FREQUENCY ALLOCATION

E UTRA Absolute Radio Frequency Channel Number (EARFCN)	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz	Uplink (UL) eNode B receive UE transmit	Downlink (DL) eNode B transmit UE receive	UL-DL Band Separation	Duplex Mode
							FUL_low-FUL_high	FDL_low-FDL_high		
1			✓	✓	✓	✓	1920-1980 MHz	2110-2170 MHz	130 MHz	FDD
2	✓	✓	✓	✓	✓	✓	1850-1910 MHz	1930-1990 MHz	20 MHz	FDD
3	✓	✓	✓	✓	✓	✓	1710-1785 MHz	1805-1880 MHz	20 MHz	FDD
4	✓	✓	✓	✓	✓	✓	1710-1755 MHz	2110-2155 MHz	355 MHz	FDD
5	✓	✓	✓	✓			824-849 MHz	869-894MHz	20 MHz	FDD
6			✓	✓			830-840 MHz	875-885 MHz	35 MHz	FDD
7	✓	✓	✓	✓	✓	✓	2500-2570 MHz	2620-2690 MHz	50 MHz	FDD
8	✓	✓	✓	✓			880-915 MHz	925-960 MHz	10 MHz	FDD
9			✓	✓	✓	✓	1749.9-1784.9 MHz	1844.9-1879.9 MHz	60 MHz	FDD
10			✓	✓	✓	✓	1710-1770 MHz	2110-2170 MHz	340 MHz	FDD
11			✓	✓	✓	✓	1427.9-1452.9 MHz	1475.9-1500.9 MHz	23 MHz	FDD
12	✓	✓	✓	✓			698-716 MHz	728-746 MHz	12 MHz	FDD
13	✓	✓	✓	✓			777-787 MHz	746-756 MHz	21 MHz	FDD
14	✓	✓	✓	✓			788-798 MHz	758-768 MHz	20 MHz	FDD
...										
17	✓	✓	✓	✓			704-716 MHz	734-746 MHz	18 MHz	FDD

- Source : http://web.cecs.pdx.edu/~fli/class/LTE_Reource_Guide.pdf

FREQUENCY ALLOCATION

E UTRA Absolute Radio Frequency Channel Number (EARFCN)	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz	Uplink (UL) eNode B receive UE transmit	Downlink (DL) eNode B transmit UE receive	UL-DL Band Separation	Duplex Mode
							FUL_low-FUL_high	FDL_low-FDL_high		
33			✓	✓	✓	✓	1900-1920 MHz		N/A	TDD
34			✓	✓	✓		2010-2025 MHz		N/A	TDD
35	✓	✓	✓	✓	✓	✓	1850-1910 MHz		N/A	TDD
36	✓	✓	✓	✓	✓	✓	1930-1990 MHz		N/A	TDD
37			✓	✓	✓	✓	1910-1930 MHz		N/A	TDD
38			✓	✓			2570-2620 MHz		N/A	TDD
39			✓	✓	✓	✓	1880-1920 MHz		N/A	TDD
40				✓	✓	✓	2300-2400 MHz		N/A	TDD

- Source : http://web.cecs.pdx.edu/~fli/class/LTE_Reource_Guide.pdf

RESOURCE BLOCKS

- MIMO
  - 4×4 in LTE, 8×8 in LTE-Advanced
  - Separate resource grids per antenna port
- eNodeB assigns RBs with channel-dependent scheduling
    - Use PDCCH to communicate these decisions to the UEs
- *Multiuser diversity* can be exploited
  - To increase bandwidth usage efficiency
  - Assign resource blocks for UEs with favorable qualities on certain time slots and subcarriers
  - Can also include
    - Fairness considerations
    - Understanding of UE locations
    - Typical channel conditions versus fading
    - QoS priorities.

PHYSICAL SIGNAL

- A set of resource element used in support of physical layer, but not originating from high layer
  - Reference signal:
    - Used as beacons for measurement signal quality
    - Reference signal is transmitted in each resource block with pattern based on Cell Physical Layer ID
    - UE measures two parameters on reference signal: RSRP(Reference Signal Received Power), RSRQ(Reference Signal Received Quality)
  - Synchronization signal :
    - Used to obtain synch and network information

PHYSICAL SIGNAL

- Downlink

Downlink Physical Signal	Name	Use
P-SCH	Primary Synchronization Signal	Used by UE to synch with network and cell search contains first part of cell ID
S-SCH	Secondary Synchronization Signal	Used for cell search and identification
R-S	Reference Signal	Used for channel estimation

- Uplink

Uplink Physical Signal	Name	Use
R-S	Reference Signal Demodulation, Sounding RS	Used for channel estimation

PHYSICAL TRANSMISSION

- Release 8 supports up to 4×4 MIMO
- The eNodeB uses the Physical Downlink Control Channel (PDCCH) to communicate
  - Resource block allocations
  - Timing advances for synchronization
- Two types of ⅓ rate convolutional codes
- QPSK, 16QAM, and 64QAM modulation based on channel conditions
- UE determines a CQI index that will provide the highest throughput while maintaining at most a 10% block error rate
  - Incorporated in the Downlink Control Information

PHYSICAL TRANSMISSION

Table 14.7 4-Bit CQI Table

CQI Index	Modulation	Code Rate × 1024	Efficiency
0	Out of Range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

Total bit rate = (Channel BW) x Efficiency

Example : for CQI index of 14, and BW=20 MHz,

Total bit rate= 20 MHz x 5.1152 bps/Hz=102 Mbps

POWER-ON PROCEDURES

1. Power on the UE
2. Select a network
3. Select a suitable cell

   - UE must be successfully hear downlink and eNodeB must be successfully hears uplink

4. Use contention-based random access to contact an eNodeB

   - UE use PRACH to get the response from eNodeB

5. Establish an RRC connection

   - UE sends RRC Connection Request to eNodeB to move its state to RRC_CONNECTED
   - eNodeB responds with connection setup that configures UE physical layer, MAC protocol and signaling radio bearer
   - Completion notification is also forwarded to MME for mobility management purpose

POWER-ON PROCEDURE

6. Attach:

   - Register location with the MME and the network configures control and default EPS bearers.
   - Configures radio bearer for Non Access Stratum messages
   - Network will assign an IP address to UE

7. Transmit a packet

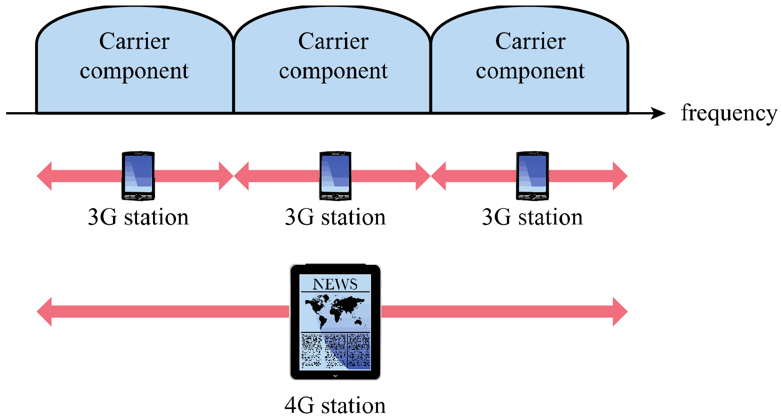
   - Downlink :
     - eNodeB send a scheduling command on PDCCH channel
       - Specifies parameters of the amount of data, resource block allocation and modulation scheme
     - Data are sent using PDSCH
     - Acknowledgement from UE can be sent using PUCCH or PUSCH
   - Uplink :
     - If connected, use PUCCH to notify eNodeB. If UE is idle, use PRACH
     - eNodeB sends scheduling grant to UE using PDCCH channel
     - Data are sent (UE to eNodeB) using ULSCH and PUSCH

LTE-ADVANCED

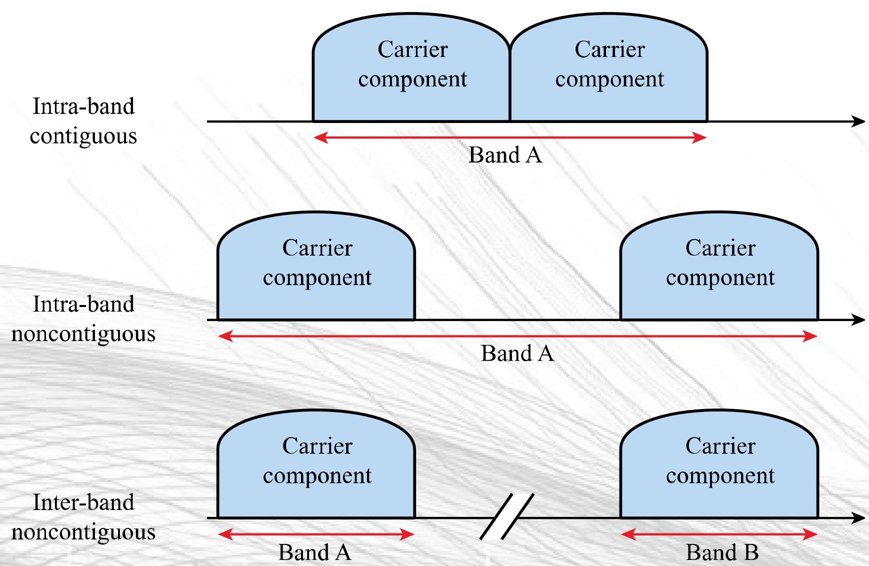
- So far we have studied 3GPP Release 8
  - Releases 9-12 have been issued
- Release 10 meets the ITU 4G guidelines
  - Took on the name LTE-Advanced
- Key improvements
  - Carrier aggregation
  - MIMO enhancements to support higher dimensional MIMO
  - Relay nodes
  - Heterogeneous networks involving small cells such as femtocells, picocells, and relays
  - Cooperative multipoint transmission and enhanced intercell interference coordination
  - Voice over LTE

CARRIER AGGREGATION

- Ultimate goal of LTE-Advanced is 100 MHz bandwidth
  - Combine up to 5 component carriers (CCs)
  - Each CC can be 1.4, 3, 5, 10, 15, or 20 MHz
  - Up to 100 MHz
- Three approaches to combine CCs
  - Intra-band Contiguous: carriers adjacent to each other
  - Intra-band noncontiguous: Multiple CCs belonging to the same band are used in a noncontiguous manner
  - Inter-band noncontiguous: Use different bands



(a) Logical view of carrier aggregation



(b) Types of carrier aggregation

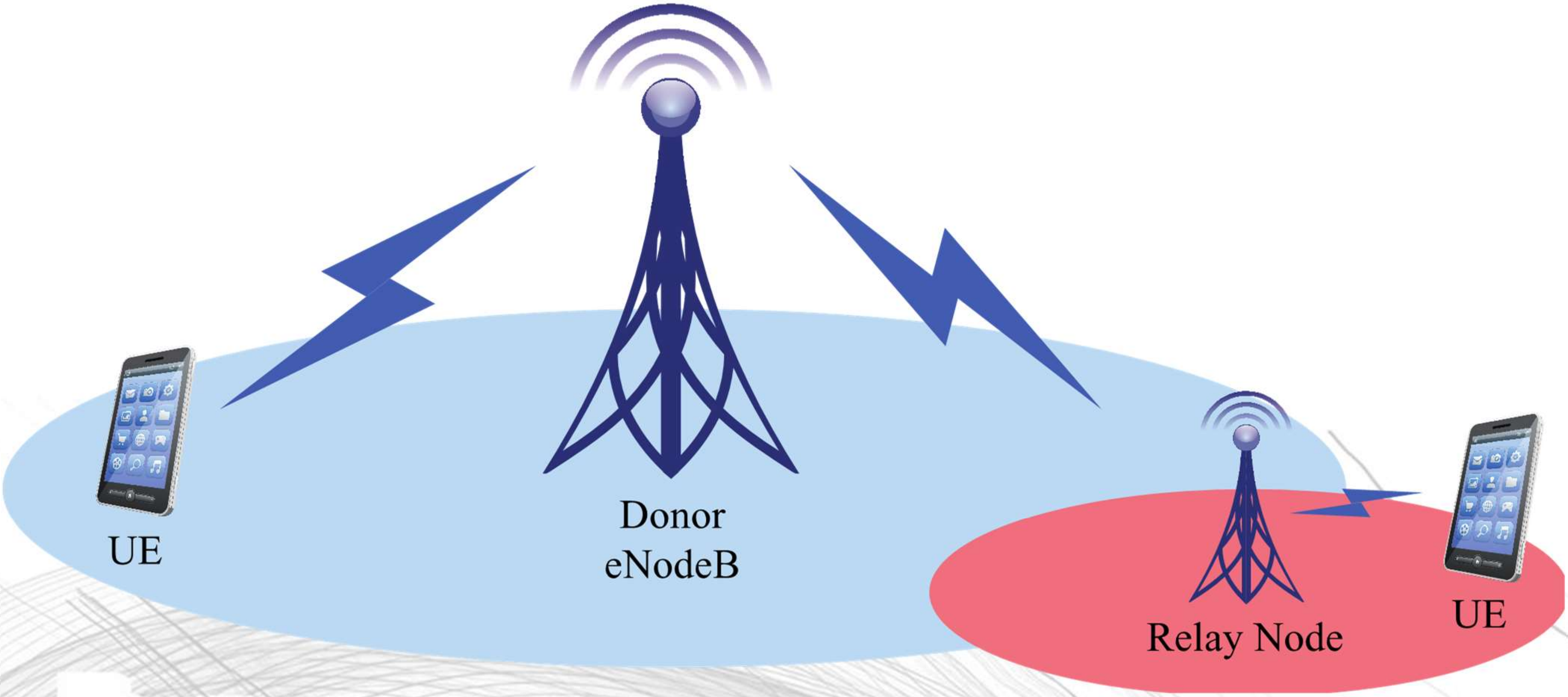
14.14 CARRIER AGGREGATION

ENHANCED MIMO

- Expanded to 8 × 8 for 8 parallel layers
- Or multi-user MIMO can allow up to 4 mobiles to receive signals simultaneously
  - eNodeB can switch between single user and multi-user every subframe
- Downlink reference signals to measure channels are key to MIMO functionality
  - UEs recommend MIMO, precoding, modulation, and coding schemes
  - Reference signals sent on dynamically assigned subframes and resource blocks

RELAYING

- Relay nodes (RNs) extend the coverage area of an eNodeB
  - Receive, demodulate and decode the data from a UE
  - Apply error correction as needed
  - Then transmit a new signal to the base station
- An RN functions as a new base station with smaller cell radius
- RNs can use out-of-band or inband frequencies



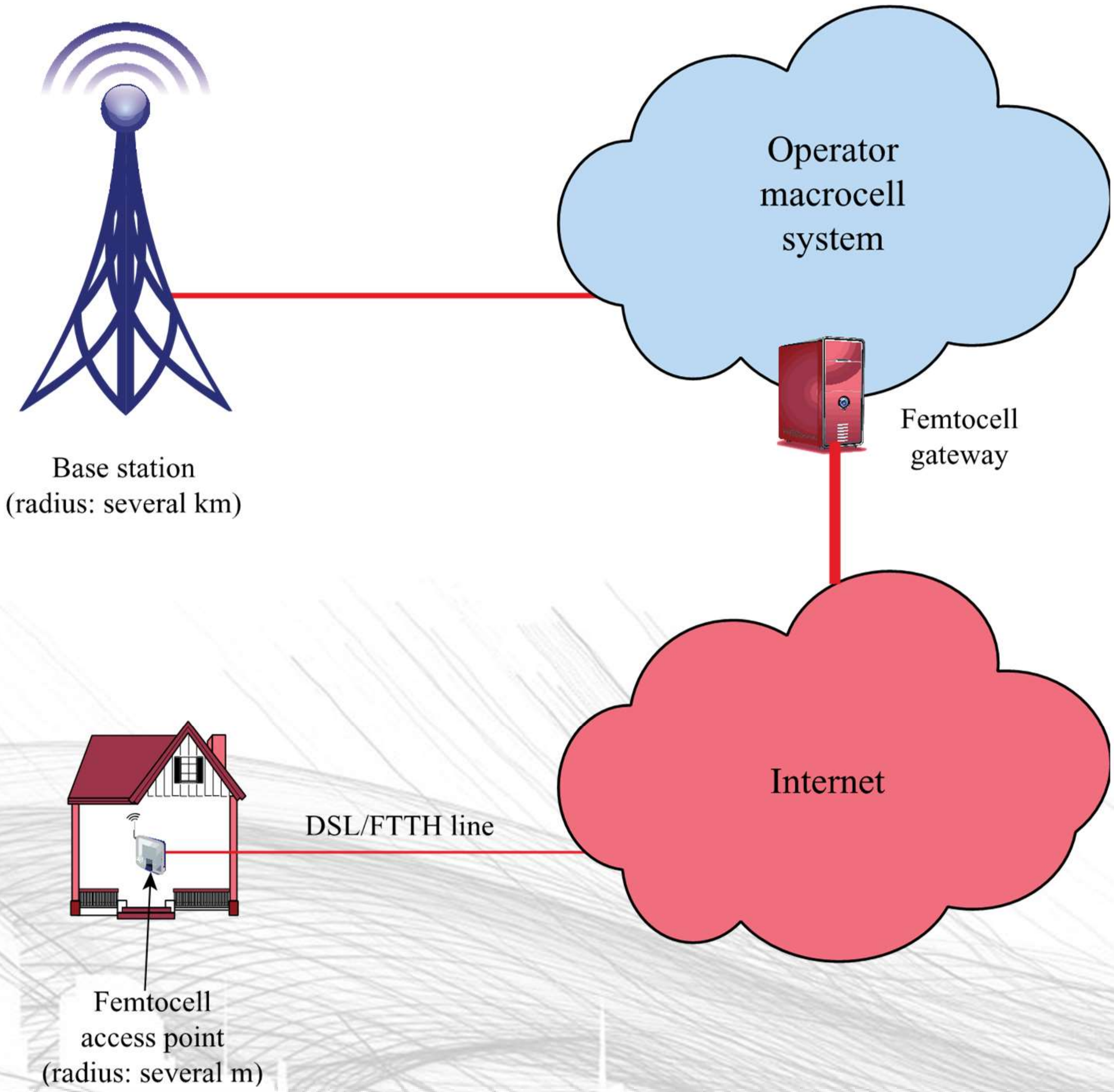
14.15 RELAY NODES

HETEROGENEOUS NETWORKS

- It is increasingly difficult to meet data transmission demands in densely populated areas
- *Small cells* provide low-powered access nodes
  - Operate in licensed or unlicensed spectrum
  - Range of 10 m to several hundred meters indoors or outdoors
  - Best for low speed or stationary users
- *Macro cells* provide typical cellular coverage
  - Range of several kilometers
  - Best for highly mobile users

HETEROGENEOUS NETWORKS

- Femtocell
  - Low-power, short-range self-contained base station
  - In residential homes, easily deployed and use the home’s broadband for backhaul
  - Also in enterprise or metropolitan locations
- *Network densification* is the process of using small cells
  - Issues: Handovers, frequency reuse, QoS, security
- A network of large and small cells is called a *heterogeneous network* (*HetNet*)



14.16 THE ROLE OF FEMTOCELLS

COORDINATED MULTIPOINT TRANSMISSION AND RECEPTION

- Release 8 provides intercell interference coordination (ICIC)
  - Small cells create new interference problems
  - Release 10 provides enhanced ICIC to manage this interference
- Release 11 implemented Coordinated Multipoint Transmission and Reception (CoMP)
  - To control scheduling across distributed antennas and cells
  - *Coordinated scheduling/coordinated beamforming* (CS/CB) steers antenna beam nulls and mainlobes
  - *Joint processing* (JT) transmits data simultaneously from multiple transmission points to the same UE
  - *Dynamic point selection* (DPS) transmits from multiple transmission points but only one at a time

OTHER ENHANCEMENTS IN LTE-ADVANCED

- Traffic offload techniques to divert traffic onto non-LTE networks
- Adjustable capacity and interference coordination on PDCCH
- Enhancements for machine-type communications
- Support for dynamic adaptation of TDD configuration so traffic fluctuations can be accommodated

OTHER ENHANCEMENTS IN LTE-ADVANCED

- Release 12 also conducted studies
  - Enhancements to small cells and heterogeneous networks, higher order modulation like 256-QAM, a new mobile-specific reference signal, dual connectivity (for example, simultaneous connection with a macro cell and a small cell)
  - Two-dimensional arrays that could create beams on a horizontal plane and also at different elevations for user-specific elevation beamforming into tall buildings.
    - Would be supported by *massive MIMO* or *full dimension MIMO*
    - Arrays with many more antenna elements than previous deployments.
    - Possible to still have small physical footprints when using higher frequencies like millimeter waves

VOICE OVER LTE

- The GSM Association is the cellular industry's main trade association
  - GSM Association documents provide additional specifications for issues that 3GPP specifications left as implementation options.
- Defined profiles and services for Voice over LTE (VoLTE)
- Uses the IP Multimedia Subsystem (IMS) to control delivery of voice over IP streams
  - IMS is not part of LTE, but a separate network
  - IMS is mainly concerned with signaling.
- The GSM Association also specifies services beyond voice, such as video calls, instant messaging, chat, and file transfer in what is known as the Rich Communication Services (RCS).