Long Term Evolution (LTE) and LTE-Advanced (LTE-A)

LTE: Long Term Evolution

- Standardized by 3GPP (3rd Generation Partnership Project).
- 3GPP is a partnership of 7 regional standards organizations.
  - ARIB (Japan)
  - ATIS (USA)
  - CCSA (China)
  - ETSI (Europe)
  - TTA (South Korea)
  - TTC (Japan)
  - TSDSI (India)*

**Joined on Jan. 1, 2015*

University of Glasgow

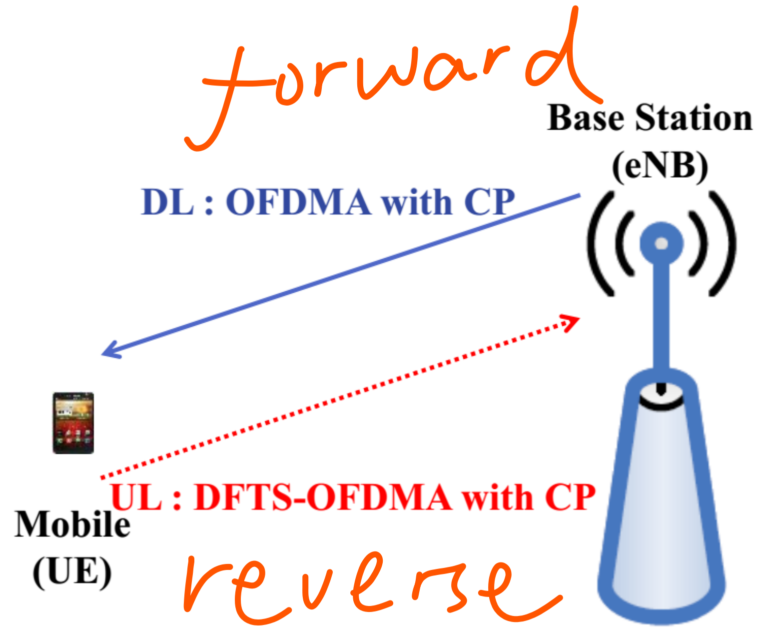
3GPP Evolution

- Release 99 (2000): UMTS/WCDMA
- Rel. 5 (2002): HSDPA
- Rel. 6 (2005): HSUPA
- Rel. 7 (2007) and beyond: HSPA+
- Long Term Evolution (LTE)
  - 3GPP work on the Evolution started in November 2004.
  - Standardized in the form of Rel. 8 (Dec. 2008).
- LTE-Advanced (LTE-A)
  - More bandwidth (up to 100 MHz) and backward compatible with LTE.
  - Standardized in the form of Rel. 10 (Mar. 2011).
  - Meets IMT-Advanced requirements.

LTE Introduction

- Long Term Evolution (LTE) was the next step forward in cellular 3G services.
- It provides for an uplink speed of up to 50 Megabits per second (Mbps) and a downlink speed of up to 100 Mbps.
- Bandwidth is scalable from 1.25 MHz to 20 MHz.
- LTE improved the spectral efficiency in 3G networks

LTE-Basic Terminologies



DL (Downlink), **UL** (Uplink), **CP** (Cyclic Prefix)

eNB (e Node B), **UE** (User Equipment)

DFTS-OFDMA (DFT Spread OFDMA) : also called as **SC-FDMA** (Single Carrier FDMA)

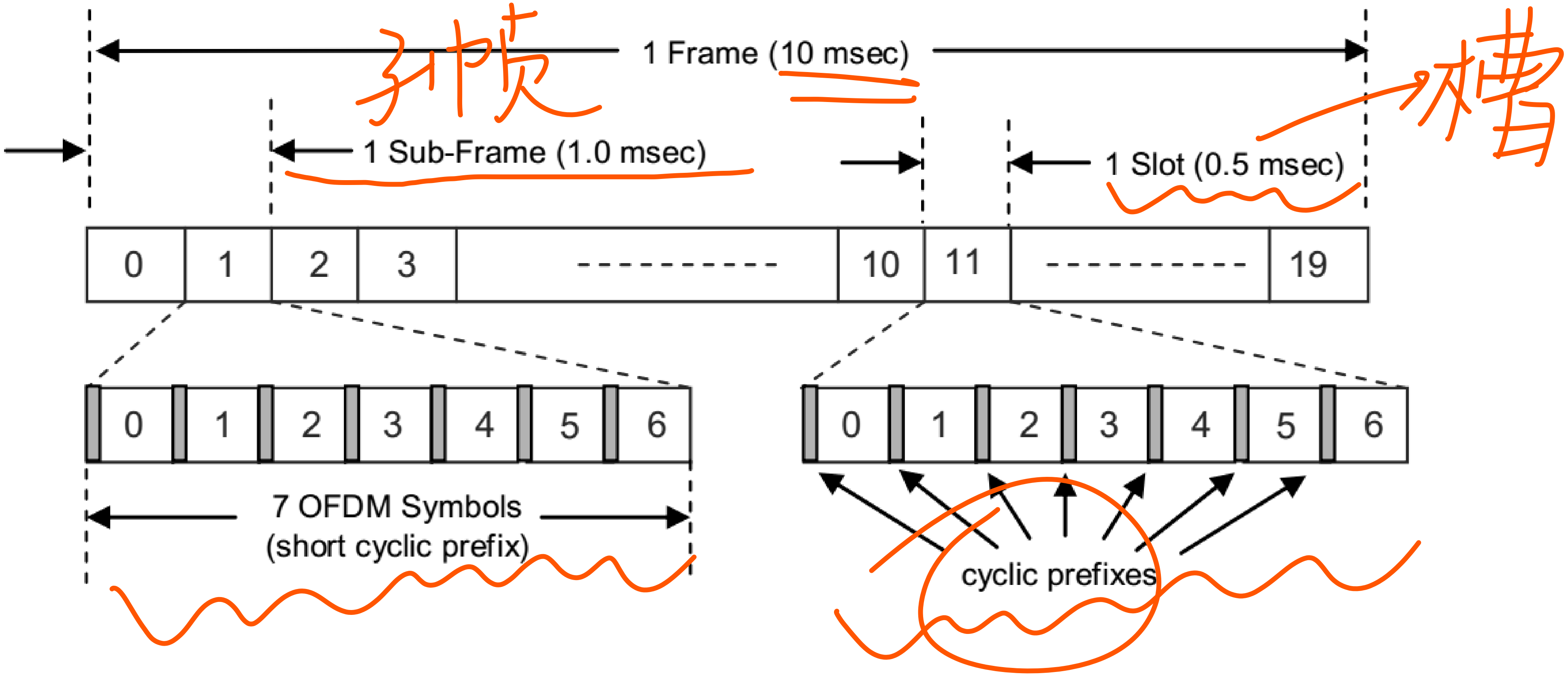
(Reference : p7, 3GPP TS 36.201 V8.3.0 (2009-03))

OFDMA

- OFDMA is employed as the multiplexing scheme in the LTE downlink.
- OFDMA is an excellent choice of multiplexing scheme for the 3GPP LTE downlink.
- In OFDMA, users are allocated a specific number of subcarriers for a predetermined amount of time.
- These are referred to as physical resource blocks (PRBs) in the LTE specifications.
- PRBs thus have both a time and frequency dimension. Allocation of PRBs is handled by a scheduling function at the 3GPP base station (eNodeB).

LTE Generic Frame Structure

Figure 2.3.2-1 LTE Generic Frame Structure 帧结构



Bandwidth distribution

Table 2.3.2-1 Available Downlink Bandwidth is Divided into Physical Resource Blocks

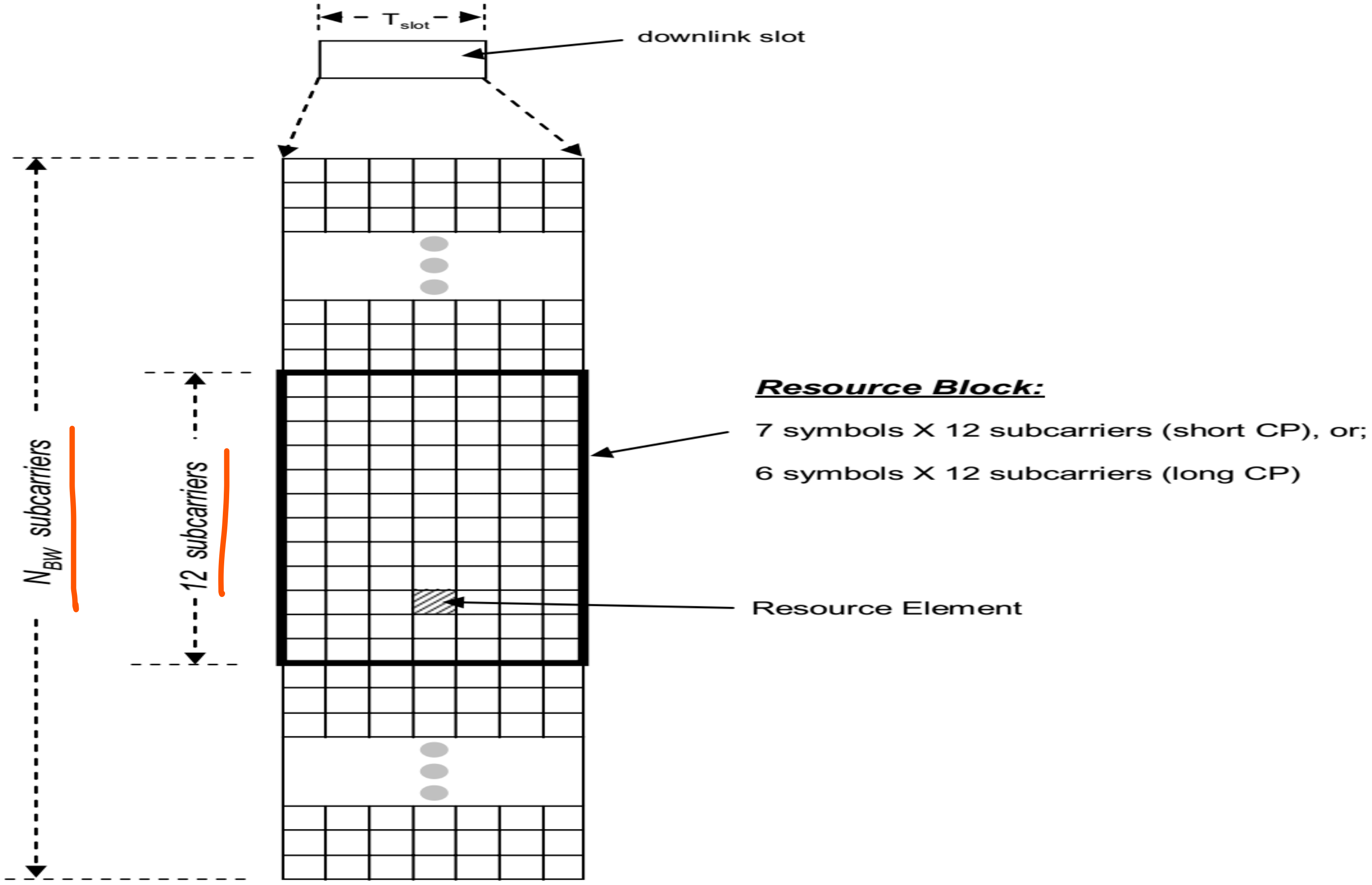
Bandwidth (MHz)	1.25	2.5	5.0	10.0	15.0	20.0
Subcarrier bandwidth (kHz)	15					
Physical resource block (PRB) bandwidth (kHz)	180					
Number of available PRBs	6	12	25	50	75	100

memorize !!

- The total number of available subcarriers depends on the overall transmission bandwidth of the system. The LTE specifications define parameters for system bandwidths from 1.25 MHz to 20 MHz as shown in Table 2.3.2-1.
- A PRB is defined as consisting of 12 consecutive subcarriers for one slot (0.5 msec) in duration.
- A PRB is the smallest element of resource allocation assigned by the base station scheduler.

Downlink resource grid

Figure 2.3.2-2 Downlink Resource Grid



Calculating LTE Data Rates

LTE Physical Layer Recap

还要

OFDM分 OFDMA登记

- LTE employs OFDMA as its base multiple access scheme, leveraging OFDM.
- OFDM splits the carrier frequency bandwidth into several small subcarriers spaced at 15 kHz intervals and **modulates** individual subcarriers using QPSK, 16-QAM, or 64-QAM modulation.
- OFDMA then assigns each user the bandwidth needed for their transmission, using a scheduler such as Proportional Fair, Proportional Demand, etc.
- Unassigned subcarriers remain off, reducing power consumption and interference

Adaptive Modulation and Coding (AMC)

- AMC is employed to encode data onto the subcarrier, whereby a digital modulation and code rate scheme is chosen dynamically based on channel conditions reported by the User Equipment (UE).

- When channel conditions are poor, due to high interference or low signal strength, a simpler scheme will be chosen, conversely when the channel is clean a more complex encoding can be chosen.

- There are two components to AMC: digital modulation, and code rate.

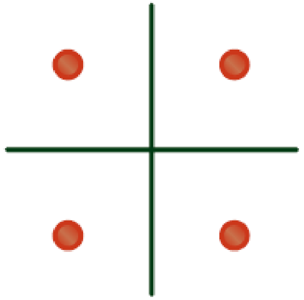
数字调制 码率

Digital Modulation

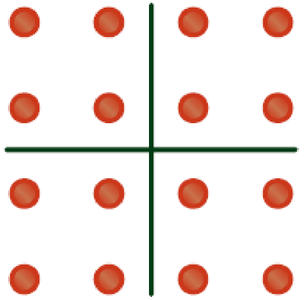
QPSK和 QAM 关系与区别

- A digital modulation scheme is simply a manner of encoding a number of information bits (i.e., binary zero or one) in each time period called a symbol, by varying amplitude and phase of the subcarrier wave.
- Constellation diagrams are used to represent the possible amplitude and phase variations

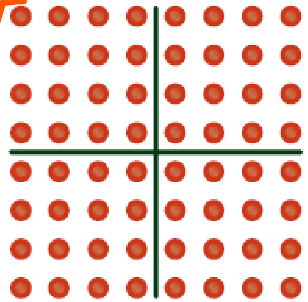
$$\boxed{2^n = M}$$



QPSK (4-QAM)
2 bits per symbol



16-QAM
4 bits per symbol



64-QAM
6 bits per symbol

Code Rate

- Coding refers to a forward error-correction methodology in which the data stream is padded with additional bits to permit error detection and correction.
- For example, a code rate of 1/3 results in one bit being sent as three bits i.e., two duplicate copies for each bit of information.

- As channel conditions improve, the code rate is adjusted so that more data is encoded with less duplication.
- Under very poor channel conditions, the code rate may drop as low as 1/12 (1 bit + 11 copies), and under clean channel, conditions may reach as high as 11/12 (11 bits + 1 copied bit).

防止如ISI的损耗，有如CP

Typical modulation and coding scheme for LTE

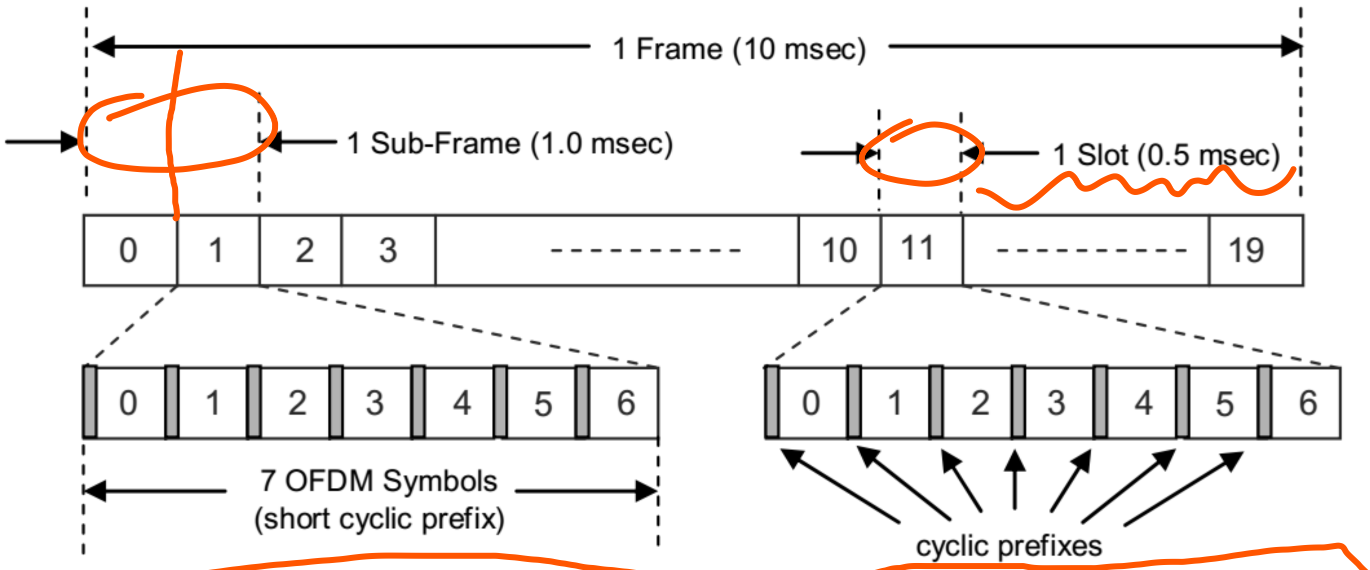
Radio Bearer Index	Name	Modulation	Channel Coding Rate	Bearer Efficiency (bits/symbol)
1	QPSK 1/12	QPSK	0.0761719	0.1523
2	QPSK 1/9	QPSK	0.117188	0.2344
3	QPSK 1/6	QPSK	0.188477	0.377
4	QPSK 1/3	QPSK	0.300781	0.6016
5	QPSK 1/2	QPSK	0.438477	0.877
6	QPSK 3/5	QPSK	0.587891	1.1758
7	16QAM 1/3	16QAM	0.369141	1.4766
8	16QAM 1/2	16QAM	0.478516	1.9141
9	16QAM 3/5	16QAM	0.601563	2.4063
10	64QAM 1/2	64QAM	0.455078	2.7305
11	64QAM 1/2	64QAM	0.553711	3.3223
12	64QAM 3/5	64QAM	0.650391	3.9023
13	64QAM 3/4	64QAM	0.753906	4.5234
14	64QAM 5/6	64QAM	0.852539	5.1152
15	64QAM 11/12	64QAM	0.925781	5.5547

1帧=10子帧 1子帧=2槽 1槽=7 OFDM码元 1码元 = 0.071428 毫秒

LTE Frame Structure

bit rate ⇒ bits/s 反过来 1bit 几秒?
(data)

Figure 2.3.2-1 LTE Generic Frame Structure



- FDD LTE radio frame – 10 msec
  - 10 subframe of 1 msec
- 1 subframe – two slots of 0.5 msec
- Each radio frame – 20 slots
- Each slot – 7 OFDM symbols in length
- Each symbol – 0.071428 msec in length

0.071428 ms/sym ⇒ 1400 sym/s

- 1 subcarrier can transmit 7 x 2 x 10 = 140 symbols per radio frame = 140 symbols x (1000 ms/s / 10 ms) = 14,000 symbols per second

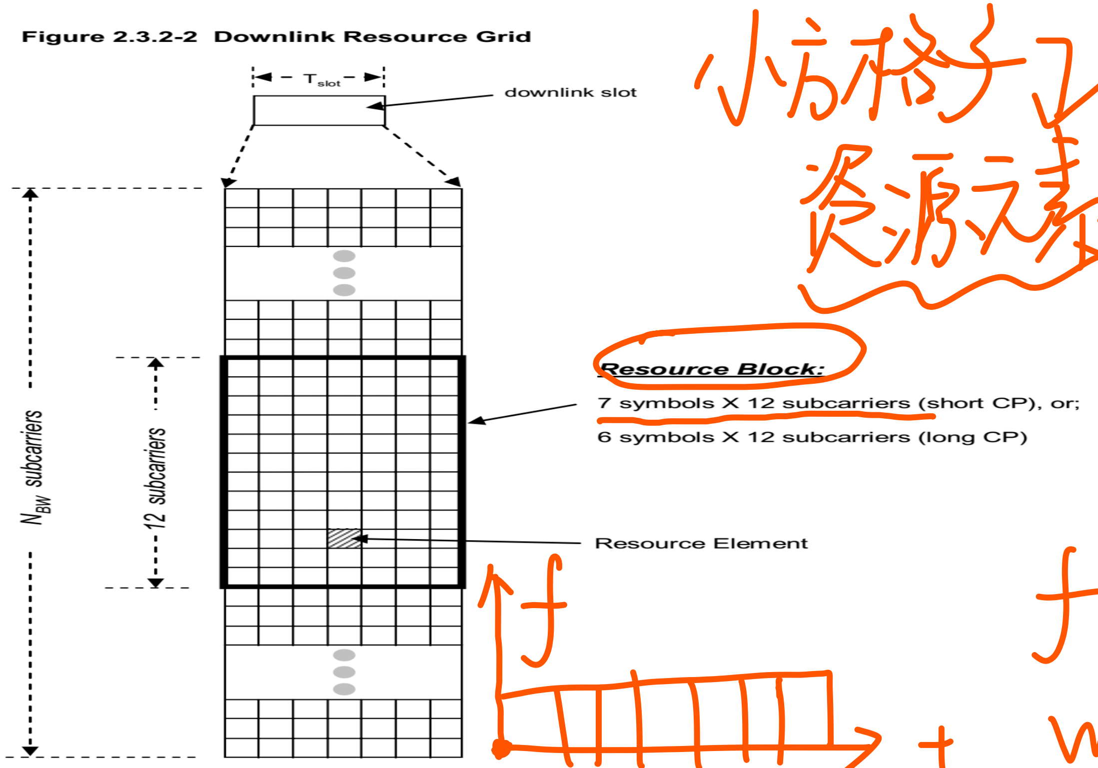
sym/s

2^6, n = 6 bits/sym ⇒ 6 x 0.925781 ⇒

- For radio bearer index 15 with 64 QAM modulation, 0.925781 coding rate i.e., 5.5547 bits/symbol
  - 5.5547 bits/symbol x 14000 symbols/second = 77765 bits per second per subcarrier

77765 bits/s/sub

Bandwidth Structure & Rate Calculation



- Note that earlier calculation is the number of bits per second per subcarrier

n bits/s/sub

- One symbol per one subcarrier forms the smallest structure in LTE, called the Resource Element (RE)

1 sym/sub

$\frac{1}{14}$ ms

- RE can be thought of as having two dimensions – width (one subcarrier, 15 kHz), and length (one symbol, 0.071428 ms).
- Physical Resource Block (PRB) has a width of 12 subcarriers totaling 180 kHz, and a length of seven symbols totaling 0.5 ms

f w RE t

$12 \times \frac{180}{12}$ kHz; 7×0.5 ms

- In a 20 MHz channel, we have 100 RBs, each 12 subcarriers in width, giving us 1200 subcarriers.
- Hence, the total calculation for a 20 MHz channel is 77765 bits per second per subcarrier x 1200 subcarriers = 93318000 b/s = 93.318Mb/s at the highest modulation and coding scheme.

Example

$10 \times 0.9 = 9\,MHz$ $\quad 9M/600 = 1.5 \times 10^4 = 15kHz$

A long-term evolution (LTE) system is using frequency division duplexing (FDD) with a channel bandwidth 10MHz. Given that the number of subcarriers is 600, and a perfect ideal condition such that 64 QAM and short cyclic prefix (CP) can be used. Obtain the maximum data rate at the physical layer.

$64QAM \Rightarrow 2^6 \Rightarrow n = 6$ bits/symbol

data rate $= 1400 \times 6$ bits/s $\times 600$ subcarriers

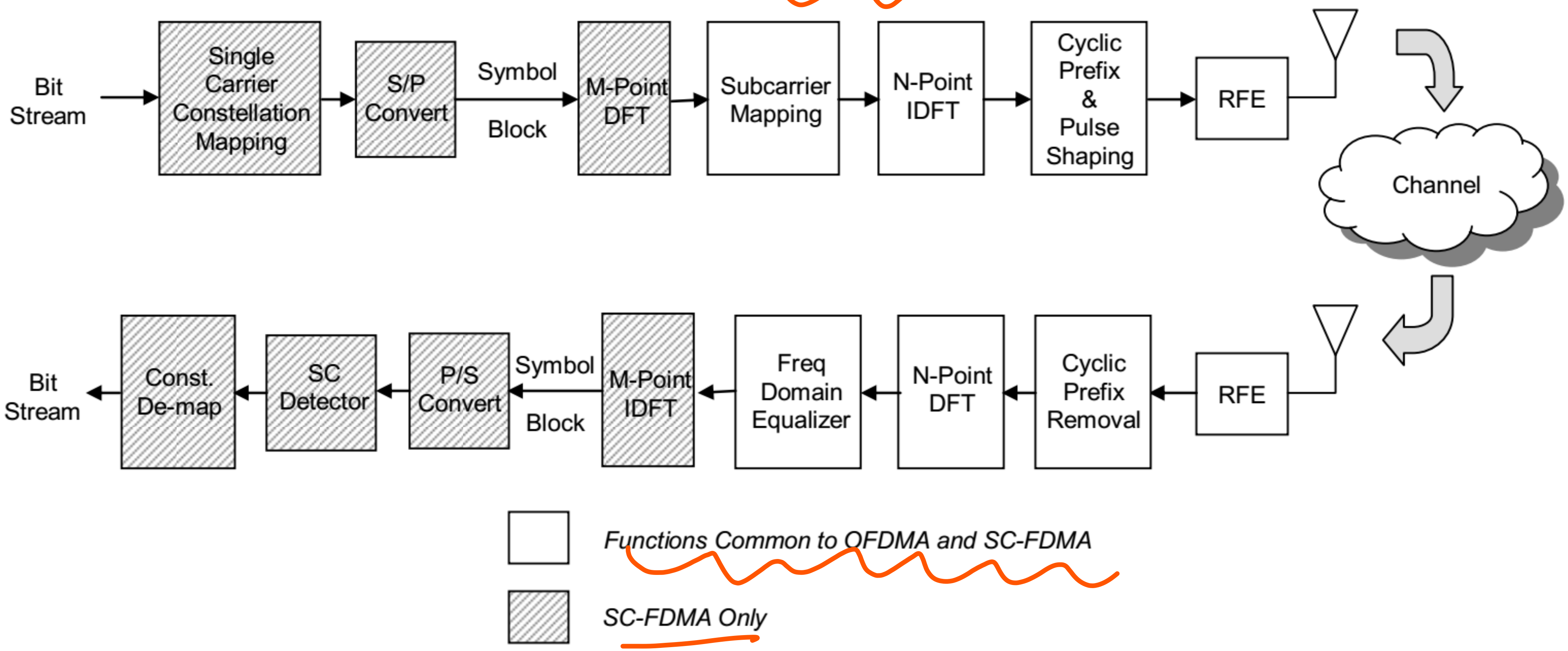
$= 5040000$ bits/s

SC-FDMA

- LTE uplink requirements differ from downlink requirements in several ways.
- Not surprisingly, power consumption is a key consideration for UE terminals.
- The high **PAPR** and related loss of efficiency associated with OFDM signalling are major concerns. As a result, an alternative to OFDM was sought for use in the LTE uplink.
- Single Carrier – Frequency Domain Multiple Access (SC-FDMA) is well suited to the LTE uplink requirements.
- The basic transmitter and receiver architecture is very similar (nearly identical) to OFDMA, and it offers the same degree of multipath protection.
- Importantly, because the underlying waveform is essentially single-carrier, the **PAPR is lower**.

SC-FDMA Transceiver

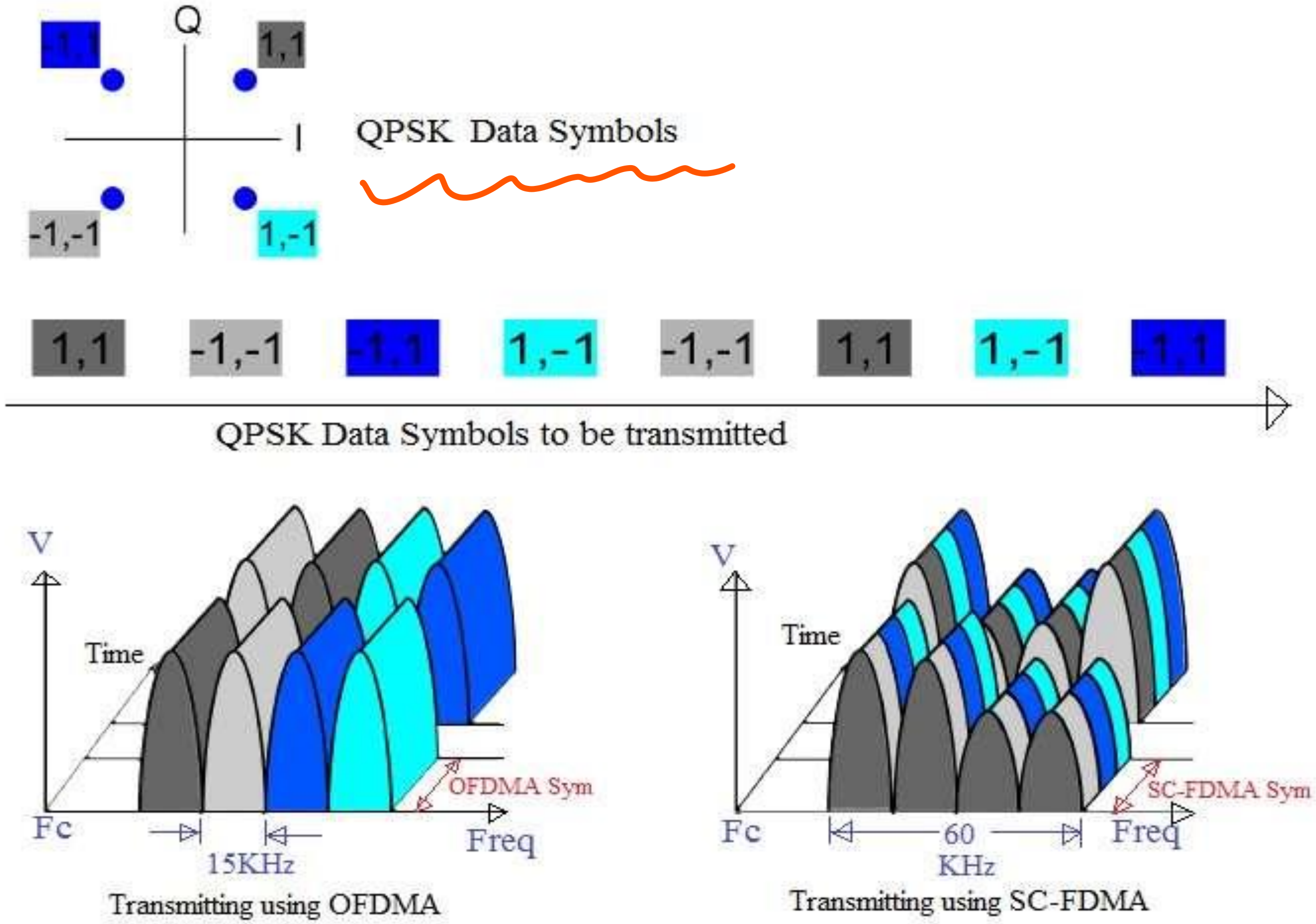
Fig. 2.5-1 SC-FDMA and OFDMA Signal Chains Have a High Degree of Functional Commonality



SC-FDMA Transceiver

- Note that many of the functional blocks are common to both SC-FDMA and OFDMA. The functional blocks in the transmit chain are:
  1. **Constellation mapper**: Converts incoming bit stream to single carrier symbols (BPSK, QPSK, or 16QAM depending on channel conditions)
  2. **Serial/parallel converter**: Formats time domain SC symbols into blocks for input to FFT engine
  3. **M-point DFT**: Converts time domain SC symbol block into M discrete tones
  4. **Subcarrier mapping**: Maps DFT output tones to specified subcarriers for transmission.
- 5. **N-point IDFT**: Converts mapped subcarriers back into time domain for transmission
  6. **Cyclic prefix and pulse shaping**: Cyclic prefix is pre-pended to the composite SC-FDMA symbol to provide multipath immunity in the same manner as described for OFDM. As in the case of OFDM, pulse shaping is employed to prevent spectral regrowth.
  7. **RFE:** Converts digital signal to analogue and up convert to RF for transmission
- **Unlike OFDM, the underlying SC-FDMA signal represented by the discrete subcarriers is—not surprisingly—single carrier. This is distinctly different than OFDM because the SC-FDMA subcarriers are not independently modulated. As a result, PAPR is lower than for OFDM transmissions**.

SC-FDMA vs OFDMA

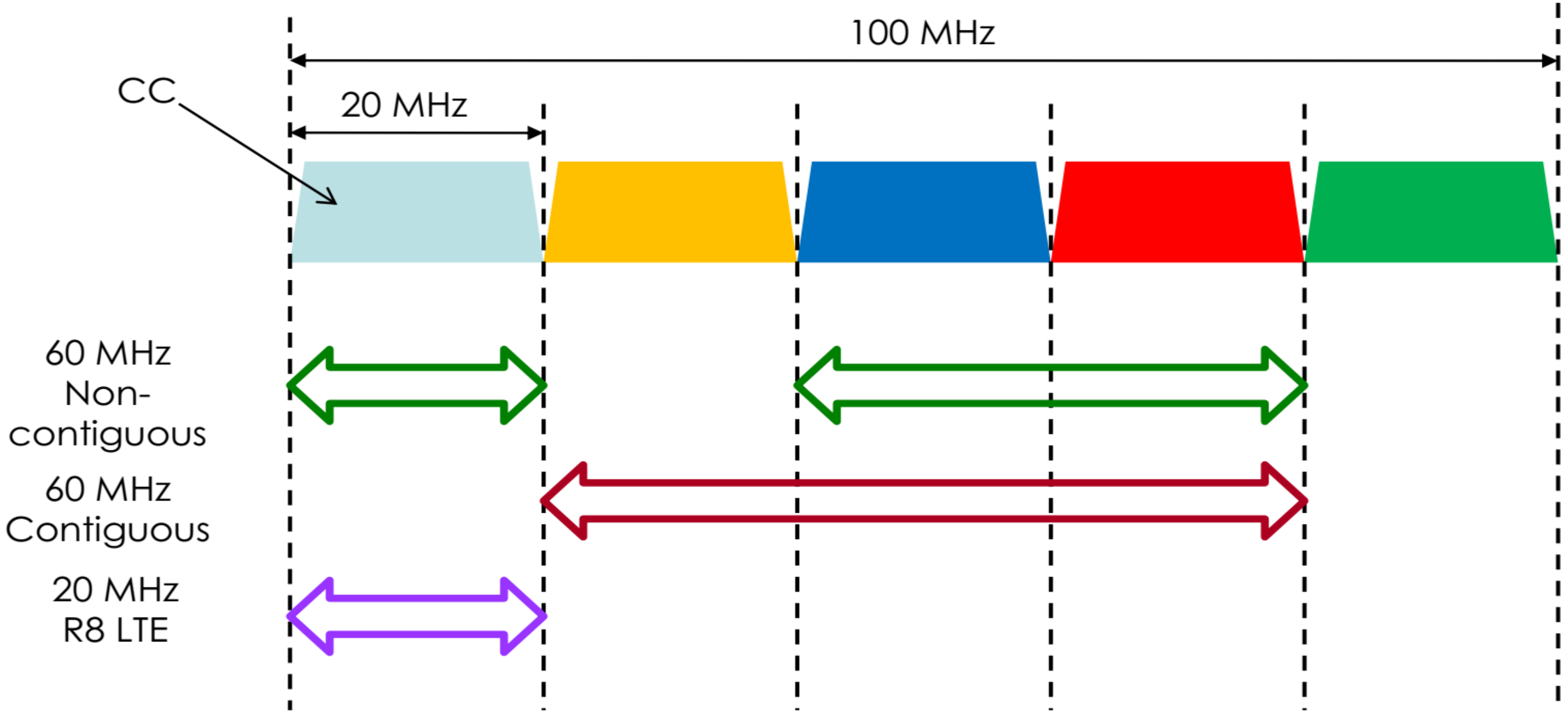


LTE-A: Carrier Aggregation

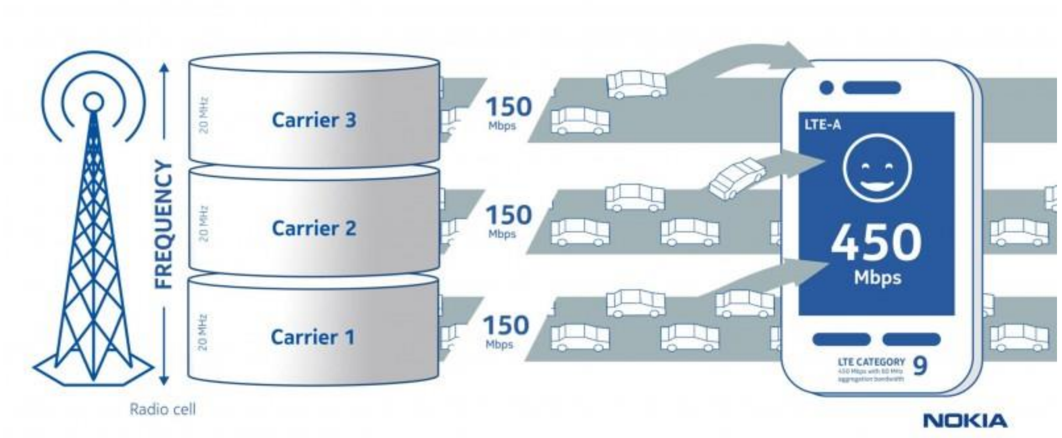
- In order to support up to 100 MHz bandwidth, two or more component carriers aggregated
  – Component carrier (CC): Basic frequency block which comply with R8 LTE numerology
  – Each CC is limited to 20 MHz bandwidth.
  – Maintains backward compatibility with R8 LTE.
- Supports both contiguous and non-contiguous spectrum.
- Also supports asymmetric bandwidth for FDD.

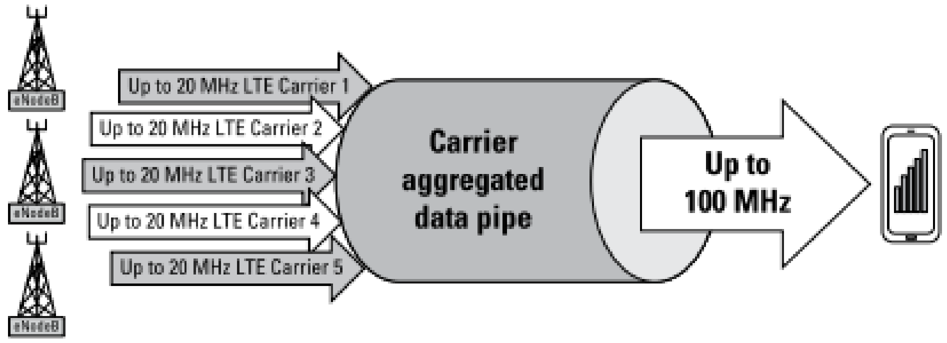
LTE-A: Carrier Aggregation

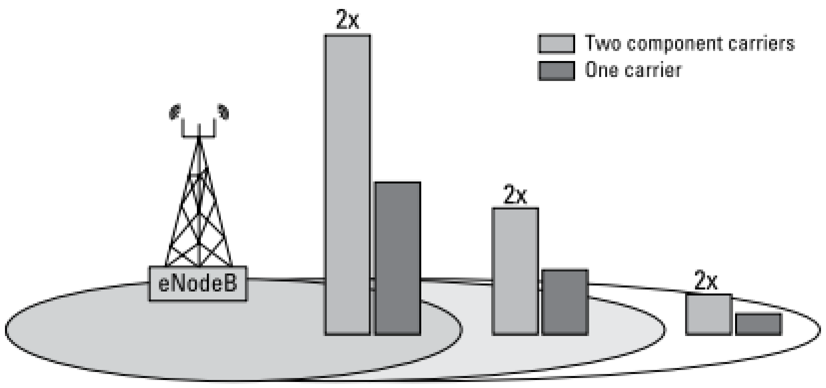
– cont.



LTE Carrier Aggregation: Data rate improvement

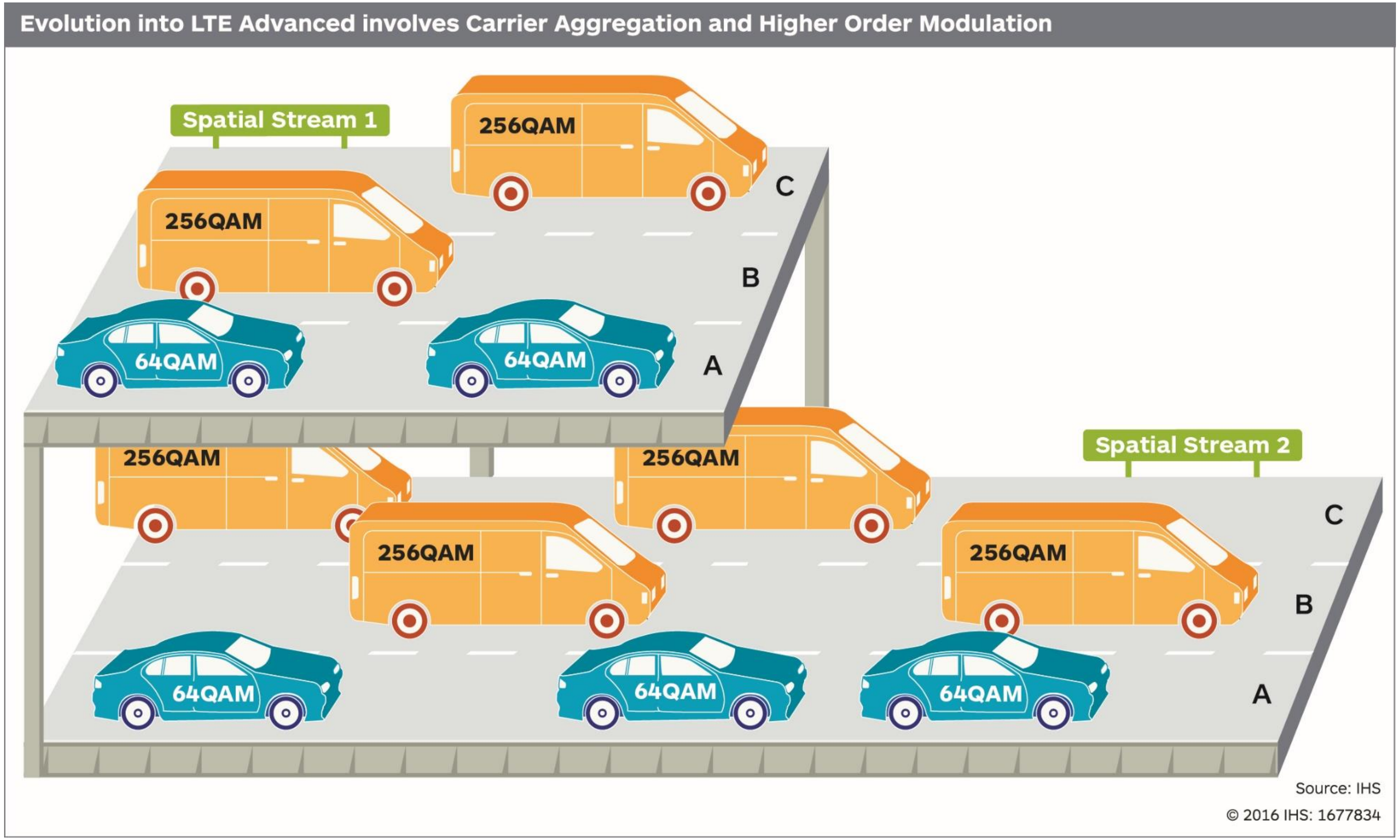






100 percent improvement in physical layer output

LTE Carrier Aggregation: Data rate improvement



LTE-A - MIMO (Multiple input multiple output)

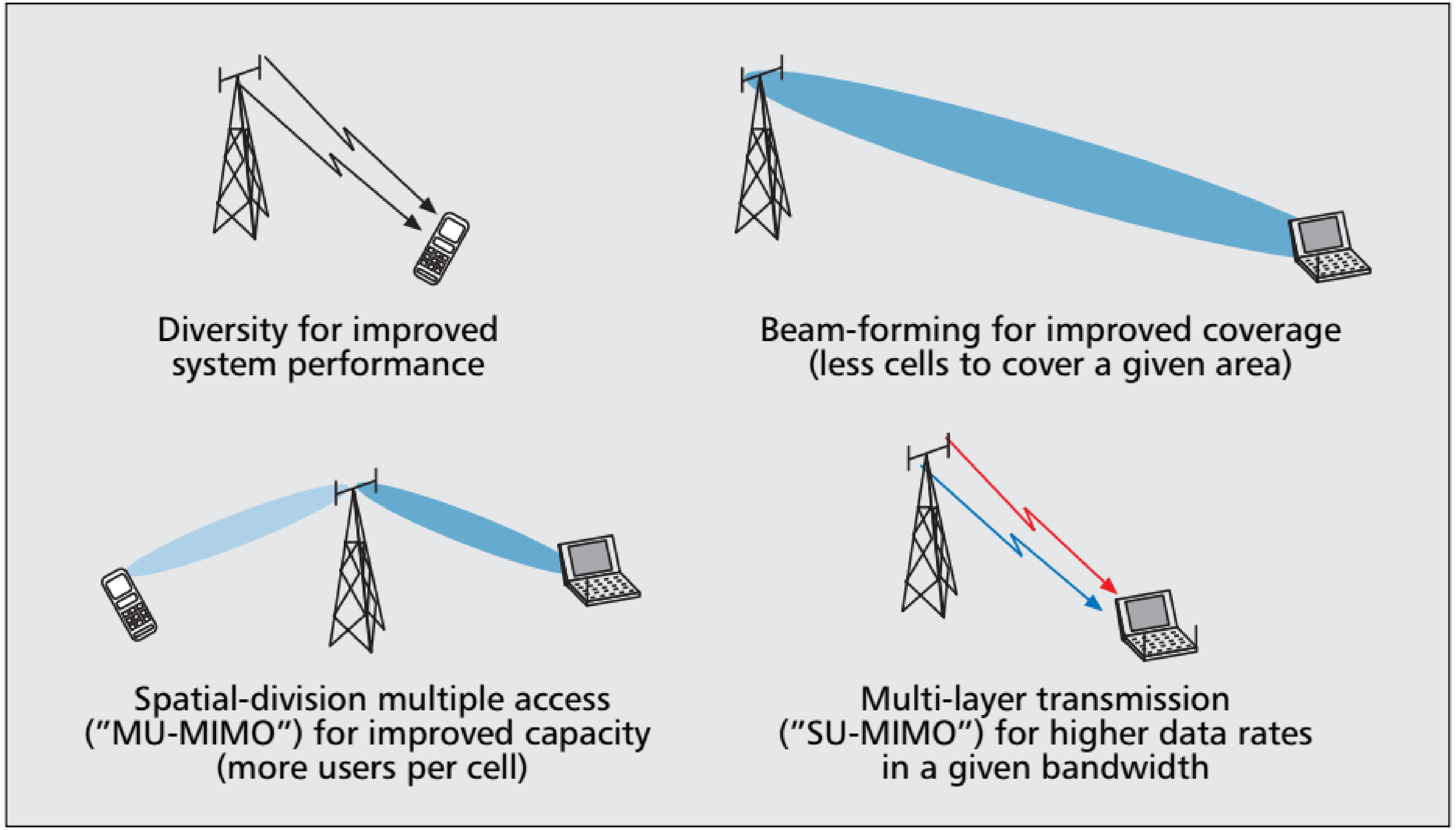


Figure 5. *Multiple-antenna techniques in LTE.*

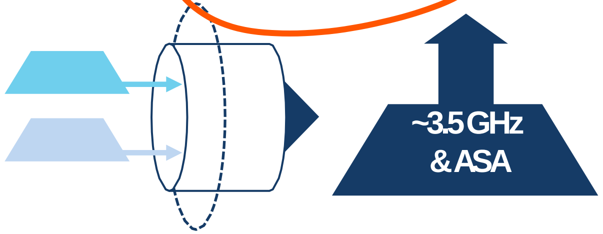
Mobile technologies are evolving for more data capacity

Shannon's Law

$$C \approx W \cdot n \cdot \log_2(1 + SNR)$$

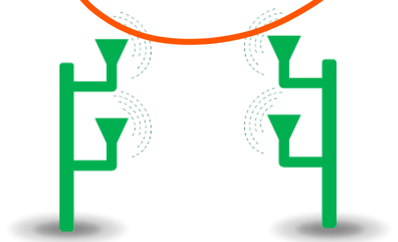
Capacity | Spectrum | Antennas | Signal Quality

More Spectrum



Making the best use of all spectrum types with more licensed spectrum as the top priority, e.g., ASA, ~3.5 GHz, unlicensed spectrum

More Antennas



Advanced multiple antenna techniques to create spatially separated data paths, e.g., 4 way receive diversity, 4x4 MIMO

Interference Mitigation

Advanced receivers and antenna techniques, e.g., LTE FeICIC/IC, HSPA+ advanced device receiver

Review Question

occupy: $5 \times 0.9 = 4.5$ MHz

A long-term evolution (LTE) system is using frequency division duplexing (FDD) with a channel bandwidth 5MHz.

$4500 \div 15 = 300$ subcarriers

I. Calculate the number of available physical resource blocks and subcarriers. [25, 300]

$300 \div 12 = 25$ PRB $n=4$ $4 \times 3/5 = 12/5 = 2.4$ bits/sym

II. Given that the system utilizes a 16 QAM, channel coding rate of 3/5, and the short cyclic prefix (CP), determine the maximum achievable download rate. [10.08Mb/s]

$14000 \times 2.4 \times 300 = 10.08$ Mbit/s.

III. What is the download achievable rate if 10 physical resource blocks are utilized? [4.032Mb/s]

$10/25 \times 10.08 = 4.032$ Mb/s

IV. Determine the maximum achievable download rate for the ideal condition with 64QAM modulation and no coding required. [25.2Mb/s]

V. Repeat (II) and (IV) assuming a 2 by 2 MIMO system. [20.16 Mb/s, 50.4 MB/s]

$n=6 \Rightarrow 14000 \times 6 \times 300 = 25.2$ Mb/s $\Downarrow$ 均可以乘以2