

Introduction to LTE Advanced Pro (4.5G)



Raj Jain
Washington University in Saint Louis
Saint Louis, MO 63130
Jain@cse.wustl.edu

Slides and Audio/Video recordings of this class lecture
are available at:

<http://www.cse.wustl.edu/~jain/cse574-22/>

Student Questions



1. What is LTE Advanced Pro?
2. LTE Advanced Pro Features in 3GPP Release 13
3. LTE Advanced Pro Features in 3GPP Release 14

Note: This is the 4th module in a series of lectures on 1G to 5G. 5G is covered in the next module.

Student Questions

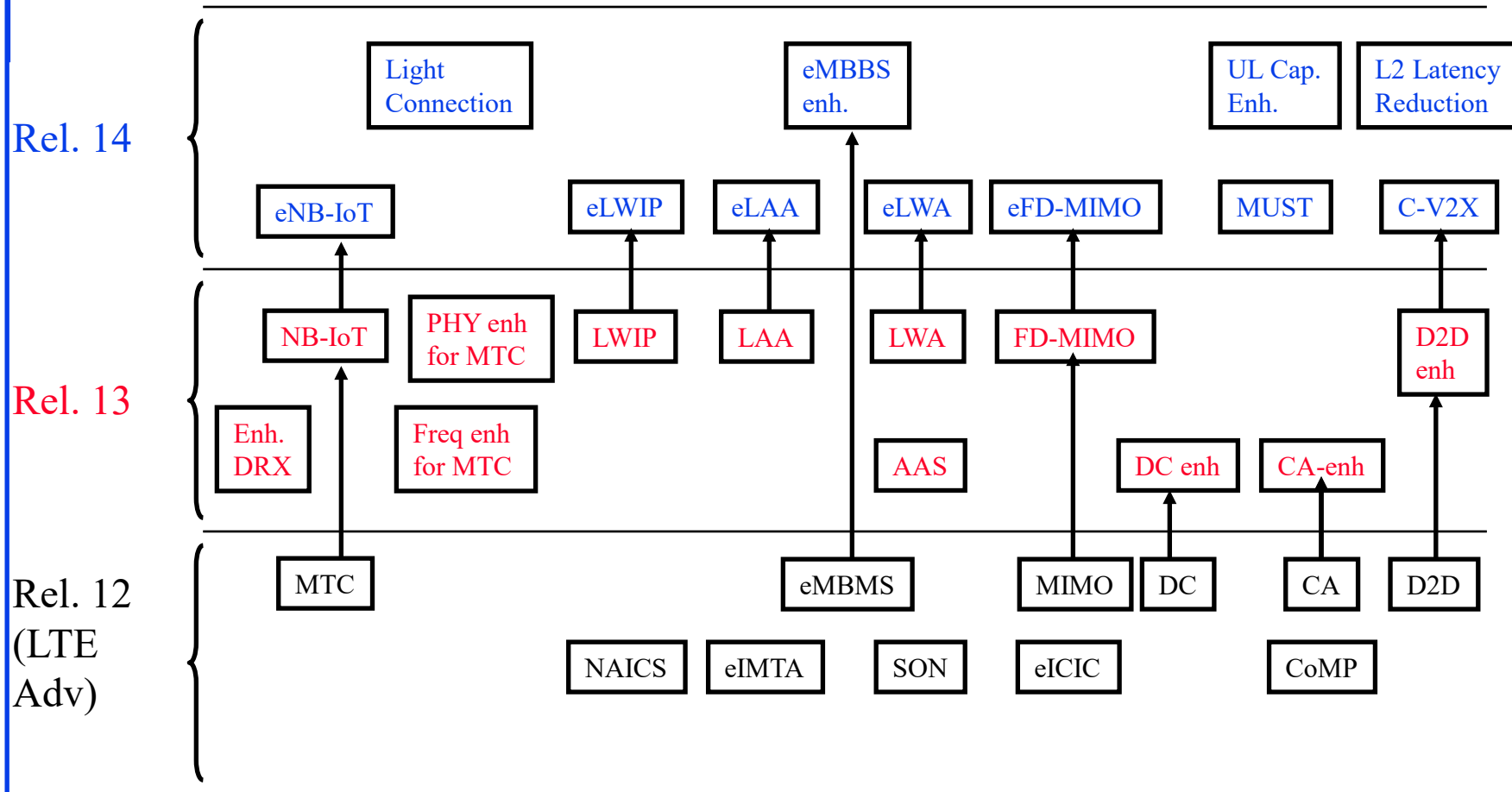
3GPP Releases

- ❑ Rel. 8-9: LTE
- ❑ Rel. 10-12: LTE-Advanced (4G)
- ❑ Rel. 13-14: LTE Advanced-Pro (**4.5G**)
- ❑ Rel. 15: 5G (Phase 1)
- ❑ Rel. 16: 5G (Phase 2)

Student Questions

- ❑ Does LTE NR mean 3.95G but on the New Radio (NR) air interface?
Release 15 is 5G (Phase 1). Release 16 is 5G (Phase 2).

LTE Advanced Pro



Student Questions

- The slide does not have red and blue parts. Does red mean everything followed by Rel 13 {, and blue part mean everything followed by Rel 14 {?

Yes.

Ref: Rohde & Schwarz, "LTE-Advanced Pro Introduction eMBB Technology Components in 3GPP Release 13/14," White paper, 50 pp., https://scdn.rohde-schwarz.com/ur/pws/dl_downloads/premiumdownloads/premium_dl_brochures_and_datasheets/premium_dl_whitepaper/LTE-Advanced-Pro_Introduction_White_paper_en_5215-8258-52_v0100.pdf

Release 13 Features

1. Active Antenna Systems (AAS)
2. Self-Organizing Networks (SON)
3. Elevation Beamforming
4. Inter-eNB CoMP
5. Indoor Positioning
6. Carrier Aggregation Enhancements
7. License Assisted Access (LAA)
8. LTE-WLAN Aggregation Enhancements
9. Wi-Fi with IP Flow Mobility
10. RAN Sharing
11. Enhanced D2D Proximity Services (PROSE)
12. Dual Connectivity Enhancements
13. MTC Enhancements
14. Single-Cell Point-to-Multipoint (SC-PTM)

Student Questions

Release 14 Features

1. Enhance Narrowband IoT (eNB-IoT)
2. Enhanced Machine Type Communications (eMTC)
3. Enhanced LWIP (eLWIP)
4. Enhanced LTE-WLAN Aggregation (eLWA)
5. Enhanced License Assisted Access (eLAA)
6. Enhanced Full-Dimension (eFD) MIMO
7. Enhanced Multimedia Broadcast Multicast Service (eMBMS)
8. **Multiuser Superposition Transmission (MUST)**
9. **Layer 2 (L2) Latency Reduction**
10. **Vehicle to Vehicle (V2X) Based on Sidelink**
11. Uplink (UL) Capacity Enhancements
12. Light Connection

Student Questions

Active Antenna Systems (AAS)

- ❑ Antenna + Transceiver combined \Rightarrow Active Antenna
- ❑ Allows Active antenna arrays
 - Produce dynamically adjustable radiation patterns depending on the current traffic
 - Beam footprint can be adjusted (beamforming)
 - Cell edge can be adapted to load demand
 - Dynamic Cell Splitting: Vertical or horizontal sectors and Smaller footprints \Rightarrow Reduced real-estate costs
 - Software reconfigurations allow easy evolution
- ❑ Allows multi-radio access technologies
- ❑ Allows combining local and wide area technologies

Student Questions

- ❑ It seems that the video talks about this slide, but Slide 19-6 is being seen. Which reference are we talking about?

Rohde and Schwarz removed the referenced link, so we have removed it from the slide.

Self-Organizing Networks (SON)

- ❑ For AAS-based deployments
- ❑ Parameters are now dynamically computed and applied
- ❑ Previous releases had static optimization.
Release 13 extended to dynamic optimization
- ❑ eNB can now signal to neighbor cells any changes in configuration
- ❑ Planned changes are notified in advance to avoid failures

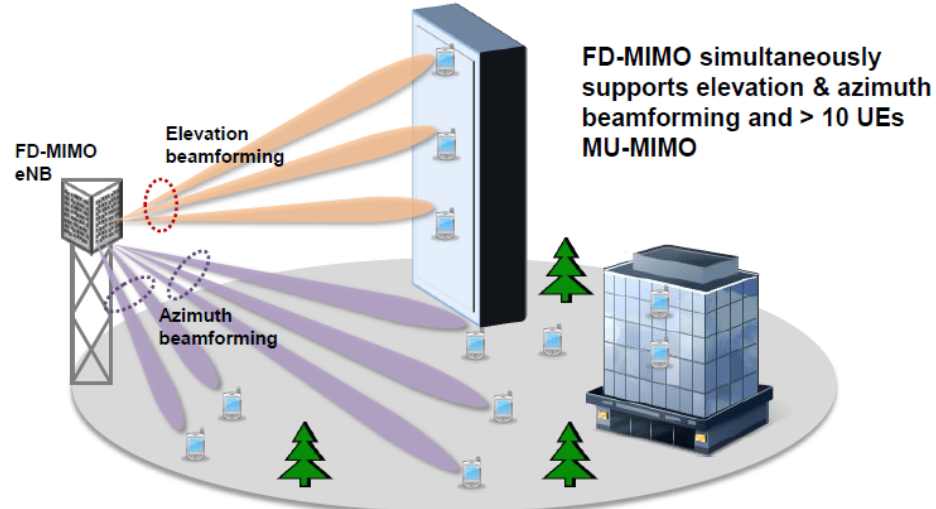
Student Questions

- ❑ How to notify the changes in advance?

When a company plans a change, they input it into the database of one tower and it notifies others automatically.

Elevation Beamforming

- ❑ Aka 3D-MIMO or Full-dimension MIMO (**FD-MIMO**)
- ❑ Infinite Antennas = **Massive MIMO**
- ❑ Require appropriately coded Channel State Information Reference signals (CSI-RS), and Sounding Reference Signals (SRS), and demodulation reference signals (DMRS)
- ❑ 16 Antennas in R13, 32 in R14



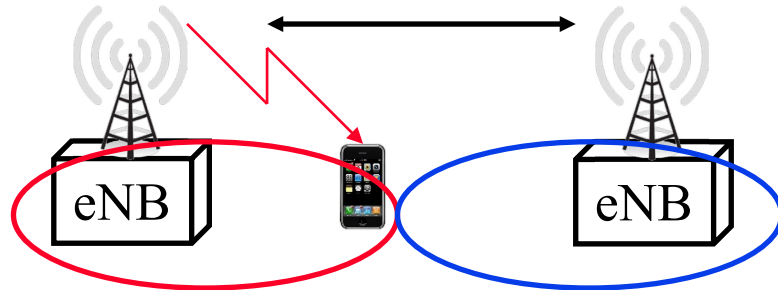
Ref: G. Xu, et al, "Full-Dimension MIMO: Status and Challenges in Design and Implementation," May 2014,
http://www.ieee-ctw.org/2014/slides/session3/CTW_2014_Samsung_FD-MIMO.pdf

Student Questions

- ❑ Is elevation beamforming the same as vertical sector support?
Sectors are more static than beamforming.

Inter-eNB CoMP

- ❑ Coordinated Multipoint Operation (CoMP) in Release 11 was restricted to eNBs connected via ideal backhaul
⇒ No need for network interfaces
- ❑ In Release 12, a signaling interface has been added which allows eNBs to interchange measurement and resource allocation information
- ❑ In Release 13, new signaling elements were added



Student Questions

- ❑ What are the new signaling elements and what are they used for?

New signaling elements were added for Inter-eNB CoMP.

Machine Type Communication

- ❑ **LTE Low-cast (Category 0) UE:** In Release 12.
 - Single Antenna
 - Reduced peak rate up to 1 Mbps
 - Half-Duplex \Rightarrow No duplex filter
 - Power saving mode (PSM)
- ❑ **MTC LTE (LTE Cat-M1) UE:** In Release 13.
 - 1 Mbps using 1.4 MHz = 6 Physical Resource Blocks (PRB)
 - All power on fewer subcarriers
 - \Rightarrow **Power Spectral Density (PSD) Boosting**
 - \Rightarrow 15 dB reduction in link budget by PSD and repetition
 - \Rightarrow Allows UEs in basements and indoors
 - Reduced Tx power to 20 dBm \Rightarrow integrated amplifier
 - Popular in North America
- ❑ **Narrow Band IoT (NB-IoT or LTE Cat-NB1)** introduced Category -2 UE:
 - 128 kbps using 200 kHz band = Single PRB
 - 23 dBm power (required to maintain the link budget)
 - Most promising IoT protocol. Already in use in China. Popular in Europe.
- ❑ Both LTE-M and NB-LTE UEs use single RF chain

Student Questions

- ❑ Can you clarify what you mean by "link budget" in Narrow Band IoT?

Link Budget = Allowed power loss in the link

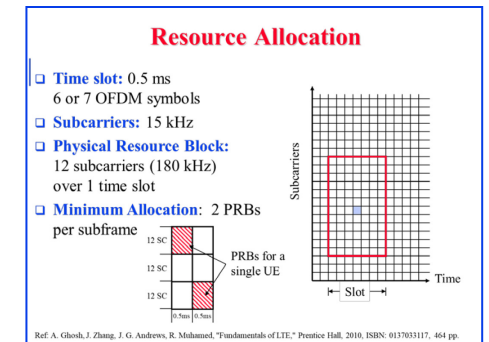
= Transmit power – Received power

If a receiver is not sensitive, it needs a larger receive power. Therefore, we need a large transmit power too.

- ❑ What is a Physical Resource Block?

Defined in Slide 17-20.

PRB = 0.5 ms x 12 subcarriers



Machine Type Communication

- ❑ **LTE Low-cast (Category 0) UE:** In Release 12.
 - Single Antenna
 - Reduced peak rate up to 1 Mbps
 - Half-Duplex \Rightarrow No duplex filter
 - Power saving mode (PSM)
- ❑ **MTC LTE (LTE Cat-M1) UE:** In Release 13.
 - 1 Mbps using 1.4 MHz = 6 Physical Resource Blocks (PRB)
 - All power on fewer subcarriers
 - \Rightarrow **Power Spectral Density (PSD)** Boosting
 - \Rightarrow 15 dB reduction in link budget by PSD and repetition
 - \Rightarrow Allows UEs in basements and indoors
 - Reduced Tx power to 20 dBm \Rightarrow integrated amplifier
 - Popular in North America
- ❑ **Narrow Band IoT (NB-IoT or LTE Cat-NB1)** introduced Category -2 UE:
 - 128 kbps using 200 kHz band = Single PRB
 - 23 dBm power (required to maintain the link budget)
 - Most promising IoT protocol. Already in use in China. Popular in Europe.
- ❑ Both LTE-M and NB-LTE UEs use single RF chain

Student Questions

- ❑ How did we calculate the 6 Physical Resource Blocks (PRB)?
 $6 \text{ PRB} = 15 \text{ kHz} * 12 * 6 = 1.08 \text{ MHz}$
- ❑ Which frequencies do the reduced bandwidth modes use? Can they occupy any 200 kHz band within the LTE frequency band allocation?
 $200 \text{ kHz} \approx 1 \text{ PRB}$
- ❑ What do "category 0" and "category -2" mean? You mentioned that it's cheaper for Category -2. Is there any relationship?
Categories are indicated in this slide.

Machine Type Communication

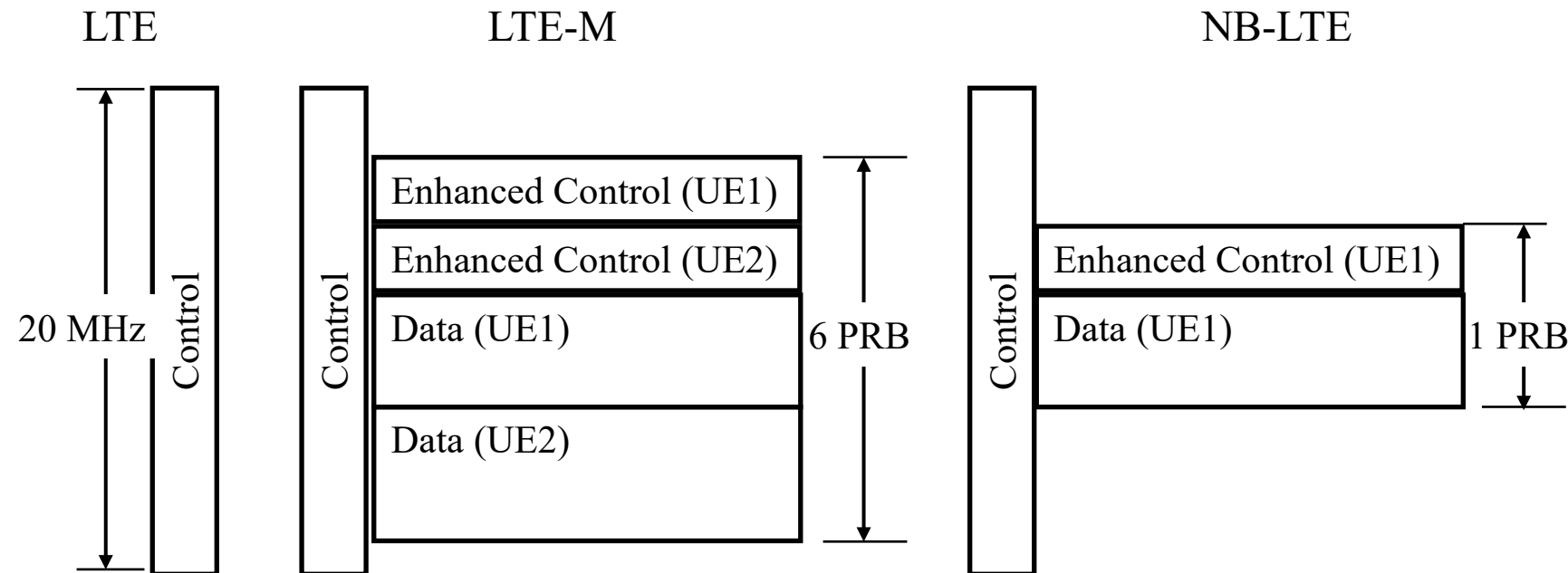
- ❑ **LTE Low-cast (Category 0) UE:** In Release 12.
 - Single Antenna
 - Reduced peak rate up to 1 Mbps
 - Half-Duplex \Rightarrow No duplex filter
 - Power saving mode (PSM)
- ❑ **MTC LTE (LTE Cat-M1) UE:** In Release 13.
 - 1 Mbps using 1.4 MHz = 6 Physical Resource Blocks (PRB)
 - All power on fewer subcarriers
 - \Rightarrow **Power Spectral Density (PSD) Boosting**
 - \Rightarrow 15 dB reduction in link budget by PSD and repetition
 - \Rightarrow Allows UEs in basements and indoors
 - Reduced Tx power to 20 dBm \Rightarrow integrated amplifier
 - Popular in North America
- ❑ **Narrow Band IoT (NB-IoT or LTE Cat-NB1)** introduced Category -2 UE:
 - 128 kbps using 200 kHz band = Single PRB
 - 23 dBm power (required to maintain the link budget)
 - Most promising IoT protocol. Already in use in China. Popular in Europe.
- ❑ Both LTE-M and NB-LTE UEs use single RF chain

Student Questions

- ❖ What is PSD boosting?
Higher power spectral density

Signaling Enhancements for MTC

- ❑ Enhanced Physical Downlink Control Channel (EPDCCH)
- ❑ LTE Cat 0 UE receives signaling in the entire 20 MHz band
- ❑ LTE-M UEs receive signaling in their 1.4 MHz band
- ❑ For NB-LTE UEs, signaling is part of the assigned PRB



Student Questions

Power Saving Mode (PSM)

- ❑ Discontinuous Reception (DRX). Introduced in Release 12
- ❑ Allows UE to stay registered while sleeping
- ❑ UE's need to monitor resource allocation channel even if it has nothing to send or receive
- ❑ Connected mode DRX (cDRX): UE can sleep and periodically wake up to check the control channel
 - Short sleep cycle: 5 to 400 ms
 - Long sleep cycle: 20 ms to 2.5s
(if no activity for four short cycles)



Student Questions

Indoor Positioning

- ❑ FCC requires indoor positioning for E911
 - x/y location within 50 m by 2021
 - Provide z location by 2023
- ❑ Position can be determined by:
 - Barometric sensors
 - Wireless LANs
 - Bluetooth beacons
 - Terrestrial beacon system broadcasting signals for positioning, e.g., Metropolitan Beacon Systems (MBS)
- ❑ R13 supports only standalone mode, and UE-assisted mode without network assistance is supported. Only MBS is supported.
- ❑ R14 introduced advanced techniques using Enhanced Cell-ID and Observed Time Difference of Arrival.

Student Questions

- ❑ Do you know if the z dimension for indoor positioning is implemented yet, seeing that 2023 is only a month and a half away?

3D positioning is a simple extension of 2D positioning with increased cost. Yes, 3D GPS is available on smartphones.

Carrier Aggregation Enhancements

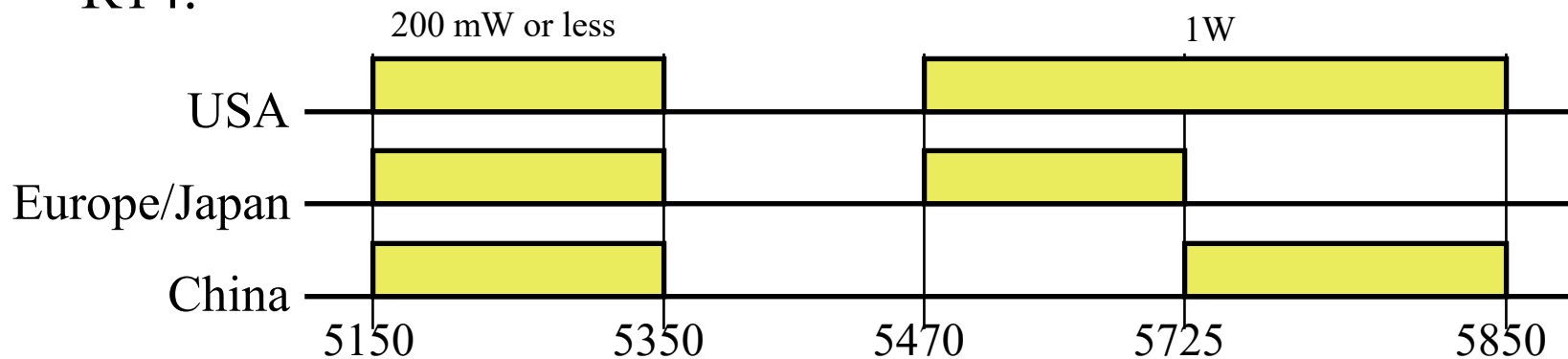
- ❑ CA was introduced in R10
- ❑ R12 limited to 5 carriers \Rightarrow 100 MHz
- ❑ R13 extended to 32 carriers \Rightarrow 640 MHz
 - Both FDD and TDD
 - Inter-band and Intra-band
 - Licensed and Unlicensed
- ❑ 64-QAM can be used with carrier aggregation

Student Questions

- ❑ What is meant by the point
Licensed and Unlicensed?
Unlicensed = ISM bands

License Assisted Access (LAA)

- ❑ 5 GHz band for public hot spots and in-building
- ❑ Different rules and bands in different countries, e.g.,
 - Avoid if a radar is operating
 - Can't block 20 MHz if using only 180 kHz
 - Transmit only if accessible. Recheck after maximum occupancy time \Rightarrow Can not transmit continuously as in standard LTE
- ❑ Carrier aggregation with the unlicensed band and licensed band when possible. DL enhancement in R13. UL enhancements in R14.



Student Questions

LAA (Cont)

- ❑ End-to-End LTE \Rightarrow Better integration than with Wi-Fi
- ❑ Before R13, several different solutions called LTE-U were used.
- ❑ R13 introduced a global standard to include a 5 GHz unlicensed band using several 20 MHz channels
- ❑ To coexist with Wi-Fi, LAA uses
 - Listen before talk
 - Discontinuous transmission on a carrier with a limited maximum transmission duration
 - Dynamic frequency selection to avoid interference with radar systems in some regions
 - Multicarrier transmission across multiple unlicensed channels

Student Questions

- ❑ Does Wi-Fi data get preference?
Yes.

LTE-WLAN Aggregation Enhancements

- ❑ LTE-WLAN aggregation (LWA) was introduced in R12
- ❑ In R13:
 - LTE_WLAN Radio Level Integration with IPsec tunnel (LWIP) allows both uplink and downlink traffic to be sent over WLAN
 - RAN Controlled LTE-WLAN interworking (RCLWL) allows eNB to send traffic steering commands to UE based on UE measurements

Student Questions

- ❑ Is this technology labeled as Wi-Fi calling by carriers?

Yes.

Wi-Fi with IP Flow Mobility

- ❑ Network Based Internet Protocol Flow Mobility (NBIFOM)
- ❑ IP flows can be steered towards PDN or Wi-Fi
- ❑ Trusted and untrusted WLAN interfaces have been defined.
- ❑ Similar to but different from LTE-WLAN aggregation (LWA)
- ❑ Even Voice and Video traffic can be sent over Wi-Fi
⇒ Allows increased coverage area.

Student Questions

- ❑ What are the differences from LWA?

See the previous two bullets

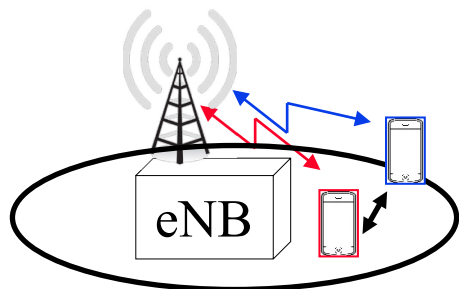
RAN Sharing

- ❑ Multiple operators can share a radio access network (RAN)
- ❑ Each operator runs a “Public Land Mobile Network (PLMN).”
- ❑ Owner operator can put limits on the total UL/DL load of sharing PLMNs
- ❑ QoS profile can also be limited as agreed

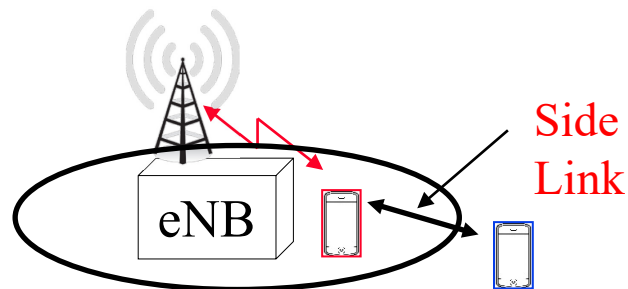
Student Questions

Enhanced D2D Proximity Services (PROSE)

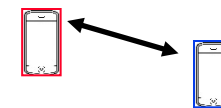
- ❑ Device-to-Device (D2D) was introduced in R12
- ❑ In R13:
 - UEs can search multiple PLMNs for “side-link.”
 - Out-of-coverage D2D discovery
 - Support for relaying using D2D. L3 relay was defined. Public safety personnel can connect to the network through other mobiles.



(a)



(b)



(c) First Responders only

Student Questions

- ❑ What is a "side-link"? You pointed it out in the diagram, could you indicate where it is again?

Done. Slide updated.

- ❑ How could the carrier detect (and charge) side links? The traffic won't go through the base station, but we use its registered bandwidth.

Side Link is enabled only on phones paying for this service. It may not be use based

Dual Connectivity Enhancements

- ❑ Dual connectivity was introduced in R12
Allowed only downlink throughput enhancement
- ❑ In R13:
 - Uplink bearer split
 - UE splits the traffic only if the queue is over a threshold
 - Timing differences between two bears are handled
⇒ Allows dual connectivity to different operators
 - Traffic steering is supported.
Local traffic and Selective IP traffic can be directed toward small cell to avoid overloading the core network

Student Questions

Extended Discontinuous Reception (DRX)

- ❑ Power Saving Mode (PSM) was introduced in R12 to allow IoT devices to save power. Requires frequent periodic registration.
- ❑ In R13:
 - Idle mode DRX cycles can be extended to 45 minutes (for non-NB-IoT) or 3 hours for NB-IoT
 - Active mode DRX cycle can be extended to 10 s
- ❑ User Element (UE) States:
 - **Disconnected**: All electronics off. Will not ring if called.
 - **Power Saving Mode**: Sleeping. Most electronics off. Will ring if called.
 - **Idle Mode**: Nothing to send/receive. Some electronics off. Keeps track of towers if moving.
 - **Active Mode**: Transmitting/receiving. Electronics are on. DRX allows some parts off during pauses.



Student Questions

- ❑ Is the action sending done during idle mode or active mode? You said during sending you can sleep but I wasn't sure if sleep = idle?

Slide updated

LTE Cat-M1

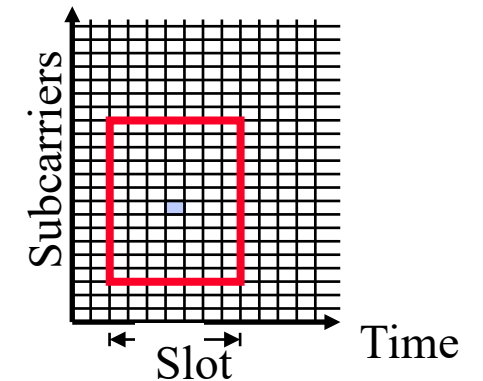
- ❑ For machine-type communication in Release 13.
- ❑ 1 Mbps using 1.4 MHz = 6 Physical Resource Blocks (PRB)
- ❑ Signaling inside 1.4 MHz \Rightarrow Do not need to listen to 20 MHz
- ❑ All power on fewer subcarriers
 - \Rightarrow **P**ower **S**pectral **D**ensity (**PSD**) Boosting
 - \Rightarrow 15 dB reduction in link budget by PSD and repetition
 - \Rightarrow Allows UEs in basements and indoors
- ❑ Reduced Tx power to 20 dBm
 - \Rightarrow integrated amplifier
- ❑ Popular in North America

Student Questions

- ❑ What is a physical resource block?

LTE Slide 17-20

Minimum allocation is 12 carriers for one slot



Cat-0 vs. Cat-M1

	Cat-0	Cat-M1
Downlink	64-QAM	16-QAM
Uplink	16-QAM	16-QAM
Bandwidth	Full	1.08 MHz
Peak Rate	1Mbps (DL/UL)	1 Mbps (DL/UL)
Power Classes	23 dBm	23 dBm, 20 dBm
Path loss	140.7 dB	155.7 dB

Not used

Student Questions

- Is the M1 category designed for sensors because of the UL peak rate is higher than DL peak rate?

Slide has been updated.

- Why is the downlink less than uplink? You also mentioned that bandwidth needs to be changed from 1.08 MHz to something, what should it be changed to?

It is 1.08 MHz.

Ref: P. Reininger, "3GPP Standards for the Internet-of-Things," Presentation at Smart Summit Singapore, Nov 2016, 17 pp.,

<https://tinyurl.com/3gpprel13>

Narrow Band IoT (NB-IoT)

- ❑ **LTE Cat-NB1** or Category -2 UE also in Release 13.
- ❑ Designed for the ultra-low-cost (<\$5), low data rate, high power efficiency, deep in-house coverage
 - No handovers while active
 - No channel measurements
 - No MIMO
 - QPSK or BPSK
 - Single RF Chain \Rightarrow Half-duplex
 - Data repetition to enable deep in-house coverage
- ❑ 15 uW in idle state, 500 mW in transmitting.
A 5 W-hr battery will last ten years
- ❑ Most promising IoT protocol. Already in use in China. Popular in Europe.

Ref: Hossam Fattah, "5G LTE Narrowband Internet of Things (NB-IoT)," CRC Press, Boca Raton, 3 September 2018, 262 pp., ISBN 9780429847585

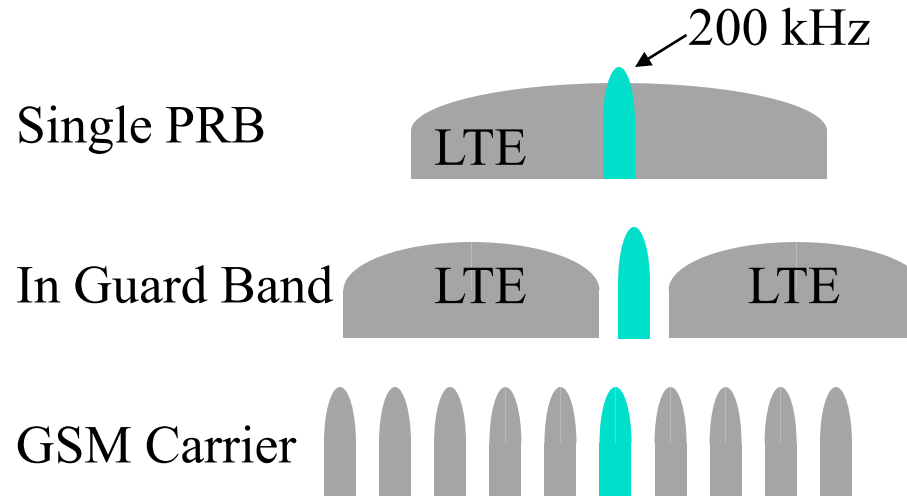
Student Questions

- ❑ What is meant by "no handover when active"? You need to reboot if you want to connect to a new master device? Or just no handover during a transmission.

IoT devices cannot move while they have active connection. They have to disconnect, move if needed, and reconnect.

Band for NB-IoT

- ❑ 128 kbps using 180 kHz band = Single PRB of 12 subcarriers (12 tones)
- ❑ Can be in-band, in-guard-band, or out-of-band using a 200 kHz GSM carrier
- ❑ All three deployments invisible to non-NB-IoT devices
- ❑ Optionally concentrate power in 3.75 kHz tone to allow longer distance transmissions.
- ❑ All 12 tones in DL.
1, 3, 6, or 12 tones in UL.



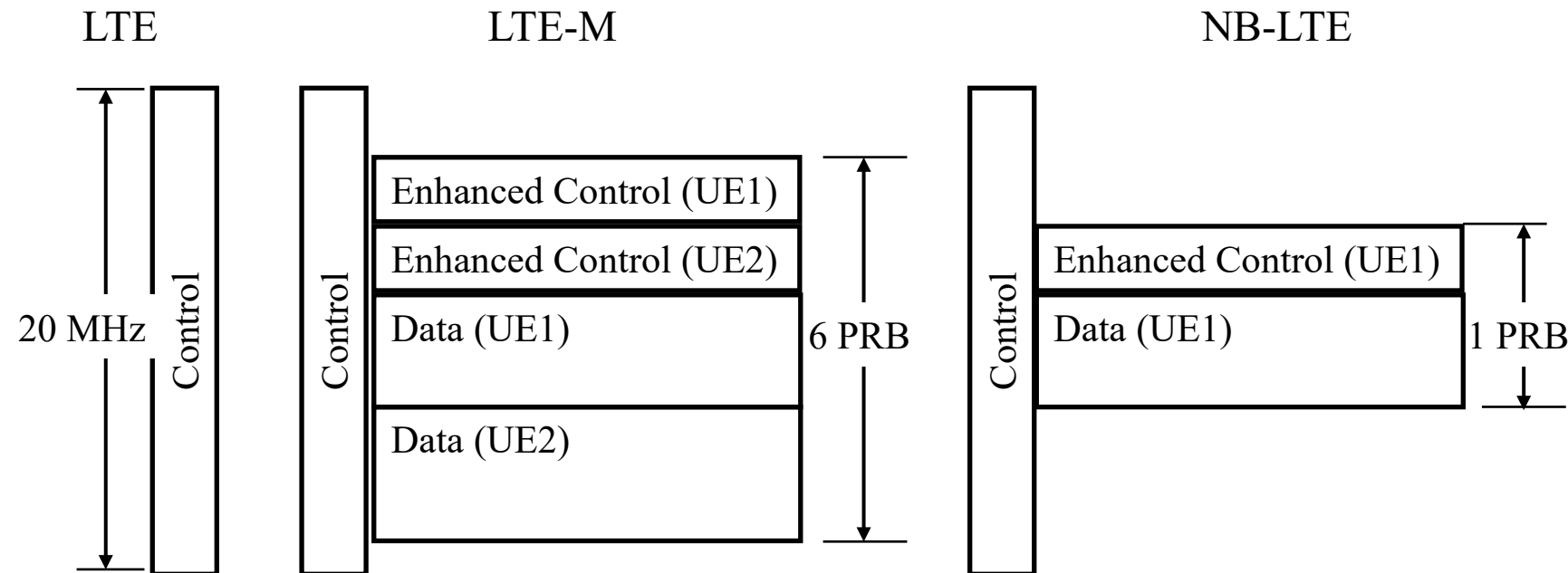
Student Questions

- ❑ What exactly is a "tone"?
subcarrier

- ❑ What is meant by tones?
See 1st bullet

Signaling Enhancements for MTC

- ❑ Enhanced Physical Downlink Control Channel (EPDCCH)
- ❑ LTE Cat 0 UE receives signaling in the entire 20 MHz band
- ❑ LTE-M UEs receive signaling in their 1.4 MHz band
- ❑ For NB-LTE UEs, signaling is part of the assigned PRB



Student Questions

Carriers for NB-IoT

- ❑ Several NB-IoT channels/carriers per sector. One anchor carrier is used to broadcast system information, control, and shared channels.
- ❑ All devices in idle state camp on this anchor carrier. Can be scheduled to receive/transmit on non-anchor carriers.
- ❑ Can serve up to 50,000 devices per sector
- ❑ In R13, paging and random access only on anchor carriers
In R14, this can be done on non-anchor carriers also.
- ❑ In R13, two UE power classes: 20 dBm and 23 dBm
In R14, one more UE power class with 14 dBm

Student Questions

- ❑ So does this mean that as of R14, the anchor channel is no longer used because any channel can be used as an anchor channel?

Anchor carriers are used. Not at a fixed location.

NB1 Energy Saving Mechanisms

❑ **Extended Idle Mode Discontinuous Reception (eDRX):**

- Normal LTE devices listen to paging every 1.28s in an idle state.
- NB1 devices can request to extend this to 5.12s to 43.69 minutes. If the network accepts, the device can power off for that long without losing its state, including the IP address.

❑ **Power Save Mode:** LTE devices must perform periodic tracking area updates. NB1 devices can extend this update timer to several days.

❑ **Control Plane CIoT EPS Optimization:**

NB1 user data can be sent/received in control channels
⇒ No need to schedule user data bearer

❑ **Non-IP Data Delivery (NIDD):** A Service Capability Exposure Function (SCEF) encapsulates/decapsulates IP packets and sends/receives data without IP headers to/from NB1 device

Student Questions

MTC Enhancements in R14

- ❑ More accurate positioning
- ❑ Multicast to several UEs
- ❑ Improvement to VoLTE speech with enhanced coverage
Packet bundling at application and MAC layers
- ❑ Higher data rates: Cat NB2
 - 2536 bits per transmission in UL and DL
compared to 1000 bits in UL and 680 bits in DL for NB1
 - Two HARQ processes instead of one
 - 127 kbps in DL and 159 kbps in UL

Student Questions

- ❑ What does it mean for R14 to have 2 HARQ processes? How do 2 repeat request processes help?

Two different methods to detect and correct errors.

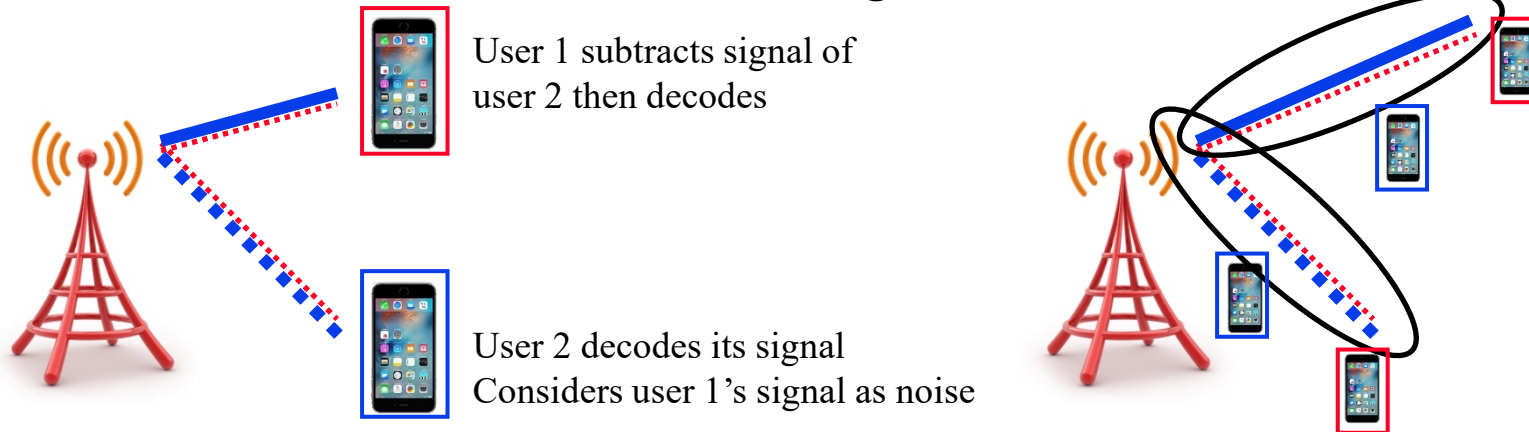
Single-Cell Point-to-Multipoint (SC-PTM)

- ❑ Enhancement of enhanced Multimedia Multicast Broadcast (eMBMS)
- ❑ eMBMS allows multi-cell broadcasts but requires synchronization among eNBs.
- ❑ SC-PTM does not require synchronized networks as in eMBMS
- ❑ Each cell handles its own broadcasts.
- ❑ A physical downlink shared channel (PDSCH) is used
- ❑ Control information is broadcast on a “single-cell multicast control channel (SC-MCCH). Indicates active MBMS sessions and information about each session
- ❑ Data is broadcast on a “Single Cell multicast transport channel (SC-MTCH).
- ❑ In R14, SC-PTM was extended to NB-IoT devices

Student Questions

Multi-User Superposition Transmission (MUST)

- ❑ Users are distinguished by power levels
Non-Orthogonal Multiple Access (NOMA)
- ❑ Users with poor channel conditions get higher power
- ❑ Users with higher power decode their signal treating others as noise
- ❑ Users with lower power subtract the higher-powered signals before decoding.
- ❑ Can also be used with beamforming and MIMO



Ref: G. Ding, et al, "Application of Non-orthogonal Multiple Access in LTE and 5G Networks,"

<https://pdfs.semanticscholar.org/a404/21a9762db528bfe848166765fee43e740c94.pdf>

Washington University in St. Louis

<http://www.cse.wustl.edu/~jain/cse574-22/>

©2022 Raj Jain

Student Questions

L2 Latency Reduction

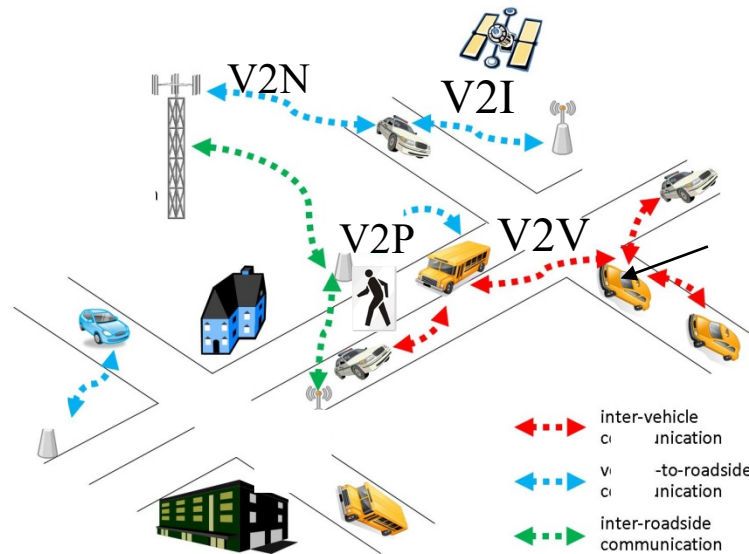
- ❑ Instant Uplink Access (IUA): A.k.a Fast uplink
 - A long-lasting grant with recurring resources is provided to the device
 - Extension of Semi-Persistent Scheduling (SPS) with shorter recurring periods of up to 1 ms
 - Device transmits only if there is data
Does not need to transmit padding if there is no data
⇒ Saves power
 - eNB sends Nack if no data is received during a scheduled grant
- ❑ Short Transmit-time Travel Interval (TTI):
 - Time to switchover from receive to transmit
 - Two symbols for FDD, seven symbols for TDD

Student Questions

- ❑ Are 2/7 symbols the new times?
What was done to achieve this?
Faster electronics
- ❑ The latency should also be reduced in the core. What improvements are there?
Not sure about core changes.

Cellular Vehicle-to-X (C-V2X)

- ❑ Vehicle-to-Vehicle (V2V): Collision avoidance
- ❑ Vehicle-to-Infrastructure (V2I): Traffic lights
- ❑ Vehicle-to-Pedestrians (V2P): Safety alerts
- ❑ Vehicle-to-Network (V2N): Maps, routing
- ❑ Use 5.9 GHz VANET spectrum direct PC5 interface for V2I, V2P, V2V
- ❑ Use licensed spectrum for V2N
- ❑ Direct communication using enhanced LTE D2D sidelink w PC5 Interface
- ❑ Another alternative is to use UE to eNB Uu interface for upload and retransmission/broadcast from eNB



Student Questions

- ❑ What are PC5 and Uu interfaces?
PC5=Device-to-Device
Uu= Traditional User-to-Base
- ❑ For V2N connection to the cellular network, is it always also connected to the Internet?
Yes, the Internet is the core.

Ref: Qualcomm, "Expanding the 5G NR ecosystem and roadmap in 3GPP Release 16 and beyond," Sep 2018, 35 pp.,

<https://www.qualcomm.com/media/documents/files/expanding-the-5g-nr-ecosystem-and-roadmap-in-3gpp-rel-16-beyond.pdf>

Washington University in St. Louis

<http://www.cse.wustl.edu/~jain/cse574-22/>

©2022 Raj Jain

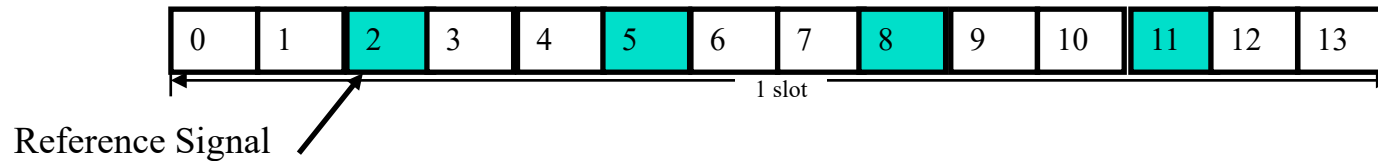
D2D vs. V2V

	D2D	V2V
Application	Voice	M2M
Packet Size	Small	Large
Latency	Not Critical	Critical 20-100 ms
UE Density	Low # of safety personnel	High number of vehicles
Dynamics	Pedestrian speeds	250 km/h

Student Questions

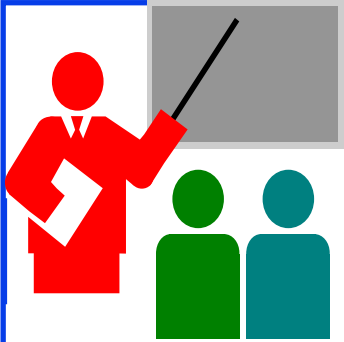
V2V Extensions

- Higher Doppler due to high speed: Doubled the number of demodulation reference symbols (DMRS) to 4



- Lower Latency: Scheduling and data in the same subframe
- Collision Avoidance: UEs can sense the load on the channel and request resources in advance to avoid collisions
- Global Navigation Satellite Systems (GNSS) based Synchronization: V2Vs almost always have GPS. It can be used in addition to eNB timing.
- Enhanced sidelink configuration and signaling

Student Questions



Summary

1. LTE Advanced Pro is 4.5G technology developed by 3GPP as Release 13 and 14
2. Release 13 introduced several new features:
 1. AAS and FD-MIMO
 2. Spectrum Aggregation enhancements: LAA, LWA, LWIP
 3. IoT/MTC
 4. D2D for Safety personnel
3. Release 14 mostly further enhanced these features and added:
 1. MUST
 2. V2X

Student Questions

Reading List

1. Rohde & Schwarz, "LTE-Advanced Pro Introduction eMBB Technology Components in 3GPP Release 13/14," White paper, 50 pp.,
https://cdn.rohde-schwarz.com/pws/dl_downloads/dl_common_library/dl_brochures_and_datasheets/pdf_1/LTE-Advanced-Pro_Introduction_White_paper_en_5215-8258-52_v0100.pdf
2. G. Pfeifer, "5G Technology Introduction, Market Status Overview and Worldwide Trials," 5G and IoT Seminar, Italy, May 2017,
https://cdn.rohde-schwarz.com/it/seminario/5G_Seminar_Part1_Standardization_Market_PHY_170509_Italy.pdf

Student Questions

References

- ❑ G. Xu, et al, "Full-Dimension MIMO: Status and Challenges in Design and Implementation," May 2014, http://www.ieee-ctw.org/2014/slides/session3/CTW_2014_Samsung_FD-MIMO.pdf
- ❑ Hossam Fattah, "5G LTE Narrowband Internet of Things (NB-IoT)," CRC Press, Boca Raton, 3 September 2018, 262 pp., ISBN 9780429847585
- ❑ G. Ding, et al, "Application of Non-orthogonal Multiple Access in LTE and 5G Networks," <https://pdfs.semanticscholar.org/a404/21a9762db528bfe848166765fee43e740c94.pdf>
- ❑ Qualcomm, "Expanding the 5G NR ecosystem and roadmap in 3GPP Release 16 and beyond," Sep 2018, 35 pp., <https://www.qualcomm.com/media/documents/files/expanding-the-5g-nr-ecosystem-and-roadmap-in-3gpp-rel-16-beyond.pdf>
- ❑ P. Zhu, "5G Enabling Technologies," PIMRC, Sep 2014, 20 slides, <http://www.ieee-pimrc.org/2014/2014-09-03%205G%20>
- ❑ W. Afifi and M. Krunz, "Adaptive Transmission-Reception-Sensing Strategy for Cognitive Radios with Full-duplex Capabilities," April 2010, 12 pp.,

Student Questions

References (Cont)

- ❑ I. S. Simic, "Evolution of Mobile Base Station Architectures," Microwave Review, Jun 2007, 6pp., http://www.mtt-serbia.org.rs/microwave_review/pdf/Vol13No1-07-ISimic.pdf
- ❑ I. Hwang, B. Song, and S. S. Soliman, "A Holistic View on Hyper-Dense Heterogeneous and Small Cell Networks," IEEE Communications Magazine, Jun 2013, pp. 20-27
- ❑ P. Skillermark and P. Frenger, "Enhancing Energy Efficiency in LTE with Antenna Muting," 75th Vehicular Technology Conf. (VTC Spring), Yokohama, 2012, pp. 1-5
- ❑ ITU-R M.2290-0, "Future Spectrum Requirements estimate for Terrestrial IMT," Dec 2013, http://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2290-2014-PDF-E.pdf

Student Questions

Wikipedia Links

- ❑ <https://en.wikipedia.org/wiki/Device-to-device>
- ❑ <https://en.wikipedia.org/wiki/Laa>
- ❑ https://en.wikipedia.org/wiki/LTE-WLAN_Aggregation
- ❑ [https://en.wikipedia.org/wiki/LTE_\(telecommunication\)](https://en.wikipedia.org/wiki/LTE_(telecommunication))
- ❑ https://en.wikipedia.org/wiki/LTE_Advanced
- ❑ https://en.wikipedia.org/wiki/LTE_Advanced_Pro
- ❑ https://en.wikipedia.org/wiki/LTE_in_unlicensed_spectrum
- ❑ <https://en.wikipedia.org/wiki/MIMO>
- ❑ https://en.wikipedia.org/wiki/Multi-Operator_Radio_Access_Network
- ❑ https://en.wikipedia.org/wiki/Multimedia_Broadcast_Multicast_Service
- ❑ https://en.wikipedia.org/wiki/Narrowband_IoT
- ❑ https://en.wikipedia.org/wiki/Radio_access_network
- ❑ https://en.wikipedia.org/wiki/Telecom_infrastructure_sharing
- ❑ <https://en.wikipedia.org/wiki/Vehicle-to-everything>
- ❑ https://en.wikipedia.org/wiki/Vehicular_ad_hoc_network

Student Questions

Acronyms

- ❑ 3GPP Third Generation Partnership Project
- ❑ AAS Active Antenna System
- ❑ BPSK Binary Phase Shift Keying
- ❑ CA Carrier Aggregation
- ❑ CDN Content Distribution Networks
- ❑ cDRX Continuous Mode DRX
- ❑ CoMP Coordinated Multi-Point Operation
- ❑ dB deciBel
- ❑ DC Dual Connectivity
- ❑ DL Downlink
- ❑ DMRS Demodulation Reference Signal
- ❑ DRX Discontinuous Reception
- ❑ eICIC Enhanced Inter-Cell Interference Cancellation
- ❑ eIMTA Enhanced Interference Mitigation and Traffic Adaptation
- ❑ eLAA Enhanced License Assisted Access
- ❑ eLWA Enhanced LTE/WLAN Aggregation

Student Questions

Acronyms (Cont)

- ❑ eLWIP Enhanced LTE/WLAN over IP Tunnel
- ❑ eMBB Enhanced Mobile Broadband
- ❑ eMBMS Enhanced Multicast Broadcast Multimedia Service
- ❑ eMTC Enhanced Machine Type Communication
- ❑ eNB Evolved Node-B
- ❑ EPDCCH Enhanced Physical Downlink Control Channel
- ❑ EPS
- ❑ FCC Federal Communications Commission
- ❑ FD Full Dimension
- ❑ GHz Giga Hertz
- ❑ GNSS Global Navigation Satellite Systems
- ❑ HARQ Hybrid Automatic Repeat Request
- ❑ HTTP Hyper-text Transfer Protocol
- ❑ ICS IMS Centralized Services
- ❑ ID Identifier
- ❑ IMS Internet Multimedia System

Student Questions

Acronyms (Cont)

- ❑ IoT Internet of Things
- ❑ IP Internet Protocol
- ❑ ISBN International Standard Book Number
- ❑ IUA ICS User Agent
- ❑ kHz Kilo Hertz
- ❑ LAA License Assisted Access
- ❑ LAN Local Area Network
- ❑ LTE Long-Term Evolution
- ❑ LWA LTE/WLAN Aggregation
- ❑ LWIP LTE/WLAN over IPsec Tunnel
- ❑ MBMS Multimedia Broadcast Multicast Service
- ❑ MBS Metropolitan Beacon System
- ❑ MCCH Multicast Control Channel
- ❑ MHz Mega Hertz
- ❑ MIMO Multiple Input Multiple Output
- ❑ MPD Media Presentation Description

Student Questions

Acronyms (Cont)

- ❑ MTC Machine Type Communication
- ❑ MUST Multi-User Superposition Transmission
- ❑ mW milliWatt
- ❑ NAICS Network Assisted Interference Cancellation and Supression
- ❑ NB Narrow-Band
- ❑ NOMA Non-Orthogonal Multiple Access
- ❑ NR New Radio
- ❑ PC5 One of LTE V2X Interfaces
- ❑ PDN Public Data Network
- ❑ PDSCH Physical Downlink Shared channel
- ❑ PHY Physical
- ❑ PLMN Public Land Mobile Network
- ❑ PRB Physical Resource Block
- ❑ PROSE Proximity Services
- ❑ PSD Power Spectral Density
- ❑ PSM Power save mode

Student Questions

Acronyms (Cont)

- ❑ PTM Point-to-Multipoint
- ❑ QAM Quadrature Amplitude Modulation
- ❑ QoS Quality of Service
- ❑ QPSK Quadrature Phase Shift Keying
- ❑ RAN Radio Access Network
- ❑ RF Radio Frequency
- ❑ RS Reference Signal
- ❑ SC-PTM Single-Cell Point-to-Multipoint
- ❑ SON Self-Organizing Network
- ❑ SRS Sounding Reference Signals
- ❑ TDD Time-Division Duplex
- ❑ TTI Transmit Transition Interval
- ❑ UE User Element
- ❑ UL Uplink
- ❑ URL Uniform Resource Locator
- ❑ VANET Vehicular Area Network

Student Questions

Acronyms (Cont)

- ❑ WAN Wide-Area Network
- ❑ WLAN Wireless Local Area Network

Student Questions

Scan This to Download These Slides



Raj Jain

<http://rajjain.com>

http://www.cse.wustl.edu/~jain/cse574-22/j_19lap.htm

Student Questions

Related Modules



CSE567M: Computer Systems Analysis (Spring 2013),
https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcg5e_10TiDw



Recent Advances in Networking (Spring 2013),
<https://www.youtube.com/playlist?list=PLjGG94etKypLHyBN8mOgwJLHD2FFIMGq5>

CSE571S: Network Security (Fall 2011),
<https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u>



Video Podcasts of Prof. Raj Jain's Lectures,
<https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw>

Student Questions