UNIVERSITÀ DELLA CALABRIA

Master Degree in Telecommunications Engineering

"Mobile Radio Networks" Class

Introducing the Course

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Multiple Access in Radio Mobile Systems

- **First Generation Systems: TACS (Europe) & AMPS (United States)**
  - **FDM/FDMA (downlink/uplink)**
- **Second Generation Systems: GSM (Europe) D-AMPS (United States)**
  - **Multi-carrier TDM/TDMA**
- **Third Gen. Systems: UMTS (worldwide)**
  - **CDM/CDMA**
- **Fourth Gen. Systems: LTE (worldwide)**
  - **OFDMA/SC-FDMA**
- **Fifth Gen. Systems: 5G (worldwide)**
  - **Under investigation alternatives, such as Non-orthogonal Multiple Access (NOMA)**

NOMA
Non-orthogonal Multiple Access (NOMA)

- It is a common idea that none of the orthogonal multiple access (OMA) techniques the current cellular networks implement can meet the high demands of future radio access systems (5G and 6G).
- NOMA is fundamentally different as, in NOMA, each user operates in the same band and at the same time where they are distinguished **by their power levels** (power domain multiplexing) or **by coding** (code domain multiplexing) .
- We focus only on NOMA via power domain multiplexing, meaning that
  - different users are allocated **different power levels** according to their channel conditions to obtain the maximum gain in system performance
  - NOMA **successive interference cancellation** (SIC) receiver can separate the users both in the uplink and in the downlink channels.
- Several NOMA via code domain multiplexing have also been studied *(Low-Density Spreading CDMA, Low-Density Spreading OFDM, Sparse Code Multiple Access, Multi-User Shared Access*, etc…)

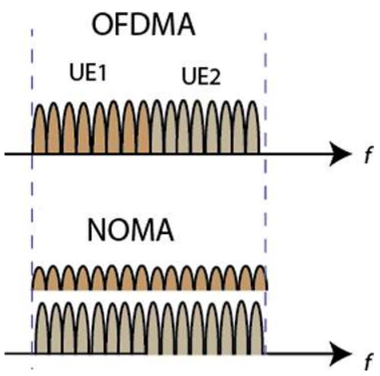
NOMA
Non-orthogonal Multiple Access (NOMA)

- NOMA was proposed as a candidate radio access technology for 5G cellular systems
- Practical implementation of NOMA in cellular networks requires high computational capability to implement real-time power allocation and successive interference cancellation algorithms.
- By the time that 5G networks are targeted to be deployed, the computational capacity of both handsets and access points is expected to be high enough to run NOMA algorithms.

NOMA
Non-orthogonal Multiple Access (NOMA)

- We can keep the modulation scheme used in OFDMA and introduce NOMA as the multiple access scheme.
- In conventional 4G networks, as natural extension of OFDM, orthogonal frequency division multiple access (OFDMA) is used where each user has a subset of subcarriers assigned.
- In NOMA, on the other hand, all the subcarriers can be used by each user.
- The concept applies both to uplink and downlink transmission.

NOMA
Non-orthogonal Multiple Access (NOMA)



- Superposition coding at the transmitter and successive interference cancellation (SIC) at the receiver makes it possible to utilize the same spectrum for all users.

NOMA
Non-orthogonal Multiple Access (NOMA)

- At the **transmitter site**, all the individual information signals are superimposed into a single waveform.
- At the **receiver**, SIC decodes the signals one by one until it finds the desired signal.
- The success of SIC depends on the perfect cancellation of the signals in the iteration steps.
- The transmitter should accurately split the power between the user information waveforms and superimpose them.
- The methodology for power split differs for uplink and downlink channels.

NOMA
Non-orthogonal Multiple Access (NOMA)

- In the illustration, the three information signals indicated with different colors are superimposed at the transmitter.
- The received signal at the SIC receiver includes all three signals.
- The first decoded signal is the strongest (others are interference).
- The first decoded signal is then subtracted from the received signal and, if the decoding is perfect, the waveform with the rest of the signals is accurately obtained.
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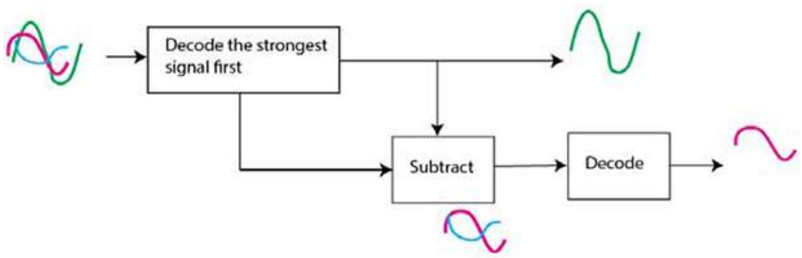
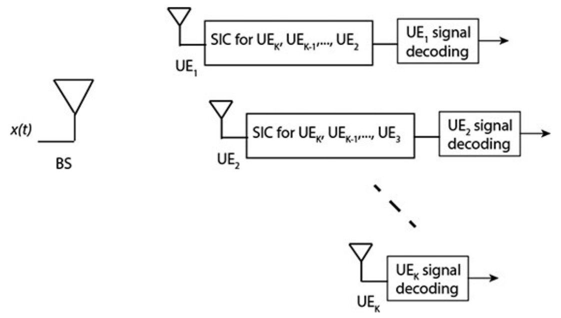


NOMA
Non-orthogonal Multiple Access (NOMA)

- In downlink, the BS superimposes the information waveforms for its serviced users. Each user equipment (UE) employs SIC to detect their own signals.
- The challenge for BS is to decide how to allocate the power among the individual information waveforms, which is critical for SIC.
- In NOMA downlink, more power is allocated to UE located farther from the BS and the least power to the UE closest to the BS.
- In the network, all UEs receive the same signal that contains the information for all users.

NOMA
Non-orthogonal Multiple Access (NOMA)

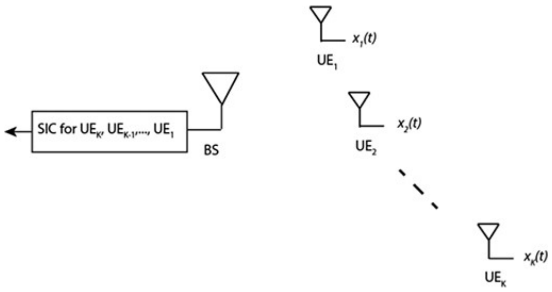
- Each UE decodes the strongest signal first, and then subtracts the decoded signal from the received signal.
- SIC receiver iterates the subtraction until it finds its own signal.
- UE located close to the BS can cancel the signals of the farther UEs.
- Since the signal of the farthest UE contributes the most to the received signal, it will decode its own signal first.



- *One BS and K UEs with SIC receivers.*
- *The UE$_1$ is the closest to the base station (BS), and UE$_K$ is the farthest.*

NOMA
Non-orthogonal Multiple Access (NOMA)

- Uplink implementation of NOMA is slightly different than the downlink.
- This time, BS employs SIC in order to distinguish the user signals.
- In the uplink, the UEs may again optimize their transmit powers according to their locations as in the downlink.



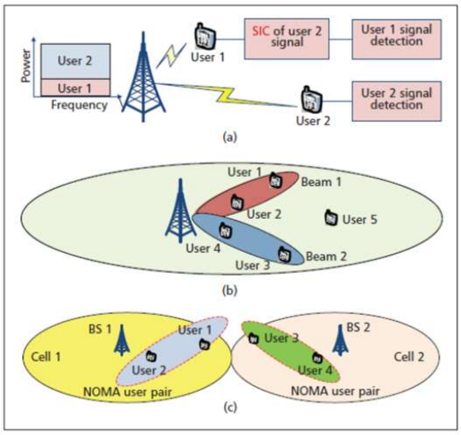
- *One BS and K UEs with SIC receivers.*
- *The UE_1 is the closest to the base station (BS), and UE_K is the farthest.*

NOMA
Non-orthogonal Multiple Access (NOMA)

- NOMA can have superior performance over conventional OFDMA in terms of sum capacity, energy efficiency and spectral efficiency.
- There are, however, still some challenges for successful implementation of NOMA.
  - NOMA requires high computational power to run SIC algorithms particularly for high number of users at high data rates.
  - Power allocation optimization remains as a challenging problem, particularly when the UEs are moving fast in the network.
  - Finally, SIC receiver is sensitive to cancellation errors which can easily occur in fading channels. Imperfectness at the SIC receiver impacts on the system performance.
- It can be implemented with some other diversity techniques like multiple-input-multiple-output (MIMO) or with coding schemes in order to increase the reliability and accordingly reduce the decoding errors.
- The current state of the art for NOMA, however, requires further investigation.

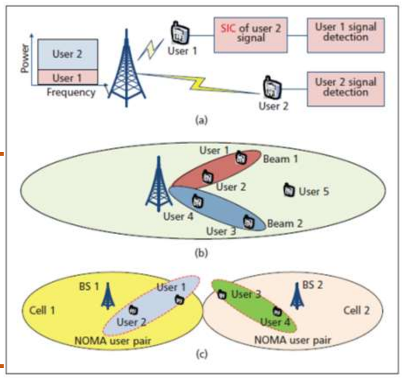
NOMA
Non-orthogonal Multiple Access (NOMA)

- We discussed basic NOMA based on power domain multiplexing.



NOMA
Non-orthogonal Multiple Access (NOMA)

- NOMA can be used in conjunction with multi-user multiple-input multiple-output (MU-MIMO) to further improve the system spectral efficiency.
- Multiple transmit antennas at a BS are used to form different beams in the spatial domain, where each beam adopts the basic NOMA discussed above.
- At the receiver, the inter-beam interference can be suppressed by spatial filtering, and then intra-beam SIC can be used to remove the inter-user interference.

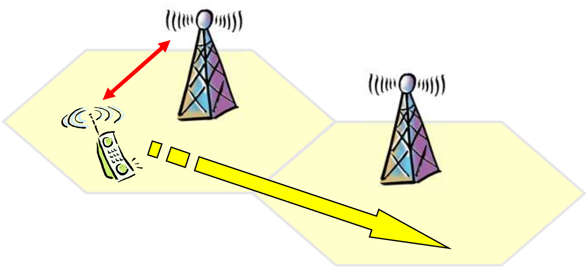


Mobile Radio Networks

❑ Mobility management

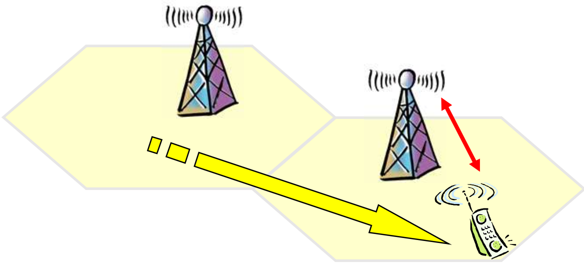
Mobility management

- In cellular networks, users can move around the system area and thus move from one cell to another
- This obviously poses information routing problems (or, more simply, call routing in the case of voice service)
- All the procedures that the network puts in place to allow mobile users to communicate go under the name of **mobility management**



Mobility management

- WHILE ON THE GO cellular system users can:
  - Call
  - be called
  - converse
- Some "intelligence" is needed to support all of this (ROAMING functionality).



Mobility management

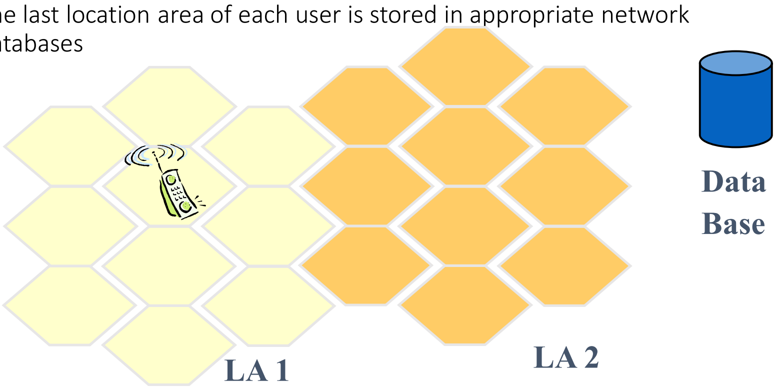
- In the case of circuit service, the mobility management procedures differ according to whether the moving user is in IDLE status (no active circuit) or in ACTIVE status (in conversation)
  - ACTIVE: there is an active circuit that must be rerouted after each cell change (Handover)
  - IDLE: the user must be able to be located in order to direct a call to her/him (Location Update, Cell Selection, Cell Reselection)

Mobility management: Cell selection

- An idle mobile terminal "locks" to a cell based on the signal received from the base station
- On a suitable common downlink control channel, the radio base station transmits system information which, among other things, specifies its identifier
- The mobile terminal scans radio frequencies to decode the control channel of the base stations in the area
- The terminal selects the base station from which it receives the strongest signal
- The terminal never stops scanning periodically also the other frequencies and if it finds a stronger signal from another base station it changes the selection

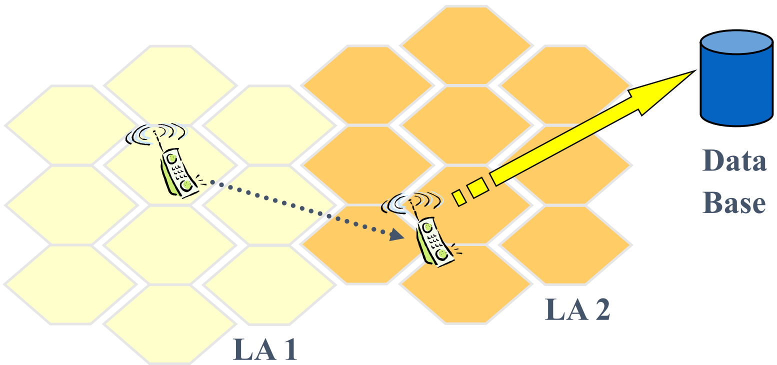
Mobility management: Location Update

- *Location Area:* topological entity hierarchically superior to the cell (group of several cells)
- An IDLE user is located by the system on a Location Area basis (and not on a cell basis)
- The last location area of each user is stored in appropriate network databases



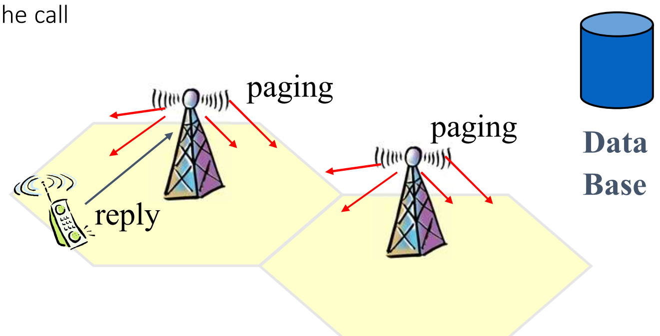
Mobility management: Location Update

- If a user in IDLE status passes from one LA to another, he triggers a Location Update procedure
- Information about the LA a user belongs to is used to route calls



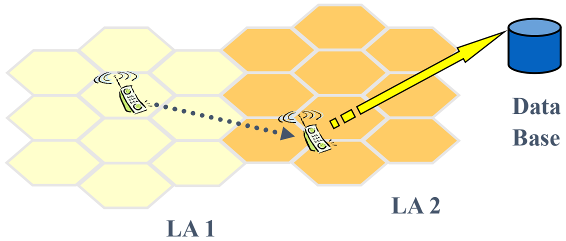
Mobility management: Paging

- When a call for the mobile user is received, the register is consulted
- Once the LA is known, a paging procedure is initiated
- Each base station of the LA sends a broadcast control message with the ID of the user being sought
- When the mobile terminal answers, the network knows the cell and routes the call



Mobility management: Paging vs. Location Update

- QUESTION:
  - How big should the Location Areas be?
    - small Two many location updates
    - big Excessive paging signalling
  - What pushes in one direction, what in the other?



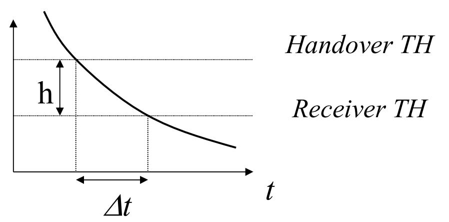
Mobility management: Handover (or Handoff)

- Procedure by which a mobile terminal in conversation changes the base station which it is connected to
- The process is completely controlled by the network that adapts routing and command the UE to switch to the new cell
- Efficient and fast handover procedures are required

Mobility management: Handover

When triggering an handover?

- The choice of the handover procedure activation thresholds is a critical factor



- If h is too small Δt is too small, and you risk losing the connection
- If h is large, the number of handover requests and thus the signaling traffic on the network increases

Mobility management: Handover

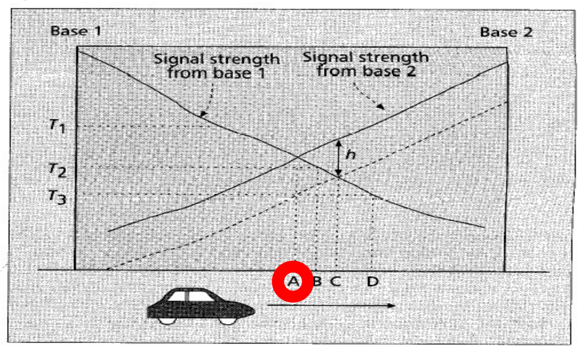
When triggering an handover?

- There are several HO methods

  1 - *relative signal strength* method

  - the handover takes place at point A

- **many bounces are possible due to signal fluctuations (ping-pong effect)**



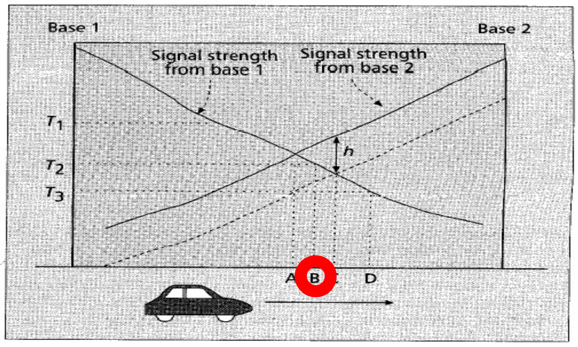
Mobility management: Handover

When triggering an handover?

- There are several HO methods

  2 - strongest signal with threshold method

  - if the signal from the previous BS is below a threshold (e.g. T_2) and the power of another BS is stronger, the handover takes place at point B



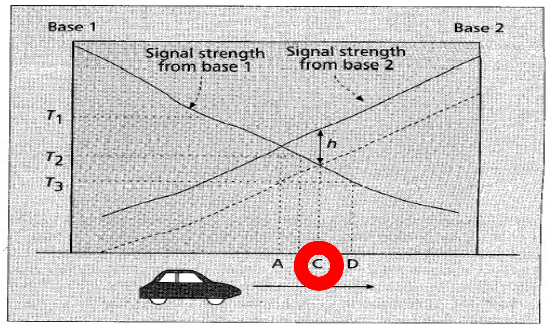
Mobility management: Handover

When triggering an handover?

- There are several HO methods

  3 - strongest signal with hysteresis method

  - if the power of the other BS is stronger than a value ≥ h, the handover takes place at point C



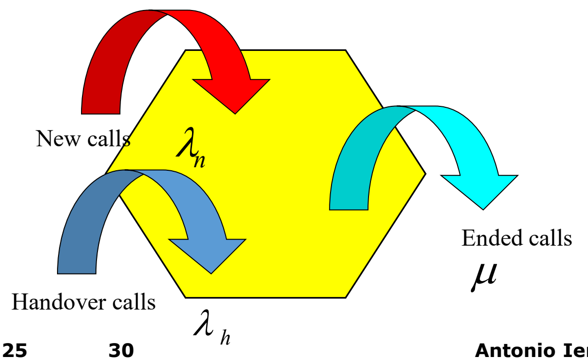
Mobility management: handover performance

- When a handover occurs, the channel in the old cell is released and a channel is requested in the new one; the channel in the new one may not be available
- We define the *handover rejection probability* (P_{drop}) as the probability that a handover request cannot be fulfilled and the *block probability* (P_{block}) as the probability of rejecting a new call
- In systems that treat *handover requests* as new incoming requests (*call setup requests*) $P_{drop}=P_{block}$
- In fact, it's better to block an incoming call than to miss an active one
- You can try to handle handover requests with a higher priority

Mobility management: handover performance Guard Channels

- *Guard Channels*
  - A number of channels are reserved for handover requests
  - P_{drop} becomes lower but system capacity is lower
  - The sizing of the system is critical and requires accurate estimates of the traffic trend over time (how many channels do I reserve for handover requests?)

Hypothesis:
- N available channels
- of which N-T for handover calls only

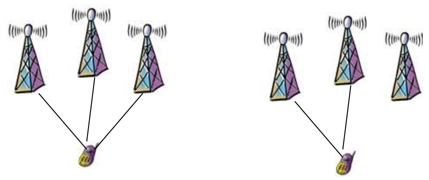


Mobility management: types of Handover

- Hard Handover (e.g., inGSM-2G)

It assumes the removal and establishment of a new radio link

- Soft Handover (e.g., UMTS-3G)



Taking advantage of the macrodiversity, the user is connected to several base stations at the same time