This lecture is being recorded

18-452/18-750
Wireless Networks and Applications
Lecture 17: LTE Advanced

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Spring Semester 2021

http://www.cs.cmu.edu/~prs/wirelessS21/

Announcements

- There is no lecture on Wednesday
  - Schedule on the web page has been adjusted
- Survey topics have been assigned
- Homework 3 will be released at the end of the week
- Please sign up for P2 meetings if you have not done so

Overview LTE

- Motivation
- Architecture
- Resource management
- LTE protocols
- Radio access network
- LTE advanced

LTE Radio Access Network

- LTE uses OFDM and MIMO
- OFDM offers benefits similar to those of CDMA
  - » Good immunity to fading as only a small portion of the energy for any one link is typically lost due to a fade
  - » Fast power control to keep the noise floor as low as possible
- Additional advantages
  - » Highly resistant to fading and inter-symbol interference
  - » Low modulation rates on each of the many sub-carriers
  - » Sophisticated error correction
  - » Scales rates easier than CDMA
  - » Allows more advanced antenna technologies, like MIMO
- Breaks information into pieces and assigns each one to a specific set of sub-carriers

OFDMA: OFDM with Multiple Access

- LTE downlink uses OFDM with Multiple Access:
- In any time slot, multiple clients receive data on separate groups of subcarriers
  - » This is a form of FDMA (similar to GSM), but using groups of orthogonal subcarriers in
- For each group of subcarriers, multiple clients receive data in separate time slots
  - » TDMA (also similar to GSM)
  - » Multiple low bandwidth users can share subcarriers
- For each client, this enables frequency hopping to mitigate effects of narrowband fading

OFDM disadvantages SC-FDMA

- As the number of sub-carriers increases, the composite time-domain signal starts to look like Gaussian noise
- This translates into a high peak-to-Average Power ratio (PAPR)
- Avoiding distortion requires increases in cost, size and power consumption
- To avoid this cost on mobile devices, the uplink uses Single-Carrier FDMA
  - » Does some preprocessing of the signal to reduce the high PAPR, at the cost of some loss in efficiency
  - » Provides better energy and cost efficiency for battery-operated mobiles

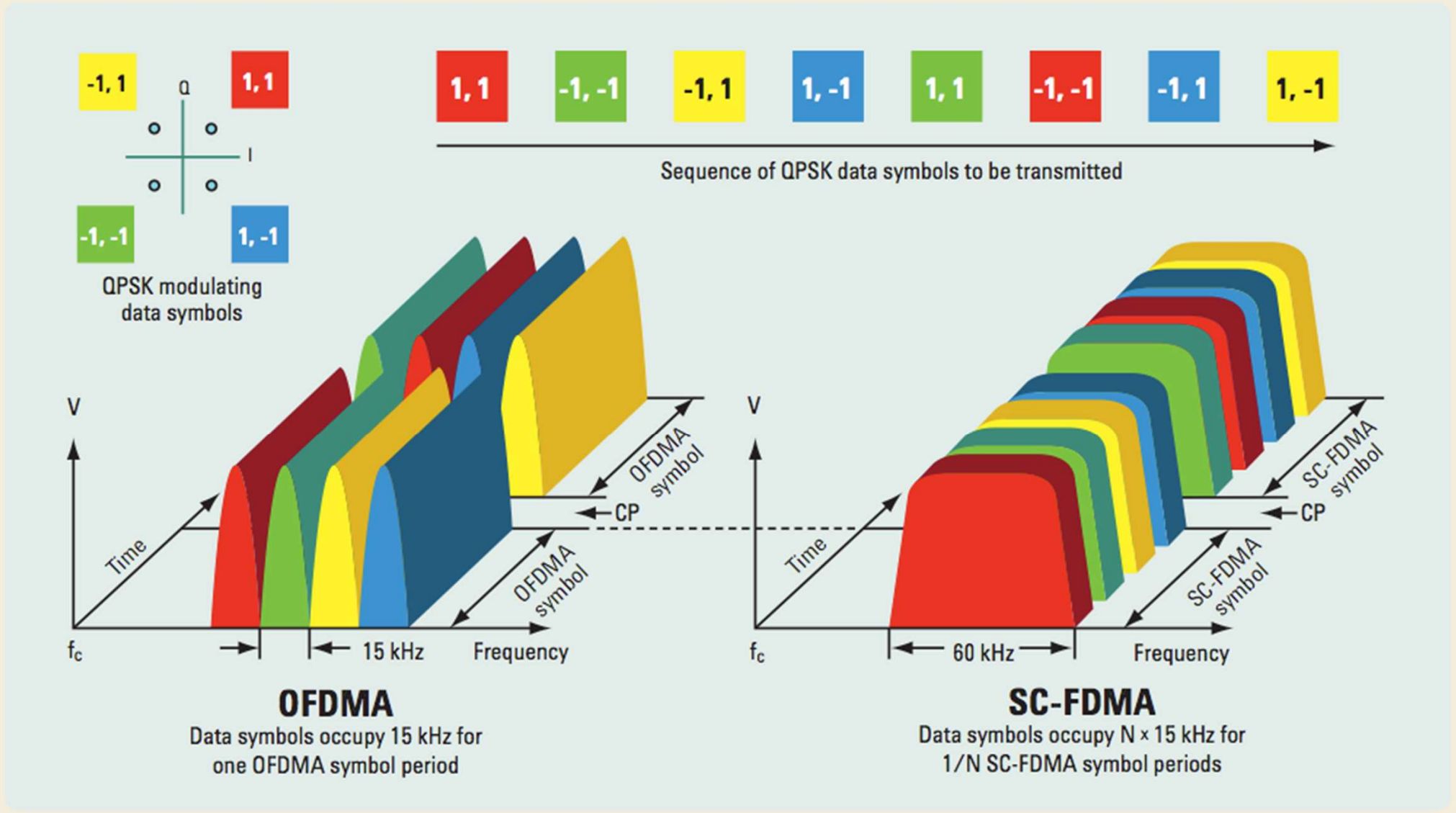
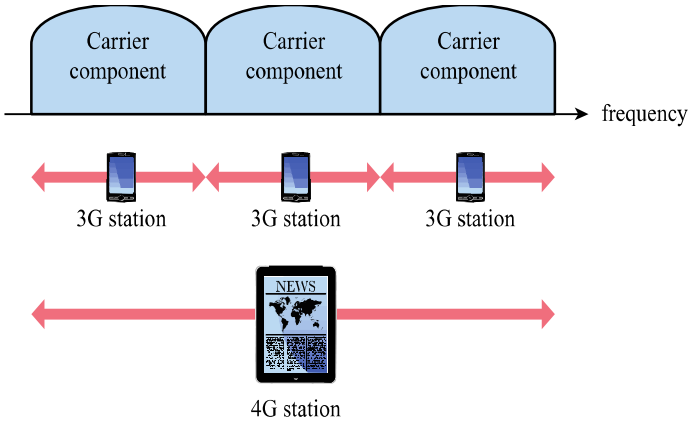


Figure 2. Comparison of how OFDMA and SC-FDMA transmit a sequence of QPSK data symbols

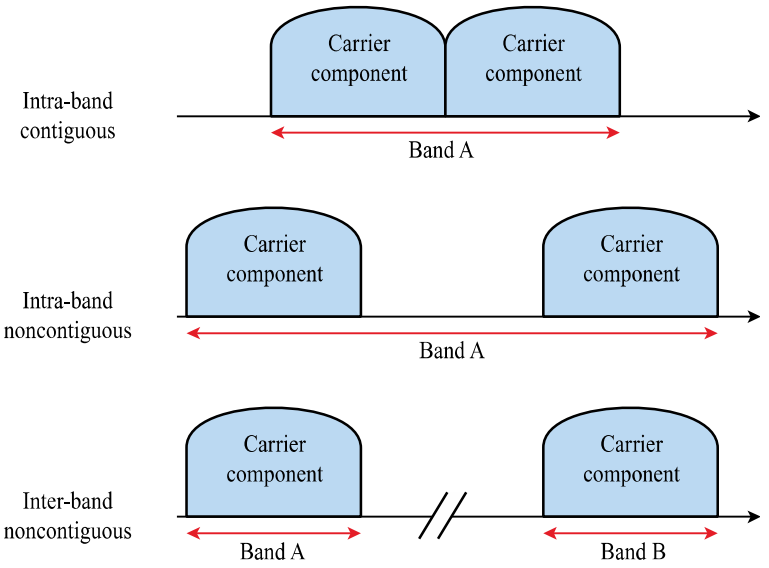
http://cp.literature.agilent.com/litweb/pdf/5989-7898EN.pdf

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**



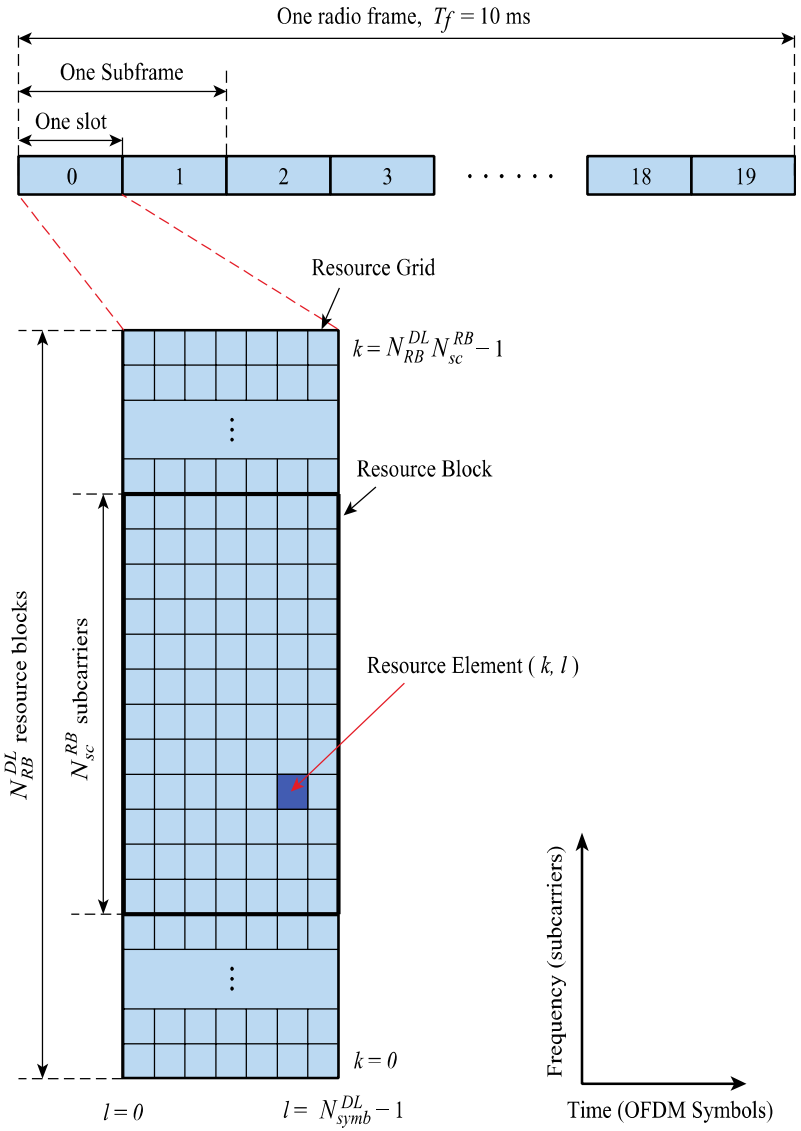
(a) Logical view of carrier aggregation



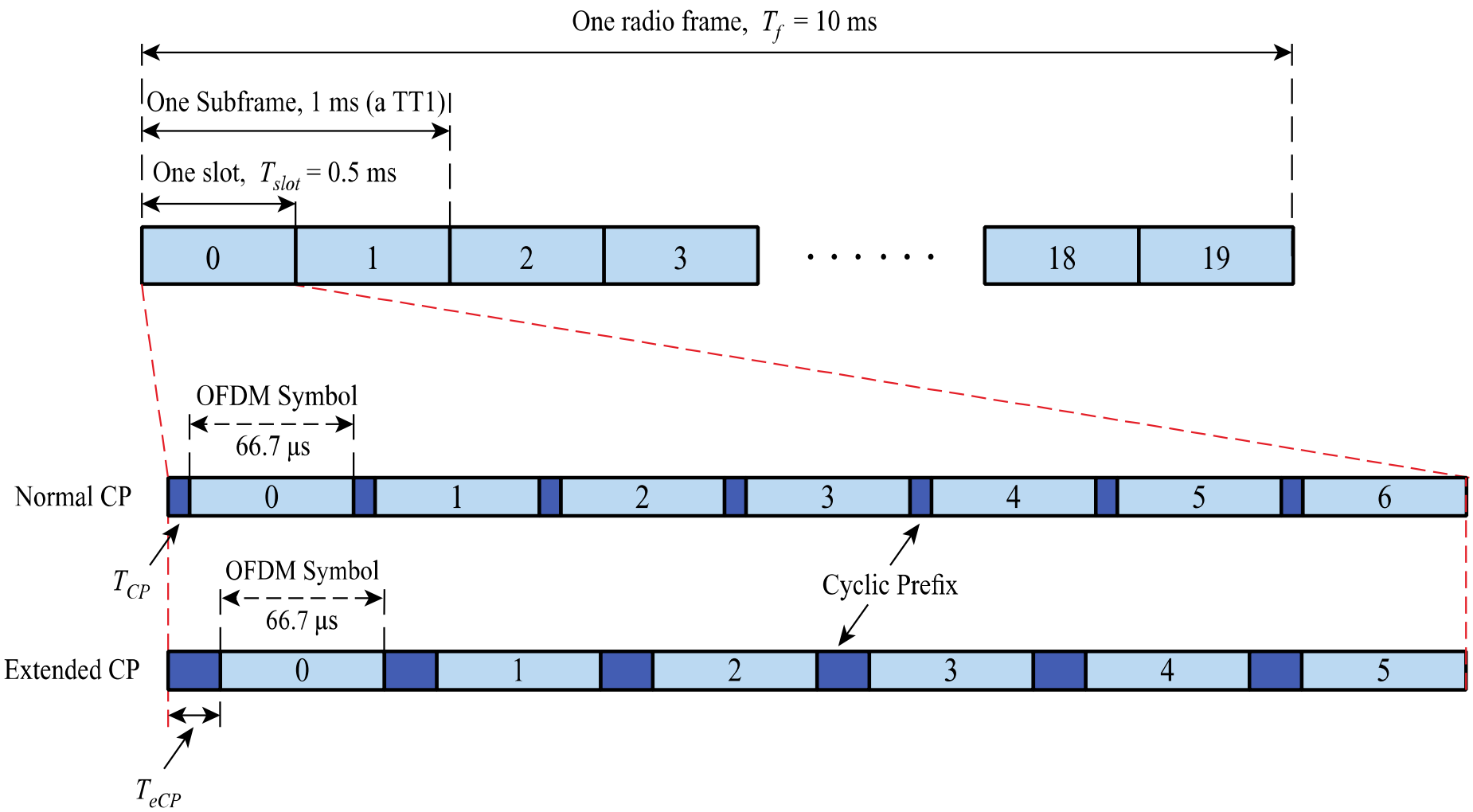
(b) Types of carrier aggregation

Resource Blocks

- A time-frequency grid is used to illustrate allocation of physical resources
- Each column is 6 or 7 OFDM symbols per slot
- Each row corresponds to a subcarrier of 15 kHz
  - » Some subcarriers are used for guard bands
  - » 10% of bandwidth is used for guard bands for channel bandwidths of 3 MHz and above



FDD Frame Structure



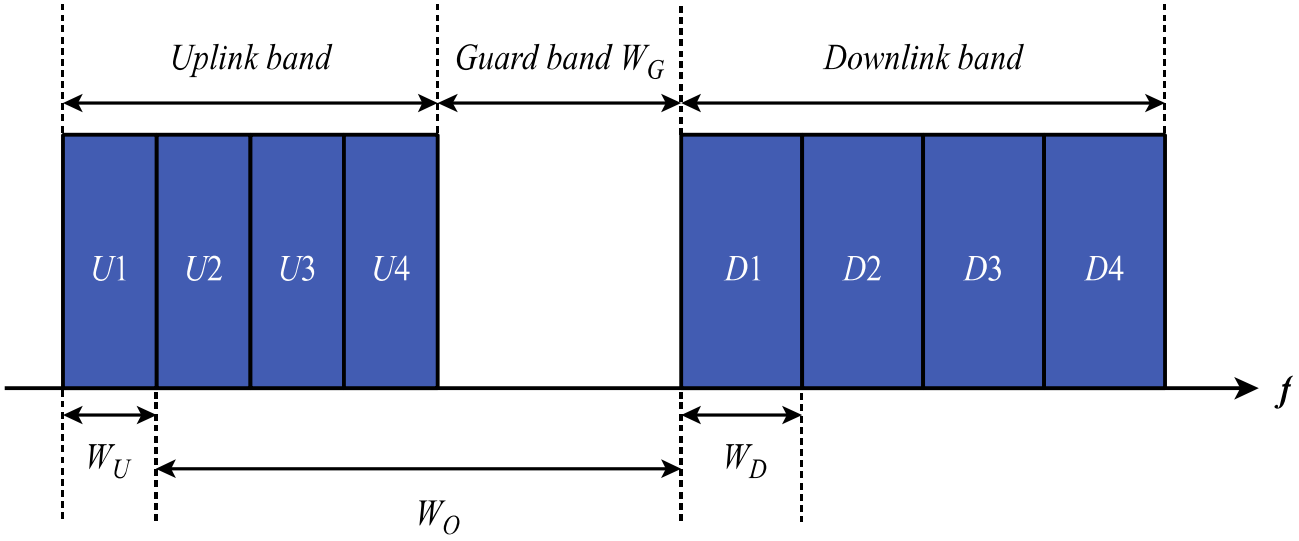
Resource Blocks

- **Resource Block**
  - » 12 subcarriers, 6 or 7 OFDM symbols
  - » Results in 72 or 84 *resource elements* in a *resource block*
- **MIMO: 4×4 in LTE, 8×8 in LTE-Advanced**
  - » Separate resource grids per antenna port
- **eNodeB assigns RBs with channel-dependent scheduling**
- ***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 consider fairness, QoS priorities, typical channel conditions, ..

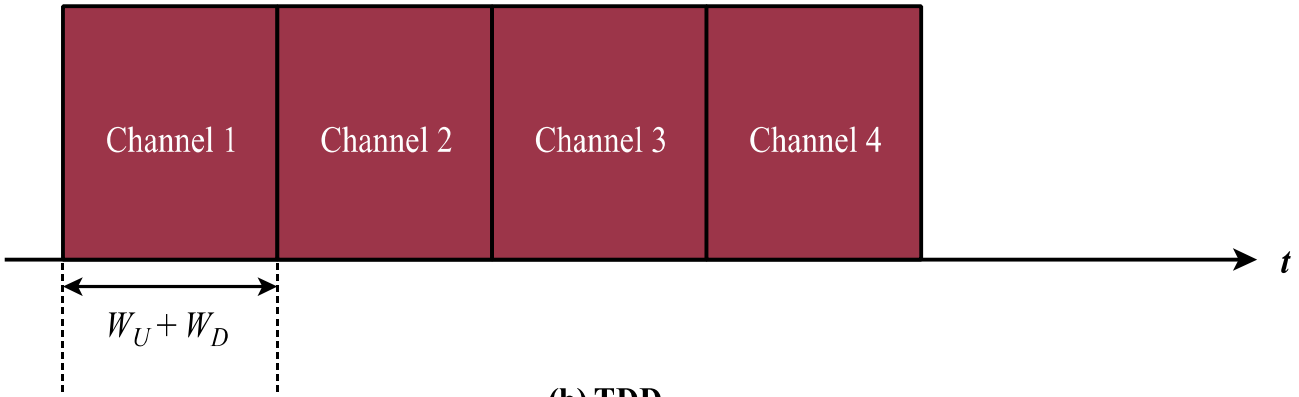
Managing Uplink and Downlink

- LTE uses both TDD and FDD
  - » Both have been widely deployed
- Time Division Duplexing (TDD)
  - » Uplink and downlink transmit in the same frequency band, but alternating in the time domain
- Frequency Division Duplexing (FDD)
  - » Different frequency bands for uplink and downlink
- LTE uses two cyclic prefixes (CPs)
  - » Extended CP is for worse environments

Spectrum Allocation for FDD and TDD



(a) FDD



(b) TDD

Overview LTE

- Motivation
- Architecture
- Resource management
- LTE protocols
- Radio access network
  - » OFDM refresher
- LTE advanced

LTE-Advanced

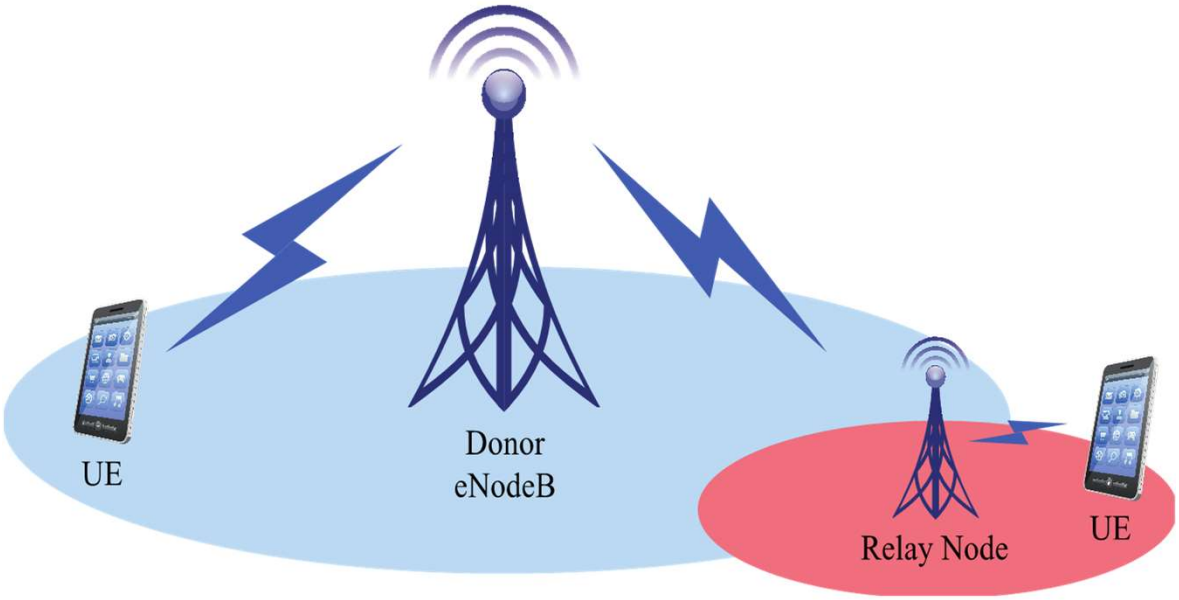
- Carrier aggregation – up to 100 MHz
- MIMO enhancements to support higher dimensional MIMO – up to 8 x 8
- Relay nodes
- Heterogeneous networks involving small cells such as femtocells, picocells, and relays
- Cooperative multipoint transmission and enhanced intercell interference coordination
- Voice over LTE

Comparison
LTE and LTE-Advanced

System Performance		LTE	LTE-Advanced
Peak rate	Downlink	100 Mbps @20 MHz	1 Gbps @100 MHz
	Uplink	50 Mbps @20 MHz	500 Mbps @100 MHz
Control plane delay	Idle to connected	<100 ms	< 50 ms
	Dormant to active	<50 ms	< 10 ms
User plane delay		< 5ms	Lower than LTE
Spectral efficiency (peak)	Downlink	5 bps/Hz @2×2	30 bps/Hz @8×8
	Uplink	2.5 bps/Hz @1×2	15 bps/Hz @4×4
Mobility		Up to 350 km/h	Up to 350—500 km/h

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**
  - » **Transmit a new signal to the base station**



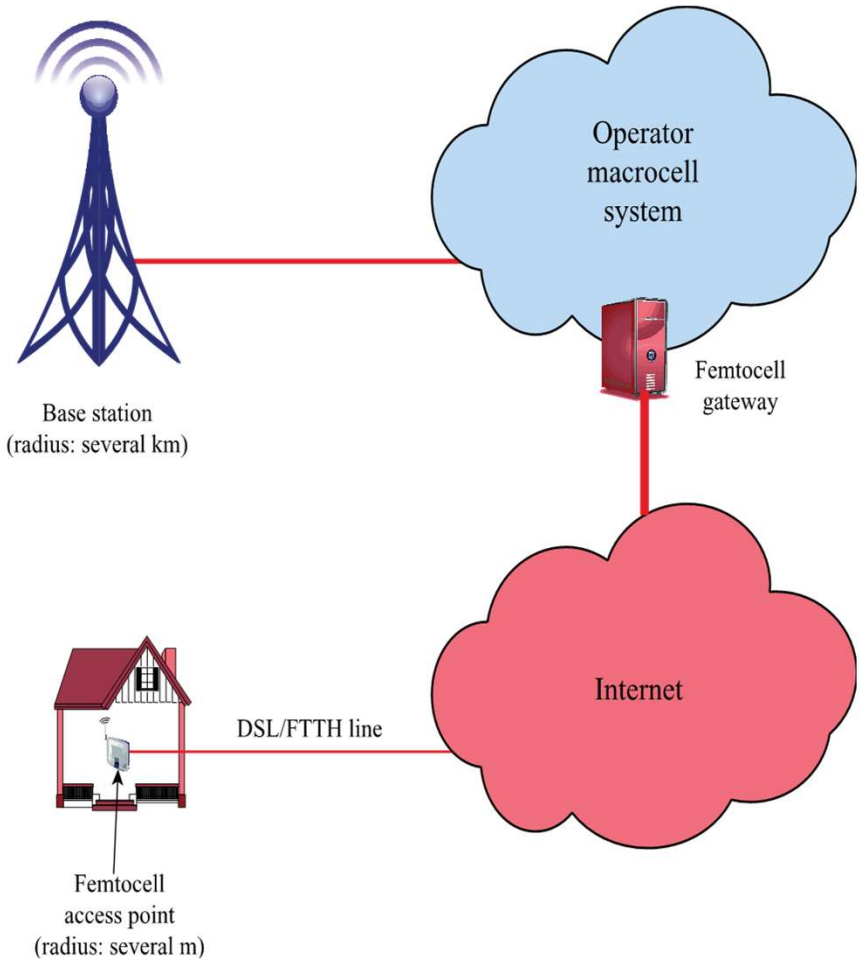
- **An RN functions as a new base station with smaller cell radius**
- **RNs can use out-of-band or inband frequencies**

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 Network Examples

- **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*)**



Trends

- **Cloud RAN optimizes spectrum use**
  - » Goal is to reuse frequencies very aggressively
  - » Leverage cloud technology to centralize the processing for many cells
- **Standards are complex and rigid and need to support several generations**
  - » E.g., switch seamlessly from 4G to 3G
  - » Still need to support 2G (legacy phones, voice)
- **Scalability of infrastructure wrt signaling traffic is a growing concern**
  - » Hardware cannot keep up with changes in usage
- **Wide-spread use of custom hardware**
  - » Move to commodity, programmable equipment