Mobility Management

- Roaming support, handoff connection for continuity
- frequency of cell crossing increases with the speed of the user
- new location of the mobile station must be known
- backbone network, wired and wireless links need routers
- base station as a hub, also known as access point
- MSC - controller to handle the handoff functions and wired with other MSCs
- MSC responsible for collecting and accumulating information all cells in the cluster
- handoff management - connection transferred to one BS to another BS

- user subscribe to a regional subnetwork (home network)
- subscriber's identity (permanent address) resides in subscriber's home location register (HLR)
- in foreign network, it must update its registration with the HLR through its VLR to facilitate message delivery to its new location
- procedure of maintaining an association between the mobile and its HLR when it is away from its home network is referred to as location management
- Capacity of base station is number of basic channels; capable of handling the information transmission in one connection (N_c)
- total capacity is used to handle ongoing connections and to admit new and handoff requests
- call admission control (CAC) - oversees the admission of new and handoff calls to protect the integrity of the network and satisfy user QoS requirements

- QoS - packet level factor - packet loss rate, packet delay, packet delay variation, and throughput rate
- GoS - call level factor - new call blocking probability (NCBP) , handoff call dropping probability (HCDP) and connection forced termination probability (CFTP)
- CAC ensures network integrity by restricting access to the network so as to avoid overload and congestion and to ensure QoS
- new request - new call or handoff call - admitted or denied depending upon resources available with QoS
- CAC algorithm needs to determine the amount of unallocated capacity - number of basic channels available for accepting new and handoff requests
- handoff call request is given preference to new call requests

- handoff requests should be offered a higher admission priority than new requests
- P_n new call blocking probability and P_h handoff call dropping probability

$$\text{GoS} \quad = P_n + \alpha P_h$$

- $\alpha > 1$ balancing factor between new call and handoff call
- to manage the admission of requests based on priority reserve capacity for admitting handoff requests
- N_g number of basic channels reserved for admitting handoff requests - common technique is guard channel method
- N_{ua} number of unallocated channels

- with guard channel method, the admission rule
  - if $N_{ua} > N_g$ admit a new or handoff request
  - if $N_{ua} < N_g$ admit a handoff request only
- fixed reservation or dynamic reservation for guard channel method
- if MSC knows exactly the number (rate) of handoff requests during any epoch, it can determine N_g exactly
- handoff procedure - initiation phase and execution phase
- initiation phase - decision making based on received signal level with or without hysteresis
  - without hysteresis: handoff initiated *as soon as* average signal level from new BS exceeds that from the current BS
  - with hysteresis: *hysteresis level (threshold) specified*
- execution phase - channel assignment and the exchange of control messages

- MSC obtains status information for all the base stations - channel occupancy
- MSC handles handoff initiation and execution phases
- intraswitch and interswitch handoff
  - first one - no need to copy connection identification states
  - later needs to transfer state information
- depending on the information used and the action taken to initiate the handoff
  - mobile controlled handoff (MCHO)
  - network controlled handoff (NCHO)
  - mobile assisted handoff (MAHO)

- MCHO - reduces burden on network but increases complexity of MS
- NCHO - APs monitor the signal quality from MS and report to MSC; MSC responsible for handoff and MS is passive
- MAHO - variant of NCHO and employed by GSM;
  - MS measures the signal levels from various APs using a periodic beacon generated by the APs (to keep track of the locations of the mobiles)
  - MS feeds the power levels from different APs back to MSC via AP
- Hard handoff - break before make - one radio link with only one AP
- Soft handoff - make before break e.g. CDMA
- Backward handoff - handoff is predicted ahead of time and initiated via the existing radio link
- Forward handoff - handoff is initiated via the new radio link associated with the candidate AP

- Issues
  - during transition time some packets leftover with old serving AP
  - order of packets delivered should be preserved
- handoff: fast and lossless, minimal number of control signal exchanges, scalable with network size, capable of recovering from link failures
- low handoff delay, low cell loss, small buffer required and efficient use of resources
- Feedback based MAHO
  - on the downlink from BS to MS, APs broadcast pilot (beacon) signals to the mobile
  - the MS sends the strengths of beacon received from APs to MSC via serving AP; creates a profile of signal strengths and sends the profile
  - AP computes and sends the distance information to MSC (direction of movement can be known)

- feedback profiles is overhead on system; small profiles desirable
- MS receives equal signal strengths from at most three APs - highest signal strength being sufficient for decision making
- MS is located in the middle of the boundary between two cells
- three scenarios
  - three APs are located in the same cluster
  - three APs are divided between two clusters
  - three APs are divided among three clusters
- necessary to identify a single cluster or at most three adjacent clusters uniquely to the current serving MSC
- each MSC (or cluster) has six adjacent MSCs

- 3-bit AP/MSC identification - 3-bit codeword uniquely identify a superclus-ter of 7 MSCs
- MSC maintains a list of all adjacent MSCs
- identification process can continue until all the tiers are exhausted
- in order to have equal size identities, if MSCs in tier L (the highest tier) have a K bit identity (3 of the K bits identifying the MSCs and the other $(K-3)$ bits for tier identification)
- with 7 APs per MSC, and additional 3 bits are needed for AP identification so $(K+3)$ bits required for identification in the profile
- profile has to carry three power fields (signal strength)

- λ_d and λ_p - data generation rate and profile generation rate
- MS transceiver compares data rate λ_d with the profile rate λ_p
- if $\lambda_d > \lambda_p$ the profile is queued in the profile buffer
- on next data packet, the profile is dequeued and piggy-backed - only one profile in the queue at any time
- if $\lambda_d < \lambda_p$ the profile is transmitted separately if there is no overlap
- degradation if the data rate is small
- performance measure: buffer requirement, mean handoff delay, feedback interval and system resource utilization

Mobility Model

- critical to design of handoff algorithm
- mobility pattern defined by the speed and the direction of movement
- monitor and measure or model based on assumed statistics
- two variable: speed of travel and change in direction of movement relative to the MS' current direction of movement
- most important is the expected time interval between the time a mobile initiates a call in a cell and the time mobile reaches the cell boundary referred as sojourn time t_s
- X random variable - the distance traveled by the MS before reaching the cell boundary and Y random variable - the velocity of MS
- X is uniformly distributed between 0 and D_{max} and Y is uniformly distributed between V_{min} and Y_{max}

$$t_s = X/Y$$

- pdf of sojourn time t_s

$$f_{t_s}(t) = \frac{(\alpha+\beta)}{2}[u(t)-u(t-\beta)] + \left[\frac{\alpha\beta}{2t^2(\alpha-\beta)} - \frac{\beta}{2\alpha(\alpha-\beta)}\right] \times[u(t-\beta)-u(t-\alpha)]$$

$$E[t_s] = \frac{\alpha\beta}{2(\alpha-\beta)} \ln\left(\frac{\alpha}{\beta}\right)$$

$$\lim_{\frac{\alpha}{\beta}\to 1} E[t_s] = \alpha/2 \quad \text{and} \quad \lim_{\frac{\alpha}{\beta}\to \infty} E[t_s] = \beta/2$$

$$\beta = \frac{D_{max}}{V_{max}} \quad \alpha = \frac{D_{max}}{V_{min}} \quad \frac{\beta}{\alpha} = \frac{V_{min}}{V_{max}}$$

- performance depends on the frequency with which the MS feeds information back to MSC
- too frequently feedback reduces efficiency and too infrequently degrades effectiveness
- I_f average feedback interval and $r_p = 1/I_f$ rate of transmitting profiles
- N_p mean number of profiles sent by the MS before the MS moves to the cell boundary $\approx E[t_s] \times r_p$

Intraswitch Handoff: Example

- MSC send message NEW-AP-READY to mobile via AP-0: indicates that the candidate AP-1 is ready
- AP-0 responds with the message LAST-PKT which contains the sequence number of the packet sent (or waiting to be sent) to the mobile prior to receiving (1) message; MSC calculates the sequence number of the last downlink packet transmitted to AP-0 by MSC and MSC sends the next number of the sequence number of the following downlink packet to AP-1 using message SEQ-PKT
- HO-MUST indicates the last downlink packet from the MSC to AP-0 and also indicates the end of uplink packets from the mobile; AP-0 sends all uplink packets to the MSC and flags the termination of the connection by sending the message UP-NO-MORE to MSC

- the mobile switches its operating frequency and sends the message READY to AP-1 and continues uplink transmission via the new connection; it contains the sequence number of the last packet correctly received by the mobile
- AP-1 starts the downlink transmission and buffers all uplink packets arriving from the mobile. It sends the message LAST-UP to MSC requesting for the approval of uplink transmission
- MSC waits for the message NO-MORE from AP-0 and then MSC switches the uplink connection from AP-0 to AP-1 and sends message UP-READY to indicate that the uplink flow can resume

Location Management

- registration process: association between the mobile and its home network
- database of a location register: identity of the mobile
- update registration with HLR when the mobile moves to foreign or visitor network through VLR
- HLR performs authentication process using cryptographic messages
- footprint covered by all the cells in a subnet of the cellular network constitutes a registration area (RA)
- no need to update registration with its HLR when moving within a RA, update registration only when it moves into a new RA
- signal flows for location update and call delivery are supported by a specific network architecture and control signals are supported by a specific control signaling network

Two-Tiered Architecture of IS-41

- second generation IS-41 and Mobile Applications Part (MAP) of GSM
- maintain a database in the HLR and the VLR
- cluster of cells connected to an MSC is RA
- a VLR is associated with each RA which contains an entry for all mobiles which are currently visiting its RA
- an HLR associated with each mobile and there is a central HLR
- HLR also indicates the current VLR at which the mobile is registered