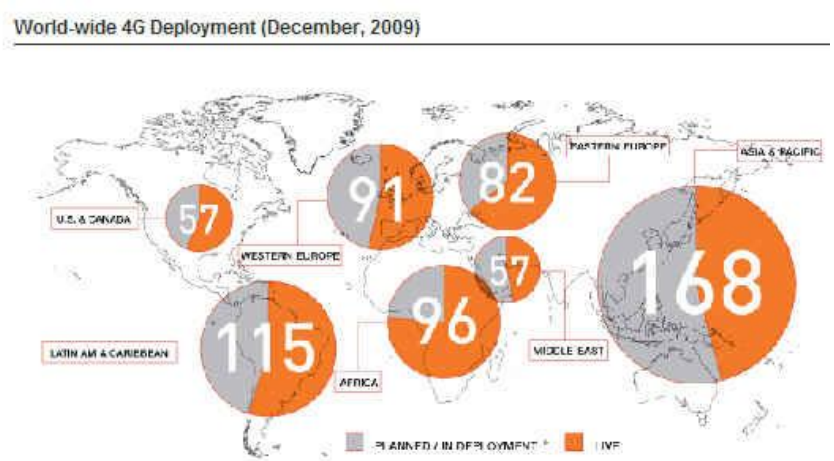
Chapter 6

Applications: 4G (LTE for UMTS)

Office Hours:
BKD 3601-7
Tuesday 14:00-16:00
Thursday 9:30-11:30

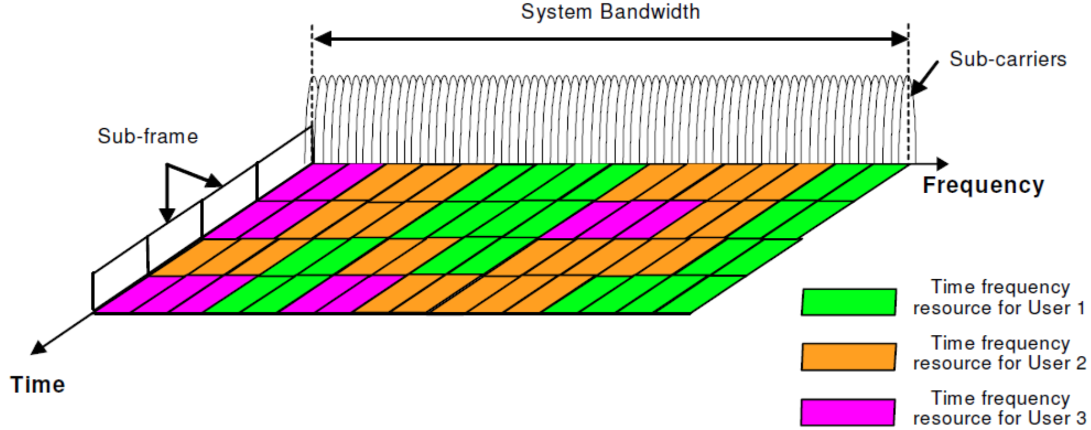
4G

- Unlike the 3G networks, which use both circuit switching and packet switching, 4G uses packet switching only.

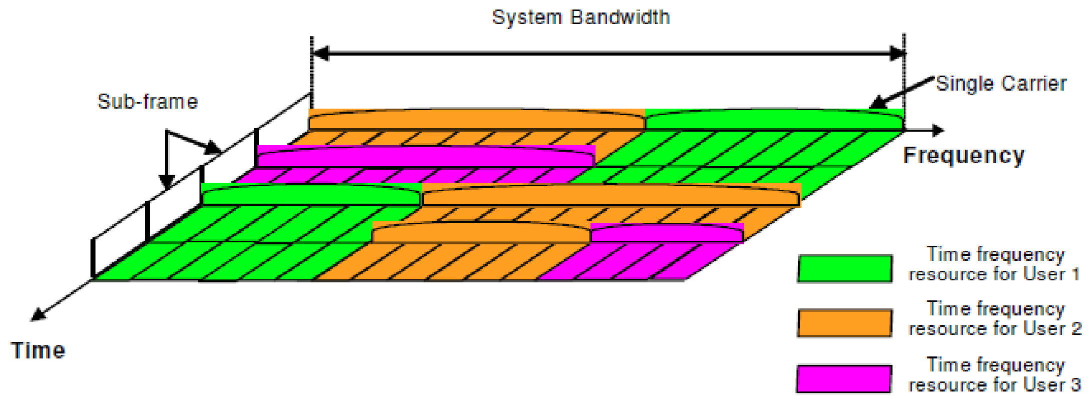


LTE: Multiple Access

- Downlink: OFDMA
- Uplink: SC-FDMA



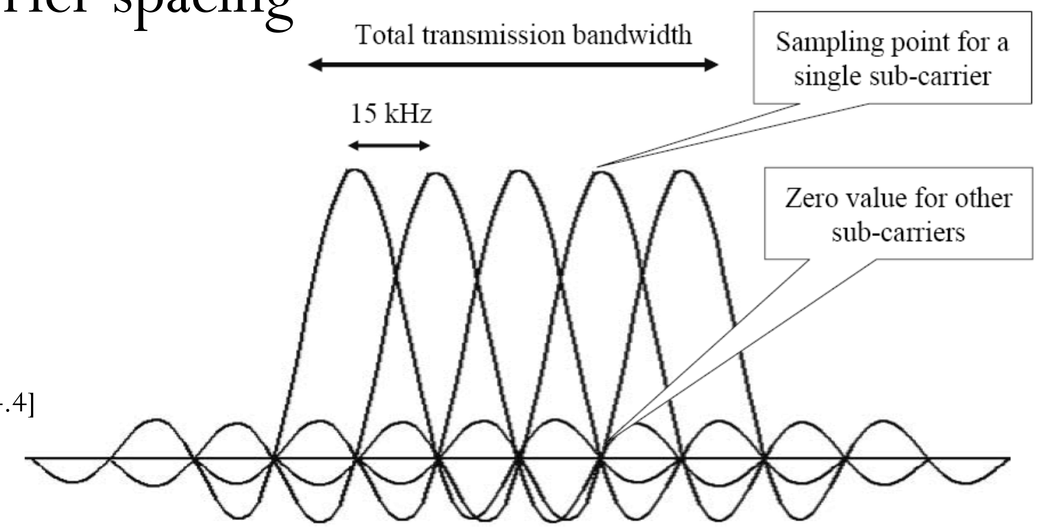
DL OFDMA 173M



UL SC-FDMA 84M

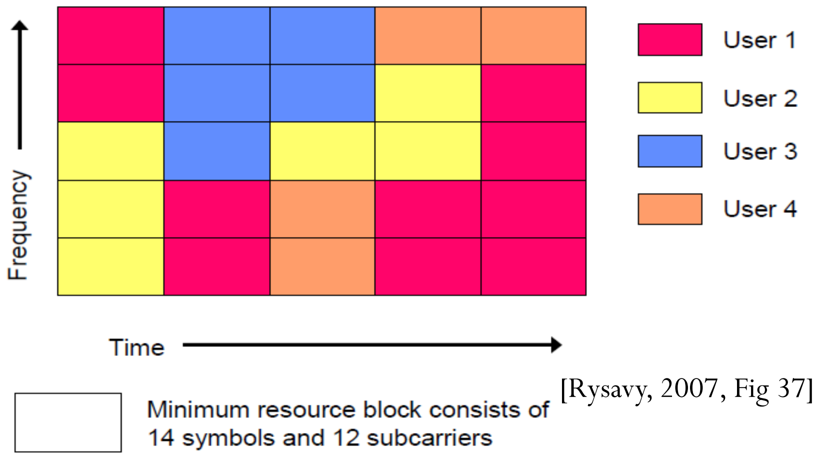
LTE: OFDMA

- 15 kHz subcarrier spacing



[Holma and Toskala, 2009, Fig 4.4]

- Downlink Resource Assignment in Time and Frequency



[Rysavy, 2007, Fig 37]

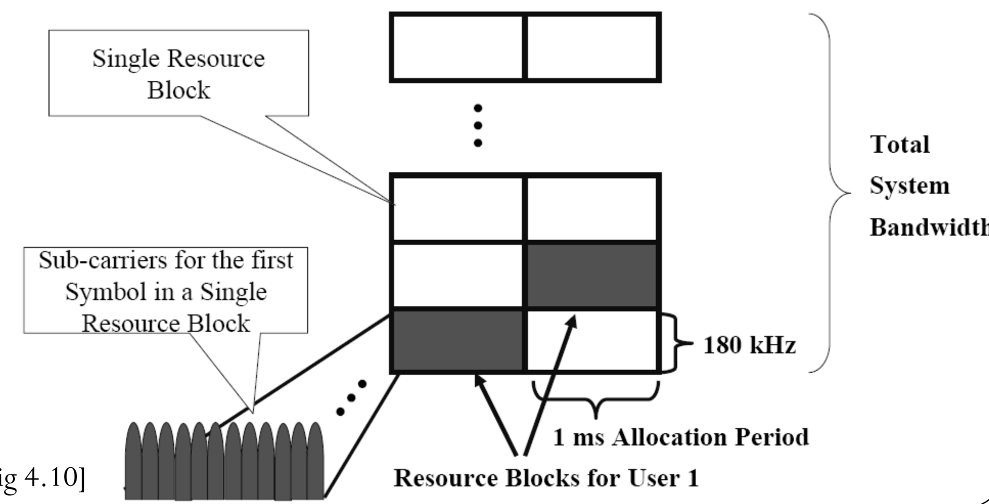
OFDMA: Resource Allocation (1)

- HSDPA
  - Allocations were only in the time domain and code domain but always occupied the full bandwidth.
- OFDMA
  - The possibility of having different sub-carriers to allocated users enables the scheduler to benefit from the diversity in the frequency domain.
  - This element of allocating resources dynamically in the frequency domain is often referred to as **frequency domain scheduling** or **frequency domain diversity**.

OFDMA: Resource Allocation (2)

- Allocation is not done on an individual sub-carrier basis but is based on **resource blocks**.
  - It would be far too inefficient to try either to obtain feedback with 15 kHz sub-carrier resolution or to signal the modulation applied on a individual sub-carrier basis.
- Each resource block consisting of 12 sub-carriers, thus resulting in the minimum bandwidth allocation being 180 kHz.
- When the respective allocation resolution in the time domain is 1 ms, the downlink transmission resource allocation thus means filling the resource pool with 180 kHz blocks at 1 ms resolution.

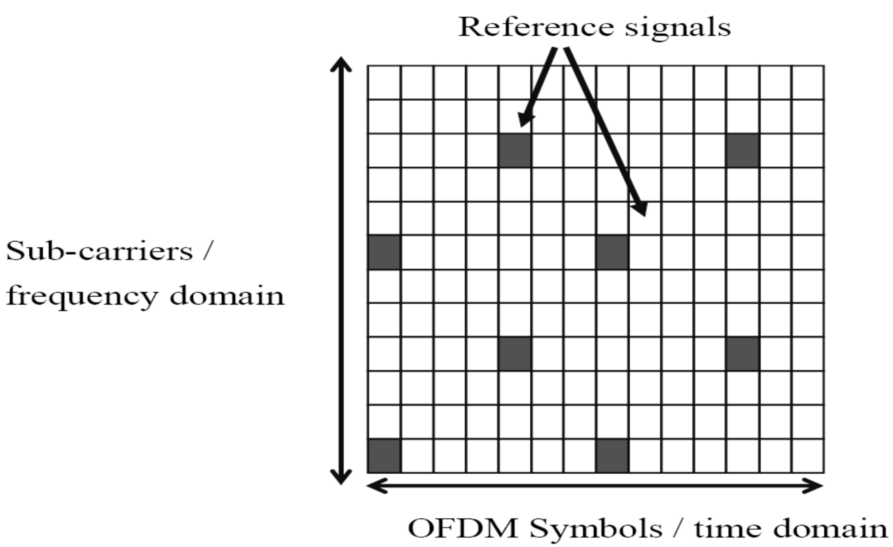
Note that the resource block in the specifications refers to the 0.5 ms slot, but the resource allocation is done anyway with the 1 ms resolution in the time domain.



[Holma and Toskala, 2009, Fig 4.10]

OFDMA: Channel Estimation

- Have reference or pilot symbols.
- With the proper placement of these symbols in both the time and frequency domains, the receiver can interpolate the effect of the channel to the different sub-carriers from this time and frequency domain reference symbol ‘grid’.



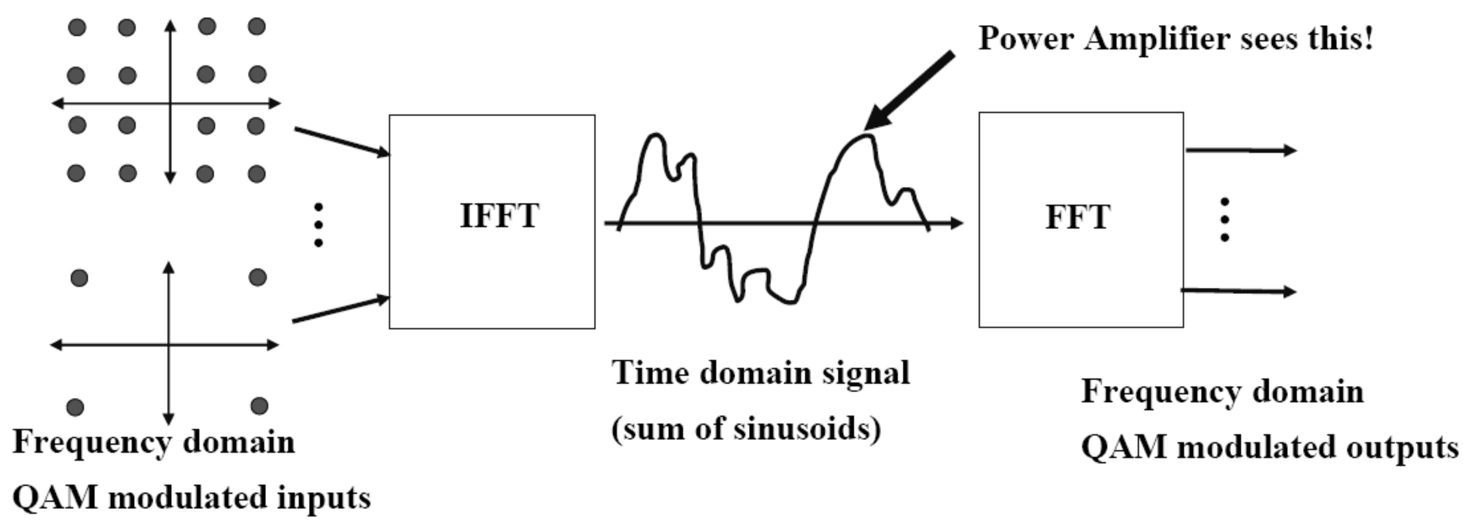
[Holma and Toskala, 2009, Fig 4.8]

OFDMA: Equalizer

- Frequency domain equalizer basically reverts the channel impact for each sub-carrier.
- The frequency domain equalizer in OFDMA simply multiplies each sub-carrier (with the complex-valued multiplication) based on the estimated channel frequency response (the phase and amplitude adjustment each sub-carrier has experienced) of the channel.
- This is clearly a simpler operation compared with WCDMA and is not dependent on channel length (length of multipath in chips) as is the WCDMA equalizer.

OFDMA Problem: PAPR

- The OFDMA signal envelope varies strongly, compared to a normal QAM modulator, which is only sending one symbol at a time (in the time domain).



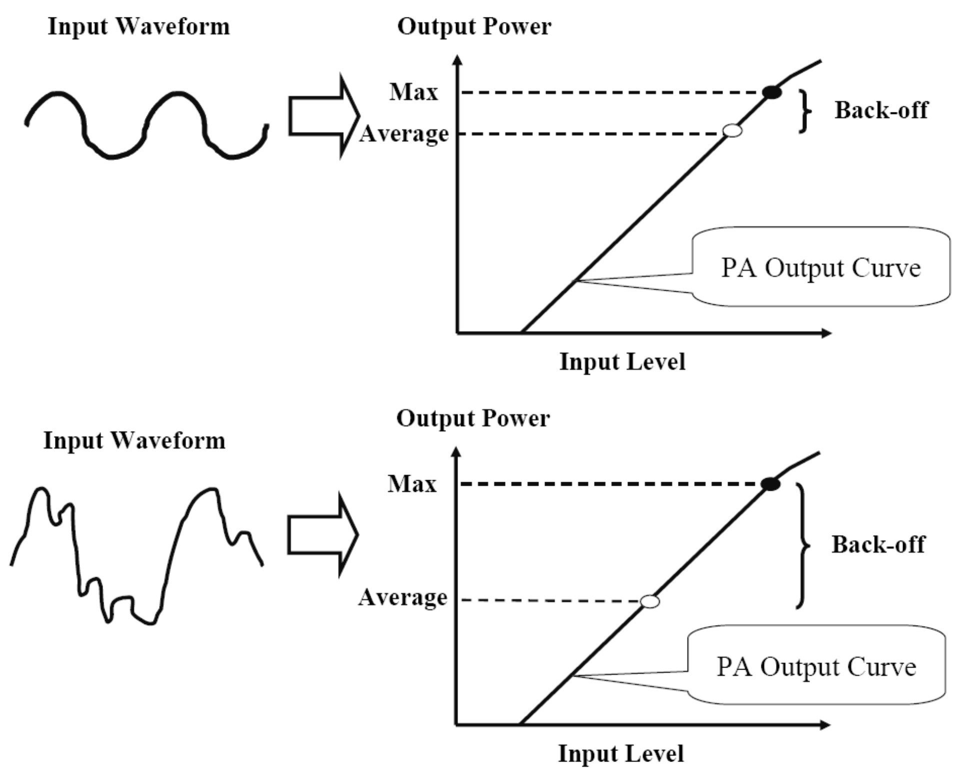
[Holma and Toskala, 2009, Fig 4.11]

OFDMA Problem: PAPR (2)

- This causes some challenges to the amplifier design as, in a cellular system, one should aim for maximum power amplifier efficiency to achieve minimum power consumption.
- A signal with a higher envelope variation (such as the OFDMA signal in the time domain) requires the amplifier to use **additional back-off.**
  - The amplifier must stay in the linear area with the use of extra power back-off.
  - The use of additional back-off leads to a **reduced amplifier power efficiency** or a smaller output power.
  - This either causes the uplink range to be shorter or, when the same average output power level is maintained, the battery energy is consumed faster due to higher amplifier power consumption.
    - The latter is not considered a problem in fixed applications where the device has a large volume and is connected to the mains, but for small mobile devices running on their own batteries it creates more challenges.
- This was the key reason why 3GPP decided to use OFDMA in the downlink direction but to use the power efficient SC-FDMA in the uplink direction.

Power amplifier back-off requirements

- Power amplifier back-off requirements for different input waveforms



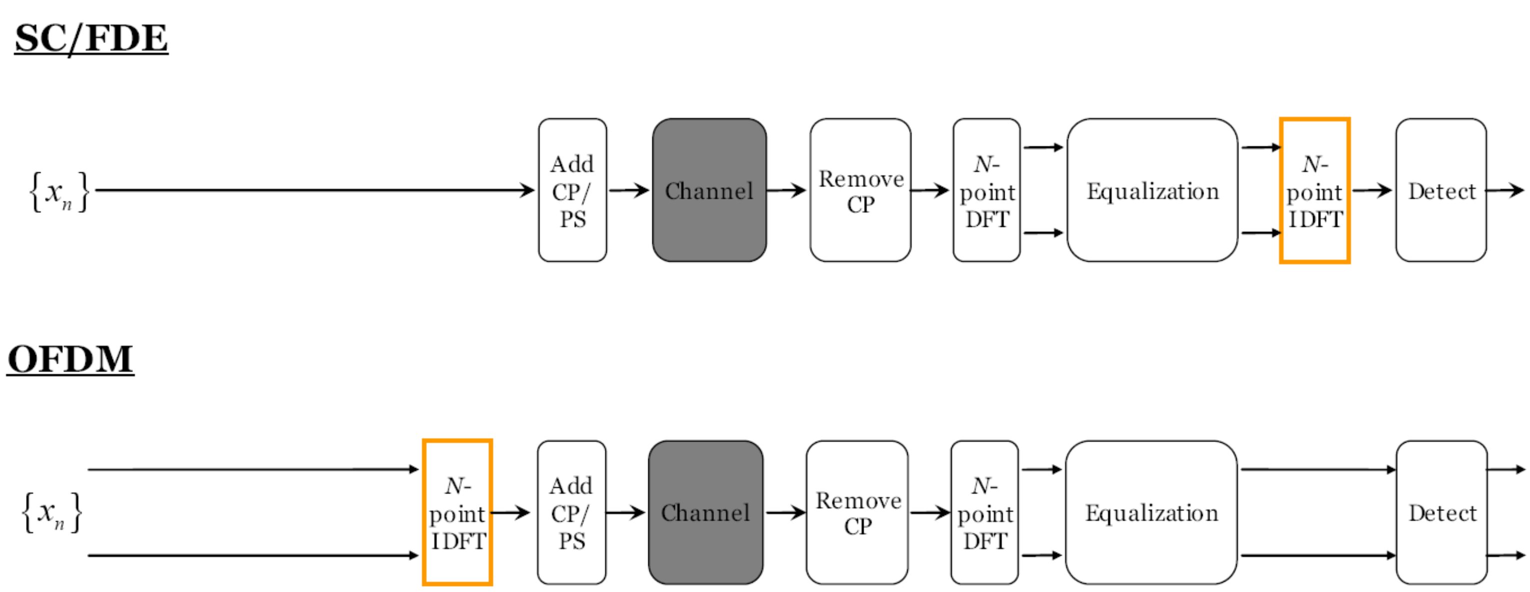
[Holma and Toskala, 2009, Fig 4.12]

SC/FDE

- Single Carrier with Frequency Domain Equalization (SC/FDE)
- For broadband multipath channels, conventional time domain equalizers are impractical because of the complexity (very long channel impulse response in the time domain).
- Frequency domain equalization (FDE) is more practical for such channels.
- Single carrier with frequency domain equalization (SC/FDE) technique is another way to fight the frequency-selective fading channel.
- It delivers performance similar to OFDM with essentially the same overall complexity, even for long channel delay

SC/FDE (2)

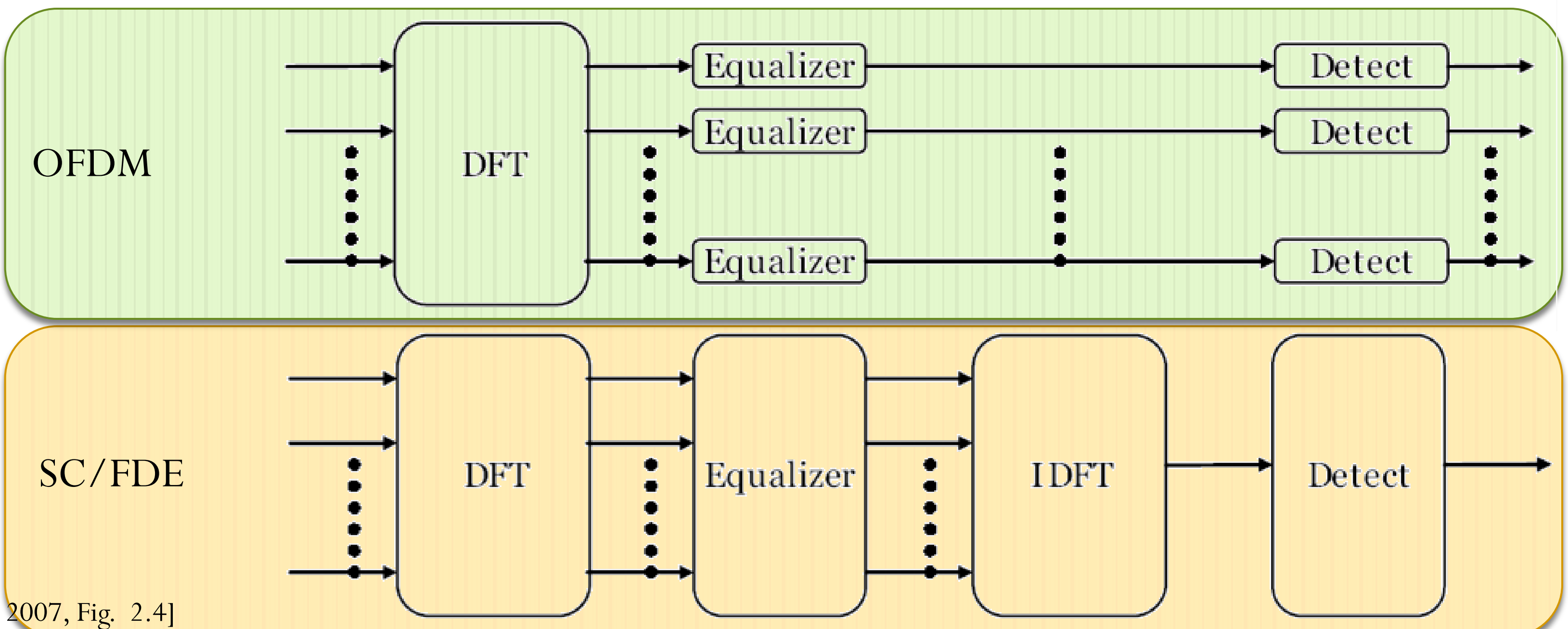
- SC/FDE receiver transforms the received signal to the frequency domain by applying DFT and does the equalization process in the frequency domain.
- Most of the well-known time domain equalization techniques, such as minimum mean-square error (MMSE) equalization, decision feedback equalization, and turbo equalization, can be applied to the FDE



[Myung, 2007, Fig. 2.3]

SC/FDE vs. OFDM (1)

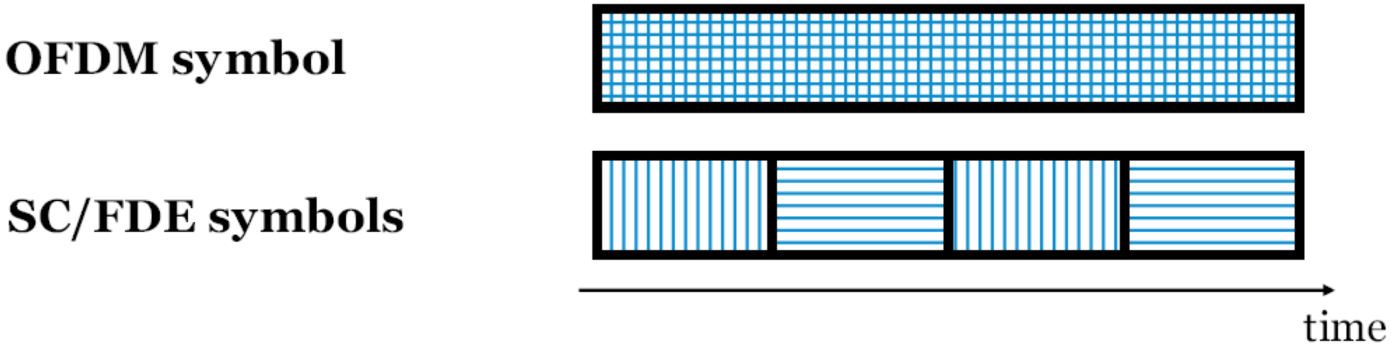
- OFDM performs data detection on a per-subcarrier basis in the frequency domain whereas SC/FDE does it in the time domain after the additional IDFT operation.
  - Because of this difference, OFDM is more sensitive to a null in the channel spectrum and it requires channel coding or power/rate control to overcome this deficiency.



[Myung, 2007, Fig. 2.4]

SC/FDE vs. OFDM (2)

- The duration of the modulated time symbols are expanded in the case of OFDM with parallel transmission of the data block during the elongated time period.



[Myung, 2007, Fig. 2.4]

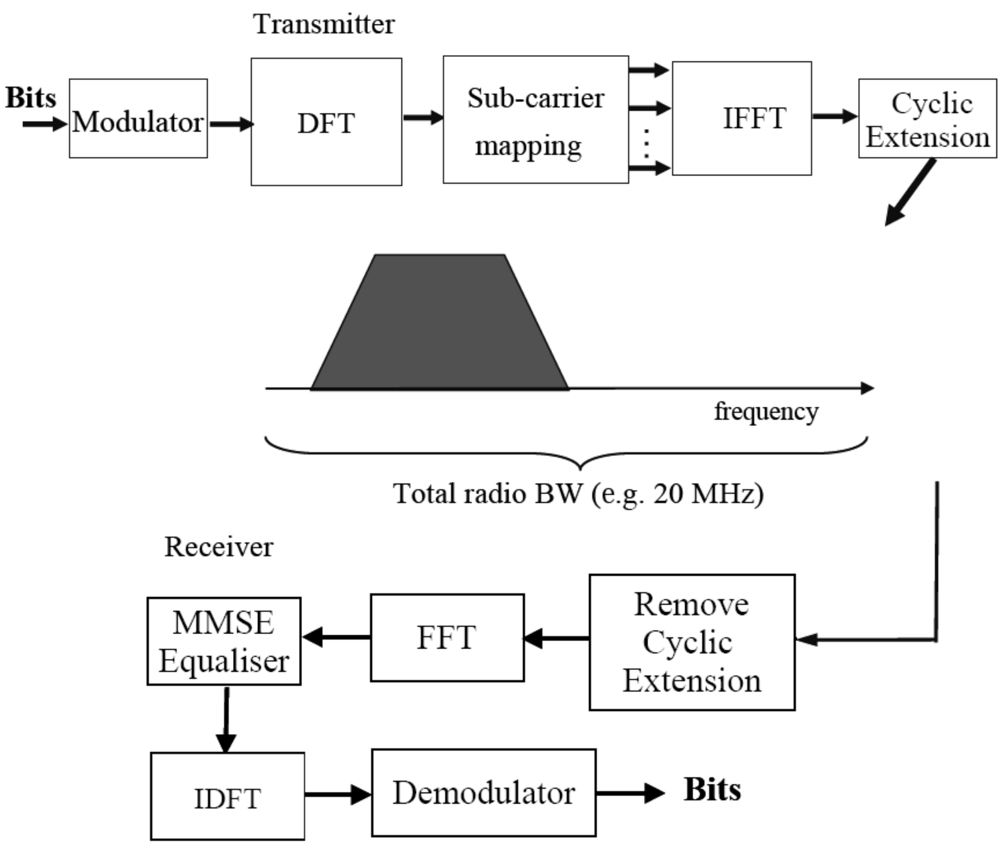
SC/FDE vs. OFDM (3)

SC/FDE has advantages over OFDM as follows:

- Low PAPR due to single carrier modulation at the transmitter.
- Robustness to spectral null.
- Lower sensitivity to carrier frequency offset.
- Lower complexity at the transmitter which will benefit the mobile terminal in cellular uplink communications.

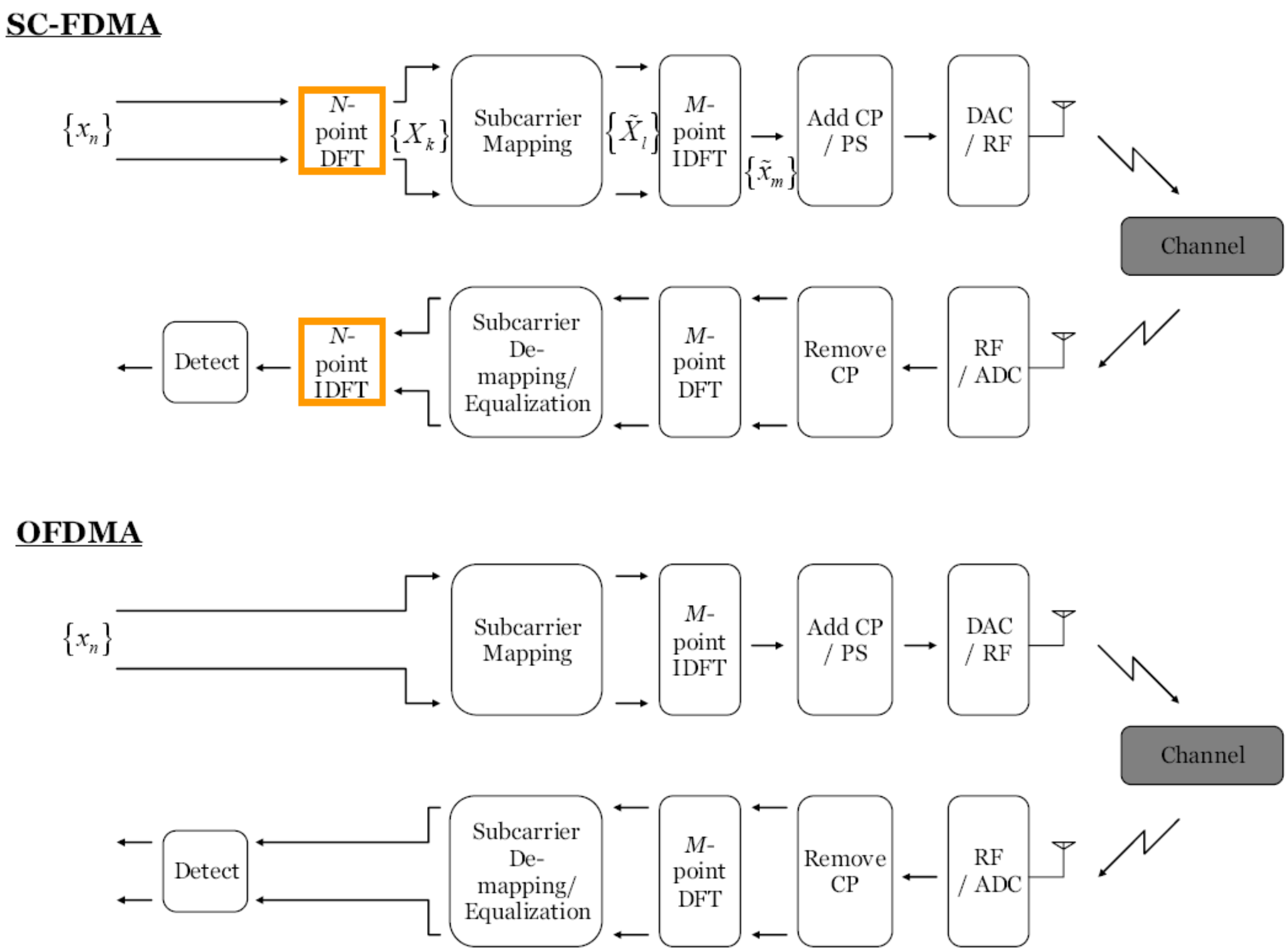
SC-FDMA

- Single carrier FDMA (SC-FDMA) is an extension of SC/FDE to accommodate multi-user access.



[Holma and Toskala, 2009, Fig 4.13]

SC-FDMA vs. OFDMA



* CP: Cyclic Prefix, PS: Pulse Shaping

[Myung, 2007, Fig. 3.1]

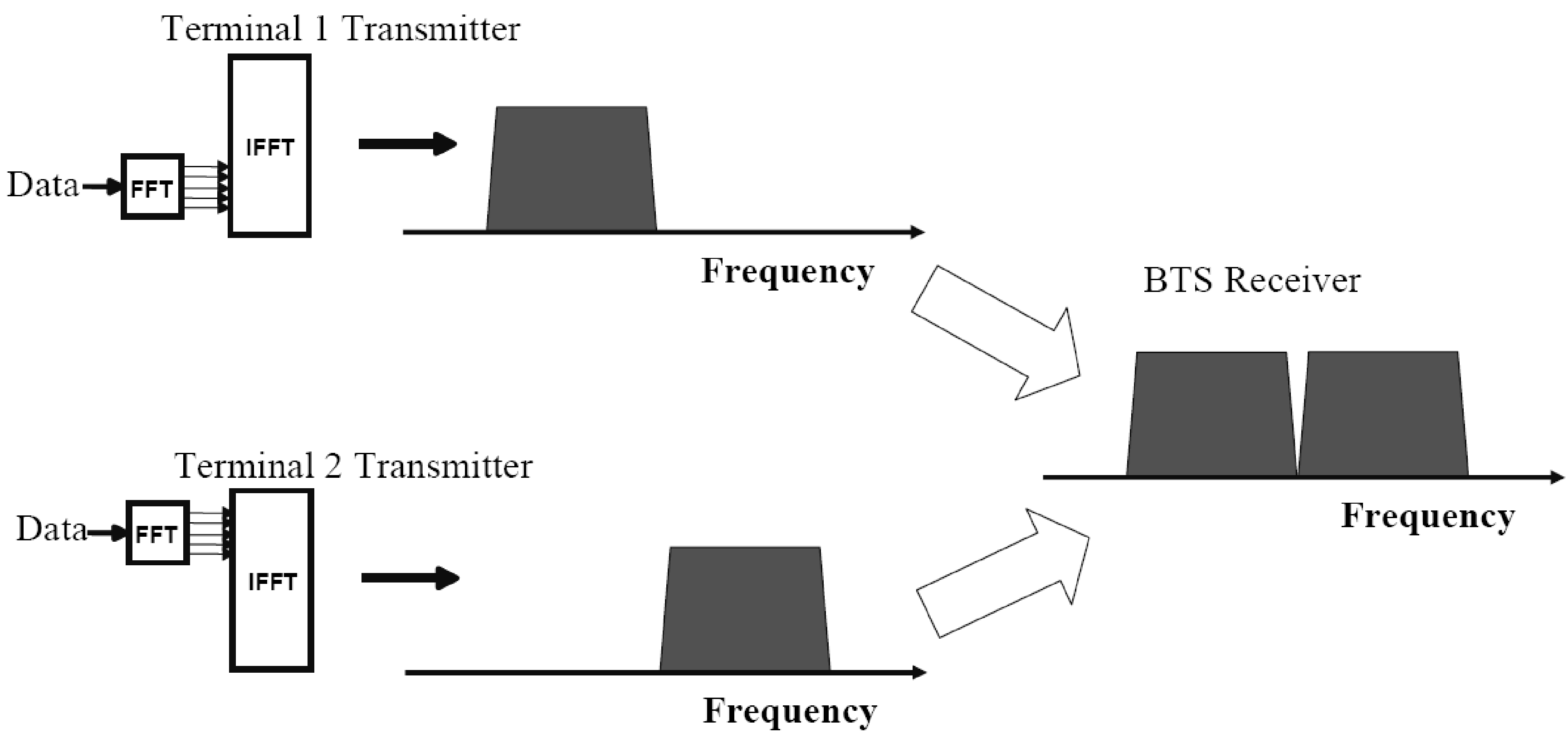
SC-FDMA (2)

- Lower peak-to-average power ratio (PAPR) because of its inherent single carrier structure.
  - 2 to 6 dB PAR advantage over the OFDMA method used by other technologies such as IEEE 802.16e.
- Used uplink direction for multiple access
- Can be regarded as DFT-spread OFDMA, where time domain data symbols are transformed to frequency domain by DFT before going through OFDMA modulation.
- The orthogonality of the users stems from the fact that each user occupies different subcarriers in the frequency domain, similar to the case of OFDMA.
- QAM modulation, where each symbol is sent one at a time as in TDMA.

SC-FDMA (3)

- Frequency domain generation of the signal adds the OFDMA property of good spectral waveform in contrast to time domain signal generation with a regular QAM modulator.
  - The need for guard bands between different users can be avoided, similar to the downlink OFDMA principle.
- As in an OFDMA system, a cyclic prefix is also added periodically – but not after each symbol as the symbol rate is faster in the time domain than in OFDMA – to the transmission to prevent inter-symbol interference and to simplify the receiver design.
  - The receiver still needs to deal with inter-symbol interference as the cyclic prefi x now prevents inter-symbol interference between a block of symbols, and thus there will still be inter-symbol interference between the cyclic prefixes.
  - The receiver will thus run the equalizer for a block of symbols until reaching the cyclic prefix that prevents further propagation of the inter-symbol interference.

SC-FDMA (4)


Terminal 1 Transmitter
Data
FFT
IFFT
Frequency
BTS Receiver
Frequency
Terminal 2 Transmitter
Data
FFT
IFFT
Frequency