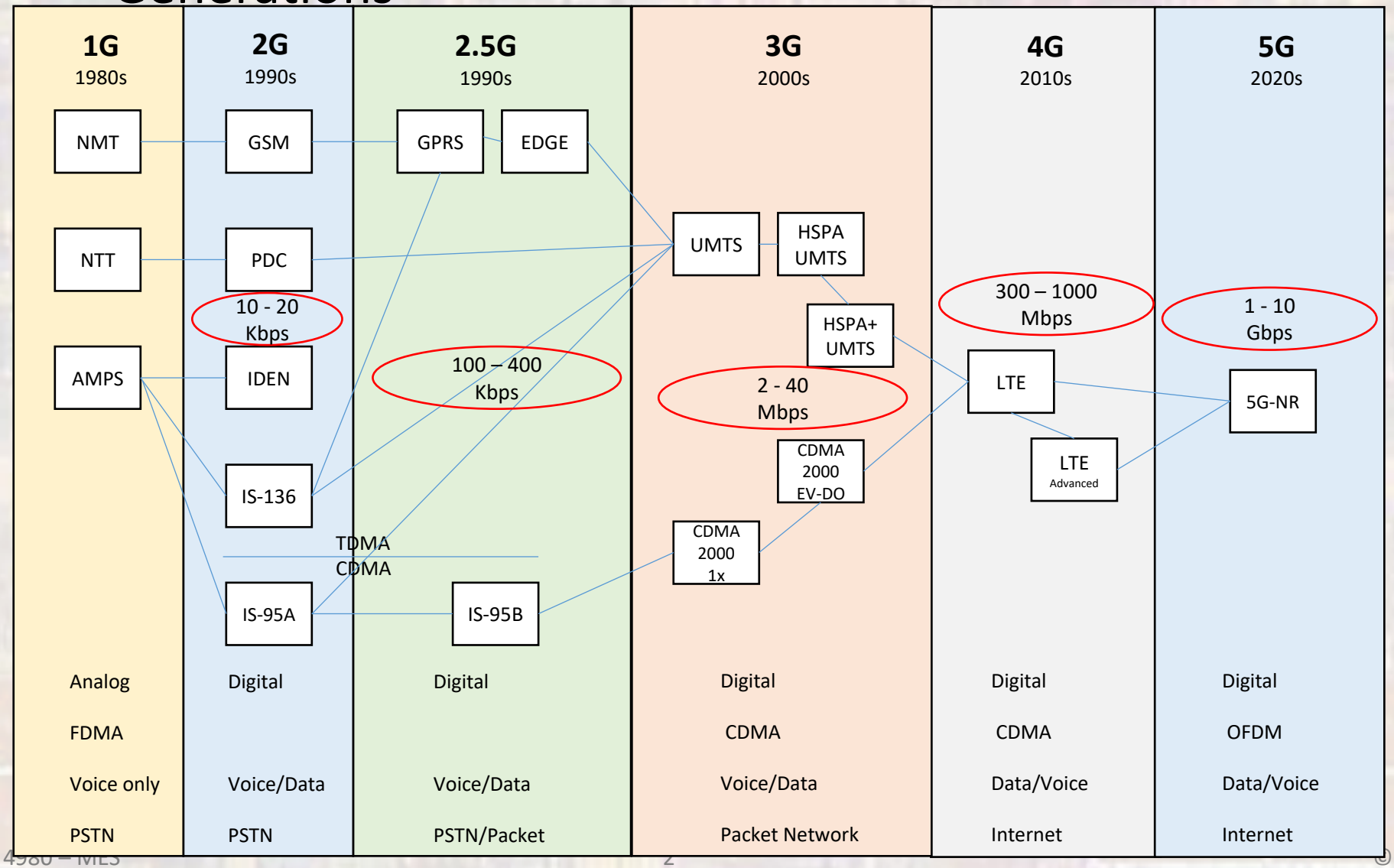
Cellular Networks

Last updated 5/3/21

Cellular - Background

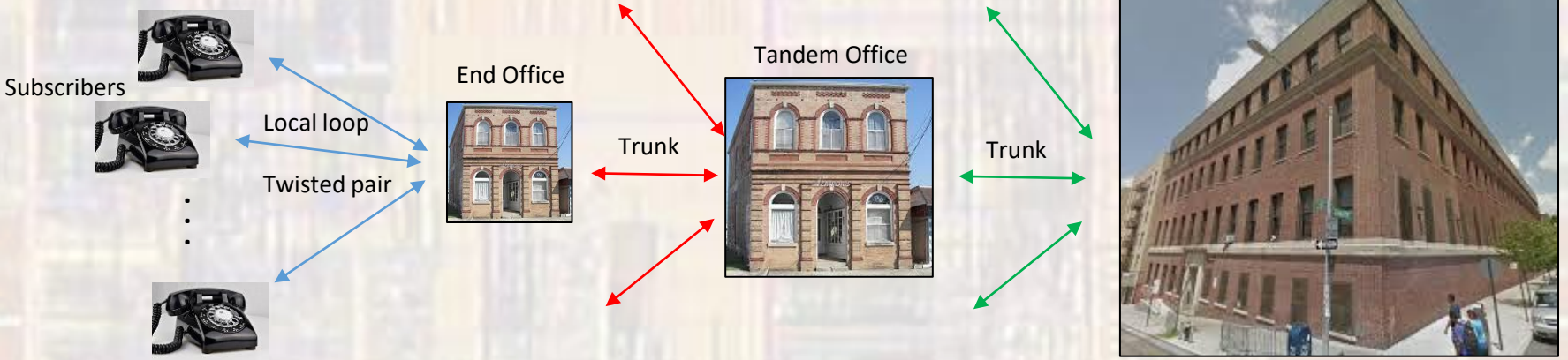
- Generations



Cellular - Background

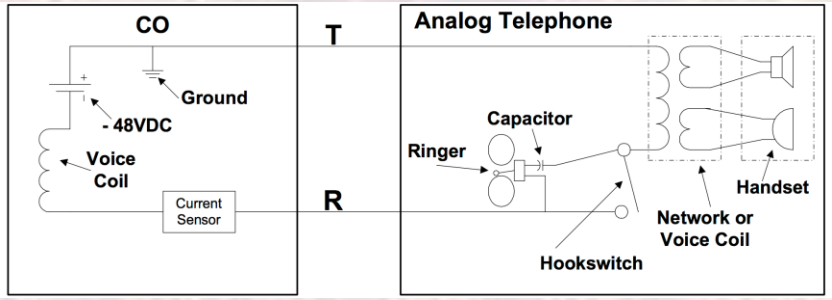
- POTS
  - Plain Old Telephone Service
  - ca. 1877 → mid 1980's in US
  - Still used in many countries
  - Wired analog communication
    - 2 wires – local loop
    - Full duplex
    - Circuit Switched

src: nationalww2museum.org



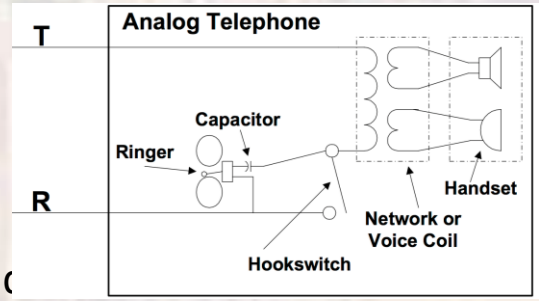
Cellular - Background

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



src: pbxbook.com

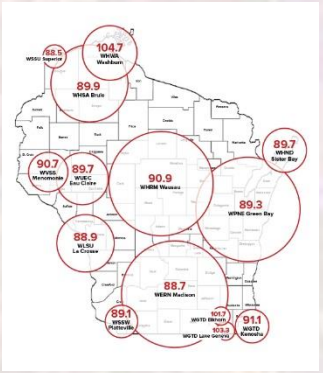
  - Outgoing call
    - Pick up handset → Hook switch → closed
    - Current flows → sensed by the current sensor
      - CO generates a dial tone on the line
      - CO connects digit decoder to the line
    - CO connects calling line to Receiving line
      - Voice coil and speaker signals transferred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



  - 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 (10 minutes – sorry about the ads)
  - Very limited subscriber numbers
    - Wide BW signals, narrow available BW → few channels

Cellular - Background

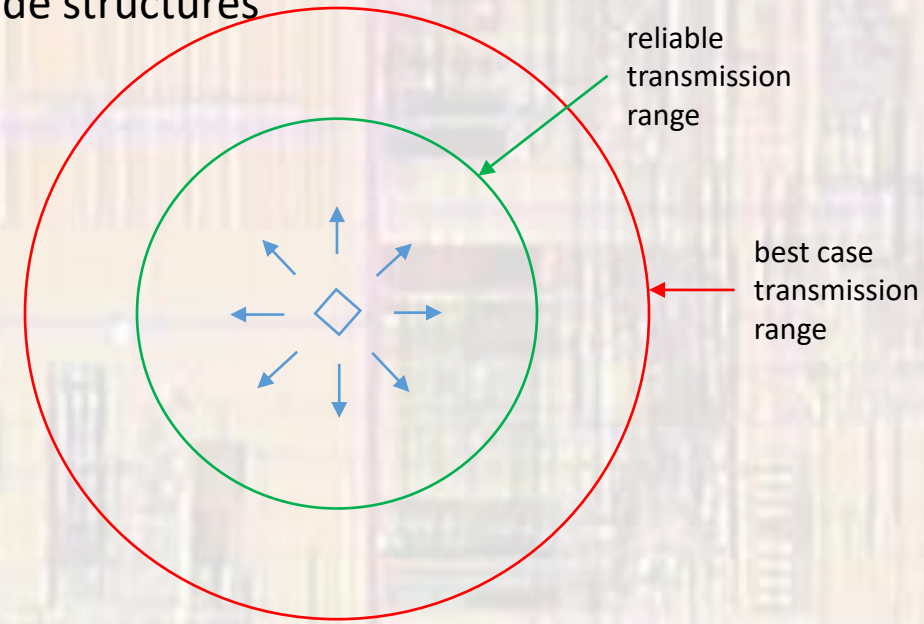
- Tx/RX sequencing
  - Simplex
    - Receive or transmit only
    - Garage door opener
    - Pagers
    - Broadcast radio and TV
  - Half duplex
    - non- simultaneous Rx/Tx
    - Walky-talky
  - Full duplex
    - Simultaneous Rx/Tx (effectively)
    - Cellular

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

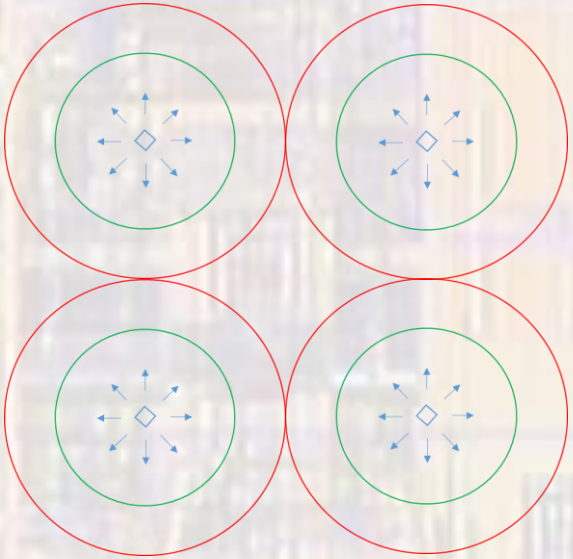
- Cellular
  - Transmitter
    - Fixed location
    - Range dependent on transmission power
    - Range varies with
      - Atmospheric conditions
      - Geographic topology
      - Man made structures



Cellular - Background

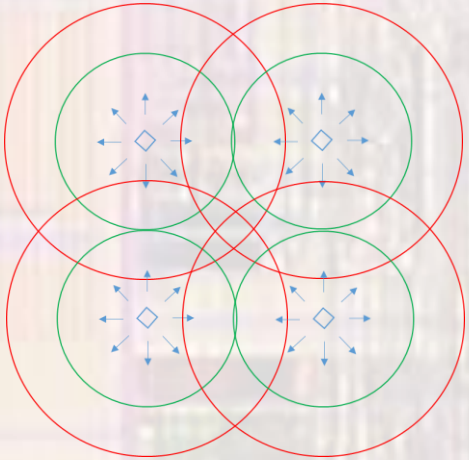
- Cellular
  - Transmitter(s)
    - Common frequency

Common Frequency



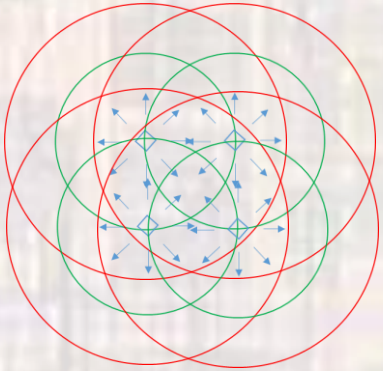
No interference
GAPS !

Common Frequency



Interference !
GAPS !

Common Frequency

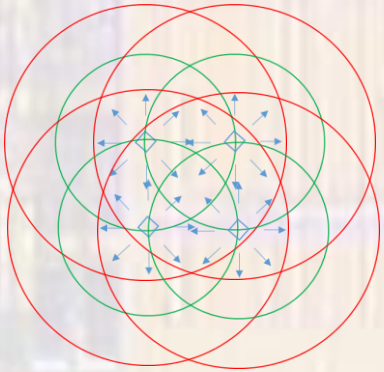


INTERFERENCE !
No gaps

Cellular - Background

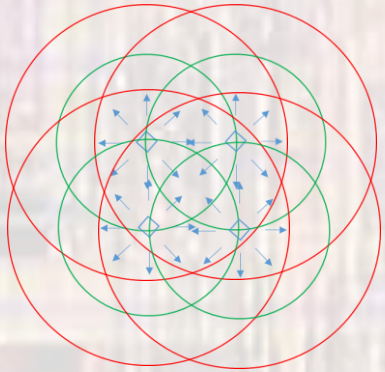
- Cellular
  - Transmitter(s)
    - Non-common frequencies

4 frequencies



No interference
No gaps

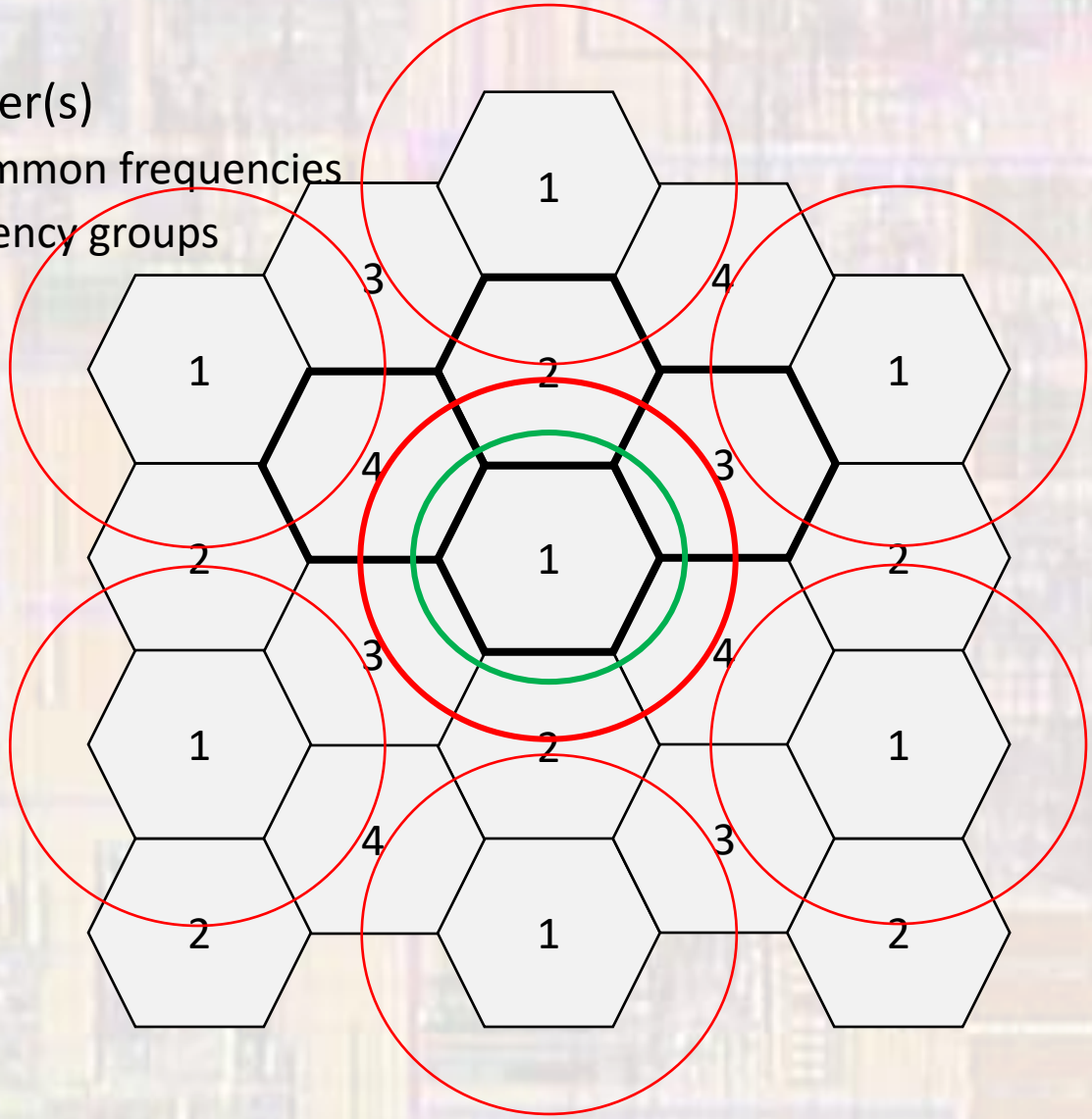
64 frequencies
16 per transmitter (co-channels)



No interference
No gaps

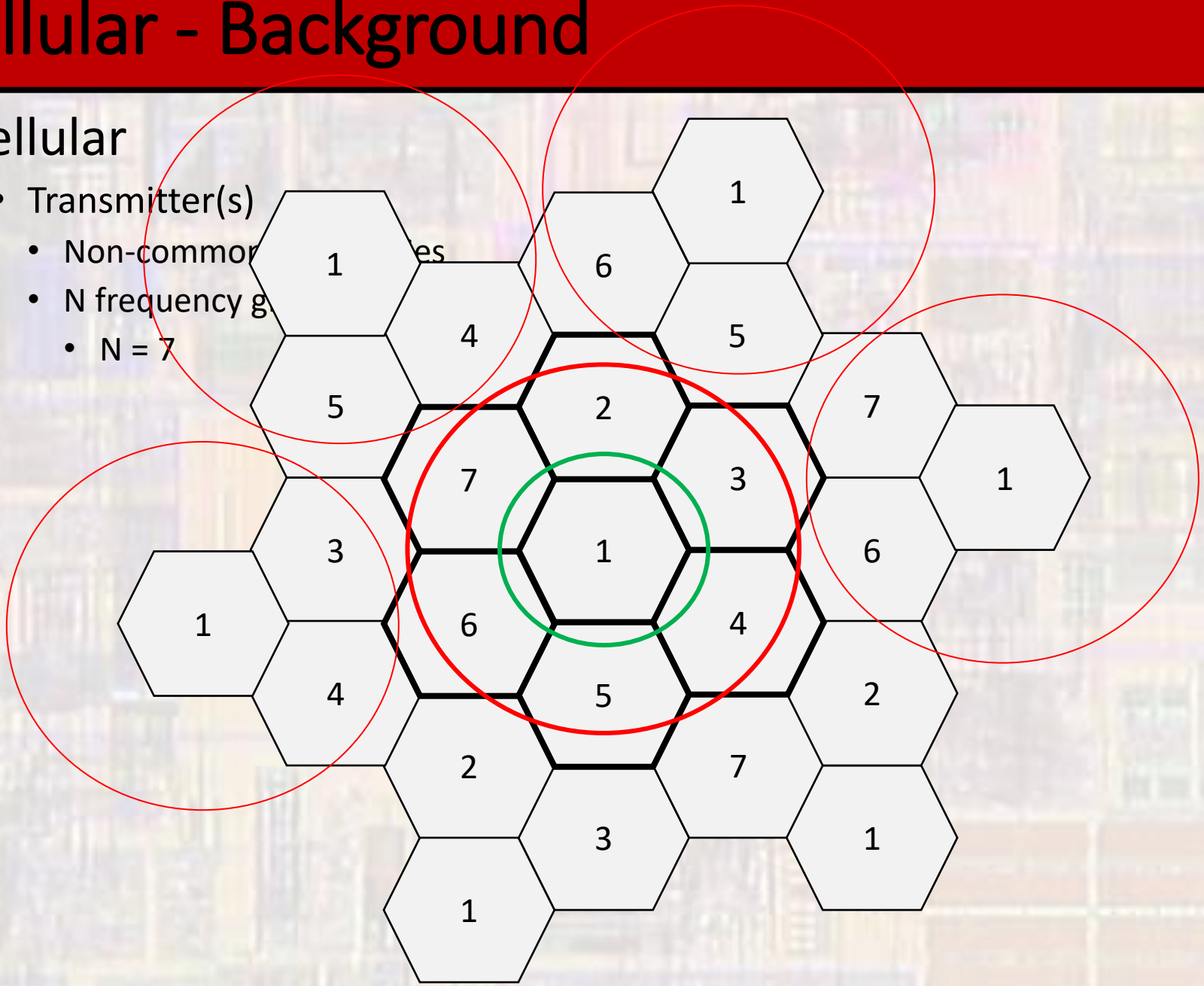
Cellular - Background

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

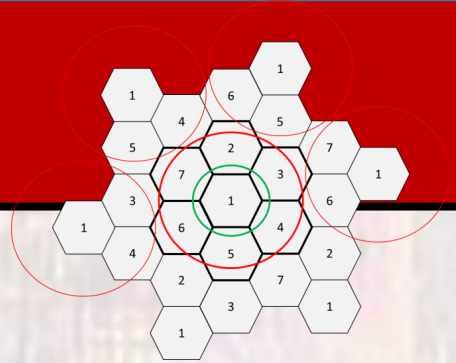


Cellular - Background

- Cellular
  - Transmitter(s)
    - Non-commo[illegible]es
    - N frequency g[illegible]
      - N = 7

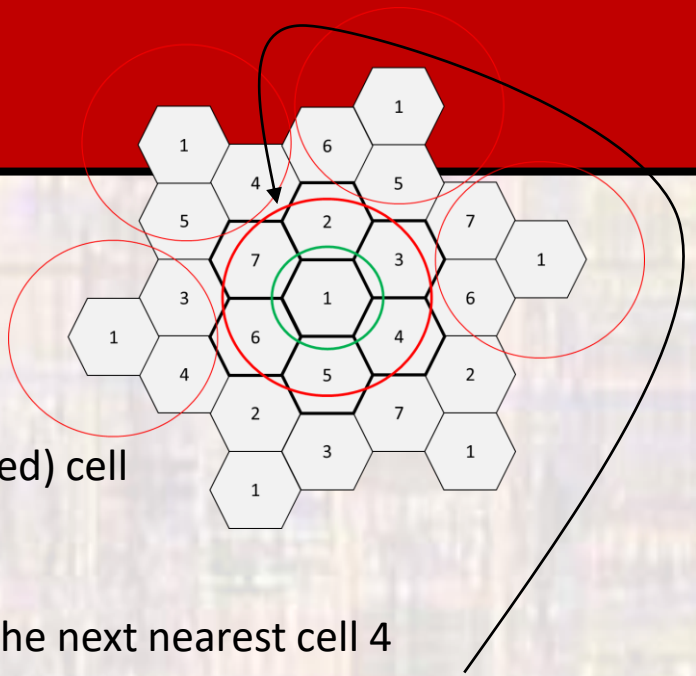


Cellular - Background

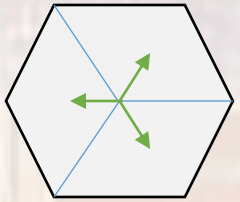


- Cellular
  - Transmitter(s)
    - D – distance between cell centers using the same frequencies(channels)
    - R – radius of a cell
    - N – number of cells in a pattern
      - N = 1, 3, 4, 7, 9, 12, 13, 16, 19, … $N = I^2+J^2+(I \times J)$ I, J = 0, 1, 2, …
    - $D/R = (3N)^{1/2}$
    - Example:
      - Assume 5 co-channels/cell, 25 users/channel at one time, desire to support 625 users in a 25km^2 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*R^2 = 25km^2 → 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

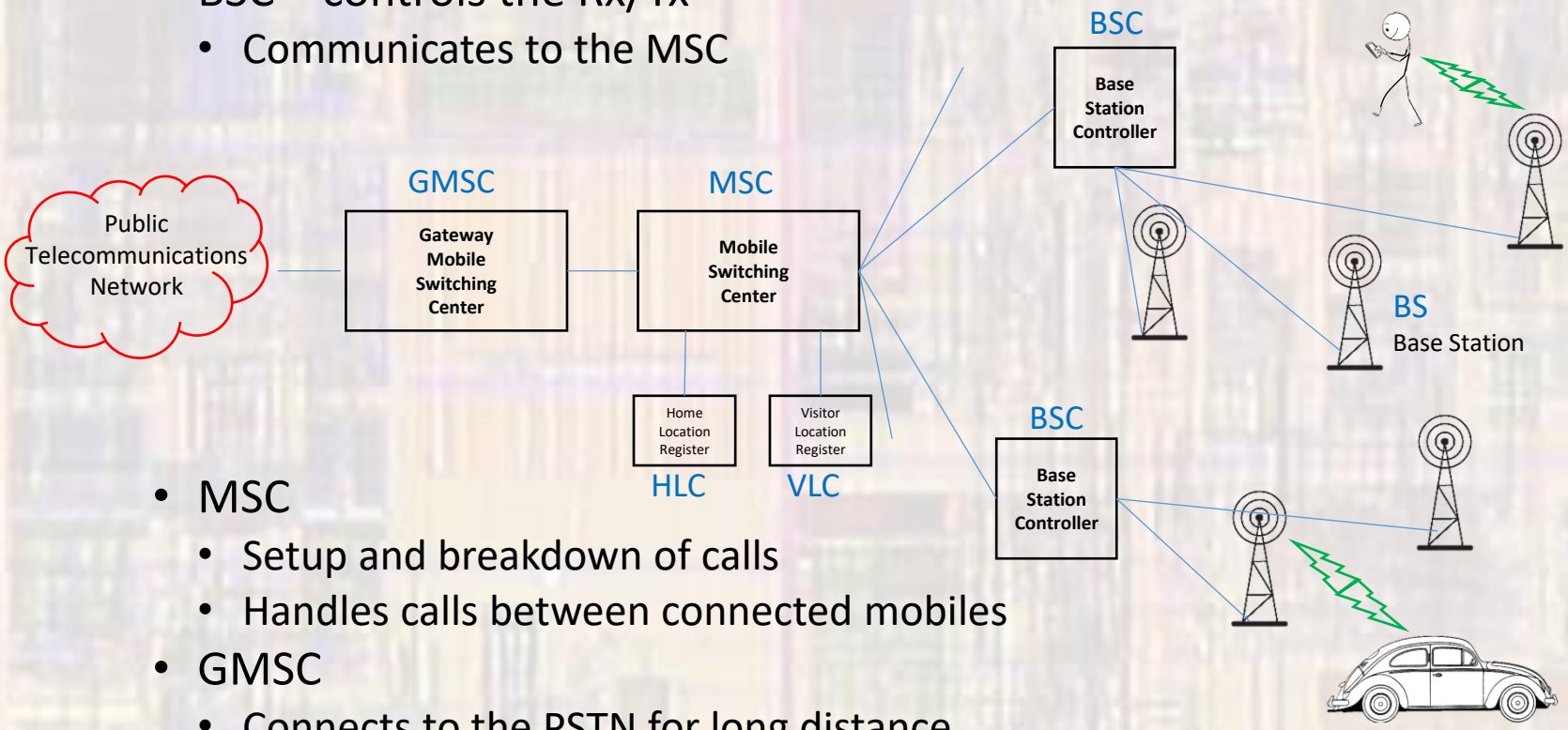
- Circuit Switched
  - Operate similarly to the POTS system
  - Dedicated lines(channels) between callers

- 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

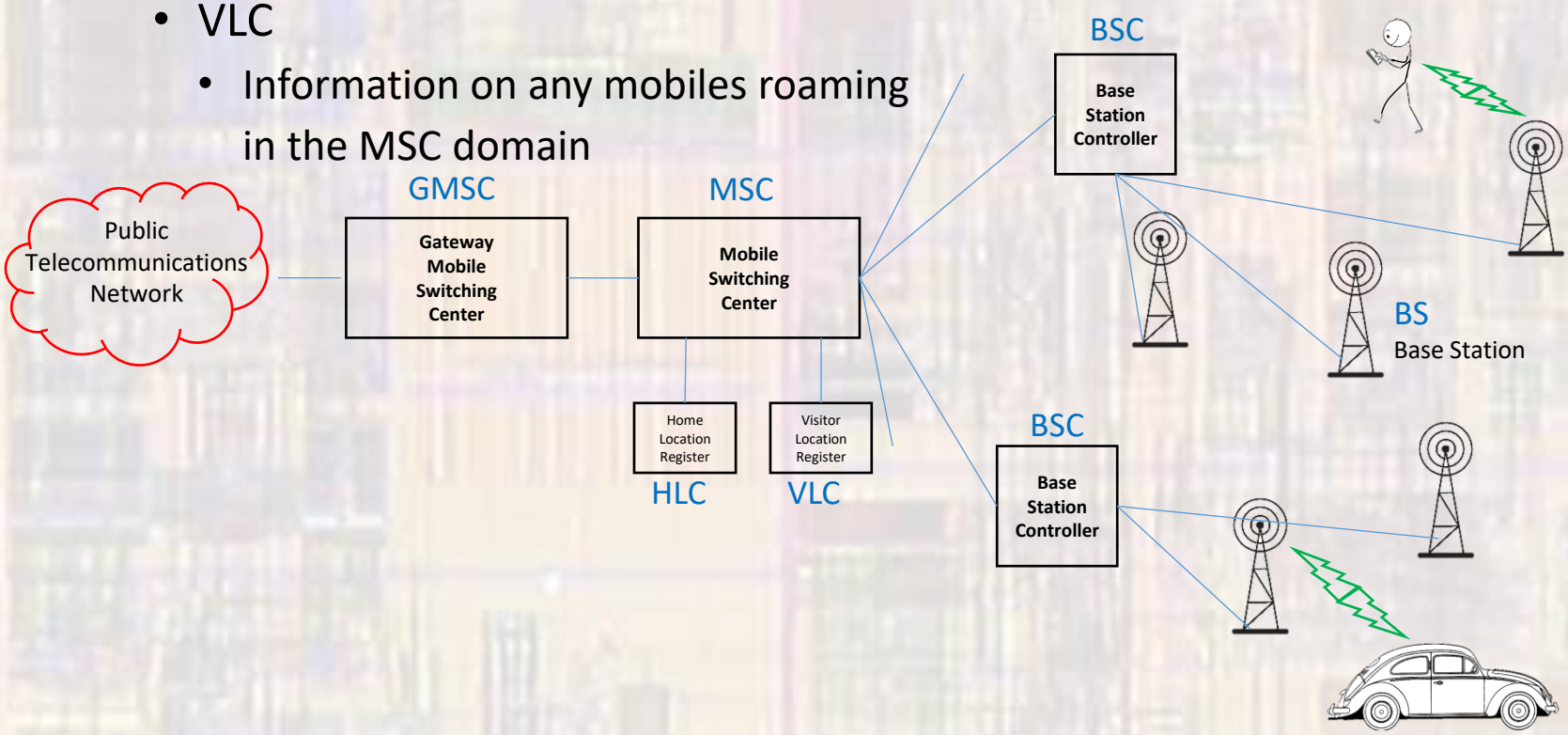
- Components
  - BS – Rx/Tx
    - At least 2 channels: Control, Traffic
  - BSC – controls the Rx/Tx
    - Communicates to the MSC



  - 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

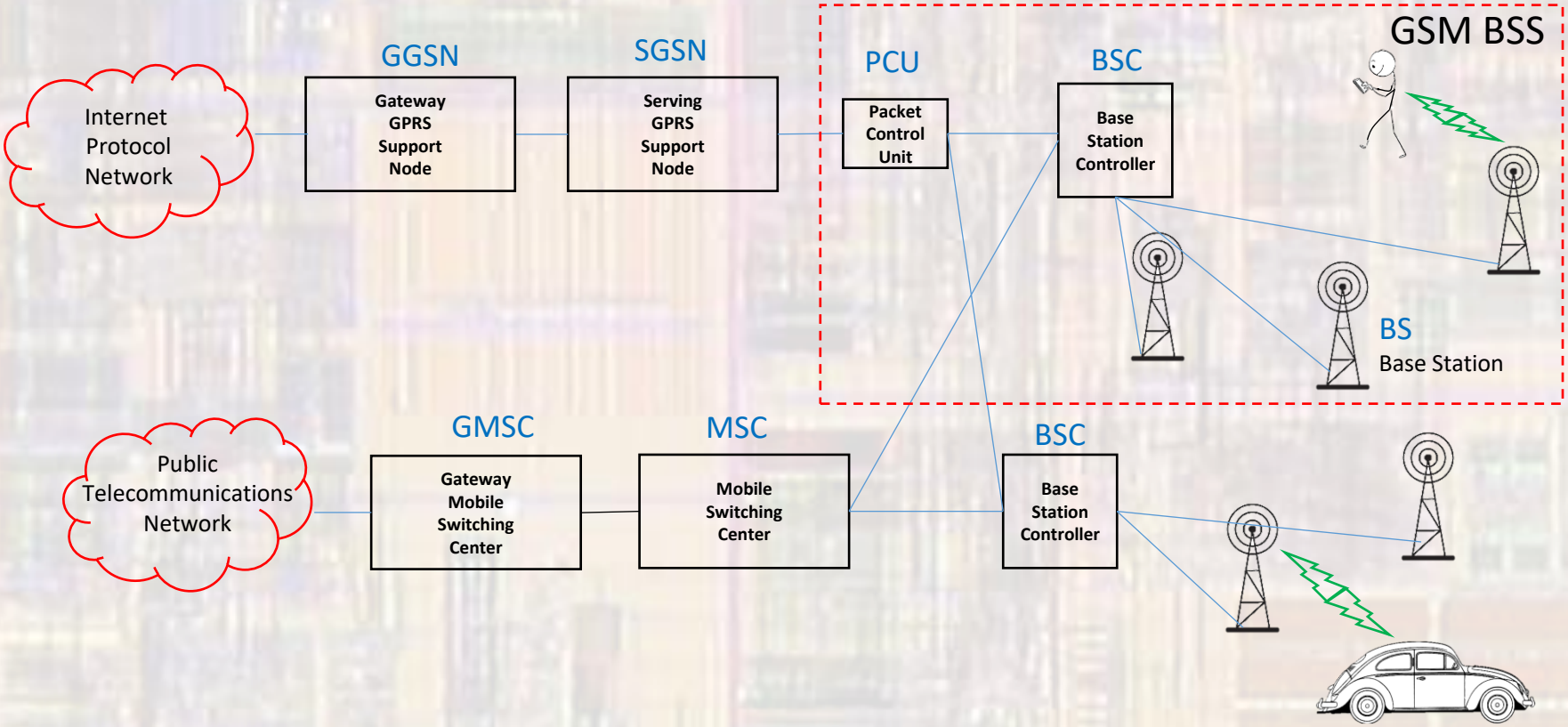
- Packet Switched
  - Uses the IP (internet protocol)
  - Channels are not dedicated to a call
    - Locations identified in packet headers
  - Can carry digitized voice
  - Can carry data
- Systems are backwards compatible to Circuit Switched
- GPRS – 2.5G
  - General Packet Radio Service
  - TDM/FDM 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

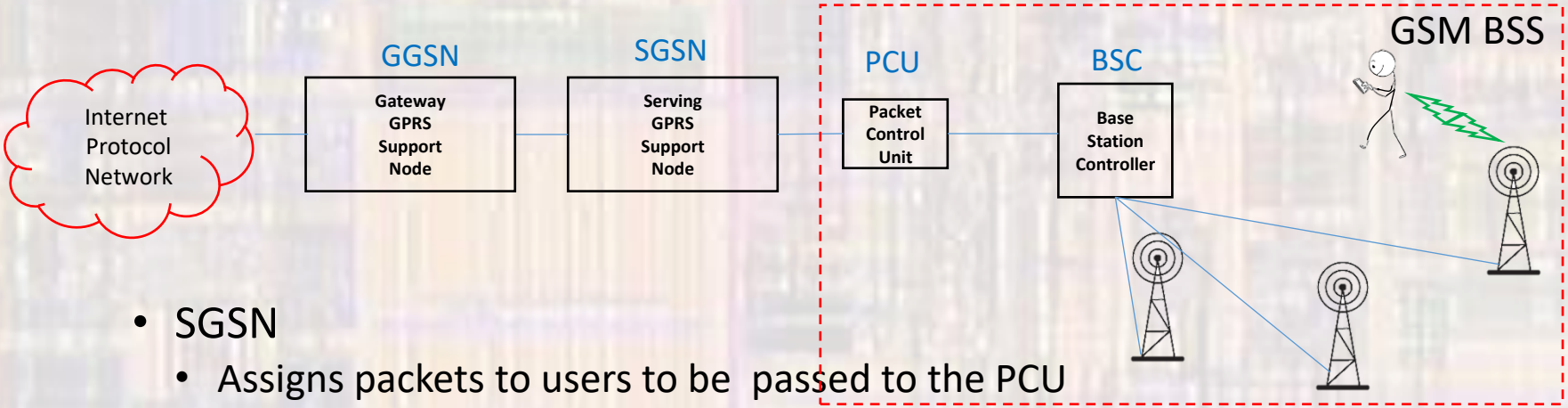
Cellular – Packet Switched

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



Cellular – Packet Switched

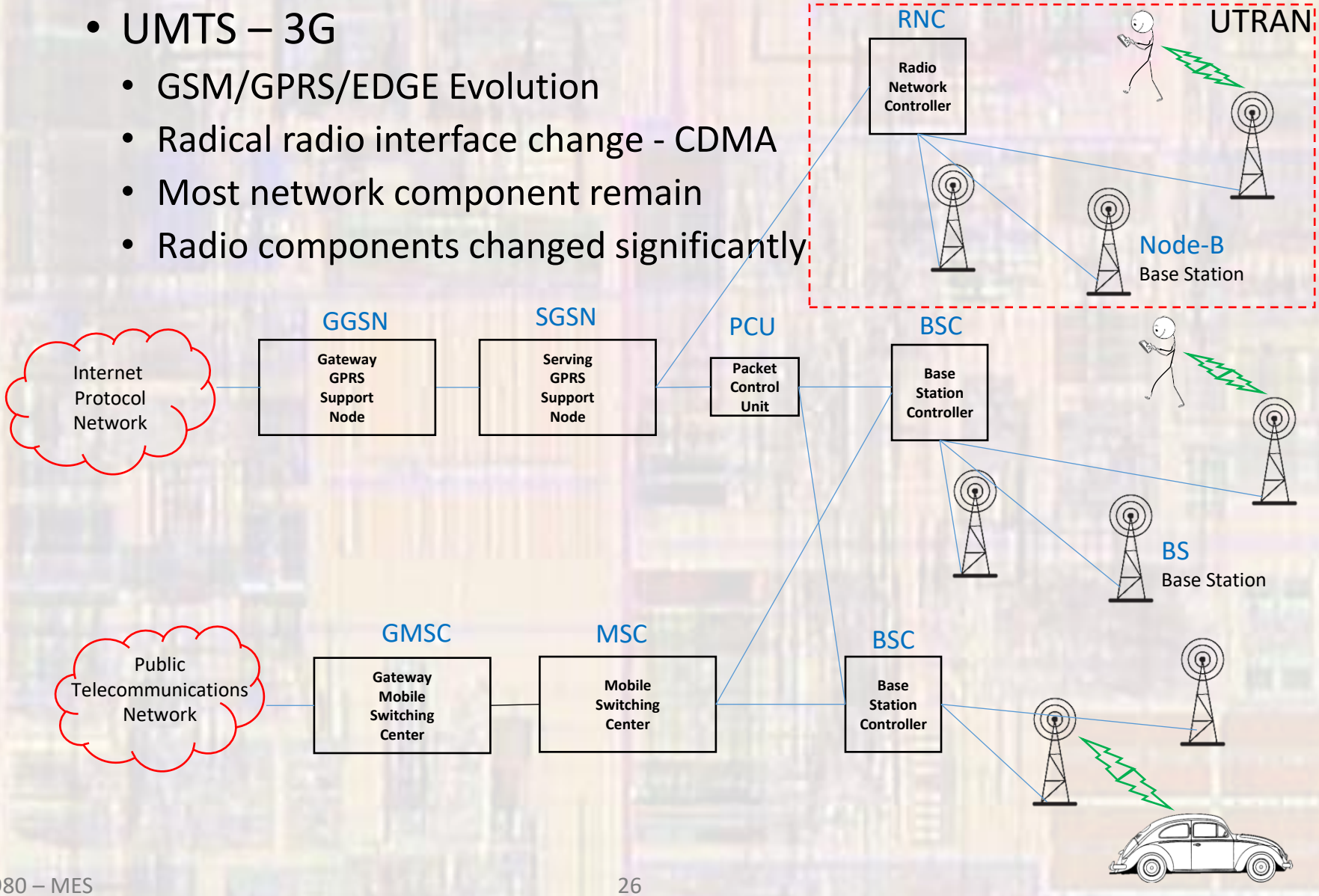
- Packet Switched Systems
  - PCU
    - Assignment of timeslots to users
    - Flow control



  - 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

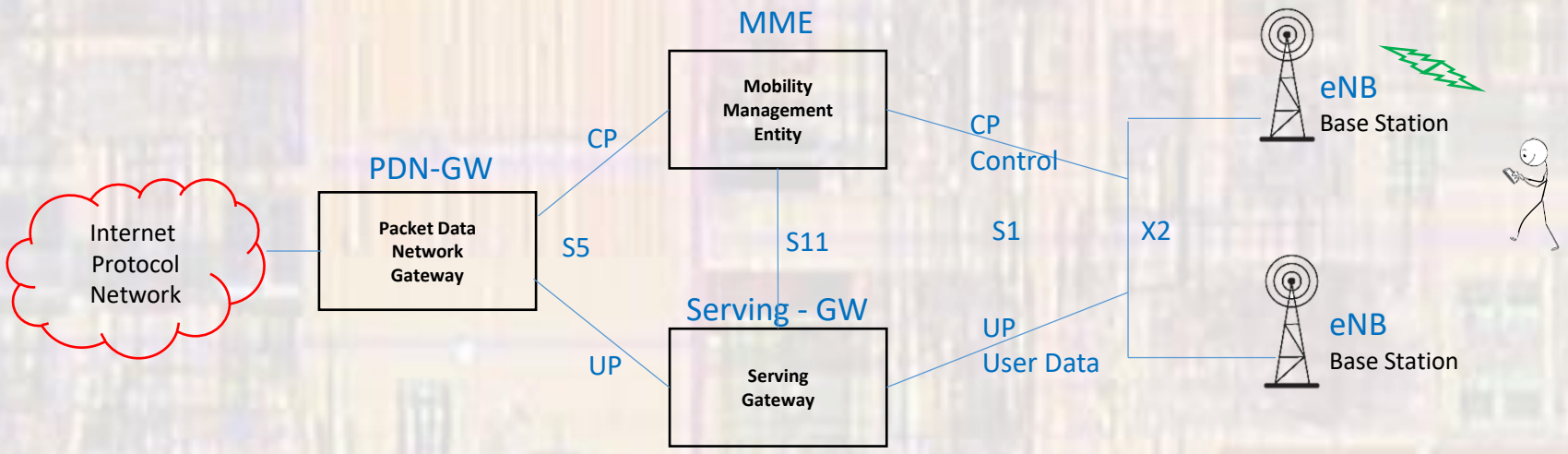
Cellular – Packet Switched

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



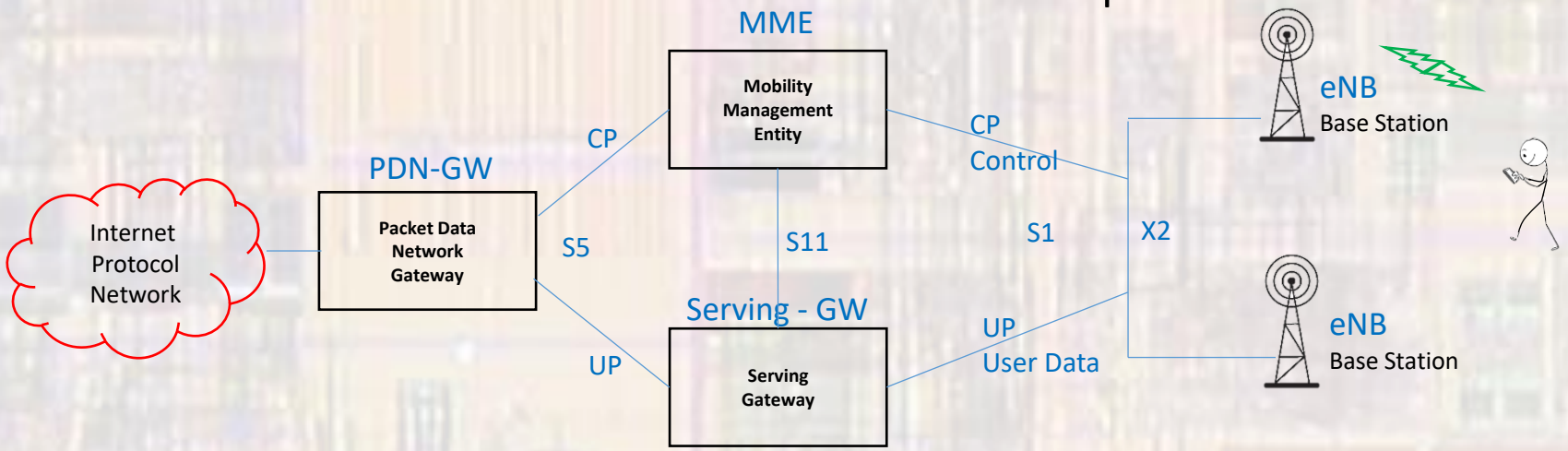
Cellular – Internet

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



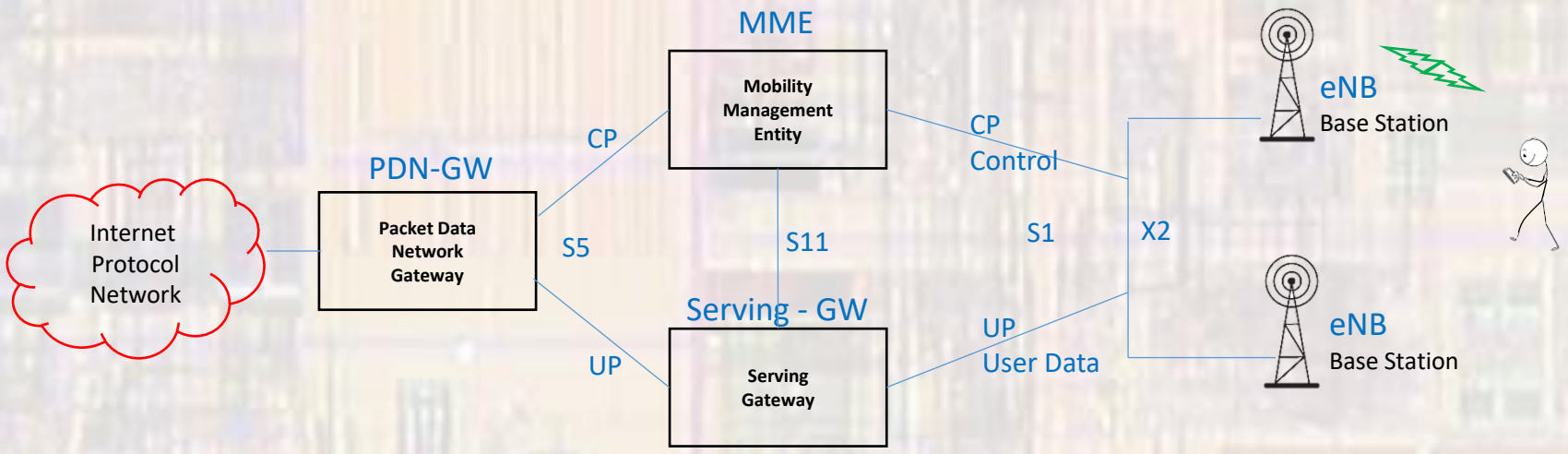
Cellular – Internet

- 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



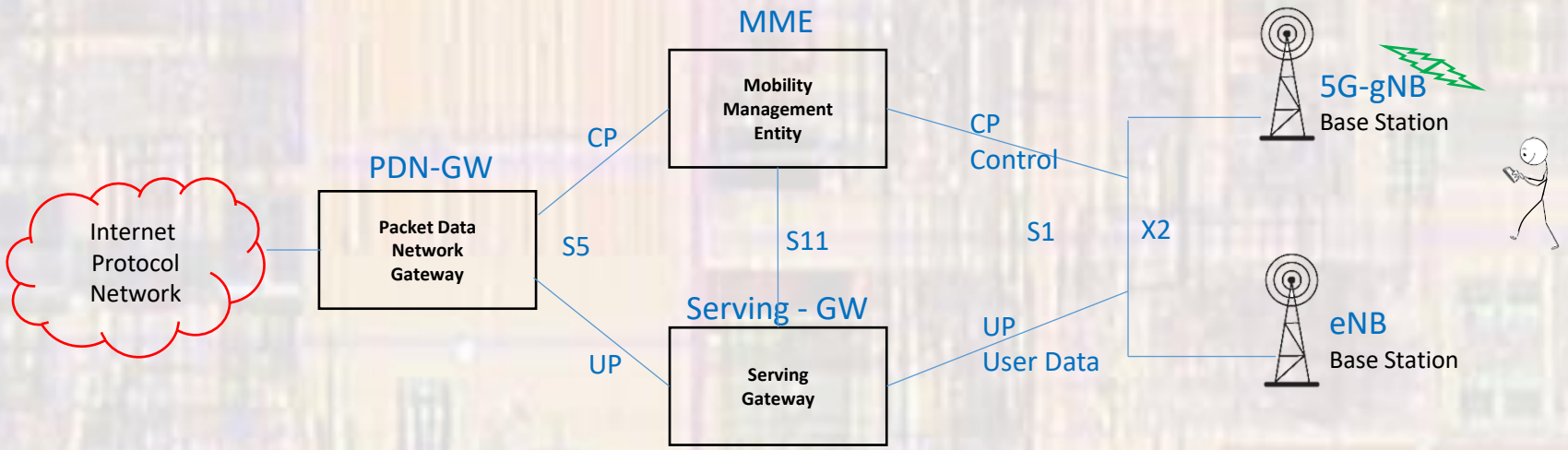
Cellular – Internet

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



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