Channel Assignment
and Handoffs in Cellular Networks
Cellular architecture

One low power transmitter per cell
channel reuse–limited spectrum
Handoff - moving to other cells

Co-channel interference:
transmission on same channel

Reuse distance: minimum distance between two cells using same channel for satisfactory signal to noise ratio

Propagation path loss for signal power: exponent ranges between 2 and 4
One channel can be (re)used in all cells of the same color
reuse pattern 7
Desirable qualities of CA algorithms

- Minimize connection set-up time
- Adapt to changing load distribution
- Fault tolerance
- Scalability
- Low computation and communication overhead
- Minimize handoffs
- Maximize number of calls that can be accepted concurrently
Call Admission Control

- The function of call admission control is to determine whether or not to grant radio resources to a new incoming/handoff call based on information such as the current channel occupation, the bandwidth and QoS requirements of calls in service, and the characteristics of the call that requests admission
  - Call rejection (reject the admission of new call)
  - Call dropping (forcing an ongoing call to premature termination)
Channel Assignment

- **Fixed channel assignment (FCA):** channels are pre-allocated to the cells during planning phase.
- **Dynamic channel assignment (DCA):** no pre-allocation. When a call comes/arrives at a cell then a channel not in use (that does not violate the reuse conditions) is selected
  - It requires the MSC to collect real time data, channel occupancy data, traffic distribution, radio signal strength, etc.
  - Centralized (complex - provide upper bounds on network performance)
  - Distributed (suboptimal- interesting from practical point of view)
- DCA schemes perform better under non-uniform and low traffic density (as traffic increases the trunking gain is dominated by the randomness in the reuse distance)
- FCA performs well under high and uniform traffic
Maximum Packing (MP)

- It is the optimum traffic adaptive channel allocation scheme.
- It assumes that a new call will be blocked only if there is no possible channel allocation (including any number of channel reassignments) to calls that would result in room for the new call.
- That is, MP finds the minimum number of channels needed to carry all the existing calls while satisfying the compatibility constraints (two cells that are not compatible if, due to interference conditions, can not use the same channel).
- The problem is equivalent to graph coloring problem (NP-complete). If two cells are not compatible then there is an edge connecting these two nodes. If a cell has multiple users we simply duplicate the node as many times as the number of users in that cell and connect the duplicated nodes by edges.
- MP provides only the performance bound that traffic-adaptive DCA can achieve.
Channel Borrowing

- **Basic mechanism:**
  - It is a combination of fixed and dynamic channel assignment. A channel set is nominally assigned to each cell (like in FCA).
  - When all the channels in a cell are occupied, the cell borrows channels from other cells to accommodate the incoming new/handoff calls, as long as the borrowed channels do not interfere with the ones used by existing calls (at this point it works like DCA). Otherwise the call is blocked.
  - The channel borrowing schemes are more flexible in the sense that by "moving" (borrowing) channels from less busy cells to more busy cells, a balanced performance throughout the system can be achieved.
  - Borrowing a channel x carries a penalty: cells that were originally allocated this channel x, may not be able to use this channel, since they may be within the co-channel interference range of the cell that borrowed the channel.
  - Thus the decreased blocking probability at the cell that borrowed a channel is obtained at the cost of decreasing the capacity of other cells, which in turn causes QoS degradation in these cells.
The basic channel borrowing strategy gives better performance (lower blocking) than FCA strategy under light and moderate traffic conditions, especially under unbalanced traffic. In heavy traffic conditions channel borrowings may proliferate to such an extent that the channel usage efficiency drops drastically (so that FCA outperforms borrowing strategy).

Combining the advantages of these two mechanisms: A set of nominal channels is assigned to each cell. This set is subdivided into two subsets A and B. Subset A channels are used in the local cell only, while subset B channels can be lent to the neighboring cells. The optimal ratio #A/#B depends on the traffic load.
Channel Borrowing Enhancements/Variations

- **Borrowing with channel-ordering (BCO):** All channels are ordered and the first channel has the highest priority to be assigned to the next local call, while the last channel has the highest priority to be borrowed by the neighboring cells. As a result the ratio (#A/#B) varies according to the traffic load. After a channel is borrowed it is locked in the co-channel cells within the channel reuse distance of the borrowing cell.

- **Minimum influence borrowing:** The minimum influence borrowing algorithm aims to borrow the channel that has minimum impact on the overall performance of the system. When channel borrowing in necessary, all the borrow-able channels are compared in terms of the traffic conditions in the blocked cells of each borrow-able channel, and predictions are made accordingly. Then the channel that will cause the least QoS degradation in the expected future is chosen.
Channel Borrowing Enhancements/Variations (cont.)

- **Channel Reallocation**: The channel reallocation process aims at minimizing the time that a borrowed channel is used. Instead of returning the channel when the call that uses the borrowed channel completes or hands off, if there is a channel that is released by another call in the borrower cell, the borrowed channel is returned and the released channel (which belongs to its nominal set) is allocated to this call.

- **Borrowing with directional channel locking (BDCL)**: In the basic borrowing scheme after a channel is borrowed it is locked in the co-channel cells within the channel reuse distance of the borrowing cell. This is too stringent and therefore locking should refer only to those cells (in that direction) in the co-channel set that are actually affected by the borrowing of the channel.
Channel Allocation/Assignment Depending on Bandwidth Dedication Mechanism

- Circuit switching (dedication of bandwidth/channels for call duration)
- Packet Switching: dedication of channels for packet duration
- Burst switching: dedication of channels for duration of burst data
- Random access transmission (Common Channel Packet Switching). It does not require any reservation of channels.
• **Circuit Switching:**
  • It is a static admission control and the negotiation is done for the call duration in a specific cell.
  • Steps: specification of QoS requirements, negotiation for agreed specification between all parties, admission control process, resource reservation (if admitted)
  • Acceptance/Rejection is based on the impact of call under consideration on other active users’ QoS requirements (e.g. if feasible power and rate vectors exist).
• **Packet/Burst switching:**
  
  It is a dynamic admission control. It is more effective for bursty multimedia data and highly variable wireless channels.

  It involves the renegotiation of a “contract” and adaptation to changes of the system. In packet switching, terminals contend for a channel for each packet. Thus utilization is maximized while access delay per packet increases.

  Burst switching tries to avoid the problems of poor utilization and high per packet delay of circuit and packet switching schemes, respectively. Channels are allocated to a burst of data while they are released at the beginning of idle period.

  Admission control in burst switching depends not only on active users but also on the registered users in the inactive state (since they may re-access the system) in order to foresee the potential to admit a new user.
• **Common Channel Packet Switching**
  
  Previous methods require exchange of resource allocation control information. This can be avoided by using Aloha type random access methods where terminals compete for resources. This approach requires the resolution of collisions and the use of retransmissions.
  
  It has been shown to be efficient for non-real-time packets data applications (such as: HTTP, FTP, E-mail).
  
  There is no guaranteed QoS during packet transmission. Positive or negative acks are used.
  
  Advantage of burst reservation schemes for data services is the minimization of interference for voice and data packets at the expense of higher overhead to control and measure the channel load. Common Channel packet switching requires a higher rate of retransmission for data users while a simpler control mechanism is required.
  
  **Hybrid schemes:** They are used for integrated voice/data services where voice traffic is transmitted in a circuit mode while data traffic is transmitted in packet/burst mode or on a common channel.
Examples of Hybrid Schemes

• **Dynamic TDMA/TDD mode**: Users send transmission requests to the base station that processes them with a schedule table based on the QoS parameters of user traffic. For Constant Bit Rate (CBR) and Variable Bit Rate (VBR) traffic, allocation is performed once during call establishment, as in circuit mode. For Available Bit Rate (ABR) and Unspecified Bit Rate (UBR) traffic, allocation is performed on a burst by burst basis (as in burst switching).

• **In Packet Reservation Multiple Access (PRMA)**, each of the slots are classified as being either reserved or available. Reservations are limited to terminals transmitting real-time data such as voice or video. Data terminals must contend for a time slot for each packet that must be sent as in packet switching. Speech activity detectors are used to hold reservations only for the duration of the talk spurt and to release them during quiet spurts so that the channel bandwidth can be used by other terminals with packets to send.
Handoffs

- When a user/call moves to a new cell, then a new base station and new channel should be assigned (handoff)
- Handoffs should be transparent to users, while their number should be kept to minimum
- A threshold in the received power ($P_r, \text{handoff}$) should be determined to trigger the handoff process. This threshold value should be larger than the minimum acceptable received power ($P_r, \text{acceptable}$)
- Define: $\Delta = P_r,\text{handoff} - P_r,\text{acceptable}$
  - If $\Delta$ is large then too many handoffs
  - If $\Delta$ is small then insufficient time to complete a handoff
• In order to correctly determine the beginning of handoff, we need to determine that a drop in the signal strength is not due to the momentary (temporary) bad channel condition, but it is due to the fact that the mobile is moving away from BS.

• Thus the BS needs to monitor the signal level for a certain period of time before initiating a handoff. The length of the time (running average measurements of signal) and handoff process depends on speed and moving pattern.

• First generation systems typical time interval to make a handoff was 10 seconds (large Δ). Second generations and after typical time interval to make a handoff is 1-2 seconds (small Δ).

• First generation systems: handoff decision was made by BS by measuring the signal strength in reverse channels.

• Second generation and after: Mobile Assisted Hand-Off (MAHO). Mobiles measure the signal strength from different neighboring BSs. Handoff is initiated if the signal strength from a neighboring BS is higher than the current BS’s signal strength.
**Cell Dwell Time**

- It is the time over which a call maybe maintained within a cell (without handoff).
- It depends on: propagation, interference, distance between BS and MS, speed and moving pattern (direction), etc.
- Highway moving pattern: the cell dwell time is a r.v. with distribution highly concentrated around the mean.
- Other micro-cell moving patterns mix of different user types with large variations of dwell time (around the mean).
Prioritizing Handoffs

- **Guard Channels:** Fraction of total bandwidth in a cell is reserved for exclusive use of handoff calls. Therefore, total carried traffic is reduced if fixed channel assignment is used. However, if dynamic channel assignment is used the guard channel mechanisms may offer efficient spectrum utilization.
  - Number of channels to be reserved: If it is low (under-reservation) the QoS on handoff call blocking probability can not be met. If reservation is high (over-reservation) may result in waste of resources and rejection of large number of new calls.
  - Static and Dynamic schemes: Advantage of static scheme is its simplicity since no communication and computation overheads are involved. However problems of under-reservation and over-reservations may occur if traffic does not conform to prior knowledge. Dynamic schemes may adjust better to changing traffic conditions.
Prioritizing Handoffs

- **Queuing Handoffs**: The objective is to decrease the probability of forced determination of a call due to lack of available channels. When a handoff call (and in some schemes a new call) cannot be granted the required resources at the time of its arrival, the request is put in a queue waiting for its admitting conditions to be met.
  - This is achieved because there is a finite time interval between the time that the signal of a call drops below the handoff threshold, and the time that the call is terminated due to low (unacceptable) signal level. Queuing and size of buffer depend on traffic and QoS. Queueing in wireless systems is possible because signaling is done on separate control channels (without affecting the data transmission channels).

- According to the types of calls that are queued, queuing priority schemes are classified as: handoff call queuing, new call queuing and handoff/new call queuing (handoff calls are given non-preemptive priority over new calls).
Practical Issues (Capacity/Handoff)

- To increase capacity, use more cells (add extra sites).
- Using different antenna heights and powers, we can provide “large” and “small” cells co-located at a signal location (it is used especially to handle high speed users and low speed users simultaneously.
- Reuse partitioning (use of different reuse patterns)
- Cell splitting: Change cell radius $R$ and keep co-channel reuse ratio $(D/R)$ unchanged. If $R' = R/2$ than the transmit power needs to be changed by $(1/2)^4 = 1/16$.
- Another way is to keep cell radius $R$ unchanged and decrease $D/R$ ratio required (that is decrease the number of cells in a cluster). To do this it is required to decrease interference without decreasing transmit power.
- Sectoring: Use directional antennas (instead of omni-directional) and therefore you receive interference from only a fraction of the neighboring cells.
- Hard handoffs vs. soft handoffs: more than one BSs handle the call during handoff phase (used in CDMA systems)