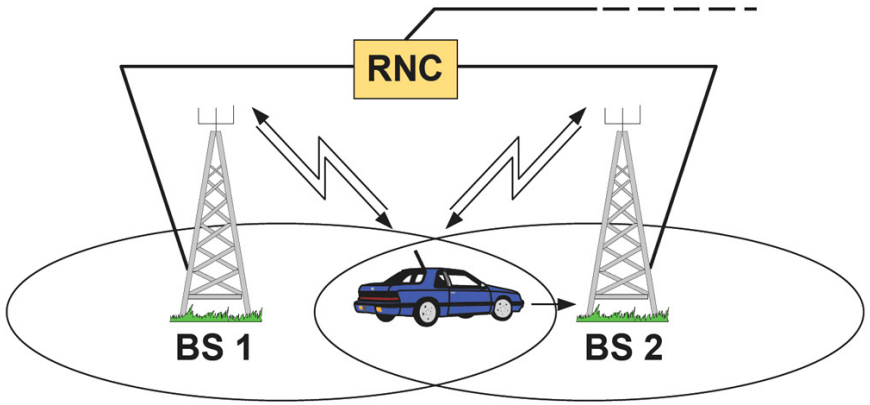
Handover f1- f2 always needed between layers



Handover f1- f2 needed sometimes at hot spot

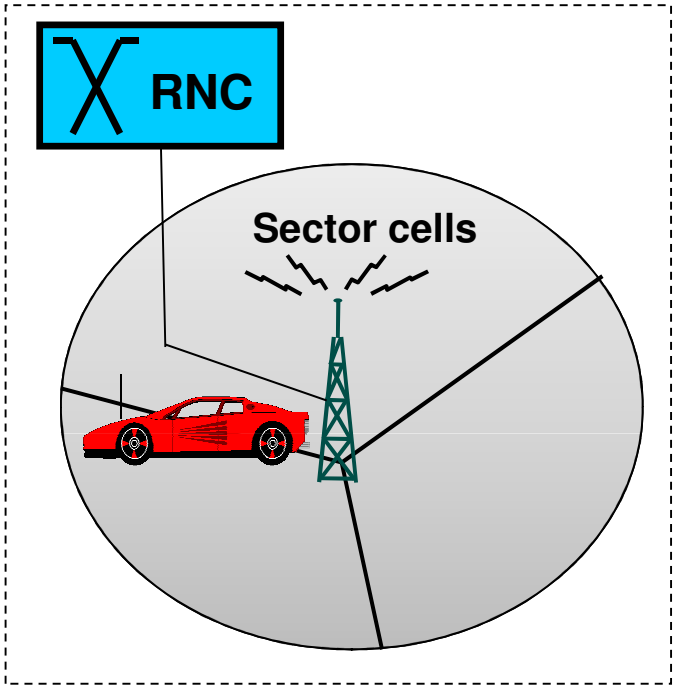
UTRA Soft Handover

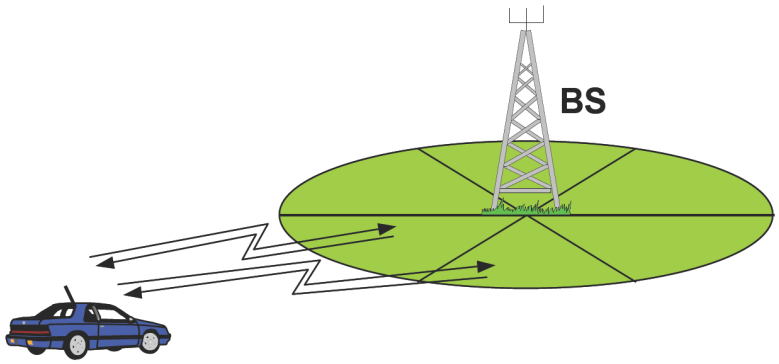




- Soft handovers refer to handovers in which a mobile station (MS) transmits its user information via more than one base station at the same time.
- Soft handovers can be used in CDMA systems in order to prevent an increase in power of the MS in boundary areas between different cells.
- This reduces the interference level and therefore increases the capacity of the system.
- Moreover, the contact with more than one base station ensures the connection to a moving MS in difficult terrain.
- Soft handovers are used during FDD / FDD handovers (without frequency changes).

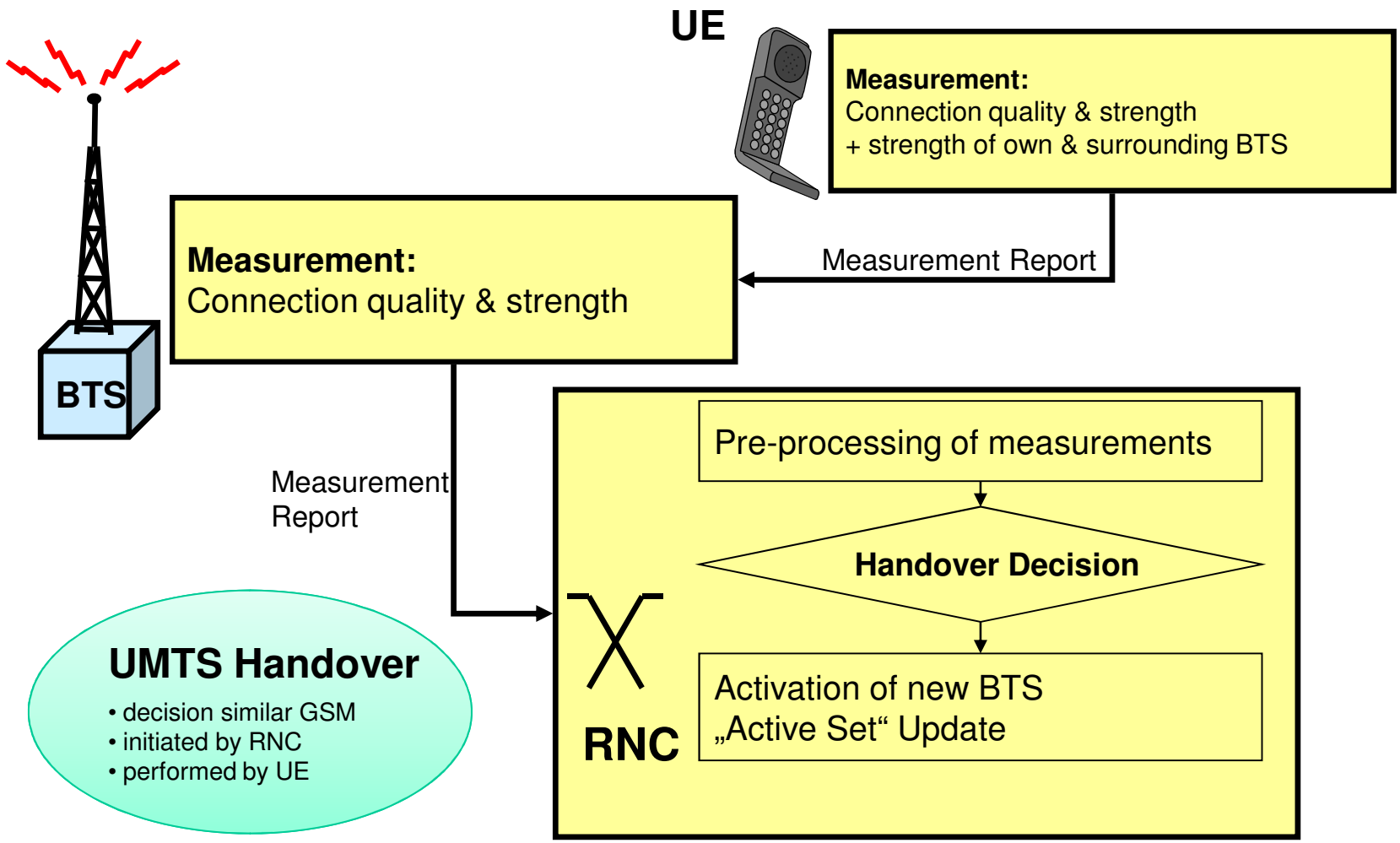
UTRA - Softer Handover



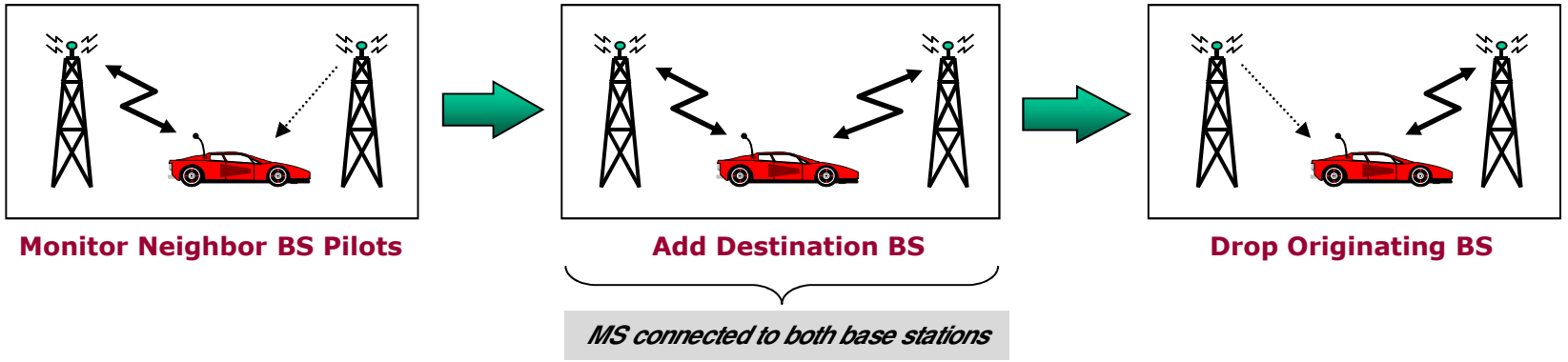


- Softer handovers are handovers between sector cells in the same Node B.
- The transmission information received via the antennae of the different sector cells is handled by different receivers and combined in the Node B itself (Maximum Ratio Combining – MRC).
- Softer handovers are internal Node B affairs.
- Additional transmission capacity to the RNC is not required.
- The gain due to reception of additional signals in softer handovers is also known as ***macro diversity***.

UTRA Handover



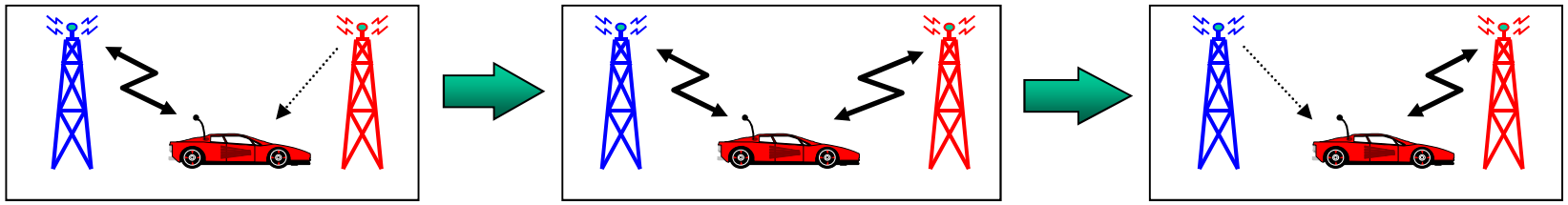
UTRA – Soft Handover



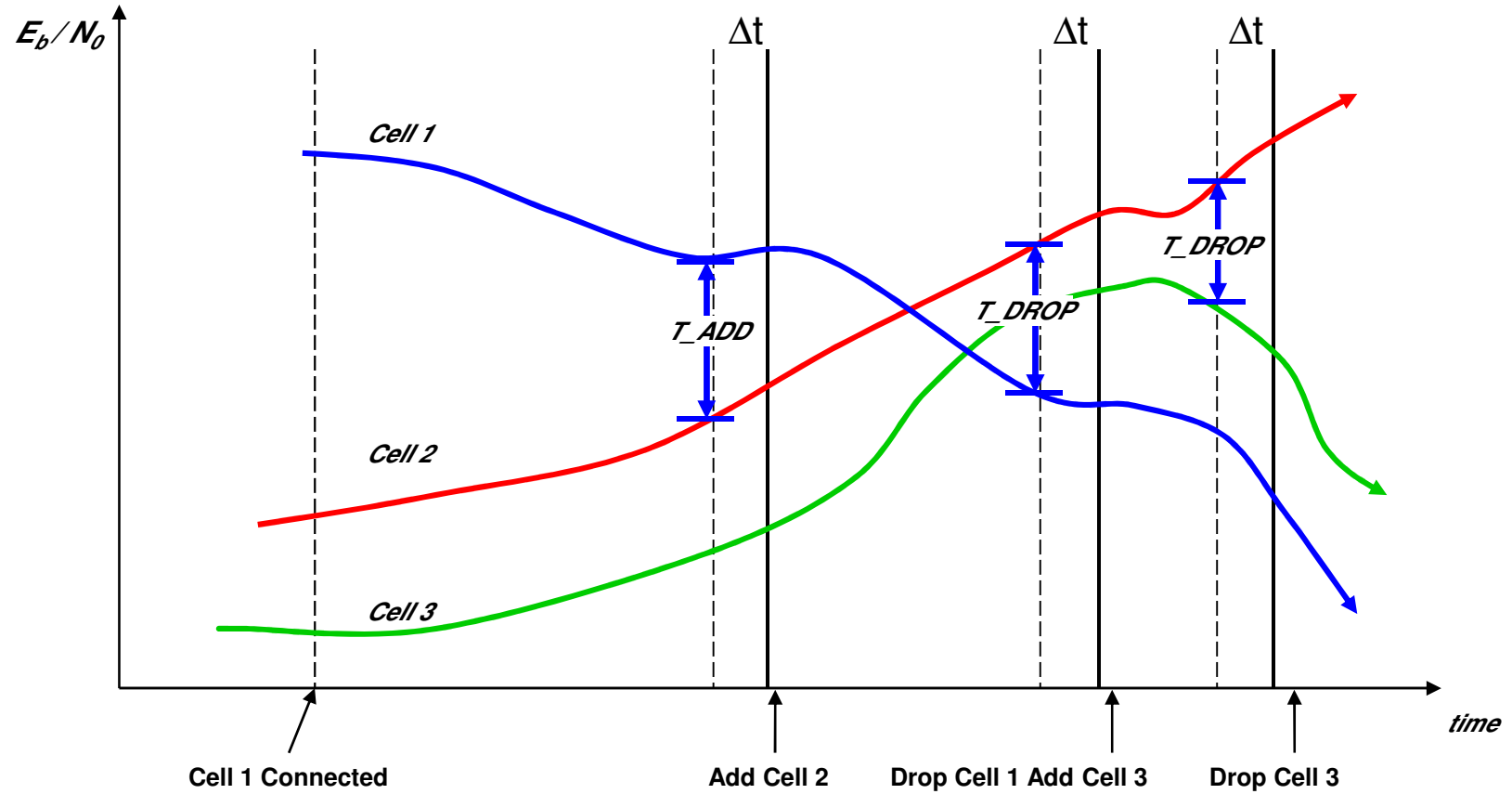
- One finger of the RAKE receiver is constantly scanning neighboring Pilot Channels.
- When a neighboring Pilot Channel reaches the t_add threshold, the new BS is added to the active set

- When the original Base Station reaches the t_drop threshold, originating Base Station is dropped from the active set

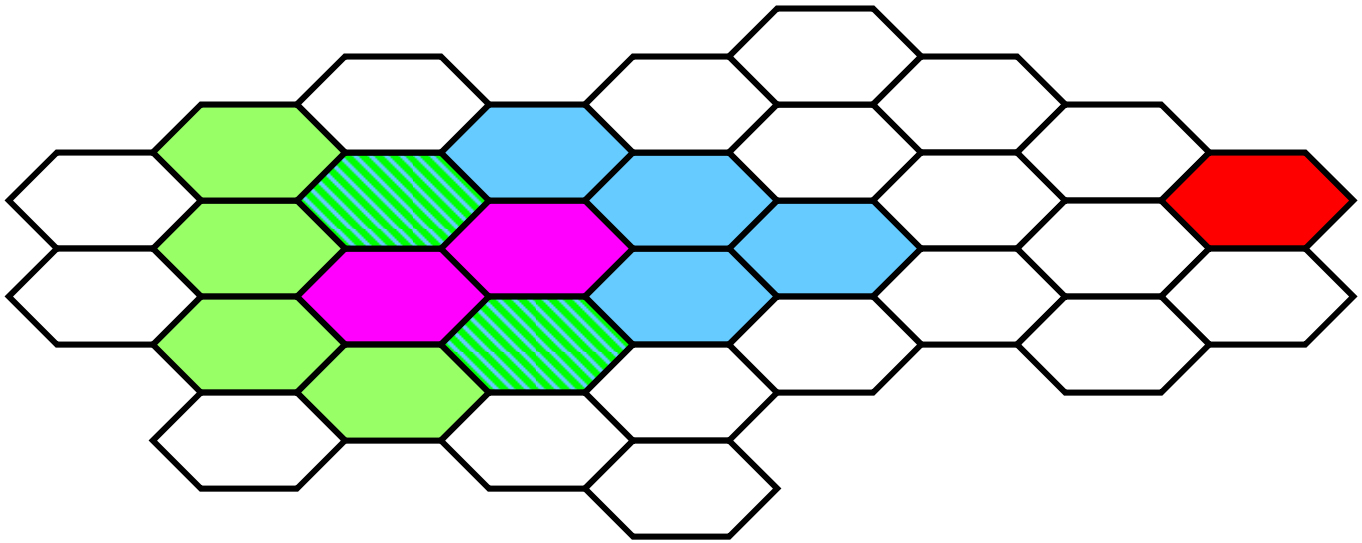
Soft Handover Add/Drop Thresholds



Monitor Neighbor BS Pilots | Add Destination BS | Drop Originating BS



Different cell sets defined in 3GPP



The cells in the active set form a soft handover connection to the UE

= Active set

= Monitored set

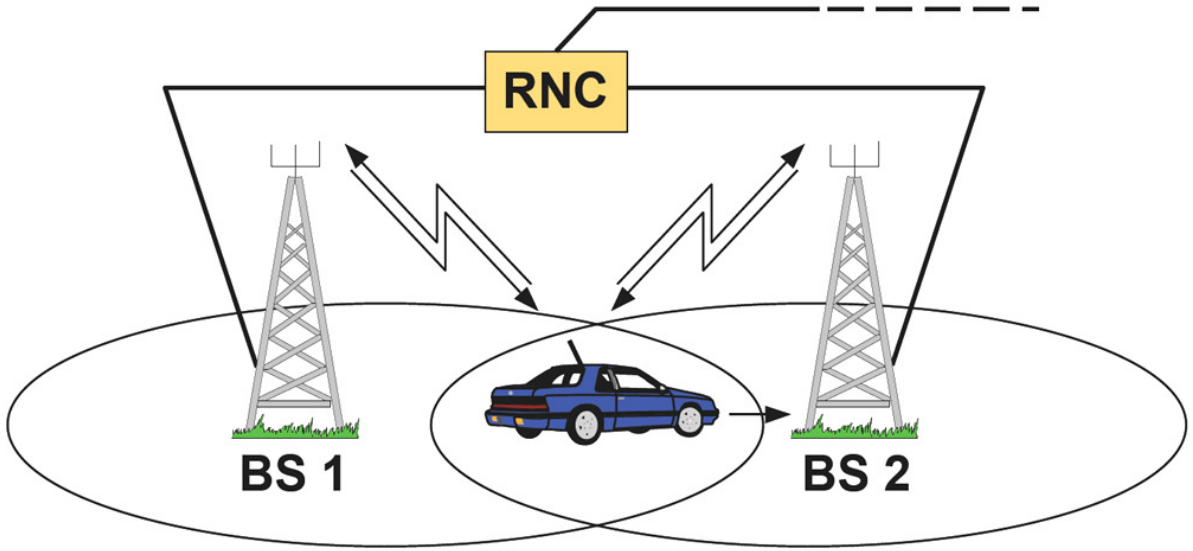
= Detected set

The neighbor set or monitored set is the list of cells that the UE continuously measures, but whose signals are not strong enough to be added to the active set.

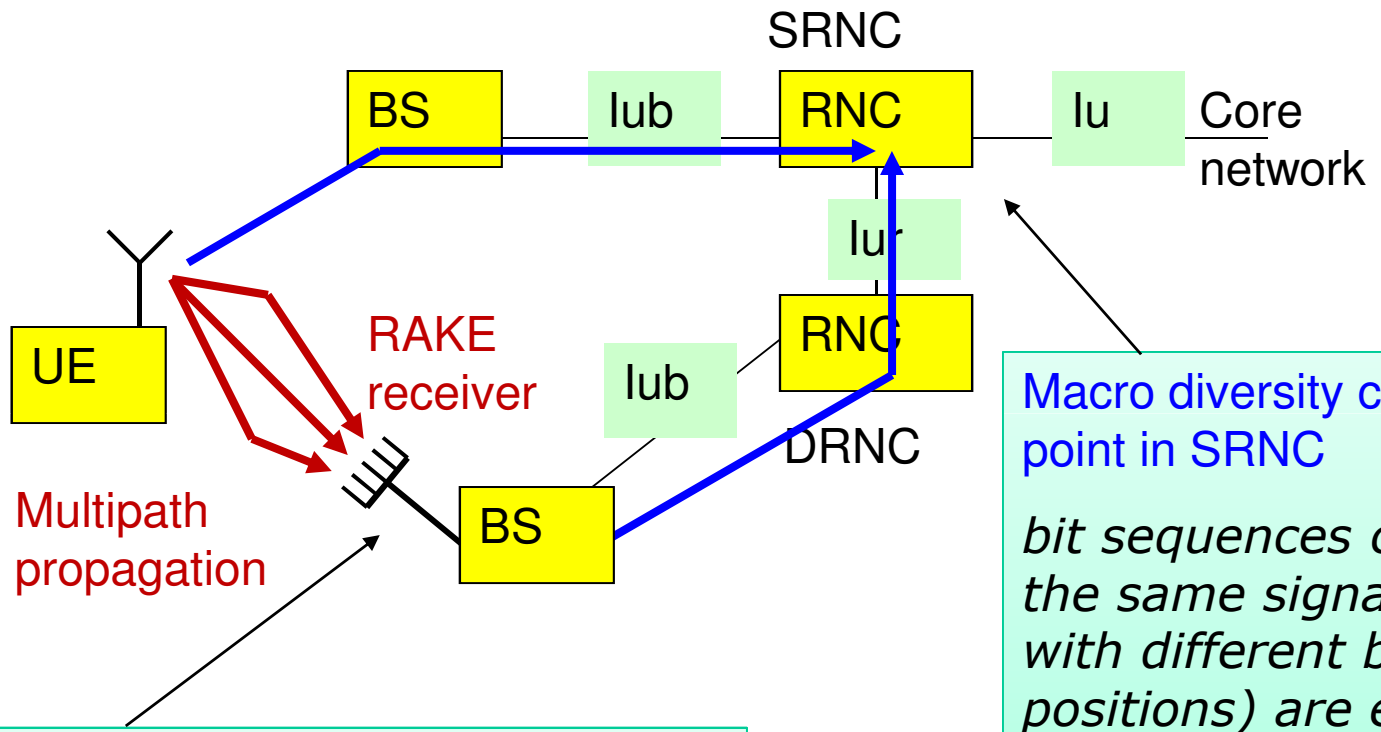
Advantages and Disadvantages of Soft-Handover

- **Advantages:**
  - Reducing the incidence of dropped calls due to handoff failures dramatically improving the call quality
  - Eliminating the audible effects of multipath fading Reducing average transmitted power (Saves handset power)
  - Improving Coverage of the cell.
  - Increasing Capacity

- **Disadvantages**
  - Requires more network resources
  - Increased infrastructure cost



Micro- / Macro diversity combining (Uplink)



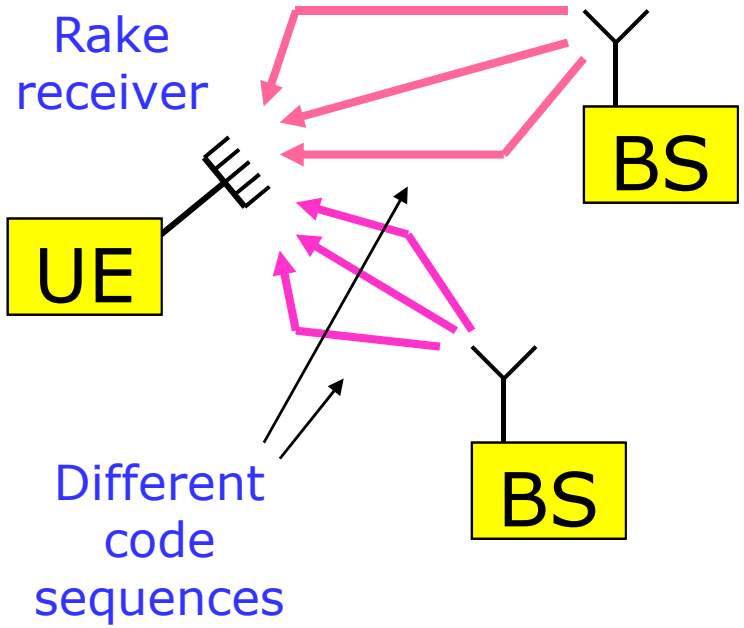
Micro diversity combining point in base station

multipath signal components are processed in RAKE branches and combined (MRC = Maximum Ratio Combining)

Macro diversity combining point in SRNC

bit sequences carrying the same signal (but with different bit error positions) are either combined at SRNC (bit-by-bit majority voting), or best quality signal is selected.

Micro diversity combining (Downlink)



Soft handover: same signal is transmitted via several base stations

Advantage: number of multipath components is increased

Draw-back: in downlink, soft handover decreases capacity