5.3 Gestione delle risorse radio nell’UMTS
5. Power control

6. Hard, Soft and Softer Handover

7. Micro and Macro Diversity

8. Cell breathing

9. Capacity of CDMA
Near-Far Problem (uplink)

✓ All MSs operate at the same time in the same frequency band
   ⇒ MSs are separable at BS only by their own codes

✓ For equal transmitted power in UL, the closest MS could overshoot the far MS; so, a single overpowered mobile could block a whole cell

✓ Such *Near-Far problem* is typical of WCDMA: in GSM the MS operate at different frequencies and/ or times so that they are easily separable at BS

✓ In WCDMA the power received by the BS must be the same, in order to avoid that one MS overshout another MS
To overcame the Near-Far Problem:

- Goal: equal received power at BS by each MS
- Solution: carefully control the power transmitted by each MS

The optimum strategy (in the sense of maximising capacity) is to equalise the received power per bit of all mobile stations at all time, so as to minimise intra-cell interference.

Power of every transmitter should be adjusted to the level required to meet the requested QoS.

In GSM Power control is applied once or twice per second, in UMTS is adjusted 1500 times per second: GSM schemes not applicable.
Open Loop Power Control (OLPC): is used for uplink power adjusting, the UE adjusts its transmission power based on an estimate of the received signal level from the BS and on the indication about the allowed power parameters transmitted in the BCCH.

- In case of FDD-WCDMA, OLPC alone is not adequate, because fading characteristics vary very rapidly.
“Fast” Closed-loop Power Control

- Fast closed-loop power control (CLPC) in the UL: employed for adjusting the transmission power when the radio connection is already been established
- For each MS, from each received timeslot the BS estimates the received Signal-to-Interference Ratio (SIR) and then commands the MS to increase or decrease the transmitted power
- For each mobile the measure/command/react cycle is then executed at a rate of 1500 times per second (1.5 kHz)
- This prevents possible changes of path loss during one cycle even in the case of fast Rayleigh fading (but moderate mobile speed)
“Fast” Closed-loop Power Control

- **Closed loop PC** commands the mobile station to increase/decrease the transmitted power according to measured SIR.
- When the channel or the distance cause a deep fading, the BS gives Up-command.
- Of course if the state of the channel or MS velocity have fast variations, it is difficult to give right commands.
Two simultaneous strategies for CLPC:

- **Inner Loop Power Control**: with a frequency of 1500 times per second, with increase/decrease by 1, 2 or 3 dB step-sizes
- **Outer Loop Power Control**: the RNC being aware of the connection conditions and quality is able to define the allowed power levels of the cell and target SIR to be used by the BS
Summary

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✅ **Handover**: transition from one cell to another (link control from BS1 to BS2)

✅ **Soft-Handover**: MS concurrently communicates with both BS1 and BS2 ⇒ macro-diversity gain. The same signal is sent from both BSs to MS, except for the power control commands

✅ **Advantages**: gain in signal quality

✅ **Drawbacks**: need of more radio (Uplink) and network (Downlink) resources
Handover process

- Measurement criteria
- Measurement reports

- Algorithm parameters
- Handover criteria

- Handover signaling
- Radio Resource Allocation

Measurement → Decision → Execution
**Handover control**

- **Signal Quality Reason**: handover occurs when the quality or the strength of the radio signal falls below certain parameters specified in the RNC.
- The deterioration of the signal is detected by the constant signal measurement carried out by both the UE and the BS. Signal Quality handover can be applied both for the uplink and the downlink radio links. The decision is made by the the RNC (i.e. SRNC).
- **Traffic Reason**: handover occurs when the traffic capacity of a cell has reached its maximum or is close to it. The decision is made by the the RNC or the MSC (Core Network).
The number of handovers is straightforwardly dependent on the degree of UE mobility.

- **Network Evaluated Handover (NEHO)**

- **Mobile Evaluated Handover (MOHO)**
Intra-frequency measurements: strength of the physical channel for signals with same frequencies

Inter-frequency measurements: strength of the downlink physical channel for signals with different frequencies

Inter-system measurements: strength of the downlink physical channels belonging to other radio access system (e.g. GSM)

Traffic volume measurements: measurement of the uplink traffic volume

Quality measurements: quality parameters (e.g. downlink transport block error rate)

Internal measurement: UE transmission power and UE received signal level
**Hard handover**: connection is released before the new connection is set up:

- Inter-frequency: the carrier frequency changes during the handover (e.g. the BSs use different frequencies or two different RANs are involved)
- Intra-frequency: the carrier frequency

**Soft handover**: a new connection is established before the old one is released. In this case the source and the target cells have the same frequency.

**Softer handover**: a new signal is added to or deleted from the active set.
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Micro and Macro Diversity

*Up-link micro diversity:*

as in GSM, the base station can be equipped with two receiving antennas

*Up-link macro diversity:*

typical of UMTS, the mobile at edge cell can be connected to two different base stations
Microdiversity - Macrodiversity

✓ **Microdiversity**: the multipath components are combined in the BS (RAKE receiver)

✓ **Macrodiversity** is the situation when UE uses cells belonging to different BSs or different RNCs. Different data stream are combined and summed at the RNC level

R. Cusani, Comunicazioni Mobili 2, Marzo 2009
☐ La diversità in trasmissione (downlink) e in ricezione (uplink) può essere anche realizzata fra un MS ed una singola BS, dotando questa di due antenne opportunamente distanziate (almeno qualche lunghezza d’onda).

☐ Nell’UMTS il MS può indicare alla BS le fasi e le ampiezze da utilizzare sulle antenne per massimizzare la potenza del segnale ricevuto al MS (diversità ad anello chiuso, closed loop).
L’ uso di un ricevitore Rake permette di trasmettere il segnale destinato ad una stazione mobile da più stazioni base, realizzando una forma di diversità in trasmissione (downlink) che migliora le prestazioni e consente l’esecuzione di soft-handover.

\[ r(t) = a_0 s(t - \tau_0) + a_1 s(t - \tau_1) \]

*Il segnale ricevuto è lo stesso che nel caso multipath*
La diversità può essere usata anche in ricezione (uplink). In questo caso il segnale trasmesso viene ricevuto da due BS.

Non è possibile realizzare un ricevitore Rake (perché le BS, pur connesse allo stesso RNC, hanno ricevitori separati).

Ma il RNC può scegliere la BS che riceve la versione di segnale migliore (es. con maggiore SNR).
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In case of uniformly-distributed traffic the MSs transmit a power level related to the propagation conditions (basically, the distance).

Increasing traffic in Cell #2 forces users in the cell to increase the transmitted power, to counteract the increased interference.

Power increase can be very large for users close to the cell edge.
Cell breathing

- cell #1 is less interferenced: for users close to cell edge, connection to BS1 could be more effective as they can reduce the transmitted power.

- Area covered by BS1 (i.e. the area of cell #1) increases while the area of cell #2 reduces with the goal to balance Signal-to-Interference Ratios between adjacent cells.
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CDMA provides high bit rate $R$ through wide band $B$ and low $S/N$
Assuming N users and *perfect power control*

⇒ the base station receives N equipower signals

C = power received by 1 user

C(N-1) = interference received by the other (N-1) users

SIR (Signal-to-Interference Ratio) is then:

\[
\frac{C}{I} = \frac{C}{C(N-1)} = \frac{1}{N-1}
\]
The ratio between the Energy per Bit $E_b$ and the Interference spectral power density $I_o$ is:

$$\frac{E_b}{N_0} = \frac{C}{R} \frac{W}{I/W} = \frac{CW}{IR} = \frac{W}{R} \frac{1}{N-1}$$

where:

- $R = \text{bit rate}$ of the source
- $W = \text{chip rate}$ on the air interface
- $W/R$ is the processing gain
In up-link, the number $N$ of active users allowed in one cell is proportional to the processing gain and inversely proportional to the ratio $E_b/I_0$:

$$\frac{E_b}{N_0} = \frac{W}{R} \frac{1}{N-1} \quad \Rightarrow \quad N \approx \frac{W}{R} \frac{1}{E_b/N_0}$$

This capacity can be increased as:

1) the source has its own activity factor $D$, i.e. only for $D\%$ of the time it is active and the mobile transmits power. for speech, $D \approx 0.4$

2) the antenna can have $G_s$ sectors (typically, $G_s=3$) and the total received interference is reduced by $1/G_s$

In total we have:

$$N \approx \frac{W}{R} \frac{1}{E_b/N_0} \frac{1}{D} G_s$$
The above formulas are valid for an isolated cell, where only intra-cell interference is present.

- For *isofrequency systems* (e.g., UMTS), users active in other cells originates *inter-cell interference*:
  - $$$\Rightarrow$$ total interfering power raises by a factor $1+F$, with $F \approx 0.5-0.6$
  - $$$\Rightarrow$$ capacity is reduced by the factor $1+F$

- *Imperfect power control* reduces the number of users per cell by a factor $A$, with $A \approx 0.5 - 0.9$

$$\Rightarrow \quad N \approx \frac{W}{R} \frac{1}{E_b/N_0} \frac{1}{D} G_s \frac{1}{1+F} A$$

Up-link cell capacity for a WCDMA system
EXAMPLE number of voice users in a trisectorial cell, assuming:

Source bit rate $R = 16$ kbps;
Chip rate on air $W = 3.84$ Mchip per second;
Antenna sectorization gain $G_s = 3$;
Interference factor for the external cells $F = 0.6$;
Voice activity factor $D = 0.4$;

Signal-to-Interference ratio $Eb/Io = 6$ dB (4)

@ $BER = 0.001$.

Imperfect power control factor $A = 0.8$

The processing gain $W/R$ is 240 and it results: $N \approx 225$

i. e. about 75 users for each 120° sector.
Le trasmissioni da un unica sorgente possono essere facilmente sincronizzate. Quelle da diverse sorgenti no.

Nei sistemi cellulari basati su CDMA l’ interferenza multiutente è sempre presente ed è il disturbo principale (il rumore termico ha un effetto minore).

IL SNR al decisore è

\[
\gamma = \frac{P_s}{\sum_i P_t} \frac{B}{R} = \frac{P_u}{\sum_i P_t} SF = \frac{P_s}{\sum_i P_t} G_p
\]

dove Pu è la potenza utile, Pi sono le potenze dei segnali interferenti, B la banda e R la velocità di trasmissione. Gp è il guadagno di processo.
Un utente che trasmette genera interferenza agli altri utenti in maniera proporzionale alla sua potenza → la risorsa condivisa è la potenza trasmessa

Per un fissato SNR ed una data interferenza, la potenza trasmessa è proporzionale alla velocità di trasmissione

E necessario controllare accuratamente la potenza trasmessa. Inviare più potenza del necessario è un inutile spreco, che aumenta l interferenza

In assenza di controllo della potenza, un problema tipico è quello in cui un utente vicino oscura un utente lontano (Problema Near-Far)

Inoltre se l interferenza è dominata da un singolo segnale il rumore non è più Gaussiano e il BER aumenta considerevolmente
Oltre che per combattere il problema Near-Far il controllo di potenza e’ anche utile per combattere il fading e per allungare la durata della batteria

Nel sistema UMTS il ricevitore conosce il SNR al quale deve operare. E ordina al trasmettitore di incrementare o diminuire la potenza trasmessa a seconda che il SNR effettivo sia minore o maggiore di quello desiderato. Controllo di potenza ad anello chiuso (closed loop).
In presenza di controllo di potenza perfetto, se tutti gli utenti operano con lo stesso SNR e la stessa velocità di trasmissione, il numero di utenti che è possibile servire è:

\[ N_u = \frac{B}{R\gamma} = \frac{G_p}{\gamma} = \frac{SF}{\gamma} \]

Il numero di utenti serviti in un sistema CDMA non è dunque fisso, ma è inversamente proporzionale alla velocità di trasmissione.
+ Il CDMA consente l’ uso di reti SFN (Single frequency network) con fattore di riuso pari a 1. Aumenta la capacità. Semplifica la progettazione della rete.

+ L’ uso di DTX (Discontinuous transmission) riduce l’ interferenza e quindi aumenta la capacità (non vero per TDMA e FDMA).

+ Non richiede sincronizzazione precisa dei segnali trasmessi da diverse sorgenti (come invece richiede il TDMA).

+ Consente l’ uso del ricevitore di Rake.
  - Richiede un controllo accurato della potenza trasmessa per evitare il problema near-far.
  - L’ interferenza proveniente da altre celle non è trascurabile.
  - E’ più complesso (opera a frequenza di chip, non di simbolo).