

# Introduction to LTE-Advanced



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

<http://www.cse.wustl.edu/~jain/cse574-14/>



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

Note: This 2<sup>nd</sup> 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](http://www.3gpp.org/ftp/specs/archive/36_series/36.913)

# LTE-Advanced Requirements (Cont)

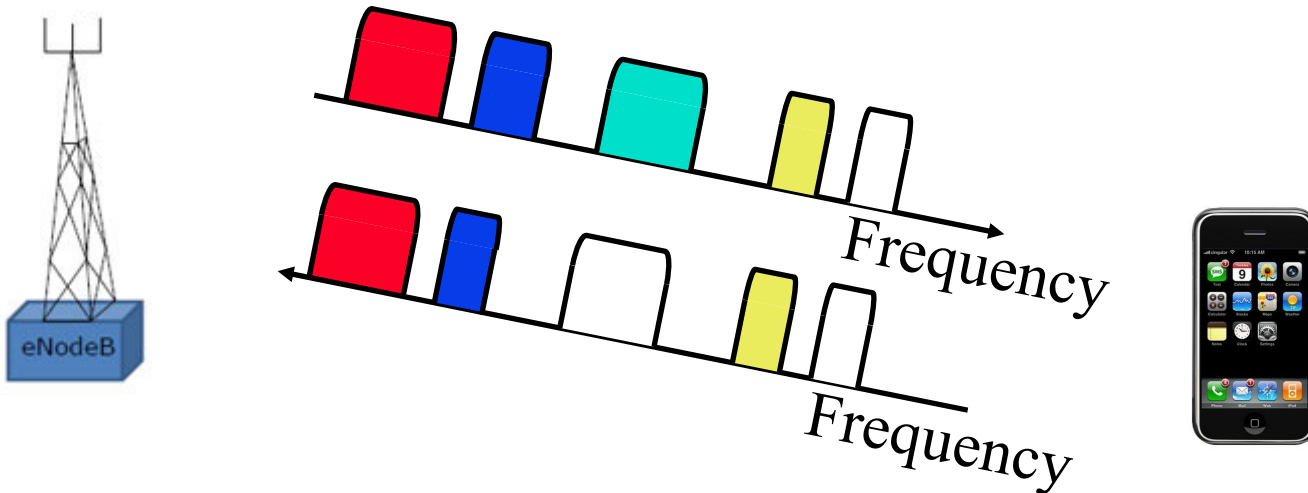
- ❑ Latency: Less than 10 ms from dormant to active;  
Less than 50 ms from camped to active
- ❑ Mobility: up to 500 kmph
- ❑ Spectrum Flexibility: FDD and TDD, Wider channels up to 100 MHz

# LTE Advanced Techniques

- ❑ Three Key Factors: Spectrum (Band, Bandwidth), Spectral Efficiency, and Cell sizes
- ❑ Bandwidth: 100 MHz using carrier aggregation
- ❑ 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

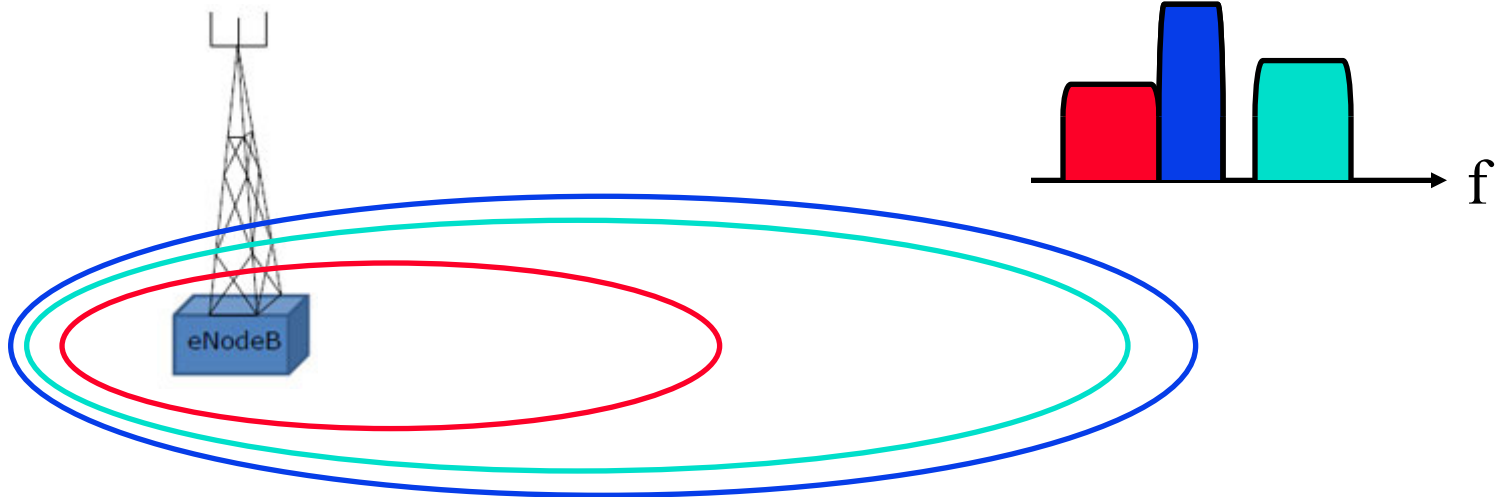
- Aggregation = Combine multiple bands (Component Carriers)



- 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  $\geq$  Number of components in UL

# Carrier Aggregation (Cont)

- ❑ Components can be contiguous (adjacent or intra-band) or non-contiguous (inter-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



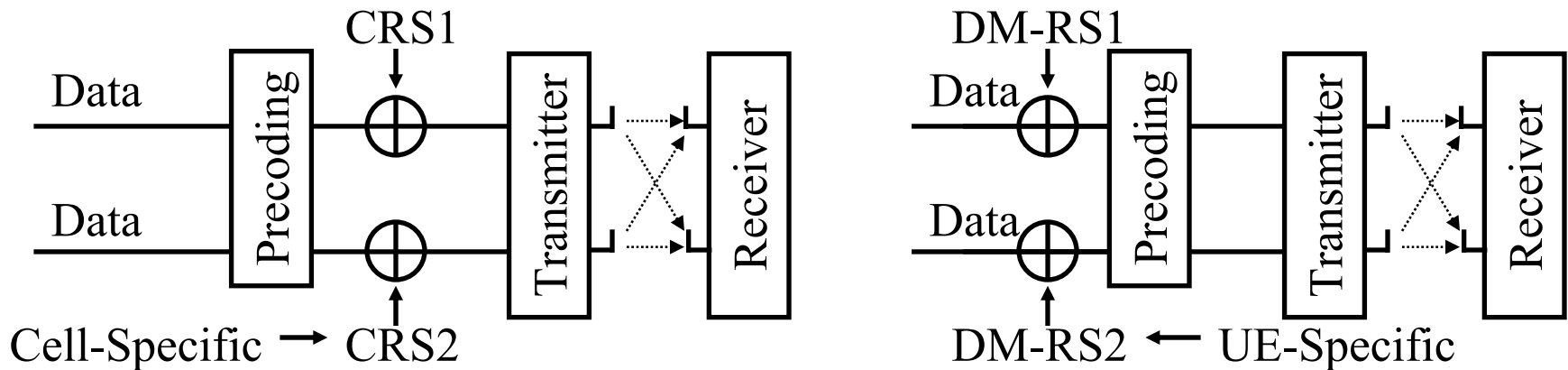


# MIMO

- ❑ 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 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

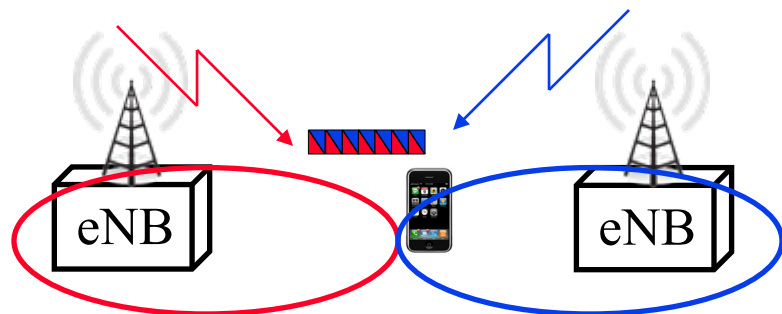
# Precoding

- ❑ 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.

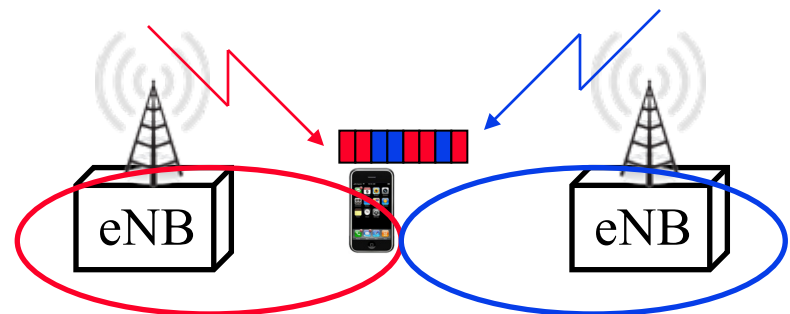


# Coordinated Multipoint Operation (CoMP)

- ❑ 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



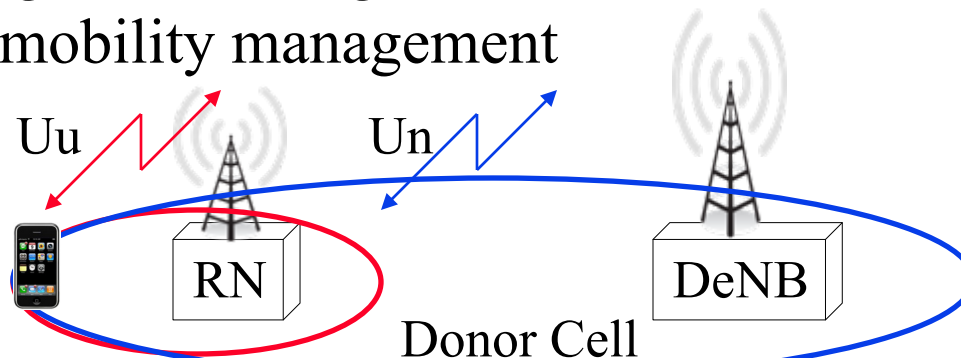
(a) Joint Transmission



(b) Dynamic Point Selection

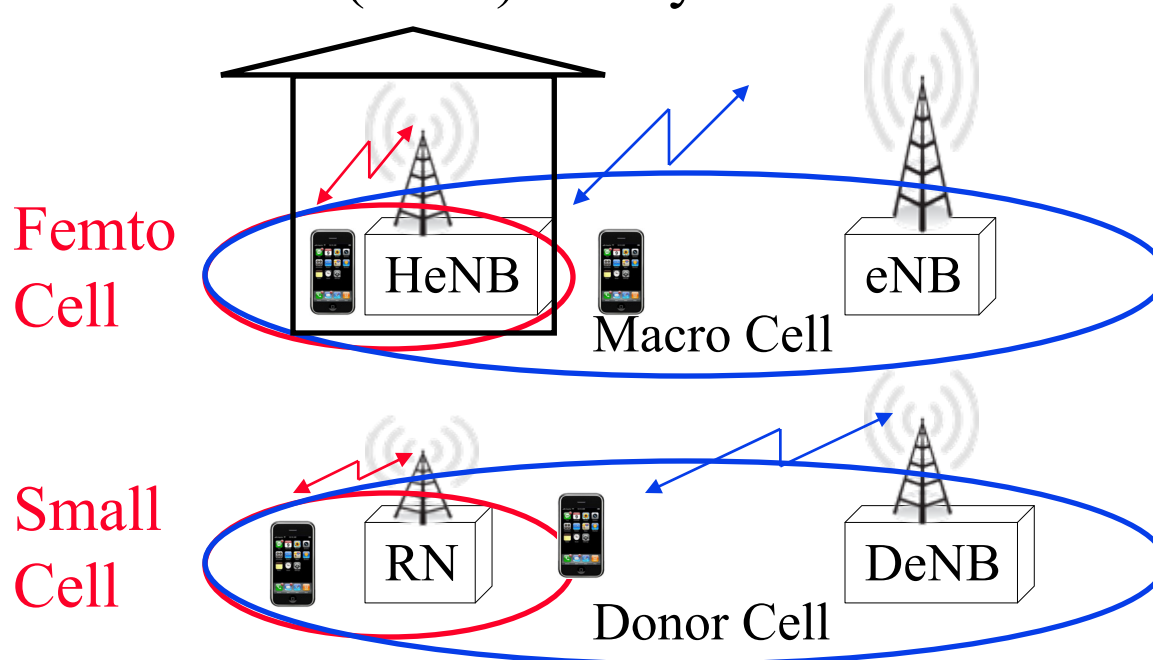
# Relay Nodes

- ❑ 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>

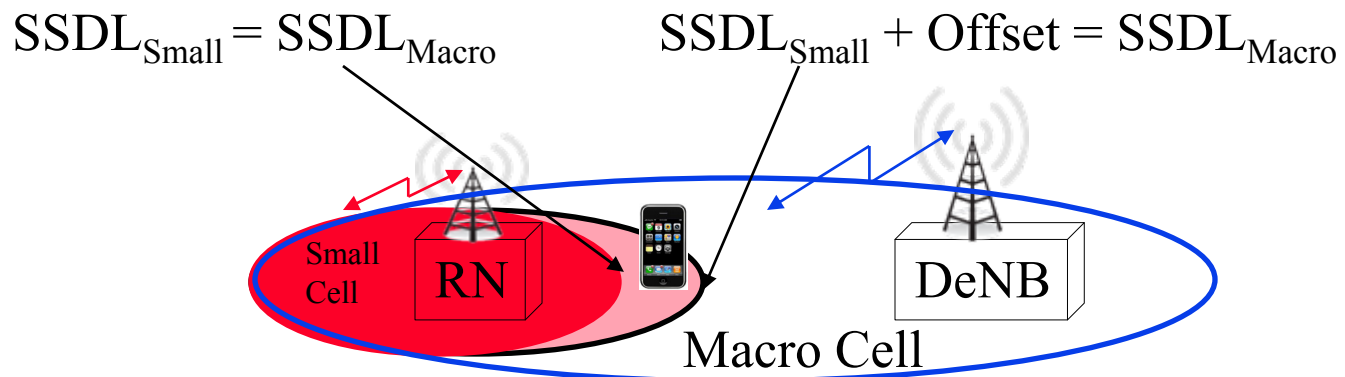
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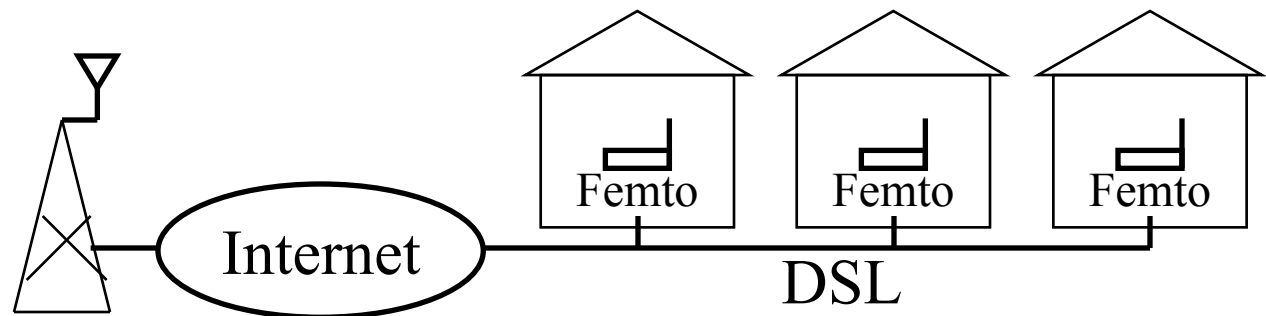
# HetNet/Small Cells (Cont)

- ❑ 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.

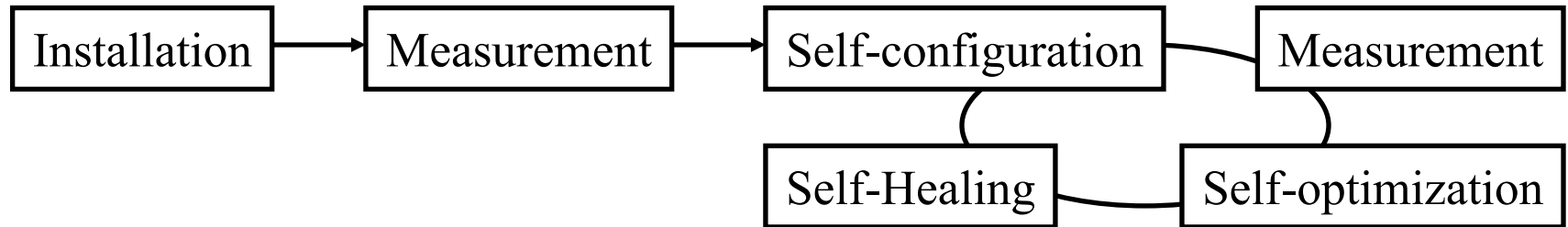


# FemtoCells: Key Features

- ❑ 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)



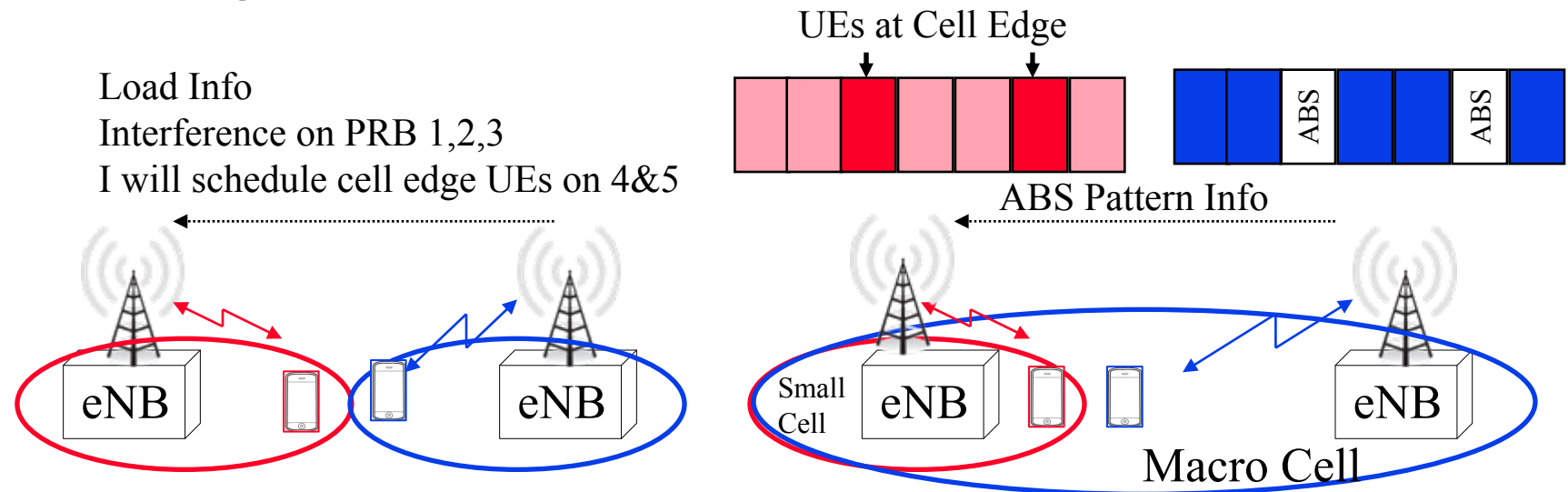
- ❑ User installable. 70M UMTS femtocells expected in 2012
- ❑ Not-physically accessible to the carrier
- ❑ Operator provides femtocell ID. Customer registers location
- ❑ Self-Configures:
  - Transmission Frequencies
  - Transmission Power
  - Preamble: Identifies the segment (IDcell). Some IDs for 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

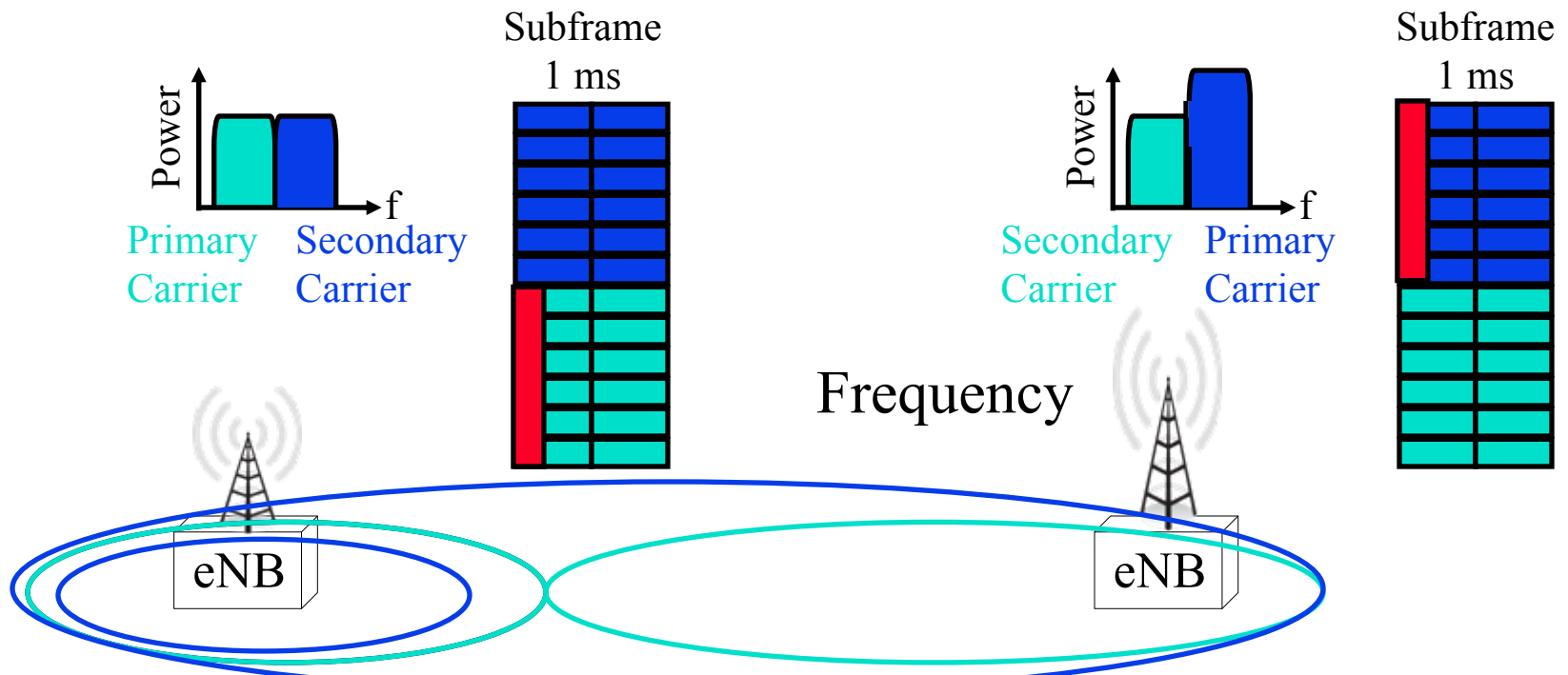
# Inter-Cell Interference Coordination

- ❑ 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  $\Rightarrow$  Allows UEs in CRE region to mitigate macro-cell interference



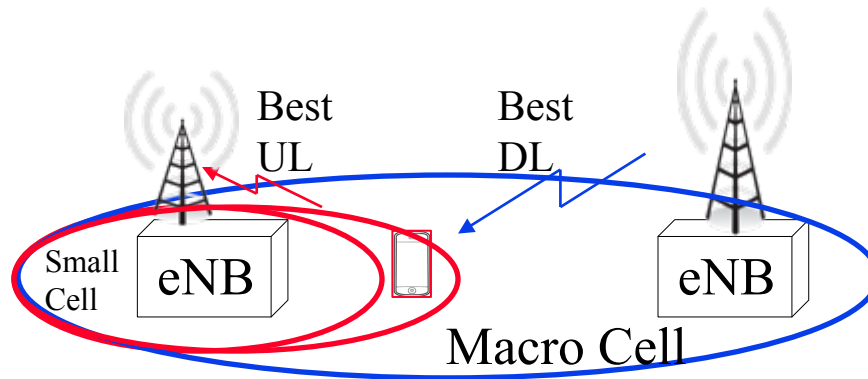
# Carrier Aggregation with Cross-Carrier Scheduling

- 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



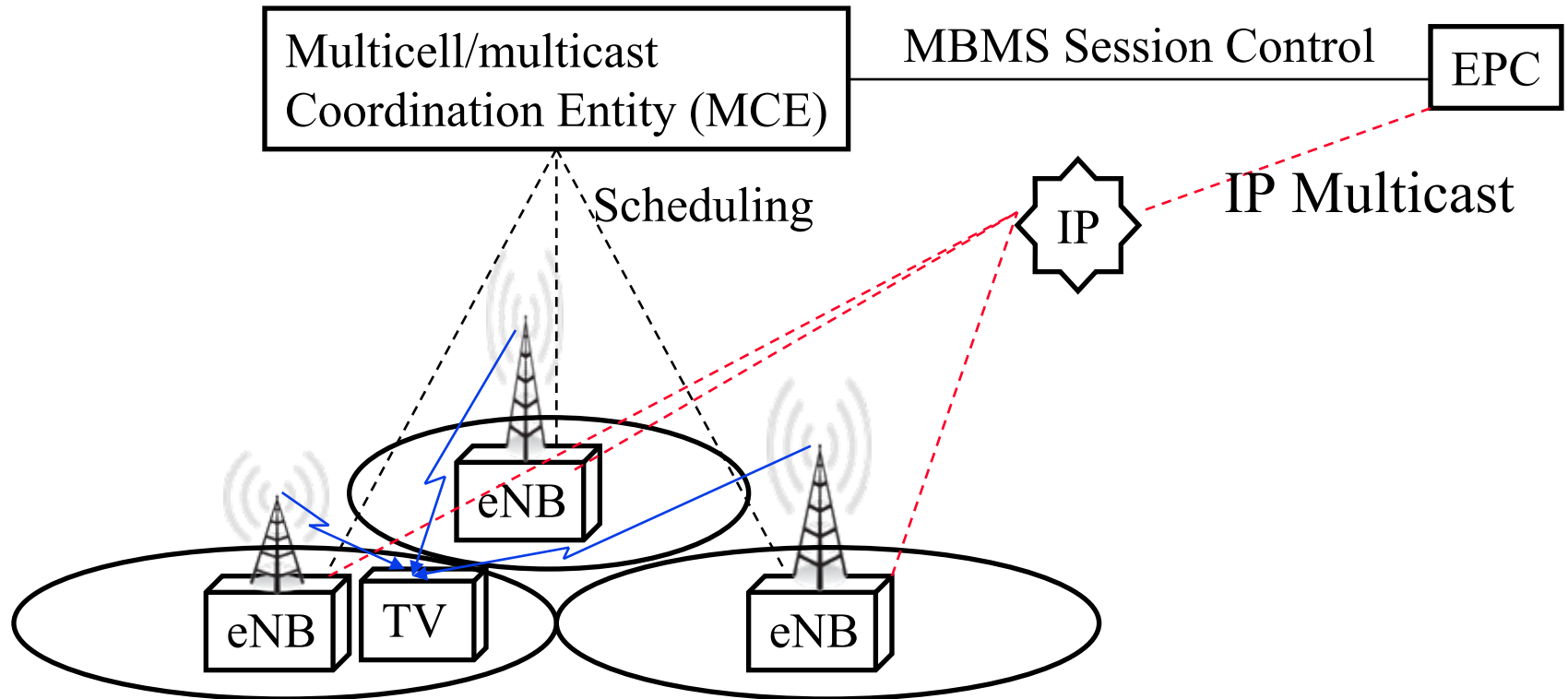
# CoMP with Small Cells

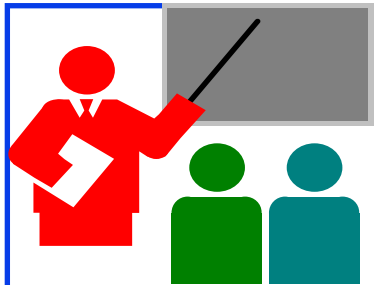
- A UE can get service from multiple BSs (eNB, RN, HeNB, RRH)
  - Can get data through multiple BSs
  - Can send data through multiple BSs
  - Can send data to one BS and receive from another



# Multimedia Broadcast Multicast Service (MBMS)

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





# 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 allows 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

- ❑ [http://en.wikipedia.org/wiki/LTE\\_Advanced](http://en.wikipedia.org/wiki/LTE_Advanced)
- ❑ <http://en.wikipedia.org/wiki/Femtocell>
- ❑ [http://en.wikipedia.org/wiki/Home\\_Node\\_B](http://en.wikipedia.org/wiki/Home_Node_B)
- ❑ [http://en.wikipedia.org/wiki/Self-Optimizing\\_Networks](http://en.wikipedia.org/wiki/Self-Optimizing_Networks)

# LTE-Advanced Books

- ❑ E. Dahlman, S. Parkvall, J. Skold, "4G: LTE/LTE-Advanced for Mobile Broadband, 2nd Edition," Academic Press, 2013, ISBN: 9780124199859, 544 pp. Safari book.
- ❑ S. Ahmadi, "LTE-Advanced," Academic Press, 2013, ISBN: 9780124051621, 1152 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.
- ❑ C. Cox, "An Introduction to LTE: LTE, LTE-Advanced, SAE and 4G Mobile Communications," Wiley, 2012, ISBN: 9781119970385, 352 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.
- ❑ S. Yi, S. Chun, Y. Lee, S. Park, S. Jung, "Radio Protocols for LTE and LTE-Advanced," Wiley, 2012, ISBN: 9781118188538, 352 pp. Safari book.
- ❑ X. Zhang, X. Zhou, "LTE-Advanced Air Interface Technology," CRC Press, 2012, ISBN: 9781466501522, 528 pp. Safari book.
- ❑ H. Holma, A. Toskala, "LTE Advanced: 3GPP Solution for IMT-Advanced," Wiley, 2012, ISBN: 9781119974055, 248 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/>
- ❑ Rhode & Schwarz, “1MA232: LTE-Advanced (3GPP Rel. 11) Technology Introduction,” [http://www.rohde-schwarz.com/en/applications/lte-advanced-3gpp-rel.11-technology-introduction-application-note\\_56280-42753.html](http://www.rohde-schwarz.com/en/applications/lte-advanced-3gpp-rel.11-technology-introduction-application-note_56280-42753.html)



# Femto Cell References

- Airvana, “LTE Femtocells,” <http://www.airvana.com/technology/lte-femtocells/>

# 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
- ❑ 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
- ❑ FDMA      Frequency Division Multiple Access

# Acronyms (Cont)

- ❑ GPS                    Global Positioning System
- ❑ HD                    High Definition
- ❑ HeNB                 Home eNB
- ❑ HetNet               Heterogeneous Network
- ❑ 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
- ❑ MAC                 Media Access Control
- ❑ MBMS                Multimedia Broadcast Multicast Service

# Acronyms (Cont)

- ❑ 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
- ❑ RLC Radio Link Control
- ❑ RN Relay Node
- ❑ RRC Radio Resource Control

# Acronyms (Cont)

- ❑ 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
- ❑ UE User Element
- ❑ UL Uplink
- ❑ UMTS Universal Mobile Telecommunications System
- ❑ UTRA UMTS Terrestrial Radio Access

# Acronyms (Cont)

- ❑ UTRAN UMTS Terrestrial Radio Access Network
- ❑ WG Working Group
- ❑ WiMAX Worldwide Interoperability for Microwave Access