

LTE Measurements

Contents

1	Overview of LTE Measurements	2
2	Physical Layer Measurements	5
2.1	Examples of measurement items	6
3	Timing Advance	10
4	CQI Measurements	15
5	Cell Selection and Reselection	17
5.1	Overall process	18
5.2	PLMN selection	18
5.3	Service types	20
5.4	Cell selection and reselection	22
5.5	Selection procedure and criteria	24
5.6	Cell selection: evaluation process	26
6	Handover Measurements	33

1 Overview of LTE Measurements



The important LTE measurements are as follows:

List of detected preambles: The eNB shall report a list of detected PRACH preambles to higher layers. Higher layer utilize this info for the RACH procedure

Transport BLER: The ACK/ NACKs for each transmission of the HARQ process are reported to the MAC. Based on these ACK/NACKs the higher layers compute the BLER for RRM issues.

TA: The eNB needs to measure the initial timing advance (TA) of the uplink channels based on the RACH preamble

Average RSSI: Measured in UL by eNB. It can be used as a level indicator for the UL power control. The RSSI measurements are all UE related and shall be separately performed for (TTI intervals)

- UL data allocation (PUSCH)
- UL control channel (PUCCH)

Sounding reference signal (SRS)

Average SINR: In UL the eNB measures SINR per UE. The average SINR can be used as a quality indicator for the UL power control

UL CSI: channel state information per PRB for each UE. The CSI shall be the received signal power averaged per PRB.



LTE Measurements

• Physical layer measurements have not been extensively discussed in the LTE standardization. They could change.

Intra LTE measurements (from LTE to LTE)

– UE measurements

- CQI measurements
- Reference Signal Received Power (RSRP)
- Reference Signal Received Quality (RSRQ)

– eNB measurements

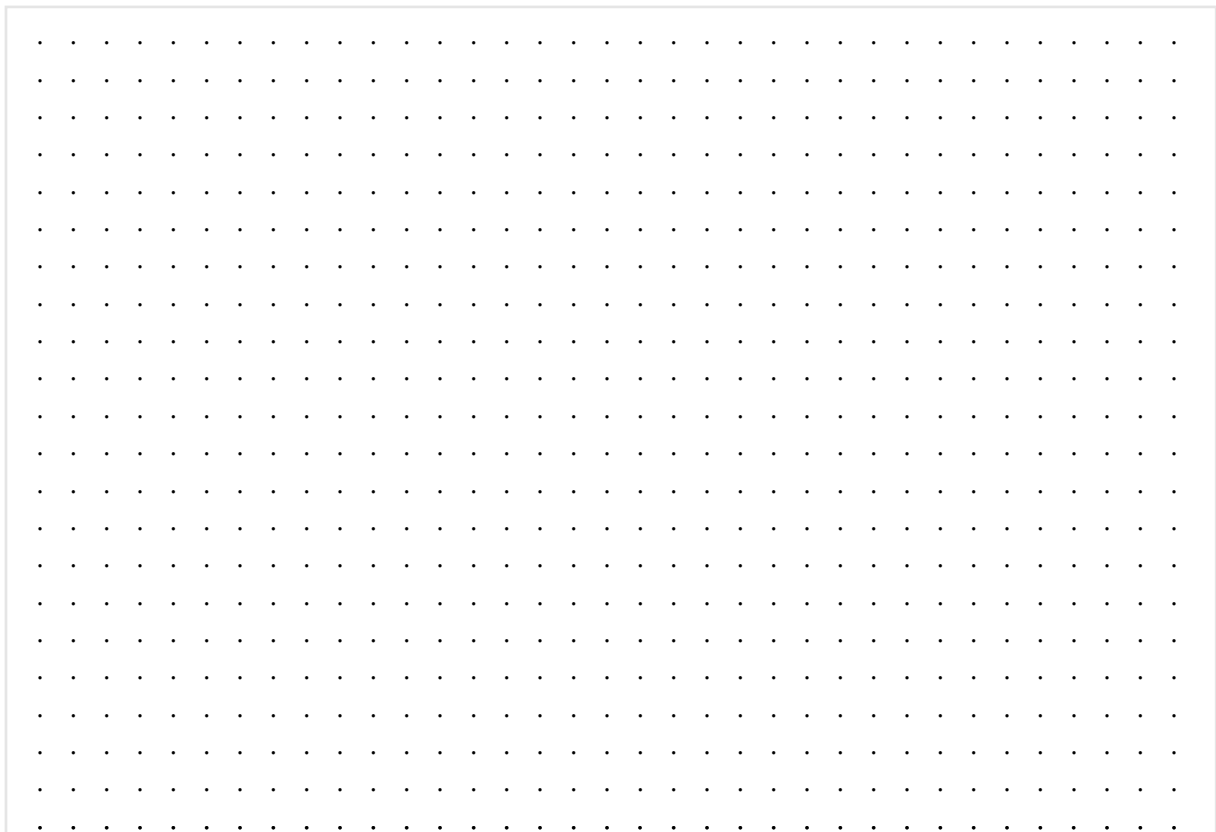
- **Non standardized (vendor specific):** TA, Average RSSI, Average SINR, UL CSI, detected PRACH preambles, transport channel BLER
- **Standardized:** DL RS Tx Power, Received Interference Power, Thermal Noise Power

• Measurements from LTE to other systems

– UE measurements are mainly intended for handover.

- **UTRA FDD:** CPICH RSCP, CPICH Ec/No and carrier RSSI
- **GSM:** GSM carrier RSSI
- **UTRA TDD:** carrier RSSI, RSCP, P-CCPCH
- **CDMA2000:** 1xRTT Pilot Strength, HRPD Pilot Strength

Fig. 1LTE Measurements



2 Physical Layer Measurements

One of the key services provided by the physical layer is the measurement of various quantities, which are used to trigger or perform a multitude of functions. Both the UE and EUTRAN are required to perform a variety of measurements.

To initiate a specific measurement the UTRAN transmit a “measurement control message” to the UE.

Included is a measurement identifier and type, the measurement objects and quantity, the reporting quantities, criteria (periodical or event) and mode (acknowledged or unacknowledged).

Reporting events are defined which trigger the UE to send a report to the UTRAN. When the reporting criterion is fulfilled the UE answers with a “measurement report message” to the UTRAN including the measurement identifier and the results.

2.1 Examples of measurement items

REFERENCE SIGNAL RECEIVED POWER (RSRP)

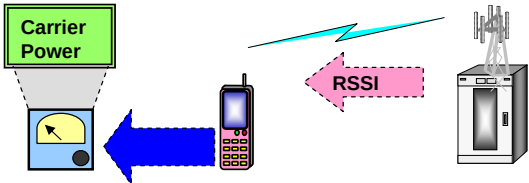
The received power on the resource elements that carry cell-specific reference signals define the RSRP. The number of resource elements is depending on the UE implementation. All shall be averaged.

The RSRP represents the received level. Hence it is given by transmitted power and pathloss. $PL = \text{referenceSignalPower} - \text{higher layer filtered RSRP}$.



Reference Signals Received Power (RSRP)

$RSRQ = N \cdot RSRP / RSSI$
RSSI = Received Signal Strength Indicator
RSRQ = Reference Signal Received Quality

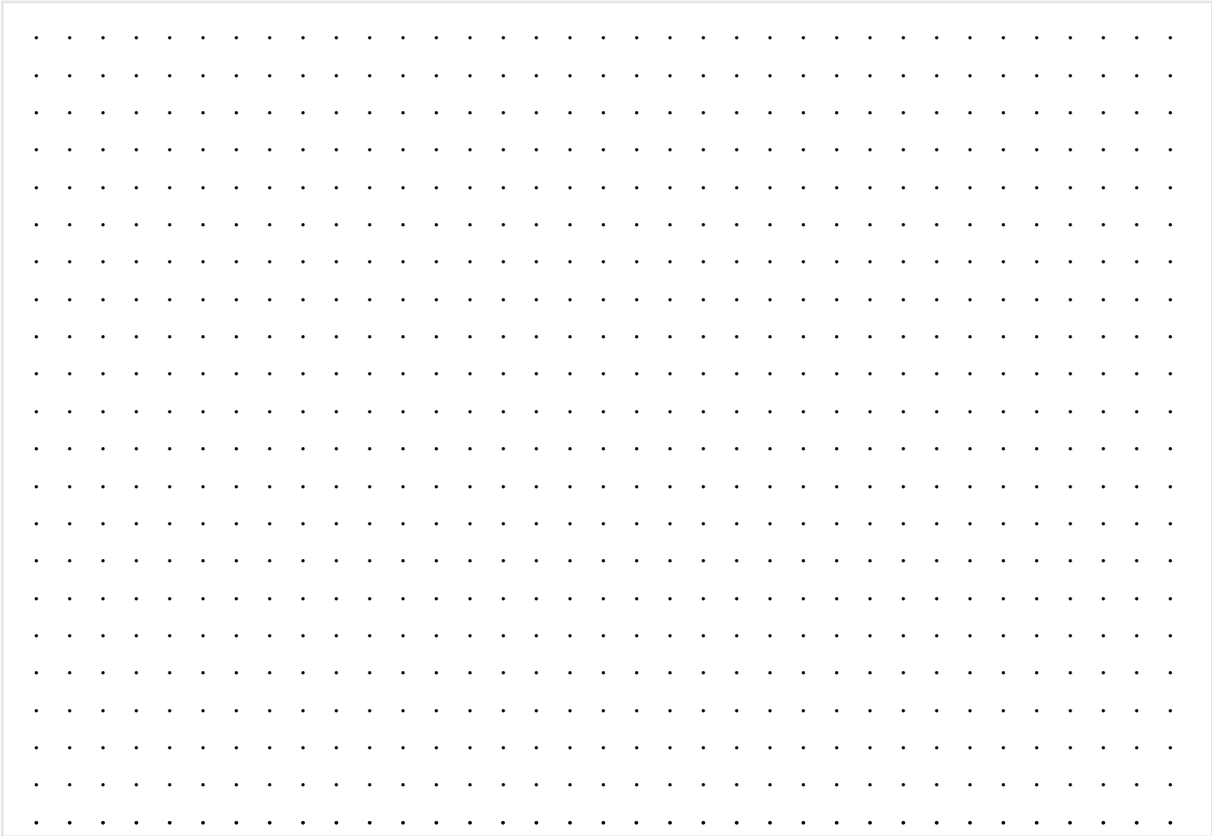


Reported value*	Measured quantity value	Unit
RSRP_00	$RSRP < -140$	dBm
RSRP_01	$-140 \leq RSRP < -139$	dBm
RSRP_02	$-139 \leq RSRP < -138$	dBm
...	...	...
RSRP_95	$-46 \leq RSRP < -45$	dBm
RSRP_96	$-45 \leq RSRP < -44$	dBm
RSRP_97	$-44 \leq RSRP$	dBm

*3GPP TS 36.133

Definition	Is the received power $N \cdot RSPR$ divided by the power density in the band. (N: number of RB's)
Applicable	RRC Idle and RRC Connected Mode (intra and inter frequency)
Range	[dBm]

Fig. 2Reference Signals Received Power (RSRP)



2.1.1 Reference Signal Received Quality (RSRQ)



Is the relation of N times the Reference Signal Received Power divided by the total received power in the channel bandwidth, i.e. RSRQ is identical to $N \cdot \text{RSRP} / \text{RSSI}$. Within the RSRQ also the noise and interference contributions are considered.

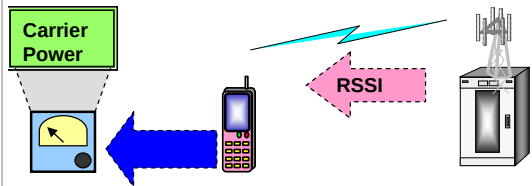
Note, RSRQ/RSSI shall be taken from the same resource blocks



Reference Signals Received Quality (RSRQ)

$$RSRQ = N \cdot RSRP / RSSI$$

RSRQ = Reference Signal Received Quality

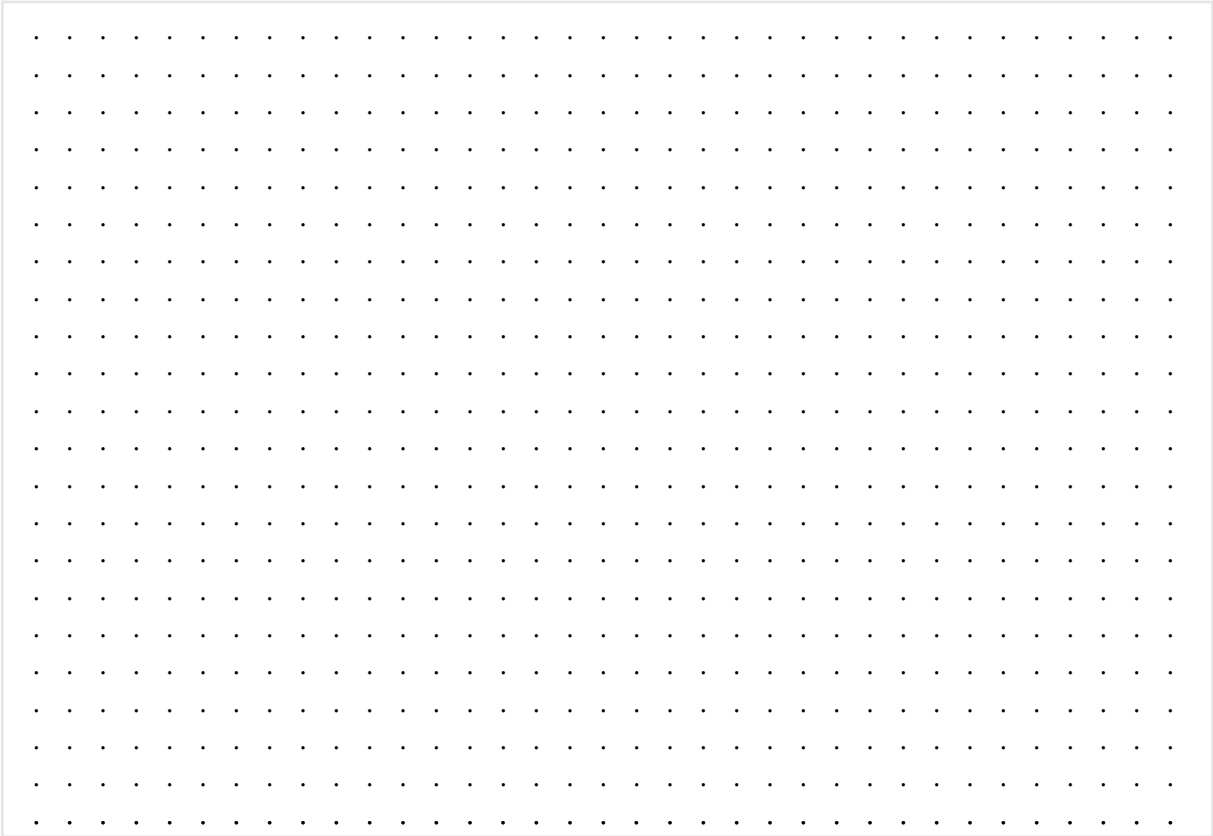


Reported value*	Measured quantity value	Unit
RSRQ_00	$RSRQ < -19.5$	dB
RSRQ_01	$-19.5 \leq RSRQ < -19$	dB
RSRQ_02	$-19 \leq RSRQ < -18.5$	dB
...	...	...
RSRQ_32	$-4 \leq RSRQ < -3.5$	dB
RSRQ_33	$-3.5 \leq RSRQ < -3$	dB
RSRQ_34	$-3 \leq RSRQ$	dB

*3GPP TS 36.133

Definition	Is the received power N*RSRP divided by the power density in the band. (N: number of RB's)
Applicable	RRC Connected mode only (intra and inter frequency)
Range	[dB]

Fig. 3Reference Signals Received Quality (RSRQ)



3 Timing Advance



Why timing advance??

Because the UL resources are orthogonal and this fact has to be maintained

Different UEs in the cell may have different position and therefore different propagation delay -> this may affect synchronisation

Only UL timing advance no DL

In DL possible to manage synchronised transmission to several UEs



The eNB measures the required timing advance based on the received UE signal arrival time. It commands the UE to adjust the transmission time. This is performed on a per-need basis.

It is signalled by means of a special MAC control element; LCID = 11101.

The signalled granularity is 16 Ts. The value range for adjustment is 8 bit and related to the current UL timing.

As $T_s = 1 / (2048 \times 15000) \text{ sec} = 1 / 30720000 \text{ sec}$ the granularity is given by 0.52 μsec (corresponding to 78 m).

If UE is in-sync the timing advance is valid. Otherwise the RACH-procedure establishes a valid timing advance. An 11 bit value (range 0,1..1282) is signalled to establish the initial offset.

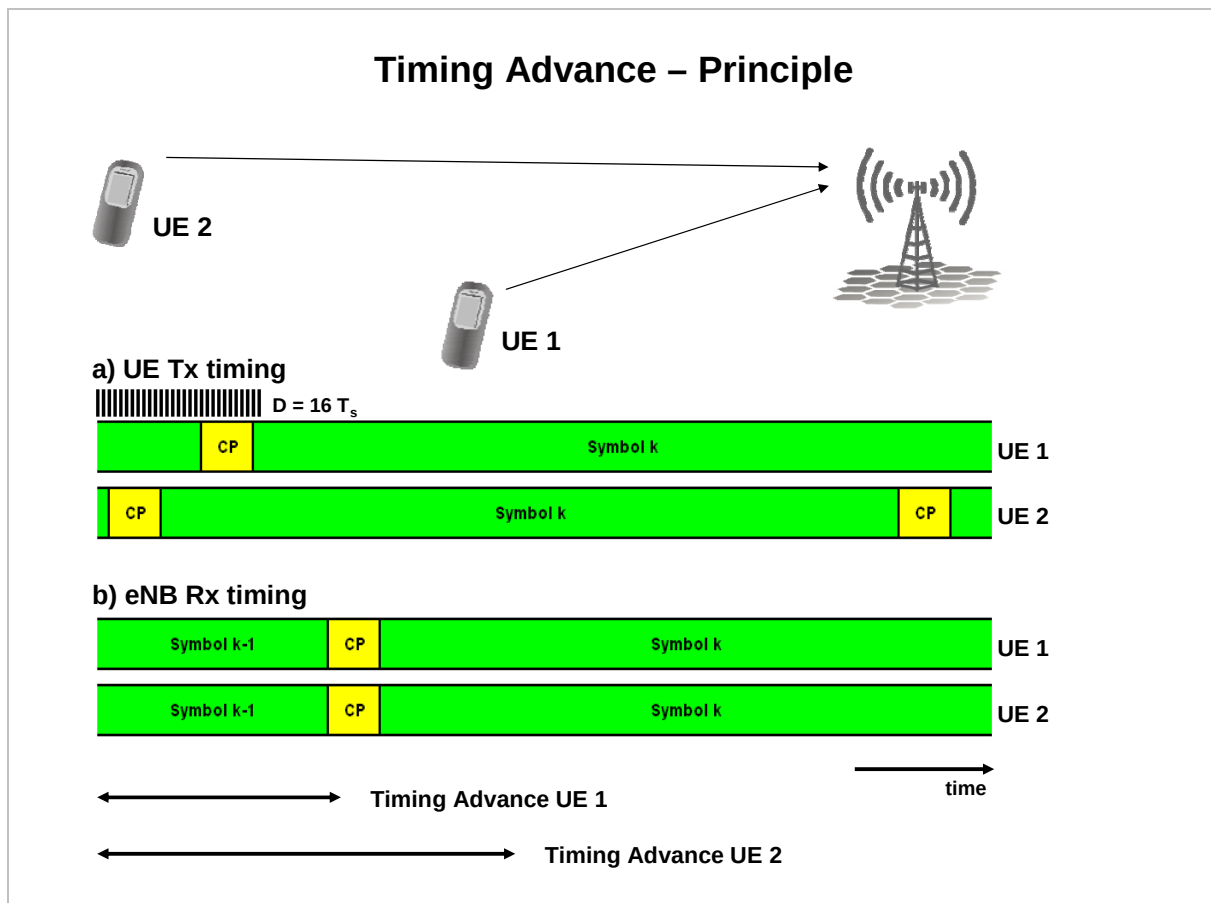
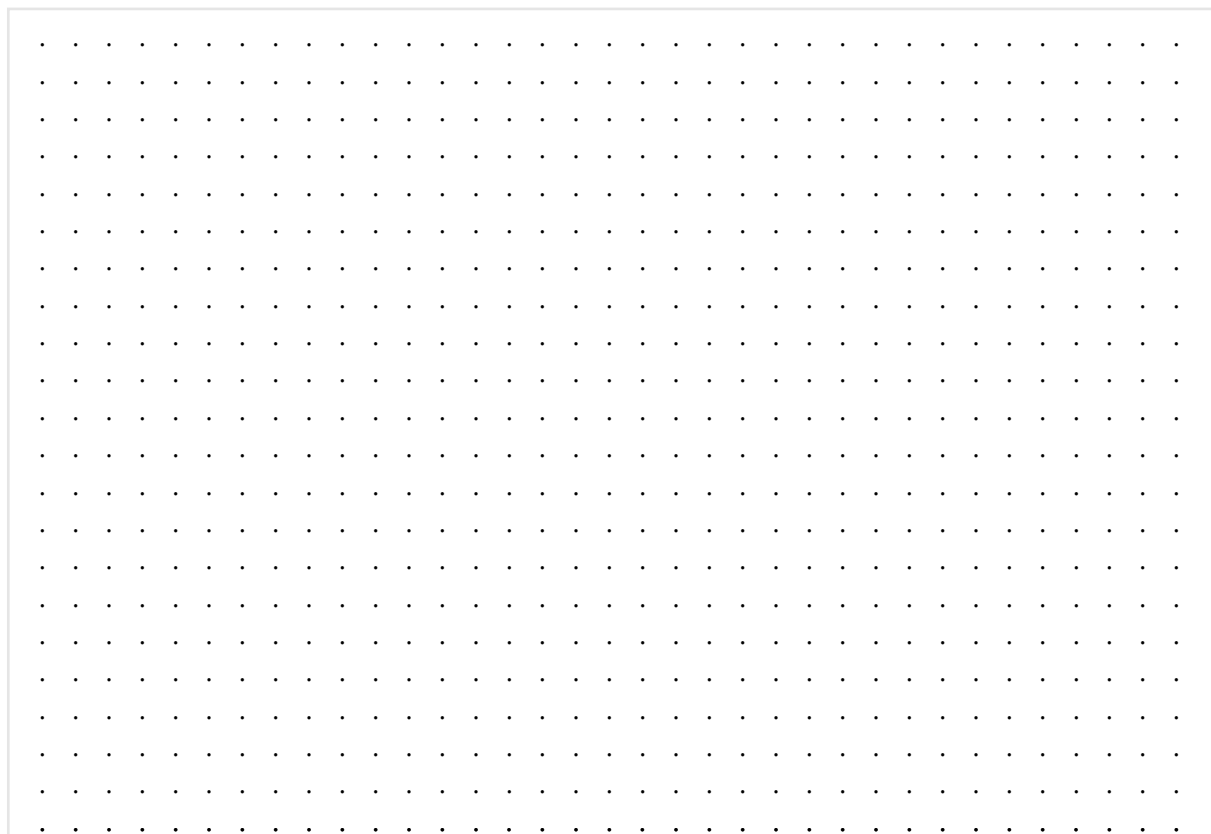


Fig. 4Timing Advance – Principle





How often -> what is the frequency of Timing Advance?

Granularity of 0,52us corresponding to 78 m

Dependent on the UE speed:

1. E.g. 72 km/h = 20 m/s

-> 78 m in approx 4 s

-> an update every 4 seconds

2. E.g. 500 km/h = 130 m/s

78 m approx 2 times per second

-> Maximum of 2 updates per second

How is the Node-B measuring the TA?

Based on received PUSCH on TTI basis

CQI reports on PUCCH

How is the timing advance signalled to the UE??

At MAC layer (peer to peer signalling)

4 CQI Measurements



CQI Measurements

4-bit CQI Table

CQI index	modulation	code rate x 1024	efficiency
0	out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

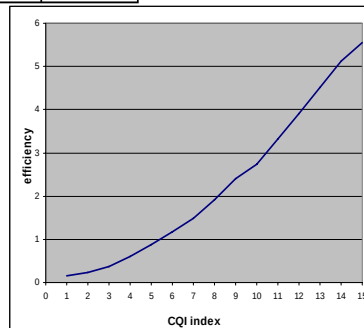
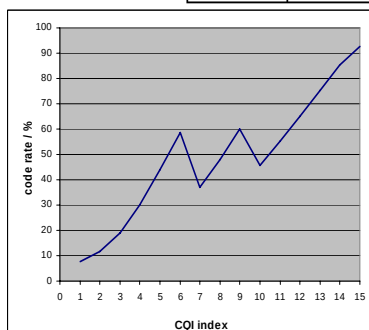
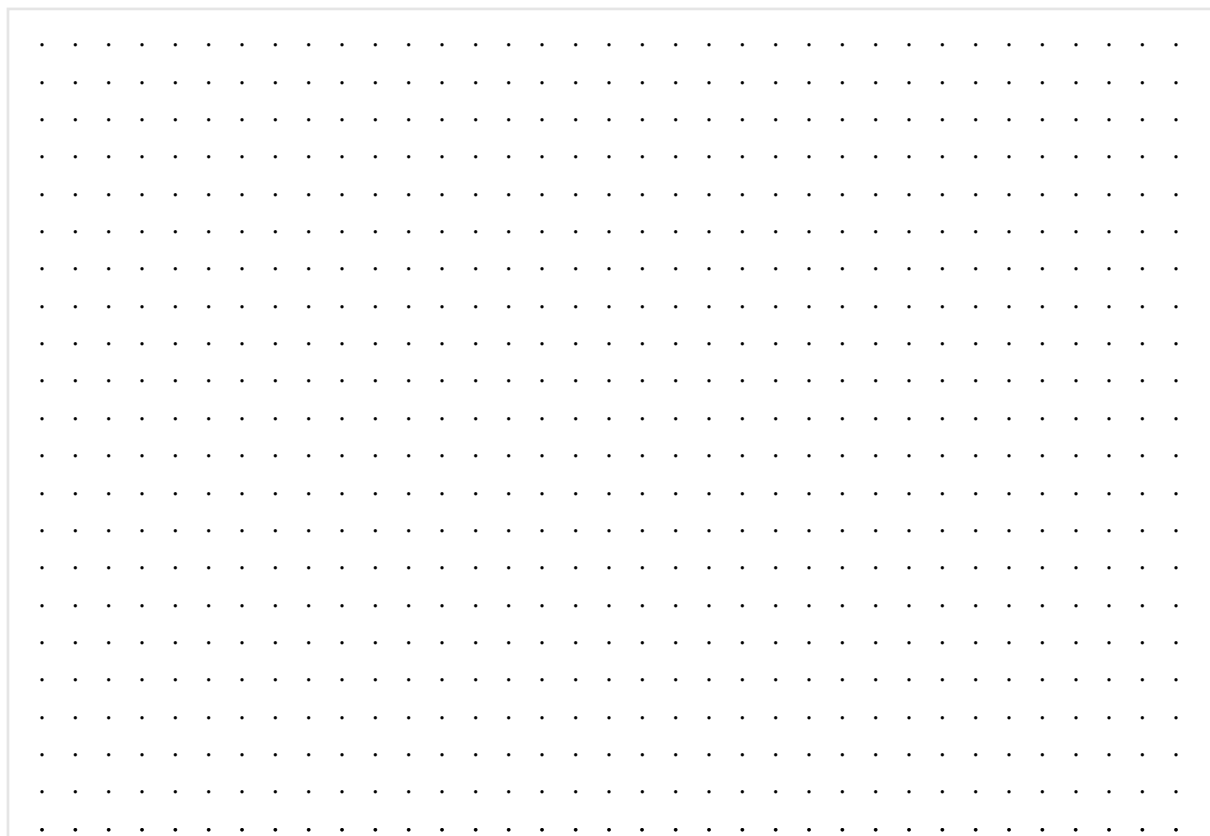


Fig. 5CQI Measurements



5 Cell Selection and Reselection

5.1 Overall process



When the UE is switched on, it attempts to establish a contact with a public land mobile network (PLMN) using a certain radio access technology.

In the selected PLMN a suitable cell is selected and if this new cell is not in a registered area, location registration is performed via RNC to the core network.

The overall process is divided into three sub-processes:

- PLMN selection and reselection to search for an available mobile network.
- Cell selection and reselection to search for a suitable cell belonging to the selected PLMN.
- Location registration to register the UE's presence in a registration area

5.2 PLMN selection

When an UE is switched on, it attempts to make contact with a PLMN. The selection of the PLMN could be either automatically or manually.

- Automatic mode: Utilizes a list of PLMN to be selected in priority order.
- Manual mode: The mobile station indicates available PLMN to the user. Upon the user selection the UE fetches service from the new PLMN.

Normally the UE operates on its home PLMN. At home PLMN, the **MCC** (Mobile Country Code) and **MNC** (Mobile Network Code) of the PLMN identity match the MCC and MNC of the IMSI (International Mobile Subscriber Identity) stored on the USIM (UMTS Subscriber Identity Module).

If the UE loses its present PLMN coverage, a new available PLMN is selected automatically or manually. If necessary, the UE will do "reselection" by searching a suitable cell on a different PLMN.

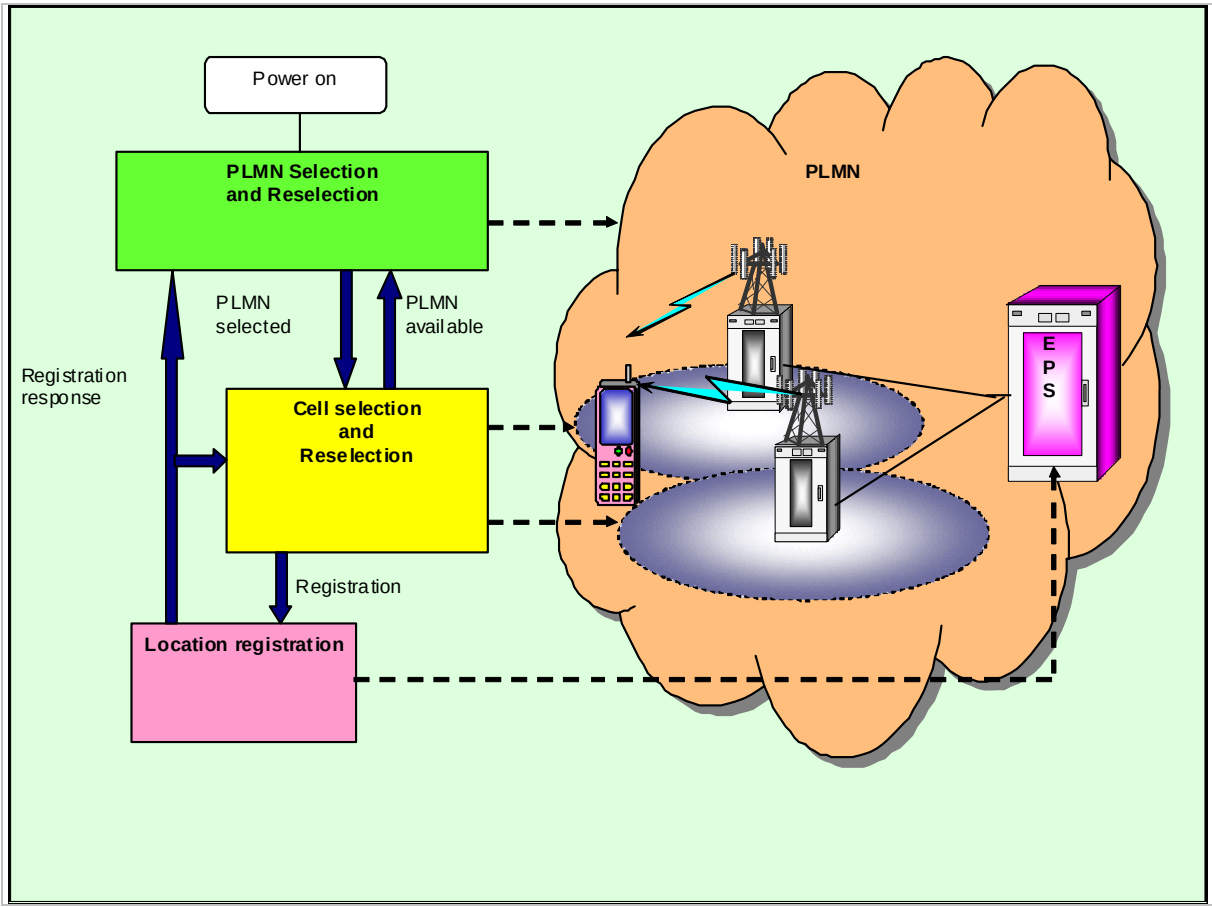
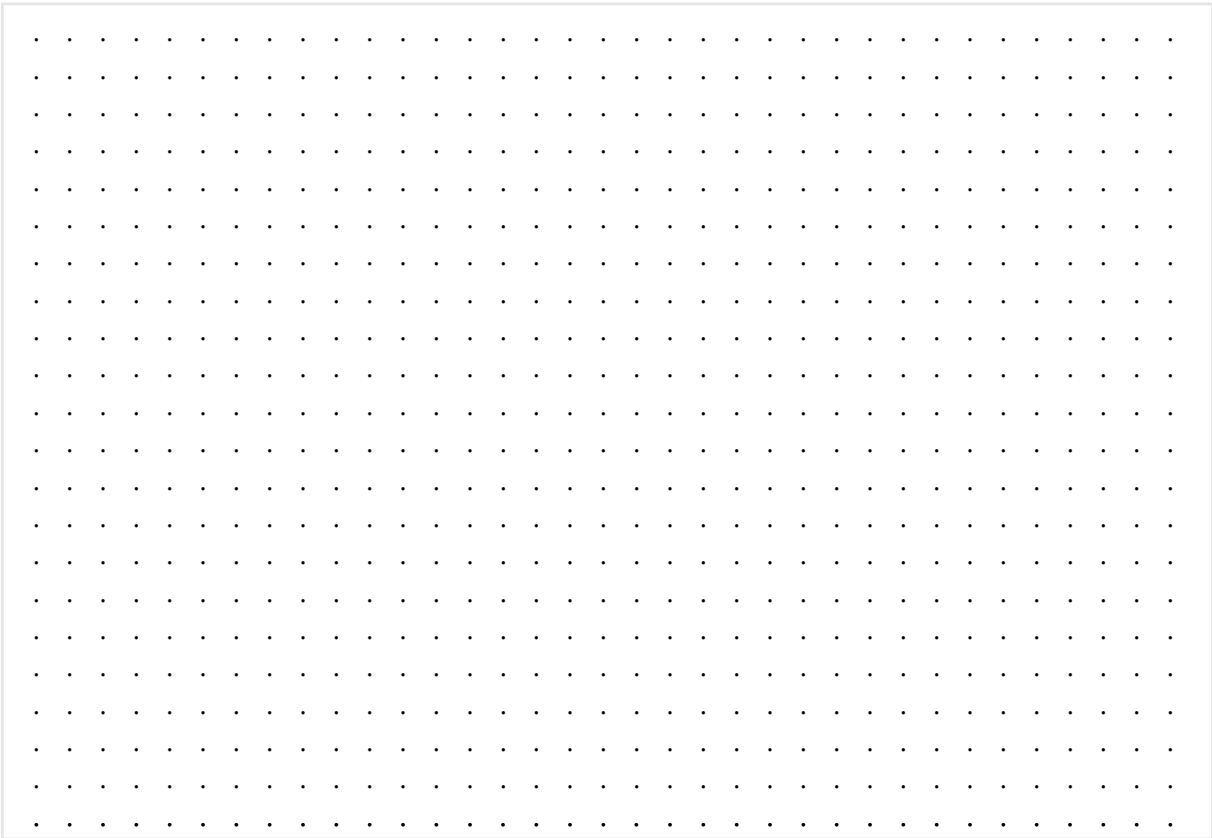


Fig. 6 Overall selection process



5.3 Service types



The action of camping on provides access to services. The network provides different levels of service to a UE in either Idle mode or Connected mode. Three levels of services are defined:

LIMITED SERVICE: emergency calls on an acceptable cell.

Acceptable cell:

UE may camp to obtain limited service like emergency call. The minimum set of requirements for initiating an emergency call in a UTRAN network are:

- The cell is not barred.
- The cell selection criteria are fulfilled.

NORMAL SERVICE: for public use on a suitable cell.

Suitable cell:

UE may camp on to obtain normal service. Such a cell shall fulfill all the following requirements:

- The cell is part of the selected / registered / equivalent PLMN
- The cell is not barred
- The cell is not part of a forbidden registration area
- The cell selection criteria are fulfilled
- In case of a CSG cell it is part of the white list

OPERATOR SERVICE: FOR OPERATORS ONLY ON A RESERVED CELL.

Reserved cell:

When the cell status "reserved for operator use" is indicated and the Access Class of the UE is 11 or 15 the UE may select/re-select this cell if in Home PLMN.

Set by O&M parameter.

Barred cell:

When cell status "barred" is indicated the UE is not permitted to select/re-select this cell, not even for limited services.

This information is set by office data.

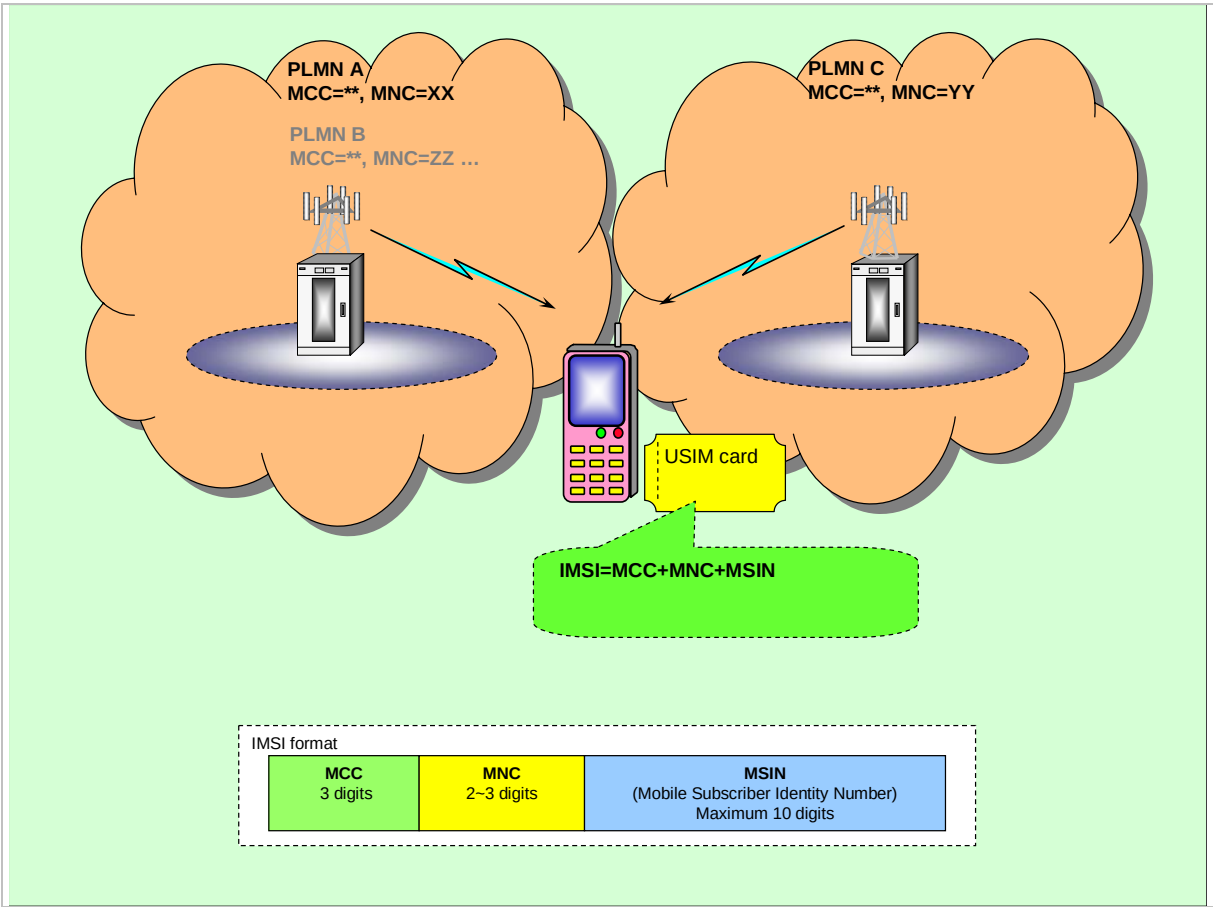
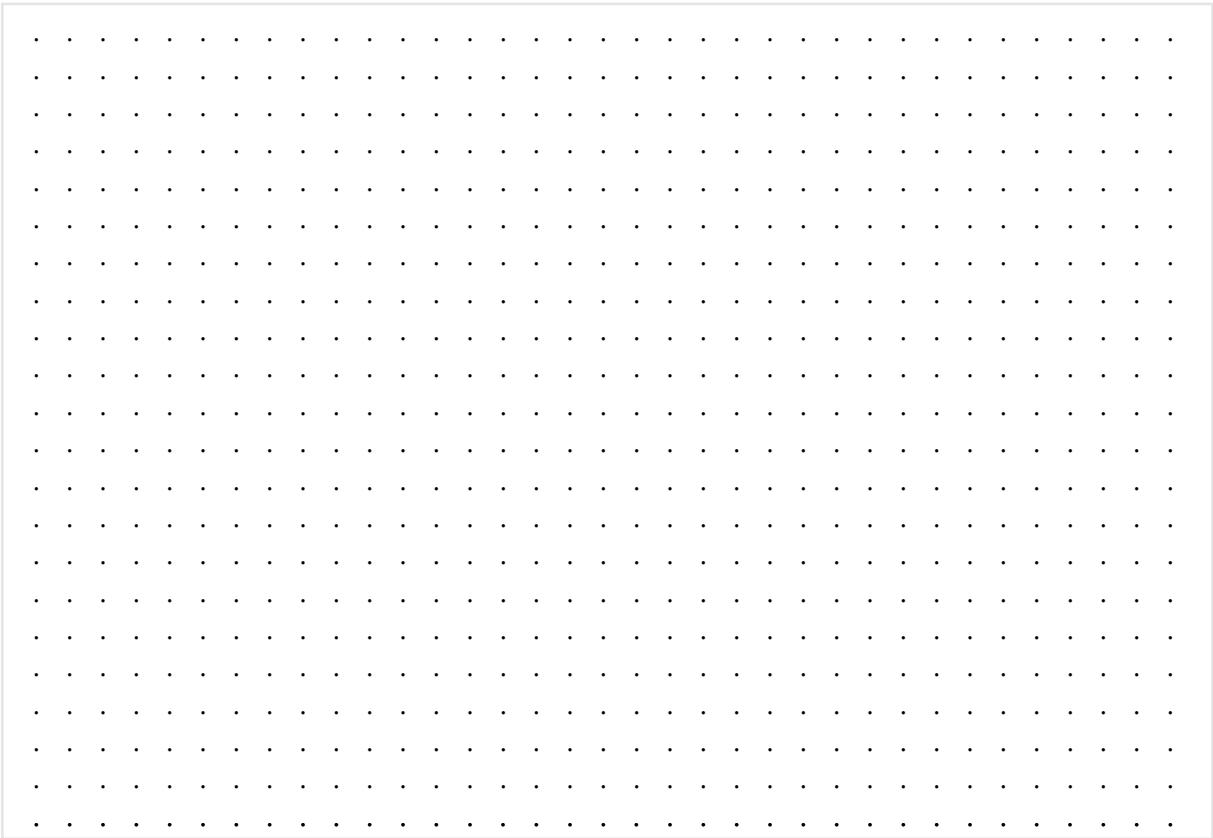


Fig. 7 PLMN Selection and reselection



5.4 Cell selection and reselection



To get service from the selected PLMN, the UE performs two types of procedures: cell selection and cell reselection

CELL SELECTION

Upon PLMN selection, UE uses "cell selection" for fast cell searching to camp on. To receive system information UE tunes to the control channels. This procedure is known as "camping on the cell".

The UE will then register its presence in the registration area of the chosen cell by NAS (Non Access Stratum) registration procedure.

NAS registration procedure means the upper layer information is transmitted from UE to CN via AS (Access Stratum). The NAS offers the E-UMTS service to the users.

The cell will be decided as suitable if it fulfils the cell selection criteria.

The purpose of camping on a cell is:

- To enable UE reception of system information from the selected PLMN
- To allow UE an RRC connection, accessing the network on the cell control channel.
- To receive paging and respond to paging messages on a tuned control channel in the registration area. The PLMN knows the tracking area of the cell in which the registered UE is camped.

CELL RESELECTION

If the UE finds a "better" cell, UE reselects it and camps on it. After camping on, UE monitors the system information to get the quality threshold and performs measurements for the cell reselection evaluation procedure. The UE evaluates whether or not a better cell exists.

The E-UTRAN controls the quality measurements for cells to be reselected. The UE measurements are triggered according to the serving cell quality level and the threshold indicated in the system information. The measurement must satisfy different requirements for intra frequency, inter frequency or inter RAT (Radio Access Technology) quality estimations.

Cell selection is performed in RRC idle mode. The camping on a cell in idle mode enables the UE to receive information from the network. UE stays in idle mode until it transmits a request to establish an RRC connection. After receiving the RRC connection set up, the mode changes into connected mode.

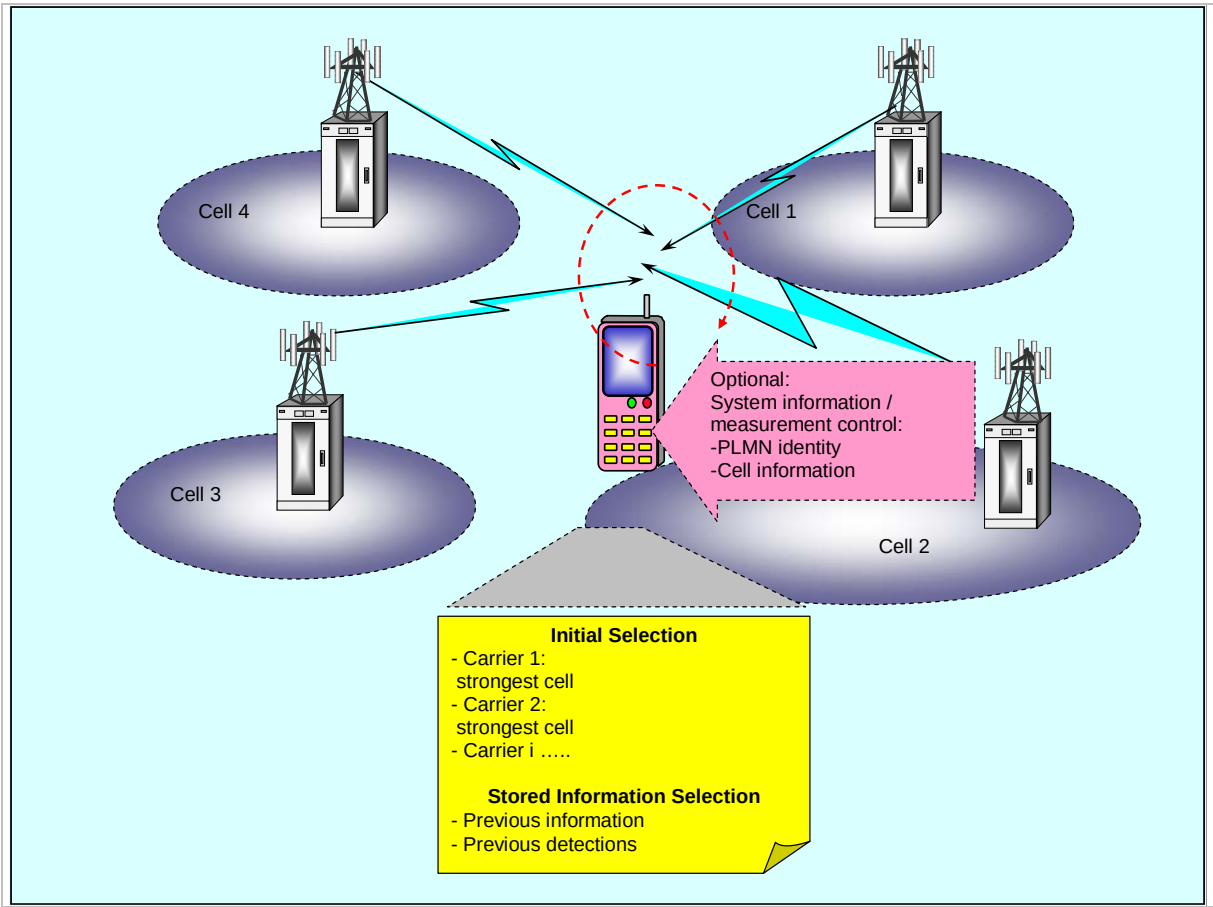
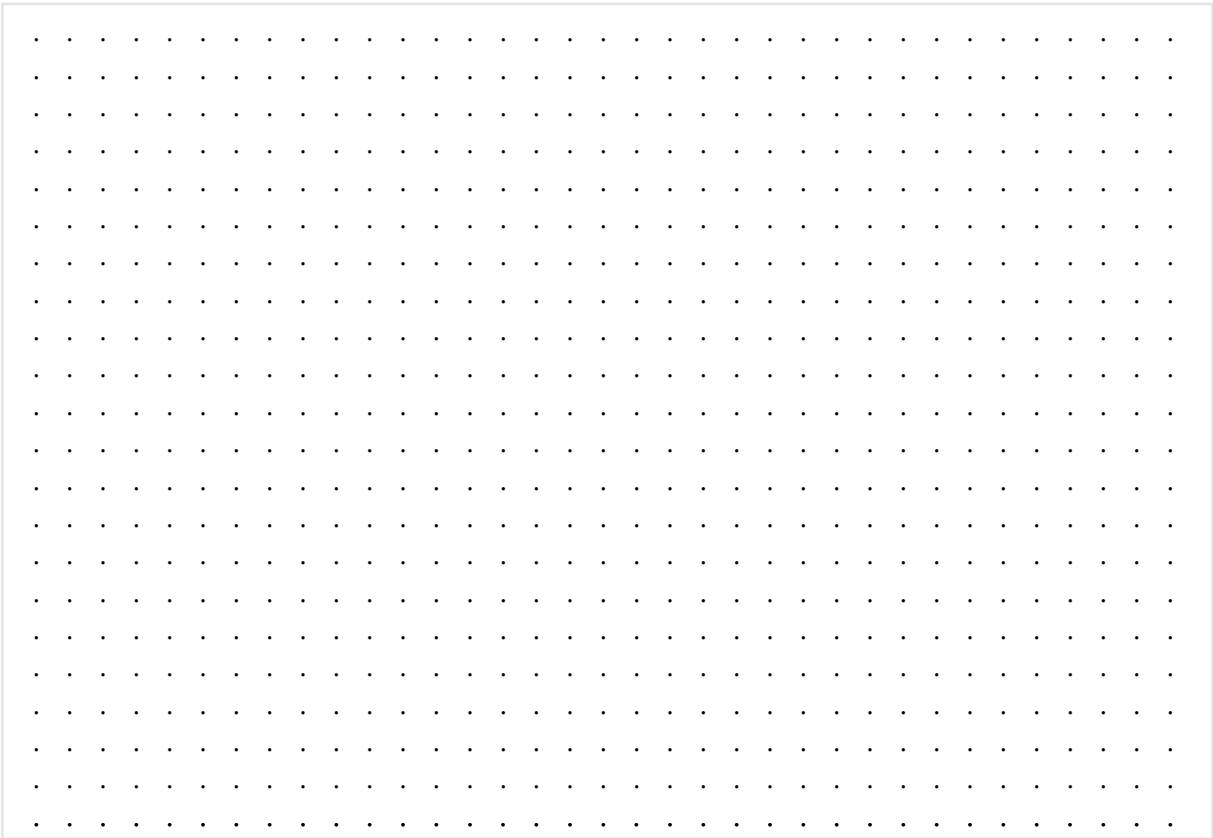


Fig. 8 Initial cell selection / stored information cell selection.



5.5 Selection procedure and criteria



PLMN Selection Process

The UE scans all RF channels in the UTRAN band according to its capabilities to find available PLMNs.

On each carrier, the UE searches for the strongest cell according to the cell search procedure (refer cell searching) and read its system information in order to find out which PLMN the cell belongs to.

If the UE can read the PLMN identity, the PLMN and the measured signal strength is reported to the NAS: if: signal $\geq -x$ dBm (high quality PLMN); without the measured signal strength if $< x$ dBm.

CELL SELECTION PROCESS

After selecting a PLMN, the cell selection process starts. The UE selects a suitable cell and the radio access mode based on idle mode measurements and cell selection criteria. The UE searches a suitable cell of that PLMN to camp on according to the following steps:

1) The UE creates a candidate list of potential cells to camp on by using one of the two search procedures:

- Initial Cell Selection UE scans all RF channels in the UTRAN band to find a suitable cell. On each carrier, UE searches for the strongest cell and reads its system information. Once the UE has found the suitable cell for the selected PLMN, the UE creates a candidate list consisting of this cell and its neighboring cells as received in measurement control information.
- Stored Information Cell Selection (optionally) This procedure requires information stored from previously received measurement control information elements (cell parameters, carrier frequencies, etc). After the UE has found a suitable cell for the selected PLMN, candidate list is created same as the initial cell selection process.

2) Each cell on the candidate list is evaluated according to the selection criteria S as described below.

3) After selecting a suitable cell (S criterion fulfilled) for camp on, UE reports this event to NAS for registration procedures. If the registration is successful, the UE enters into "camped normally" state.

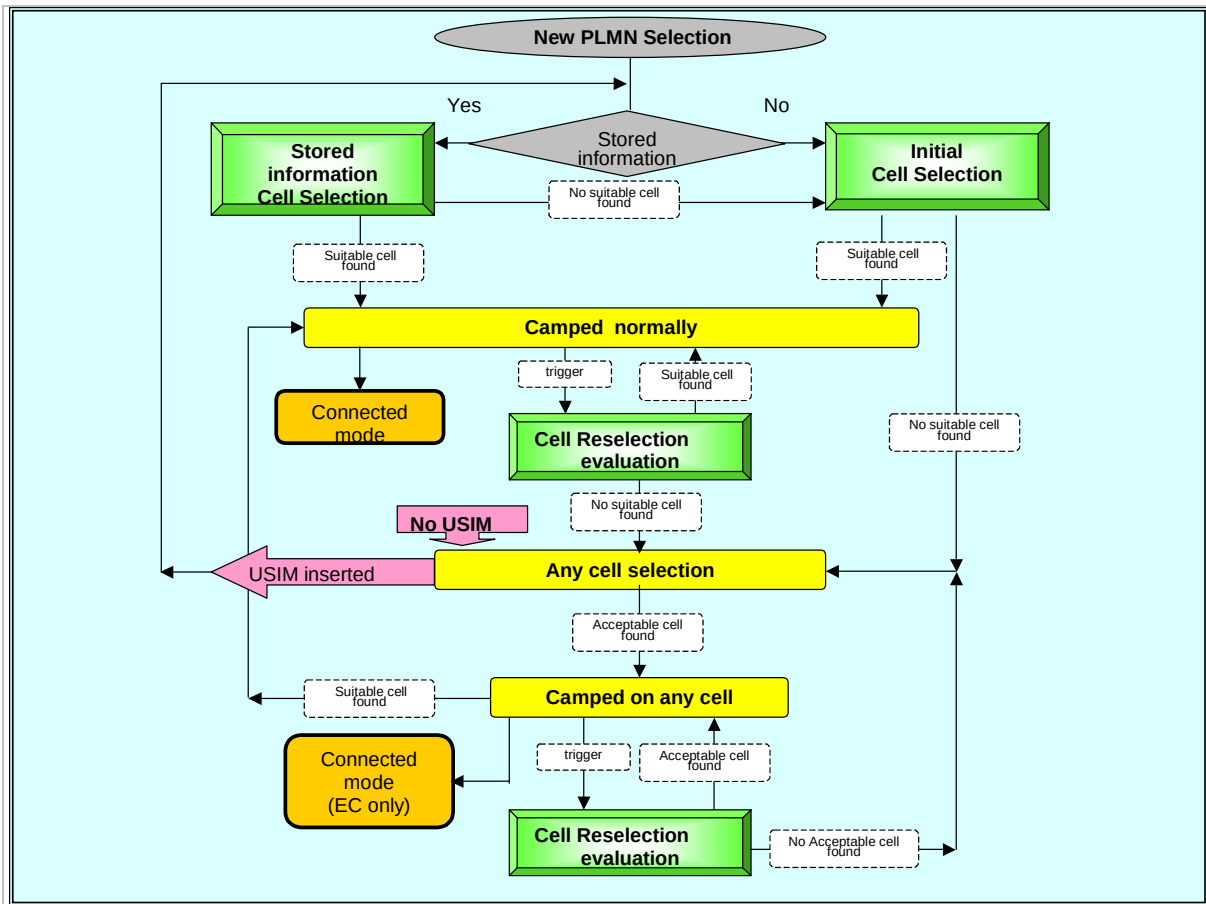
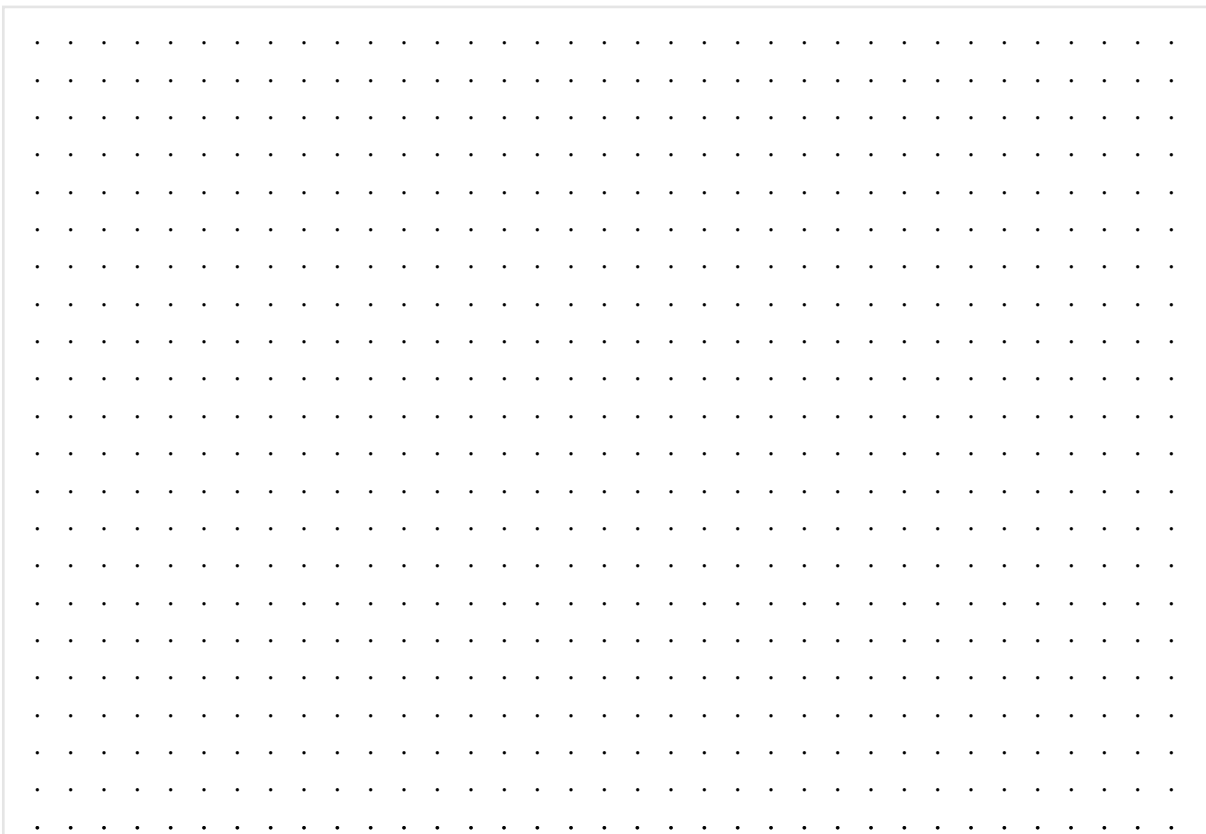


Fig. 9 Idle mode cell selection and reselection





If the UE is unable to find any suitable cell in the selected PLMN, the UE enters to "any cell selection" state.

Camped normally state: UE obtains normal service and performs the following tasks:

- Select and monitor the PCH of the cell.
- Performs system information monitoring.
- Perform necessary measurements for the cell reselection evaluation procedure.
- Execute the cell reselection evaluation procedure.

If after cell reselection evaluation process a better cell is found, the cell reselection is performed. If no suitable cell is found, the UE enters to next state "any cell selection".

Any cell selection: UE searches an acceptable cell of any PLMN to camp on. If an acceptable cell is found, the UE reports to NAS and camp on this cell obtaining limited service. And UE enters to "camped on any cell" state. If the UE can not find any acceptable cell, it stays in this state.

Camped on any cell state: UE obtains limited service and periodically searches for a suitable cell in the selected PLMN. If a suitable cell is found the state changes to Camped normally.

The figures show the initial cell selection and process for idle mode cell selection and reselection.

5.6 Cell selection: evaluation process

S-CRITERION

The cell selection criterion S is a pre-condition for suitable cells.

The conditions for E-UTRAN, UTRAN FDD and GSM cells are listed in the figure.



Cell selection criterion: S

Suitable cells:

E-UTRAN cells:	$Srxlev > 0$
UTRAN cells:	$Srxlev > 0$ AND $Squal > 0$
GSM cells:	$Srxlev > 0$

$Srxlev = Q_{rxlevmeas} - (Q_{rxlevmin} - Q_{rxlevminoffset}^*) - P_{compensation}^{**}$ $Squal = Q_{qualmeas} - Q_{qualmin}$

* $Q_{rxlevminoffset}$: only when camping in VPLMN

** $P_{compensation} = \max(UE_TXPWR_MAX_RACH - P_MAX, 0)$

Fig. 10 A cell is suitable if it fulfills S





R - CRITERION - CELL RESELECTION

The cell reselection evaluation process depends on whether Hierarchical Cell Structure (HCS) is used or not.

In order to perform cell reselection UE measures and ranks the neighbor cells.

For each type of neighbor cells (Intra-Frequency; Inter-Frequency; Inter-RAT, i.e. GSM) thresholds are definable. Measurements of neighbor cells will be triggered if these thresholds are reached.

HIGH MOBILITY / MEDIUM MOBILITY / NORMAL MOBILITY:

For faster moving UEs the procedure alters - speed dependent scaling rules are applied.

If the number of (different cells) cell reselections during the past time period $T_{CR_{max}}$ exceeds N_{CR_H} , high mobility has been detected. If the number exceeds N_{CR_M} , and not N_{CR_H} , medium mobility has been detected.

In high/medium-mobility states, a UE:

- multiplies Q_{hyst} by "Speed dependent ScalingFactor for Q_{hyst} for * mobility state" if sent.
- multiplies $T_{reselection_{RAT}}$ by "Speed dependent ScalingFactor for $T_{reselection_{RAT}}$ for * mobility state for RAT cells. (RAT = EUTRAN, UTRAN, GERAN).

* = high, medium.

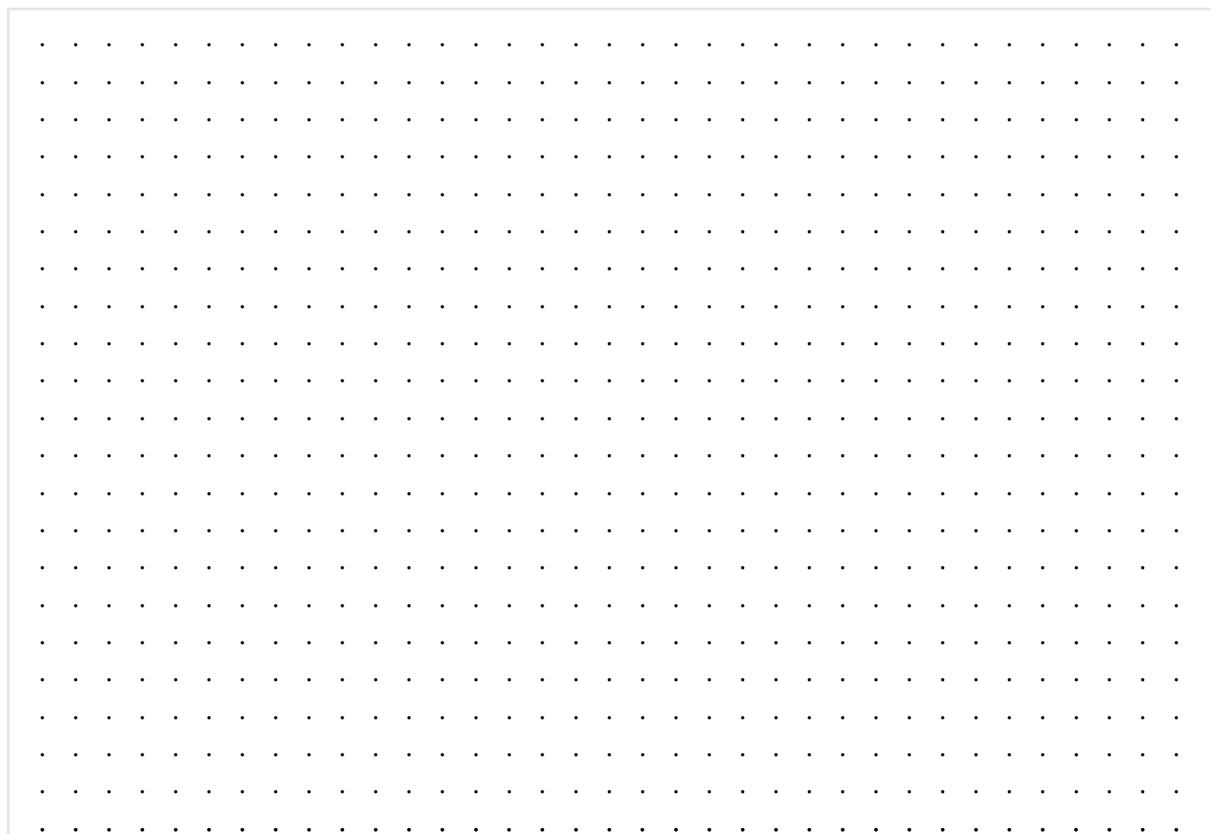
Neighbor Cell Measurements

Measurement of neighbor cells:

Intra - Frequency:	$S_{rxlev} \leq S_{intra search}$	
Inter - Frequency:	$S_{rxlev} \leq S_{nonintra search}$	<u>OR</u>
	$Prio (inter - f) > Prio (serving)$	
Inter - RAT:	$S_{rxlev} \leq S_{nonintra search}$	<u>OR</u>
	$Prio (inter - RAT) > Prio (serving)$	

For inter-frequency and inter-system measurements, depending on the UE capability, the network allocates measurement gaps during which no data are sent for the UE, so that the UE could perform the necessary measurements using a single receiver. During the measurement gaps, the particular UE cannot be scheduled for data transmission, but the vacant resources could still be used for other UEs, because of the shared channel mechanism.

Fig. 11 Neighbor Cell Measurements





Cell reselection evaluation is performed according to the UE internal triggers or if the information on the BCCH used for the cell reselection evaluation procedure has been changed.

FOR INTRA-FREQUENCY AND EQUAL PRIORITY INTER-FREQUENCY CELLS:

(Re-) Selected cell is a suitable cell (e.g. fulfills the S criterion) and is the best ranked cell (has the highest R).

The UE shall however reselect the new cell, only if the following conditions are met:

- the new cell is better ranked than the serving cell during a time interval $T_{\text{reselction}_s}$
- more than 1 second has elapsed since the UE has camped on the current serving cell.

The cell-ranking criterion R is defined as shown below:

Note,

s – indicates the serving cell,

n – indicates the candidate cell.



Intra-frequency/ Equal Priority Case: Cell Ranking Criterion: R

Ranking of cells:

$$R_s = Q_{meas,s} + Q_{hyst_s}$$
$$R_n = Q_{meas,n} - Q_{offset_{s,n}}$$

$$R_n > R_s \Rightarrow \text{"cell reselection"}$$

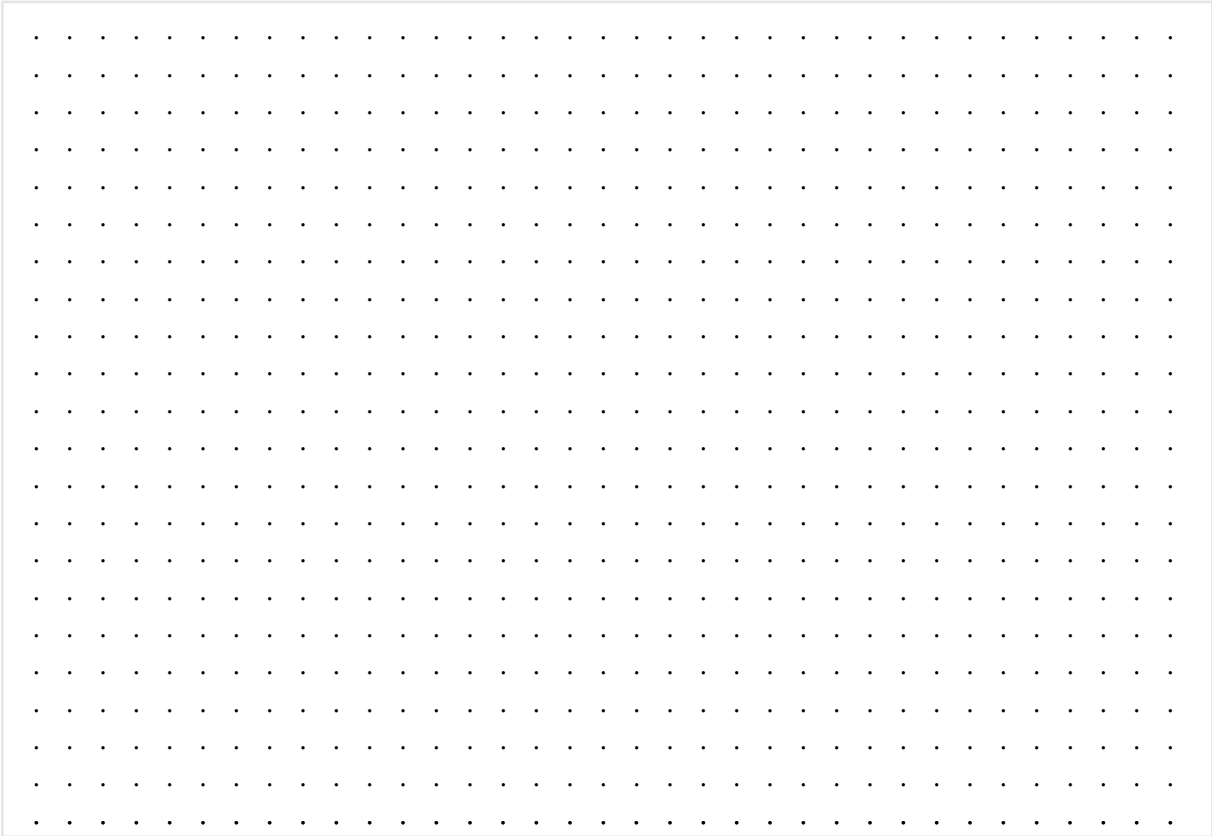
s -> for serving cell
n -> for neighbor cell

Re-selected cell: Suitable (S Criterion)
 Best Rank(Highest
R)

Qmeas*	RSRP measurement quantity used in cell reselections.
Qoffset	For intra-frequency: Equals to Qoffsets,n, if Qoffsets,n is valid, otherwise this equals to zero. For inter-frequency: Equals to Qoffsets,n plus Qoffsetfrequency, if Qoffsets,n is valid, otherwise this equals to Qoffsetfrequency.

*3GPP TS 36.304

Fig. 12Intra-frequency/ Equal Priority Case: Cell Ranking Criterion: R





FOR INTER-FREQUENCY AND INTER-RAT NEIGHBOUR CELLS:

If UE camps longer than 1 sec in the serving cell and:

- a higher priority neighbor fulfills (during $T_{\text{reselection_RAT}}$):

$S_{\text{nonServingCell},x} > \text{Thresh}_{\text{high}} \rightarrow \text{reselect neighbor cell.}$

- no cell fulfills $S_{\text{nonServingCell},x} > \text{Thresh}_{\text{high}}$:

$S_{\text{ServingCell}} < \text{Thresh}_{\text{serving,low}}$ and $S_{\text{nonServingCell},x} > \text{Thresh}_{x,\text{low}} \rightarrow \text{reselect neighbor cell.}$

6 Handover Measurements



The eNodeB sends Measurement control messages to the UE giving reporting thresholds. The UE identifies others cell ids from synchronization signals and measures other cells' signal strength based on their RS. When the reporting threshold condition is fulfilled, the UE sends handover measurement reports to the serving eNodeB.

LTE UE can detect intra LTE neighbours without neighbour lists which simplifies network management. The UE reports other cell IDs to the eNodeB. If the target cell ID is known by eNodeB, it will proceed with the handover. If the target is not known by eNodeB and no is X2 enabled, the eNodeB asks UE to decode global cell id of the target cell. The eNodeB finds out the target cell's IP address from O&M, enables an X2 connection to the target cell and proceeds with the handover

2G network operators need to define neighbour lists towards LTE. Also 3G network operators need to define the neighbour lists but it is possible for UE to detect the new cells outside neighbour list which makes neighbour list creation simpler.

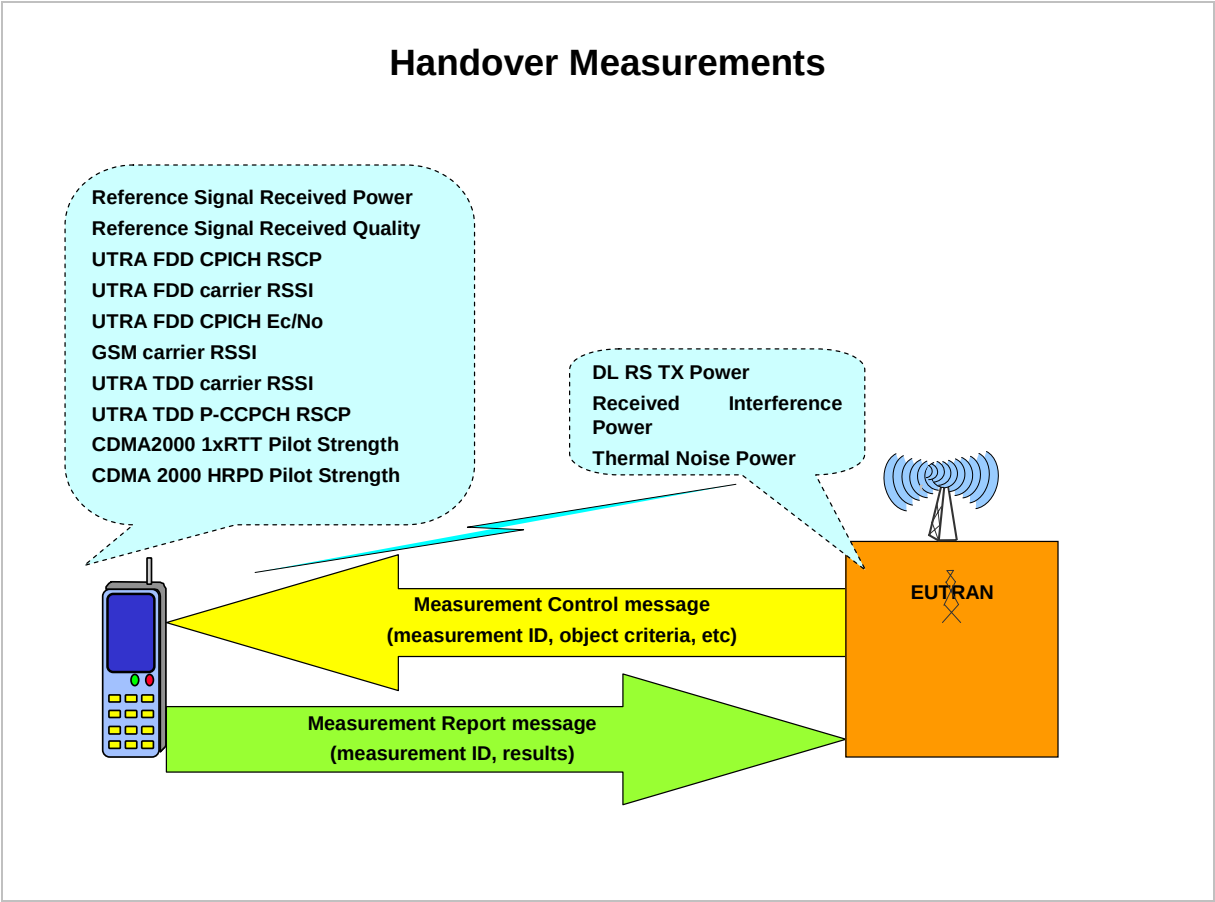
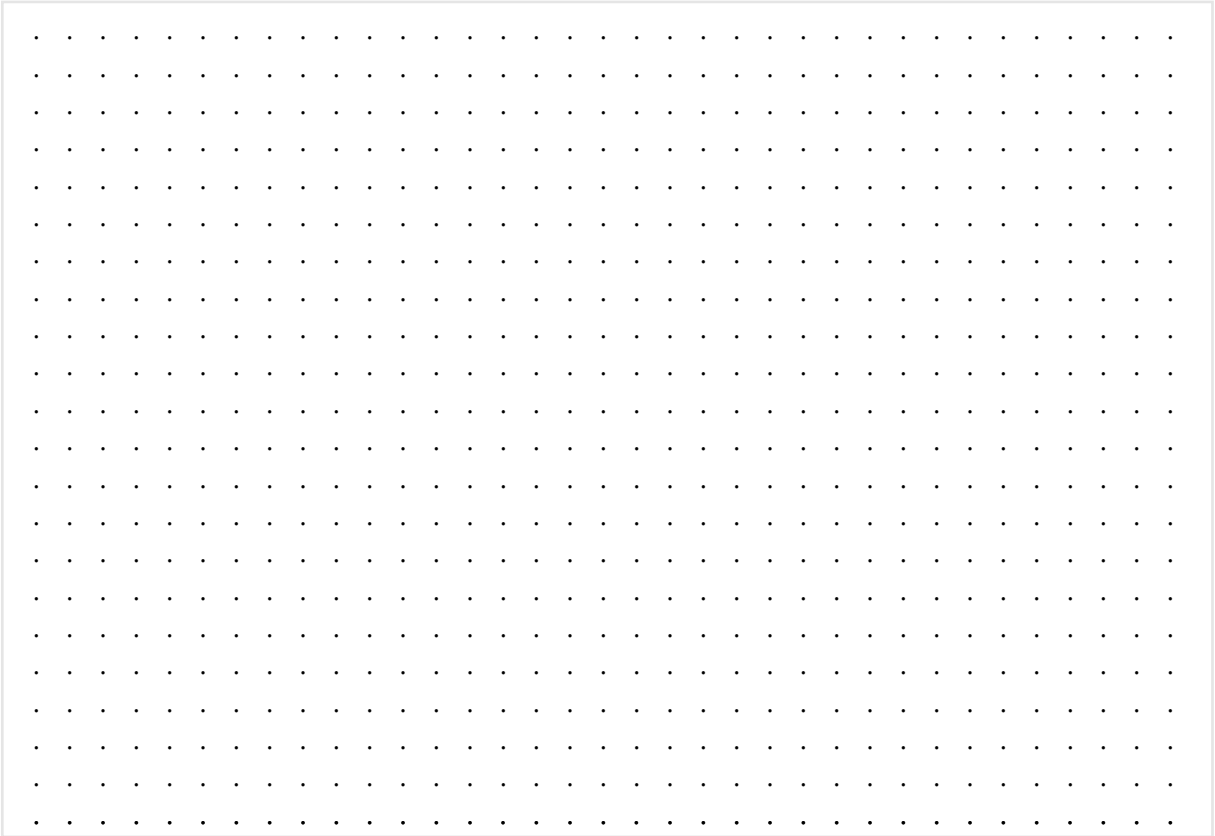


Fig. 13Handover Measurements





Higher Layer Filtering

$$F_n = (1-a) \cdot F_{n-1} + a \cdot M_n$$

$a = \frac{1}{2}^{(k/4)} \rightarrow$ strong dependence on k

$k = 0 \rightarrow$ no filtering

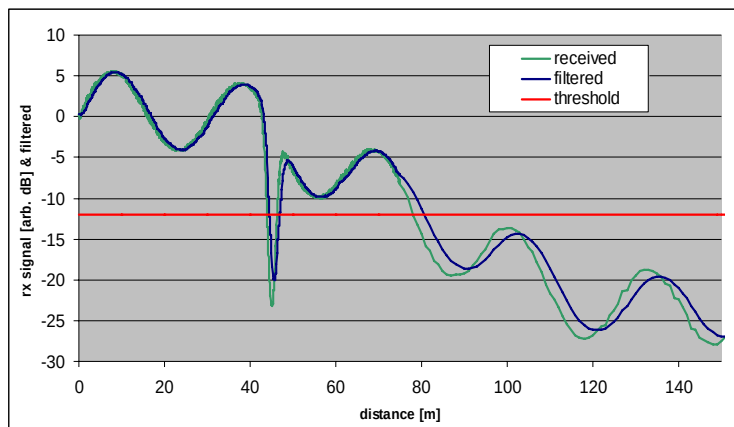
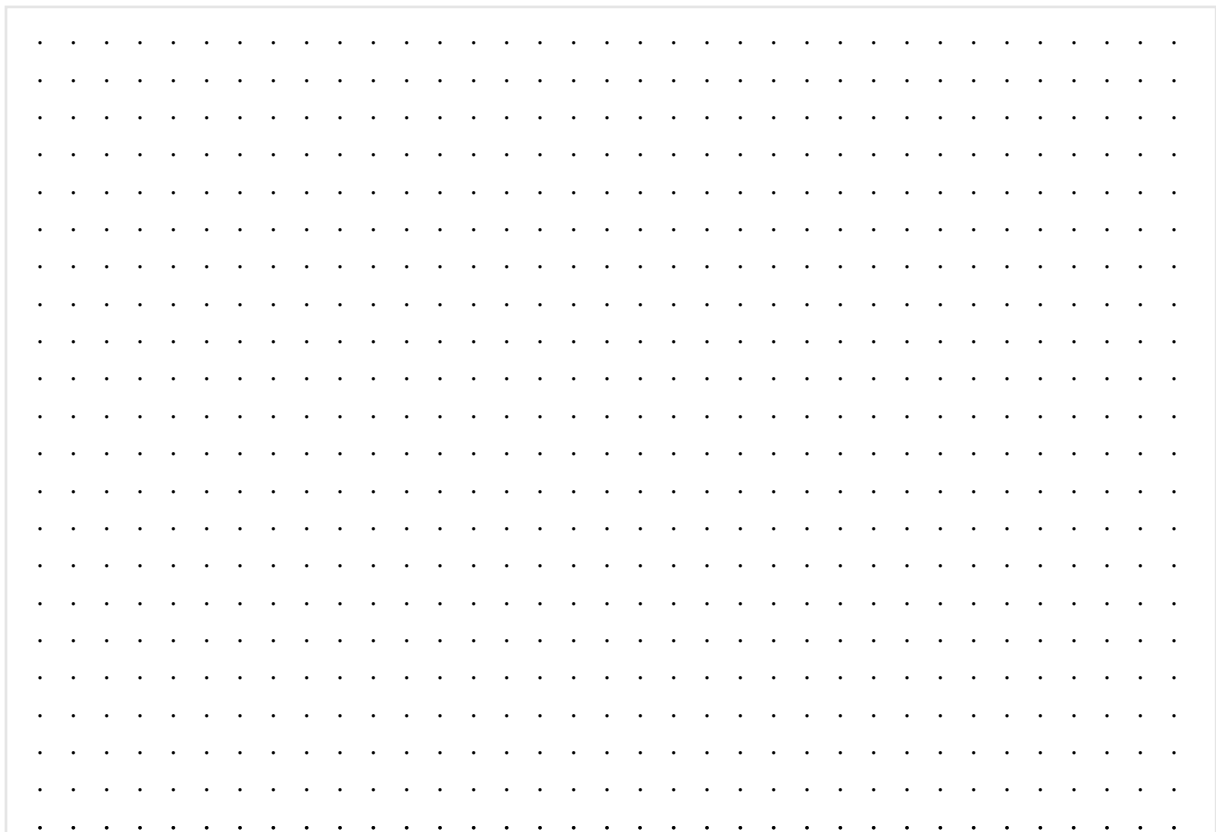


Fig. 14 Higher Layer Filtering





Intra RAT HO events

A1 -> Serving cell becomes better than threshold

A2 -> Serving cells becomes worse than threshold

A3 -> Neighbour becomes offset better than serving

A4 -> Neighbour becomes better than threshold

A5 -> Serving becomes worse than threshold 1 & neighbour becomes better than threshold

Event B1 -> Inter RAT neighbour becomes better than threshold

Event B2 -> serving becomes worse than threshold 1 and neighbour becomes better than threshold 2

