

# Introduction to 4G LTE-Advanced



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

<http://www.cse.wustl.edu/~jain/cse574-24/>

**Student Questions**



1. LTE-Advanced: Requirements and New Technologies
2. Carrier Aggregation
3. Coordinated Multipoint Operation
4. Small Cells
5. Inter-Cell Interference Coordination

Note: This is the 3<sup>rd</sup> lecture in a series of lectures on 1G to 5G.  
4.5G and 5G are covered in subsequent modules.

## Student Questions

# What is 4G?

- ❑ International Mobile Telecommunication (IMT) Advanced Requirements in ITU M.2134-2008
- ❑ IP-based packet switch network
- ❑ 1.0 Gbps peak rate for fixed services with 100 MHz
- ❑ 100 Mbps for mobile services. High mobility to 500 km/hr

Feature	Cell	Cell Edge	Peak
DL Spectral Efficiency (bps/Hz)	2.2	0.06	15
UL Spectral Efficiency (bps/Hz)	1.4	0.03	6.75

- ❑ Seamless connectivity and global roaming with smooth handovers
- ❑ High-Quality Multimedia
- ❑ ITU has approved two technologies as 4G (Oct 2010)
  - LTE-Advanced
  - WiMAX Release 2 (IEEE 802.16m-2011)

## Student Questions

- ❑ Why would they pick a mobility that far exceeds the possible use case (planes are much faster than 500km/hr, cars are much slower, why not use 200km/hr or something more realistic)?

*To goal is to cover high-speed trains.*

- ❑ How can ITU predict the advancement of technology over the 10 years correctly? Suppose ITU overshoots by a lot, and no technology met ITU's requirement within 10 years. What would happen?

*They do not meet the goals exactly in 10 years. For example, 4G was a bit late. LTE was the first result at creating 4G.*

- ❑ By ""high mobility to 500km/hr,"" does it mean the technology should support devices moving at 500km/hr?

*Yes*

- ❑ Can you give an example of fixed services? Is microwave relaying also a fixed service?

*Microwave relay will be a service if the link is offered/sold to customers.*

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## Student Questions

- ❑ Are there still only 2 approved technologies for 4G?

*WiMAX is not there in the market place and so there is only one.*

- ❑ What was it which allowed LTE-Advanced to push WiMAX out of the 4G market?

*Qualcomm worldwide monopoly on 3G market.*

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## Student Questions

- ❑ How can LTE-Advanced "beat" WiMAX? Why can the former be used everywhere, but the latter is not, except for the small packet size mentioned in the video?

*Qualcomm had a good hold on the carrier market and a good marketing machinery.*

# LTE-Advanced Requirements

- ❑ UMTS Rel. 10, 2011H1
- ❑ **Goal:** To meet and exceed IMT-advanced requirements
- ❑ **Data Rate:** 3 Gbps downlink, 1.500 Mbps uplink (low mobility) using 100 MHz
- ❑ **Spectral Efficiency:** 30 bps/Hz using 8x8 MIMO downlink, 15 bps/Hz assuming 4x4 MIMO uplink
- ❑ **Cell Spectral Efficiency:** DL 3.7 bps/Hz/cell assuming 4x4 MIMO, 2.4 bps/Hz/cell assuming 2x2 MIMO (IMT-Adv requires 2.6 bps/Hz/cell)
- ❑ **Downlink Cell-Edge Spectral Efficiency:** 0.12 bps/Hz/User assuming 4x4 MIMO, 0.07 bps/Hz/user assuming 2x2 MIMO (IMT-Adv requires 0.075 bps/Hz/user)

Ref: 3GPP, "Requirements for Further Advancements for E-UTRA (LTE-Advanced),," 3GPP TR 36.913 v8.0.1 (03/2009),  
[http://www.3gpp.org/ftp/specs/archive/36\\_series/36.913/](http://www.3gpp.org/ftp/specs/archive/36_series/36.913/)

## Student Questions

- ❑ Why don't we use 8x8 MIMO for uplink if the resources are already available for downlink?

*They are saying with 4x4 MIMO in the uplink you should be able to get 15 bps/Hz. You can do 8x8 MIMO in the uplink.*

- ❑ Are the contents in this slide the advanced version of the previous slide 3, like LTE (slide 3) vs. LTE-Advanced (slide 4)?

*Yes. But these are not ITU requirements like those in Slide 3. These are 3GPP goals set for their release 10. See reference.*

# LTE-Advanced Requirements (Cont)

- ❑ **Latency:** Less than 10 ms from dormant to active;  
Less than 50 ms from camped to active
- ❑ **Mobility:** up to 500 kmph
- ❑ **Spectrum Flexibility:** FDD and TDD, Wider channels up to 100 MHz

## Student Questions

- ❑ Are states like dormant and camped referring to base stations? Are there other states?

*These are states of mobiles.*

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# LTE Advanced Techniques

- ❑ **Three Key Factors:** Spectrum (Band, Bandwidth), Spectral Efficiency, and Cell sizes
- ❑ **Bandwidth:** 100 MHz using carrier aggregation  
5 carriers are allowed now—32 in the future.  
Higher UE power  $\Rightarrow$  Used if high throughput needed
- ❑ **Spectral Efficiency:**
  - Frequency Reuse Factor of 1
  - Higher order MIMO (8x8 DL, 4x4 UL)
  - New MIMO Techniques: Single-user uplink MIMO
  - Inter-Cell Interference Co-ordination and cancellation
- ❑ **Cell Sizes:**
  - Relays
  - Home eNB

## Student Questions

- ❑ Why can we only use 5 different carriers currently?  
What is needed before we can use all 32 that are possible?

*Just more complexity. We started with 2 contiguous bands (802.11n), then 2 non-contiguous bands, then 5, then 32, .... You can't just design the most complex system first. No one would be able to afford it.*

- ❑ What're the differences between eNB and NB?  
*NB is for 3G. Evolved NB (eNB) is for 4G.*
- ❑ For single-user uplink MIMO, does it require multiple antennas on the mobile device?

*Yes, unless it is a multi-user MIMO, in which multiple users act as one virtual device.*

- ❑ How does cell size effect the data rate?

*For shorter distances, you can send faster.*

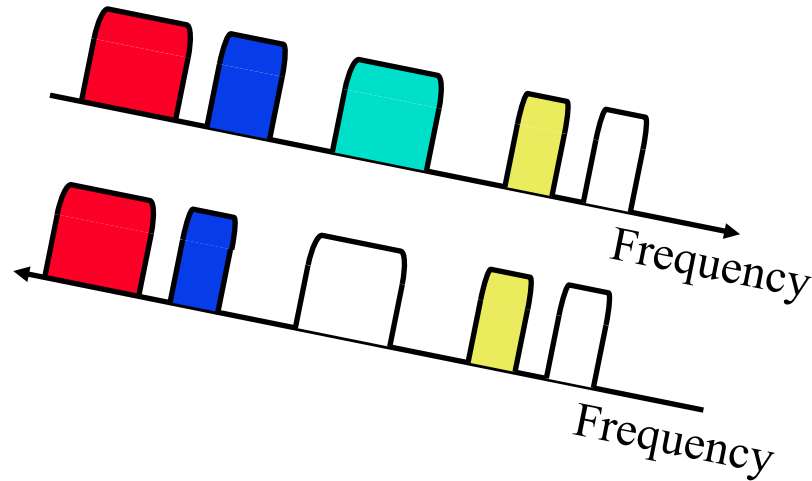
- ❑ What does "Single-user uplink MIMO" mean?

*Opposite of multi-user MIMO is single-user MIMO. Uplink is from the mobile to the tower.*



# Carrier Aggregation

- ❑ Aggregation = Combine multiple bands (Component Carriers)



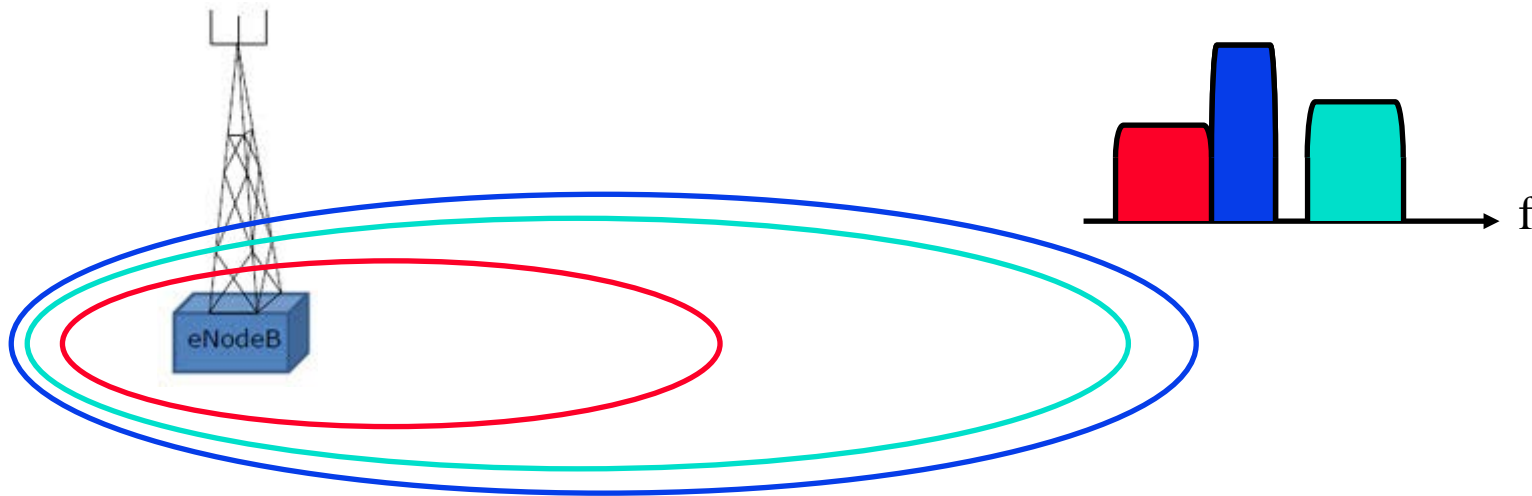
- ❑ Backward compatible with LTE (Single carrier)  
⇒ Each band can be 1.4, 3, 5, 10, or 20 MHz
- ❑ Maximum 5 component carriers ⇒ 100 MHz max
- ❑ Each component can be a different width
- ❑ Number of components in DL and UL can be different, but  
Number of components in DL  $\geq$  Number of components in UL

## Student Questions

- ❑ Why is the number of components in DL  $\geq$  the number of components in UL?  
*DL has orders of magnitude more traffic.*

# Carrier Aggregation (Cont)

- ❑ Components can be contiguous (adjacent) or non-contiguous (inter-band or intra-band)
- ❑ Each component carrier has a serving cell.  
The size of different component carrier cells may differ
- ❑ PHY, MAC, and RLC are all extended to handle varying numbers of components  
e.g., Larger buffers in RLC to accommodate a larger data rate



## Student Questions

Ref: <http://www.3gpp.org/technologies/keywords-acronyms/97-lte-advanced>

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# MIMO

- ❑ 8x8 MIMO in DL and 4x4 in UL
- ❑ MIMO used only when SINR is high  $\Rightarrow$  Good Channel
- ❑ If SINR is low, other spectral efficiency techniques, such as transmit diversity, are used.
- ❑ Many different transmission modes are defined.  
UE is informed about the mode to use via signaling
- ❑ Modes differ in the number of antennas, antenna port, precoding type, type of reference signal
- ❑ Three new categories of UE: Category 6, 7, 8  
Category 8 supports maximum features.

## Student Questions

- ❑ What's the difference between SNR and SINR?

*SNR = Signal to noise ratio*

*SINR = Signal to Interference and Noise Ratio*

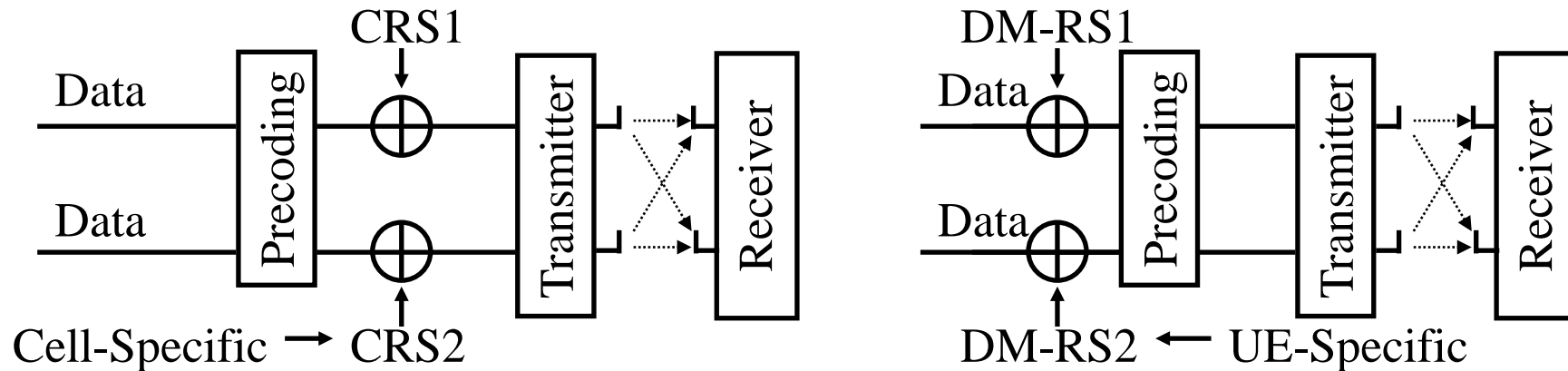
- ❑ Why does MIMO require high SINR, given that multiple TX/RX antennas can help communication in a noisy environment?  
*It only helps if the interference+ or noise is low.*
- ❖ Why does MIMO depend upon SINR for determining whether to transmit or not?

*See the previous question.*

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# Precoding

- ❑ Used to map the modulation symbols to different antennas  
It depends upon the number of antennas and number of **layers**
- ❑ Reference (Pilot) signals are transmitted with the data
- ❑ **Code-Book based precoding**: Cell Reference Signals (CRS)
- ❑ **Non-Code-book-based precoding**: Demodulation Reference Signals (DM-RS) are added before precoding.  
A receiver can infer precoding from the pilots.



## Student Questions

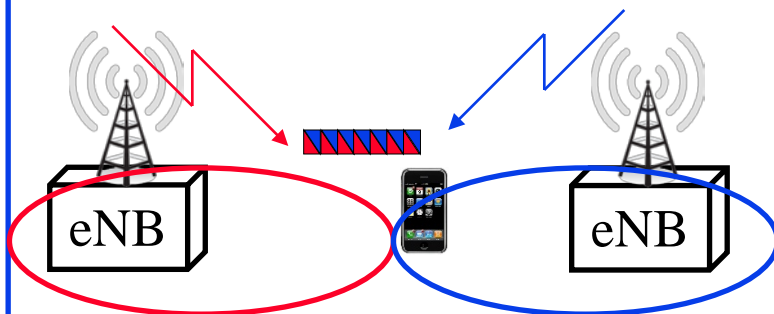
- ❑ What is a layer?  
*Number of layers in a printed circuit board. Multi-layer boards are quite common.*
- ❑ Why is CRS2 cell-specific whereas DM-RS2 is UE-specific?  
*There are two types of pilots. The first is common for a cell. Another is specific to a user.*
- ❑ When do we use Code-book based vs. Non-code-book-based?  
*At all times.*

- ❑ Are there any advantages of Code-Book-based precoding over Non-Code-Book-based precoding?

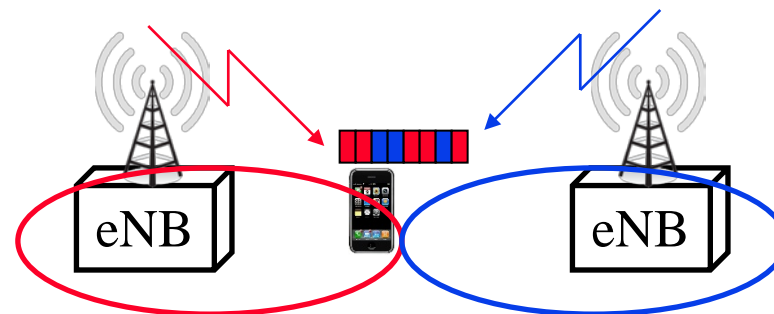
*No. Non-code-book-based precoding can be changed dynamically as the decoding signals are in the pilot. So it can be user specific.*

# Coordinated Multipoint Operation (CoMP)

- ❑ To improve performance at the cell edge
- ❑ Base stations coordinate transmissions and reception
- ❑ Joint Transmission: Multiple transmitters in the same subframe
- ❑ Dynamic Point Selection: Transmission scheduled from one BS
- ❑ Joint Reception: Multiple BS receive the signal from one UE and combine
- ❑ UE is informed about different UL/DL decisions



(a) Joint Transmission



(b) Dynamic Point Selection

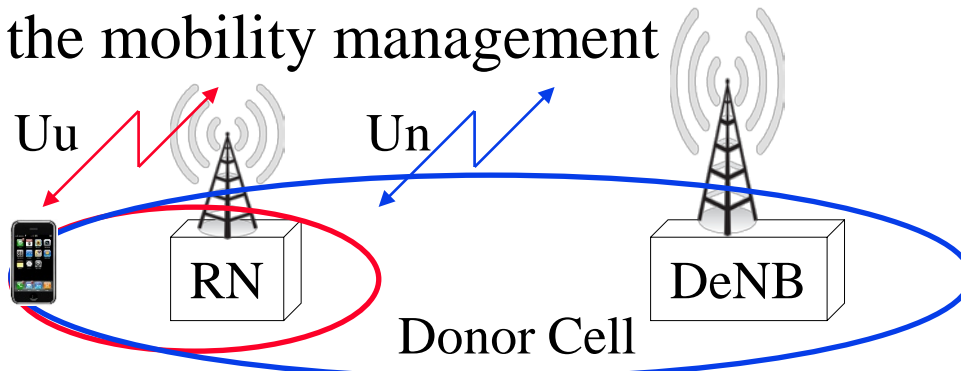
## Student Questions

- ❑ How does CoMP manage latency when multiple base stations share data?

*The frames are synchronized and so the latency difference is lower than the frame size.*

# Relay Nodes

- ❑ **Relay Nodes:** Low-power base stations  
Used to enhance performance at cell edges, hot-spot areas, indoor coverage
- ❑ **Donor eNB (DeNB):** Primary base station
- ❑ A modified version of E-UTRAN air interface Uu is defined:  
Un
- ❑ Both Donor and Relays may use the same/different frequencies
- ❑ **Self-Interference:** Relay transmission may interfere with its reception on the same frequency  
⇒ Avoided using time-sharing
- ❑ Donor does the mobility management



## Student Questions

- ❑ In what particular situations are relay nodes more productive, cost-efficient, etc. compared to traditional macrocell deployments?

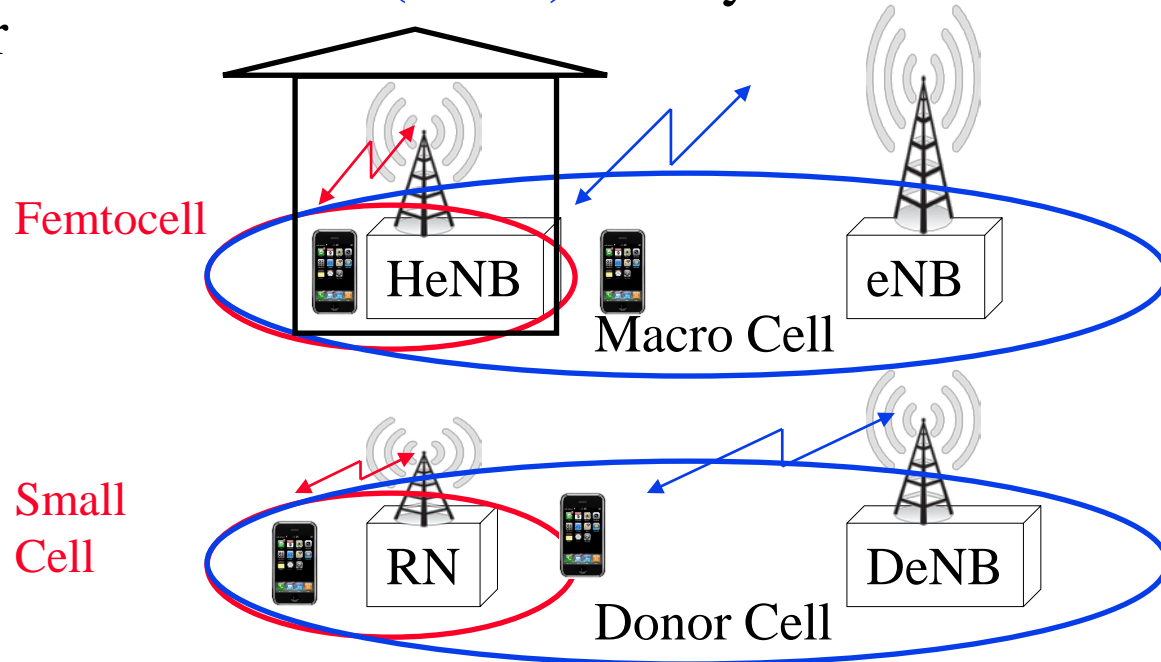
*Macrocell may cost more to cover a particular sub-area. A relay can help cover it at a much lower cost than macro cell.*

- ❑ Are relay nodes fixed stations, or are they mobile for dynamic hotspots?

*Both. COWs (Cells on Wheels) are used for dynamic hot spots.*

# HetNet/Small Cells

- ❑ **Macro eNB:** Normal Base Station
- ❑ **Relay Node (RN):** Micro or Pico Cell.
- ❑ **HeNB:** Home eNB for indoor coverage in homes, offices, and malls. Privately owned and operated. Femtocell.
- ❑ **Remote Radio Heads (RRH):** Relay nodes connected to DeNB via fiber



## Student Questions

Ref: 3GPP, "HetNet/Small Cells," <http://www.3gpp.org/hetnet>

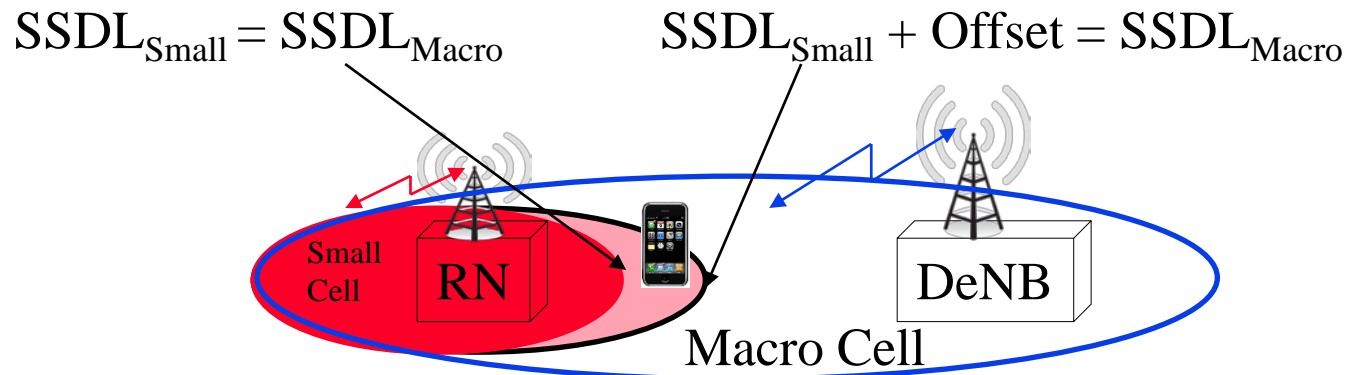
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# HetNet/Small Cells (Cont)

- ❑ UE selects the BS with the strongest signal in DL (SSDL)  
⇒ Both BS have the same SSDL at the edge
- ❑ **Cell Range Extension (CRE):** Allow small cell to serve more users by requiring UE to join the small cell even if the power is slightly below the macro cell ⇒ Interference from the macro is mitigated by coordination



## Student Questions

- ❑ So just to clarify, the mobile unit in this diagram will connect to RN, right?

*Yes.*

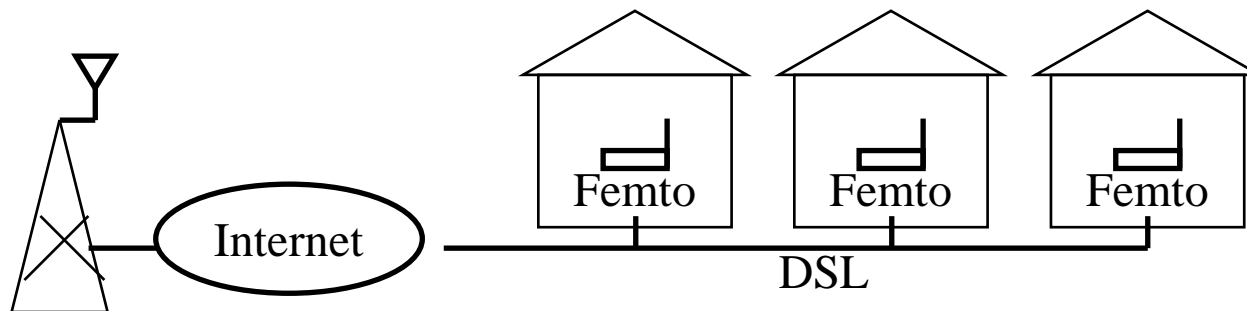
- ❖ Why does requiring UE to join small cell benefit the network?

*Joining the small cell benefits the users at the cell boundary.*



# Types of Cells

- ❑ **Cell (Macrocell)**: Cover a few miles. Public Access. Open Area.
- ❑ **Microcell** ( $10^{-6}$ ): Less than a mile wide. Public Access. Malls, Hotels, Train Stations
- ❑ **Picocell** ( $10^{-12}$ ): in-Building with public access
- ❑ **Femtocell** ( $10^{-15}$ ): In-Building with restricted access
- ❑ **Attocell** ( $10^{-18}$ ): In-room
- ❑ **Zeptocell** ( $10^{-21}$ ): On-Desk
- ❑ No milli, nano cells.



## Student Questions

- ❑ Could you talk about mmWave?  
*A mm-wave has a wave length of 1 to 10 mm, i.e., 30 to 300 GHz.*

# Femtocells: Key Features

- ❑ 50-100 m cell radius
- ❑ Indoor
- ❑ Residential, small office/home office (SOHO)
- ❑ Backhaul over DSL
- ❑ Plug and Play: *Self-Organizing*, Self-optimizing
- ❑ Omni-directional antenna. No sectorization
- ❑ 10-50 users, 10-40 Mbps, Low cost
- ❑ Defined User group
- ❑ Continuation of macro network: Handover of calls
- ❑ Regular mobile equipment work in femtocells
- ❑ Multiple femtocells should coexist
- ❑ New Applications: HD video streaming, LAN services

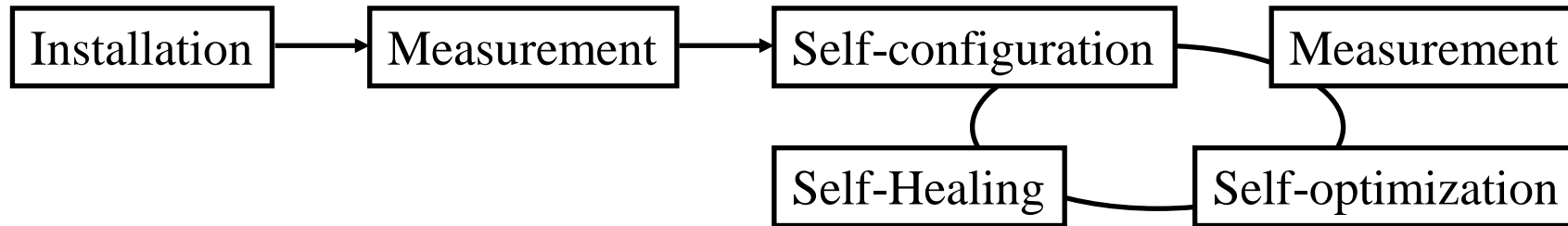
## Student Questions

- ❑ Why are there two different notations of femtocell in this slide (femtocell, FemtoCell)? Do they mean the same thing?

*Thanks for pointing out. It has been corrected throughout.*

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# Self-Organizing Network (SON)



- ❑ User installable.
- ❑ Not physically accessible to the carrier
- ❑ Operator provides femtocell ID. Customer registers location
- ❑ Self-Configures:
  - Transmission Frequencies
  - Transmission Power
  - Preamble: Identifies the segment (IDcell). Some IDs for reserved for femtocells. Helps differentiate from macrocells.
  - Neighbor Cell list: Helps in handover
- ❑ Turned on/off by the consumer ⇒ Dynamic topology

## Student Questions

- ❑ How can SON devices connect to the cell companies' network? Does user register their device and pay for the services?

*Yes, users register and pay for the service and/or equipment.*

- ❑ How popular is SON today compared to the expectation for 2012?

*SON ≠ femtocell. I have a femtocell in my home. Not sure about the worldwide numbers. Most devices today are self-organizing.*

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# Management and Configuration

- ❑ Self-Configuration
- ❑ Remote configuration by the service provider
- ❑ Femtocell senses the channel to detect neighboring cells
- ❑ May broadcast messages to neighbors

## Student Questions

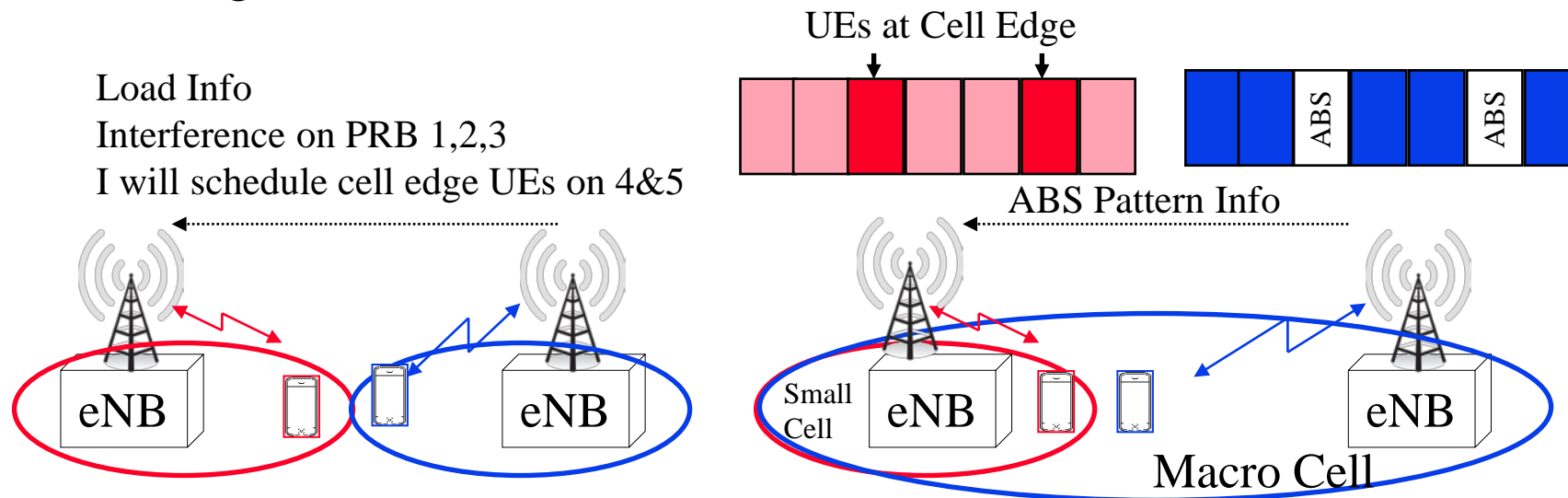
- ❑ What about virtual operators? Does the primary carrier prioritize traffic based on their subscription, or is it just based on the traffic type (Voice/Data)?

*Carriers may have to sign a QoS contract with virtual operators to not discriminate against their traffic.*

---

# Enhanced Inter-Cell Interference Coordination (eICIC)

- ❑ **ICIC:** A eNB sends a “load information” message to the neighbor eNB about the interference level per physical resource block. The neighbor adjusts DL power levels at those blocks
- ❑ **Almost Blank Subframes (ABS):** Only control channels and cell-specific pilots, no user data ⇒ Allows UEs in CRE region to mitigate macro-cell interference = eICIC



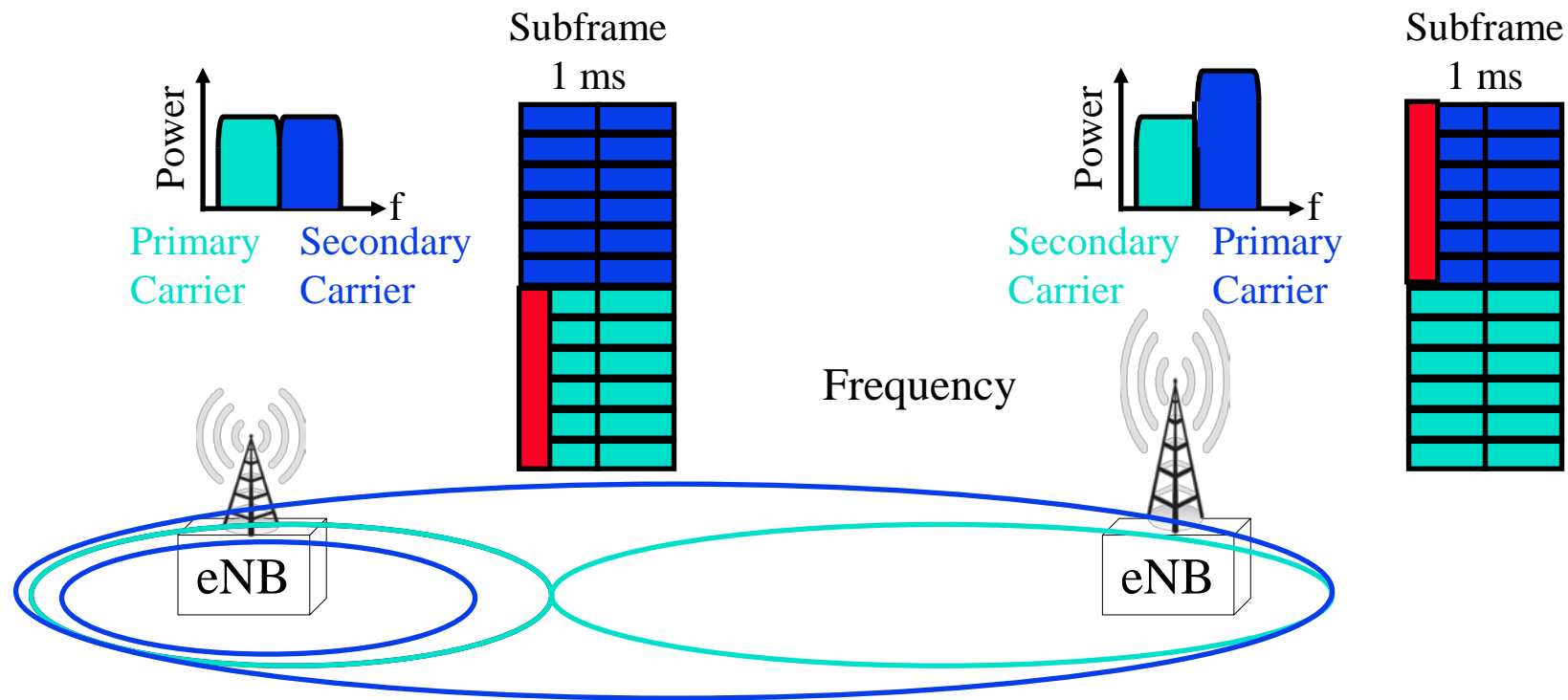
## Student Questions

- ❑ Can you go over the figures in this slide again? I don't follow how the interference on PRB 1, 2, 3 results on cell edge being scheduled on 4, 5.  
*Basically, the right eNB says "I will not use 1, 2, 3. Instead, I will use 4, 5. You can use 1, 2, 3."*
- ❑ Could you please explain the two figures on this slide again?

*Sure.*

# Carrier Aggregation with Cross-Carrier Scheduling

- Physical DL Control channel (PDCCH) in macro cell and small cell is sent on different carriers and may be at a higher power than traffic channels
- A UE can talk to both BSs using control channels on different carriers

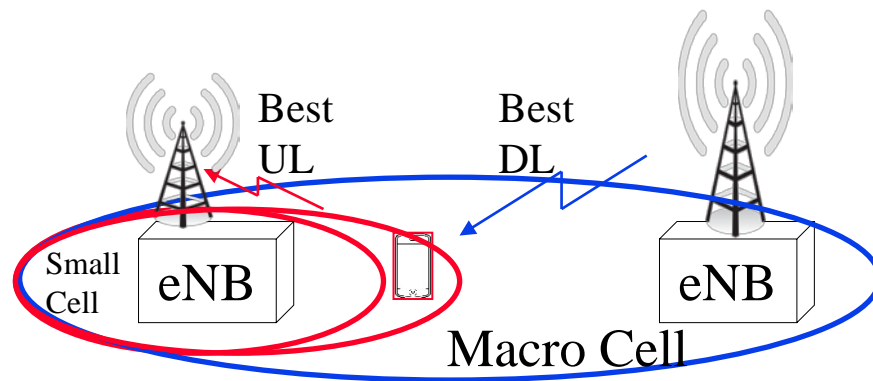


## Student Questions

- What is the red box in the figure.  
*This is the subframe header. It is called a "map." It contains what PRB's in the subframe belong to which user. All users find their PRB's by reading the map first.*
- What do the different colors in each subframe mean? Can you please explain the figure?  
*Color=data and control carriers  
Red is the control channel. The control channel is always on the primary carrier.*
- What does the red rectangle refer to?  
*Red=Control*

# CoMP with Small Cells

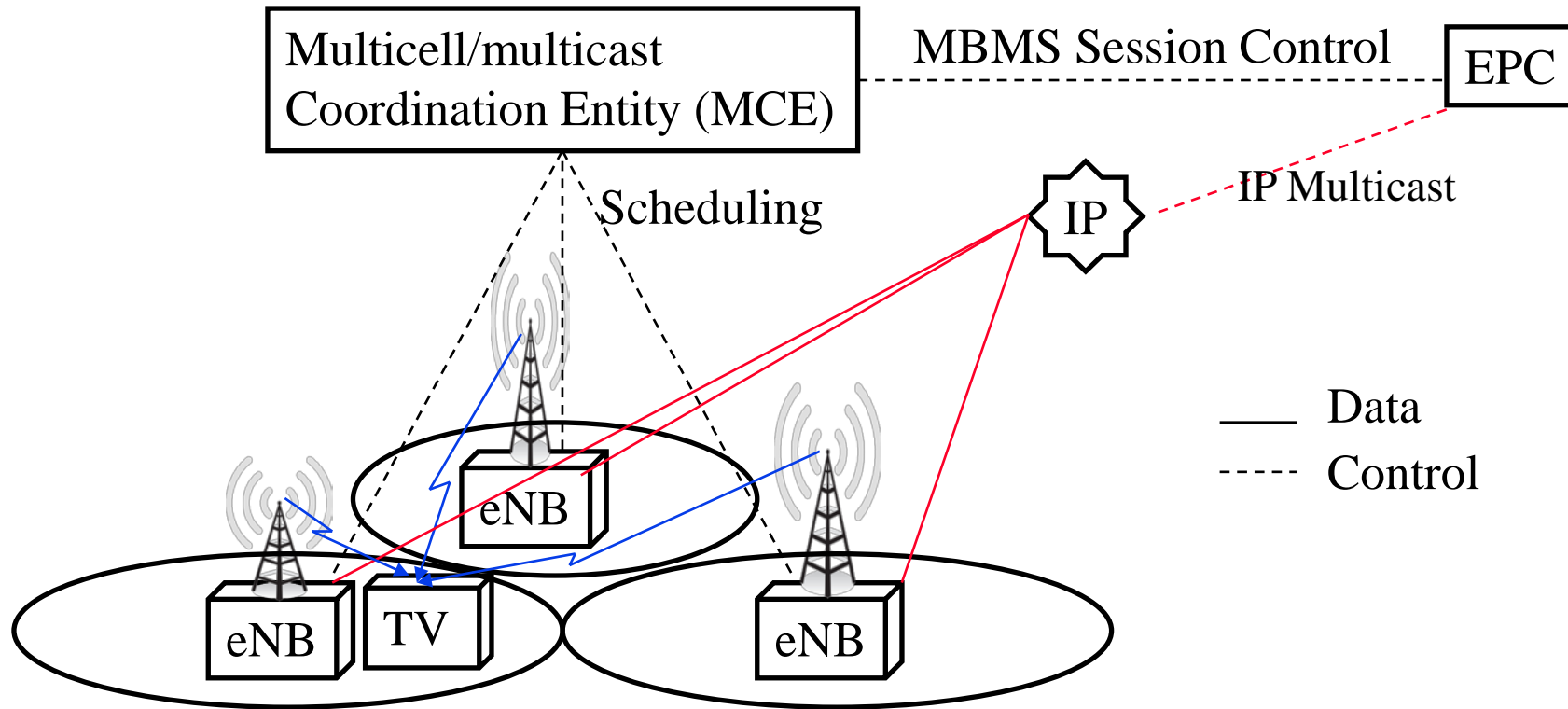
- A UE can get service from multiple BSs (eNB, RN, HeNB, RRH)
  - Can get data through multiple BSs
  - Can send data through multiple BSs
  - Can send data to one BS and receive it from another



## Student Questions

# Multimedia Broadcast Multicast Service (MBMS)

- ❑ MBMS Single Frequency Network (MBSFN)
- ❑ MCE handles synchronized data delivery



## Student Questions

- ❑ What is the function of EPC and who manages this service?

*Evolved packet core (See Module 17)*

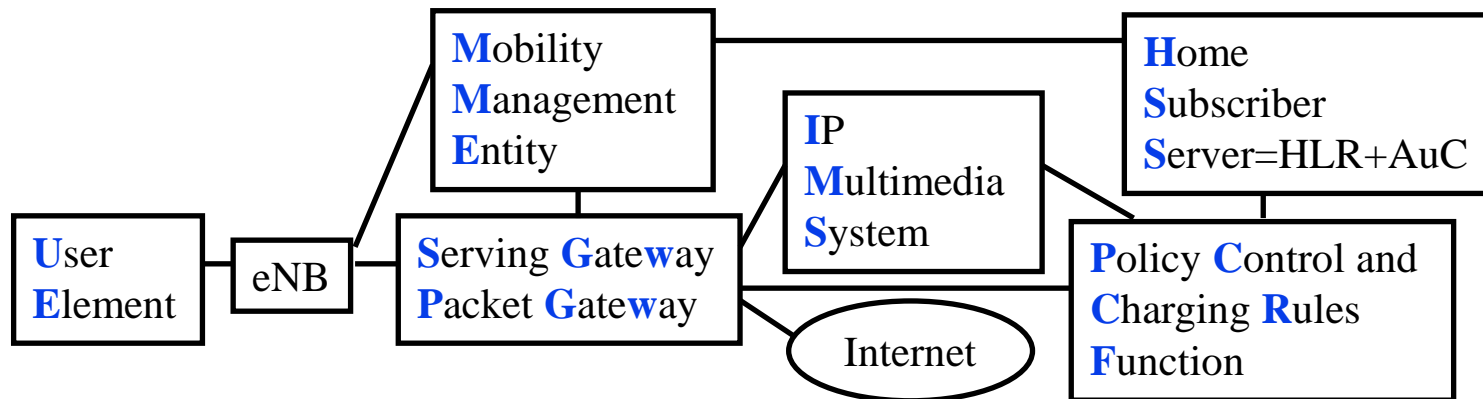
- ❑ What are the chances that multiple users are requesting the same data? When does this get used?

*Many users look at the same hot topic/movie/video/update.*



# Voice over LTE (VoLTE)

- ❑ Original LTE is not circuit switched  
⇒ Voice needed to go through GSM or 3G circuits.  
Called **Circuit Switch Fall Back (CSFB)** ⇒ Need dual radios
- ❑ **IP Multimedia Services (IMS)** handles the call setup signaling
- ❑ **Transmission Time Interval (TTI) bundling** allows to repeat of the uplink transmission in 4 consecutive subframes ⇒ 4x power ⇒ Improves link budget by 6 dB ⇒ reduces the block error rate
- ❑ **Semi-persistent scheduling** saves scheduling overhead.  
Cannot adapt continuously to changing channel conditions
- ❑ **Packet Bundling**: Send only when two voice packets



## Student Questions

- ❑ Is VoLTE new in LTE Advanced or is it part of LTE?

*LTE-Advanced.*

- ❑ Is VoLTE a part of 4G standard? If the voice data go through "4G LTE" channels, is that actually LTE advanced?

*4G requirements are set by ITU. It does not include mechanisms. VoLTE came about in one release after LTE.*

# Enhancements in Release 12

1. Enhanced Small Cells
2. Device to Device Communication (D2D)
3. WLAN/3GPP Radio Interworking
4. HetNet Mobility Enhancements
5. Smart Congestion Mitigation (SCM)
6. Machine-Type Applications
7. FDD-TDD Carrier Integration
8. Dynamic TDD
9. Inter-eNB CoMP

Ref: Rohde & Schwarz GmbH & Co, "1MA252: LTE- Advanced (3GPP Rel.12) Technology Introduction White Paper,"

[https://www.rohde-schwarz.com/us/applications/lte-advanced-3gpp-rel.12-technology-introduction-white-paper-white-paper\\_230854-108294.html](https://www.rohde-schwarz.com/us/applications/lte-advanced-3gpp-rel.12-technology-introduction-white-paper-white-paper_230854-108294.html)

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## Student Questions

- When was release 12, and what is the current release?

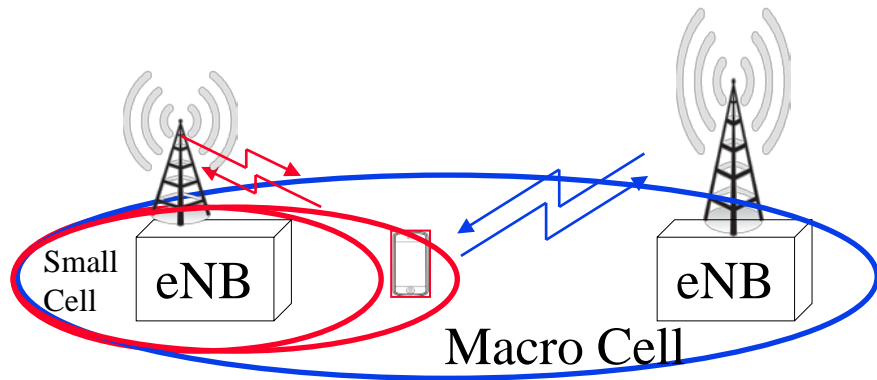
*Slide 20-6 has the latest release schedule.*

- When my phone says LTE, is it on the current release?

*May or may not be. It is up to the carrier.*

# Enhanced Small Cells

- **Higher order modulations:** Small cells  $\Rightarrow$  Higher SINR  
 $\Rightarrow$  Higher order modulations  $\Rightarrow$  256-QAM
- **Dual Connectivity:** Mobile can have two radios  
Mobile can connect to both macro and pico cells.



## Student Questions

- Will traffic for a single stream split across both radios, or does connecting to two radios just allow you to interface with two streams at once?

*This is an issue for higher layers in the protocol stack. If you split a flow (application), packets will arrive out-of-order and so higher layers will have to handle it.*

- when I am connected to both cells, to whom do I transfer my data to?

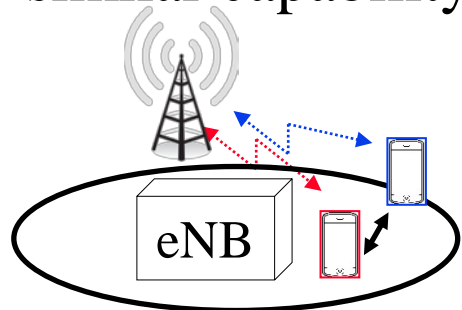
*Some to left and some to right.*

- What are the differences between enhanced small cells and Cross-Carrier Scheduling in Slide 18-20?

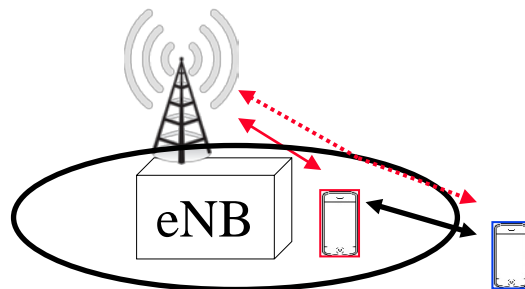
*Cross-carrier scheduling was between two cells. This slide is for coordination between a small cell and a macro cell of which the small cell is a part.*

# Device to Device Communication (D2D)

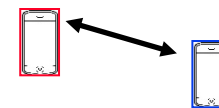
- ❑ In 2012, 10 MHz of paired spectrum in 700 MHz was set aside by FCC for use by first responders.
- ❑ 3GPP has extended LTE to allow direct communication between first responders even when there is no tower
- ❑ Others can also use this facility if at least one of them is connected to a tower
- ❑ Signaling to inform capability and discover other mobiles with similar capability has been developed.



(a) Network Control



(b) D2D Relaying



(c) Out-of-Coverage D2D  
(First Responders only)

## Student Questions

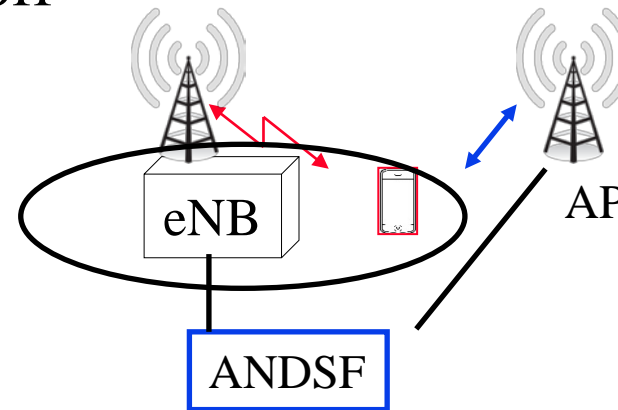
- ❑ Why is D2D First Responders only? (why don't telecom companies want this too?)  
*Reserved for citizen services*
- ❑ What is the range of D2D? Since both parties are mobile devices, wouldn't the range be very short?  
*Yes. But, it can be used even when there is no tower nearby.*
- ❑ Is D2D relaying (second picture) also limited to first responders?

*Yes*

- ❑ How is the range of D2D communication extended in the absence of towers, with the limitations of mobile device transmission power?  
*These mobile devices have stronger transmitters/receivers and implement relay protocols.*

# WLAN/3GPP Radio Interworking

- ❑ If a mobile connected to LTE discovers a WLAN access point:
  - Carrier may want to move the traffic to WLAN APs that it owns
- ❑ **Access Network Discovery and Selection Function (ANDSF)** has been added in Release 12 to enable this. It helps decide which APs to join per carrier's preference and which traffic should be offloaded.
- ❑ User decides whether to turn WiFi on/off
- ❑ ANDSF function is present in both AP and eNB decides
- ❑ Mobile may have built-in rules for carriers that have not yet implemented ANDSF



## Student Questions

# HetNet Mobility Enhancements

- ❑ Pico cells have small range  $\Rightarrow$  Mobiles may get in/out without enough time to have seamless handover  $\Rightarrow$  Handover failures
- ❑ Depending upon the speed of the mobile and traffic type, eNB may decide not to handoff call to the pico cell
- ❑ Mobile can start early recovery from handover failures using shortened recovery timers.

## Student Questions

- ❑ How do eNBs determine the speed of the mobile?  
*They know the exact location of the mobile every millisecond*
- 

- ❑ Is there a time threshold that indicates whether a mobile device should undergo the handover process?

*No. It is a quality threshold. When a tower discovers that you will be better off with the next tower, it hands you over.*

# Smart Congestion Mitigation (SCM)

- ❑ Too many mobiles at a sports event  $\Rightarrow$  overload
- ❑ Better to prioritize traffic rather than deny all services
- ❑ Voice traffic is allowed, but data traffic is not allowed for all users

## Student Questions

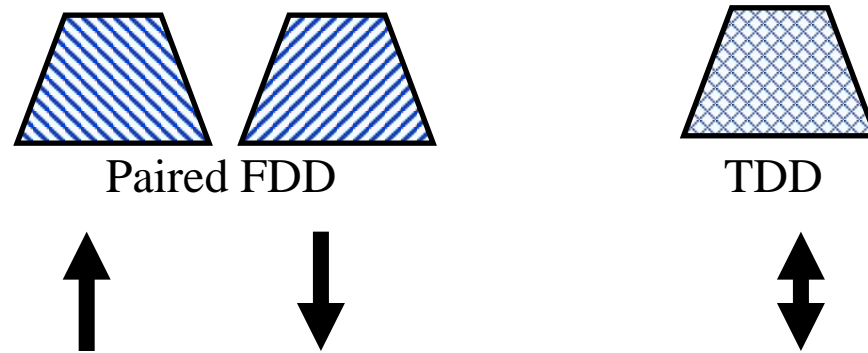
# Machine-Type Applications

- ❑ Three types of IoT:
  - Cameras: High UL traffic, no mobility
  - Fleet tracking: Low traffic, high mobility
  - Meter reading: Very low traffic, no mobility
- ❑ Signaling Overhead Reduction
  - Reduce signaling overhead for devices with infrequent data transfer
  - Expected UE behavior is communicated to eNB, indicating expected activity time, idle time, and activity behavior
- ❑ Power consumption optimization
  - Meters may be using battery
  - Power saving mode allows them to sleep for a long time

## Student Questions



# FDD-TDD Carrier Integration



- ❑ Can aggregate Down FDD band with TDD in the downlink
- ❑ Aggregate Up FDD band with TDD in uplink
- ❑ Use only FDD in Primary Cells and TDD in Small Cell or vice versa
- ❑ Generally, FDD bands are lower frequency  $\Rightarrow$  Used for primary
- ❑ In the future, 32 carriers could be aggregated

## Student Questions

- ❑ How does FDD-TDD work?

*This whole slide is on that.*

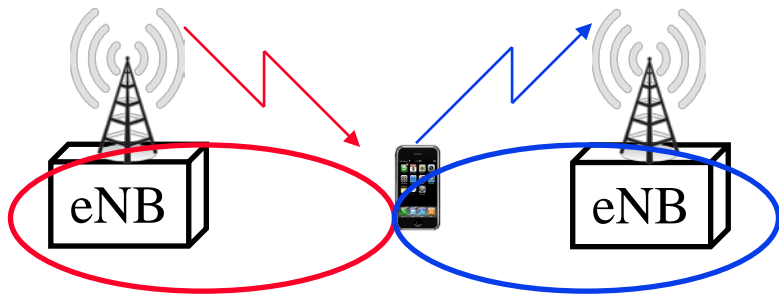
- ❑ Are we using TDD over FDD?

*No.*

---

# Dynamic TDD

- ❑ Time Division Duplexing (TDD) allows varying uplink-to-downlink ratio
- ❑ All cells in an area must synchronize their UL/DL subframe pattern. Otherwise, mobile's transmission gets interference from neighboring BS
- ❑ LTE allows 7 variations of UL/DL subframe patterns.  
S=Switchover time from D to U



TDD Conf	TTI index									
	0	1	2	3	4	5	6	7	8	9
0	D	S	U	U	U	D	S	U	U	U
1	D	S	U	U	D	D	S	U	U	D
2	D	S	U	D	D	D	S	U	D	D
3	D	S	U	U	U	D	D	D	D	D
4	D	S	U	U	D	D	D	D	D	D
5	D	S	U	D	D	D	D	D	D	D
6	D	S	U	U	U	D	S	U	U	D

Ref: V. Pauli, Y. Li, E. Seidel, "Dynamic TDD for LTE-A and 5G," Nomor Research GmbH, Sep 2015, 8 pp.,

[http://nashville.dyndns.org:823/YourFreeLibrary/\\_lte/LTE%20advanced/WhitePaperNomor\\_LTE-A\\_5G-eIMTA\\_2015-09.pdf](http://nashville.dyndns.org:823/YourFreeLibrary/_lte/LTE%20advanced/WhitePaperNomor_LTE-A_5G-eIMTA_2015-09.pdf)

Washington University in St. Louis

<http://www.cse.wustl.edu/~jain/cse574-24/>

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## Student Questions

- ❖ Why does the synchronization of the UL/DL subframe pattern reduce interference from neighboring base stations?

*The tower signal is strong and can drown out mobiles.*

- ❑ Can you go over the grid diagram again with your mouse?

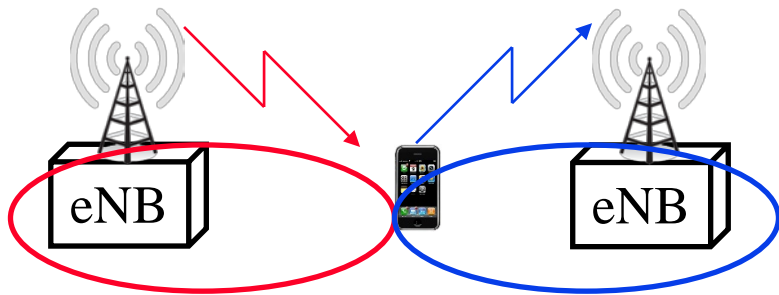
*Sure.*

- ❑ Why is there no switchover time from U to D?

*Downlink signal is stronger and can cause more interference in the neighboring cells.*

# Dynamic TDD

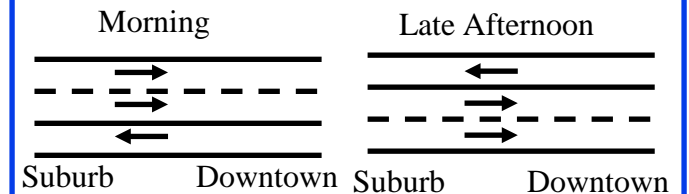
- Time Division Duplexing (TDD) allows varying uplink-to-downlink ratio
- All cells in an area must synchronize their UL/DL subframe pattern. Otherwise, mobile's transmission gets interference from neighboring BS
- LTE allows 7 variations of UL/DL subframe patterns.  
S=Switchover time from D to U



TDD Conf	TTI index									
	0	1	2	3	4	5	6	7	8	9
0	D	S	U	U	U	D	S	U	U	U
1	D	S	U	U	D	D	S	U	U	D
2	D	S	U	D	D	D	S	U	D	D
3	D	S	U	U	U	D	D	D	D	D
4	D	S	U	U	D	D	D	D	D	D
5	D	S	U	D	D	D	D	D	D	D
6	D	S	U	U	U	D	S	U	U	D

## Student Questions

- How does Dynamic TDD address the challenges of varying traffic loads in different areas? What mechanisms are in place to ensure efficient resource allocation?
- This is like lane reassignments during peak traffic hours on the highway.*



Ref: V. Pauli, Y. Li, E. Seidel, "Dynamic TDD for LTE-A and 5G," Nomor Research GmbH, Sep 2015, 8 pp.,

[http://nashville.dyndns.org:823/YourFreeLibrary/\\_lte/LTE%20advanced/WhitePaperNomor\\_LTE-A\\_5G-eIMTA\\_2015-09.pdf](http://nashville.dyndns.org:823/YourFreeLibrary/_lte/LTE%20advanced/WhitePaperNomor_LTE-A_5G-eIMTA_2015-09.pdf)

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# Dynamic TDD (Cont)

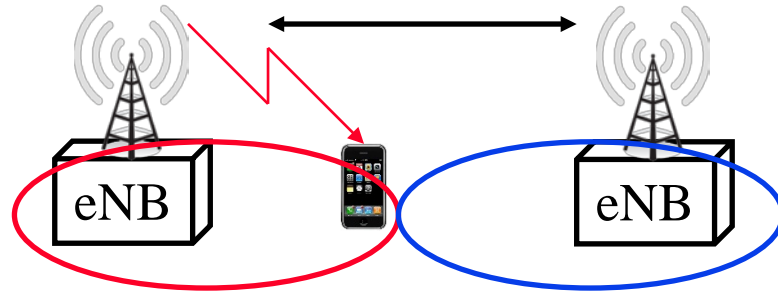
- ❑ Too many U's or D's in a row delay acks/nacks and affect the usefulness of HARQ.
- ❑ Release 12 added flexible "F" subframes that can be declared as S, D, or U  $\Rightarrow$  Can change every 10 ms.
- ❑ **Enhanced Interference Mitigation and Traffic Adaptation (eIMTA):** Cells can change UL/DL patterns as needed. Mobiles are asked to transmit at higher power if needed.
- ❑ This will be further enhanced for 5G

TTI index									
0	1	2	3	4	5	6	7	8	9
D	S	U	F	F	D	S/D	F	F	F

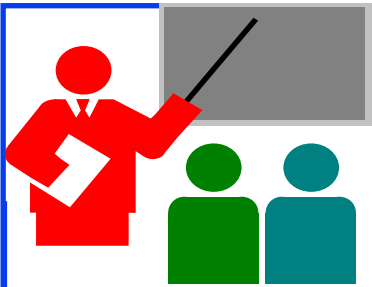
## Student Questions

# Inter-eNB CoMP

- ❑ CoMP in Release 11 was restricted to eNBs connected via ideal backhaul  $\Rightarrow$  No need for network interfaces
- ❑ In Release 12, a signaling interface has been added which allows eNBs to interchange measurement and resource allocation information



## Student Questions



# Summary

1. LTE-A meets and exceeds all requirements for 4G as specified in IMT-Advanced.
2. Three key factors that affect data rate are: spectrum, spectral efficiency, and cell size
3. LTE-A can aggregate up to 5 carriers to make up to 100 MHz
4. LTE-A has a frequency reuse factor of 1 since the spectrum is expensive and uses high-order MIMO.
5. LTE-A uses relay nodes to cover remote areas and hot spots. It also allows Home eNB (femtocells).
6. Code-book and non-code book precoding improves MIMO
7. Coordinated Multipoint operation (CoMP) allows mitigation of interference at the cell edge. CoMP can also be used with cross-carrier scheduling.

## Student Questions

- Can you please review the slides after 49 that are not in the video?

*Sure*

---

# Reading List

- ❑ 3GPP, “LTE-Advanced,”  
<http://www.3gpp.org/technologies/keywords-acronyms/97-lte-advanced>
- ❑ Rohde & Schwarz GmbH & Co, “1MA252: LTE- Advanced (3GPP Rel.12) Technology Introduction White Paper,”  
[https://www.rohde-schwarz.com/us/applications/lte-advanced-3gpp-rel.12-technology-introduction-white-paper-white-paper\\_230854-108294.html](https://www.rohde-schwarz.com/us/applications/lte-advanced-3gpp-rel.12-technology-introduction-white-paper-white-paper_230854-108294.html)
- ❑ 3GPP, “HetNet/Small Cells,” <http://www.3gpp.org/hetnet>
- ❑ 3GPP, “Heterogeneous Networks in LTE,”  
<http://www.3gpp.org/technologies/keywords-acronyms/1576-hetnet>
- ❑ 3GPP, “Carrier Aggregation Explained,”  
<http://www.3gpp.org/technologies/keywords-acronyms/101-carrier-aggregation-explained>

## Student Questions

# Wikipedia Links

- ❑ [https://en.wikipedia.org/wiki/LTE\\_Advanced](https://en.wikipedia.org/wiki/LTE_Advanced)
- ❑ <https://en.wikipedia.org/wiki/Femtocell>
- ❑ [https://en.wikipedia.org/wiki/Home\\_Node\\_B](https://en.wikipedia.org/wiki/Home_Node_B)
- ❑ [https://en.wikipedia.org/wiki/Self-organizing\\_network](https://en.wikipedia.org/wiki/Self-organizing_network)
- ❑ [https://en.wikipedia.org/wiki/Voice\\_over\\_LTE](https://en.wikipedia.org/wiki/Voice_over_LTE)

## Student Questions



# LTE-Advanced Books

- ❑ S. Ahmadi, "LTE-Advanced," Academic Press, 2013, ISBN: 9780124051621, 1152 pp. Safari book.
- ❑ E. Dahlman, S. Parkvall, J. Skold, "4G: LTE/LTE-Advanced for Mobile Broadband, 2nd Edition," Academic Press, 2013, ISBN: 9780124199859, 544 pp. Safari book.
- ❑ C. Cox, "An Introduction to LTE: LTE, LTE-Advanced, SAE and 4G Mobile Communications, 2<sup>nd</sup> Edition" Wiley, 2014, ISBN: 9781118818039, 486 pp. Safari book.
- ❑ A. Ghosh, R. Ratasuk, "Essentials of LTE and LTE-A," Cambridge University Press, 2011, ISBN: 9780521768702, 264 pp. Safari book.
- ❑ A. Ghosh, J. Zhang, J. G. Andrews, R. Muhamed, "Fundamentals of LTE," Prentice Hall, 2010, ISBN: 0137033117, 464 pp. Safari book.
- ❑ H. Holma, A. Toskala, "LTE Advanced: 3GPP Solution for IMT-Advanced," Wiley, 2012, ISBN: 9781119974055, 248 pp. Safari book.
- ❑ X. Zhang, X. Zhou, "LTE-Advanced Air Interface Technology," CRC Press, 2012, ISBN: 9781466501522, 528 pp. Safari book.
- ❑ A. Taha, H. Hassanein, N. Ali, "LTE, LTE-ADVANCED AND WiMAX: TOWARDS IMT-ADVANCED NETWORKS," Wiley, 2012, ISBN: 9780470745687, 303 pp. Safari book.

## Student Questions

# Small Cells - Books

- J. Zhang and G Roche, “Femtocells: Technologies and Deployment,” Wiley, 2010, ISBN:0470742983

## Student Questions

# LTE-Advanced Specifications

- ❑ TR 36.806 E-UTRA Relay architectures for E-UTRA (LTE-Advanced)
- ❑ TR 36.808 E-UTRA Carrier Aggregation; Base Station (BS) radio transmission and reception
- ❑ TR 36.814 E-UTRA Further advancements for E-UTRA physical layer aspects
- ❑ TR 36.815 Further Advancements for E-UTRA; LTE-Advanced feasibility studies in RAN WG4
- ❑ TR 36.817 E-UTRA Uplink multiple antenna transmission; Base Station (BS) radio transmission and reception
- ❑ TR 36.819 Coordinated multi-point operation for LTE physical layer aspects
- ❑ TR 36.823 E-UTRA Carrier Aggregation Enhancements; UE and BS radio transmission and reception
- ❑ TR 36.826 E-UTRA Relay radio transmission and reception
- ❑ TR 36.871 E-UTRA Downlink Multiple Input Multiple Output (MIMO) enhancement for LTE-Advanced
- ❑ TR 36.912 Feasibility study for Further Advancements for E-UTRA (LTE-Advanced)

## Student Questions

# LTE-Advanced Specifications (Cont)

- ❑ TR 36.913 Requirements for further advancements for E-UTRA (LTE-Advanced)
- ❑ TR 36.932 Scenarios and requirements for Small Cell Enhancements for E-UTRA and E-UTRAN
- ❑ TS 36.101 E-UTRA User Equipment (UE) radio transmission and reception
- ❑ TS 36.211 E-UTRA Physical channels and modulation
- ❑ TS 36.212 E-UTRA Multiplexing and channel coding
- ❑ TS 36.213 E-UTRA Physical layer procedures
- ❑ TS 36.216 E-UTRA Physical layer for relaying operation
- ❑ TS 36.221 E-UTRA Medium Access Control (MAC) protocol specification
- ❑ TS 36.300 Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2
- ❑ TS 36.306 E-UTRA User Equipment (UE) radio access capabilities
- ❑ TS 36.331 E-UTRA Radio resource Control (RRC) protocol specification
- ❑ TS 36.423 Evolved Universal Terrestrial Radio Access Network (E-UTRAN); X2 Application Protocol (X2AP)

All available at <http://www.3gpp.org/>

## Student Questions

# Femtocell Specifications

- ❑ 3GPP Rel 8 specifies HNB (Home Node B) and HeNB (22.\*)
- ❑ Rel 9 includes an IMS (IP Multimedia Subsystem) capable HNB (23.\*)
- ❑ TS 22.220: Service Requirements for HNB and HeNB
- ❑ TR 23.830: Architecture aspects of HNB and H3NB
- ❑ TR 23.832: IMS aspects of architecture for HNB
- ❑ TR 25.820: 3G HNB study item
- ❑ TR 25.967: FDD HNB RF Requirements
- ❑ TR 32.821: Study of self-organizing networks related OAM interfaces for HNB  
TR33.820: Security of HNB/HeNB
- ❑ TS 25.467: Mobility procedures for HNB
- ❑ TS 25.468: UTRAN Iuh Interface RANAP (Radio Access Network Application Part)  
User adaptation signaling
- ❑ TS 25.469: UTRAN Iuh Interface HNB application part signaling
- ❑ TS 32.581: HNB OAM&P (Operation, Administration, Management and Provisioning) concepts and requirements for Type 1 interface HNT to HNT  
Management system

## Student Questions

# Femtocell Specifications (Cont)

- ❑ TS 32.582: HNB OAM&P information model for Type 1 interface HNT to HNT Management system
- ❑ TS 32.583: HNB OAM&P procedure flows for Type 1 interface HNT to HNT Management system
- ❑ Broadband Forum TR-069 management protocol has been adopted to include femtocells.

## Student Questions

# LTE-Advanced References

- ❑ ITU-R Report M.2134, “Requirements Related to Technical Performance for IMT-Advanced Radio Interface(s),” November 2008.
- ❑ 4G LTE News, 4G LTE Forum, LTE-Advanced and more, <http://www.lteportal.com/MediaChannel/Articles/>
- ❑ Rohde & Schwarz, “1MA232: LTE-Advanced (3GPP Rel. 11) Technology Introduction,” [https://www.rohde-schwarz.com/en/applications/lte-advanced-3gpp-rel.11-technology-introduction-application-note\\_56280-42753.html](https://www.rohde-schwarz.com/en/applications/lte-advanced-3gpp-rel.11-technology-introduction-application-note_56280-42753.html)

## Student Questions

# Acronyms

- ❑ 3GPP      3rd Generation Partnership Project
- ❑ ABS      Almost Blank Subframes
- ❑ ANDSF    Access Network Discovery and Selection Function
- ❑ AP        Access Point
- ❑ BS        Base Station
- ❑ CoMP     Coordinated Multipoint Operation
- ❑ CRE      Cell Range Extension
- ❑ CRS      Cell Reference Signals
- ❑ CSFB     Circuit Switch Fall Back
- ❑ dBm      deciBel miliwatt
- ❑ DeNB     Donor eNB
- ❑ DFT      Discrete Fourier Transform
- ❑ DL        Down Link
- ❑ DM-RS    Demodulation Reference Signal
- ❑ DSL      Digital Subscriber Line
- ❑ eICIC     Enhanced Inter-Cell Interference Cancellation

## Student Questions



# Acronyms (Cont)

- ❑ eNode-B      Enhanced Node Basestation
- ❑ eNB          eNode B
- ❑ EPC          Evolved Packet Core
- ❑ FDD          Frequency Division Duplexing
- ❑ FCC          Federal Communications Commission
- ❑ FDMA        Frequency Division Multiple Access
- ❑ GPS          Global Positioning System
- ❑ GSM          Global System for Mobile Communication
- ❑ HARQ        Hybrid Automatic Repeat Request
- ❑ HD          High Definition
- ❑ HeNB        Home eNB
- ❑ HetNet      Heterogeneous Network
- ❑ HSS          Home Subscriber System
- ❑ ID          Identifier
- ❑ IDFT        Inverse Discrete Fourier Transform
- ❑ IEEE        Institution of Electrical and Electronic Engineers

## Student Questions

# Acronyms (Cont)

- ❑ IMS Internet Multimedia System
- ❑ IMT-Advanced International Mobile Telecommunications Advanced
- ❑ IP Internet Protocol
- ❑ ITU International Telecommunications Union
- ❑ LAN Local Area Network
- ❑ LTE-Advanced Long-Term Evolution Advanced
- ❑ LTE Long-Term Evolution
- ❑ MAC Media Access Control
- ❑ MBMS Multimedia Broadcast Multicast Service
- ❑ MBSFN MBMS Single Frequency Network
- ❑ MCE Multicast Coordination Entity
- ❑ MHz Mega Hertz
- ❑ MIMO Multiple Input Multiple Output
- ❑ MU-MIMO Multi-User MIMO
- ❑ NTP Network Time Protocol
- ❑ OAM Operation, Administration, and Management

## Student Questions

# Acronyms (Cont)

- ❑ PDCCH Packet Data Control Channel
- ❑ PHY Physical Layer
- ❑ PRB Physical Resource Block
- ❑ RAN Radio Access Network
- ❑ RANAP Radio Access Network Application
- ❑ RF Radio Frequency
- ❑ RLC Radio Link Control
- ❑ RN Relay Node
- ❑ RRC Radio Resource Control
- ❑ RRH Remote Radio Heads
- ❑ RS Reference Signal
- ❑ SAE Service Access Gateway
- ❑ SC-FDMA Single Carrier Frequency Division Multiple Access
- ❑ SFBC Space-Frequency Block Code
- ❑ SINR Signal to Interference and Noise Ratio
- ❑ SOHO Small Office Home Office

## Student Questions

# Acronyms (Cont)

- ❑ SON Self-Organizing Network
- ❑ SSDL Strongest Signal in Downlink
- ❑ SU-MIMO Single User MIMO
- ❑ TDD Time Division Duplexing
- ❑ TTI Transmission Time Interval
- ❑ TV Television
- ❑ UE User Element
- ❑ UL Uplink
- ❑ UMTS Universal Mobile Telecommunications System
- ❑ UTRA UMTS Terrestrial Radio Access
- ❑ UTRAN UMTS Terrestrial Radio Access Network
- ❑ VoLTE Voice over LTE
- ❑ WG Working Group
- ❑ WiFi Wireless Fidelity
- ❑ WiMAX Worldwide Interoperability for Microwave Access

## Student Questions

# LTE Cat-0 Devices

- ❑ Simple device category for IoT in Release 12.
  - Single Antenna
  - Reduced peak rate up to 1 Mbps
  - Half-Duplex  $\Rightarrow$  No duplex filter
- ❑ **Power Save Mode (PSM):**
  - Previously a device could be active or idle and keep its IP address
  - eNB sends paging message if data is received for devices not connected
  - PSM allows devices to keep IP address but stop listening to incoming paging requests for long durations

## Student Questions

- ❑ What is an example of a Cat-0 device?
-

# Cell On/Off Switching

- ❑ Under low load a cell or small cell can be turned off
- ❑ Off cells broadcast “Discovery reference signals (DRS)” periodically so that they can be turned on if necessary
- ❑ Takes a few hundred ms
- ❑ Used for energy consumption during nights

## Student Questions

- ❑ What constitutes a low load? Is this determined by the Cell service company or a regulator like FCC?
-

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[http://www.cse.wustl.edu/~jain/cse574-24/j\\_18lta.htm](http://www.cse.wustl.edu/~jain/cse574-24/j_18lta.htm)

**Student Questions**

# Related Modules



CSE567M: Computer Systems Analysis (Spring 2013),  
[https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n\\_1X0bWWNyZcof](https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof)

CSE473S: Introduction to Computer Networks (Fall 2011),  
[https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcg5e\\_10TiDw](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