Cellular Networks

Last updated 5/3/21
Cellular - Background

- Generations

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Cellular - Background

• POTS
  • Plain Old Telephone Service
  • ca. 1877 → mid 1980’s in US
  • Still used in many countries

• Wired analog communication
  • 2 wires – local loop
  • Full duplex
  • Circuit Switched

src: nationalww2museum.org
Cellular - Background

- **POTS – Electrical Operation**
  - T – tip line
  - R – ring line
  - CO – central office

- **Outgoing call**
  - Pick up handset → Hook switch → closed
  - Current flows → sensed by the current sensor
    - CO generates a dial tone on the line
    - CO connects digit decoder to the line
  - CO connects calling line to Receiving line
    - Voice coil and speaker signals transferred between handsets

- **Incoming call**
  - CO generates a ring signal
  - Answered → Hook switch → closed
  - Current sensor stops the ring and connects the lines
    - Voice coil and speaker signals transferred between handsets
Cellular - Background

- Broadcast Radio
  - Transmit only
  - Line of sight

- Earliest radio-phones
  - 1946
  - FM – push to talk
  - Single high-powered transmitter
  - Several smaller receive locations
    - [https://youtu.be/xDy2tHCPdk8](https://youtu.be/xDy2tHCPdk8) (10 minutes – sorry about the ads)
  - Very limited subscriber numbers
    - Wide BW signals, narrow available BW → few channels
Cellular - Background

- Tx/RX sequencing
  - Simplex
    - Receive or transmit only
    - Garage door opener
    - Pagers
    - Broadcast radio and TV
  - Half duplex
    - non-simultaneous Rx/Tx
    - Walky-talky
  - Full duplex
    - Simultaneous Rx/Tx (effectively)
    - Cellular
Cellular - Background

- Mobile Radio
  - Full Duplex Methods
    - FDD – Frequency Division Duplex
      - Separate frequencies used for transmit and receive
    - TDD – Time Division Duplex
      - Send and receive “packets” separated in time
      - Requires the information sent/received is small compared to the channel's capacity
      - Requires “real time” information to be low BW compared to the packet BW
- Terms
  - Station to user – forward channel - downlink
  - User to station – reverse channel - uplink
Cellular - Background

• Cellular
  • Transmitter
    • Fixed location
    • Range dependent on transmission power
    • Range varies with
      • Atmospheric conditions
      • Geographic topology
      • Man made structures

reliable transmission range

best case transmission range
Cellular - Background

• Cellular
  • Transmitter(s)
    • Common frequency

Common Frequency

No interference
GAPS !

Common Frequency

Interference !
GAPS !

Common Frequency

INTERFERENCE !
No gaps
Cellular - Background

- Cellular
  - Transmitter(s)
    - Non-common frequencies

4 frequencies

No interference
No gaps

64 frequencies
16 per transmitter (co-channels)

No interference
No gaps
Cellular - Background

• Cellular
  • Transmitter(s)
    • Non-common frequencies
    • N frequency groups
      • N = 4
Cellular - Background

- Cellular
  - Transmitter(s)
    - Non-common frequencies
    - N frequency groups
      - N = 7
Cellular - Background

- Cellular
  - Transmitter(s)
  - D – distance between cell centers using the same frequencies (channels)
  - R – radius of a cell
  - N – number of cells in a pattern
    - N = 1, 3, 4, 7, 9, 12, 13, 16, 19, ... N = I² + J² + (IJ)  I, J = 0, 1, 2, ...
  - D/R = (3N)¹/²

- Example:
  - Assume 5 co-channels/cell, 25 users/channel at one time, desire to support 625 users in a 25km² area (circular)
  - With a N = 9 system, what would the value of D be?
  - 625 users, 25/channel → 25 channels → 5 cells
  - 5 x 2*PI*R² = 25km² → R = 0.89km
  - D = 4.64km
Cellular - Background

• Capacity expansion
  • Add new channels to a cell
    • Assign unused frequencies
  • Frequency borrowing
    • Assign channels from an adjacent (less loaded) cell
    • Can be done dynamically
    • Can impact the broader reuse pattern
      • Cell 1 borrows from cell 4 – may impact the next nearest cell 4

• Cell splitting
  • Shrink the footprint
    • More cells in a given area → more capacity
  • More towers
  • More handoffs

• Cell sectoring
  • Break the cell into radial sectors (3 or 6 typically)
  • Each sector can use all (most) co-channels independently
    • ~3x or 6x capacity
    • Requires directional antennas
Cellular – Circuit Switched

• Circuit Switched
  • Operate similarly to the POTS system
  • Dedicated lines (channels) between callers

• AMPS – 1G
  • Advanced Mobile Phone System
  • Analog signals
    • 3KHz voice FM modulated onto a 30KHz channel
    • 832 full-duplex (FDD) channels – 21 reserved for signaling
    • Downlink – 824MHz – 849MHz
    • Uplink – 869MHz – 894MHz
  • Approximately 800 conversations / cell cluster

• GSM – 2G
  • Global System Mobile
  • Digital signals
    • 3.1KHz voice GMSK modulated onto a 200KHz channel
    • Each channel time division multiplexed into 8 timeslots
    • A timeslot is dedicated to a single call
    • Most systems operate in 25Mz bands around 900MHz and 1800MHz
  • Approximately 1000 conversations / cell cluster
  • 14.4Kb/s of data / timeslot
Cellular – Circuit Switched

• Components
  • BS – Rx/Tx
    • At least 2 channels: Control, Traffic
  • BSC – controls the Rx/Tx
    • Communicates to the MSC

• MSC
  • Setup and breakdown of calls
  • Handles calls between connected mobiles

• GMSC
  • Connects to the PSTN for long distance
Cellular – Circuit Switched

- Components
  - HLR
    - Billing, services, ... for subscribers
  - VLC
    - Information on any mobiles roaming in the MSC domain
Cellular – Circuit Switched

• Mobile unit / Cell identification

• While turned on, the mobile unit periodically scans for forward control channels
  • Selects the strongest (may not be the closest)
  • De-facto selects the cell for communications

• A hand-shake process ‘registers’ the mobile unit with the MSC
  • Uses the forward and reverse control channels
  • MSC knows who is in which cells

• If the mobile unit is moving, this will update as it transfers between cells

• Mobile unit ‘listens’ for pages (see later slides)
Cellular – Circuit Switched

• Mobile unit call initiation
  • Mobile unit checks to see if the forward control channel is idle
  • When idle, the mobile send the desired number to the BSC on the reverse control channel
  • BSC sends the request on to the MSC

• The MSC then determines which BSC the called unit is operating in
  • The MSC then directs the BSC to send a page to the desired called unit on the forward control channel

• The called unit detects the page – through its monitoring of the forward control channel – and responds to its BSC/MSC to complete the call
  • The MSC then directs the BSC to assign (via the forward control channel) each mobile to a traffic channel and connects the 2 mobile units to complete the call
    • Each mobile unit will have its own channel depending on cell and co-channel assigned
    • Each mobile unit continues to operate on the control channel
      • Sharing call status and signal strength info with the BSC
Cellular – Circuit Switched

- Mobile unit call initiation

  - If either of the mobile units is moving – a handoff may be required
    - Signal strength gets weak, and an alternate control channel (different cell) has a stronger signal
  - The moving mobile unit will inform the BSC of a desire to switch control channels (cells)
    - If the change is within a BSC – it can reassign a new traffic channel and inform the MSC
    - If the change crosses BSCs - the MSC assigns the moving unit a new traffic channel in the new BSC/cell
  - The original call continues un-interrupted
Cellular – Circuit Switched

- Mobile unit call initiation – other conditions
  - Call termination
    - If either unit terminates the call the MTSO informs the other unit and releases the traffic channel
  - No traffic channels free – busy tone provided after some # of attempts
  - Call dropped
    - Signal becomes too weak (and no alternative available)
    - The BSC informs the MTSO that it cannot maintain the traffic channel
    - MTSO terminates the call
  - Out of current system calls
    - GMSC connects to the PSTN to complete the call
Cellular – Packet Switched

- Packet Switched
  - Uses the IP (internet protocol)
  - Channels are not dedicated to a call
    - Locations identified in packet headers
  - Can carry digitized voice
  - Can carry data

- Systems are backwards compatible to Circuit Switched

- GPRS – 2.5G
  - General Packet Radio Service
  - TDM/FDM similar to GSM
  - GMSK modulation with 20Kb/s per timeslot with enhanced coding
  - Timeslots are not dedicated to a call
    - More calls supported with existing resources
    - Multiple timeslots combined for faster data transfer
Cellular – Packet Switched

• EDGE – 2.5G
  • GSM Evolution
  • TDM/FDM similar to GSM
  • 8-PSK modulation – 3x bits of GSM/GPRS
    • 60Kb/s per timeslot with enhanced coding
  • Timeslots are not dedicated to a call
    • More calls supported with existing resources
    • Multiple timeslots combined for faster data transfer
Cellular – Packet Switched

- Packet Switched Systems
- IP type traffic
- Bursty – does not require the kind of dedicated channels that circuit switched systems need
Cellular – Packet Switched

• Packet Switched Systems
  • PCU
    • Assignment of timeslots to users
    • Flow control

• SGSN
  • Assigns packets to users to be passed to the PCU
  • Assigns packets from specific users back to the network connection
  • Handles connections, handoffs, ...

• GGSN
  • Assigns IP addresses for users
  • Connects to the external network
Cellular – Packet Switched

• UMTS – 3G
  • GSM/GPRS/EDGE Evolution
  • Radical radio interface change - CDMA
  • Most network component remain
  • Radio components changed significantly
Cellular – Internet

- LTE – 4G
  - Long term Evolution
  - UMTS Evolution
  - Aggregated carriers – multiple radio channels/user
  - Streamlined network
  - MIMO antenna structure
Cellular – Internet

• LTE – 4G
  • Radio interface – Radio Access Bearer (Signaling Radio Bearer, Data Radio Bearer)
  • eNB – autonomous - integrates RNC functionality
    • Handovers, resource allocation, ...
  • S1 – fiber or microwave – 2 logical components
  • X2 – eNB to eNB communication – handover and power control
Cellular – Internet

- LTE – 4G
  - MME – manages users, connections
  - S-GW – IP traffic management
  - PDN-GW – IP interface – assigns IP addresses, ...

Diagram:

- Internet Protocol Network
- eNB Base Station
- eNB Base Station
- CP Control
- S11
- S5
- S1
- X2
- UP User Data
- CP
- Gateway
- Serving Gateway
- Packet Data Network Gateway
- MME Mobility Management Entity
Cellular – Internet

- LTE – 5G
  - LTE evolution
  - New radio interface – OFDM
  - Higher carrier frequencies – wider bandwidth channels
  - Non-Standard version – reuses LTE network
Cellular – Internet

- LTE – 5G
  - LTE evolution
  - New radio interface - OFDM
  - Higher carrier frequencies – wider bandwidth channels
  - 5G - Core