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/cse574-22/

Student Questions

Overview

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 3rd 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

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/

Student Questions

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

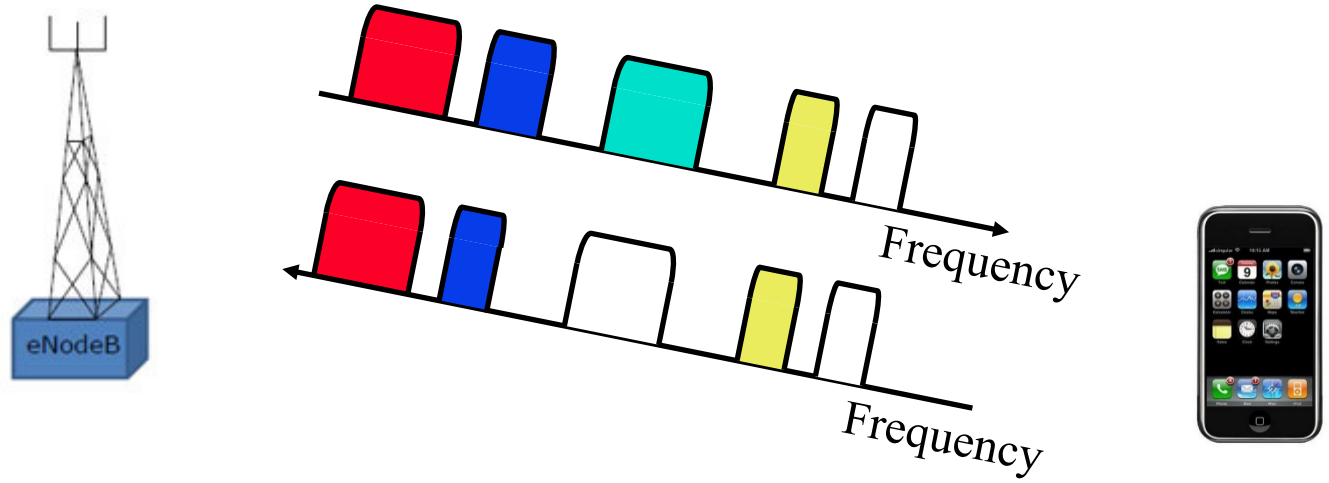
LTE Advanced Techniques

- **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 ⇒ 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

Carrier Aggregation

- Aggregation = Combine multiple bands (Component Carriers)

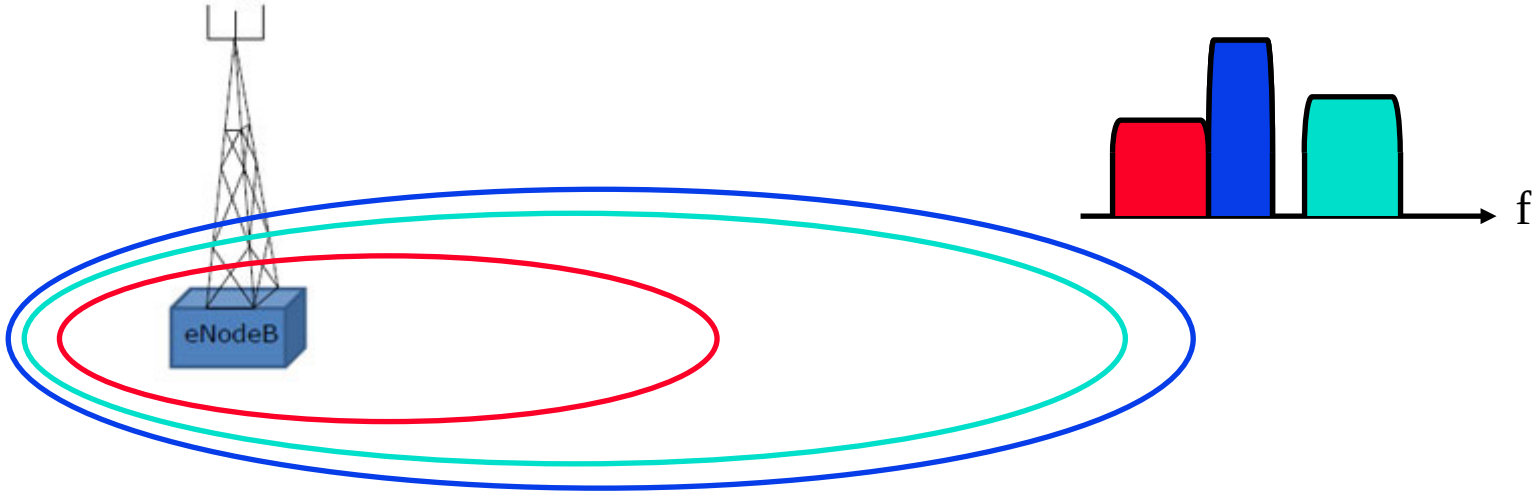


- Backward compatible with LTE (Single carrier)
  ⇒ Each band can be 1.4, 3, 5, 10, or 20 MHz
- Maximum 5 component carriers ⇒ 100 MHz max
- Each component can be a different width
- Number of components in DL and UL can be different, but
  Number of components in DL ≥ Number of components in UL

Student Questions

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



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

Student Questions

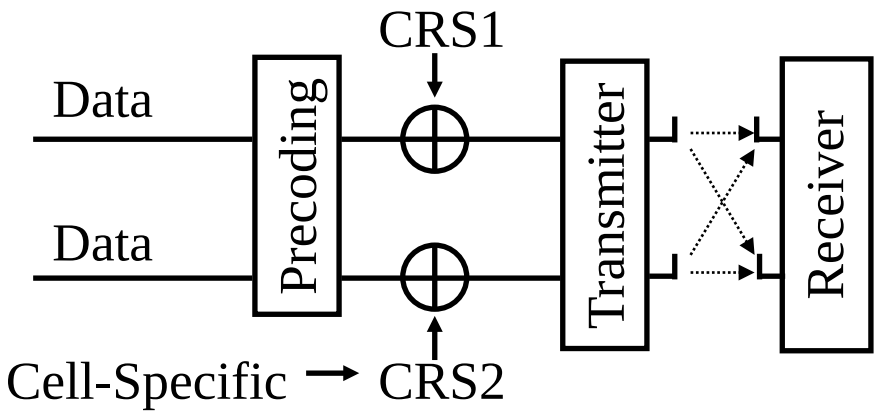
MIMO

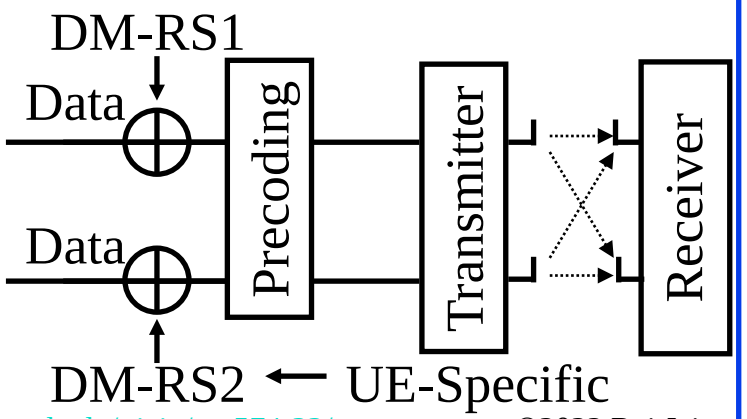
- 8x8 MIMO in DL and 4x4 in UL
- MIMO used only when SINR is high ⇒ Good Channel
- If SINR is low, other spectral efficiency techniques, such as transmit diversity, are used.
- Many different transmission modes are defined.
  UE is informed about the mode to use via signaling
- Modes differ in the number 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

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.

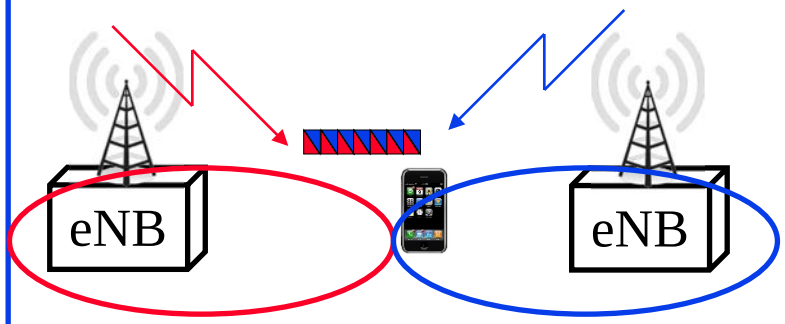




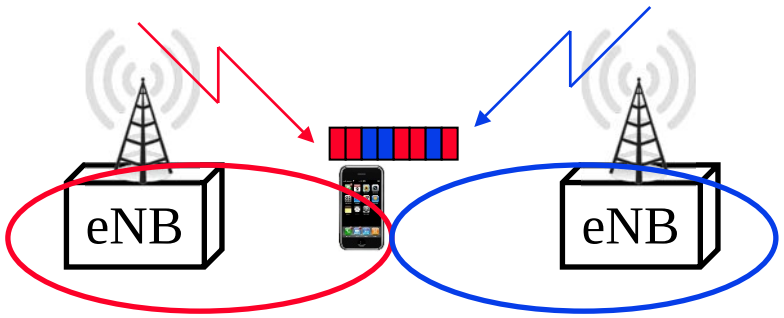
Student Questions

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

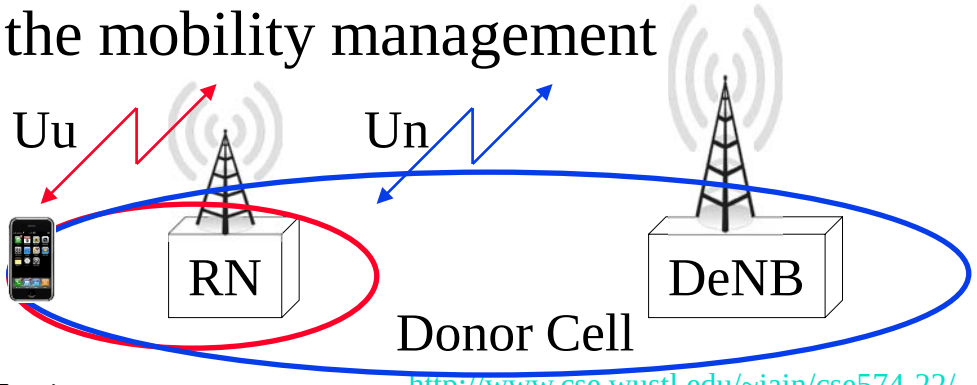


(b) Dynamic Point Selection

Student Questions

Relay Nodes

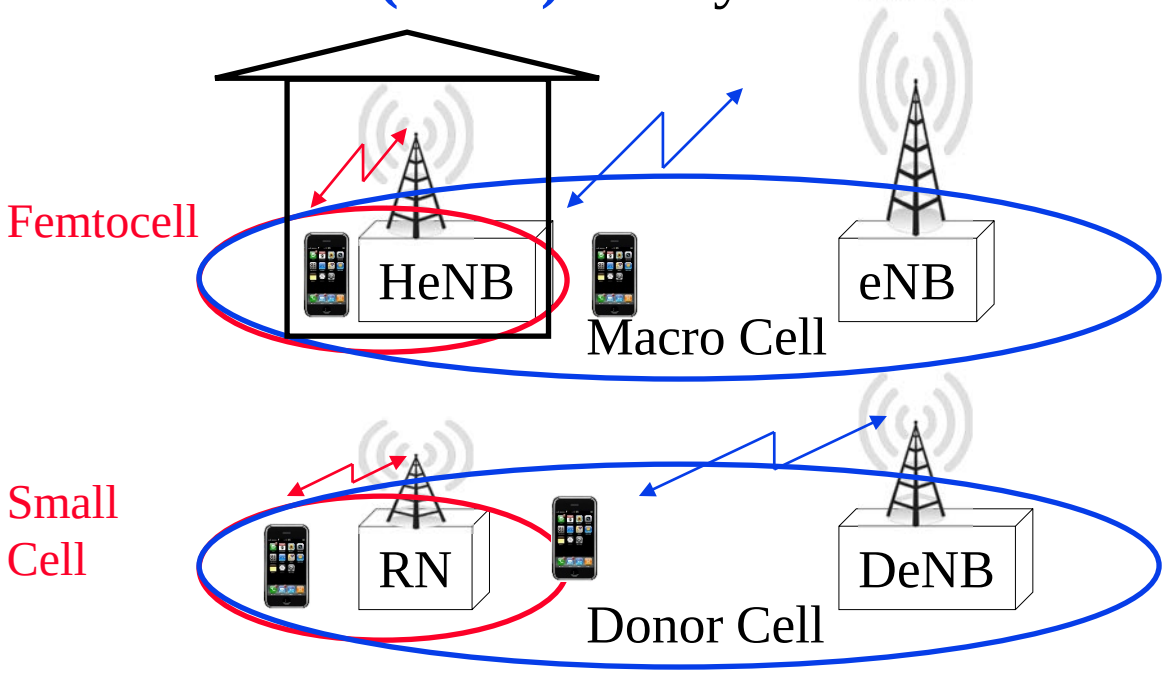
- **Relay Nodes**: Low-power base stations
  Used to enhance performance at cell edges, hot-spot areas, indoor coverage
- **Donor eNB (DeNB)**: Primary base station
- A modified version of E-UTRAN air interface Uu is defined: Un
- Both Donor and Relays may use the same/different frequencies
- Self-Interference: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



Student Questions

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

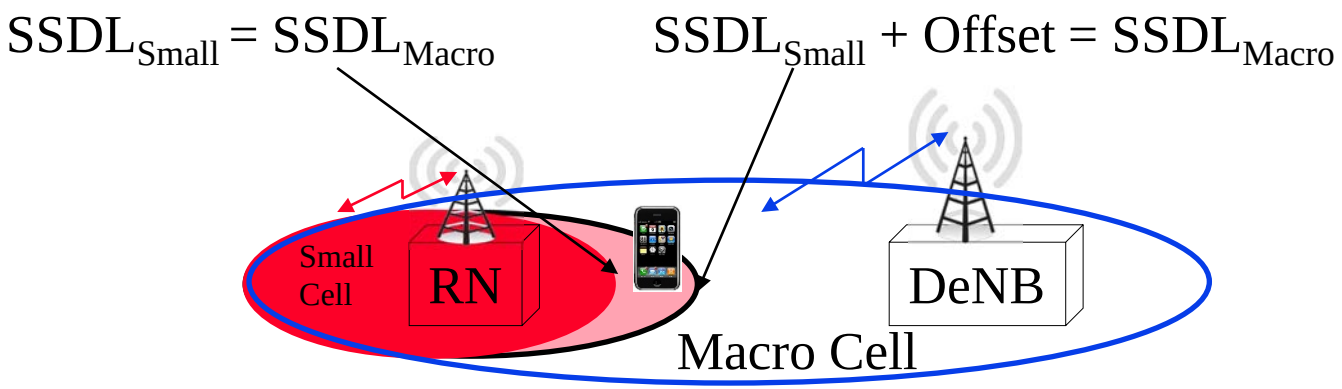


Ref: 3GPP, "HetNet/Small Cells," http://www.3gpp.org/hetnet

Student Questions

HetNet/Small Cells (Cont)

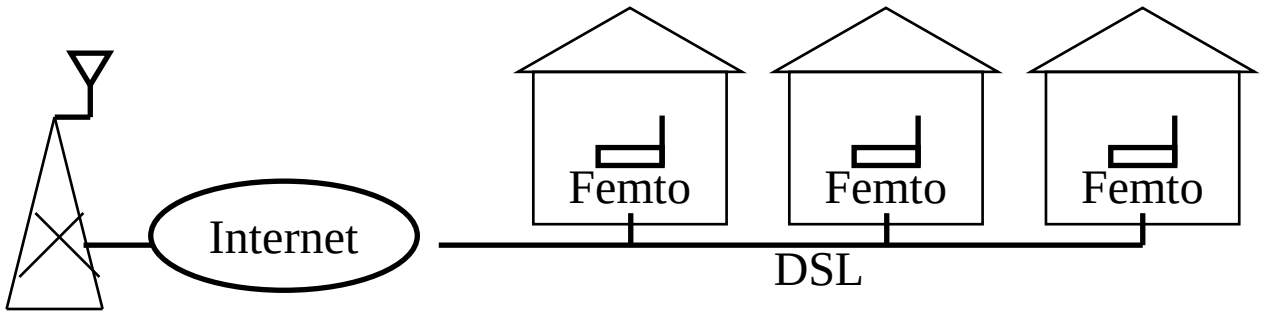
- UE selects the BS with the strongest signal in DL (SSDL) ⇒ Both BS have the same SSDL at the edge
- **Cell Range Extension (CRE)**: Allow small cell to serve more users by requiring UE to join the small cell even if the power is slightly below the macro cell ⇒ Interference from the macro is mitigated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



Student Questions

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.



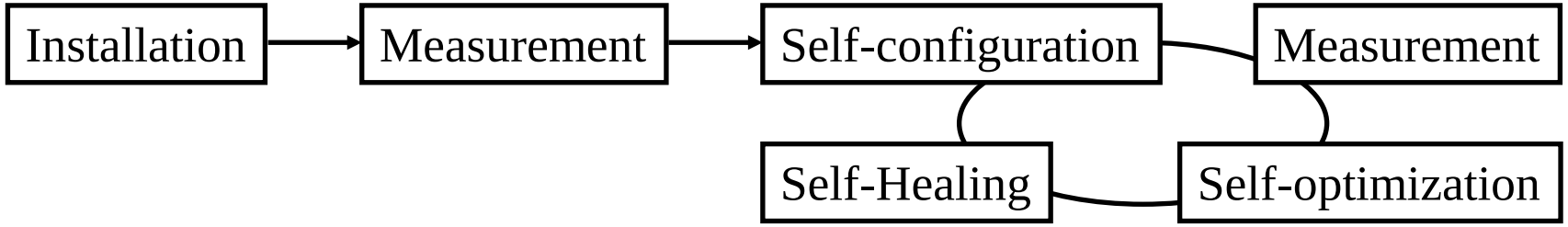
Student Questions

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

Self-Organizing Network (SON)



- User installable. 70M UMTS femtocells expected in 2012
- 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

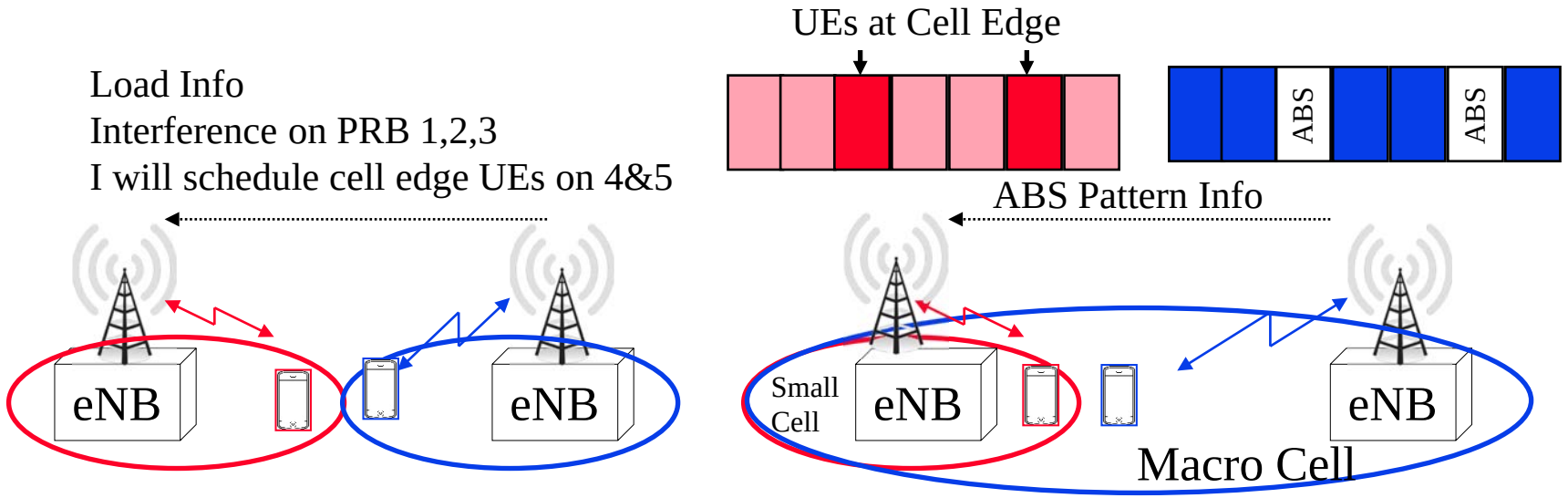
Management and Configuration

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

Student Questions

Enhanced Inter-Cell Interference Coordination (eICIC)

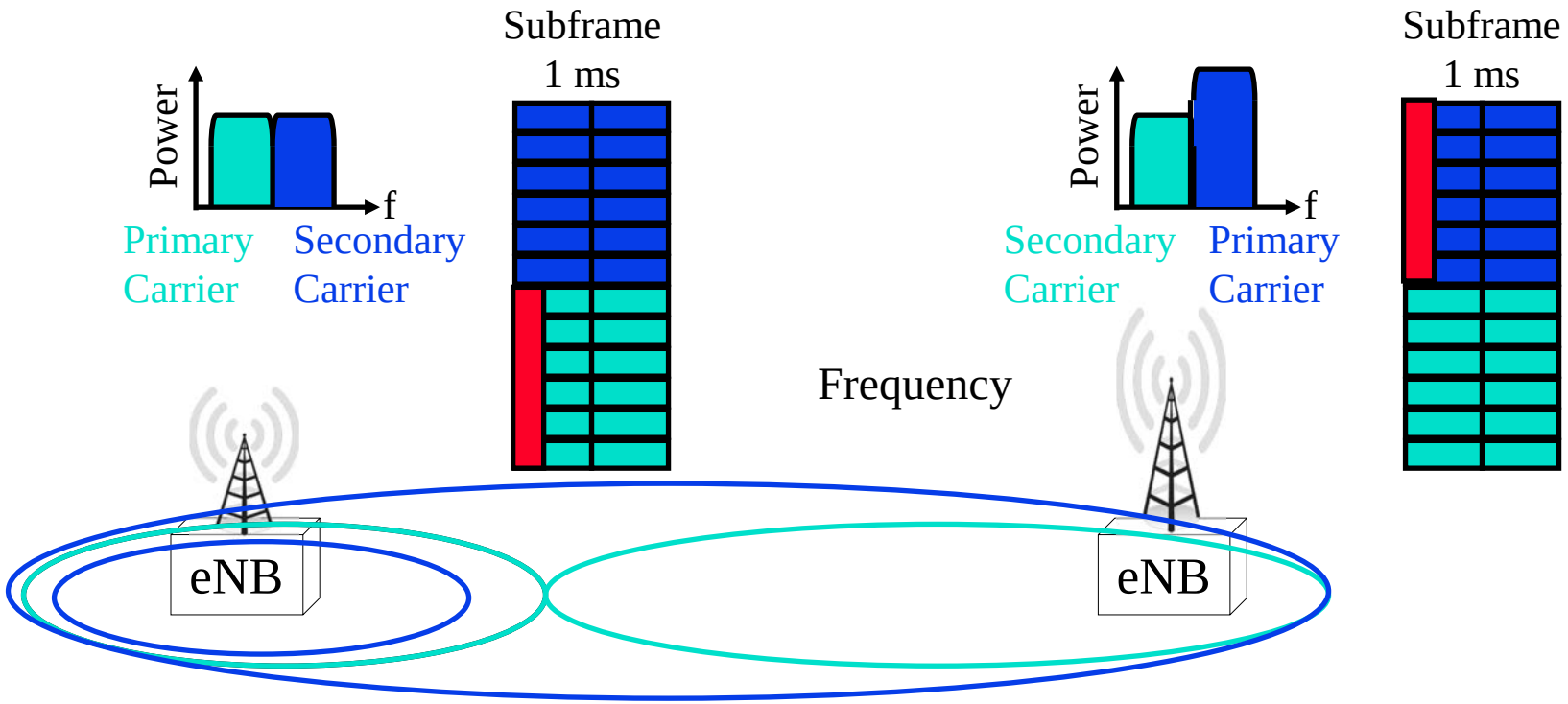
- **ICIC**: A eNB sends a "load information" message to the neighbor eNB about the interference level per physical resource block. The neighbor adjusts DL power levels at those blocks
- **Almost Blank Subframes (ABS)**: Only control channels and cell-specific pilots, no user data ⇒ Allows UEs in CRE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



Student Questions

Carrier Aggregation with Cross-Carrier Scheduling

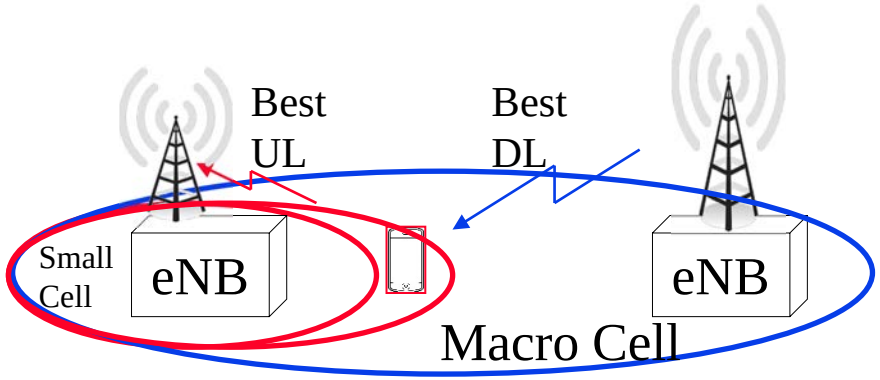
- **Physical DL Control channel (PDCCH)** in macro cell and small cell is sent on different carriers and may be at a higher power than traffic channels
- A UE can talk to both BSs using control channels on different carriers



Student Questions

CoMP with Small Cells

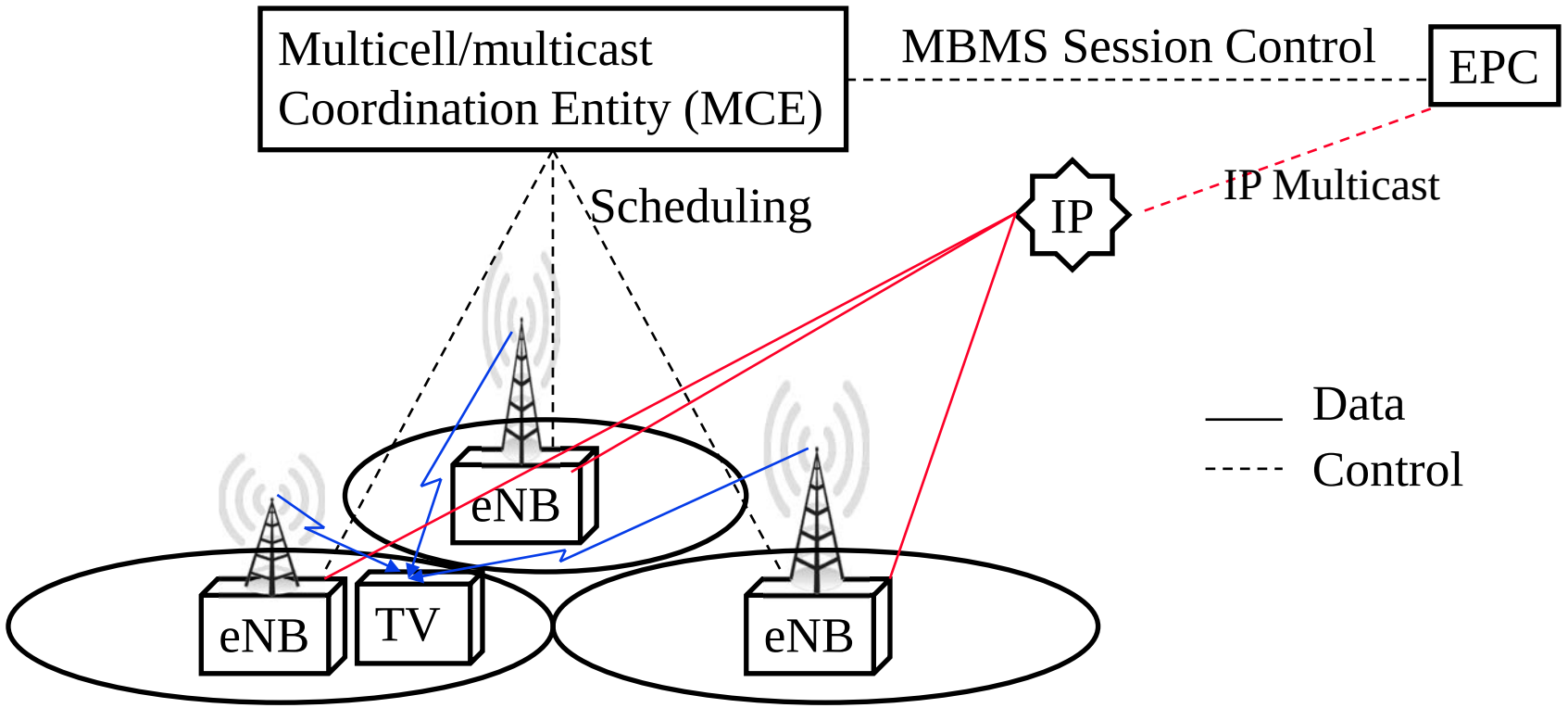
- A UE can get service from multiple BSs (eNB, RN, HeNB, RRH)
  - Can get data through multiple BSs
  - Can send data through multiple BSs
  - Can send data to one BS and receive it from another



Student Questions

Multimedia Broadcast Multicast Service (MBMS)

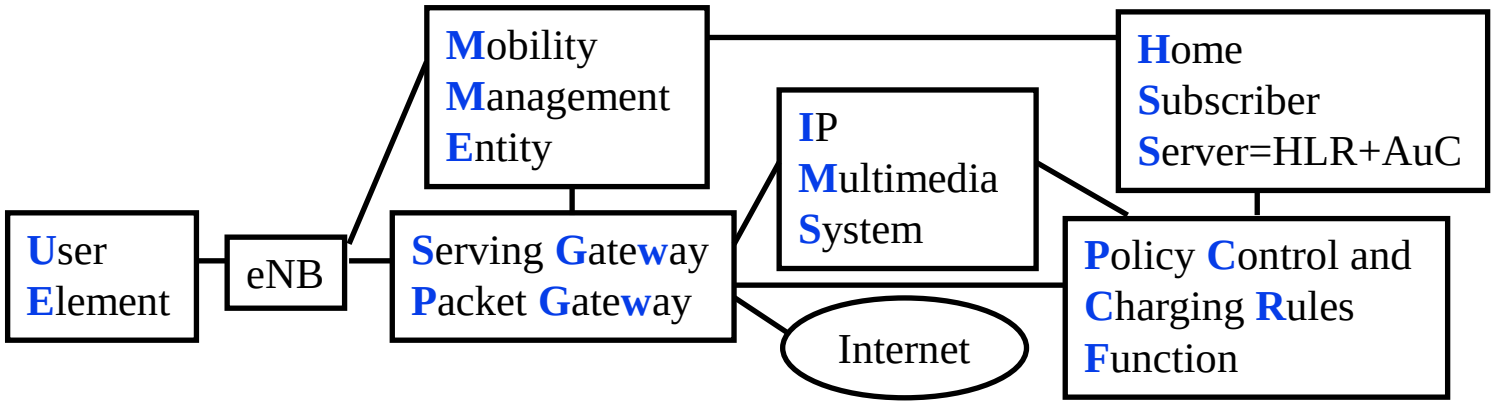
- MBMS Single Frequency Network (MBSFN)
- MCE handles synchronized data delivery



Student Questions

Voice over LTE (VoLTE)

- Original LTE is not circuit switched
  ⇒ Voice needed to go through GSM or 3G circuits.
  Called **C**ircuit **S**witch **F**all **B**ack (**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

Enhancements in Release 12

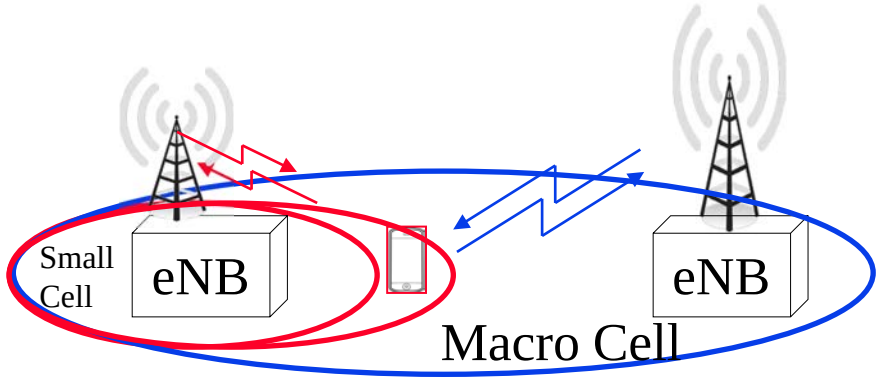
1. Enhanced Small Cells
2. Device to Device Communication (D2D)
3. WLAN/3GPP Radio Interworking
4. HetNet Mobility Enhancements
5. Smart Congestion Mitigation (SCM)
6. Machine-Type Applications
7. FDD-TDD Carrier Integration
8. Dynamic TDD
9. Inter-eNB CoMP

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

Student Questions

Enhanced Small Cells

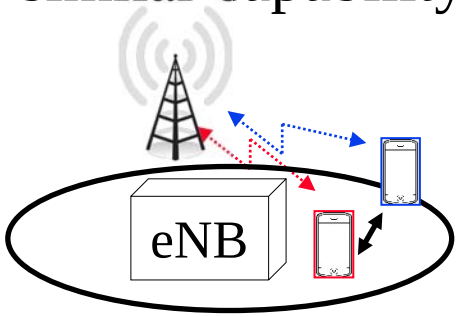
- **Higher order modulations**: Small cells ⇒ Higher SINR
  ⇒ Higher order modulations ⇒ 256-QAM
- **Dual Connectivity**: Mobile can have two radios
  Mobile can connect to both macro and pico cells.



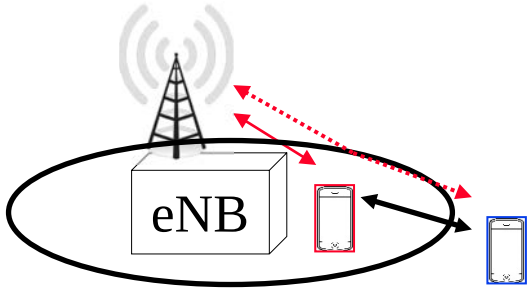
Student Questions

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



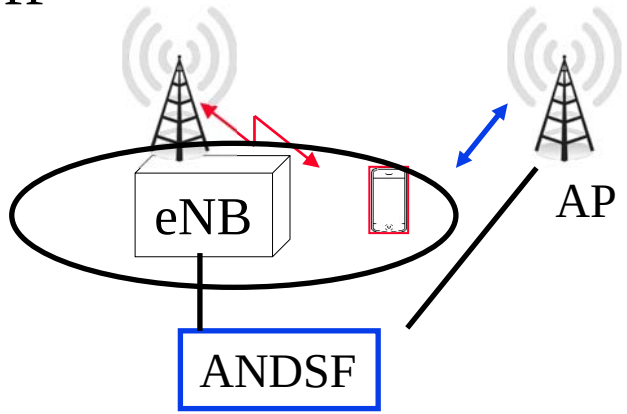
(b) D2D Relaying

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

Student Questions

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 if 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 ⇒ Mobiles may get in/out without enough time to have seamless handover ⇒ 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

Smart Congestion Mitigation (SCM)

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

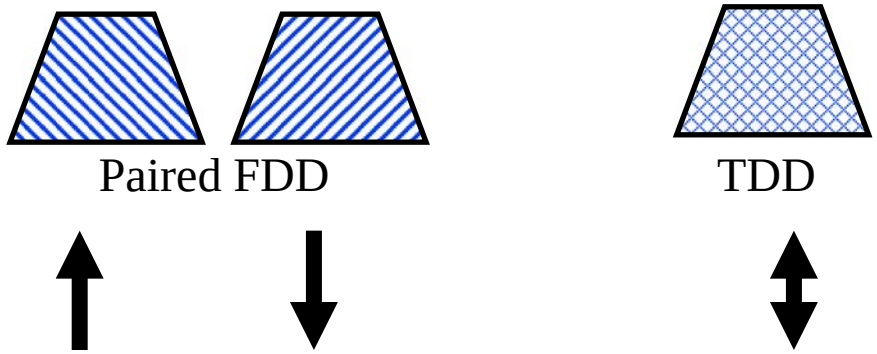
Student Questions

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

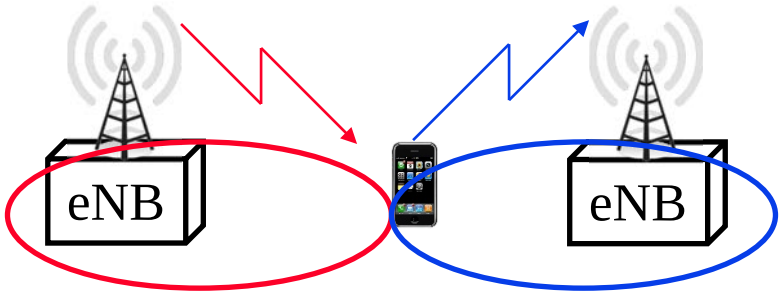


- Can aggregate Down FDD band with TDD in the downlink
- Aggregate Up FDD band with TDD in uplink
- Use only FDD in Primary Cells and TDD in Small Cell or vice versa
- Generally, FDD bands are lower frequency ⇒ Used for primary
- In the future, 32 carriers could be aggregated

Student Questions

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

Student Questions

Dynamic TDD (Cont)

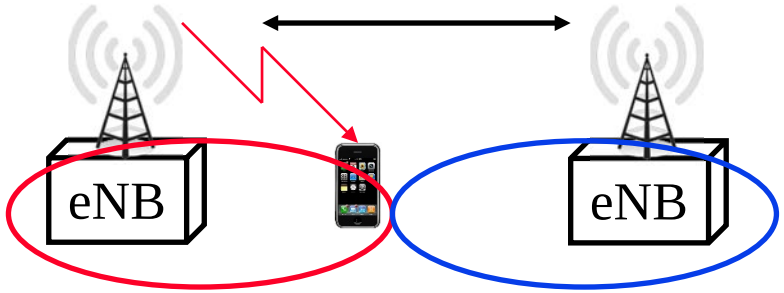
- Too many U's or D's in a row delay acks/nacks and affect the usefulness of HARQ.
- Release 12 added flexible "F" subframes that can be declared as S, D, or U ⇒ Can change every 10 ms.
- **Enhanced Interference Mitigation and Traffic Adaptation (eIMTA):** Cells can change UL/DL patterns as needed. Mobiles 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

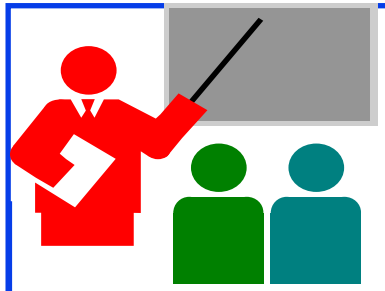
Student Questions

Inter-eNB CoMP

- CoMP in Release 11 was restricted to eNBs connected via ideal backhaul ⇒ 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

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
- 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/Femtocell
- https://en.wikipedia.org/wiki/Home_Node_B
- https://en.wikipedia.org/wiki/Self-organizing_network
- 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, 2nd 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.
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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)

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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

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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.
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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 ⇒ 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/cse574-22/j_18lta.htm

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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=PLjGG94etKypJWOSPMh8Azcgy5e_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

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