Cellular Networks: Channel Models, Handoff, Mobility Management, and Mobility Models

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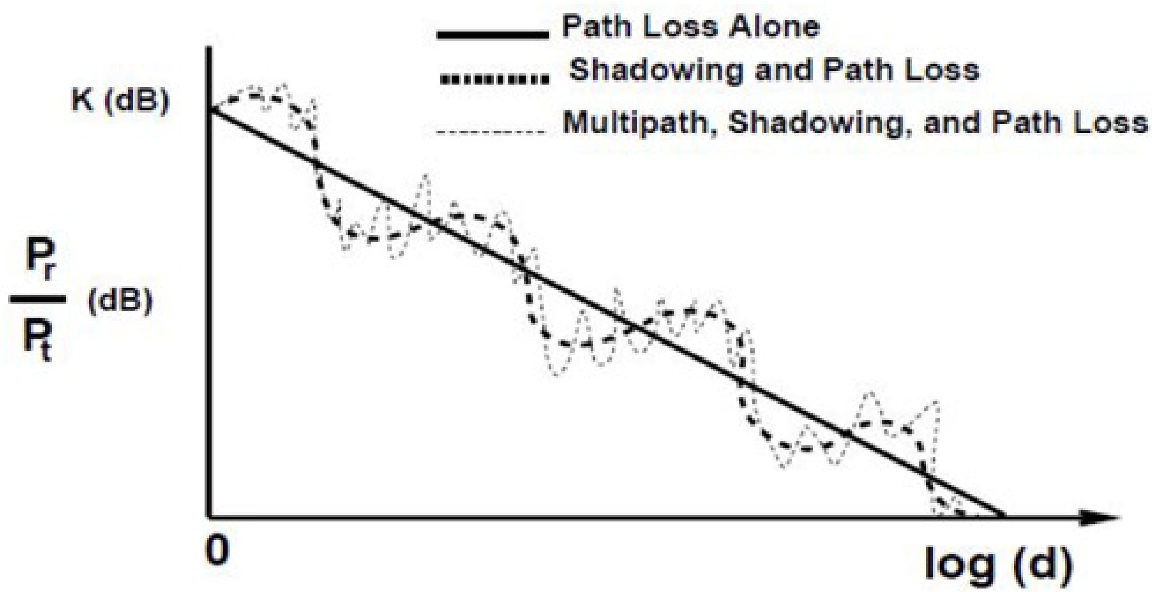
Content

- Channel Models
- Handoff
- Mobility Management
- Mobility Models

Channel Models

Fading Channels

- A portion of the transmitted signal from the transmitter is received by the mobile station.
- As the signal traverses from the transmitter to the receiver, it experiences loss which can be categorized in three sets:
  - Large scale fading:
    - path loss
    - shadowing
  - Small scale fading
    - multipath fading



Free Space Path Loss

- RSSI measurements are affected by different factors (fading) in a cellular network.
  - Path Loss Distance-dependant Fading
    - Free-space path loss is proportional to the square of the distance between the transmitter and receiver, and also proportional to the square of the frequency of the radio signal. The equation for FSPL is

$$\boxed{\mathrm{FSPL} = \left(\frac{4\,\pi d}{\lambda}\right)^2}$$

- $\lambda = c/f$ is the signal wavelength (in metres),
- f is the signal frequency (in hertz),
- d is the distance from the transmitter (in metres),
- c is the speed of light in a vacuum.

Shadowing

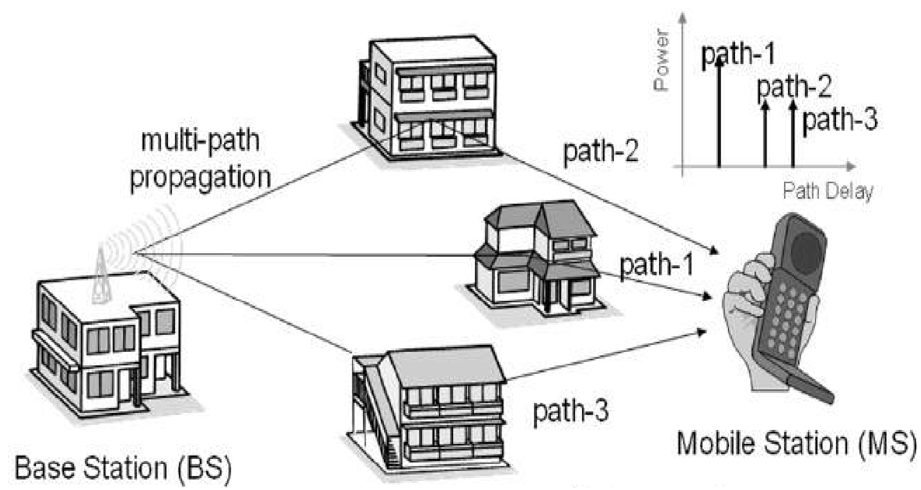
- When the transmit signal is shadowed by a obstacles, it result sin variations of local mean received signal power.
- Shadowing is modeled by log-normal variable.
- A log-normal distribution is a probability distribution of a random variable whose logarithm is normally distributed.
- Expressing the path loss in db, we have

$$\boxed{P_r(d)\ \mathrm{db} = P_t(d)\mathrm{db} + \mathrm{K} - 10\alpha\log(d) + \phi}$$

- where P_t is the transmitted power in dB, K is a constant in dB which depends on the antenna characteristics, α is the path loss exponent usually between 2 and 7, and ϕ is a Gaussian random variable in dB units which represents the effect of shadowing and has mean zero.

Small Scale Fading

- Small scale fading is used to describe rapid fluctuation of the amplitude of a radio signal over a short period of time or travel distance.
- Small scale fading is caused by destructive interference between two or more versions of the transmitted signal being slightly out of phase due to the different propagation times.
- This is also called multipath propagation.
- The different components are due to reflection and scattering form trees buildings and hills etc.



Small Scale Fading

- Multipath propagation creates small-scale fading effects. The three most important effects are:
  - Rapid changes in signal strength over a small travel distance or time interval;
  - Random frequency modulation due to varying Doppler shifts on different multipath signals;
  - Time dispersion (echoes) caused by multipath propagation delays.
- Even when a mobile receiver is stationary, the received signal may fade due to a non-stationary nature of the channel (reflecting objects can be moving).

Flat vs Frequency Selective Fading

- The wireless channel is said to be **flat fading** if it has constant gain and linear phase response over a bandwidth which is greater than the bandwidth of the transmitted signal.
- If the channel gain varies at different frequencies, then the channel experiences **frequency selective fading**.
- Flat fading results in lower SNRs while frequency selective fading results in distortion.
- Equalization is used to compensate the frequency selective fading.

Fast Fading

- Since the mobile station and the obstacles are mobile, the fading channel may vary in time. Based on the speed of the change in the channel, there are fast and slow fading.
- Fast fading
  - Fast Fading is due to reflections of local objects and the motion of the objects relative to those objects.
  - It occurs if the channel impulse response changes rapidly within the symbol duration.
  - In other words, fast fading occurs when the coherence time of the channel is smaller than the symbol period of the transmitted signal.

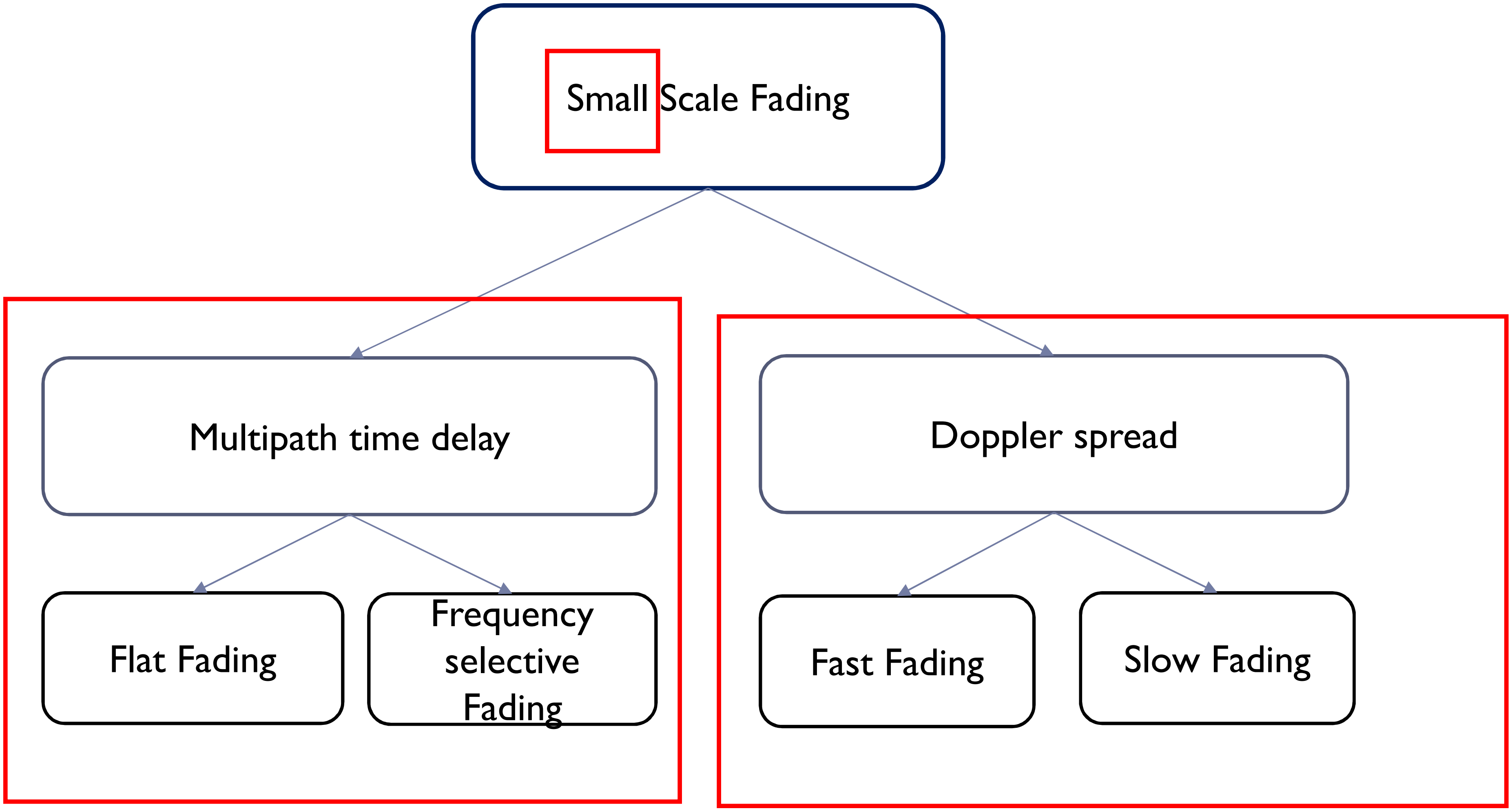
Fast Fading

- Fast fading
  - When a user (or reflectors in its environment) is moving, the user's velocity causes a shift in the frequency of the signal transmitted along each signal path. This phenomenon is known as the Doppler shift.
  - Signals traveling along different paths can have different Doppler shifts, corresponding to different rates of change in phase.
  - The difference in Doppler shifts between different signal components contributing to a signal fading channel tap is known as the Doppler spread.

Slow Fading

- Slow fading arises when the coherence time of the channel is large relative to the delay requirement of the application.
- In this regime, the amplitude and phase change imposed by the channel can be considered roughly constant over the period of use.
- Slow fading can be caused by events such as shadowing, where a large obstruction obscures the main signal path between the BTS and MS.

Small Scale Fading



Small Scale Fading – Rayleigh Channel

- Impulse response for a small fading channel can be written as

$$\boxed{h(t) = \sum_i \alpha_i(t) e^{-j2\pi f_c \tau_i(t)}}$$

- $\alpha_i(t)$ is the time-varying attenuation factor of the *ith* propagation delay, $\tau_i(t)$ is the time-varying delay and f_c is the carrier frequency.
- If we assume there is no line of sight communication and there are lots of independent components in *h*(*t*), then r=|h| is modeled as a Rayleight random variable as

$$\boxed{f(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}}}$$

Small Scale Fading – Ricean Channel

- Assuming that LOS exists, when the number of propagation path is large, central limit theorem applies and $h(t)$ can be modelled as a complex Gaussian process.
- The envelope $r = |h|$ is Ricean distributed in this case:

$$\boxed{f(r) = \frac{r}{\sigma^2} e^{-\frac{r^2+\nu^2}{2\sigma^2}} I_0\left(\frac{r\nu}{\sigma^2}\right)}$$

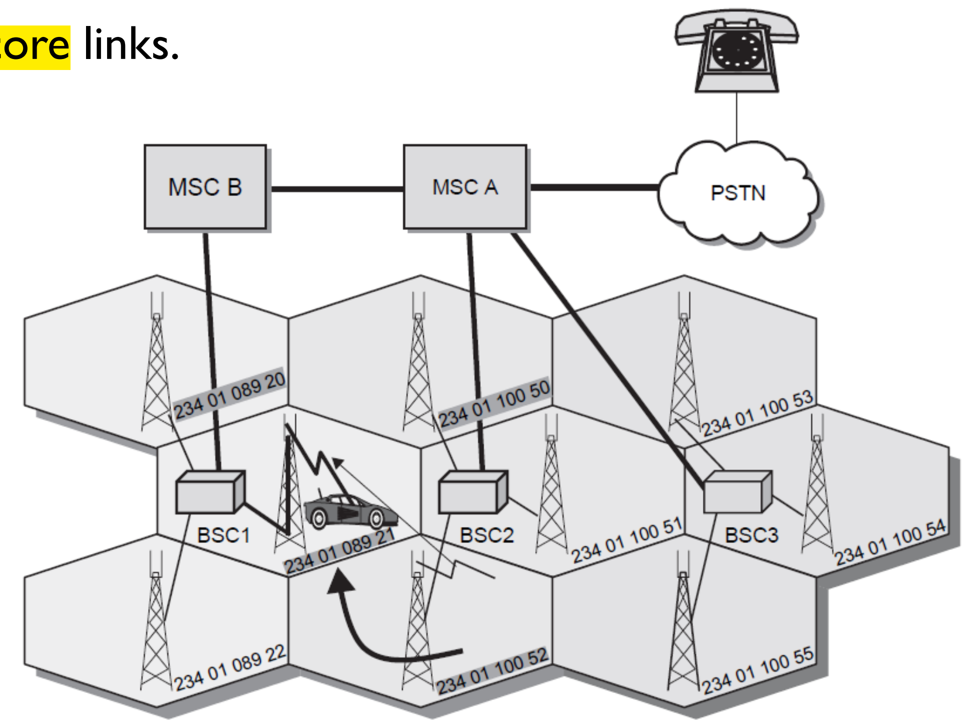
where I_0 is the modified Bessel function of order zero.

- The Rice factor $\mathrm{K} = \frac{\nu^2}{2\sigma^2}$ is the relation between the power of the LOS component and the power of the Rayleigh component.
- When K $\rightarrow \infty$ and no LOS component, then Rayleigh=Ricean.

Handoff

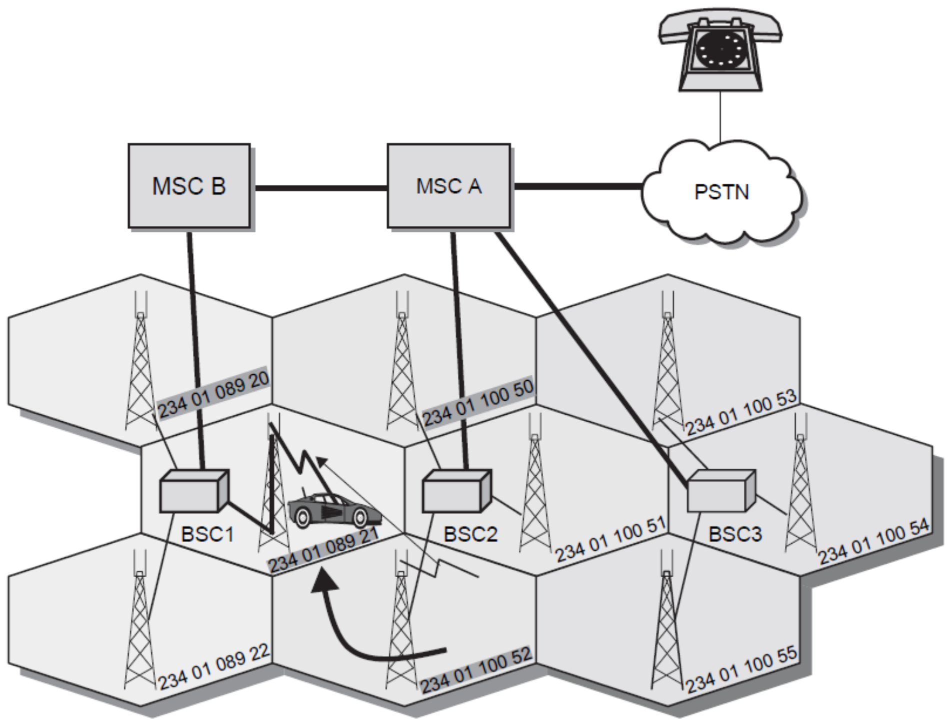
Handover/Handoff

- Handover (European) = handoff (American)
  - The process occurs when a user is handed over from one access point to another access point.
- In the GSM system, a handoff usually involves both a change of channel carrier frequency and time slot.
- In CDMA system, handoff requires change in CDMA codes.
- It also requires reservations in backhaul/core links.
- Handoff are due to
  - Signal strength deterioration
  - Load balancing



Handover/Handoff

- Handoff can be
  - BSC/RNC-wise:
    - Internal = Intra-BSS/RNC
    - External = Inter-BSS/RNC
  - MSC-wise:
    - Intra-MSC
    - Inter-MSC
  - Technology-wise
    - Horizontal
      - intra radio access technology (RAT)
    - Vertical
    - Inter-RAT or intersystem



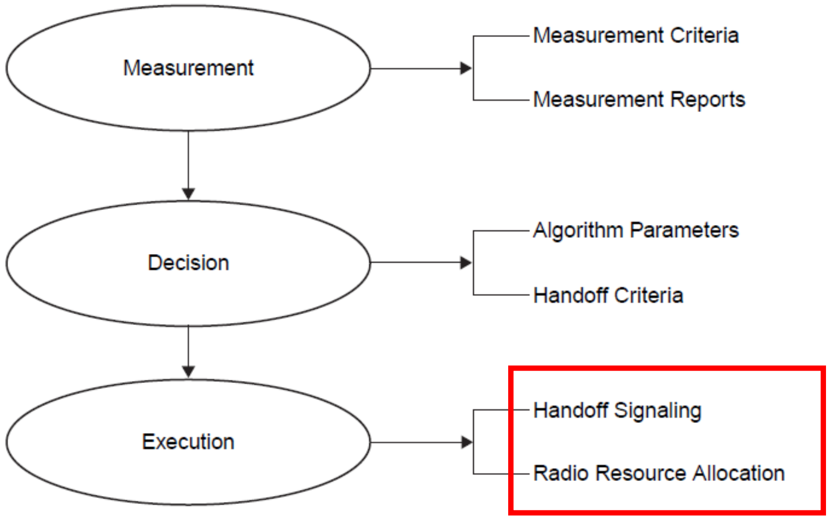
- Types:
  - Hard: old connection is terminated before making the new connection
  - Soft: the new connection is established before the old connection is released.

Handoff Techniques

- Handoff techniques can be classified as
  - mobile-controlled handoff (MCHO),
  - Network controlled handoff (NCHO),
  - Mobile-assisted handoff (MAHO)
    - The network provides a list of base station frequencies (those of nearby base stations).
    - The network asks the mobile to measure the signal strengths and signal quality from the surrounding base stations (as well as the serving base station)
    - mobile report the measurements back to the base station.
    - The BSC/RNC then decides.

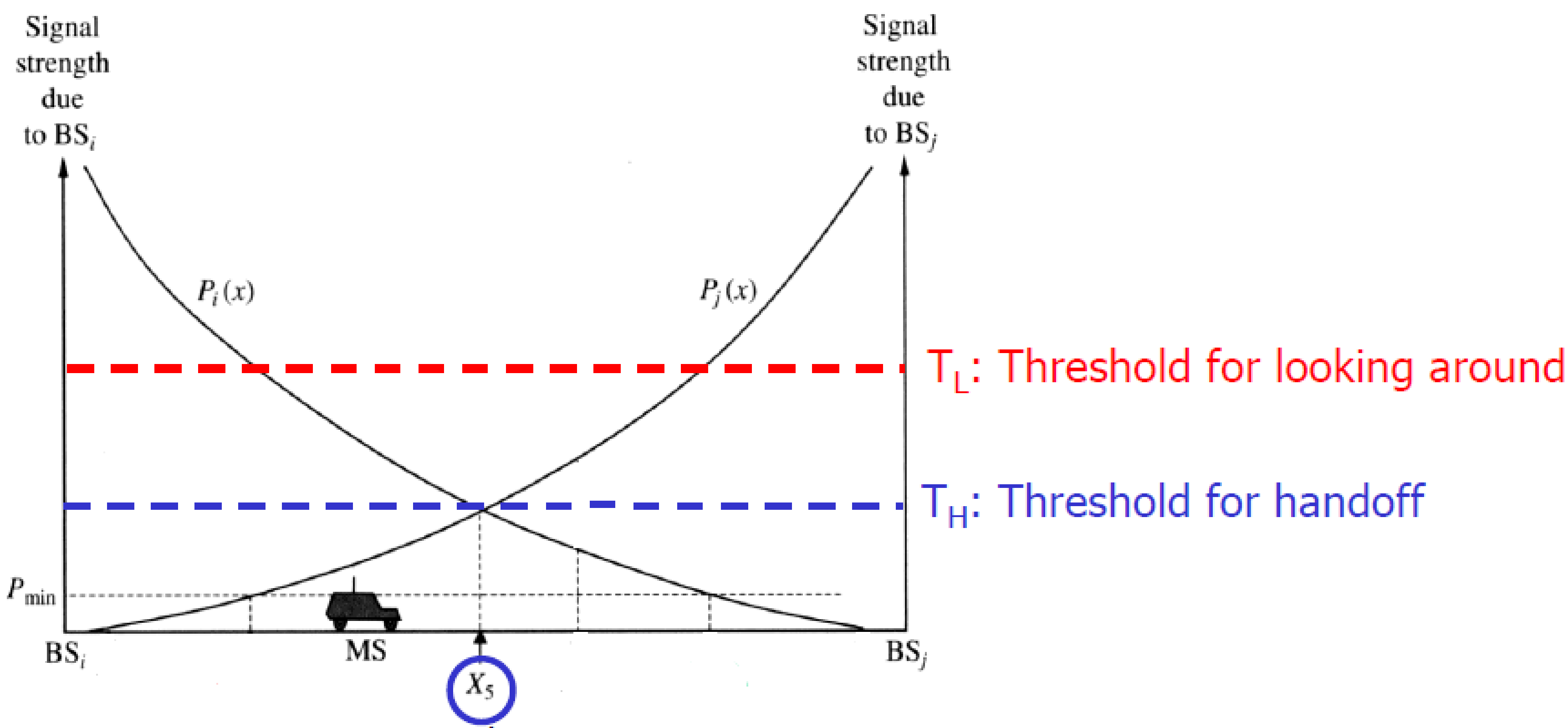
Handoff Process

- A basic handoff process consists of three main phases
  - measurements,
  - decision,
  - execution phase
- Measurement Criteria
  - RSSI (Received Signal Strength Indication)
  - SNR or QI (Quality Indicator) ,
  - WEI (Word Error Indicator)
    - bit error rate (BER),
    - Block error rate (BLER)



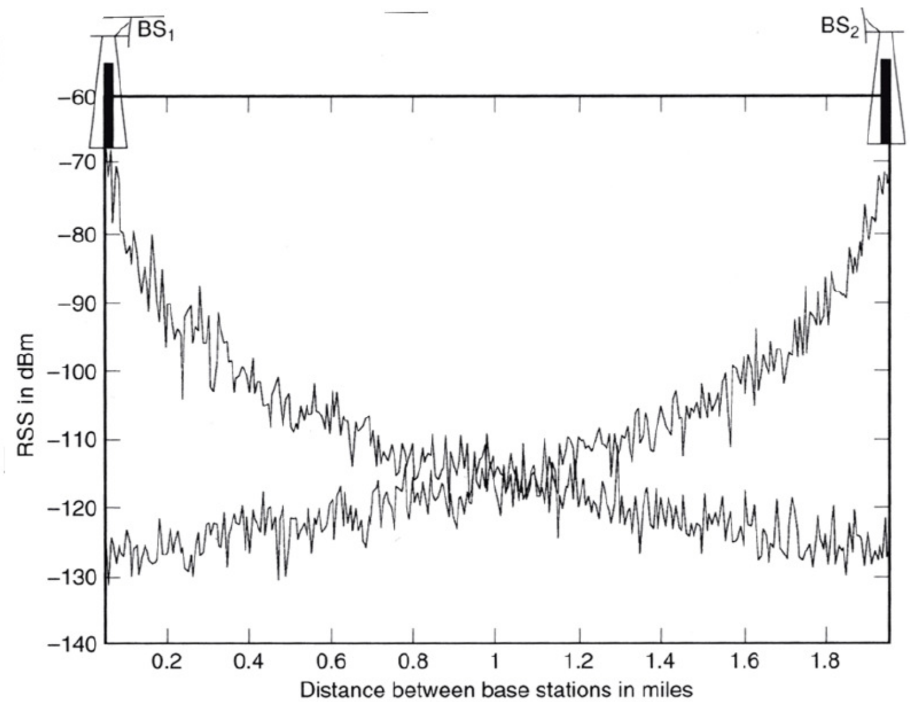
Hand-off Decision: Relative Signal Strength

- As soon as the RSSI of the target BTS is higher than the serving BTS, the handoff can be carried out.



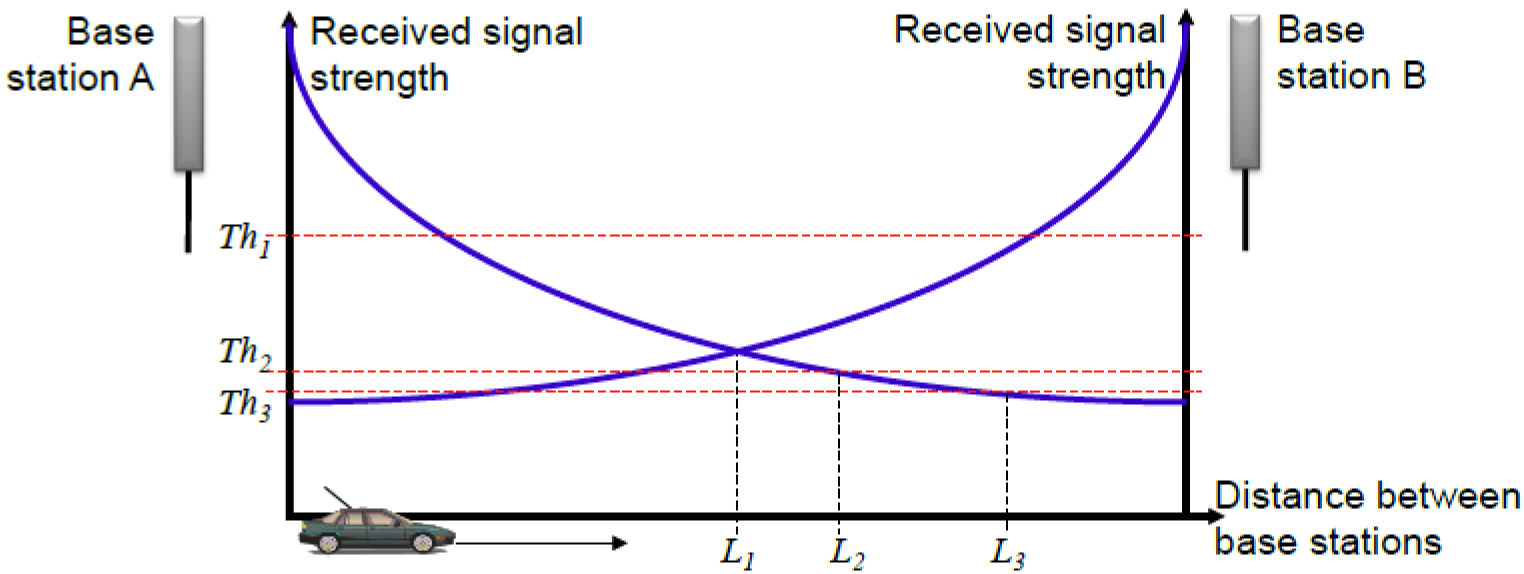
Averaging/Filtering

- RSSI measurements are affected by Fading.
- Ideally, the handoff decision should be based on distance-dependent fading and shadow fading less dependent on multipath fading.
- This can be accomplished by averaging the received signal strength for a sufficient time period.



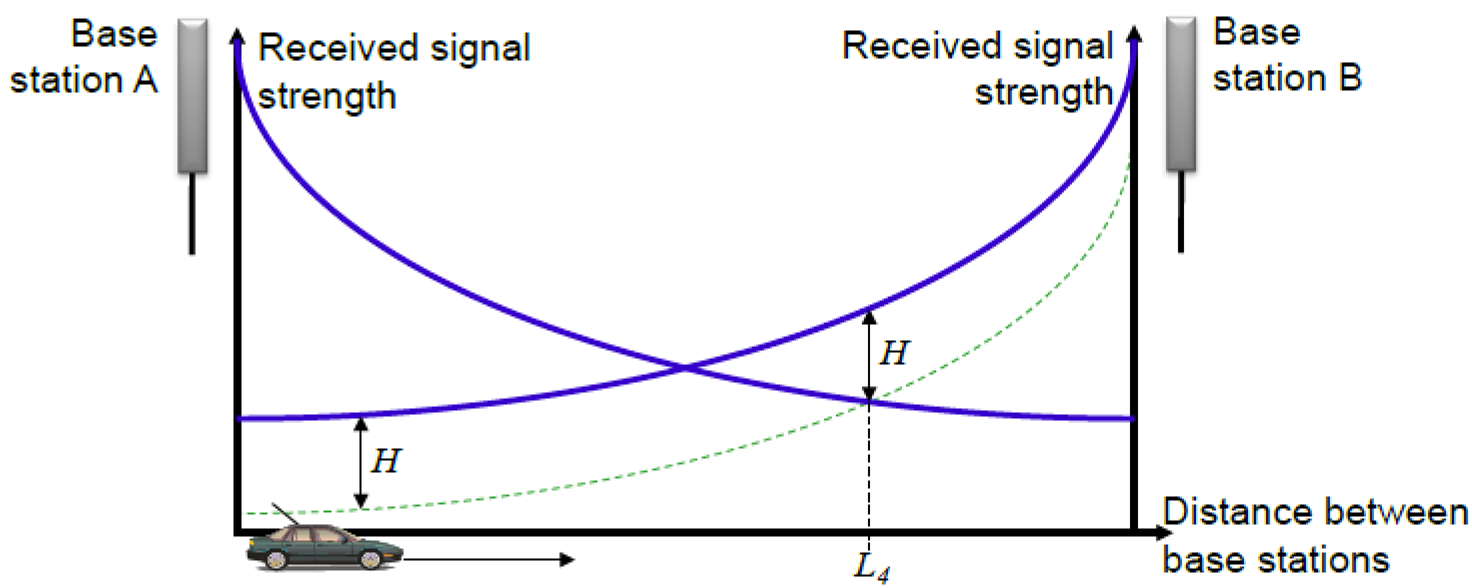
Hand-off Decision: Relative Signal Strength with Thresholds

- HO based on relative signal strength has a major drawback called Ping-Pong effect.
- Ping-Pong effect occurs when
  - UE moves back and forth from the overlapped area of BTSs,
  - Due to the fading effect
- Solution
  - Start HO if the serving cell RSSI falls below a threshold.
- Drawback: very sensitive to the threshold value.



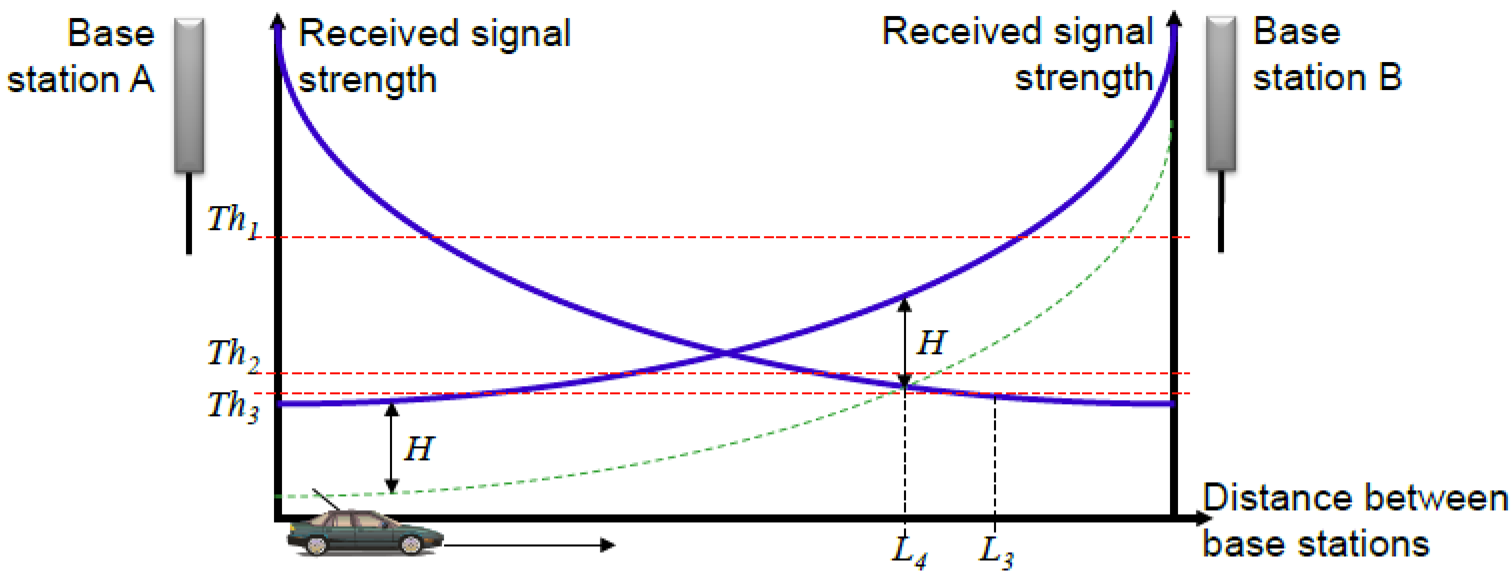
Hand-off Decision: Relative Signal Strength with Hysteresis

- Handover occurs only if the new base station is sufficiently stronger (by a margin H) than the current one.
- Advantages: Solve Ping-Pong effect, easy to adjust H.
- Disadvantage: the handover may still be unnecessary if base station A still has sufficient signal strength.



Hand-off Decision: Relative Signal Strength with Threshold and Hysteresis

- Handover occurs only if
  - the current signal level drops below a threshold
  - the target base station is stronger than the current one by a hysteresis margin H.



Handoff Call Treatment

- Non-prioritized scheme
  - handoff call treated the same as a new call
- Reserved Channel scheme
  - reserve some resources for handoffs
- Queuing Priority scheme
  - Hold the handoff until a resource is available.
- Sub-rating scheme
  - Perform a forced HO for one or more calls to free resources (i.e., code re-assignment).

Pre-emption, Directed Retry, and Queuing

- Pre-emption
  - The BSC looks for a call in the cell with a priority lower than the new TCH request.
  - It moves the lower priority call to another cell or a forced release.
  - The free TCH is then assigned to the new request.
- Directed Retry
  - Directed retry is the transition (handover) from a SDCCH in one cell to a TCH in another cell during call setup because of unavailability of an empty TCH within the first cell.
- Queuing
  - allows the queuing of TCH requests on a per cell and priority basis.

GSM Handover: Measurements

- RXQUAL
  - The received signal quality is defined as a function of the bit error rate (BER) before channel decoding.
  - Are measured on dedicated channels for the **uplink** as well as **downlink** for 100 TDMA frames (0.48 sec).
- RXLEV:
  - The received signal level is measured on the dedicated channel for the uplink as well as for the downlink for 100 TDMA frame.
- RXLEV_NCELL(n):
  - The mobile measures the level received on the BCCH frequency of each neighbor cell n.
- MS_BS_DIST:
  - The distance MS_BS_DIST between the MS and BS is calculated from the timing advance (TA) value measured by the BS and is coded as MS_BS_DIST = 0, 1, ... 35. Distance[Km]

BTS Averaging

- The measured (and reported) data are preprocessed within the BTS using a sliding (gliding) average window.
- The size of the window can be set separately for RXQUAL, RXLEV, DIST.
- Using an averaging window size of 10, short term fading is averaged for pedestrians as well as for "fast" moving MS.

Power Budget

$$\begin{aligned} PBGT(n) = \; & RXLEV\_NCELL(n) - \\ & (RXLEV\_DL + PWR\_C\_D) + \\ & Min(MS\_TXPWR\_MAX, P) - \\ & Min(MS\_TXPWR\_MAX(n), P) \end{aligned}$$

- RXLEV_NCELL(n): averaged value of the measured downlink level of the adjacent cell *n*.
- RXLEV_DL: averaged value of the measured downlink level in the serving cell,
- PWR_C_D: BS_TXPWR_MAX - BS_TXPWR
  - BS_TXPWR_MAX: maximum tx power of BTS
  - BS_TXPWR: current BTS power level
- MS_TXPWR_MAX: maximum allowed transmit power of the MS in the serving cell,
- MS_TXPWR_MAX(n): maximum allowed transmit power of the MS in the adjacent cell n
- P: the maximum power capability of the MS.

Handover Decisions

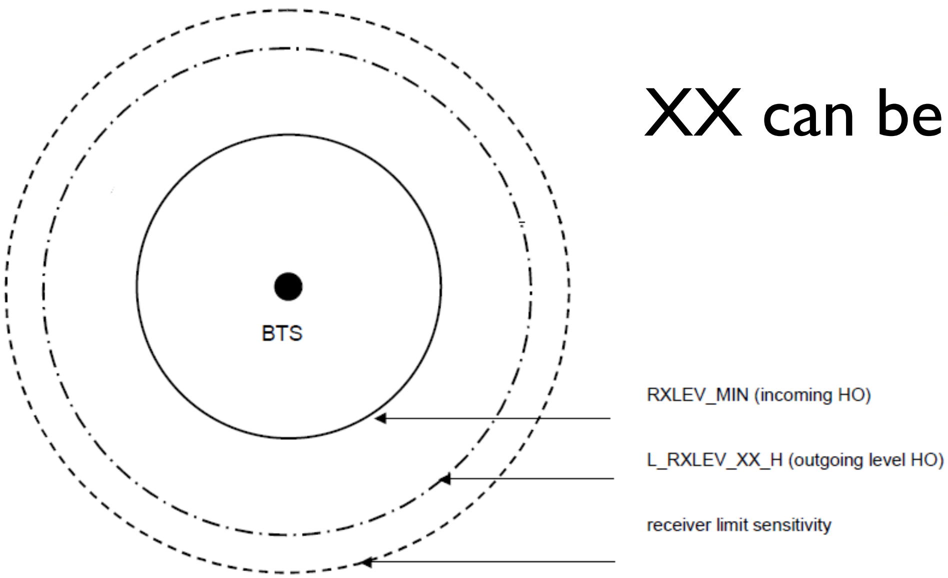
Handover Types	Decision Criteria
HO due to Level	1. RXLEV_DL < L_RXLEV_DL_H 2. RXLEV_NCELL(n) > RXLEV_MIN(n) 3. BTS cannot increase its transmission power.
HO due to Power Budget	1. RXLEV_NCELL(n) > RXLEV_MIN(n)+ max(0, MS_TXPWR_MAX(n) - P) 2. PBGT(n) > HO_MARGIN(n)

- RXLEV_DL: averaged value of the measured downlink level in the serving cell,
- L_RXLVE_DL_H: lowest value for acceptable level,
- RXLEV_NCELL(n): averaged value of the measured downlink level of the adjacent cell *n*.
- RXLEV_MIN(n): the minimum value for the downlink level of the cell *n*.
- HO_MARGIN(n): power budget margin;

Hysteresis

- There should be a hysteresis between the threshold RXLEV_MIN for incoming handover and the corresponding threshold L_RXLEV_XX_H for outgoing handover to avoid a lot of unnecessary forward and backward handover.

RXLEV_MIN - L_RXLEV_XX_H = Level hysteresis



XX can be UL or DL.

Power Budget Hysteresis

- To avoid unnecessary back and forth power budget handovers caused by long term fading fluctuations of the received levels, a hysteresis has to be introduced as

HO_MARGIN(cell1 -> cell2) + HO_MARGIN(cell2 -> cell1) = PBGT hysteresis > 0

PBGT HO Margin Considerations

- PBGT HO margin value should be a compromise between ideal power budget handover (low value) and a low rate of forward and backward handovers (high value).
- Usually, it is chosen symmetrically.
- By choosing unsymmetrical values for the handover margin, one can adapt the cell area to the traffic load, e.g. increasing HO_MARGIN(cell1 -> cell2) while keeping the power budget hysteresis constant (i.e. reducing HO_MARGIN(cell2 -> cell1) by the same amount), increases the effective area of cell 1 while reducing that of cell 2.

PBGT HO Margin Considerations

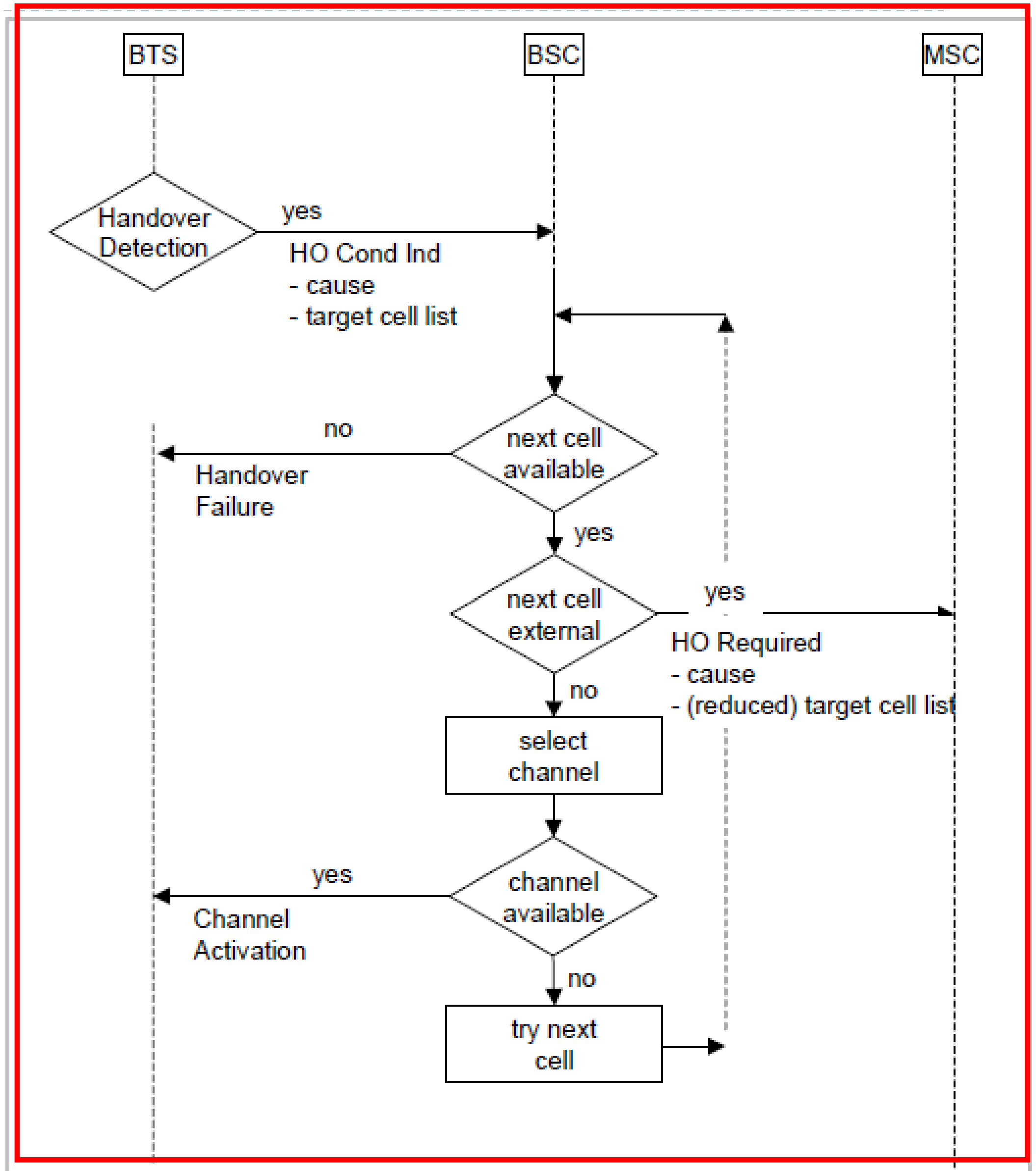
- RXLEV_MIN(n) should be set to a value so that RXLEV_NCELL(n) > RXLEV_MIN(n) for almost all locations where PBGT(n) > HO_MARGIN(n), i.e. a better cell handover is really initiated if the power budget condition is fulfilled.
- This means that there should be an overlap of the outgoing power budget area of one cell and the incoming RXLEV_MIN area of the neighbor cell n.

Order Criterion for HO Candidate Cells

- What if there are more than one qualified target cell?
- The ranking of the target cells is performed on the basis of the power budget minus handover margin values:
  - PRIO_NCELL(n) = PBGT(n) - HO_MARGIN(n)
- The cell with the highest PRIO_NCELL(n) value will be listed first.

Order Criterion for HO Candidate Cells

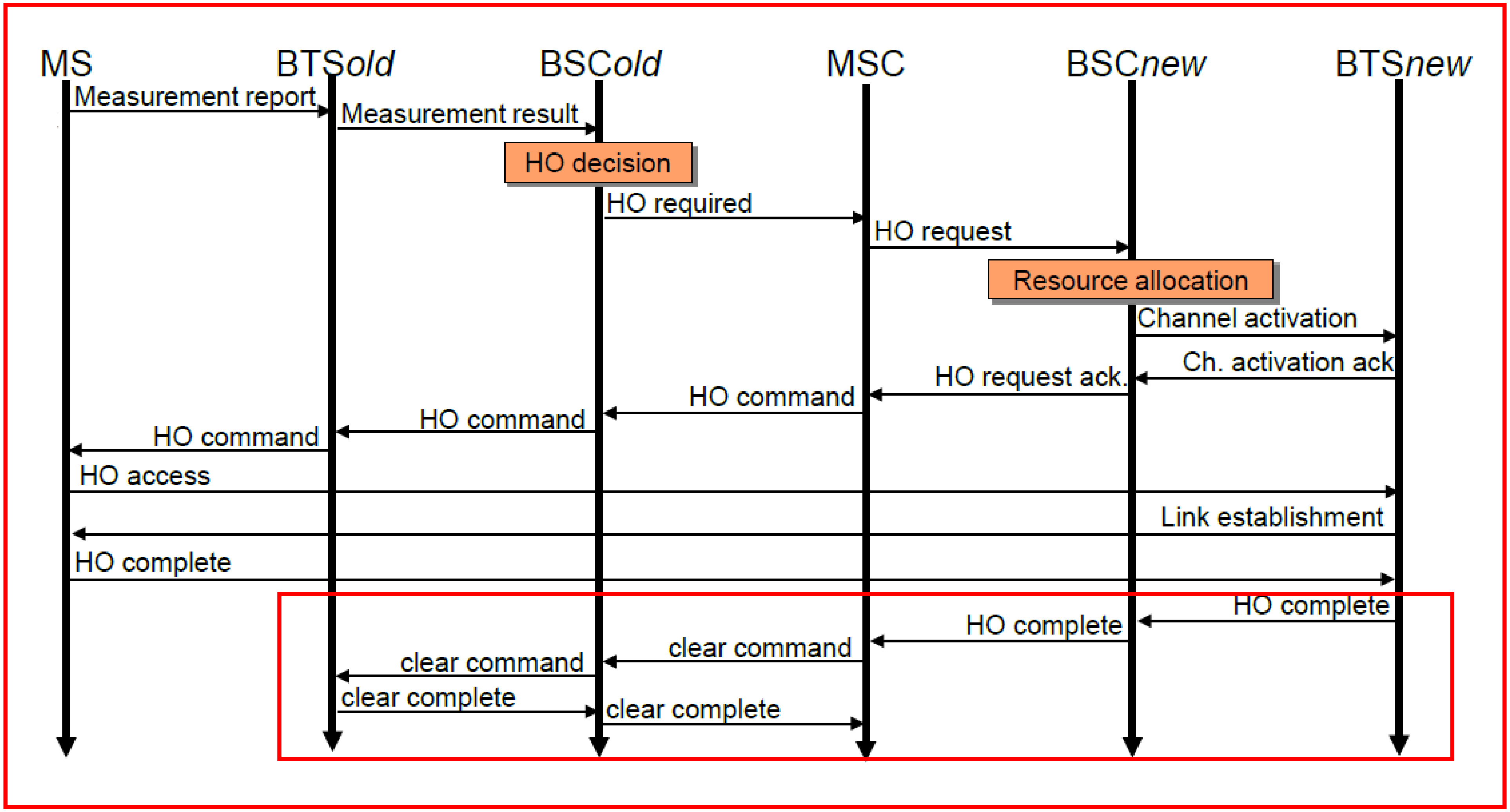
- A HO Condition Indication message containing the HO cause and the target cell list is sent from the BTS to the BSC.
- If the first cell within the target cell list is within its BSS area, the BSC selects a channel at the corresponding BTS.
- If no channel is available at that BTS, the next cell within the target cell is tried.
- If the first target cell does not belong to the own BSS area, a HO Required message is sent to the MSC.
- This message contains a reduced target cell list.



Back-Handovers Problem

- When a forced HO is carried out due to reason other than level/PBGT, there is a chance that an HO is requested by the MS due to level/PBGT.
- Solution:
  - Set a timer and do not allow such pull back for a certain time.
  - The BTS shall not trigger a HO due to PBGT for a certain time if the PBGT condition is fulfilled for the indicated cell unless it is necessary.
  - This timer range is 1,…, 350 with unit 10 sec.
  - Default is 120 sec.
  - This timer is called dwell timer.

Principal Signaling Sequence for an Inter-BSC/Intra-MSC Handover



Measurement Reporting in UMTS

- UE measurement Criteria

Measurement	Description
Intra-frequency	Measurements on downlink physical channels in cells at the same frequency as the active set
Inter-frequency	Measurements on downlink physical channels in cells at frequencies that differ from the frequency of the active set
Inter-RAT	Measurements on downlink physical channels in cells belonging to another radio access technology (RAT) than UTRAN, e.g. GSM
Traffic volume	Measurements of uplink traffic volume
Quality	Measurements of downlink quality parameters of a channel, e.g. downlink transport block error rate
UE-internal	Measurements of UE transmission power and UE received signal level

Measurement Reporting in UMTS

- Cell sets

Cell set	Description
Active set	Current set of cells in which the UE has an active connection and is sending and receiving information (i.e. >1 for soft handover)
Monitored set	A set of cells, not in the active set, that the UE has been instructed by the RNC to monitor as possible handover candidates
Detected set	All other cells that the UE has detected. Reporting of measurements only occurs for intra-frequency measurements.

- Measurement Control

Measurement	Description	Example
Command	Setup, modify or release a measurement	Release
Type	Description of what type of measurement the UE should make	Intra-frequency
Object	Description of what the UE should measure	Cell
Quantity	The quantity the UE should measure	CPICH Ec/N0
Reporting criteria	Indication of when the UE should report the measurement	500 ms

HO Related Broadcast Information

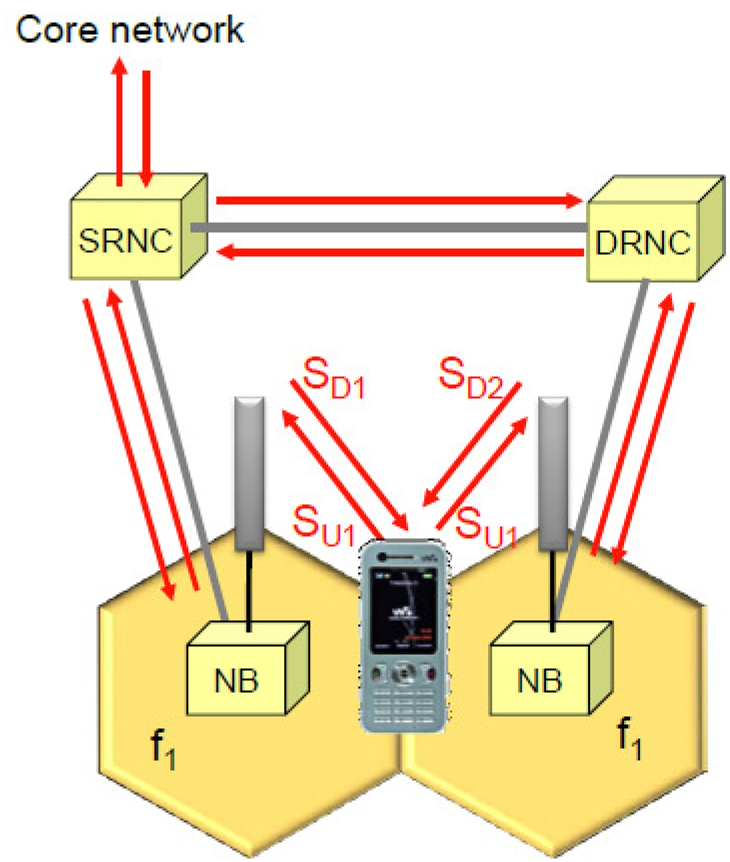
Table 6.27 SIB3 parameters

Parameter	Description
$S_{intrasearch}$	Threshold (in dB) for intra-frequency measurements and for the HCS measurement rules
$S_{intersearch}$	Threshold (in dB) for inter-frequency measurements and for the HCS measurement rules
$S_{searchHCS}$	This threshold is used in the measurement rules for cell reselection when HCS is used. It specifies the limit for cell selection receive level (Srxlev) in the serving cell below which the UE shall initiate measurements of all neighbouring cells of the serving cell
Qqualmin	Minimum required quality level in the cell in dB
Qrxlevmin	Minimum required RX level in the cell in dBm.
$Qhyst1_s$	Hysteresis value (Qhyst). It is used for cells if the quality measure for cell selection and reselection is set to CPICH RSCP
$Qhyst2_s$	Hysteresis value (Qhyst). It is used for cells if the quality measure for cell selection and reselection is set to CPICH Ec/No
$Treselection_s$	Cell reselection timer value
HCS_PRIO	HCS priority level (0–7) for serving cell and neighbouring cells
Qhcs	Quality threshold levels for applying prioritized hierarchical cell reselection
T_{CRmax}	Duration for evaluating allowed amount of cell reselection(s)
N_{CR}	Maximum number of cell reselections. Default 8
$T_{CRmaxHyst}$	Additional time period before the UE can revert to low-mobility measurements

HCS, Hierarchical cell structure: this is where there is an overlay of macro, micro and pico cells.

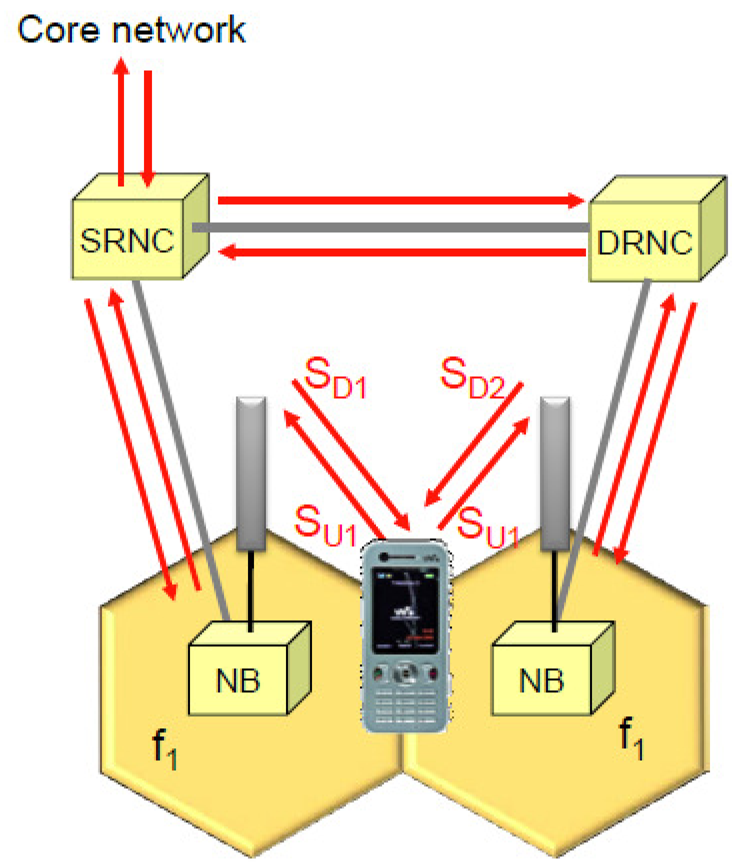
Inter-RNC Soft Handover in UMTS

- Soft handover enables simultaneous connection of the terminal to several Node-Bs.
- List of Node-Bs connected to the terminal is called the Active Set.
- Uplink: signal spread with the scrambling code S_{UI} is received by different neighboring Node-Bs.
- Downlink: Node-Bs participating in soft handover send the same user data to the terminal, but spread with different scrambling codes (here: S_{DI} and S_{D2}).



Inter-RNC Soft Handover in UMTS

- Serving Radio Network Controller (SRNC): initial RNC that controls the soft handover and decides which signal to forward into the core network
- Drift Radio Network Controller (DRNC): RNC belonging to the new cell that forwards user data to the SRNC



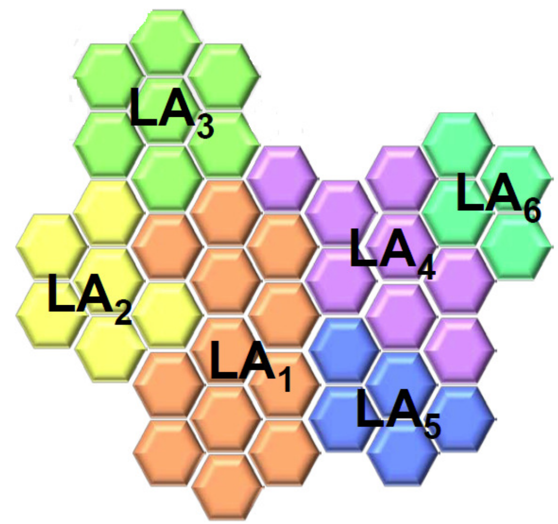
Mobility Management

Mobility Management

- To make and receive calls, the location of the mobile device has to be known by the network.
- It would be extremely inefficient if a user needed to be paged across an entire network.
- Mobility management is the mechanism that the network uses for keeping a dynamic record of the location of all of the mobile devices currently active in the network.
- Location Update (LU): it is a message that the user sends to the core whenever it changes its location in the network.

Mobility Management: Location area

- Several cells are combined to a location area (LA).
- Subscriber location is known if the system knows the LA in which the subscriber is located.
- When the system must establish a communication with the mobile, the paging only occurs in the current LA where called user resides.
- Resource consumption is limited to the respective LA: paging messages are only transmitted in the cells of this particular LA



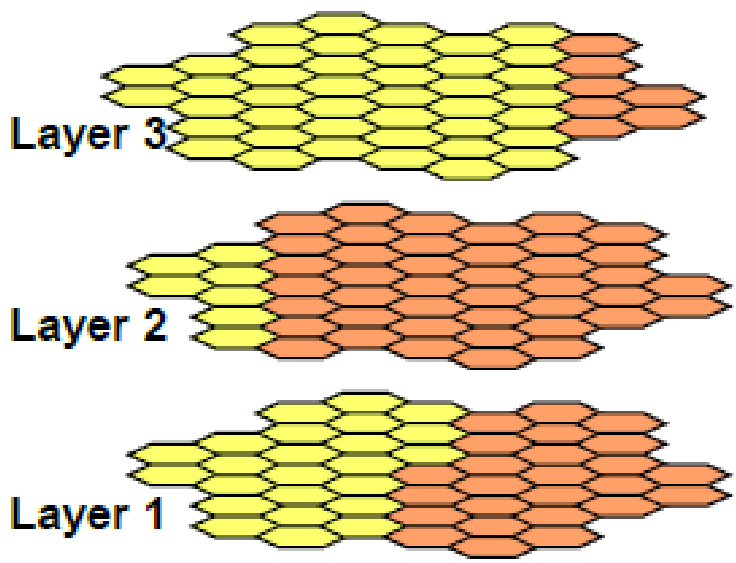
- Goal: minimizing location management cost
  - Lower LA size ⟶ Higher # of LU
  - Higher LA size ⟶ Higher # of pagings

Location Management: Location Update Strategies

- Location Updating on LA Crossing
  - BS periodically broadcasts the identity of its LA (Location Area Identifier, LAI).
  - Mobile permanently listens to the broadcast and stores the current LAI.
  - If the received LAI differs from the stored one, a location update is triggered by the mobile.
  - Advantage:
    - a highly mobile user generates a lot of LUs;
    - a low mobility user only triggers a few
- Periodic Location Updating
  - Mobile periodically transmits its identity to the network.
- Hybrid LU
  - Combination of LA crossing and periodic LU.

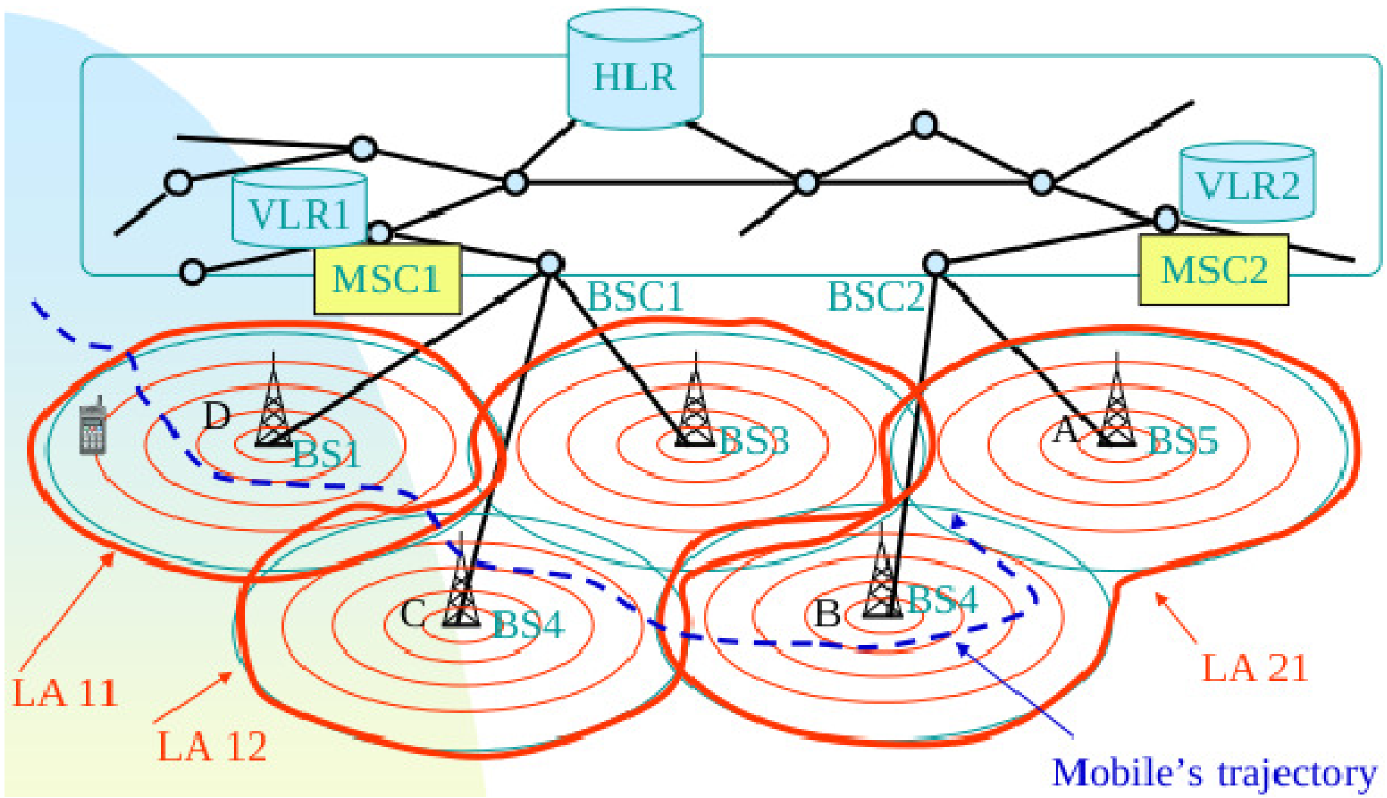
Location Management: Multi-Layer LAs

- Problem: LU traffic is mainly concentrated in the cells of the LA border.
- Each mobile is assigned to a given group.
- Each group is assigned one or several layers of LAs
- LU traffic load is distributed over all the cells



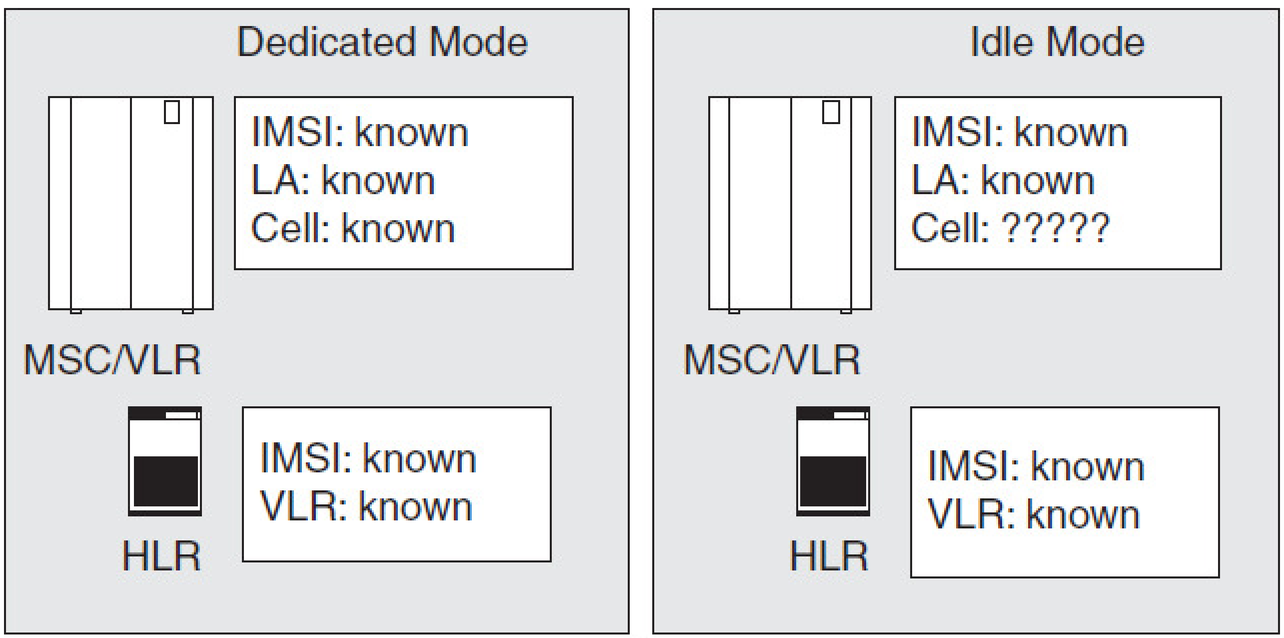
Location Management: Registers

- The HLR, which is in the home network, knows which VLR has information regarding the particular subscriber.



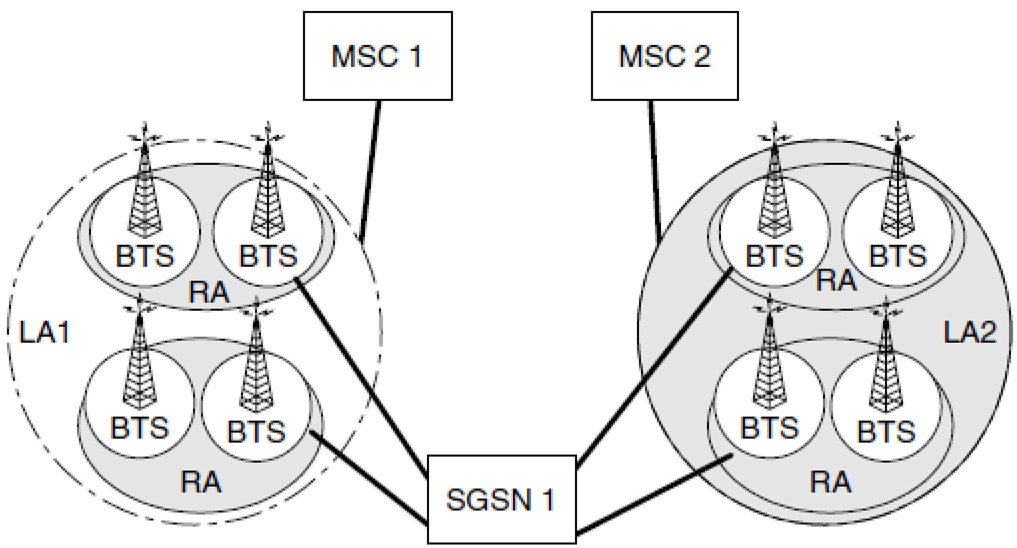
Location Management: Registers

- The information the VLR holds depends on the connection state of the mobile device
  - In idle mode, only the location area (LA) is known whereas
  - in dedicated mode the actual cell is known.



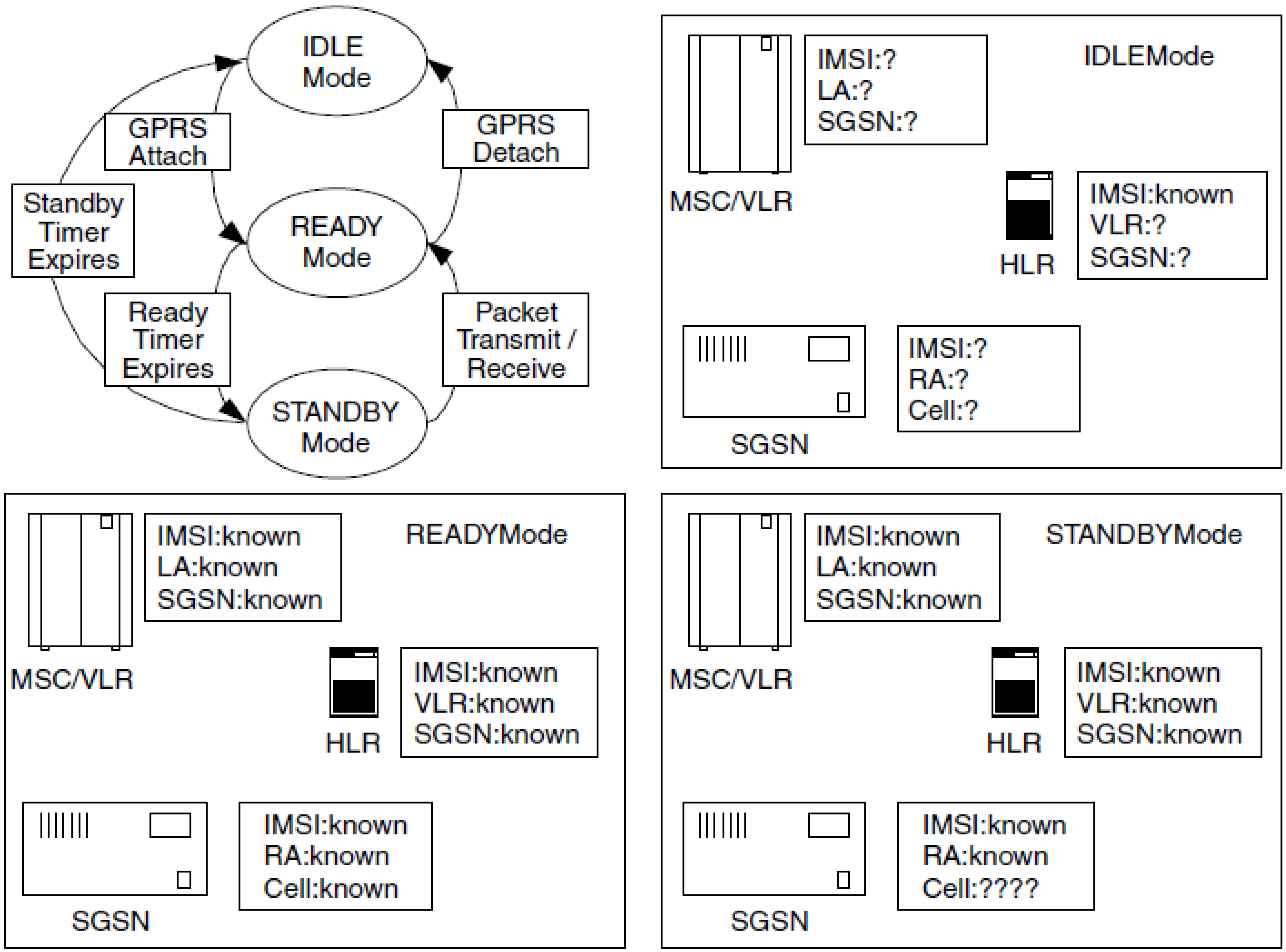
Location Management: Routing Areas

- In GPRS, we have routing areas instead of location areas.
- Why:
  - Paging of the terminal for every downlink packet (or at least for every data burst) in all cells of the user's location area is inefficient.
- Routing areas are significantly smaller than location areas



Location Management: Routing Areas

- RA is known by the SGSN rather than VLR.



RAT Selection and Re-selection

References

- S. Sesia, I. Toufik, and M. Baker, "LTE: The UMTS Long Term Evolution," 2nd Edition, John Wiley & Sons Ltd, 2011.

PLMN Selection

- Whenever a UE is switched on or re-registers after leaving connected mode, it attempts to camp on the last registered PLMN.
- If there is no registered PLMN stored in the USIM, the UE selects and attempts registration on other PLMNs using either the automatic mode or the manual mode.
- The UE scans all RF channels according to its capabilities to find available PLMNs.
- On each carrier, the UE shall search for the strongest cell and read its system information.
- The allowed PLMN information in USIM determines which PLMN will be selected finally.
- After successful registration, the selected PLMN becomes the Registered PLMN (R-PLMN).

Cell Selection

- After a UE has selected a PLMN, it performs cell selection (it searches for a suitable cell on which to camp).
- Subsequently, the UE registers its presence in the tracking area, after which it can receive paging information.
- This is performed at RRS_idle state.
- When camped on a cell, the UE regularly verifies if there is a better cell; this is known as performing cell reselection.

Cell Selection

- The simplest way from a network and signaling point of view to balance traffic is cell selection/ reselection in RRC Idle state.
- For this purpose, the eNode-Bs broadcasts information on neighboring LTE cells or RATs (GSM, UMTS and CDMA) in their system information messages.

Cell Selection

- Cell selection consists of the UE searching for the strongest cell on all supported carrier frequencies of each supported RAT until it finds a suitable cell.
- Upon leaving connected mode, the UE should normally attempt to select the cell to which it was connected.
- The connection release message may include information directing the UE to search for a cell on a particular frequency.
- When performing 'any cell selection', the UE tries to find an acceptable cell of any PLMN by searching all supported frequencies on all supported RATs.
- The UE may stop searching upon finding a cell that meets the 'level/quality' criterion applicable for that RAT.

Cell Selection

- Cell selection criterion or "S-Criterion":

  Srxlev = Qrxlevmeas - (Qrxlevmin - Qrxlevminoffset)

  - Qrxlevmeas is the measured cell receive level value,
  - Qrxlevmin is the minimum required receive level in the cell.
  - Qrxlevminoffset is the offset which may be configured to prevent ping-pong between PLMNs.
- A cells is selected if Srxlev>0.
- The cell selection related parameters are broadcast within the SIB2 message every 320 ms.

Cell Re-Selection

- After cell-selection, the UE keeps updating its selection called cell re-selection.
- The UE has a list of RATs to be connected with their corresponding priorities announced by selected eNB.
- Measurements rules:
  - Intra-frequency: The UE is required to perform intra-frequency measurements only when the quality of the serving cell is below or equal to a threshold announced by UE (SintraSearch).
  - Inter-frequencies/RATs: The UE is required to measure other frequencies/RATs of lower or equal priority only when the quality of the serving cell is below or equal to another threshold announced by UE (SnonintraSearch).
  - High priority rule: The UE is always required to measure frequencies and RATs of higher priority.

Re-Selection Evaluation

- RAT reselection is priority based.
- E-UTRAN configures an absolute priority for all applicable frequencies of each RAT.
- The UE reselects a cell on a higher priority frequency if the S-criterion of the target cell exceeds a high threshold ($T_{\text{hreshX-High}}$) for longer than a certain duration $T_{\text{reselection}}$.
- The UE reselects a cell on a lower-priority (another RAT) if the S-criterion of the serving cell is below a low threshold ($T_{\text{hreshServing-Low}}$) while the Scriterion of the target cell exceeds a threshold ($T_{\text{hreshX-Low}}$) during the time interval $T_{\text{reselection}}$.
- Thresholds and priorities are configured per frequency, while *T*reselection is configured per RAT.

Cell Ranking

- For similar priority cells (usually same RAT), if there are more than one option, the UE selects the cells which has the highest R_n-R_s

  For neighbour cell n: $R_n = Q_{rxlevmeas,n} + Q_{offes,n}$

  For serving cell s: $R_s = Q_{rxlevmeas,s} + Q_{hyst,s}$

- $Q_{offes,n}$: is an offset applicable between serving and neighbouring cells on frequencies of equal priority (the sum of the cell-specific and frequency-specific offsets).
- $Q_{hyst,s}$: is a parameter controlling the degree of hysteresis for the ranking.
- These are broadcast by BTS.

Speed Dependent Scaling

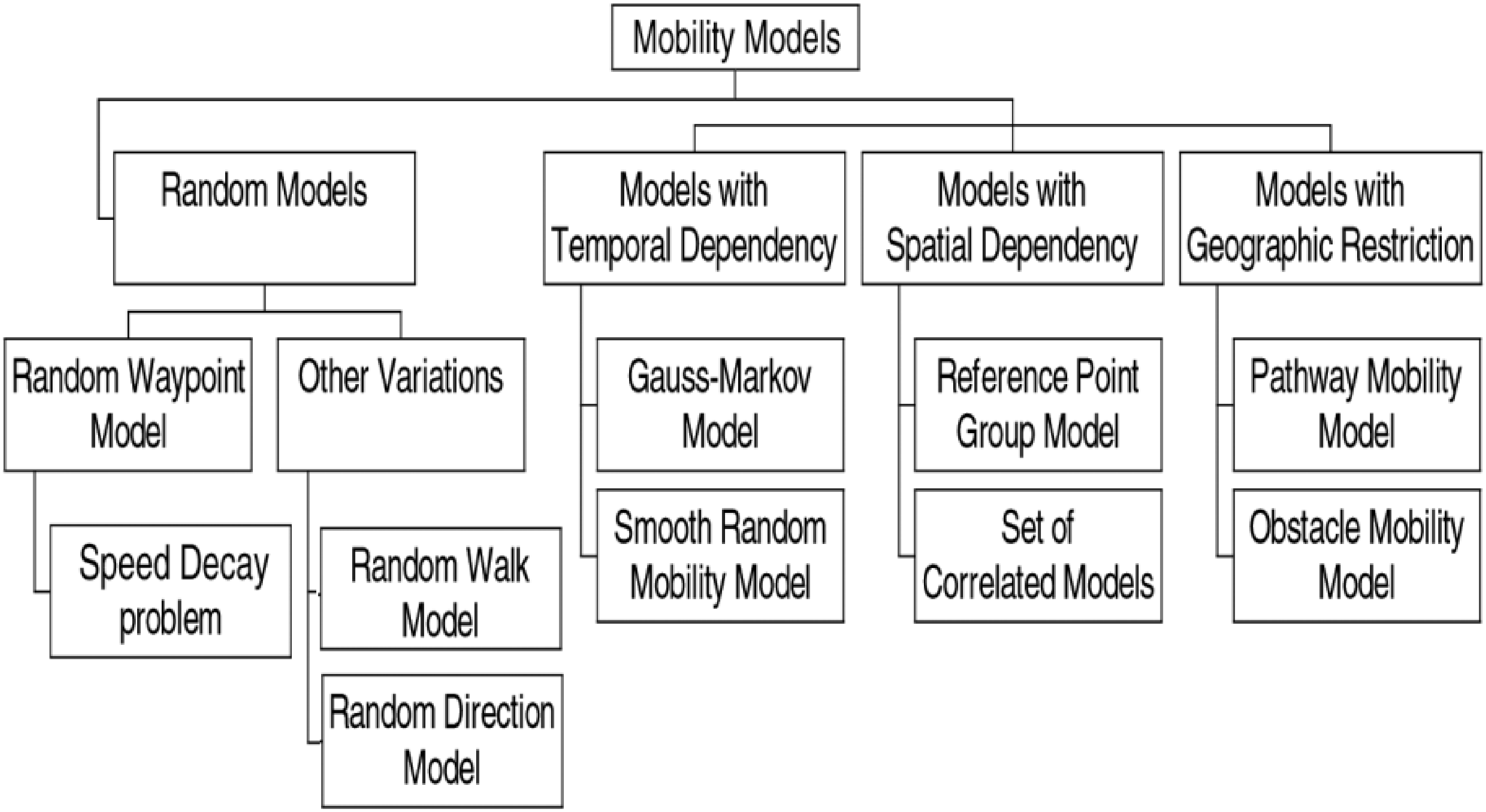
- The UE scales the cell reselection parameters depending on its speed.
- The UE speed is categorized by a mobility state (high, normal or low).
- UE determines it based on the number of cell reselections which occur within a defined period, excluding consecutive reselections between the same two cells.

Mobility Models

Mobility Models

- Due to mobility of MSs, for performance analysis of cellular networks, one need to know:
  - Current location of a MS,
  - How long the MS stays in the current cell
  - The destination cell of the MS
- Tool: mobility models
- Goal: model the location of MS as a function of time.
- In ad hoc networks, mobility models help to find the network's connectivity graph at each time.

Mobility Models in Wireless Networks



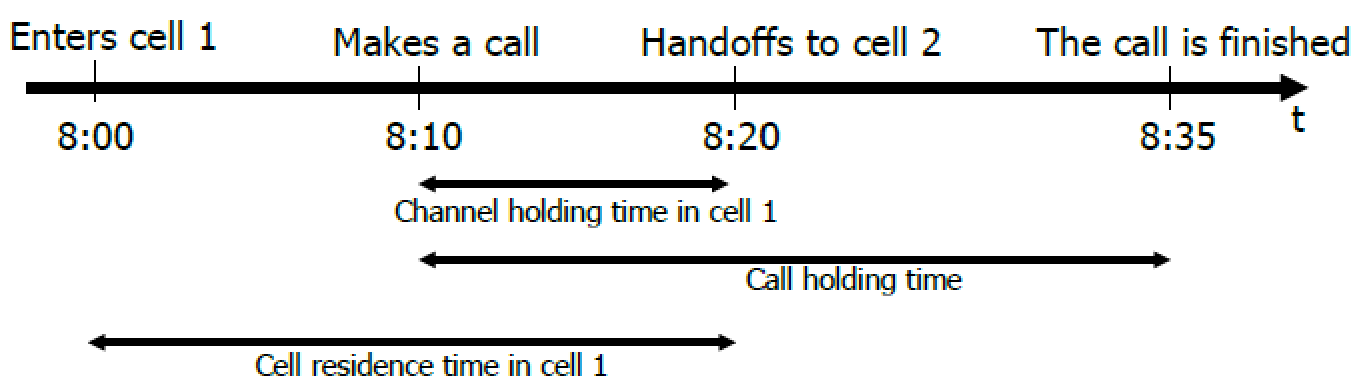
- Fan Bai and Ahmed Helmy, A SURVEY OF MOBILITY MODELS, http://www.cise.ufl.edu/~helmy/papers/Survey-Mobility-Chapter-1.pdf

Mobility Model: Terms

- Cell residence/dwell time:
  - The amount of time a user stays in a cell
- Channel holding time:
  - The amount of time a new or hand off call holds the channel in a cell.
- Call holding time:
  - Amount of time a call is active
- Residual call holding time
  - The amount of remaining time of a call after a handover
- Handover occurs if

Residual Call holding time > Cell residence time

Call holding time > Residual Cell residence time



Mobility Model: Dwell Time

- Cell residence time depends on
  - the mobility pattern,
  - cell shapes
  - Handoff scheme
- Cell residence time typically has a general distribution.
- Assume the call holding time is exponentially distributed.
- If the cell residence time is exponentially distributed, the channel holding times are exponentially distributed as well.
- Not a good model in practice. It usually gives a lower bound for the blocking probability.
- However, this is the only model which results a in tractable analysis!

General Cell Dwell Time

- Notations:
  - t_c : call holding time
  - t_m : cell residence time
  - r_m : residual call holding time
  - t_{ho} : channel occupancy time for a handoff call
  - $f_c(t)$: PDF of t_c
  - $f(t)$: PDF of t_m
  - $f_{ho}(t)$: PDF of t_{ho}

$$t_{ho} = \min(r_m, t_m)$$

$$\begin{aligned}
\Pr(t_{ho} \le t) &= \Pr(r_m \le t \text{ or } t_m \le t) \\
&= \Pr(r_m \le t) + \Pr(t_m \le t) - \Pr(r_m \le t \,\&\, t_m \le t) = \\
&= \Pr(r_m \le t) + \Pr(t_m \le t) - \Pr(r_m \le t)\Pr(t_m \le t) \\
&= \Pr(t_c \le t) + \Pr(t_m \le t) - \Pr(t_c \le t)\Pr(t_m \le t)
\end{aligned}$$

Y. Fang, Im. Chlamtac, Y.-B Lin, Channel Occupancy Times and Handoff Rate for Mobile Computing and PCS Networks, *IEEE Transactions on Computers*, vol. 47, no. 6, June 1998.

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$$f_{ho}(t) = f_c(t) + f(t) - f_c(t)\,\mathrm{Pr}(t_m \le t) - f(t)\,\mathrm{Pr}(t_c \le t)$$

$$= \mu e^{-\mu t} \int_t^{+\infty} f(\tau) d\tau + e^{-\mu t} f(t).$$

If $f(t) = \eta e^{-\eta t}$, then $f_{ho}(t) = (\mu + \eta) e^{-(\mu+\eta)t}$

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  - $f_{ho}(t)$: PDF of t_{ho}

$$f_{ho}(t) = \mu e^{-\mu t} \int_t^{+\infty} f(\tau) d\tau + e^{-\mu t} f(t).$$

$$\phi_{ho}(s) = \frac{\mu}{\mu - s} - \frac{s}{\mu - s} \phi(\mu - s)$$

$$E[t_{ho}] = \frac{1}{\mu}(1 - \phi(\mu))$$

Some Cell Residence Time Models

- SOHYP (Sum of Hyper-exponentials) model
  - Can be used to approximate the behavior of any positive random variable

$$f(x) = \sum_{i=1}^{N} \sum_{j=1}^{M} \alpha(i,j) u(i,j) e^{u(i,j)x}$$

- Hyper-Erlang model
  - Can be used to approximate the behavior of any positive random variable

$$f(x) = \sum_{i=1}^{M} \alpha_i \frac{(m_i \eta_i)^{m_i} x^{m_i - 1}}{(m_i - 1)!} e^{-m_i \eta_i t}$$

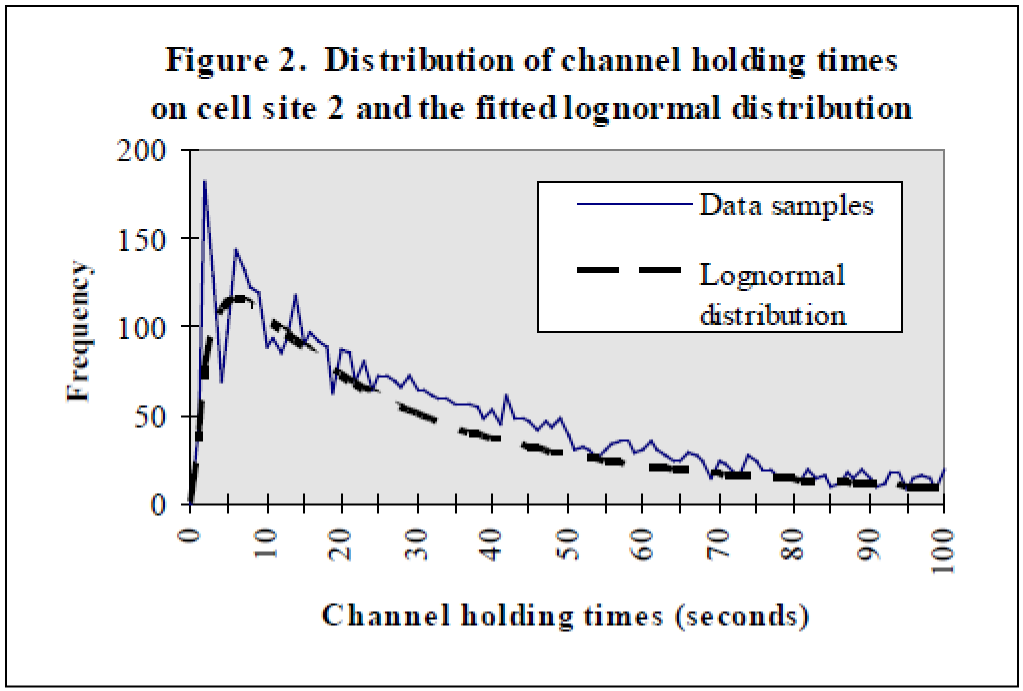
Good Review Reference

- M. Ghaderi and R. Boutaba, "Call Admission Control in Mobile Cellular Networks: A Comprehensive Survey," IEEE Transactions on Mobile Computing, Vol. 5, No. 3, March 2006.

Actual Holding Time

- Using empirical results, it is shown in [VTC96] that the channel holding times have long normal distribution with parameter depending on the cell size.

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\ln x - m)^2}{2\sigma^2}}$$



- [VTC96]C. Jedrzycki and V. C. M. Leung, "Probability distribution of channel holding time in cellular telephone systems," *in Proc. IEEE VTC*, Atlanta, GA, May 1996.

Random Way Point Mobility Model

- Consider a convex set A.
- In the RWP, a node moves in A along a straight line segment from one waypoint to another waypoint at a fixed speed.
- The waypoints are uniformly distributed in A.
- The transition velocity between two waypoints P_{i-1} and P_i is a random variable v_i.
- The node pauses at location P_i for T_i seconds which is a random time.

Random Way Point Mobility Model

- It is shown in [RWP] that in general case, the pdf of the location can be found as follows.
- Let $a_1(\mathbf{r}, \phi)$ and $a_2(\mathbf{r}, \phi)$ denote the distance from point r to the boarder of A in directions ϕ and $\phi + \pi$.
- Define function h as $$h(\mathbf{r}, \phi) = \frac{1}{2} \cdot a_1 a_2 (a_1 + a_2).$$
- The pdf for location **r** is $$f(\mathbf{r}) = \frac{1}{C} \int_0^{2\pi} h(\mathbf{r}, \phi)\, d\phi,$$
  - where *C* is a constant.
- The mean travel time can be obtained as $$\bar{\ell} = \frac{1}{A^2} \int_A \int_0^{2\pi} h(\mathbf{r}, \phi)\, d\phi\, dA.$$

- [RWP] E. Hyytia and J. Virtamo, "Spatial Node Distribution of the Random Waypoint Mobility Model with Applications," IEEE Transactions on Mobile Computing, vol. 5, issue 6, june 2006.
- [RWP1] E. Hyytia and J. Virtamo, Random Waypoint Mobility Model in Cellular Networks, Journal of Wireless Networks, vol. 13 issue 2, April 2007.

Random Way Point Mobility Model

- For a circle region with radius 1, we have

$$f(r) = \frac{45(1-r^2)}{64\,\pi} \int_0^{\pi} \sqrt{1 - r^2 \cos^2 \phi}\, d\phi,$$

- If T_i denotes the transition time on leg *i*, we have $T_i = \frac{l_i}{v_i}$ and $E[T_i] = \bar{l}\, E[1/v]$.
- In general, it is not easy to analytically find the handoff rate using these equations.