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/cse574-16/

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 2nd lecture in a series of lectures on LTE and LTE-Advanced

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)

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/

LTE-Advanced Requirements (Cont)

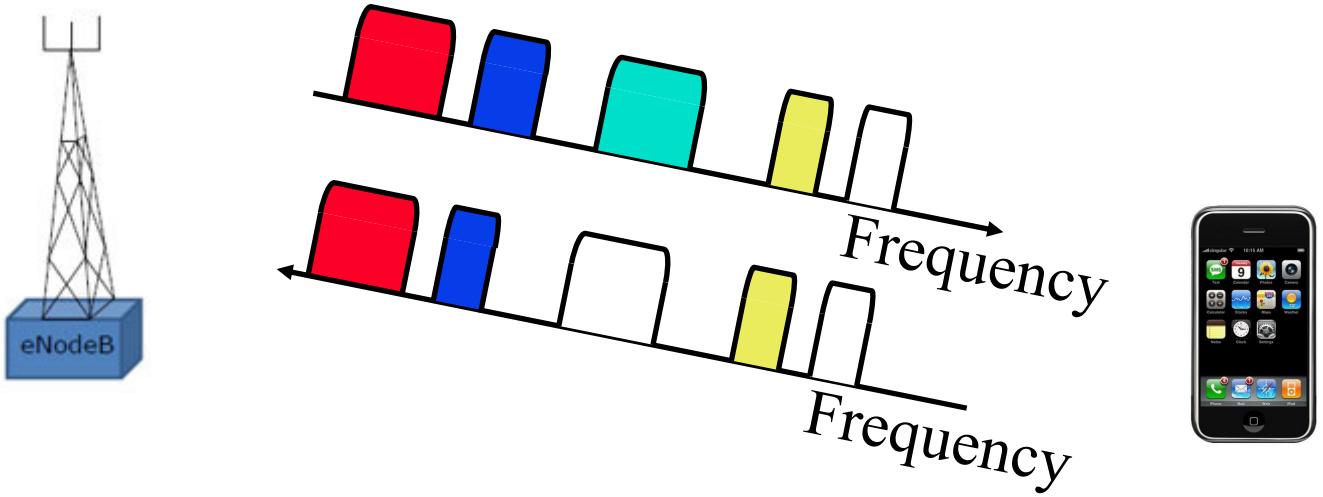
- **Latency**: Less than 10 ms from dormant to active;
  Less than 50 ms from camped to active
- **Mobility**: up to 500 kmph
- **Spectrum Flexibility**: FDD and TDD, Wider channels up to 100 MHz

LTE Advanced Techniques

- **Three Key Factors**: Spectrum (Band, Bandwidth), Spectral Efficiency, and Cell sizes
- **Bandwidth**: 100 MHz using carrier aggregation
  5 carriers allowed now. 32 in 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

Carrier Aggregation

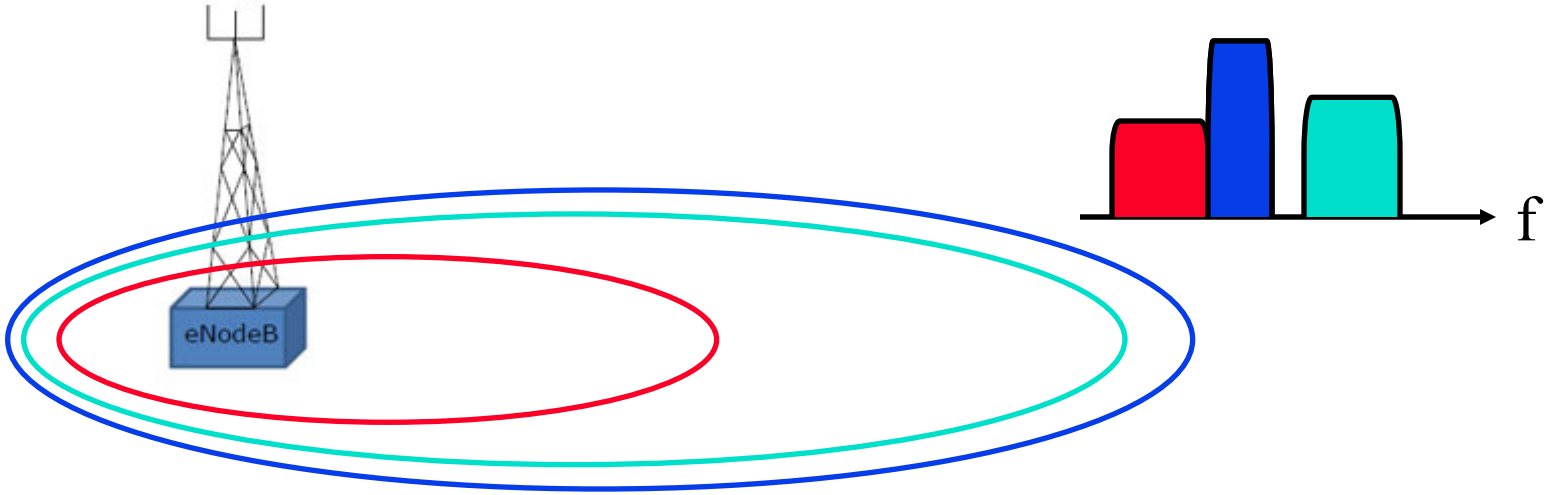
- Aggregation = Combine multiple bands (Component Carriers)



- 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 different width
- Number of components in DL and UL can be different, but
  Number of components in DL ≥ Number of components in UL

Carrier Aggregation (Cont)

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



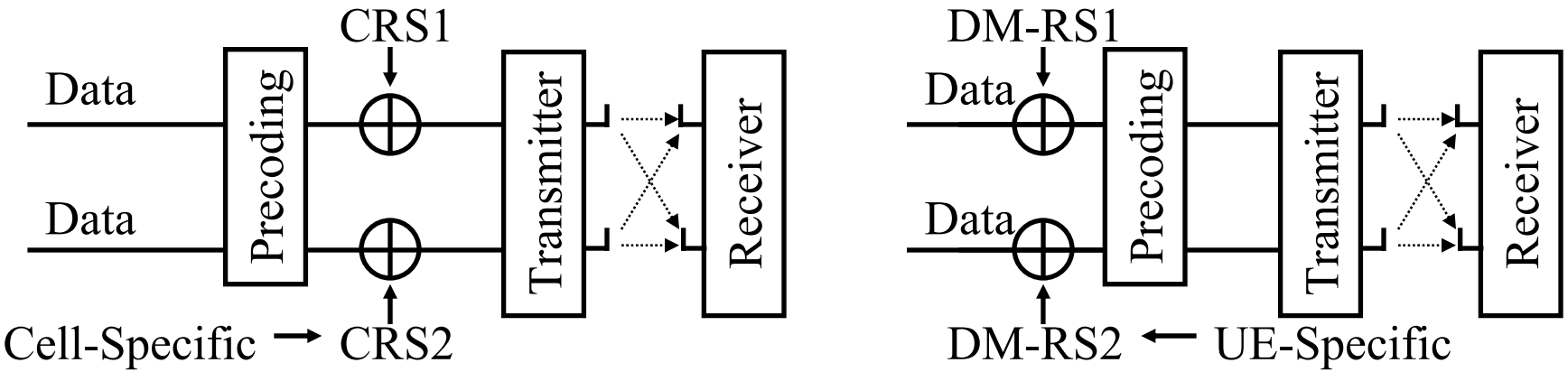
Ref: http://www.3gpp.org/technologies/keywords-acronyms/97-lte-advanced

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 defined.
  UE is informed about the mode to use via signaling
- Modes differ in 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

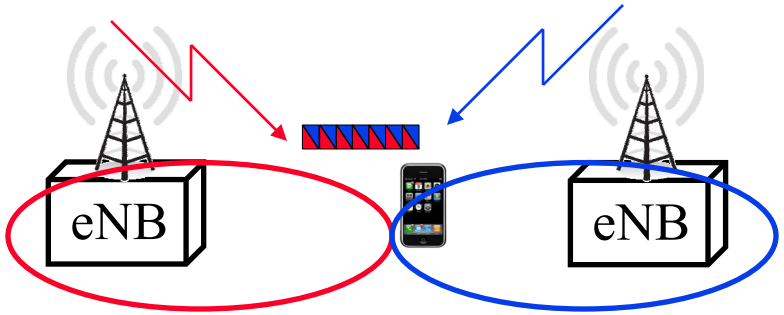
Precoding

- Used to map the modulation symbols to different antennas
  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.
  Receiver can infer precoding from the pilots.

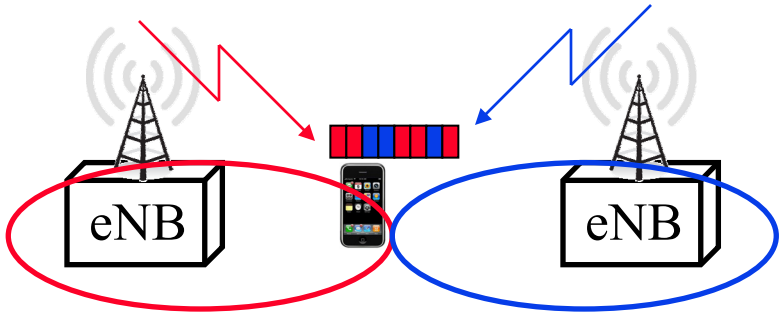


Coordinated Multipoint Operation (CoMP)

- To improve performance at 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



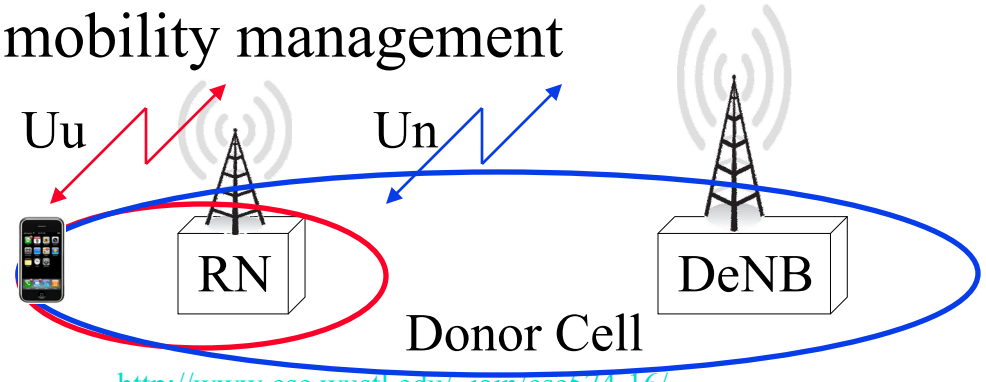
(a) Joint Transmission



(b) Dynamic Point Selection

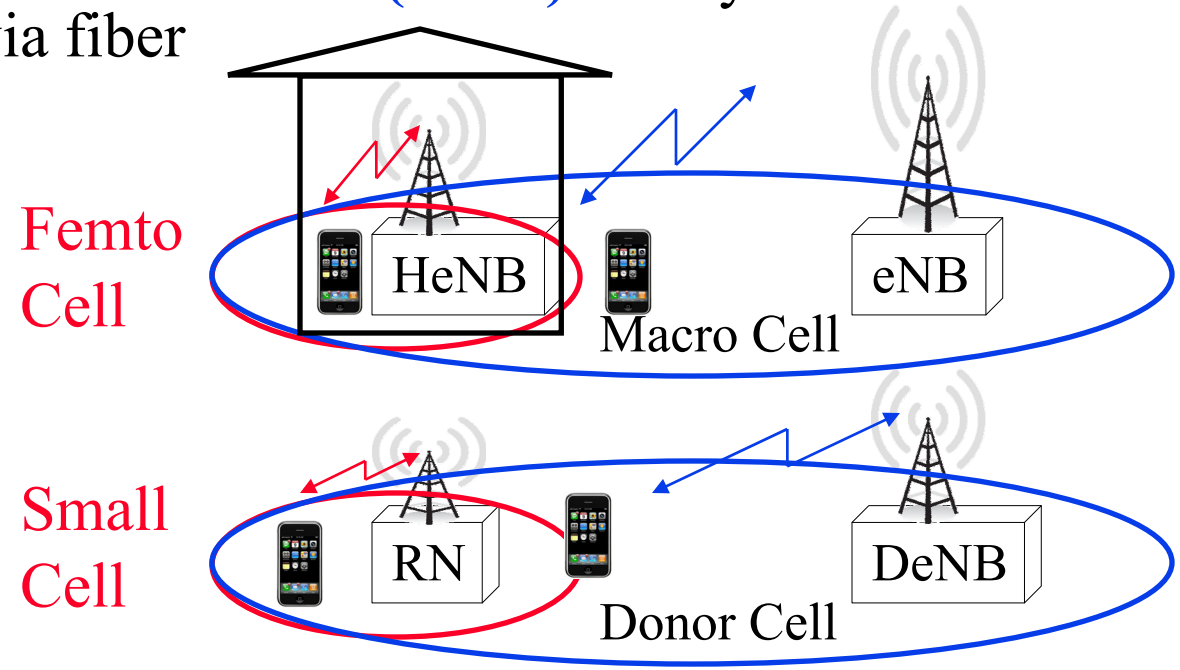
Relay Nodes

- **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



HetNet/Small Cells

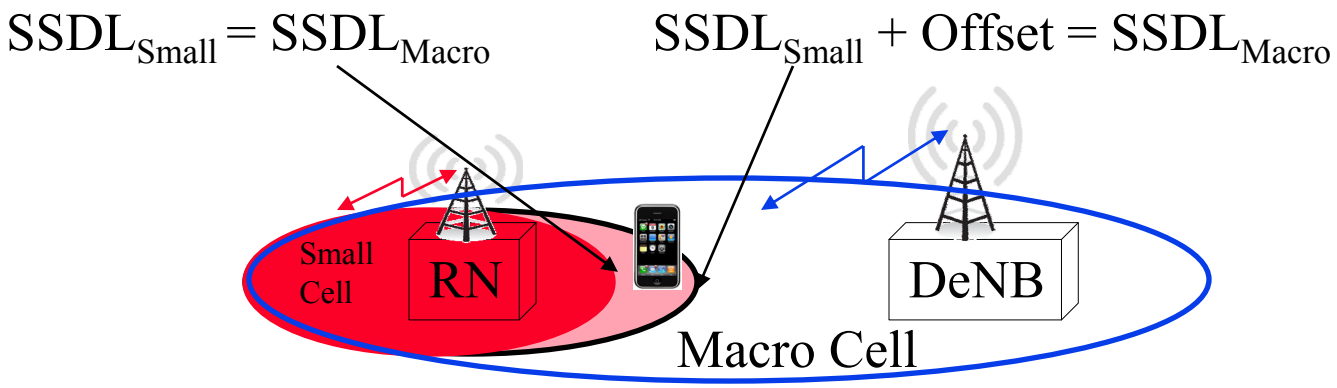
- **Macro eNB**: Normal Base Station
- **Relay Node (RN)**: Micro or Pico Cell.
- **HeNB**: Home eNB for indoor coverage in homes, offices, malls. Privately owned and operated. Femto Cell.
- **Remote Radio Heads (RRH)**: Relay nodes connected to DeNB via fiber



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

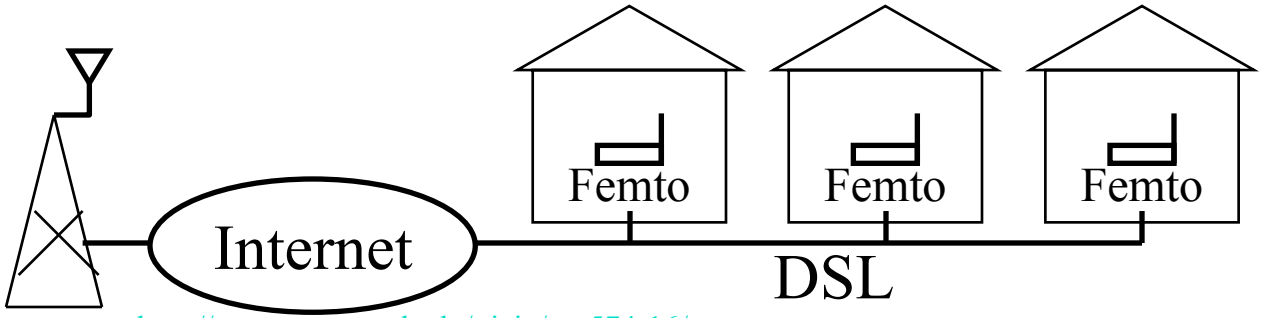
HetNet/Small Cells (Cont)

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



Types of Cells

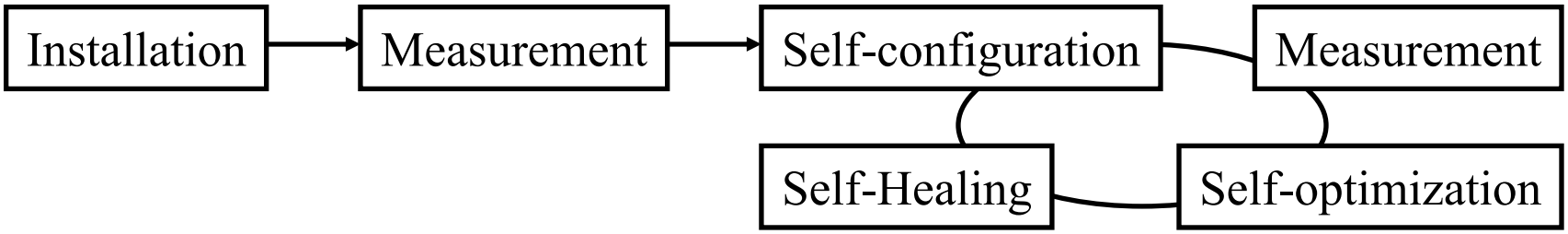
- **Cell** (**MacroCell**): Cover a few miles. Public Access. Open Area.
- **MicroCell** (10^{-6}): Less than a mile wide. Public Access. Malls, Hotels, Train Stations
- **PicoCell** (10^{-12}): in-Building with public access
- **FemtoCell** (10^{-15}): In-Building with restricted access
- **AttoCell** (10^{-18}): In-room
- **ZeptoCell** (10^{-21}): On-Desk
- No milli, nano cells.



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

Self-Organizing Network (SON)



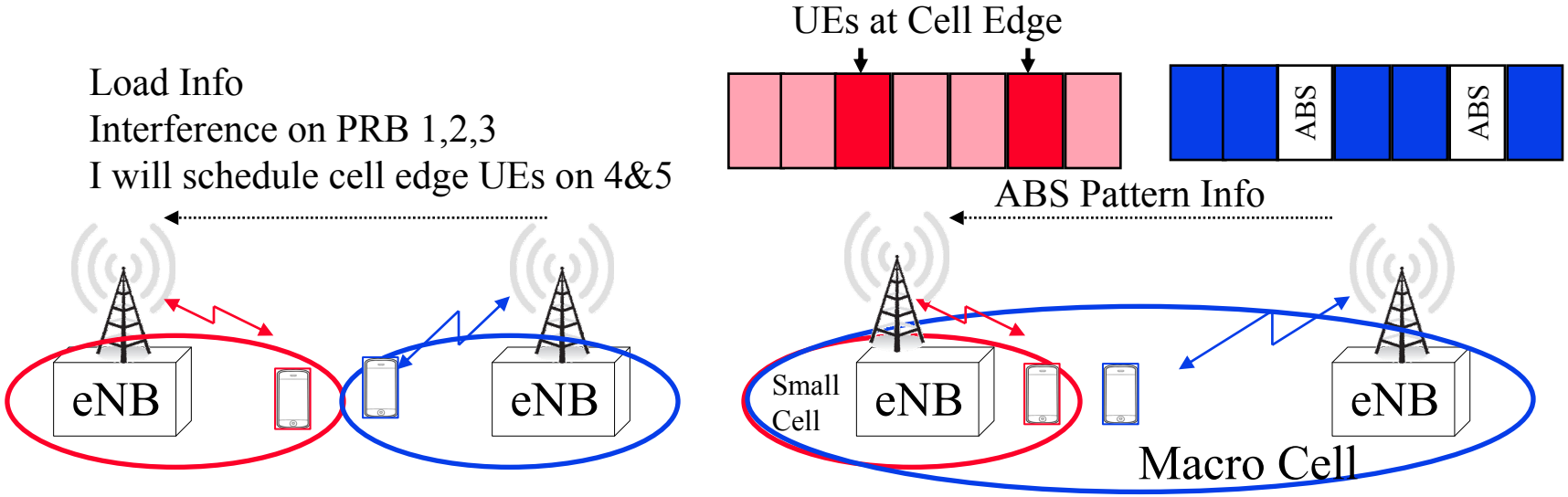
- User installable. 70M UMTS femtocells expected in 2012
- Not-physically accessible to the carrier
- Operator provides femtocell ID. Customer registers location
- Self-Configures:
  - Transmission Frequencies
  - Transmission Power
  - Preamble: Identifies the segment (IDcell). Some IDs for reserved for femtocells. Helps differentiate from macrocell.
  - Neighbor Cell list: Helps in handover
- Turned on/off by the consumer ⇒ Dynamic topology

Management and Configuration

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

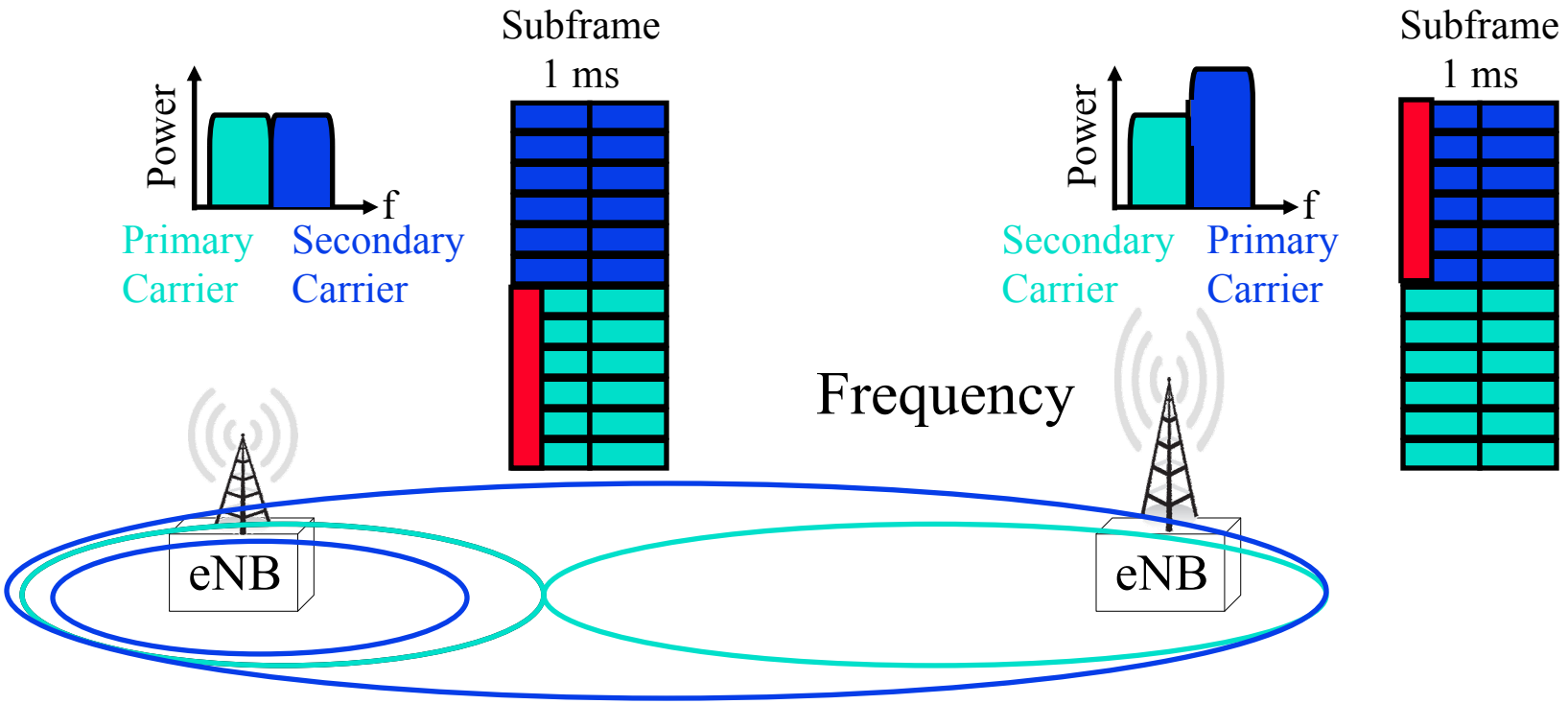
Enhanced Inter-Cell Interference Coordination (eICIC)

- **ICIC**: A eNB sends a "load information" message to the neighbor eNB about 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



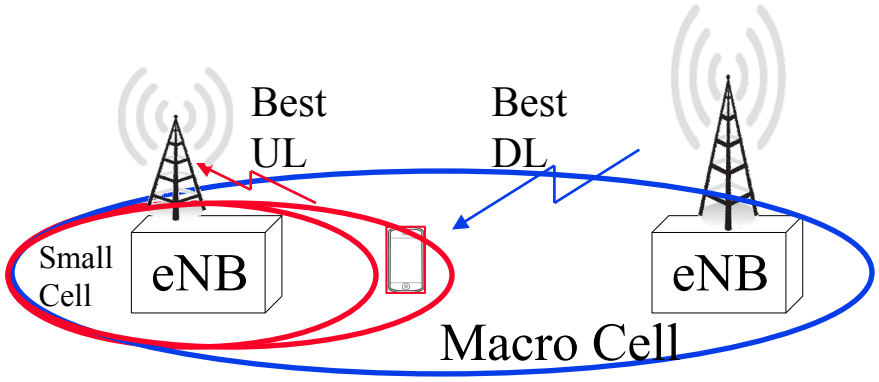
Carrier Aggregation with Cross-Carrier Scheduling

- **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 BS's using control channels on different carriers



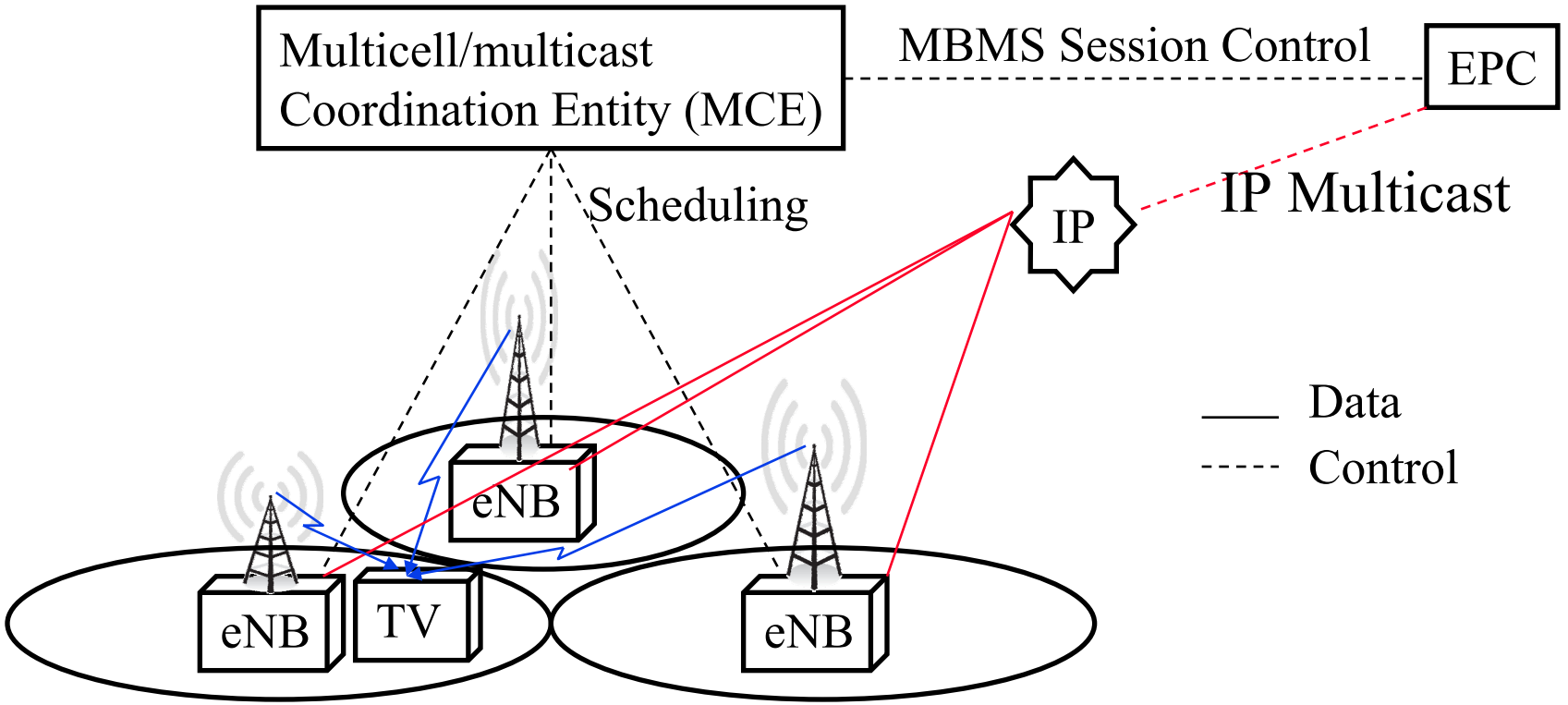
CoMP with Small Cells

- 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 from another



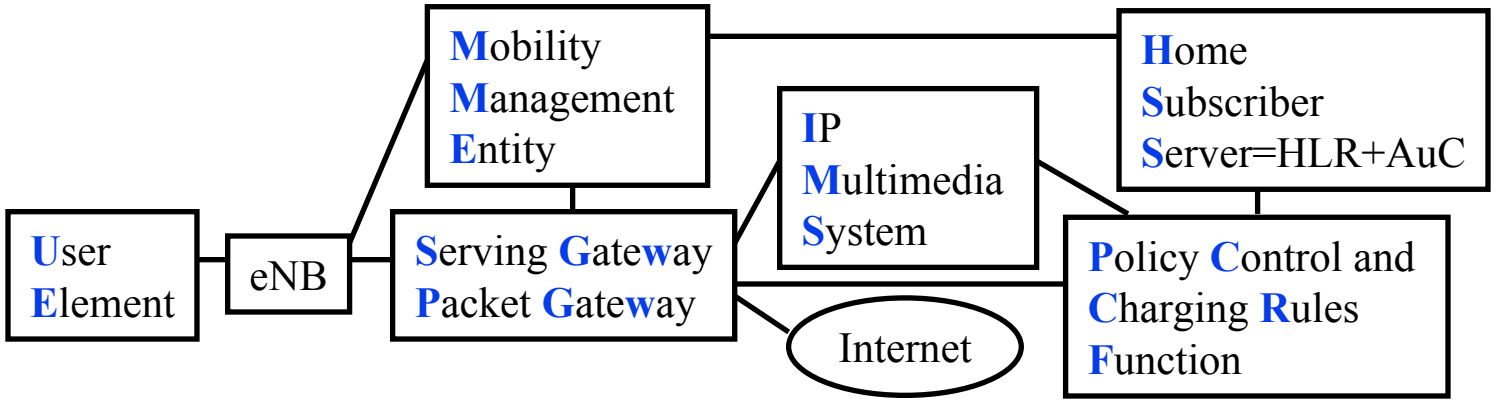
Multimedia Broadcast Multicast Service (MBMS)

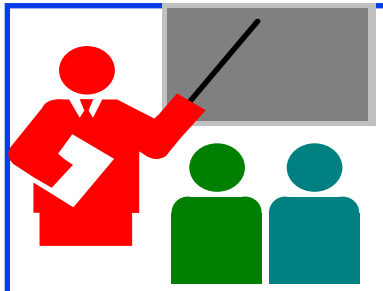
- MBMS Single Frequency Network (MBSFN)
- MCE handles synchronized data delivery



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 the uplink transmission in 4 consecutive subframes ⇒ 4x power ⇒ Improves link budget by 6 dB ⇒ reduces block error rate
- **Semi-persistent scheduling** saves scheduling overhead.
  Cannot adopt continuously to changing channel conditions
- **Packet Bundling**: Send only when two voice packets





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 frequency reuse factor of 1 since spectrum is expensive, uses high-order MIMO.
5. LTE-A uses relay nodes to cover remote areas and hot-spots. Also allowes Home eNB (Femto cells).
6. Code-book and non-code book precoding improves MIMO
7. Coordinated Multipoint operation (CoMP) allows mitigation of interference at cell edge. CoMP can also be used with cross-carrier scheduling.

Reading List

- 3GPP, "LTE-Advanced," http://www.3gpp.org/technologies/keywords-acronyms/97-lte-advanced
- 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

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

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.
- 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: 97814665015522, 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.

Small Cells - Books

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

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)

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/

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

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.

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

Acronyms

- 3GPP 3rd Generation Partnership Project
- ABS Almost Blank Subframes
- 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
- eNB eNode B
- EPC Evolved Packet Core
- FDD Frequency Division Duplexing

Acronyms (Cont)

- FDMA Frequency Division Multiple Access
- GPS Global Positioning System
- 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
- 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

Acronyms (Cont)

- 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
- PDCCH Packet Data Control Channel
- PHY Physical Layer
- PRB Physical Resource Block
- RAN Radio Access Network
- RANAP Radio Access Network Application
- RF Radio Frequency

Acronyms (Cont)

- 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
- SON Self-Organizing Network
- SSDL Strongest Signal in Downlink
- SU-MIMO Single User MIMO
- TDD Time Division Duplexing
- TV Television

Acronyms (Cont)

- 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
- WiMAX Worldwide Interoperability for Microwave Access

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Related Modules

Internet of Things,
http://www.cse.wustl.edu/~jain/cse574-16/j_10iot.htm

Introduction to LTE,
http://www.cse.wustl.edu/~jain/cse574-16/j_16lte.htm

Introduction to 5G,
http://www.cse.wustl.edu/~jain/cse574-16/j_195g.htm

Low Power WAN Protocols for IoT,
http://www.cse.wustl.edu/~jain/cse574-16/j_14ahl.htm

Audio/Video Recordings and Podcasts of Professor Raj Jain's Lectures,
https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw