Radio Resource Management for Wireless Networks

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Contents

- Power control
- Handover
- Admission control
- Load control

Chapter 1: Power control

Why transmitter power control ?

- Reduce terminal power consumption
- Mitigate near-far effects
  - efficient handling of mobility
  - efficient reduction of the dynamic range of received power
- Reduce interference / improve quality
  - "BS tx power = interference to the system"
  - "MS tx power = interference to other cells"
- PC is a radio resource management tool
  - low vs. high complexity (how much in assumed to be know about the system)
  - slow vs. fast (where the decision is done)

Open loop PC

- Two purposes for open loop PC:
  - initial power level in the beginning of a call
  - quality target updating
- Open loop PC can be non-linear
  - this is to allow fast response for negative corrections (e.g. up to 10 dB in 1 ms) but slow response for positive corrections (e.g. 1 dB in 1 ms)
  - Why non-linear PC: When attenuation is suddenly decreased, it is important to quicly decrease the TX power in order not to cause additional interference to other users.
- Since the open loop method cannot estimate reverse link fading (due to different band and related independent fading), open loop PC becomes inaccurate.
- In 3GPP, accuracy requirement for OL PC is 10 dB
- This is why closed loop PC in needed, too.

WCDMA Closed Loop Power Control

Fast Power Control

- Fast Power Control with 1.5kHz is supported in both UL and DL in WCDMA
- Only slow power control with about 2Hz is employed in GSM

Gain of Fast Power Control

- Required Eb/No values with and without fast power control

	Slow Power Control (dB)	Fast 1.5kHz power control(dB)	Gain from fast power control(dB)
ITU Pedestrian A 3 km/h	11.3	5.5	5.8
ITU Vehicular A 3 km/h	8.5	6.7	1.8
ITU Vehicular A 50 km/h	6.8	7.3	-0.5

Fast PC with 1dB step

- Required relative transmission powers with and without fast power control

	Slow Power Control (dB)	Fast 1.5kHz power control(dB)	Gain from fast power control(dB)
ITU Pedestrian A 3 km/h	11.3	7.7	3.6
ITU Vehicular A 3 km/h	8.5	7.5	1
ITU Vehicular A 50 km/h	6.8	7.6	-0.8

Fast PC with 1dB step

Note: "slow PC" here assumes that the average power is kept at ideal level.

Gain of fast PC in WCDMA

- Generally, slow PC is meant to compensate the effects of path loss and shadowing, whereas fast PC is used to compensate also for fast fading.

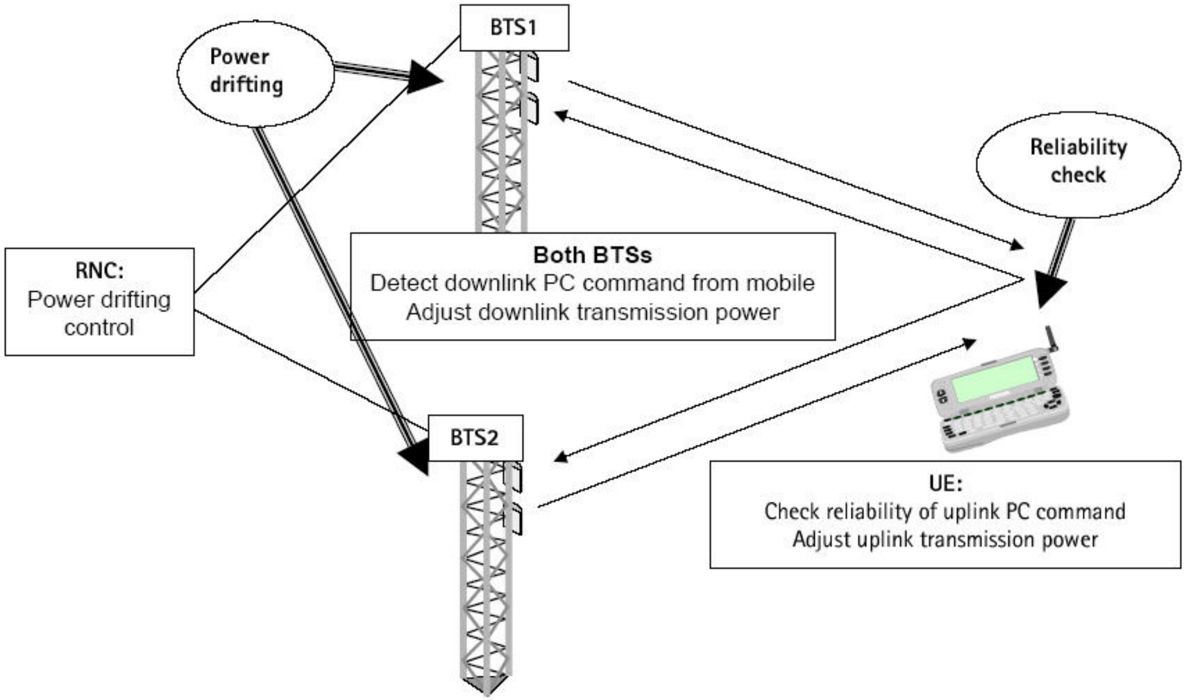
- From the tables just presented we see that fast PC gives a clear gain in WCDMA.

- It can be seen that the gain from fast PC is larger:
  - for low UE speeds than for high UE speeds
  - for those cases where only a little multipath diversity is available

- The negative gain at 50km/h indicate that ideal slow PC is better than realistic Fast PC. The reasons are
  - inaccuracies in the SIR estimation
  - power control signaling errors, and
  - the delay in the power control loop.

WCDMA PC in soft handover

- Two major issues that are different from the single-link case:
  - power drifting in Node B powers in the downlink
  - reliable detection of the UL power control commands in the UE.

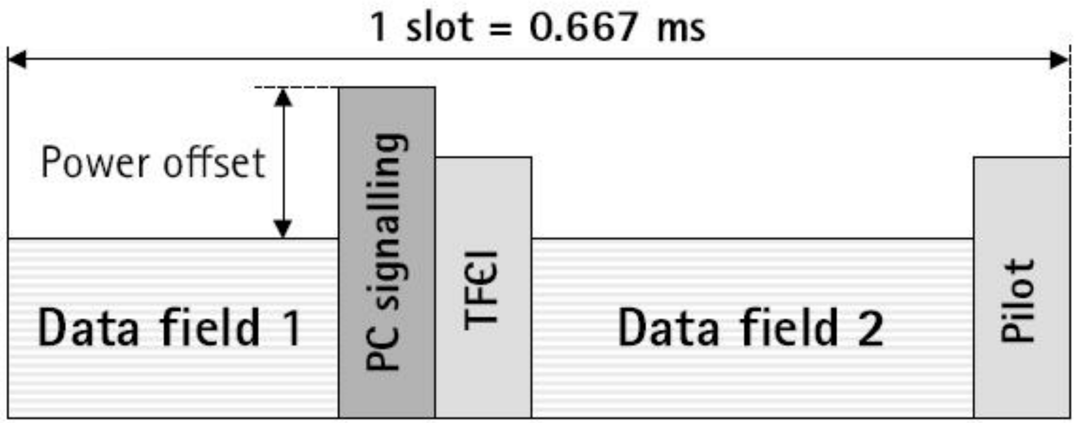


Solutions for DL power drifting

- The simplest method is to set relatively strict limits for the downlink power control dynamics.
  - Naturally, the smaller the allowed power control dynamics, the smaller the maximum power drifting.
  - On the other hand, large power control dynamics typically improve power control performance.
- Another solution:
  - RNC can receive information from the Node Bs concerning the transmission power levels of the soft handover connections.
  - Based on that information, RNC can send a reference value for the DL transmission powers to the Node Bs.
  - The idea is that a small correction is periodically performed towards the reference power.

Solution for reliable UL PC command detection

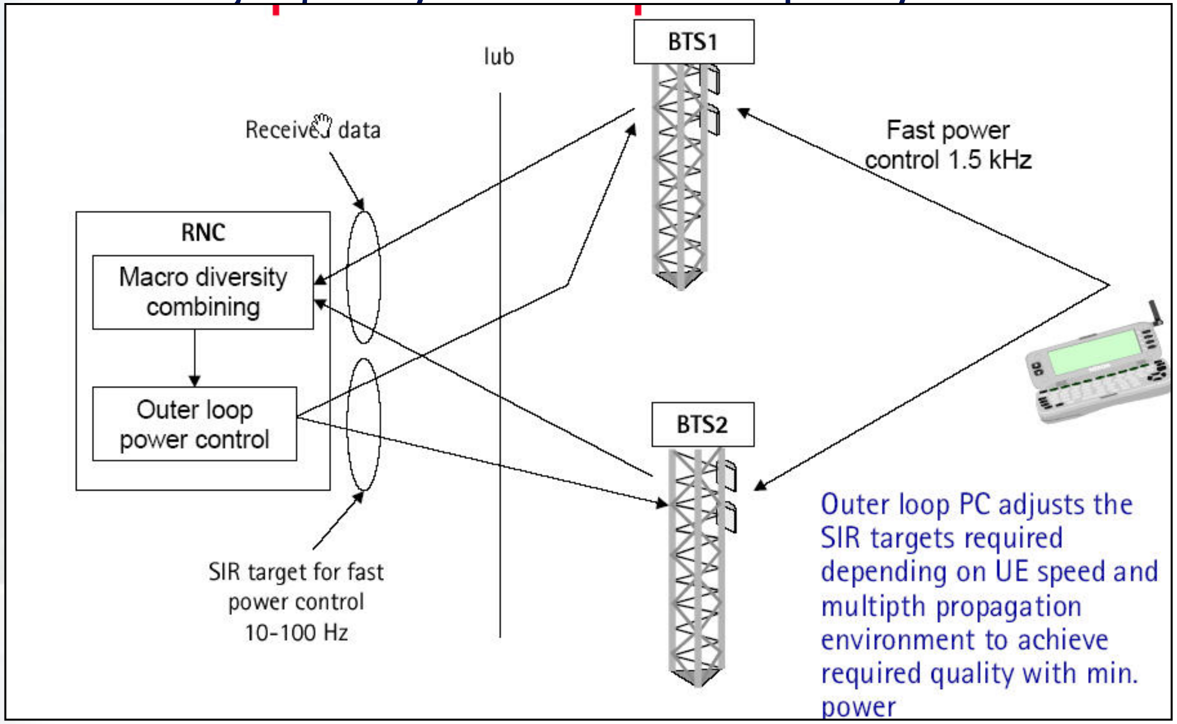
- To make UL PC command detection more reliable, a simple solution is to improve PC signaling quality in downlink as follows:



The power of DPCCH channel is more than that of DPDCH

Outer loop PC in WCDMA

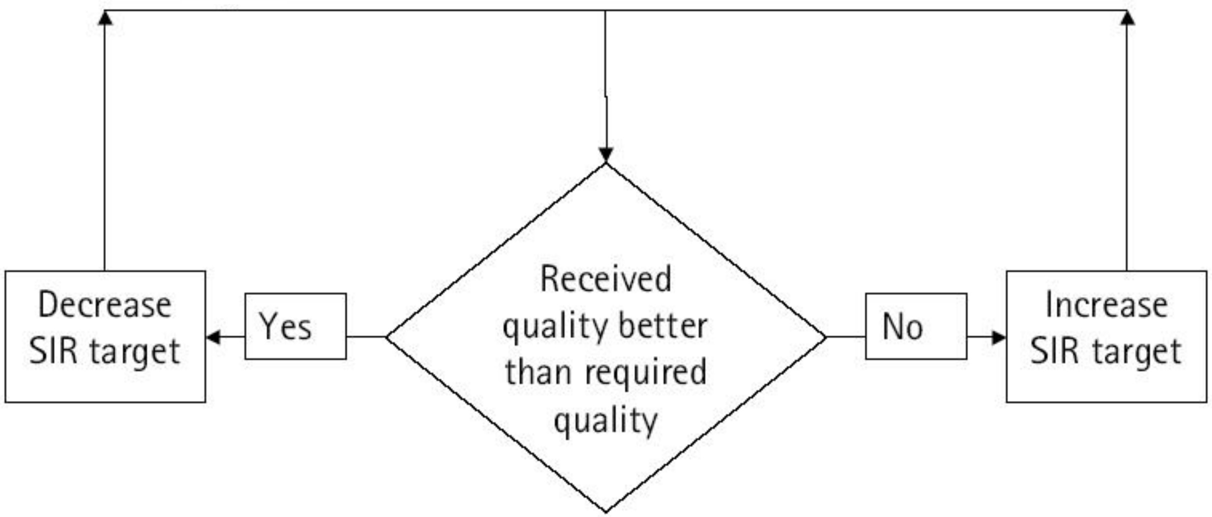
- Outer loop power control (OL PC) is needed to keep the quality of communication at the required level by setting the target for the fast power control:
  - OL PC aims at providing the required quality: no worse, no better
  - too high quality would waste capacity



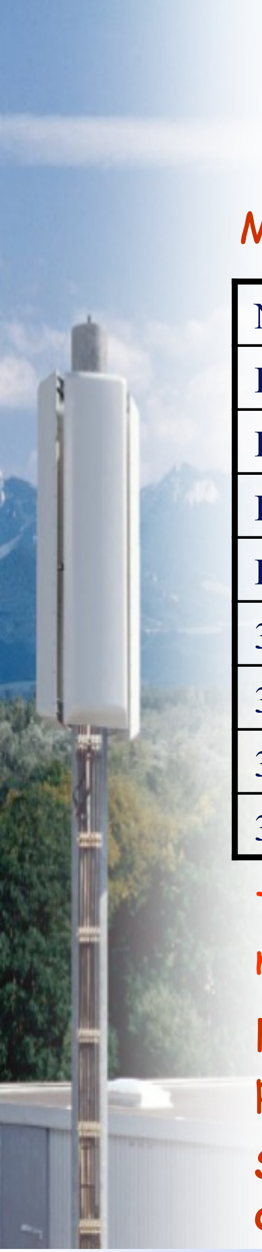
-OL PC is needed in both uplink and downlink because there is fast PC in both links, too.

- The uplink outer loop is located in RNC and the downlink outer loop is located in UE

General outer loop PC algorithm



Frequency of the outer loop power control typically 10-100Hz.



Gain of OL PC

Multi-path	UE speed (km/h)	Average SIR target (dB)
Non-fading	-	5.3
ITU Pedestrian A	3	5.9
ITU Pedestrian A	20	6.8
ITU Pedestrian A	50	6.8
ITU Pedestrian A	120	7.1
3-path equal powers	3	6.0
3-path equal powers	20	6.4
3-path equal powers	50	6.4
3-path equal powers	120	6.9

The higher the variation in the received power, the higher SIR target needs to be to provide the same quality (here, 1 % BLER).

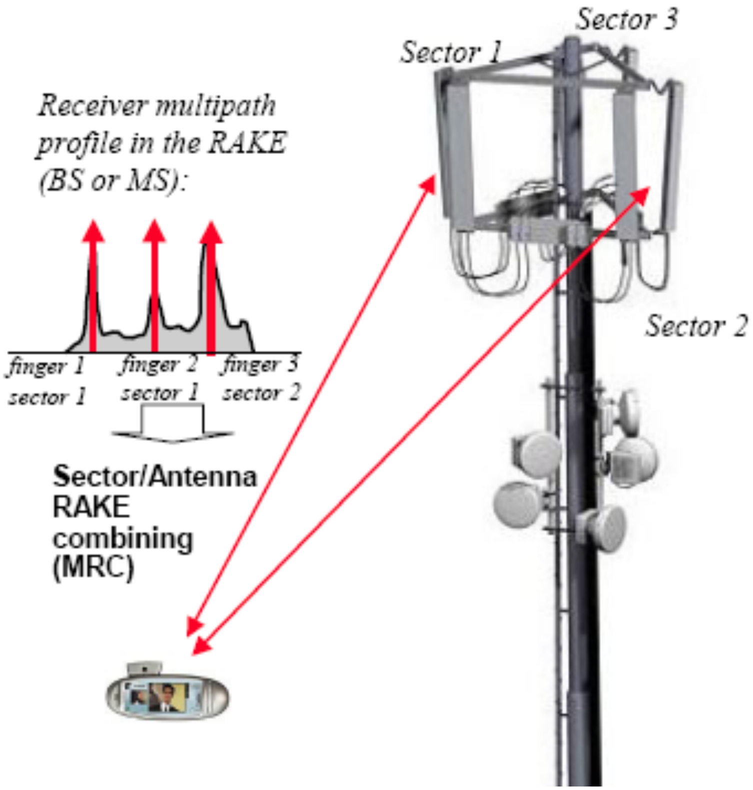
For example, if SIR target would be fixed to 7.1 dB, unnecessary high power would be used in other channels.

Since we have different SIR targets in different channels, we need to dynamically adjust the SIR target of the fast closed PC by OL PC !

Chapter 2: Handover control

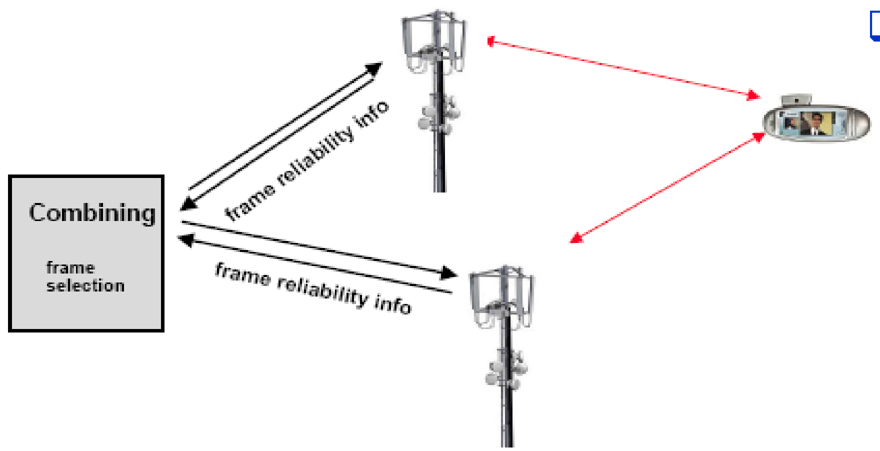
Handovers: softer handover

- During *softer* handover, a mobile station is in the overlapping cell coverage area of two adjacent sectors of the same base station.
- The communications between mobile station and base station take place simultaneously but via two different air interface channels: one for each sector separately.
- This requires the use of two separate codes in the downlink direction, so that the mobile station can distinguish the signals.
- At the MS, separate RAKE fingers are allocated to both sectors.
- Softer HO probability ~ 5-15%



Handovers: soft handover

- During *soft* handover, a mobile station is in the overlapping cell coverage area of two sectors belonging to *different* base stations.
- As in softer handover, the communications between mobile station and base station take place simultaneously via two air interface channels from each base station separately.
- RAKE processing is applied as well.
- Soft HO probability ~ 20-40%



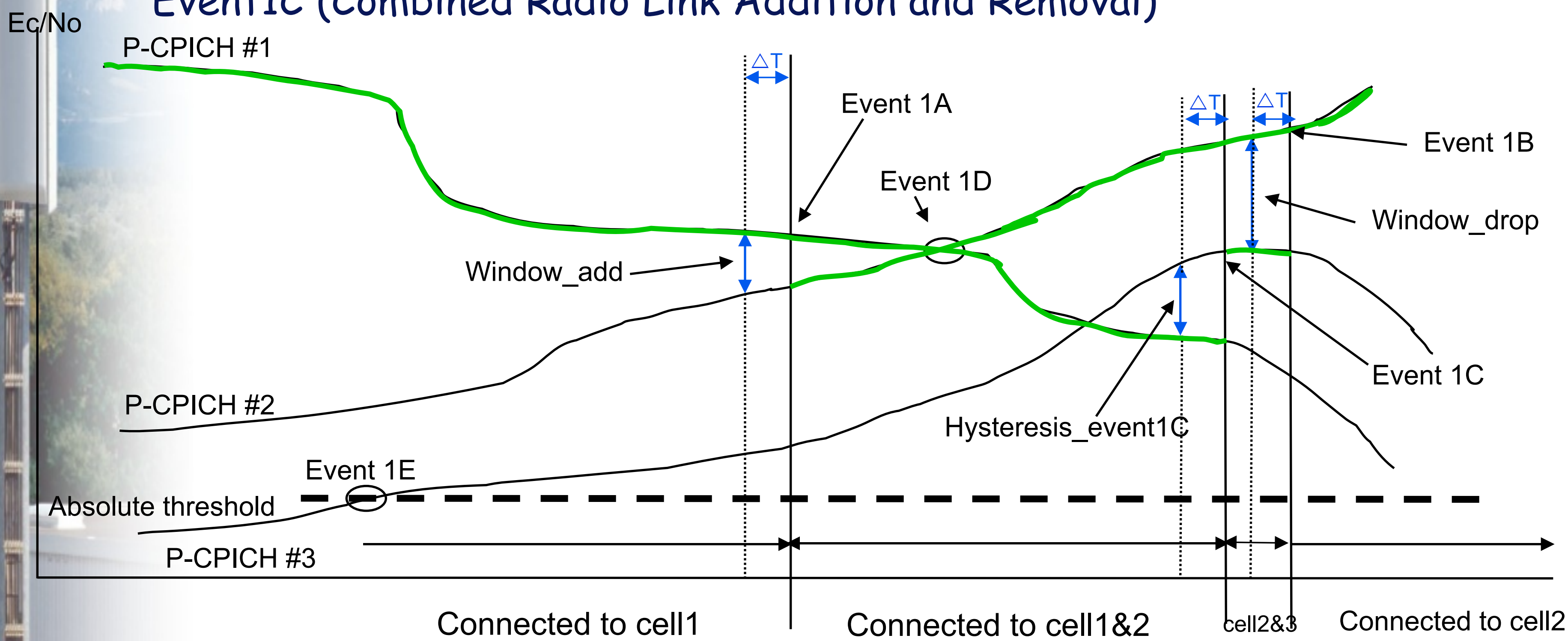
- Differences is UL/DL
  - DL: MS uses additional RAKE fingers, just like in softer HO
  - UL: both BSs route the received signal to RNC for combining

Intra-frequency HOs

- Soft handover uses typically pilot (CPICH) Ec/I0 as the handover measurement quantity, which is signaled to RNC
- Terminology:
  - Active set - the cells that a UE connects in soft handover connection
  - Neighbor set - the list of cells that the UE continuously measures, but whose pilot Ec/I0 are not strong enough to be added to the active set
- Handover Control supports the following intra-frequency measurement report events
  - Event 1a: a P-CPICH enters the reporting range
  - Event 1b: a P-CPICH leaves the reporting range
  - Event 1c: a non-active P-CPICH become better than an active P-CPICH
  - Event 1d: change of the best cell
  - Event 1e: a P-CPICH becomes better than an absolute threshold
  - Event 1f: a P-CPICH becomes worse than an absolute threshold

General HO scheme

- If "Pilot_Ec/Io > Best_Pilot_Ec/Io –Window_add" for a period of ΔT & active set not full ➔ Event1A (Radio Link Addition)
- If "Pilot_Ec/Io < Best_Pilot_Ec/Io – Window_drop" for a period of ΔT ➔ Event1B (Radio Link Removal)
- If the active set is full and "Best_candidate_Pilot_Ec/Io > Worst_Old_Pilot_Ec/Io + Hysteris_event1C" for a period of ΔT ➔ Event1C (Combined Radio Link Addition and Removal)



UE connect to cell(s) with

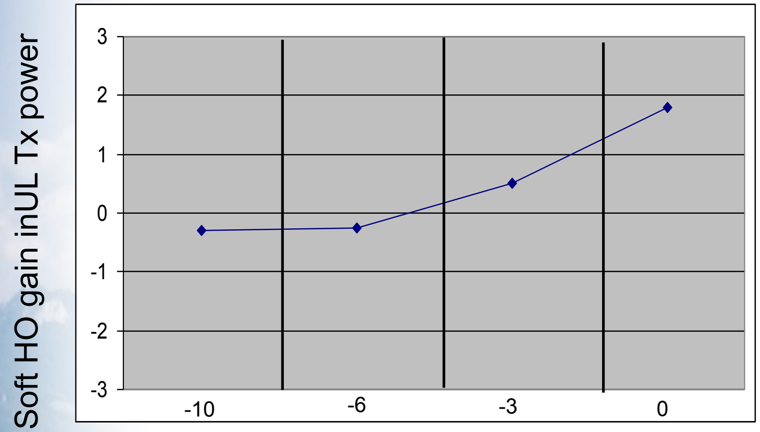
Why soft/softer handovers?

- Recall: in WCDMA all the users share the same frequency band simulateneously, which means that interference situations arise
- Roughly speaking: ”transmit power” = ”interference to the system”, so it’s beneficial to use as little power as possible.

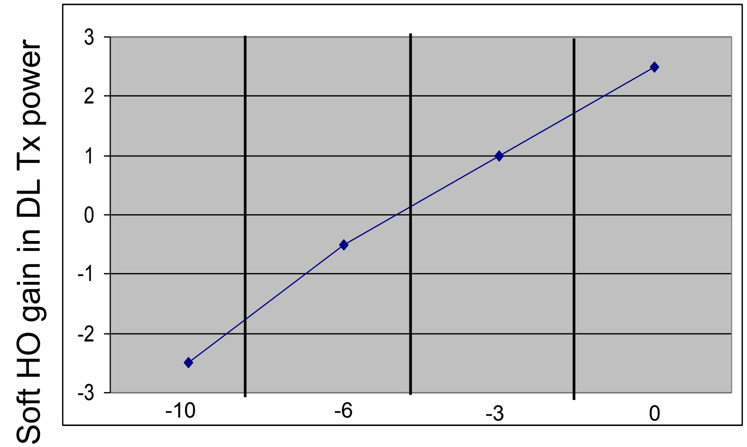
1. Soft/softer HO’s help in reducing transmit powers:
    - Uplink: if two BS’s (or two sectors of one BS) are both receiving the signal of a particular MS, then MS can reduce its transmit power.
    - Downlink: if two BS’s are sending the same signal for the same MS, both BS’s can reduce their transmit power.
2. Soft HO’s give coverage gains
    - The signal to other BS can be temporarily very weak. However, it is more unlike that *both* links are weak at the same time is. Hence, due to the existence of soft/softer handover situation the resulting signal can be relatively good.
    - Seamless handover (compared to hard handover)

- The downsides of HO:
    - Additional RAKE fingers at BS/MS, additional links between BS and RNC
    - Additional signalling

Example: Link Gains with 2-branch Node Bs



Relative path loss to BS1 vs. BS2



Relative path loss to BS1 vs. BS2

- The gains are relative to the single link case where the UE is connected to the best Node B
- The highest gain is obtained when the path loss is the same to both Node Bs
- The max soft handover gain of DL is more than that of UL, because UL has already gained from antenna diversity
- For DL, in case the path loss difference is more than 4-5dB, the UE does not experience a gain from the signal transmitted from the Node B with largest path loss
  - the power transmitted from that Node B to the UE will only contribute to total interference in the network.
- Typical values: Window_add = 1-3 dB, Window_drop = 2-5 dB

Chapter 3: Admission and load control

Air Interface Load Measurement

- If radio resource management is based on the interference levels in the air interface, the air interface load needs to be measured.
- Load estimation can be based on
  - wideband received power
  - throughput
- Uplink load estimation based on wideband received power $I_{total}=I_{own}+I_{oth}+P_N$
    - I_{total}: received wideband power
    - I_{own}: power of intra-cell users
    - I_{oth}: power of inter-cell users
    - P_N: background and receiver noise
  - Noise rise= $I_{total}/P_N = 1/(1-\eta_{UL})$
  - $\eta_{UL}=1- P_N/ I_{total}$=(Noise rise-1)/Noise rise = <u>UL load factor</u>
- UL load factor can be used as an UL load indicator.

Admission control

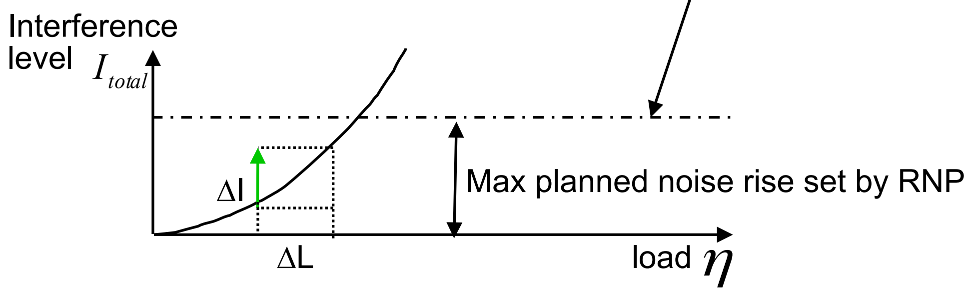
- Admission Control Principles
  - AC ensures the coverage/quality of the existing connections before accepting a new RAB and maintains network stability
  - AC functionality is located in the RNC
  - AC estimates whether a request to establish a RAB is admitted in RAN or not
  - AC needs estimation of a load increase that a new connection would cause
  - New call admitted only if both UL and DL AC admits it.

Wideband power-based AC strategy

- In uplink, a new UE is admitted if

$$I_{total\_old} + \Delta I < I_{threshold}$$

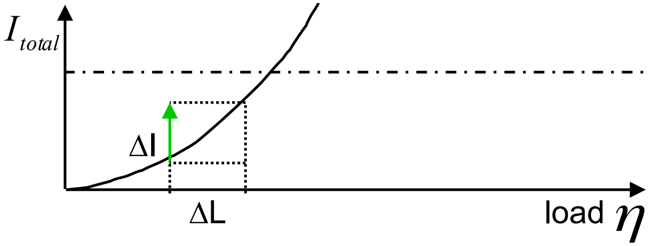
same as max. UL noise raise (set by RNP)



- The only problem is how to estimate the increase in interference.

Load increase estimation

- Load increase estimation takes into account the derivative of load curve, $\dfrac{dI_{total}}{d\eta}$



which can be calculated as follows:

$$\text{Noise raise} = \frac{I_{total}}{P_N} = \frac{1}{1-\eta} \Rightarrow$$

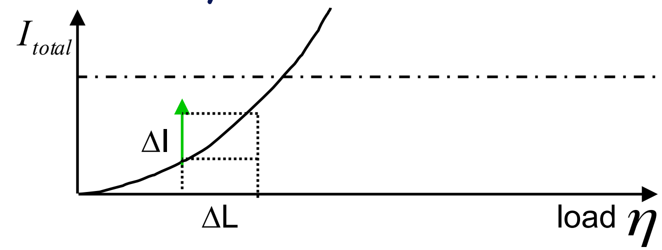
$$I_{total} = \frac{P_N}{1-\eta} \Rightarrow$$

$$\frac{dI_{total}}{d\eta} = \frac{P_N}{(1-\eta)^2}$$

Derivative method

- Replacing derivative with differentials, we have

$$\frac{dI_{total}}{d\eta} \approx \frac{\Delta I}{\Delta L}$$



where ΔL is a load factor of the new UE. It is estimated as

$$\Delta L = \frac{1}{1 + \dfrac{W}{E_b / N_0 \; R \; v}}$$

assumed values for the new connection

v = activity factor = 0…1

- Finally, this results in the following:

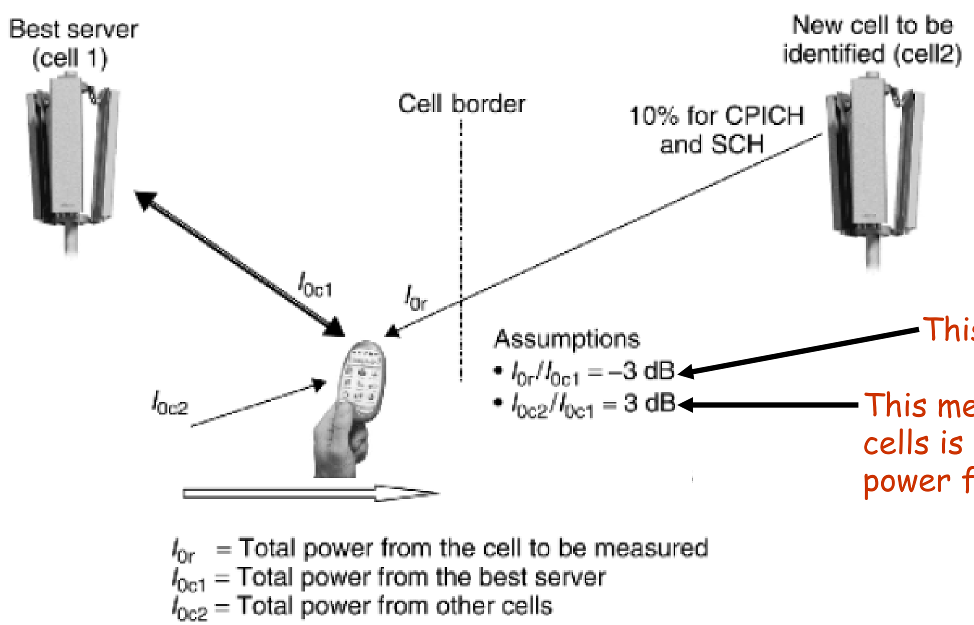
$$\Delta I \approx \frac{dI_{total}}{d\eta} \Delta L = \frac{P_N}{(1-\eta)^2} \Delta L = \frac{I_{total}}{1-\eta} \Delta L$$

Load (congestion) control

- Purpose: update the load status based on the measurements and estimations provided by AC
- Return the system quickly and controllably to/under the target load in case of an overload situation.
- LC functionalities locate in RNC and BTS
- Action taken
  - DL fast load control: deny DL power up commands received from the UE
  - UL fast load control: reduce the UL Eb/N0 target
  - Reduce the throughput of packet data traffic
  - HO to another WCDMA carrier
  - HO to GSM
  - Decrease bit rates of RT users
  - Drop calls in controlled fashion

Exercises (1/2)

- Assume that the UE (see the figure) is connected to cell 1 and needs to identify cell 2 (whose pilot strength is approaching "Window_add" value). In 3GPP handover measurement performance requirements it is said that an UE have to be able to identify a new cell (within a certain time limit) if the pilot channel wideband signal-to-interference ratio (CPICH Ec/I0) is better than -20dB. What is the CPICH Ec/I0 in the figure ?



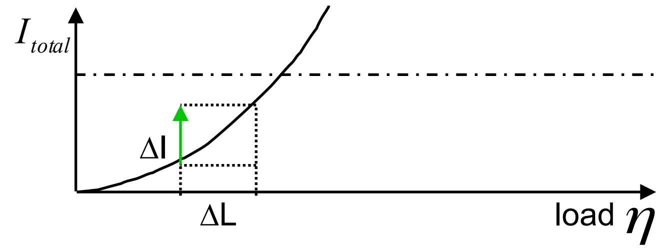
This means: Window_add=3dB

This means:interference from other cells is 3dB stronger than the signal power from the best cell

Exercises (2/2)

- Load increase estimation: another way to get an estimate of the load increase is to apply integral method:

$$\Delta I = \int_{I_{total\_old}}^{I_{total\_new}} dI_{total}$$



Solve ΔI by changing the integration variable and keeping in mind that:

$$\frac{dI_{total}}{d\eta} = \frac{P_N}{(1-\eta)^2}$$