

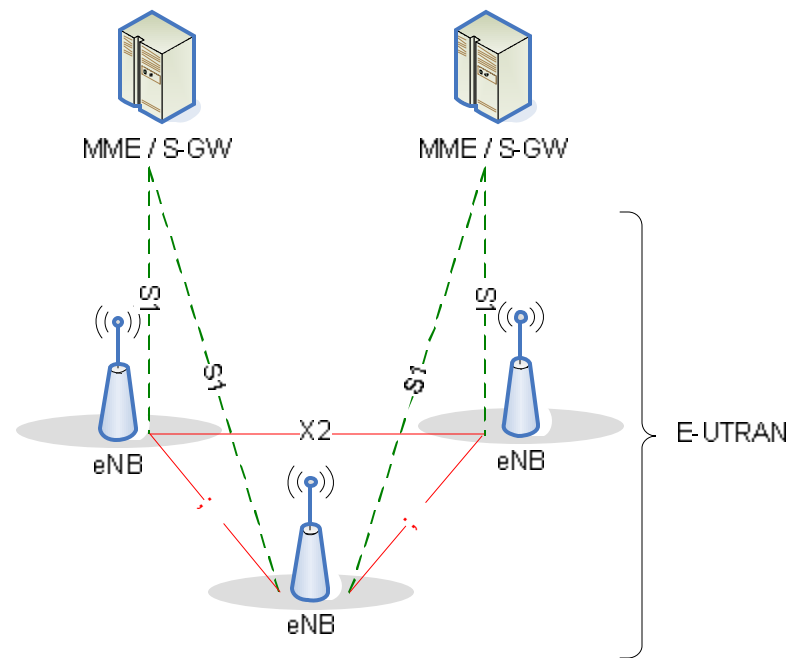


Survey of power control in LTE

Kouros Parsa, Ph.D.
2/28/2008

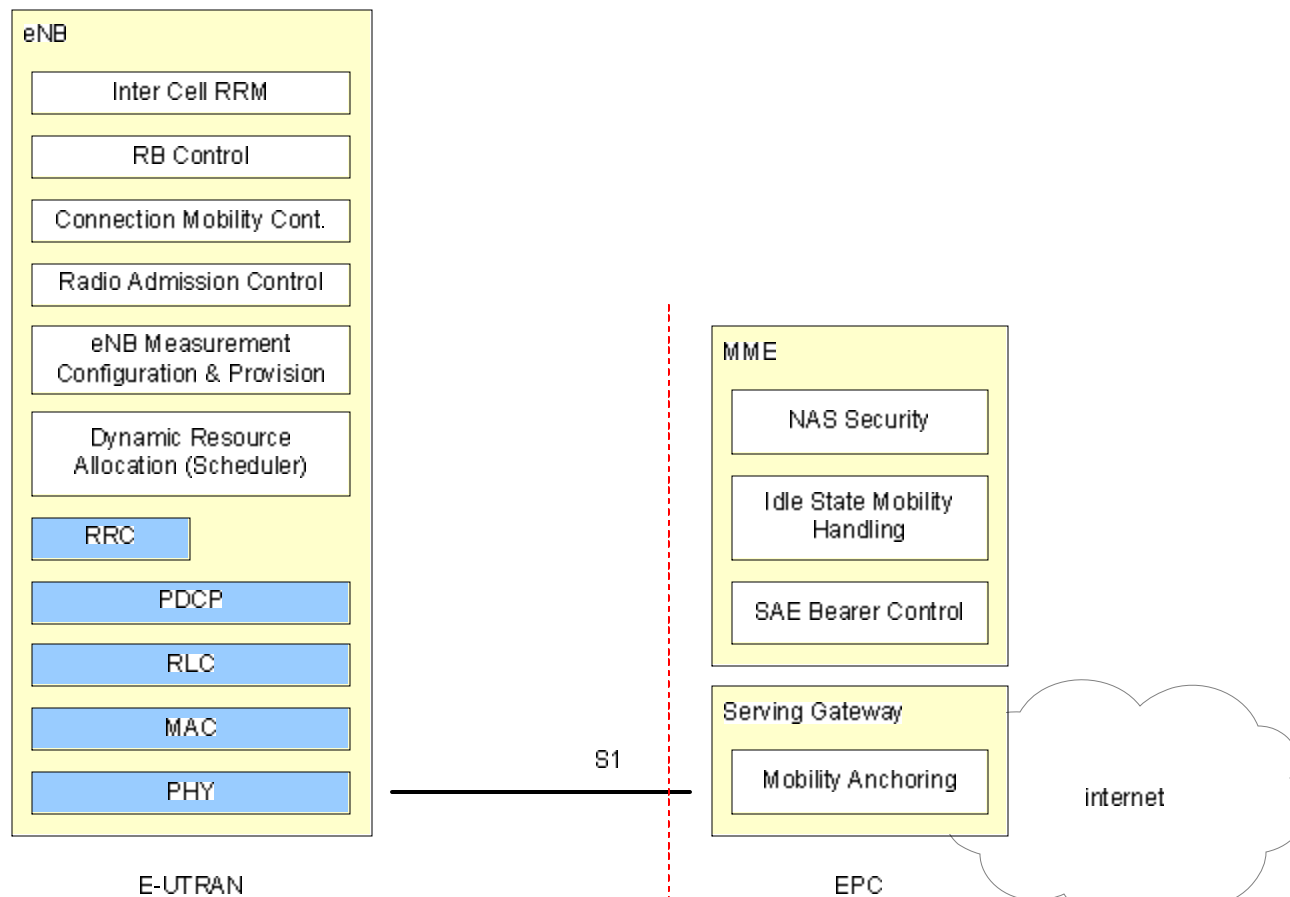
confidential: Parsa Wireless
Communications, LLC

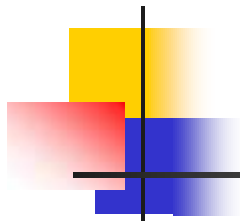
LTE Overall Architecture



confidential: Parsa Wireless
Communications, LLC

Functional Split between E-UTRAN and EPC





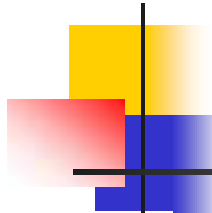
Outline

- Specification agreement
- How does it work?
- Why was each parameter adopted?
- Survey of various proposals in LTE

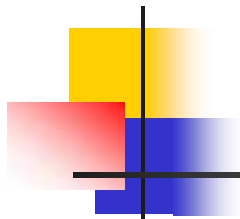
June-October 2007 agreement for PUSCH [change in P0]



- PC formula: $P = \min (P_{\max} , 10 \log M + P_0 + \alpha \times PL + \text{delta_mcs} + f(\text{delta_i}))$
 - UE obeys the power setting formulation based on the parameters signaled by the network
 - M is the number of assigned **Resource Blocks** (based on **UL grant**)
 - P_0 is a user specific parameter that is **broadcasted** (default value)
 - α is cell specific path loss compensation factor (can be set to one to allow full path loss compensation)
 - PL is downlink pathloss calculated in the UE
 - delta_mcs is signaled by RRC (table entries can be set to zero)
 - MCS signaled in **UL grant**
 - delta_i is UE specific correction value included in the **UL grant**
 - Function $f(*)$ signaled via higher layers
 - Only two possibilities
 - Accumulated vs. absolute value
 - This should be consistent with interference coordination

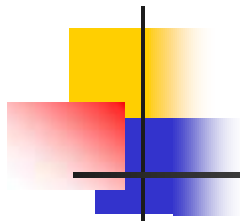


parameter	definition	Signaling scheme
M	number of assigned Resource Blocks	based on UL grant
Po	a user specific parameter Related to average received SNIR	broadcasted (default value) May be settable per UE via RRC signaling
	This value controls the variance of the received SNIR	cell specific path loss compensation factor (can be set to one to allow full path loss compensation) Broadcasted value May be settable via RRC signaling per UE
PL	Measured at the UE. Related parameters are signaled by the eNB	downlink pathloss calculated in the UE
delta_mcs	This variable controls the uplink modulation coding scheme.	is signaled by RRC (table entries can be set to zero) MCS signaled in UL grant
Function f(*)	Only two possibilities Accumulated vs. absolute value	signaled via higher layers.
delta_i is	Relative difference between wireless target SNIR in the eNB and the UE	UE specific correction value included in the UL grant



Definition

- Reference signal received power (RSRP), is determined for a considered cell as the linear average over the power contributions (in [W]) of the resource elements that carry cell-specific reference signals within the considered measurement frequency bandwidth. If receiver diversity is in use by the UE, the reported value shall be equivalent to the linear average of the power values of all diversity branches.
 - Note: The number of resource elements within the considered measurement frequency bandwidth and within the measurement period that are used by the UE to determine RSRP is left up to the UE implementation with the limitation that corresponding measurement accuracy requirements have to be fulfilled.



Definition

- E-UTRA Carrier Received Signal Strength Indicator, comprises the total received wideband power observed by the UE from all sources, including co-channel serving and non-serving cells, adjacent channel interference, thermal noise etc.

UE behaviour

physical shared channel:

Physical uplink shared channel

- The setting of the UE Transmit power for the physical uplink shared channel (PUSCH) transmissions is defined by

$$P_{pusch} = \min(P_{max}, 10\log_{10}(M) + P_o + \alpha \cdot PL + \Delta_{mcs} + f(\Delta_i))$$

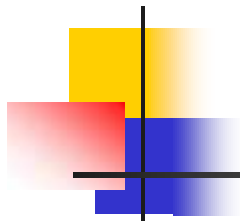
- Where,
- P_{max} is the maximum allowed power that depends on the UE power class
- M is the number of assigned resource blocks as indicated in the UL scheduling grant
- P_o is a UE specific parameter with 1 dB resolution
- α is cell specific path loss compensation factor (can be set to one to allow full path loss compensation) that has 8 values from 0.4 to 1 in steps of 0.1 with one of the possible values being zero.
- PL is the downlink pathloss calculated in the UE from a RSRP measurement and signalled RS transmit power
- Δ_{mcs} is signaled by RRC (Δ_{mcs} table entries can be set to zero). MCS is signaled in each UL scheduling grant
- Δ_i is a UE specific correction value and is defined differently dependent on scheduling as given by:
 - Scheduled
 - Δ_i is included in each UL scheduling grant
 - Function $f(*)$ signaled via higher layers
 - $F(*)$ represents either accumulation or current absolute value
 - Not scheduled
 - Δ_i is included in each DL scheduling assignment or jointly coded with other UE specific correction values on a TPC PDCCH
 - The UE attempts to detect a TPC PDCCH and a DL scheduling frame on every subframe except when in DRX.
 - The Δ_i from a DL scheduling assignment overrides any command from a TPC PDCCH when both are received in a given subframe
 - .Function $f(*)$ represents accumulation only

Physical uplink control channel UE behaviour

- The setting of the UE Transmit power for the physical uplink control channel (PUCCH) transmissions is defined by

$$P_{pucch} = \min(P_{\max}, 10\log_{10}(M_{pucch}) + P_{o_pucch} + PL + \Delta_{mcs_pucch} + g(\Delta_j))$$

- where M_{pucch} is the number of assigned resource blocks for the PUCCH
- Δ_{mcs_pucch} is signaled by RRC (Δ_{mcs_pucch} table entries can be set to zero)
 - MCS is signaled using higher layer signaling
- P_{o_pucch} is a UE specific parameter with 1 dB resolution
- j is a UE specific correction value, also referred to as a TPC command, included in a DL scheduling assignment or sent jointly coded with other UE specific correction values on a TPC PDCCH.
 - The UE attempts to detect a **TPC PDCCH** and a DL scheduling frame on every subframe except when in DRX.
 - The TPC command from a DL scheduling assignment overrides any command from a TPC PDCCH when both are received in a given subframe.
 - Function $g(*)$ represents accumulation



Outline

- Specification agreement
- How does it work?
- Why was each parameter adopted?
- Survey of various proposals in LTE

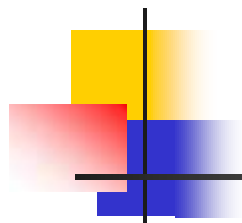


LTE Uplink power control

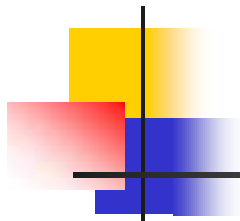
- Uplink power control consists of open and closed loop components and controls energy per resource element applied for a UE transmission. For intra-cell uplink power control the closed loop component adjusts a set point determined by the open loop power control component.
- Upon reception of an a-periodic transmit power command in an uplink scheduling grant the UE shall adjust its transmit EPRE accordingly. EPRE is set in the UE. A cell wide overload indicator (OI) is exchanged over X2 for inter-cell power control.

Power Control in LTE

36.213

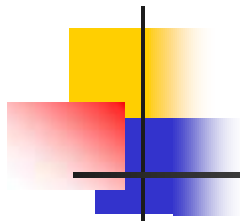


- Power control determines the energy per resource element (EPRE). The term resource element energy denotes the energy prior to CP insertion. The term resource element energy also denotes the average energy taken over all constellation points for the modulation scheme.



Resource elements

- Each element in the resource grid is called a resource element and is uniquely defined by the index pair (k, l) in a slot where $k = 0, \dots, N_{\text{RB}}^{\text{UL}} N_{\text{sc}}^{\text{RB}} - 1$ and $l = 0, \dots, N_{\text{ymb}}^{\text{UL}} - 1$ are the indices in the frequency and time domain, respectively. Resource element (k, l) corresponds to the complex value $a_{k, l}$.
- Quantities $a_{k, l}$ corresponding to resource elements not used for transmission of a physical channel or a physical signal in a slot shall be set to zero.



Resource blocks

- A resource block is defined as $N_{\text{symb}}^{\text{UL}}$ consecutive SC-FDMA symbols in the time domain and $N_{\text{sc}}^{\text{RB}}$ consecutive subcarriers in the frequency domain, where $N_{\text{symb}}^{\text{UL}}$ and $N_{\text{sc}}^{\text{RB}}$ are given by Table 5.2.3-1. A resource block in the uplink thus consists of $N_{\text{symb}}^{\text{UL}} \times N_{\text{sc}}^{\text{RB}}$ resource elements, corresponding to one slot in the time domain and 180 kHz in the frequency domain.

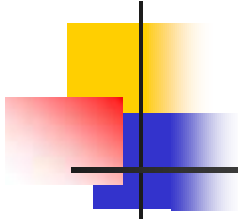


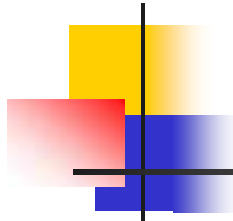
Table 5.2.3-1

Table 5.2.3-1: Resource block parameters.

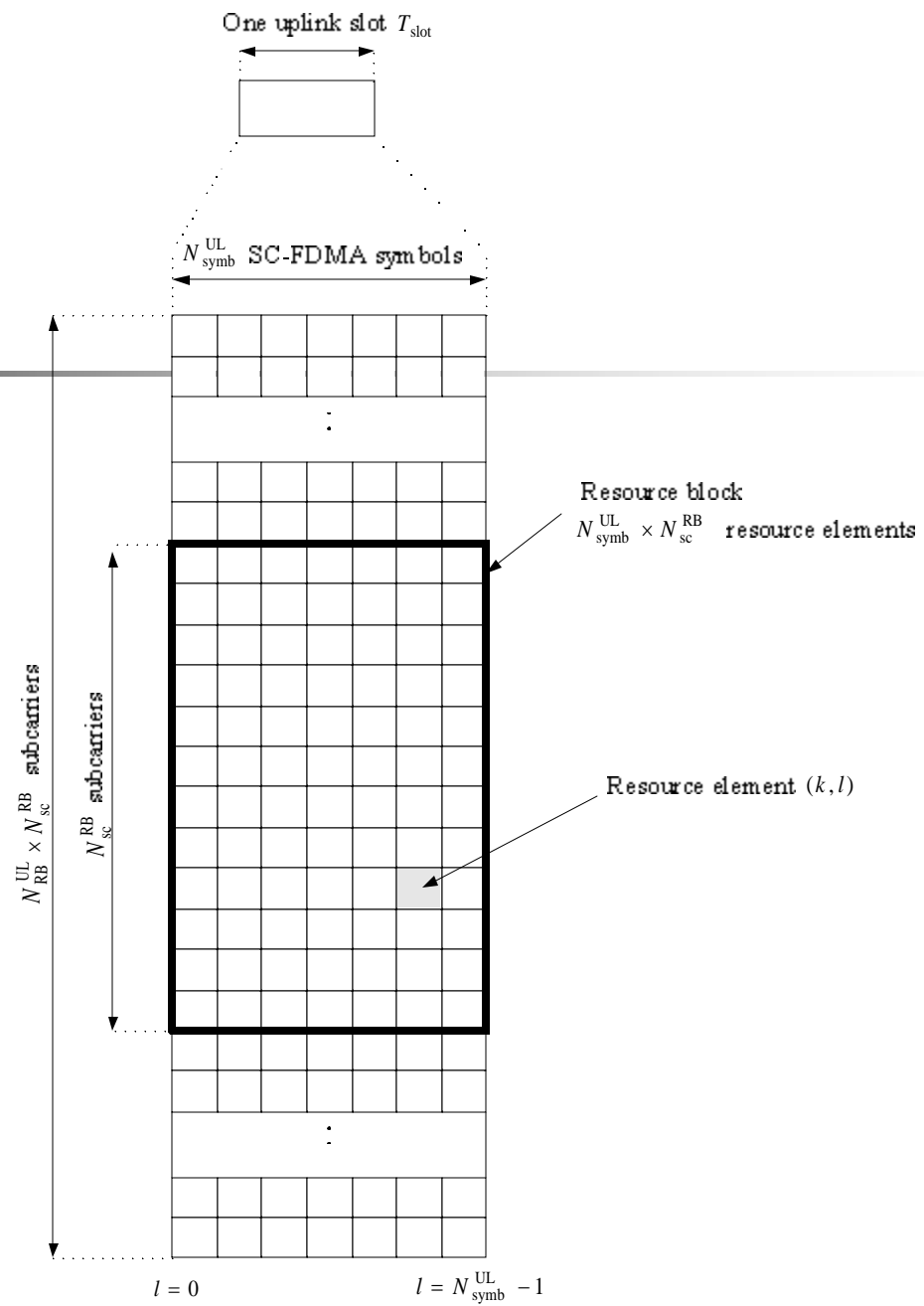
Configuration <i>(k, l)</i>	N_{sc}^{RB}	N_{symb}^{UL}	
		Frame structure type 1	Frame structure type 2
Normal cyclic prefix	12	7	9
Extended cyclic prefix	12	6	8

The relation between the resource block number n_{PRB} and resource element (k, l) in a slot is given by

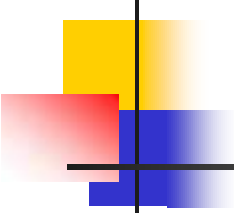
$$n_{PRB} = \left\lfloor \frac{k}{N_{sc}^{RB}} \right\rfloor$$



Uplink Resource Grid



Slot structure and physical resources: Resource grid



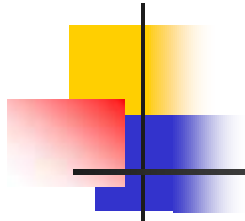
- The transmitted signal in each slot is described by a resource grid of $N_{RB}^{UL} N_{sc}^{RB}$ subcarriers and SC-FDMA symbols. The resource grid is illustrated in the next slide. The quantity N_{RB}^{UL} depends on the uplink transmission bandwidth configured in the cell and shall fulfil $6 \leq N_{RB}^{UL} \leq 110$
- The number of SC-FDMA symbols in a slot depends on the cyclic prefix length configured by higher layers and is given in Table 5.2.3-1.

Physical downlink control channel PDCCH formats



- The physical downlink control channel carries scheduling assignments and other control information. A physical control channel is transmitted on an aggregation of one or several control channel elements (CCEs), where a control channel element corresponds to a set of resource elements. Multiple PDCCHs can be transmitted in a subframe.
- The PDCCH supports multiple formats as listed in Table 6.8.1-1.

Table 6.8.1-1: Supported PDCCH formats



PDCCH format	Number of CCEs	Number of PDCCH bits
0	1	
1	2	
2	4	
3	8	

Timing issues with closed loop power control of LTE

- PDCCH is sent every sub-frame [1 ms]
- $mcs\text{-}pucch$ is signaled by RRC ($mcs\text{-}pucch$ table entries can be set to zero)
 - MCS is signaled using higher layer signaling [can be done in a single sub-frame]
- The TPC command from a DL scheduling assignment overrides any command from a TPC PDCCH when both are received in a given sub-frame.
- Power control is performed once every 2-3 ms.
- The whole contiguous frequency block is transmitted in UL LTE, as such the power control may need to track wideband signals [frequency selective fading].

OLPC component

R1-073355: IDC

- The UE first determines the open loop component based on a filtered pathloss estimate, PL , from the serving eNodeB to the UE. The UE continuously (or periodically) measures the instantaneous pathloss based on the DL RS whose transmit power is known at the UE. A filtering method is then applied to the pathloss measurements, such as :

$$PL_k = \rho \cdot PL_{k-1} + (1 - \rho) \cdot PL_k^{inst}$$

- where PL_k and PL_{k-1} represents the filtered pathloss at the k-th instance and (k-1)-th instant, respectively. PL_k^{inst} is the instantaneous pathloss at the k-th instant. Rho is a filter coefficient, $0 < \rho < 1$, which is generally determined by the UE, possibly depending on pathloss variation, fast fading rate, the time of UL transmission, etc. Alternatively, a moving averaging method may be considered for the pathloss filtering.

CLPC component: delta_i

R1-073355: IDC

$$\text{delta}_i = \left[\text{SINR}_{\text{Target}} - \text{ESINR}_{\text{est}} \right]$$

- where ESINRest and SINRTarget denote the effective SINR (ESINR) estimate at the receiver and target SINR, respectively, of the power controlled channel(s) in dB.
- The observed samples at the eNodeB for the ESINR estimation include (some of or all) SC-FDMA symbols of the UL power controlled channel(s), which have been received since the last correction command signaling in DL.
- There are two alternatives for applying the correction $f(\text{delta}_i)$ to the Tx power, accumulated or absolute value.

Possible definition of 'accumulated value'

R1-073355: IDC

- If "accumulated value" is assumed, then the value of $f(\text{delta}_i)$ depends also on previously received closed loop corrections. As an example, if we assume only a 1-bit closed loop power correction, then we have
- $f(\text{delta}_i) = f_{\text{old}} + P_{\text{step}} * \text{delta}_i,$

(1)

- where f_{old} is the old value of $f(\text{delta}_i)$, P_{step} is the power control step size, and delta_i is taken values of -1 and +1 depending on the value of the received closed loop correction bit.

Accumulated versus absolute value: Ericsson: R1-074489

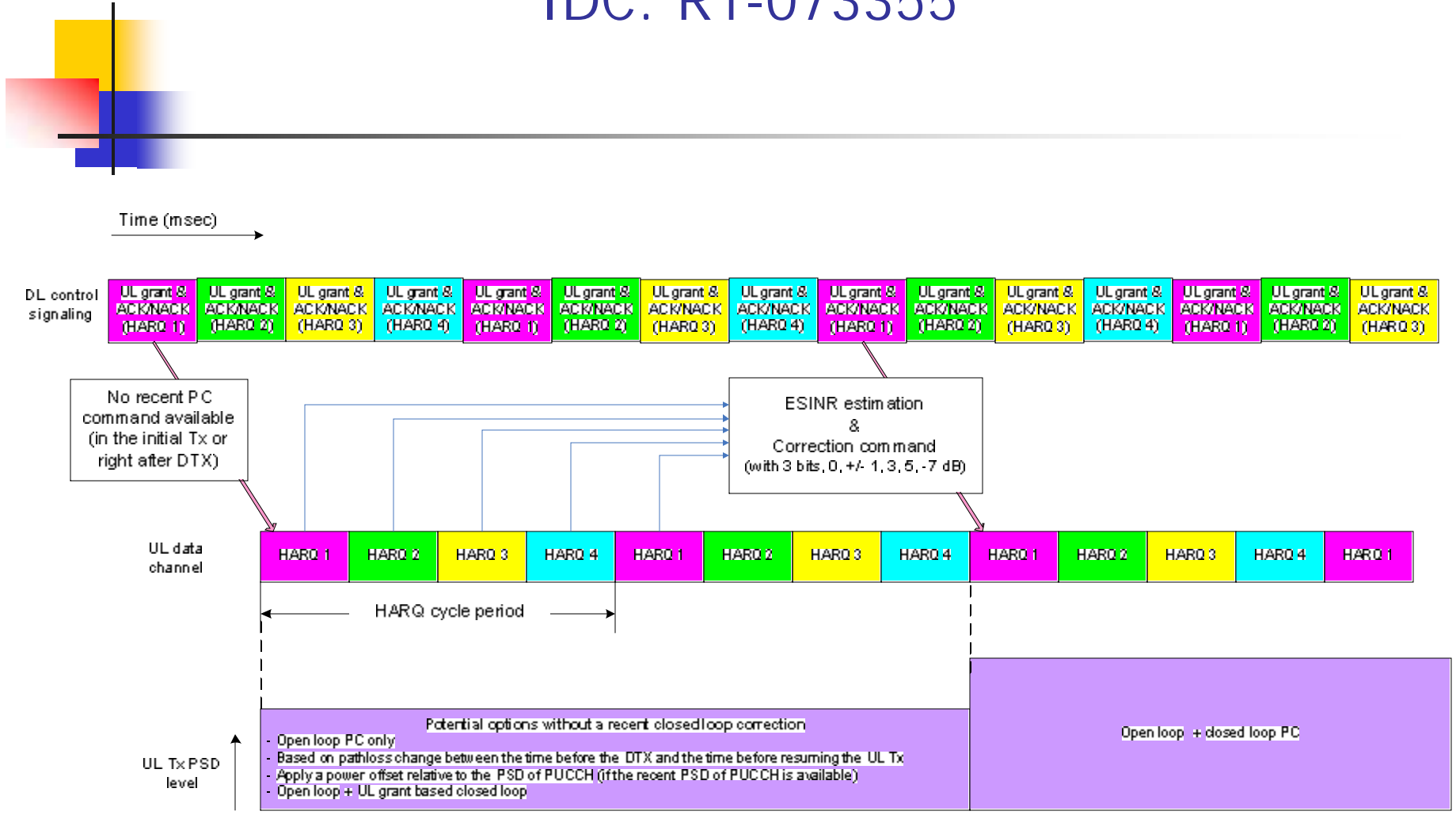


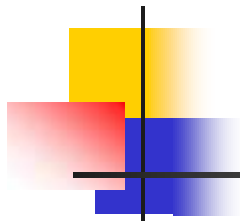
- In a given subframe i , PUSCH may be transmitted
 - on a dynamically (by an uplink grant on PDCCH) assigned resource
 - or on a persistently assigned resource
 - or not at all
- In a given downlink subframe n , a power control command $\Delta\text{PUSCH}(n)$ for PUSCH power control may be provided
 - within an UL scheduling grant on PDCCH
 - or on a TPC-PDCCH (here referred to as the TPC-PDCCHPUSCH)
 - or not at all

Accumulated versus absolute value: Ericsson: R1-074489

- K_{PUSCH} is assumed to be the scheduling delay, i.e. the UL scheduling grant provided in downlink subframe n provides the uplink scheduling for the UE valid for uplink subframe $n+K_{PUSCH}$. As can be seen below, K_{PUSCH} is also the delay in the PUSCH power control, i.e. a power control command provided in downlink subframe n will not impact the PUSCH transmit power in subframes prior to subframe $n+K_{PUSCH}$. Exact value of K_{PUSCH} is TBD.
- The variable $PPUSCH(i)$ is given by (absolute power step)
- $PPUSCH(i) = \min\{P_{max}, 10\log(M) + P_0 + a \cdot PL + \Delta_{PUSCH}(i - K_{PUSCH}) + \Delta_{mcs}\}$ [dBm]
- or (accumulated power step)
- $PPUSCH(i) = \min\{P_{max}, 10\log(M) + P_0 + a \cdot PL + \sum_{m=0}^i \{\Delta_{PUSCH}(m - K_{PUSCH})\} + \Delta_{mcs}\}$ [dBm]
- where the choice between absolute power step and accumulating power step is semi-statically decided on.
- If no power control step $\Delta_{PUSCH}(k)$ is provided on neither an UL scheduling grant or on a TPC-PDCCH/PUSCH in subframe k , $\Delta_{PUSCH}(k)$ in the equations above should be set to zero.
- If PUSCH is transmitted in subframe i , it is transmitted with the power $PPUSCH(i)$.

Possible general timing diagram for PC IDC: R1-073355





Outline

- Specification agreement
- How does it work?
- Why was each parameter adopted?
- Survey of various proposals in LTE

Motivation for alpha and P0

R1-073055: Ericsson

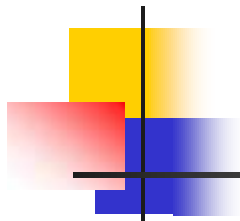


- In short, P0 and alpha are used to control the average received PSD, and thereby the SINR. The fractional compensation factor alpha enables flexible trade offs between capacity and fairness. [cell edge users transmit at lower data rates]
- Different open loop set points may be achieved by different parameter sets for data and control. In addition to being broadcast, P0 and alpha may be individually settable per UE using RRC signaling.

Motivation for alpha and P0

R1-073055: Ericsson

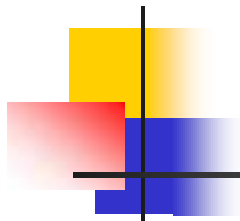
- One advantageous way to use the mechanism is to set the parameters (P_0 , α) so that the open loop reaches the desired SNR with a relatively large margin, and then use closed loop signaling (DUE) to more accurately control the power of the rather few UEs that generate the most interference.



Alpha compensation factor

- P_o and α are higher layer parameters to control the received PSD at the Node B
- For the delta path-loss measurement based schemes the difference in path-loss estimation to the serving cell and strongest neighbour cell is also taken into account.

Alpha: R1-072972: Nokia fractional power control



The following table summarizes the performance comparison in terms of throughput. As in the results above two different settings for the fractional compensation factor are used (0.8 and 1.0).

	1.0	0.8
Path-Loss Compensation		
Average Sector Throughput [kbps]	7325	7672
Average Throughput at 95% Coverage [kbps]	257	266
Average Instantaneous Noise Rise [dB]	15.80	15.34

Table 1: *Comparison full and fractional PL compensation*

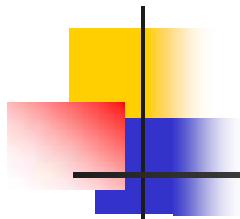
Alpha: R1-072972: Nokia fractional power control



- Fractional and full path-loss compensation for a comparable cell edge performance were compared in the above mentioned contribution.
- It was shown that the fractional compensation scheme shows a performance gain in terms of UE power consumption and received SINR which transfers into an average cell throughput gain of about 5 to 10% dependent on the detailed assumptions.
- The amount of UEs transmitting at maximum power is reduced from 20% to 13%.

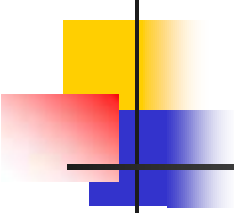
Alpha and SNR_{target}: Ericsson

R1-073036



- Open loop with a fixed received SNR target, $P = \min(P_{\max}, \text{SNR}_{\text{target}} \times P_{\text{noise}} / g)$, where P_{noise} is the noise power level, $\text{SNR}_{\text{target}}$ is a targeted received power level relative to the noise floor, and g is an estimate of the path loss to the base station (based on wideband downlink estimates). Note that the desired $\text{SNR}_{\text{target}}$ with this algorithm must include a margin for expected interference. This corresponds a pure open-loop use of the algorithm proposed in [1] with full path loss compensation.
- Open loop with fractional path loss compensation: $P = \min(P_{\max}, (\text{SNR}_{\text{target}} \times P_{\text{noise}} / g^{\alpha}))$, where α is the path loss compensation factor. Compensation factors α between 0.05 and 1 have been simulated. The special case $\alpha = 1$ means full compensation resulting in the same algorithm as 2. Also this corresponds a pure open-loop use of the algorithm proposed in [1], but with partial path loss compensation.

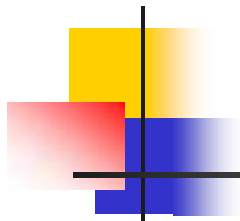
Alpha and SNR_{target}: Ericsson R1-073036

- 
- When targeting high mean bitrates, the following parameter settings were evaluated:
 - SNR_{target} = 20dB, $a = 1$
 - SNR_{target} = 15dB, $a = 0.75$:
 - This results in the same mean bitrates as the above setting, but yields higher mean **cell-edge** bitrates
 - The contribution shows that both power control schemes achieve higher mean bitrates than with fixed power, while also yielding significantly higher cell-edge bitrates. Note that using fractional compensation in this case, higher cell-edge bitrates are achieved while maintaining the same mean bitrate as with full compensation.
 - In summary, using fractional compensation, for the same cell-edge bitrate, a higher average bitrate is achieved, and for the same average bitrate, a higher cell-edge bitrate is achieved. This motivates the use of the fractional compensation parameter (a).

Alpha and $\text{SNR}_{\text{target}}$: Ericsson

R1-073036

- There are clear advantages with fractional path loss compensation. As compared to full compensation:
 - For the same cell-edge bitrate, a 20% higher average bitrate is achieved
 - For the same average bitrate, a 20% higher cell-edge bitrate is achieved
- At the same time the power consumption is reduced. The fractional compensation can be configurable with a simple broadcasted factor used by the UE in the open loop algorithm. Setting to 1 will result in a full path loss compensation (no fractional PC).



Why P0?

- P0 controls the mean received SINR
 - separate for data and control
- Alpha controls the received SINR variance ('fairness')
 - separate for data and control

P0 range: R1-073744: Lucent R1-074850: Ericsson

- Neglecting the 'short term variations' $f(D_i)$ and Δ MCS, the 'average' transmit power is
- $P = \min\{P_{\max}, 10\log M + P_0 + a \cdot PL\}$ [dBm] (1)
- Assuming an average noise plus interference level of I_N dBm per RB, the resulting uplink SINR is
- $SINR = P - PL - (I_N + 10\log M) =$
- $= \min\{P_{\max} - PL - (I_N + 10\log M), 10\log M + P_0 + a \cdot PL - PL - (I_N + 10\log M)\}$ (2)
- For a UE that just precisely uses $P = P_{\max}$, the pathloss PL is given by
- $P_{\max} = 10\log M + P_0 + a \cdot PL$ (3)
- $\rightarrow PL = (P_{\max} - P_0 - 10\log M) / a$ (4)
- Hence, for a 'cell-edge' UE, with $P = P_{\max}$ and using $M = M_0$ RBs, to reach a desired $SINR = SINR_0$, the associated P_0 value can be found by (3) and (4)
- $SINR_0 = P_{\max} - PL - (I_N + 10\log M_0) =$
- $= P_{\max} - (P_{\max} - P_0 - 10\log M_0) / a - (I_N + 10\log M_0)$
- $\rightarrow a \cdot (SINR_0 + I_N + 10\log M_0 - P_{\max}) = P_{\max} - P_0 - 10\log M_0$
- $\rightarrow P_0 = a \cdot (SINR_0 + I_N) + (1-a) \cdot (P_{\max} - 10\log M_0)$ (5)
- Note: $I_N = P_{N0} + NF + I_{oT}$ dBm
 - It is here assumed that $P_{N0} = 10 \cdot \log(180\text{kHz} \cdot 4 \cdot 10^{-21} \text{ W/Hz} / 1\text{mW}) = -121\text{dBm}$. NF is the noise figure, and I_{oT} is the rise of the interference over the thermal noise.

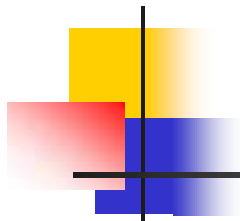
P0 range: R1-073744: Lucent R1-074850: Ericsson

- $P_0 = a \cdot (SINR_0 + I_N) + (1-a) \cdot (P_{max} - 10\log M_0)$ (5)
- Note: $I_N = P_{N0} + NF + I_{oT}$ dBm



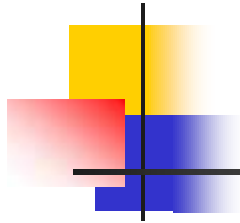
P0 [Lucent-Alcatel: R1-074266]

- Using the split of $P_o = P_o_nominal + P_o_user_i$, and following our preferred UL power control technique as described in [2], we choose to have Δ_mcs set to all zeros, set $a = 1$, and choose
- $P_o_nominal = G + I$
- where G is a nominal target SINR and I is the total uplink interference level at the e-NB (thermal noise plus other cell interference)
- $P_o_user_i = (1-b) \times (PL_{strongest_neighbor} - PL)$
- where PL is the path loss from the UE to the serving sector, $PL_{strongest_neighbor}$ is the path loss from the UE to its strongest neighboring sector, and $0 < b < 1$.
- This approach includes the interference level to the neighbor cell in the power control process to reduce interference to neighbor cells.



Why Delta_i?

- This is the slow or fast closed loop power control element which compensates the following:
 - Power amplifier error
 - Path loss estimation error
 - Interference level change from other cells: inter-cell interference level change
- Fast fading is not compensated by delta_i.

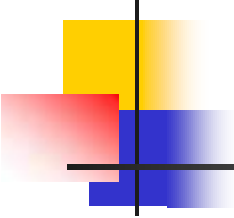


Why delta mcs?

- Helps with changing the coding and modulation level of scheduled uplink transmissions.
 - Table entries could be set to zero in which case delta mcs is signaled via RRC signaling. [UL grants]
 - Or the non-zero table entries could be broadcast via eNB.

Why delta mcs? Case of Alpha=1

LGE:R1-073506



- Delta MCS : non-zero table broadcasted by eNodeB.
 - PSD level of PUSCH is basically controlled by Delta MCS.
 - Actual PSD offset between PUSCH and SRS varies dynamically following DMCS.
 - $\text{PSD level of PUSCH} = \text{PSD level of SRS} + \text{PUSCH offset to SRS} + \text{Delta MCS} + \text{Some additional correction (described in the next slide)}$

Why delta mcs? Case of Alpha=1

LGE:R1-073506

- Link adaptation (AMC) : Fast freq. selective scheduling based on measurement of SRS
 - In case that eNodeB allocate MCS level k and there is some difference between instantaneous received SNR of SRS and target SNR (denoted as S_{target}^{SRS}) for allocated resource band (due to frequency selectivity or time variation), PUSCH has excessive or insufficient quality for an allocated MCS level. For exact link adaptation, UE should know such information as difference between target SNR and instantaneous SNR for SRS. Therefore, additional power control command (instantaneous correction value of DMCS) is necessary for efficient link adaptation of PUSCH. For example, as shown in Figure 1 (a), DMCS(k) could be determined for a k th MCS level so that received SNR of PUSCH meets pre-defined QoS level at freq. non-selective channel. However, if compensation factor of DMCS table is not defined, the received SNR of PUSCH may be excessive compared to expected SNR level as shown in figure 1 (b). In case that received SNR of SRS get away from certain range, additional power control command, Δ_{abs} , for PUSCH could complement excessive SNR gap so that the received quality of PUSCH with an allocated MCS level is guaranteed



Sounding Reference Symbol

- The UE Transmit power P_{srs} for the SRS is set equal to the PUSCH power level P_{pusch} plus an offset P_{offset_srs} .

LGE:R1-073506: Alpha=1 frequency flat fading case

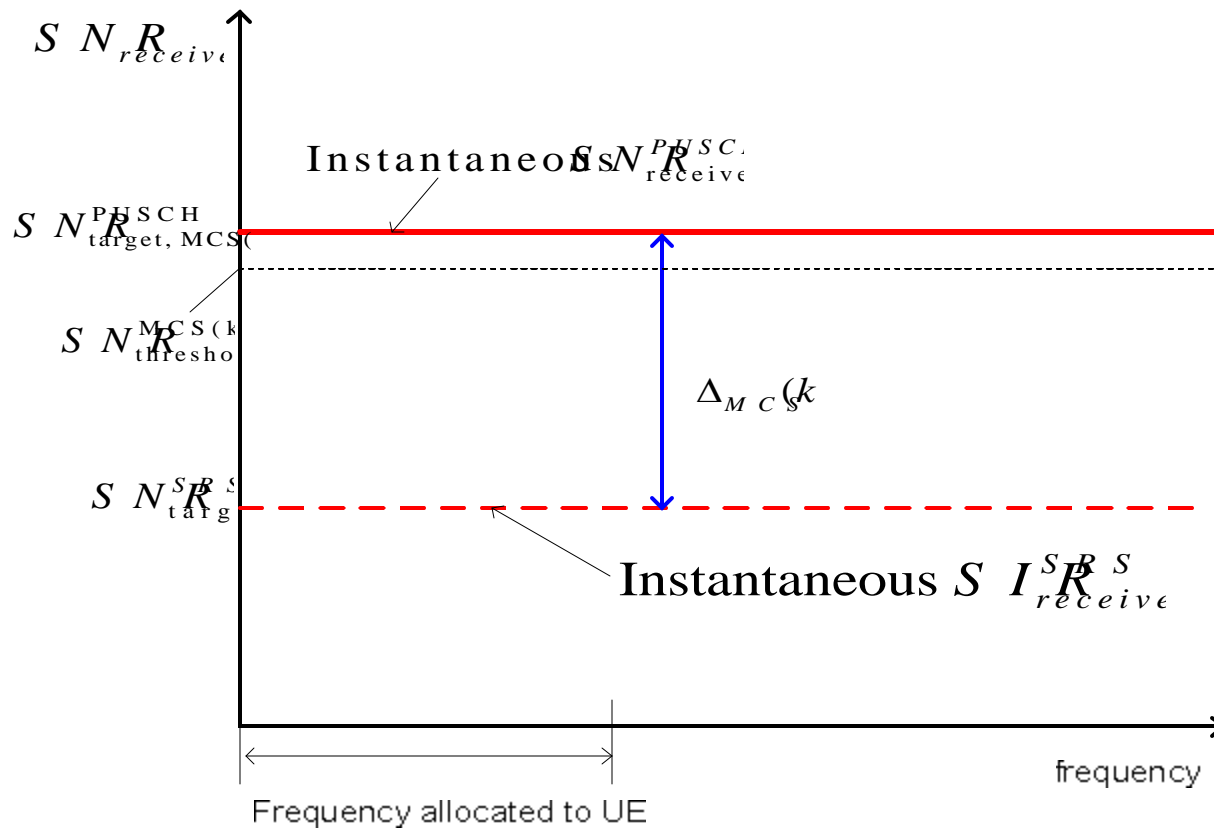
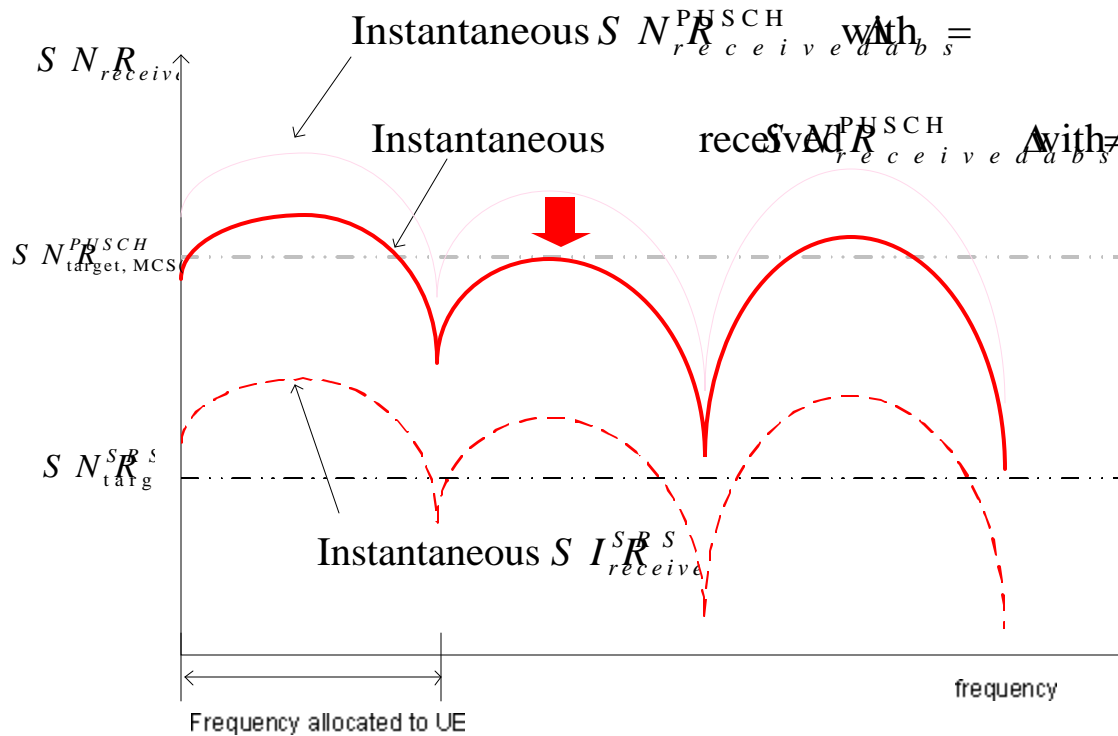
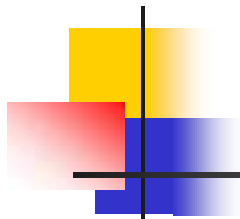


Fig 1a

LGE:R1-073506: Alpha=1 frequency selective fading case

Fig 1b





Overload Indication

- OI facilitates inter-cell interference coordination [ICIC].
- ICIC is a scheduling strategy in which the cell edge data rates are increased by taking ICI into account.
- ICIC implies certain restrictions [frequency domain] to the uplink and downlink schedulers in a cell to control ICI.
- Restrict the transmission power in certain parts of the spectrum in one cell to reduce the interference in the neighboring cell. As such the data rate in the neighboring cell can be increased [in that mentioned spectrum].
- Largely an implementation issue.

Overload indication

Ericsson: R1-073038



- “Cell wide overload indicator (OI) exchanged over X2 on a slow basis
 - according to RAN3 LS [R1-071804 (R3-070702)], expected average delay is in the order of 20ms
 - FFS: Number of bits in the OI
- Neighboring eNB can control individual UEs served by that eNB through it’s scheduler based on OI and available knowledge (e.g. pathloss obtained from normal handover measurements)”

Overload indication

Ericsson: R1-073038

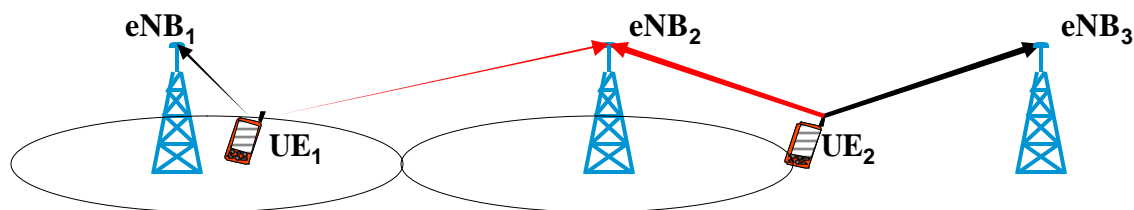


Figure 1. Overload example. eNB2 is overloaded (by UE2 but not by UE1) and sends an overload indicator (in form of an absolute RoT measure) to its neighbours. eNB1 combines the RoT with RSRP (Reference Signal Received Power) measurements from UE1, and can conclude that UE1 is not causing the overload. Similarly, eNB3 can detect that UE2 is causing the overload.

OI: Nokia: R1-074891

OI relates to Packet scheduling and PC operation

- In general the packet scheduler is designed so it aims at scheduling the different users with the objective of fulfilling the QoS requirements for the users EPS (Evolved Packet Switched) bearers such as for instance guaranteed bit rate constraints, the so-called QoS Label characteristics (as listed in 23.401), etc. The scheduler may also include some fairness mechanisms among the best effort users. Within this framework, there are many options for designing packet scheduling algorithms, so it is likely that different vendors may use different strategies.
- Similarly, it is also vendor/operator-specific how to operate the uplink power control. **The open loop power control formula is standardized, while settings of the parameters (e.g. P_0 and Alpha) are up to the network operator.** Rules for sending either power up or power down closed loop power corrections are also vendor-specific – only the signaling is standardized (included in the PDCCH UL grant).

OI: Nokia: R1-074891

OI relates to Packet scheduling and PC operation

- Two observations in the contribution:
 - Operation of PC in principle determines the sum of interference generated to the neighboring cells. That is, the sum of Tx powers from all the users in the cell.
 - As the packet scheduler decides where the users are scheduled in the freq domain, it affects the experienced SINR for the scheduled users.
- Hence, by applying some kind of frequency domain packet scheduling, we could improve the SINR for scheduled users without adjusting the PC parameters. The latter is for instance possible via scheduling of “cell-edge-users” in two neighboring cells in complementary parts of the frequency band. Applying such methods was referred to as proactive schemes in [1]-[2] as coordination is done in advance with the objective of avoiding strong interference coupling.

OI: Nokia: R1-074891

OI relates to Packet scheduling and PC operation

- The contribution concludes that there are cases where the OI could be applied for slow uplink overload coordination.
 - We recommend that OI is standardized and exchanged via X2 based on a simple UL interference measurement/triggering mechanism.
 - Exact actions by the eNode-B receiving the OI can be left open (i.e. not standardized) as the most appropriate action will in the end depend on the applied packet scheduling strategy and PC operation.
- An eNode-B receiving an OI message should take reasonable actions to improve the UL interference situation in the overloaded cell.
- The eNode-B receiving the OI will be allowed to take the QoS of its users into account before performing any actions, so the QoS aspects become part of the actions as raised in [4]. As an example of the latter, the eNode-B receiving the OI may only reduce the interference to the point where it is still able to serve its users according to their minimum QoS parameters (such as for instance guaranteed bit rate – GBR).

OI: implementation aspects

Motorola: R1-074610



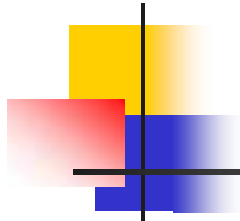
- The contents of the X2 message for uplink inter-cell power control should include the following
 - Quantized IoT level per sub-band (1 or 2 bits)
 - The load of the cell (1 or 2 bits)
 - Uplink performance satisfaction index (1 or 2 bits)
 - Other information may be included if proved to be beneficial
- The granularity of the frequency dependent IoT level should be configurable and allow the whole bandwidth IoT level be a special case. For example, in case of a relatively large site, the uplink is noise limited and the frequency dependent IoT report is not necessary.
- The X2 messages may be event-driven and sent no faster than every 20 ms. The events may include high/un-acceptable IoT, unsatisfactory uplink performance, changes of the load in the cell and etc. Due to the X2 delay (20 ms), the measurement (averaging) interval for IoT needs to be of the same order.

OI: implementation aspects

Motorola: R1-074610



- When the eNode-B receives these X2 messages, it may perform the (inter-cell) power control adaptation schemes in the following ways:
 - Approach 1: Node-B adapts the parameters of power control formula and then broadcast them to the UEs.
 - Approach 2: Node-B adjusts the transmission power of individual UEs
 - Approach 3: Node-B broadcasts the (processed) X2 messages, the UEs then adapt their transmission power accordingly
- Since the eNode-B has all the information, it is natural to adopt approach 1 or 2 and perform centralized adaptation without additional signaling defined. Approach 3 relies on UEs to adapt their power. After UE adapts its transmission power, its power headroom needs to be updated to the eNode-B for scheduling or measurement/PA errors correction.



Outline

- Specification agreement
- How does it work?
- Why was each parameter adopted?
- Survey of some additional PC contributions in LTE
 - Power control headroom
 - UE transmit power level error
 - Slow and fast power control

Power control headroom report [motivation]

R1-073676 [Nokia]

- Given the current LTE power control scheme, it is unknown by the eNode-B at which PSD level the different terminals are operating.
- Information on the PSD is important for performing correct radio resource management decisions at the eNode-B, especially when allocating the transmission format (bandwidth and modulation & coding) to the different terminals.
- Not knowing the PSD used by a certain terminal could e.g. cause the allocation of a too high transmission bandwidth (given the maximum eUE power capabilities), thus resulting in a lower SINR. Information on the PSD used at the eUE can be obtained from the power control headroom reports, provided that the eNode-B knows the transmission bandwidth used when the power measurement was performed.
- Alternatively to the power control headroom, the eUE could signal to the eNode-B the measured path-loss which is input to the OL standardized PC formula in LTE. Knowing the measured path loss at the eUE the eNode-B can easily calculate the PSD used at the terminal.



Power control headroom report [proposal] R1-073676 [Nokia]

- The power control headroom is measured and reported for the PUSCH only. No need to have power control headroom measured for the PUCCH as this channel is allocated constant bandwidth and MCS per user.
- The “power control headroom” per TTI is defined as $10 \cdot \log_{10}(P_{MAX}) - 10 \cdot \log_{10}(P_{MEASURED})$, where P_{MAX} is the maximum eUE Tx power and $P_{MEASURED}$ is the measured eUE Tx power.

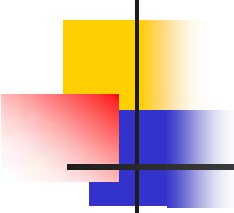


UE Transmit power level errors [MOT: R1-073406] problem statement

- Many parameters in the LTE power control formula can change substantially from sub-frame to sub-frame (for e.g. M , Δ_{mcs}). Further, since the objective of the power control algorithm is to keep the UE power spectral density (PSD) constant, total power transmitted by the UE scales with M . This implies, UE transmit power will change quite considerably between different sub-frames in LTE uplink.
- In addition, since LTE uplink is frequency division multiplexed, transmission bandwidth and frequency location will also change. In a realistic network, most UE RF hardware configurations will find it difficult to accurately make these simultaneous rapid transitions in transmit power, transmission bandwidth and also in transmission frequency.

UE Transmit power level errors [MOT: R1-073406]

proposed solutions



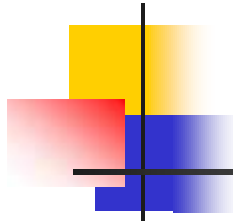
- This contribution presents system simulation results studying the impact of UE transmit power errors on LTE uplink. Transmit power accuracy for LTE UEs can only be as good as WCDMA open loop accuracy which is $\pm 5\text{dB}$ (not including path loss estimation errors).
- Results in the contribution indicate that at $\pm 5\text{dB}$ UE transmit power error, system capacity is degraded by 10 to 12% (close to 20% if an additional $\pm 2\text{dB}$ path loss estimation error is added). Results also indicate that loss in system performance is dependent on the system Hybrid ARQ operating point.
- Since the loss in system capacity at $\pm 5\text{dB}$ transmit power error is quite high (at least at some HARQ operating points), the solution may be options such as (e.g., guard duration like TDD, transient duration like WCDMA etc.) that enable the UEs to achieve a much tighter transmit power accuracy (e.g. $\pm 2\text{dB}$).

Slow and fast power control

Siemens: R1-070366



- Path loss based fractional uplink power control with and without fast fading compensation is discussed in this contribution. From the simulation results it can be seen that both fast and slow PC are means to effectively improve the cell edge behaviour and to relax the requirements on the intra cell orthogonality which is disturbed due to frequency errors. **Due to the utilization of the channel gain during the good fading states for the high SINR values the performance of slow PC together with fast link adaptation is superior.** From the investigations done so far we recommend to introduce at least a slow power control mechanism into the UL LTE system.



Traffic Model	
User distribution	Uniform
Data generation	Full Buffer
Radio Network Model	
Distance attenuation	$L = 35.3 + 37.6 \cdot \log(d)$, d = distance in meters
Shadow fading	Log-normal, 8dB standard deviation
Fast fading	Single path Rayleigh fading
Cell layout	Hexagonal grid, 3-sector sites, 57 sectors in total
Inter site distance	1732 m
Penetration loss	Not applied
System Model	
Spectrum allocation	180 kHz (chunk wise allocation) and 10MHz (full bandwidth allocation)
Maximum UE output power	250mW
Max antenna gain	15dBi
Scheduling	Random selection of UEs
Power Control Model	
Fractional Compensation	$\alpha = 0.8$
PC Schemes	Fixed transmit power, slow and fast PC
SNR Target	3 dB

Table 1: *Simulation assumptions*
 confidential: Parsa Wireless
 Communications, LLC

Slow and fast power control

Nokia: R1-070401

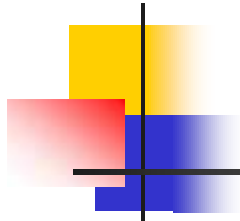


- Results of Figure 7 and Figure 8 show that slower PC rates works better with 3 km/h because of the better averaging capability against error components due to the fast fading and estimation errors. With UE speed of 120 km/h the best performance is obtained with the highest updating rate. Results show that the PC updating rate should be faster than 20 Hz in order to guarantee the tracking capability in also in the Vehicular environment. The contribution notes that in Pedestrian speeds the performance of higher PC updating rates could be improved by increasing the averaging length of the SNR measurement.

Slow and fast power control

Nokia: R1-070401

- Simulation results with UE speeds of 3 km/h and 120 km/h are shown in Figure 7 and Figure 8. The fast fading is not included in the metric of power control error in order to reflect the performance of slow power control targeting to compensate just distance depend path loss and shadowing.



Feedback Signaling period (1/rate)	10,50, 100, 200, [ms]
Measurement averaging length	Equals to feedback signaling period(10-200 ms)
Measurement activity factor	1/10
Measurement bandwidth	1.25 MHz
Antenna diversity	2 Rx
Shadow fading Correlation Distance	50 [m]
Standard deviation of shadow fading	8 dB
SNR Target	15 [dB]
Multi-path profile	TU snd 120 [km/h]
Performance metric	SNR-SNR_target
SNR	Estimated (both S and N)
Feedback signaling	Absolute signaling without errors

Table 1. Simulation parameters

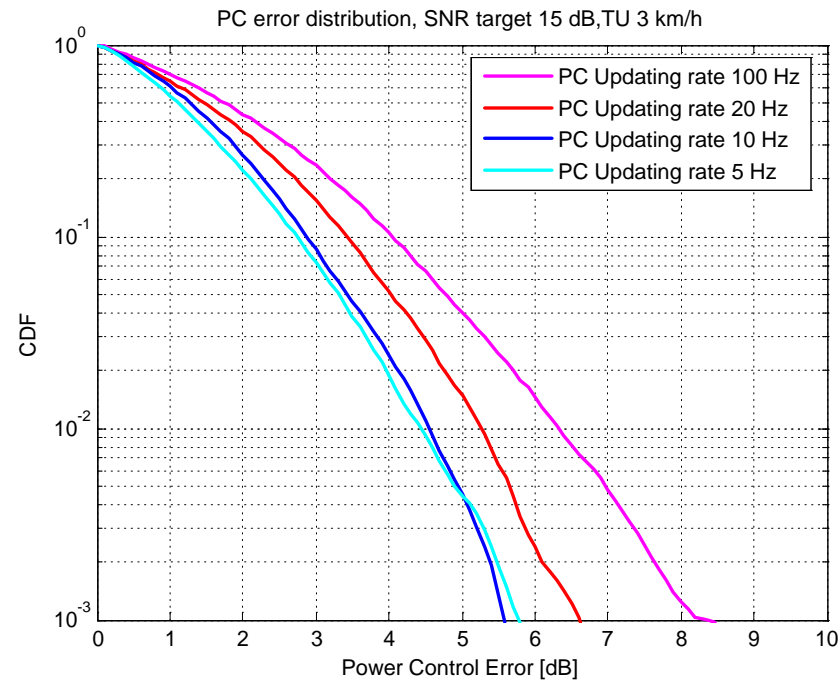
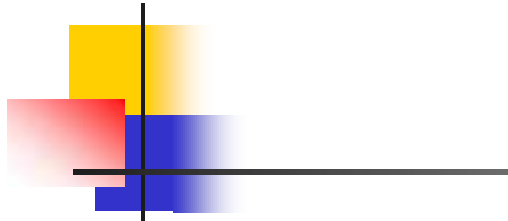


Figure 7. CCDF of power control error, $v=3$ km/h.

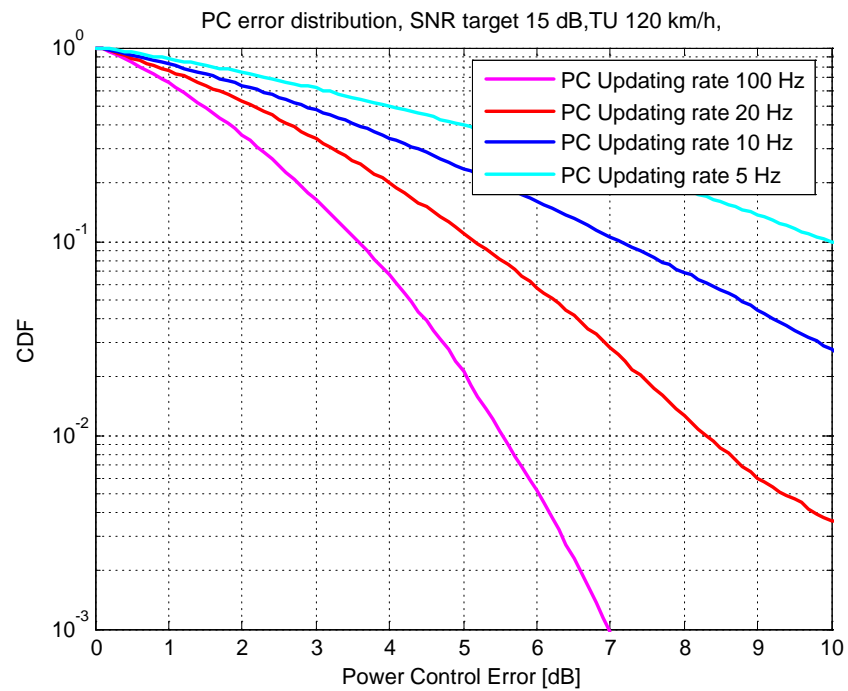


Figure 8. CCDF of power control error, $v=120$ km/h.