Wireless Access Communication

Modulasi Multicarrier

Faculty of Electrical Engineering
Bandung – 2020

Subject

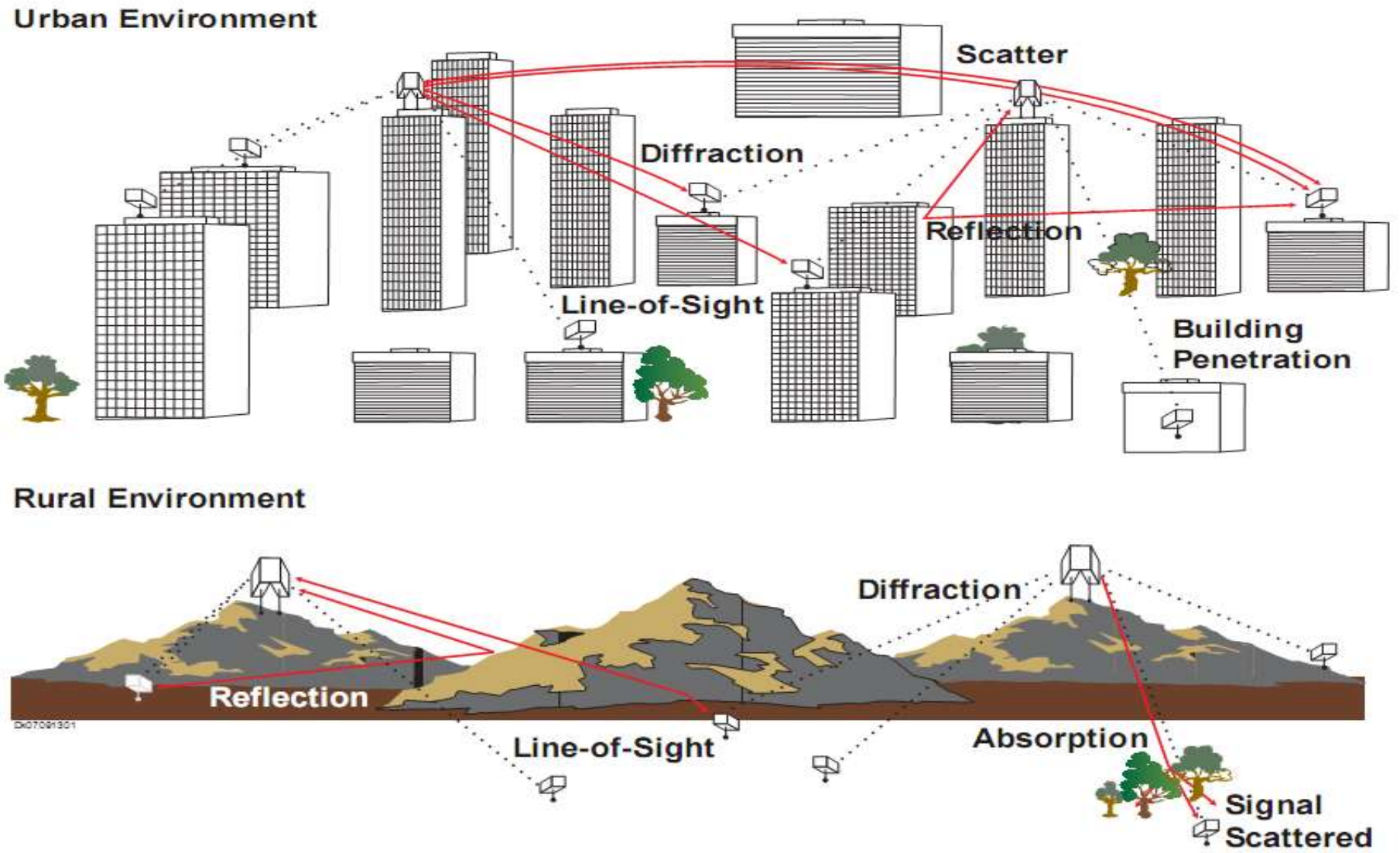
a. Konsep OFDM

b. Konsep OFDMA

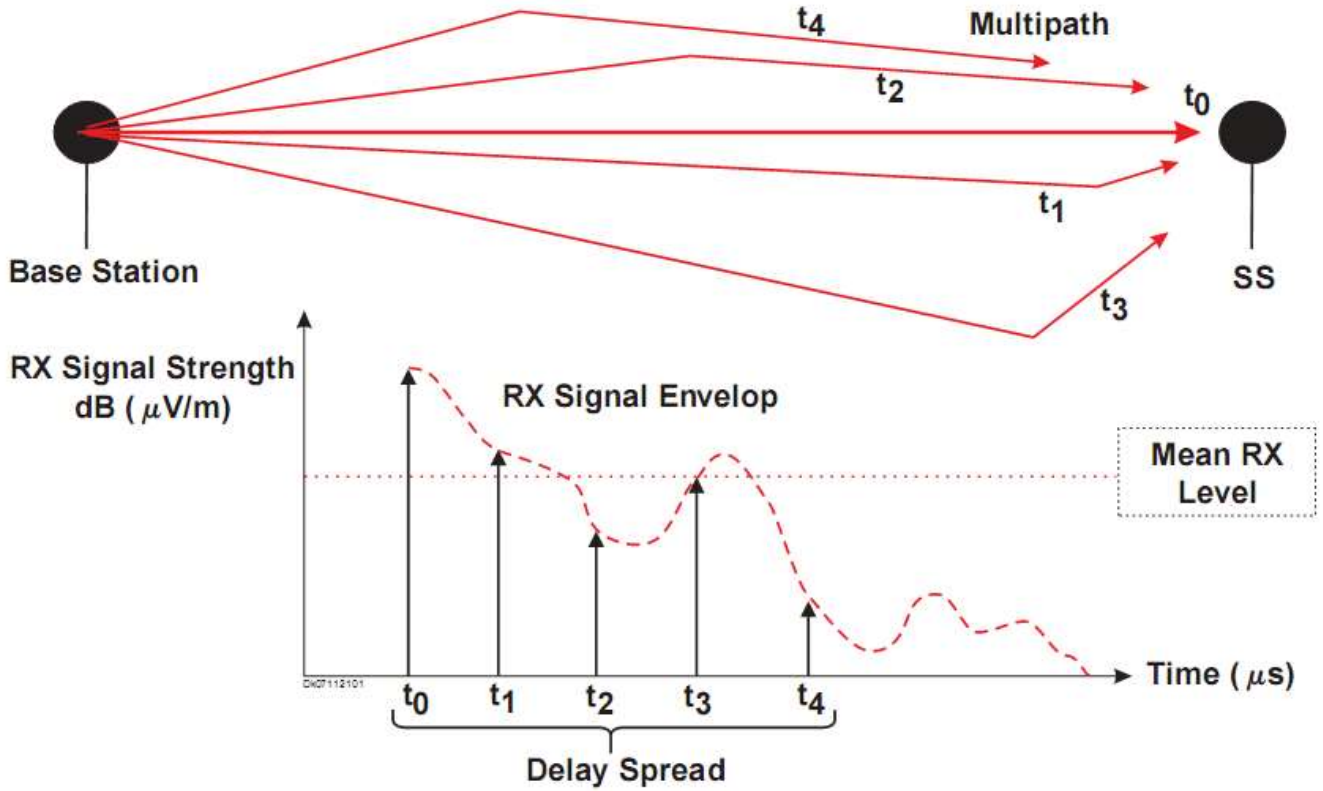
c. Pengenalan SC-FDMA

Konsep OFDM

Propagation Concept: NLOS Performance



Propagation Concept: Mutipath Propagation



- Sinyal-sinyal multipath datang pada waktu yang berbeda dengan amplitudo dan pergeseran fasa yang berbeda, yang menyebabkan pelemahan dan penguatan daya sinyal yang diterima.
- Propagasi multipath berpengaruh terhadap performansi link dan coverage.
- Selubung (envelop) sinyal Rx berfluktuasi secara acak.

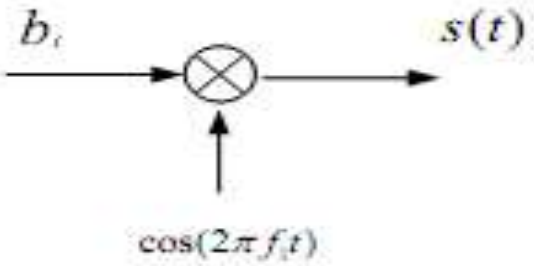
Problems of Mutipath Propagation & High Data Rate

- There are some problems when carrying high data rate via wireless channel, especially frequency selective fading
- OFDM offers the solution for the problems
- OFDM can be seen as multi-carrier transmission (MCM)
- MCM is a principle to transmit data by dividing the data into parallel bit streams
- The parallel bit streams is sometimes called subcarriers or subchannels

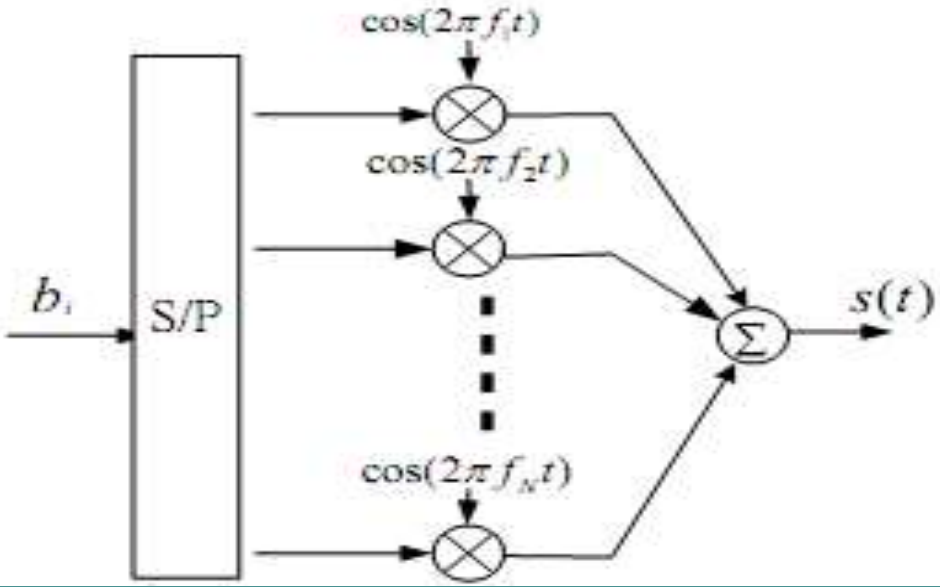
- Single carrier transmission
  - The concept of single-carrier is that each user transmits and receives data stream with only one carrier at any time.
- Multicarrier transmission
  - The concept of multi-carrier transmission is that a user can employ a number of carriers to transmit data simultaneously.

- Single and multicarrier transmission

Single carrier transmission

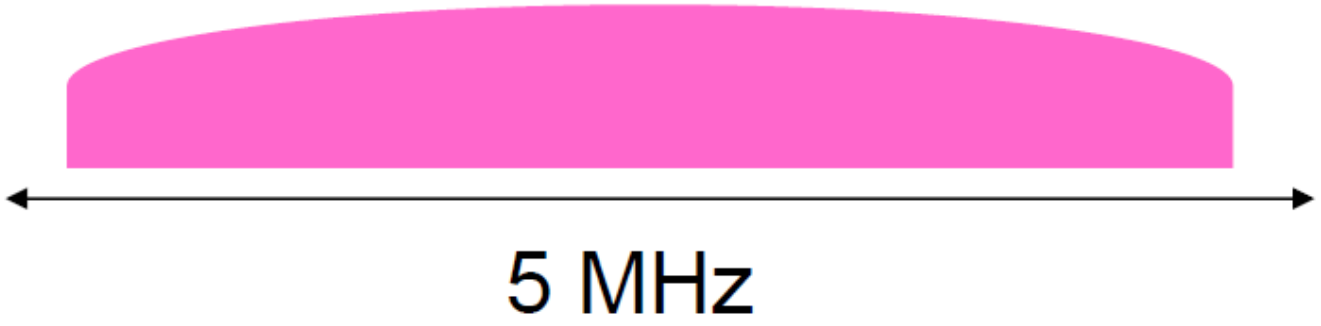


Multicarrier carrier transmission

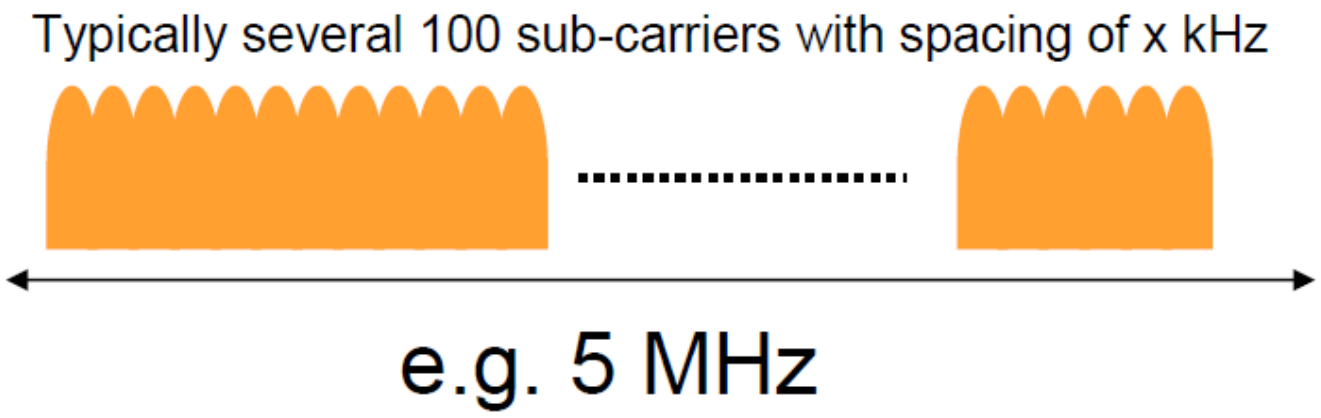


Teknologi Pendukung LTE

- Single Carrier Transmission (e.g. WCDMA)



- Orthogonal Frequency Division Multiplexing



The Idea

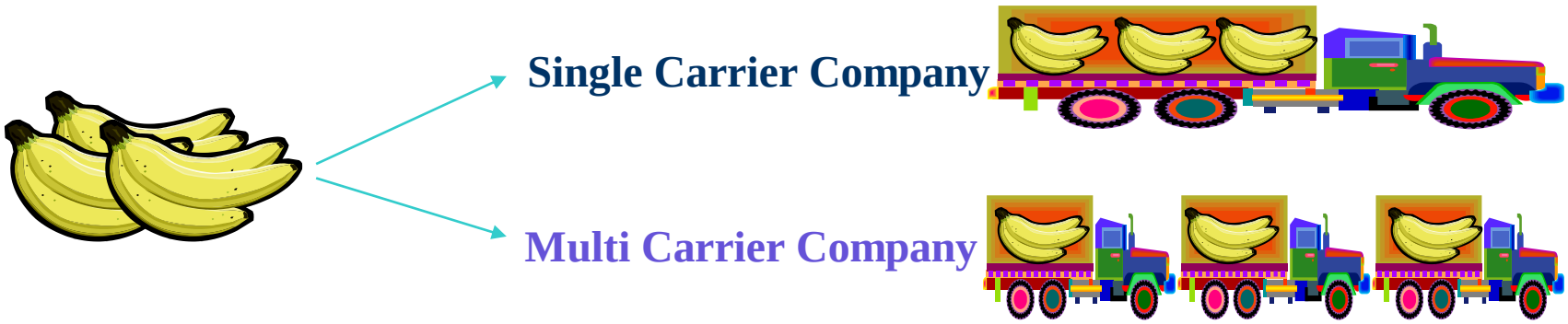
Fig. 1 – (a) A Regular-FDM single carrier – A whole bunch of water coming all in one stream. (b) Orthogonal-FDM – Same amount of water coming from a lot of small streams.

Fig. 2 – All cargo on one truck vs. splitting the shipment into more than one.

- In MCM, we split the data into different streams and transmit using separate *sub-carriers*

Multicarrier Transmission - Basic Concept

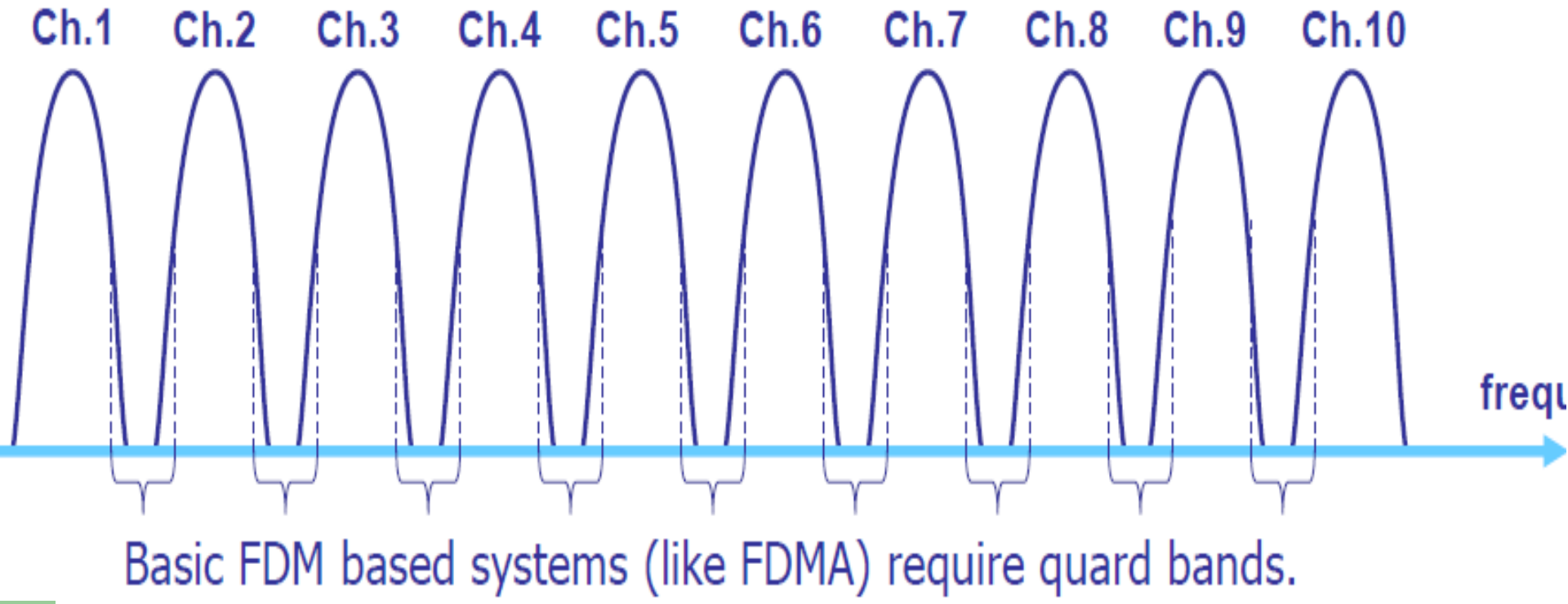
- *Orthogonal Frequency Division Multiplexing* (OFDM) is a multi-carrier modulation scheme
  - First break the data into small portions
  - Then use a number of parallel **orthogonal** sub-carriers to transmit the data
- Conventional transmission uses a single carrier, which is modulated with all the data to be sent



Basic Ideas:

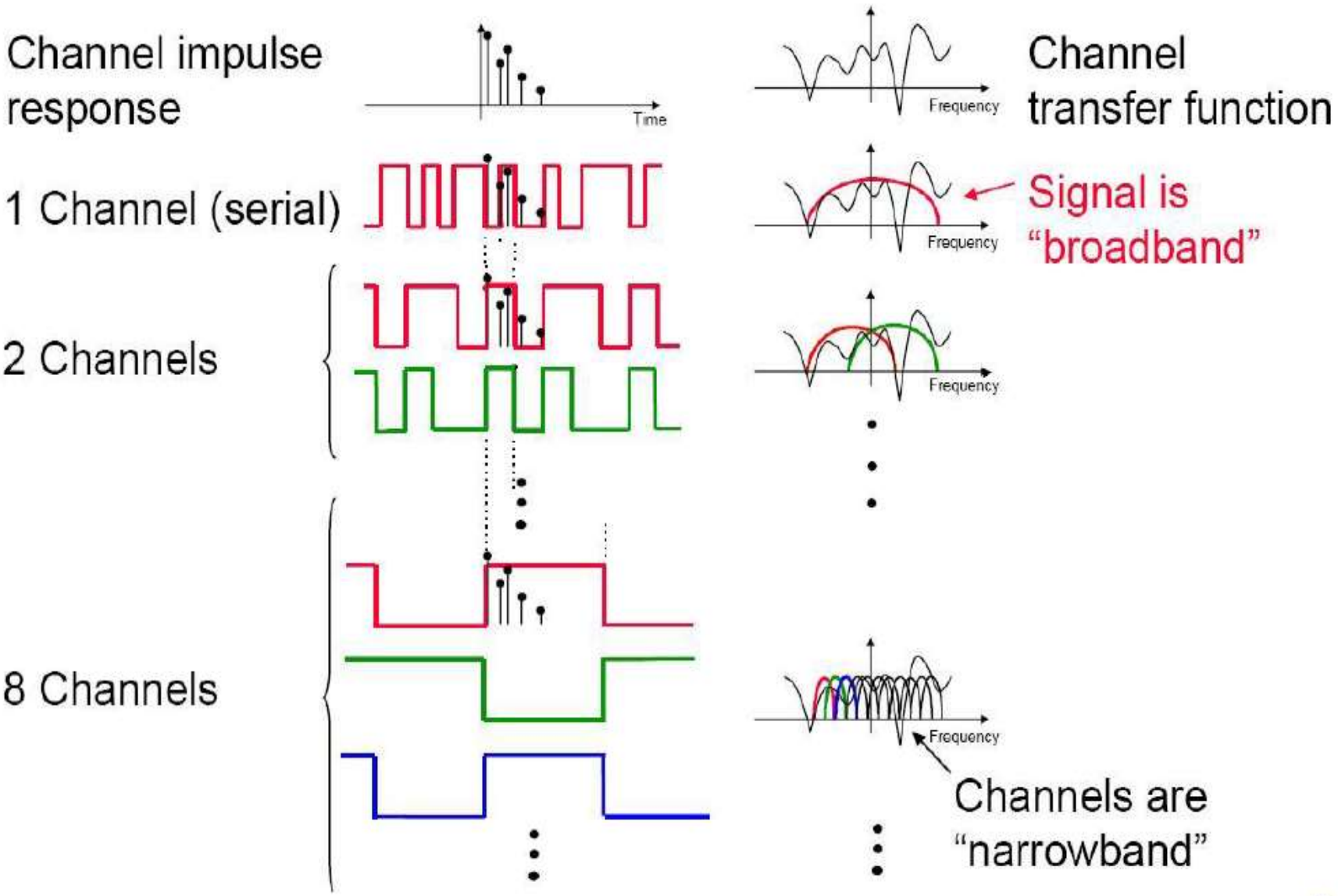
- Avoid ISI by multiplexing high rate data stream into several lower data streams
- by utilizing several distinct frequency bands

=> **Frequency division Multiplexing (FDM)**

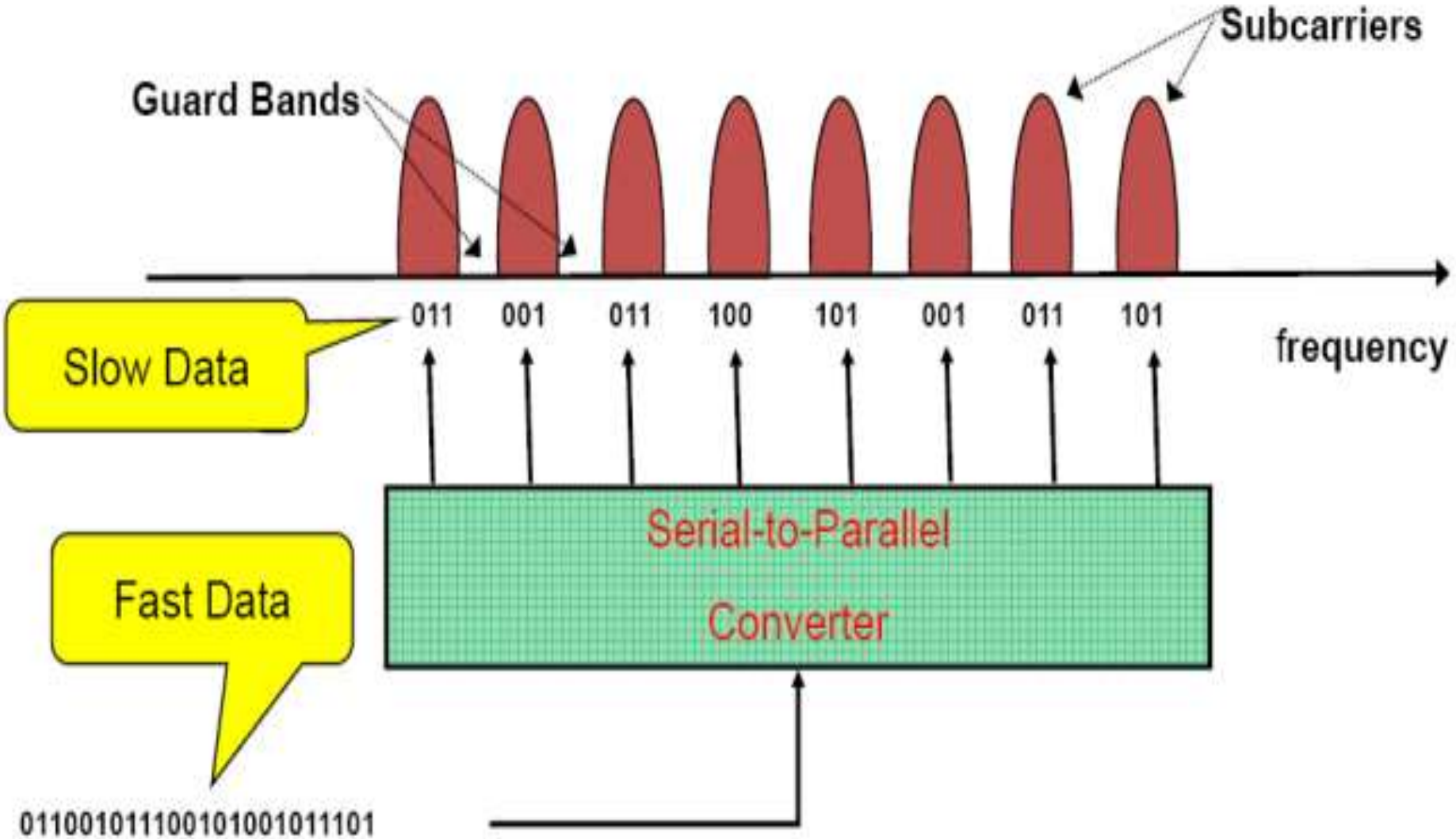


Basic FDM based systems (like FDMA) require quard bands.

Parallel Transmission to Avoid Distortions

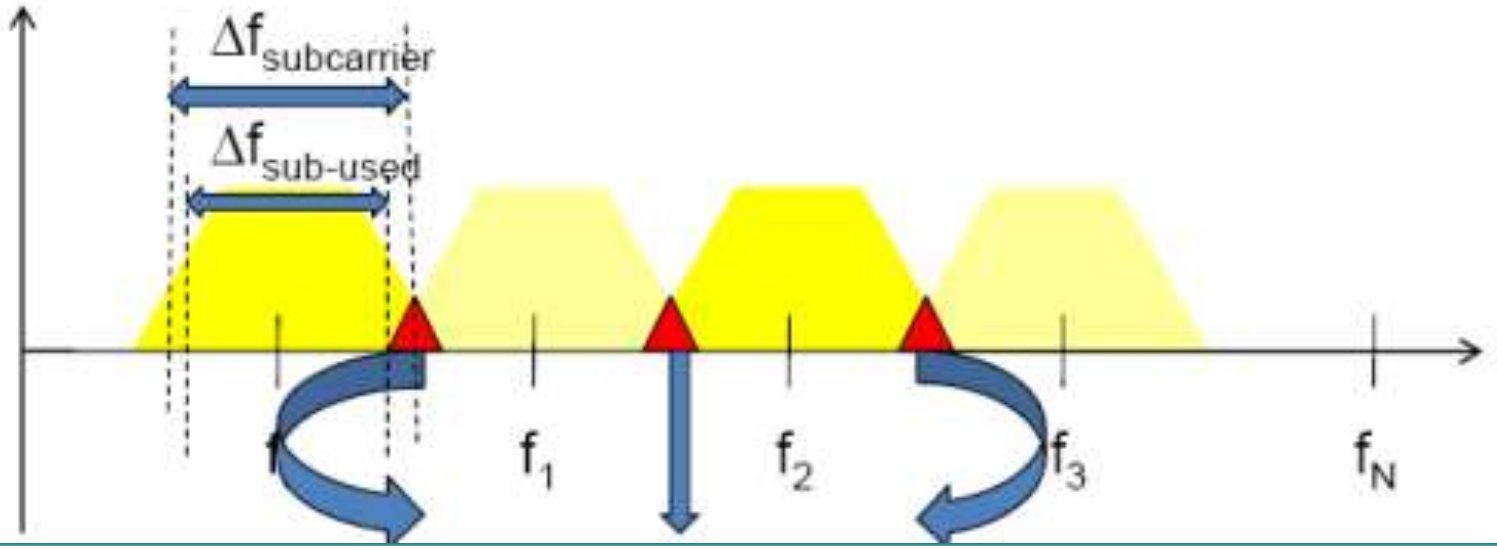


Modulasi Multicarrier



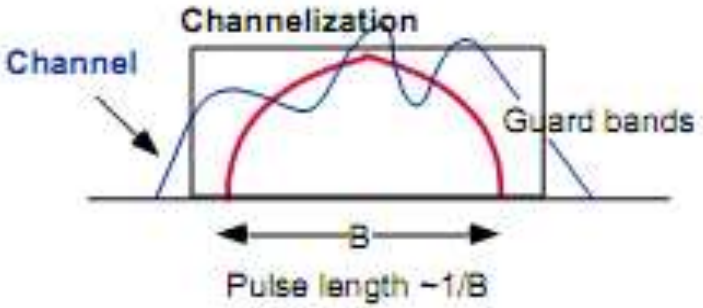
Modulasi Multicarrier

- Frekuensi tengah harus diberi jarak sehingga interference antar carrier yang berbeda atau **Adjacent Carrier Interference ACI minimal** diminimalkan namun tanpa banyak spasi frekuenasi terbuang.
- Tiap carrier menggunakan guard band atas dan bawah untuk proteksi terhadap interferensi carrier sebelah.

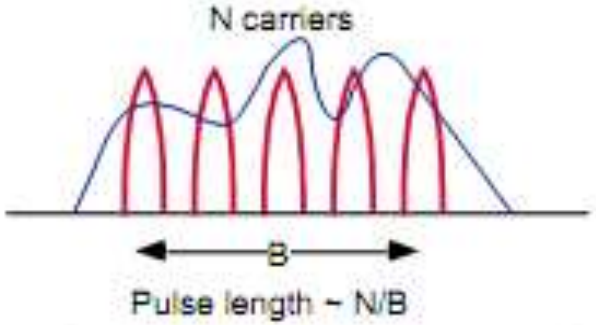


ACI = Adjacent Carrier Interference

Modulation techniques: monocarrier vs. multicarrier



– Data are transmitted over **only one carrier**



– Data are shared among **several carriers** and simultaneously transmitted

Similar to FDM technique

Drawbacks

- Selective Fading
- Very short pulses
- ISI is compartively long
- EQs are then very long
- Poor spectral efficiency because of band guards

Advantages

- Flat Fading per carrier
- N long pulses
- ISI is comparatively short
- N short EQs needed
- Poor spectral efficiency because of band guards

Furthermore

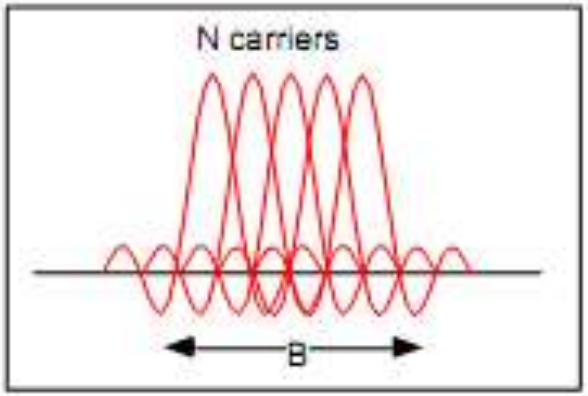
- It is easy to exploit frequency diversity
- It allows deployment of 2D coding techniques
- Dynamic signaling

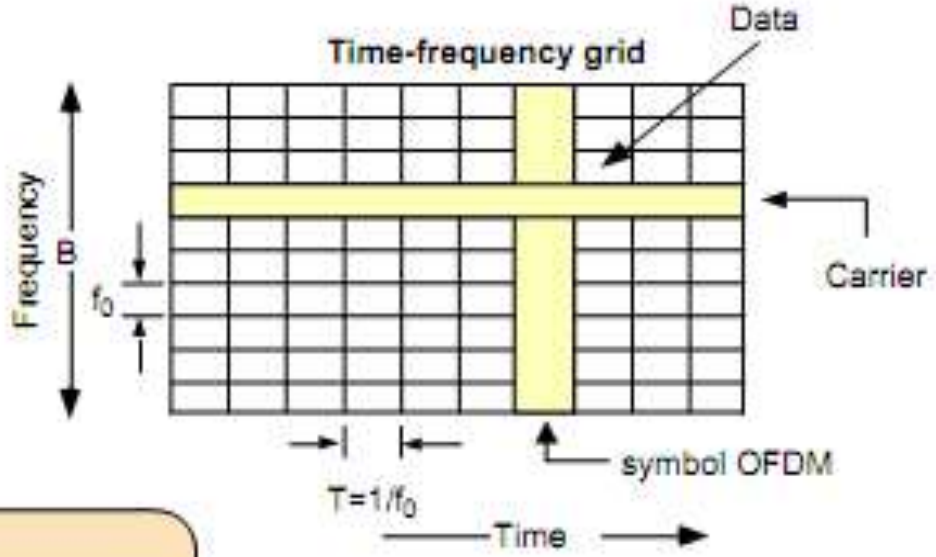
To improve the spectral efficiency:
Eliminate band guards between carriers
To use orthogonal carriers (allowing spectrum overlapping)

OFDM Concept: Mengapa OFDM

- Sinyal OFDM (Orthogonal Frequency Division Multiplexing) dapat mendukung kondisi NLOS (Non Line of Sight) dengan mempertahankan efisiensi spektral yang tinggi dan memaksimalkan spektrum yang tersedia.
- Mendukung lingkungan propagasi multi-path.
- Scalable bandwidth: menyediakan fleksibilitas dan potensial mengurangi CAPEX (capital expense).

Introduction to OFDM modulation





Features

- No intercarrier guard bands
- Controlled overlapping of bands
- Maximum spectral efficiency (Nyquist rate)
- Easy implementation using FFTs
- Very sensitive time-freq. Synchronization

Intercarrier Separation =
Any integer Multiple of 1/(symbol duration)

Modulation technique

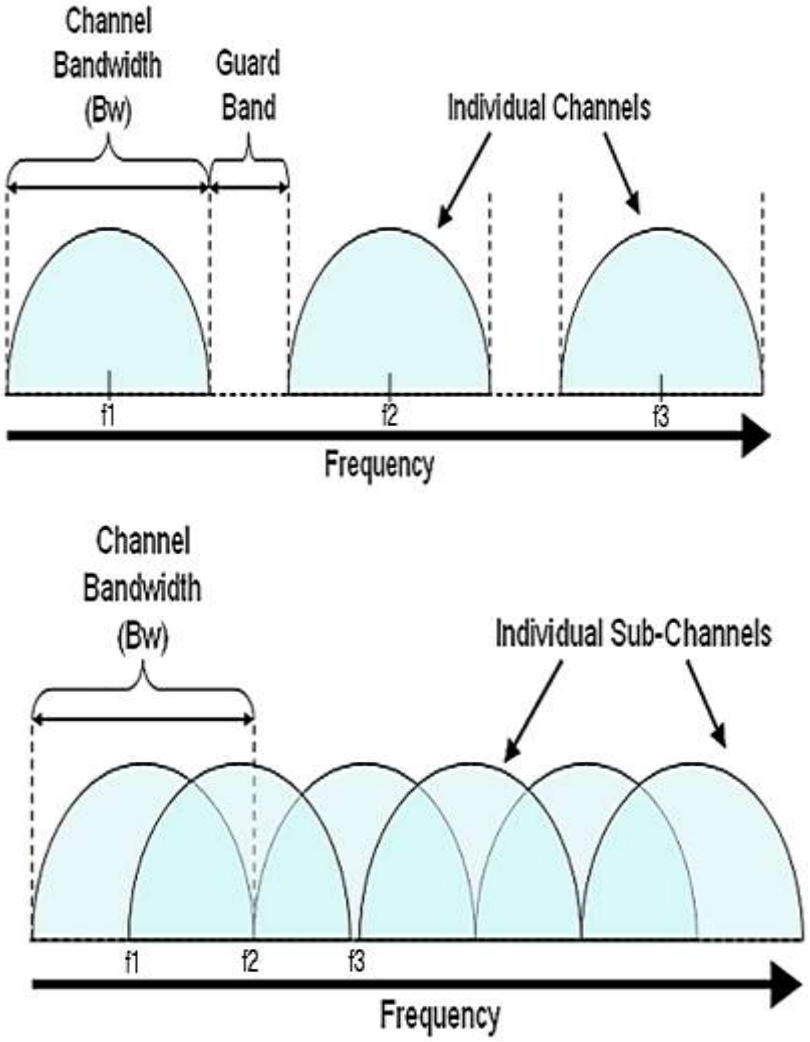
One user utilizes all carriers simultaneously to transmit its data (may be different modulations)

Access techniques (FDMA)

Several users share dynamically the carriers (traffic or service dependent) to access to the system

OFDM Basic Concept

- OFDM is a special case of *Frequency Division Multiplexing* (FDM)
- For FDM
  - No special relationship between the carrier frequencies
  - Guard bands have to be inserted to avoid *Adjacent Channel Interference* (ACI)
- For OFDM
  - Strict relation between carriers: $f_k = k \cdot \Delta f$ where $\Delta f = 1/T_U$ (T_U - symbol period)
  - Carriers are orthogonal to each other and can be packed tight



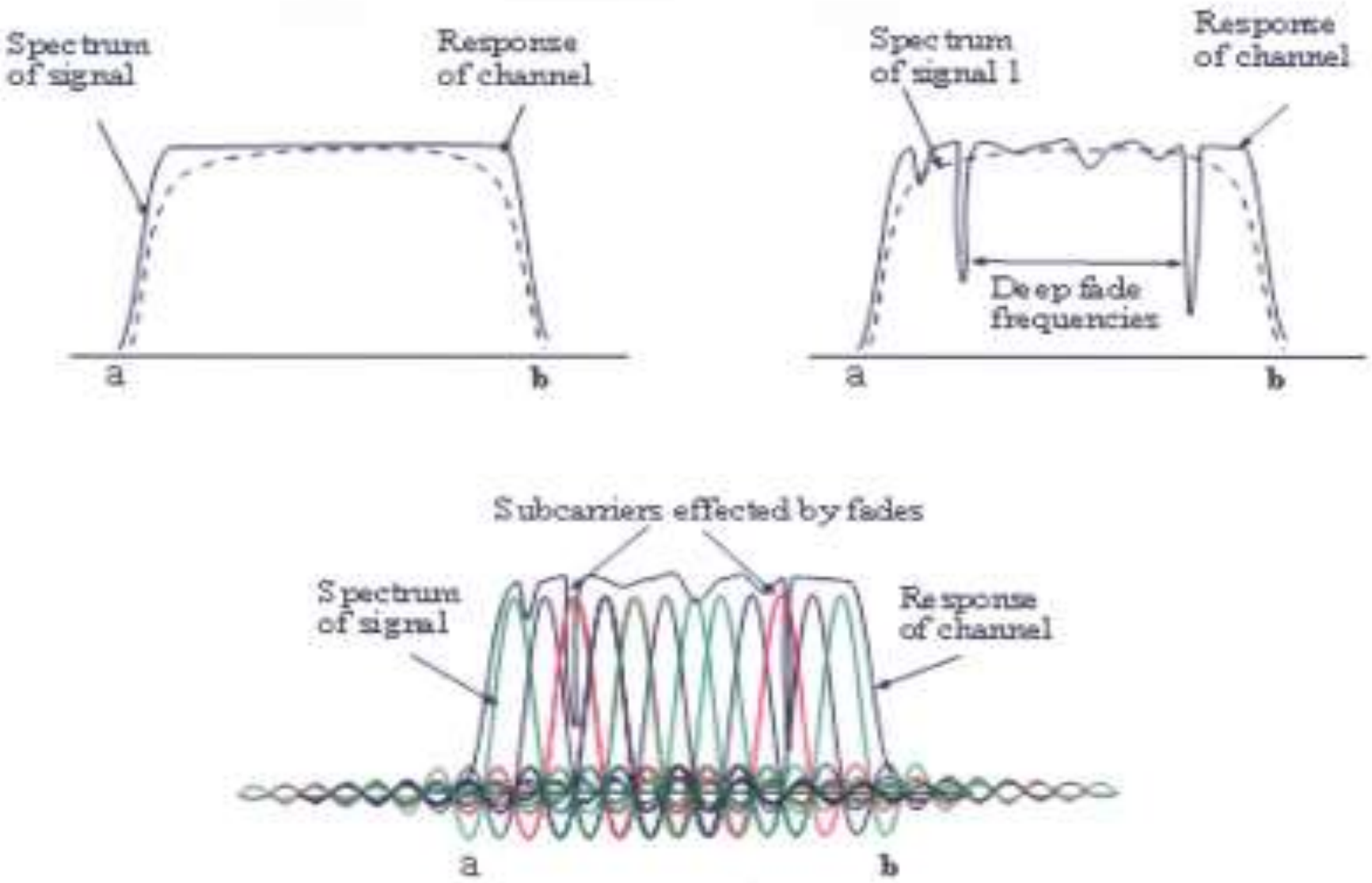
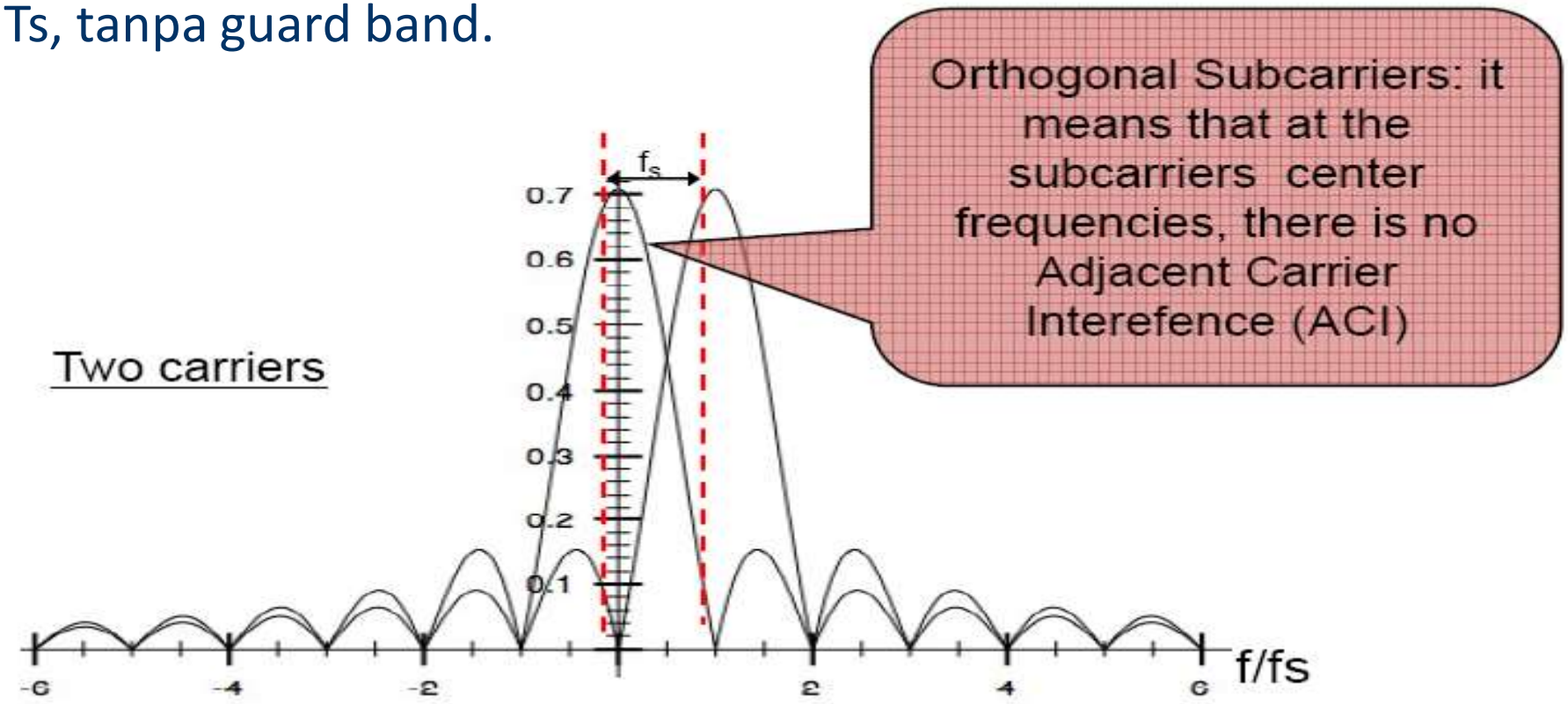


Fig. 20 – (a) The signal we want to send and the channel frequency response are well matched. (b) A fading channel has frequencies that do not allow anything to pass. Data is lost sporadically. (c) With OFDM, where we have many little sub-carriers, only a small sub-set of the data is lost due to fading.

OFDM

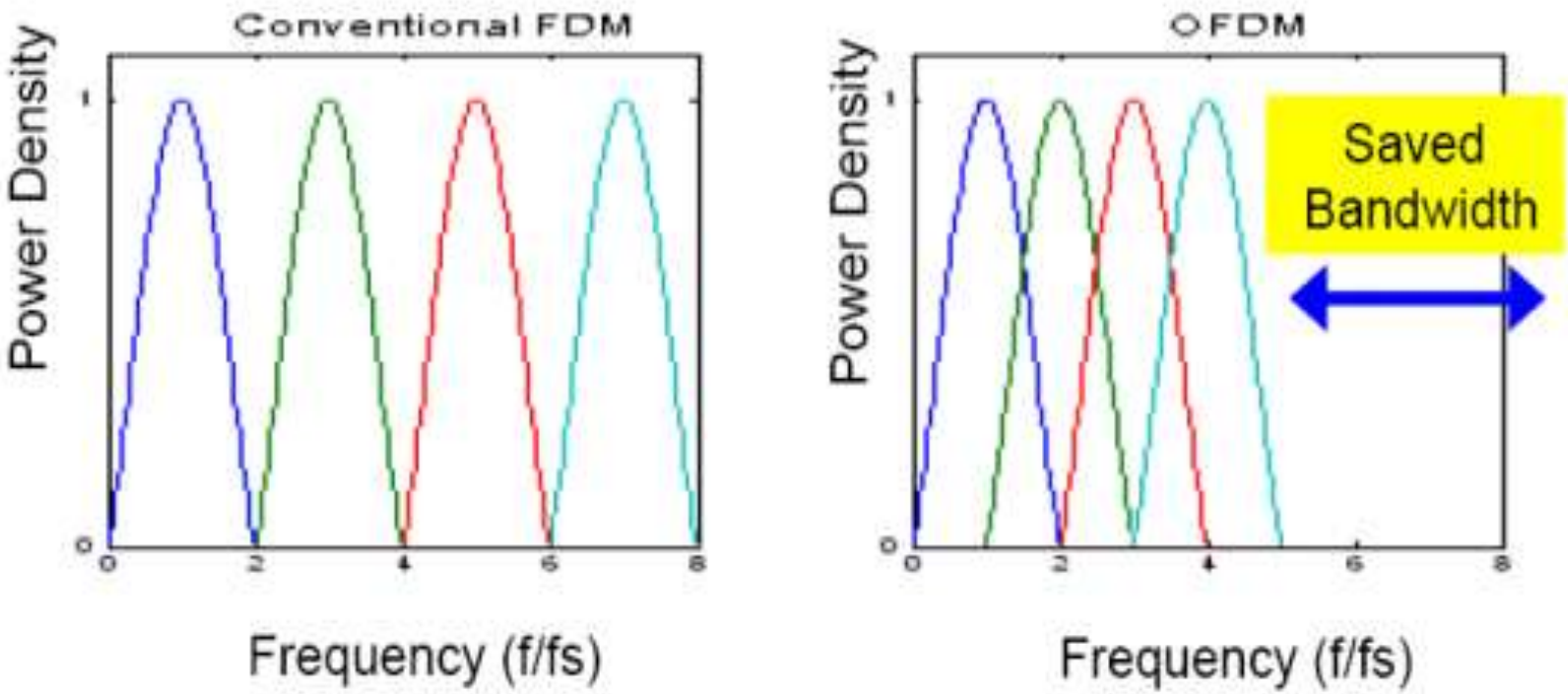
OFDM secara sederhana menempatkan next carrier persis di null pertama dari carrier sebelumnya.

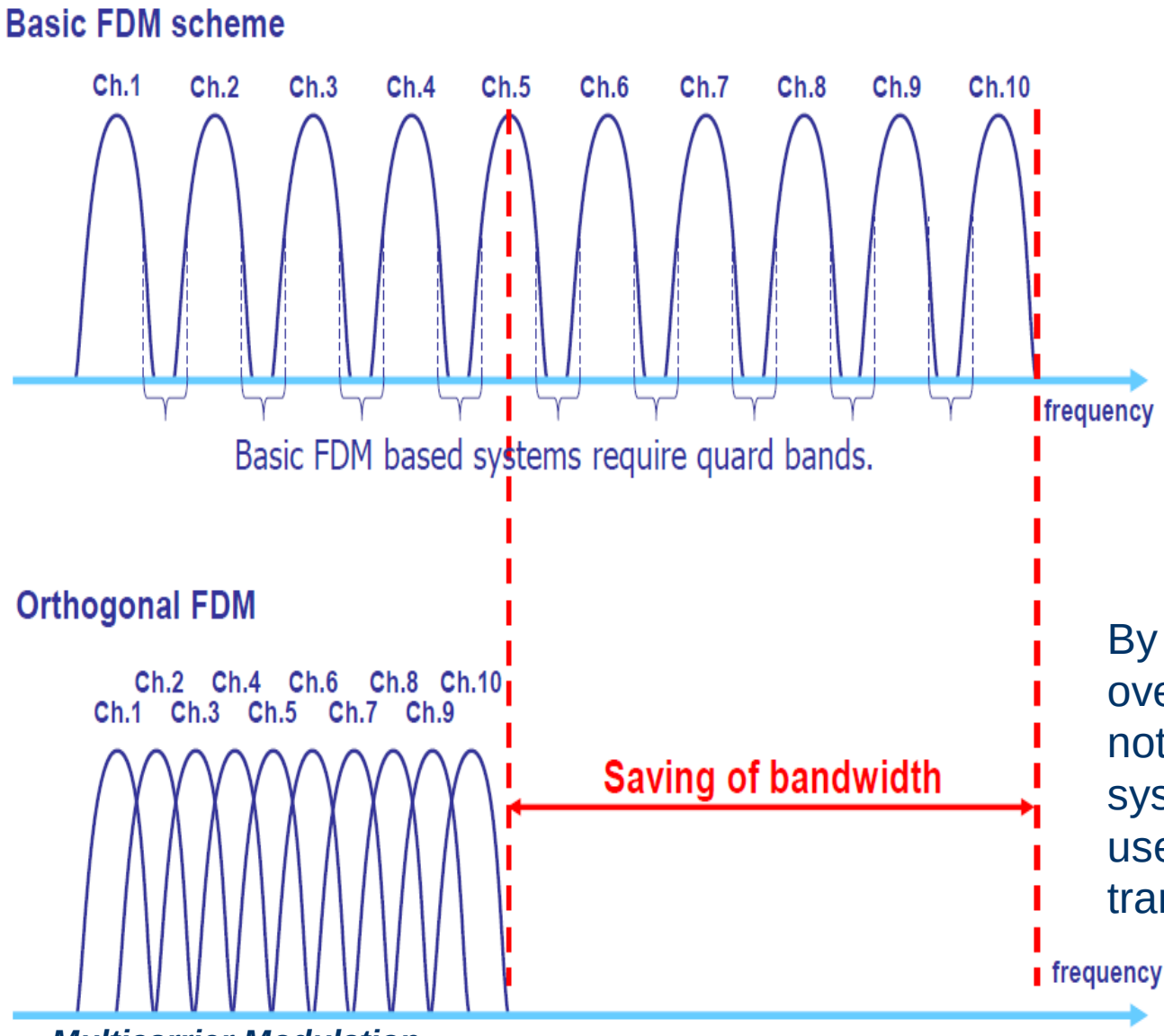
- Sehingga tidak diperlukan pulse shaping
- Antar carrier OFDM carrier menggunakan durasi simbol yang sama Ts, tanpa guard band.



OFDM

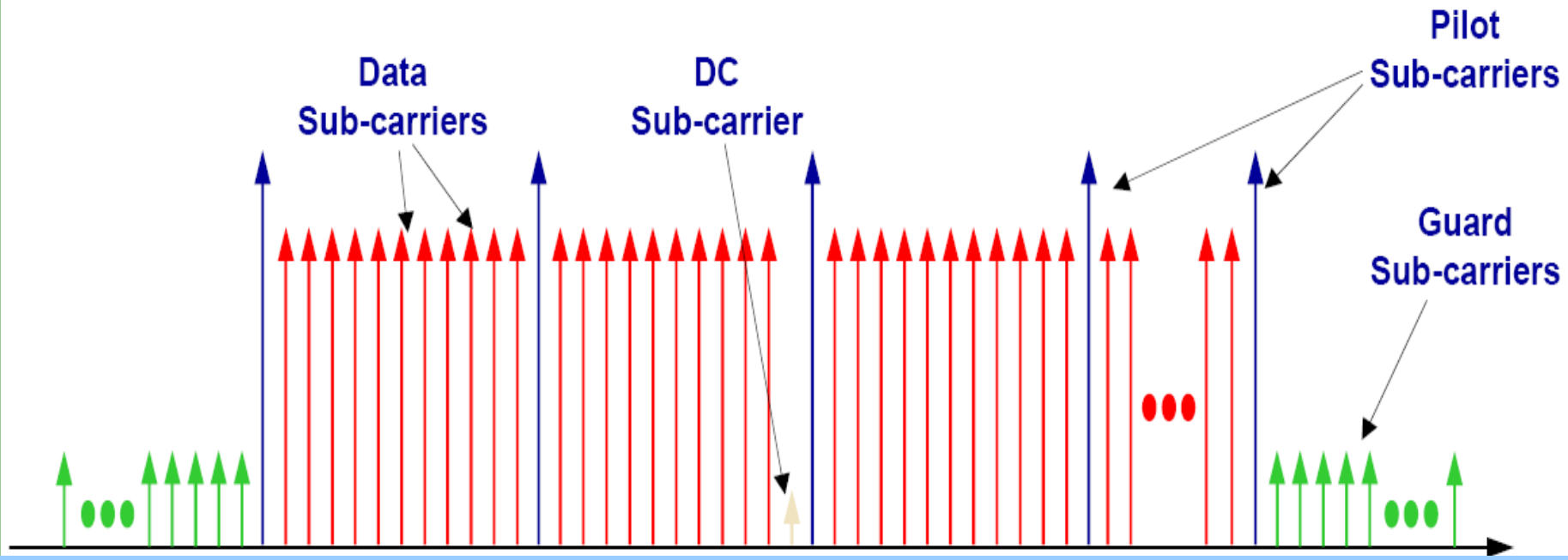
- OFDM memungkinkan packaging sejumlah subcarrier kedalam suatu bandwidth yang lebih kompak.





By allowing TX bands to overlap, guard bands are not needed and the same system bandwidth can be used to increase the transmission rate.

Tipe Sub-Carrier OFDM



Data Sub-carriers

- Membawa simbol BPSK, QPSK, 16QAM, 64QAM

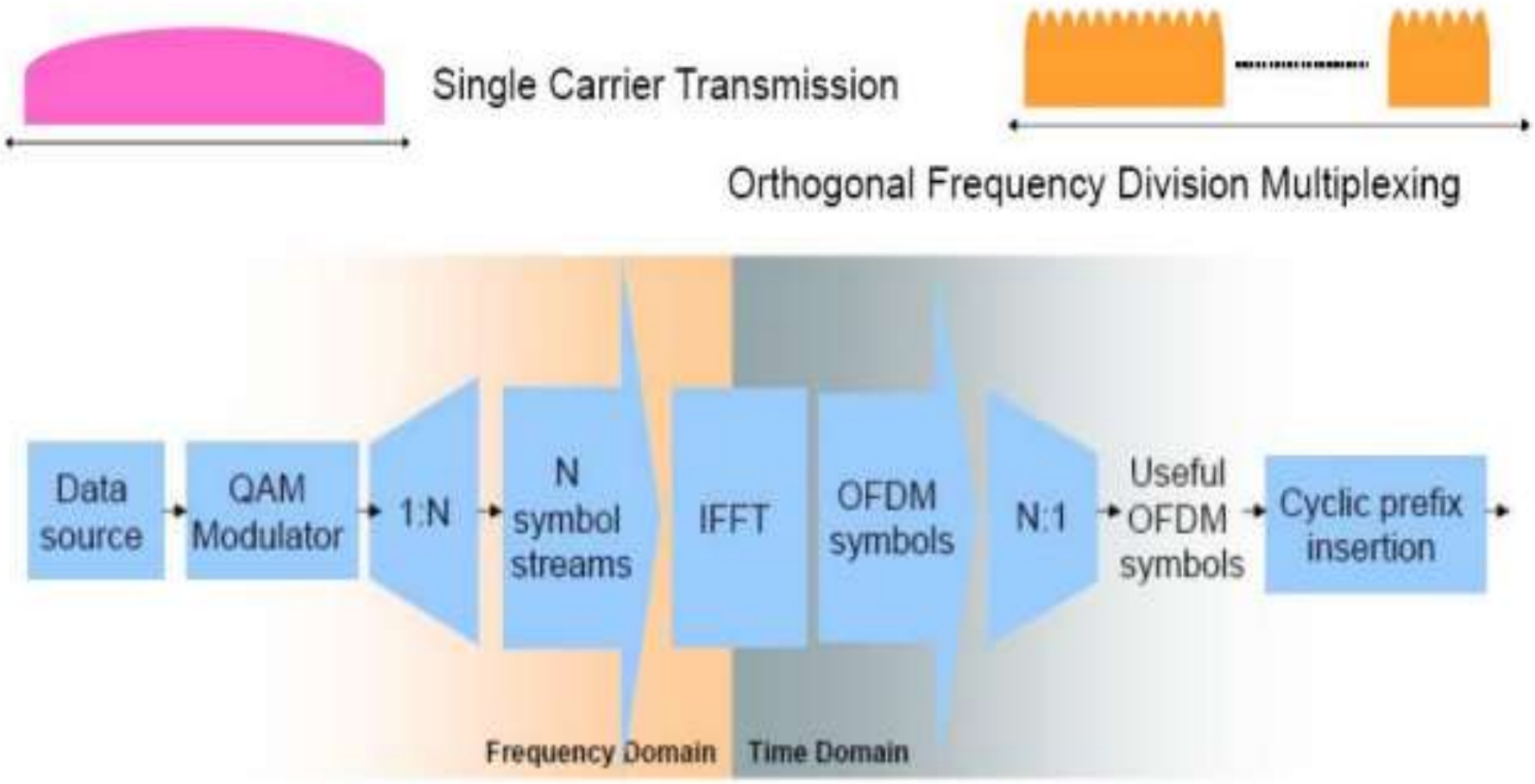
Pilot Sub-carriers

- Untuk memudahkan estimasi kanal dan demodulasi koheren pada receiver.

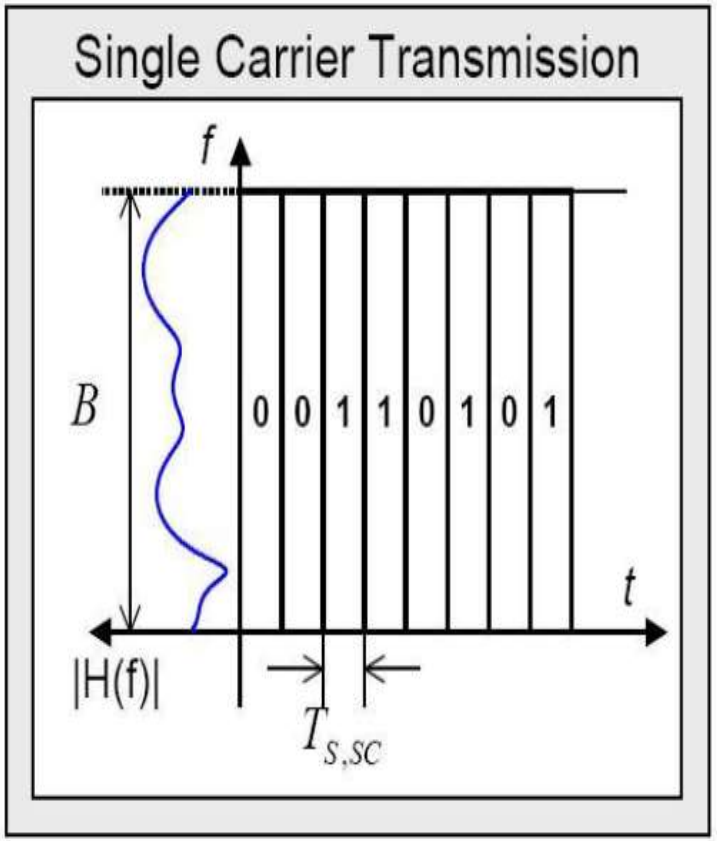
Null Subcarrier

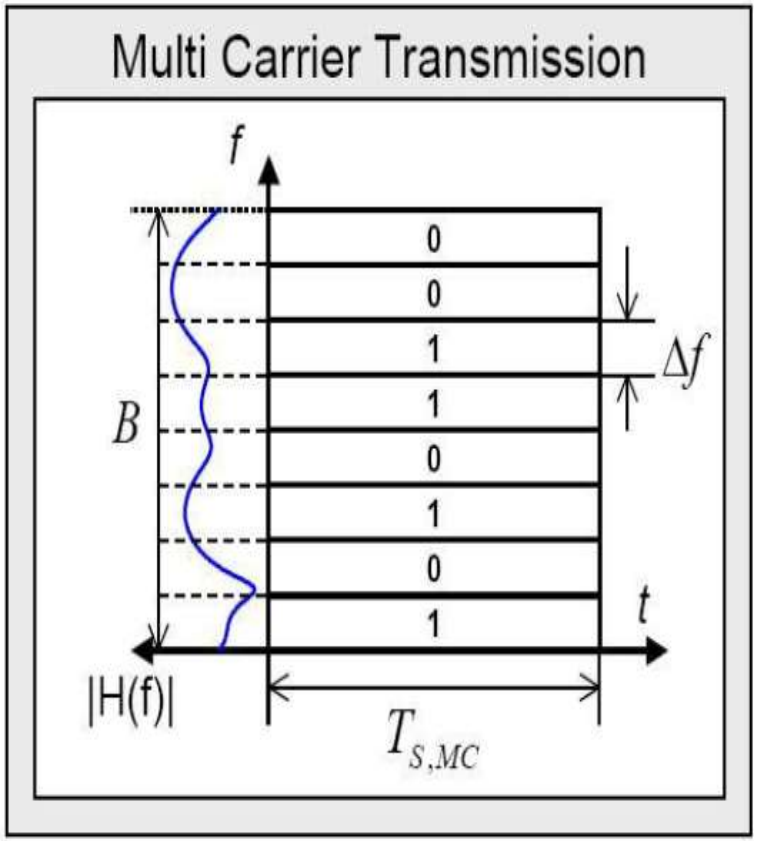
- Guard Sub-carriers
- DC Sub-carrier

OFDM



OFDM signal generation is based on Inverse Fast Fourier Transform (IFFT) operation on transmitter side. On receiver side, an FFT operation will be used.





Symbol duration:

$$T_{S,MC} = N \cdot T_{S,SC}$$

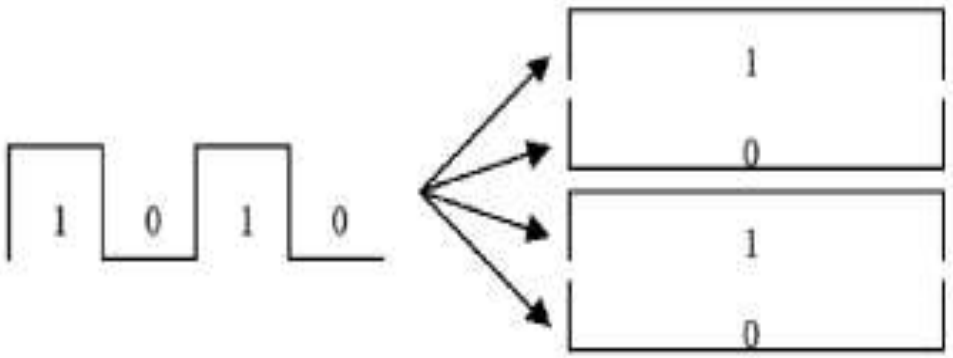
Bandwidth:

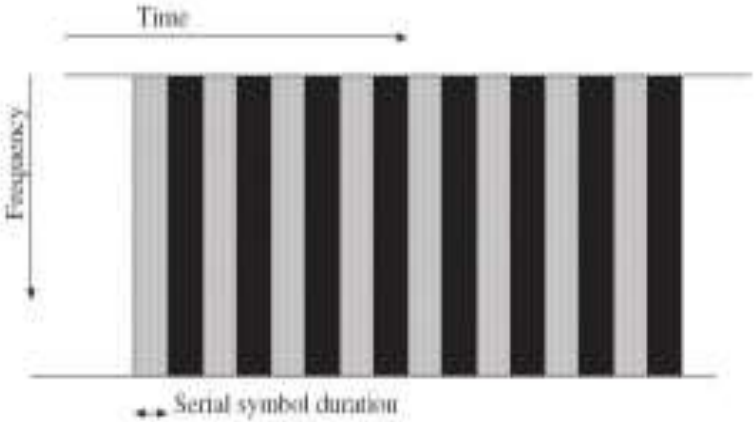
$$B = N \cdot \Delta f$$

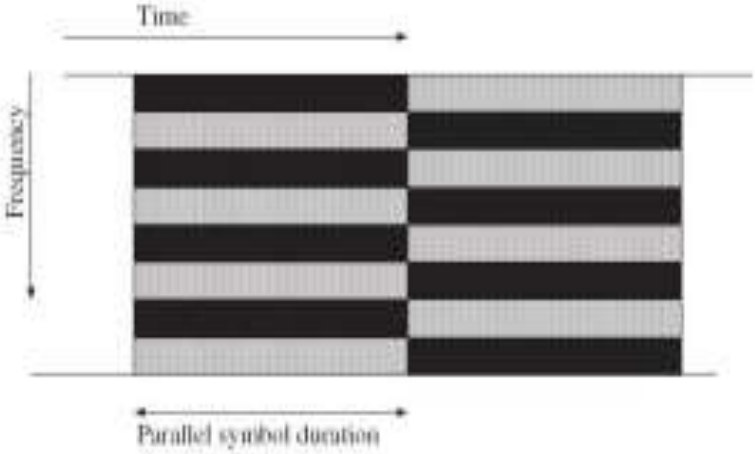
Subcarrier spacing:

$$\Delta f = \frac{1}{T_{S,MC}}$$

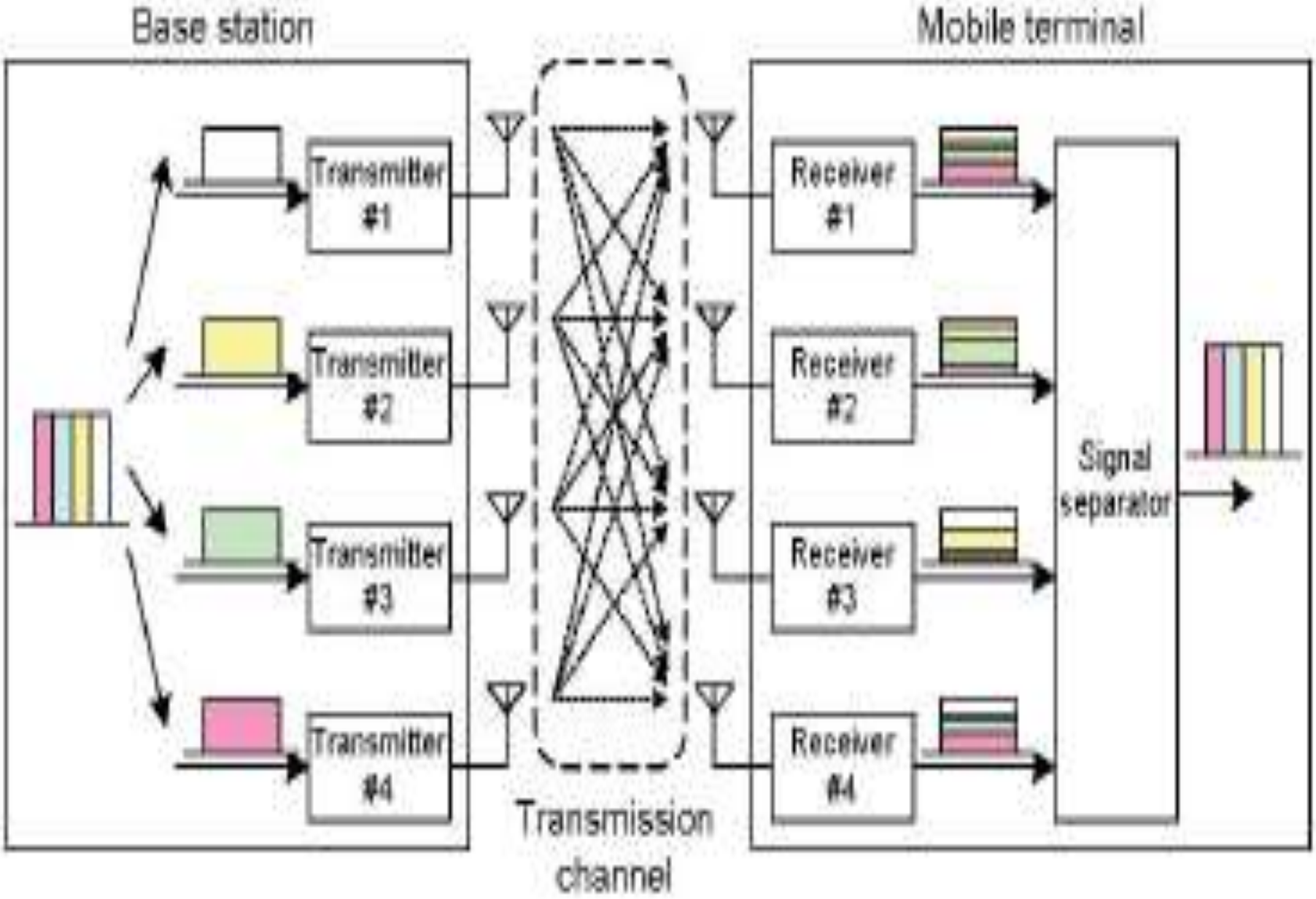
The parallel principle







LTE MIMO concept



Advantages of OFDM

Spectrally efficient because of orthogonality of the 64 carriers.
Good for channels affected by frequency selective fading because:

(i) Effects of fading, affecting a small range of frequencies, can be spread out using ‘interleaving’ so that FEC can more easily correct any bit-errors.

(ii) Cyclic extension as a guard-interval, eliminates ISI caused by multi-path propagation. Simpler way of eliminating ISI than pulse-shaping as used in single carrier systems.

(iii) Equalisation is easier than with single carrier systems which use adaptive filtering. OFDM receiver can amplify real & imag parts of FFT outputs such that they have same amplitudes.

Possible because of the cyclic extension as explained earlier.

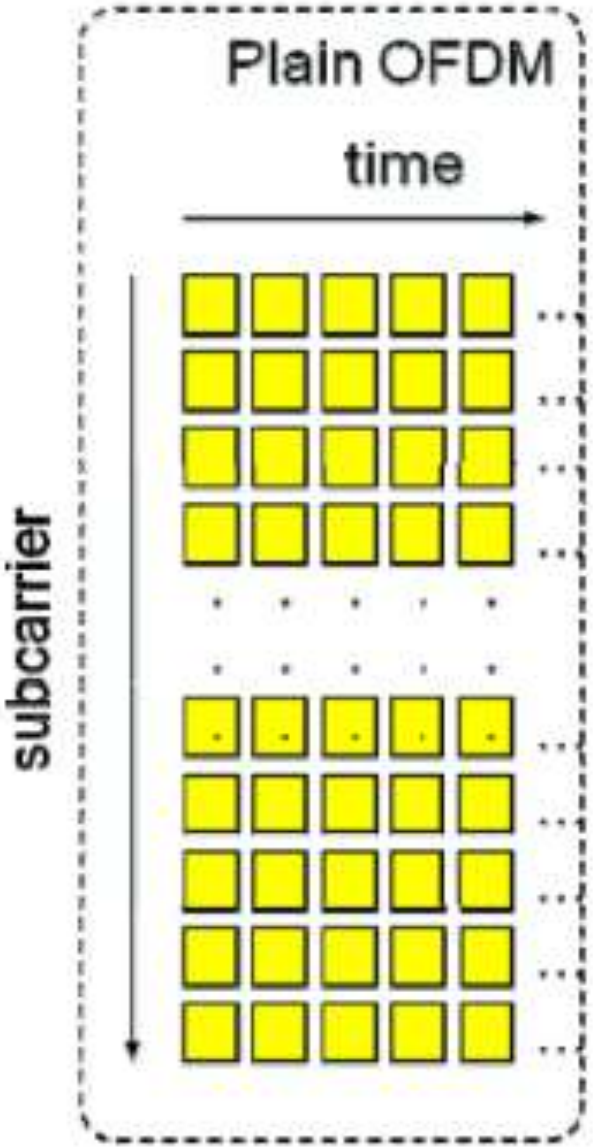
Disadvantages of OFDM

- ‘Peak to mean’ ratio of symbols can be very large by nature of FFT & Inv-FFT. (Amplitudes can become very large in comparison to the mean)
- Shapes OFDM symbols very complex & must be sent & received accurately.
- With QPSK on each sub-carrier, $\approx 10^{29}$ shapes & even more with 64-QAM
- Transmitter & receiver must be linear to preserve shape.
- Definitely not "constant envelope".
- Need ‘class A’ amplifiers: less power efficient than those for constant envelope transmissions.
- Lot of power lost in the amplifiers.
- Not ideal for mobile phones, but fine for mobile computers with bigger batteries that are not sending data continuously.
- Sensitive to ‘Doppler’ frequency shifts.

Konsep OFDMA

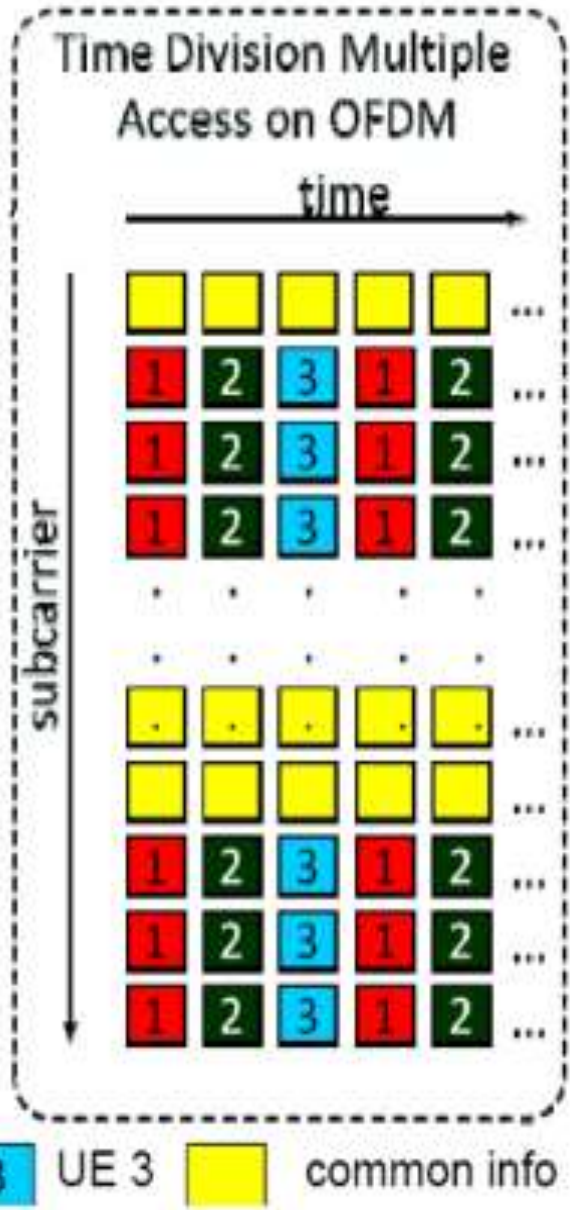
Plain OFDM

- Tidak memiliki mekanisme multipleaccess
- Hanya sesuai untuk aplikasi broadcast/multicast seperti DVB-T/H dengan tanpa kanal feedback



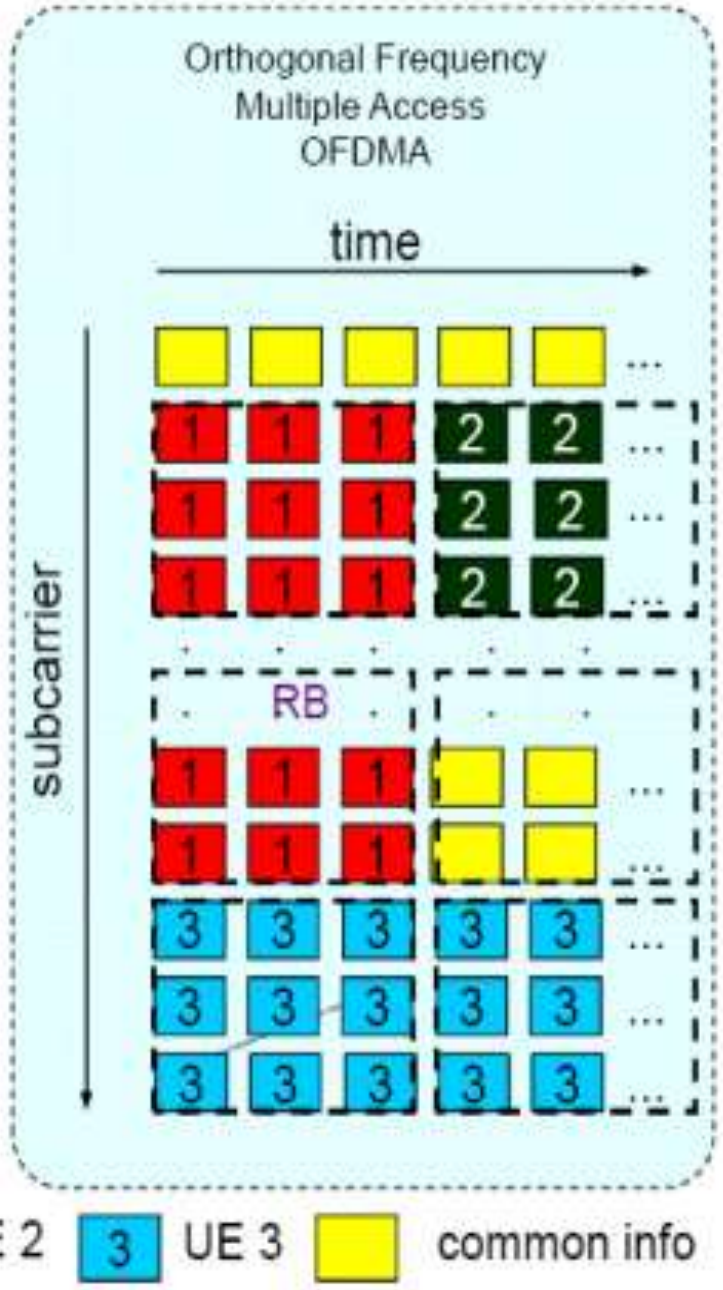
TDMA/OFDM

- Time Division Multiple Access via OFDM merupakan implementasi multiple access sederhana dari sistem OFDM dengan melakukan time multiplexing diatas OFDM.
- Kerugian dari mekanisme ini adalah bahwa setiap user akan mendapatkan jumlah kapasitas (subcarrier) yang sama sehingga tidak fleksibel untuk layanan multi data rate.
- Lebih jauh lagi, TDMA/OFDM tidak sesuai untuk menangani trafik variansi tinggi seperti internet secara efisien tanpa menggunakan higher layer signaling. Hal ini berdampak pada overhead signaling dan delay



FDMA/OFDMA

- Ide dasarnya adalah dengan penugasan sejumlah subcarrier ke suatu user dan sejumlah subcarrier lain untuk user yang lain berdasarkan kebutuhan laju data masing-maisng user.
- Untuk membantu mengatasi penanganan trafik dengan variansi tinggi, digunakan teknik **resource block atau scheduling block**
- Suatu block adalah set terkecil dari sejumlah subcarrier dengan jumlah tetap. Suatu user dapat dialokasikan lebih dari satu block.



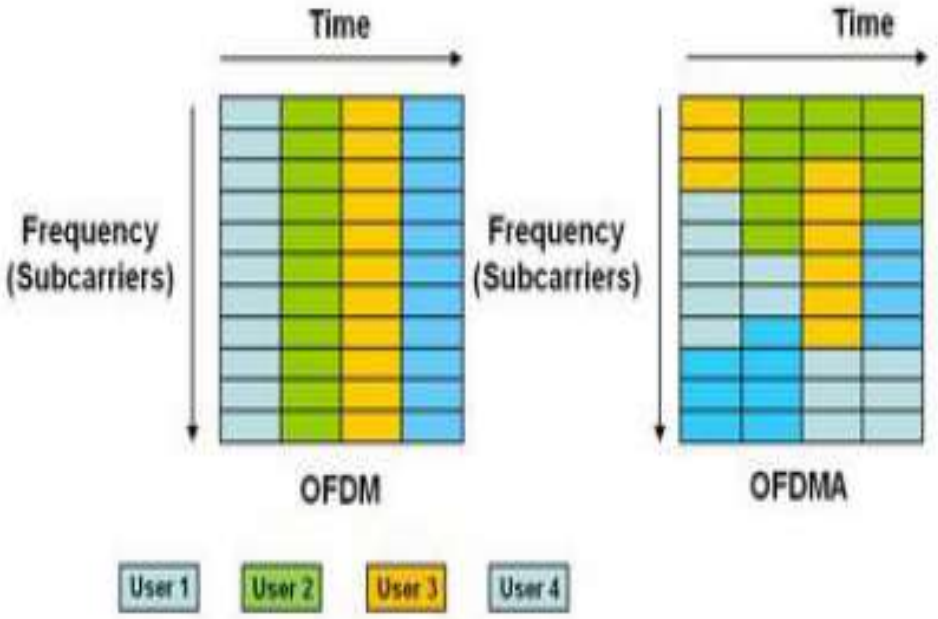
OFDMA

OFDM : In OFDM, all subcarriers of the symbol are used for providing data to a specific user

OFDMA : In OFDMA, the subscarriers of each symbol may be divided between multiple users thus enabling better use of radio resources

OFDM = Orthogonal Frequency Division Multiplexing

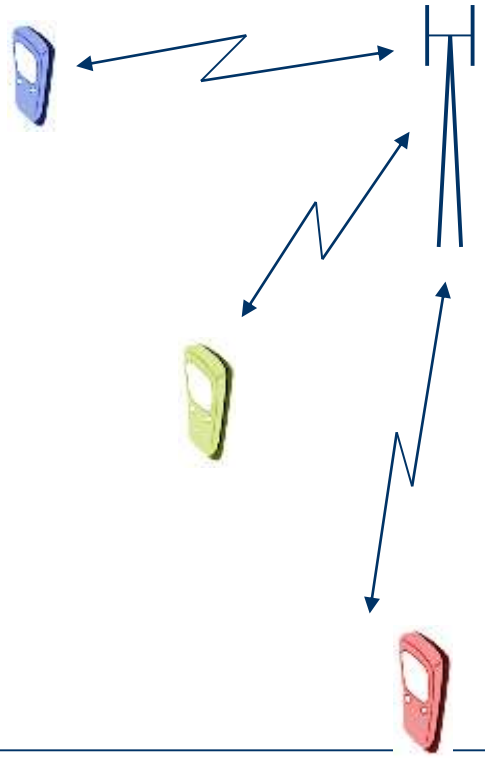
OFDMA = Orthogonal Frequency Division Multiple Access

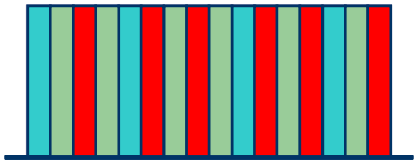


OFDMA's dynamic allocation enables better use of the channel for multiple low-rate users and For the avoidance of narrowband fading and interference

OFDM*A* – Orthogonal Frequency Division Multiple *Access*

- OFDM can be used as a multiple access scheme allowing simultaneous frequency-separated transmissions to/from multiple mobile terminals
- The number of sub-carriers can be scaled to fit the bandwidth – *Scalable OFDMA*





Distributed (diversity) mapping

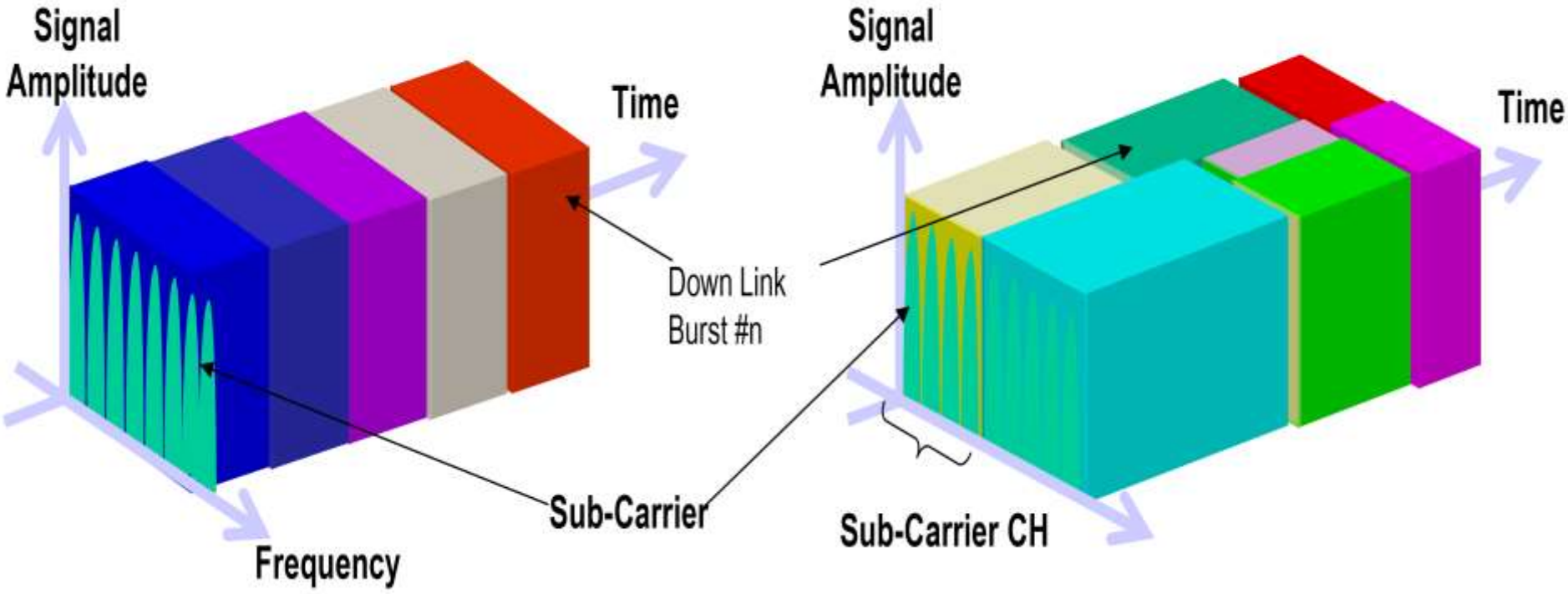
OFDM & OFDMA

OFDM

- Semua subcarrier dialokasikan untuk satu user
- Misal : 802.16-2004

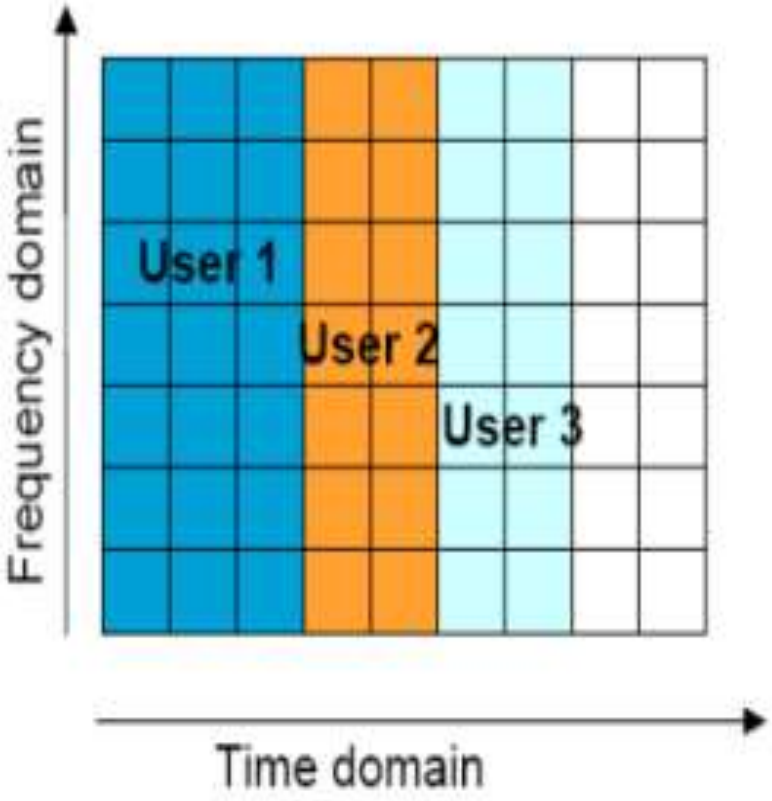
OFDMA

- Subcarrier dialokasikan secara fleksibel untuk banyak user tergantung pada kondisi radio.
- Misal : 802.16e-2005 dan 802.16m

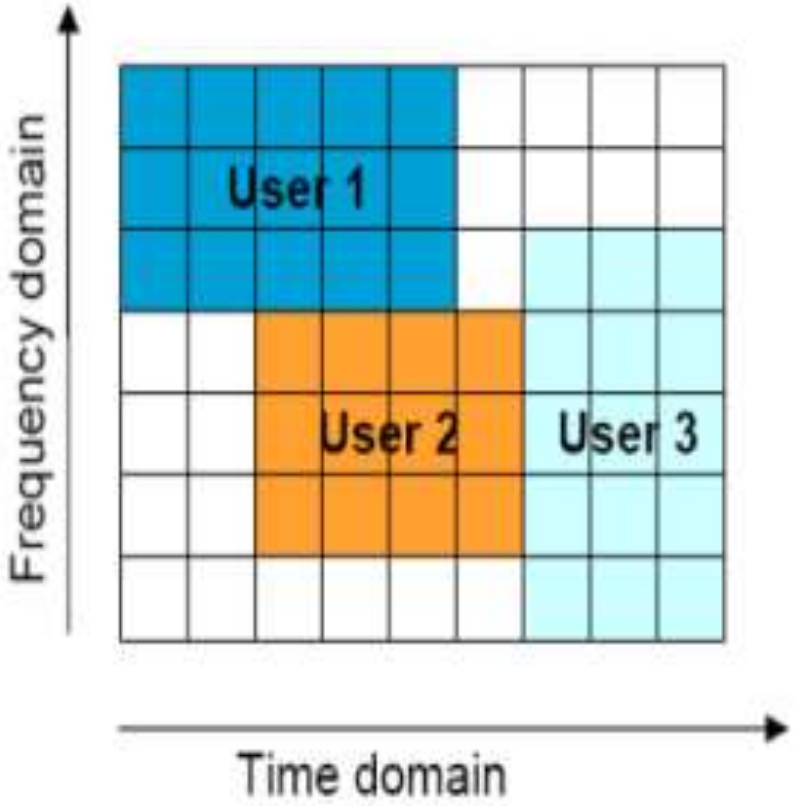


Perbedaan OFDM dan OFDMA

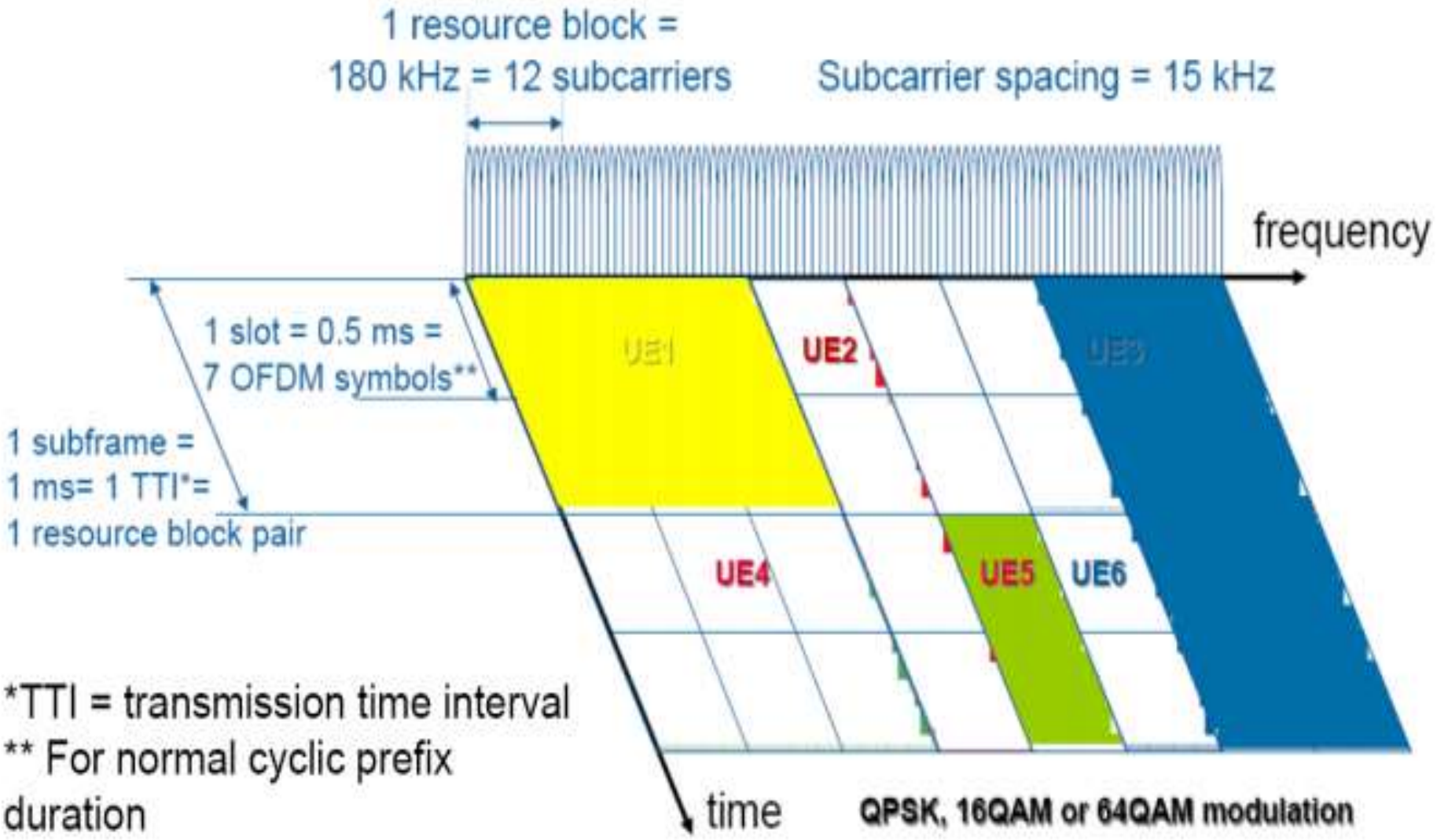
OFDM allocates users in time domain only



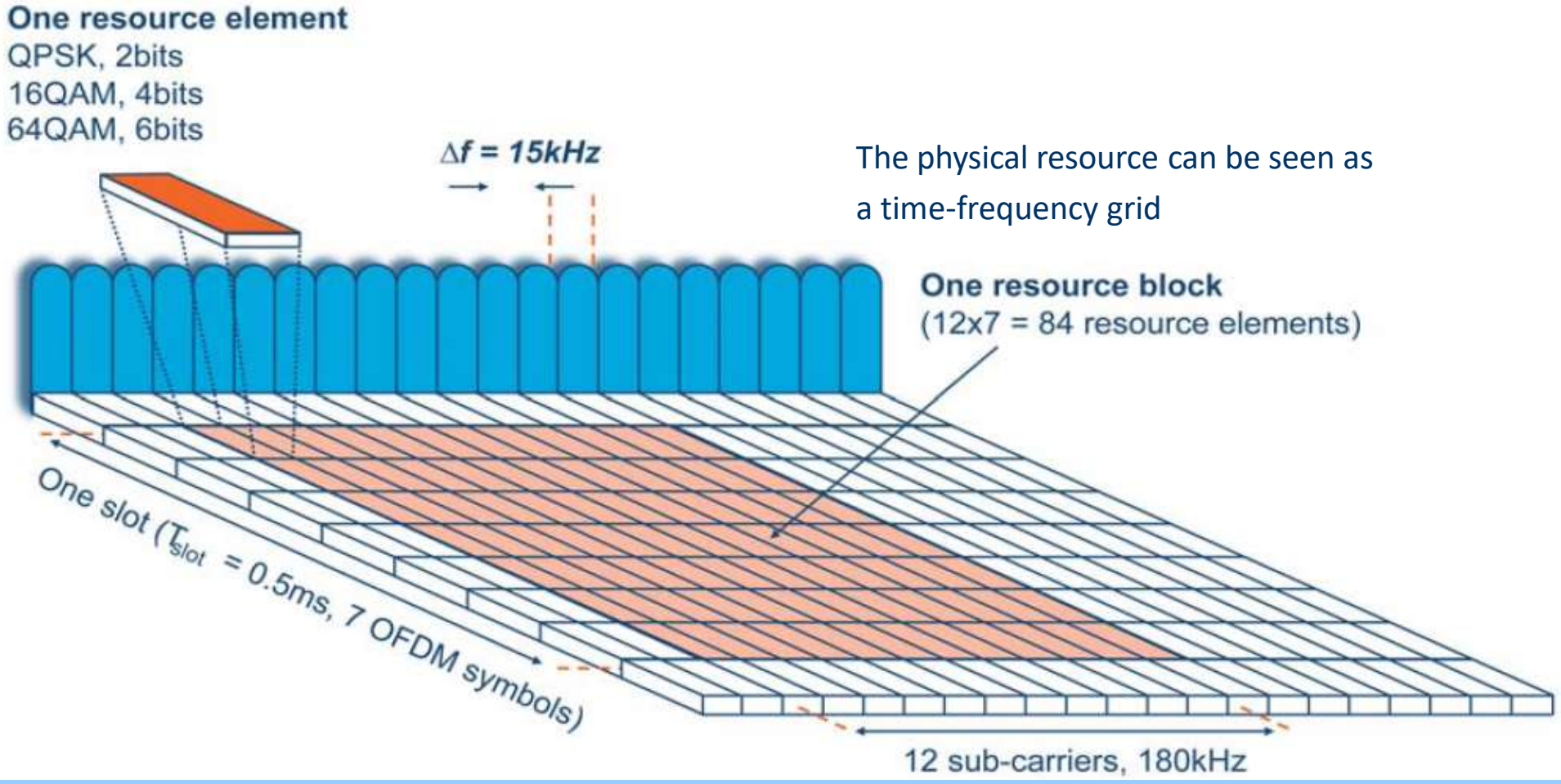
OFDMA allocates users in time and frequency domain



OFDMA Time-Frequency Multiplexing



LTE Downlink Physical Layer Design: Physical Resource



The physical resource can be seen as a time-frequency grid

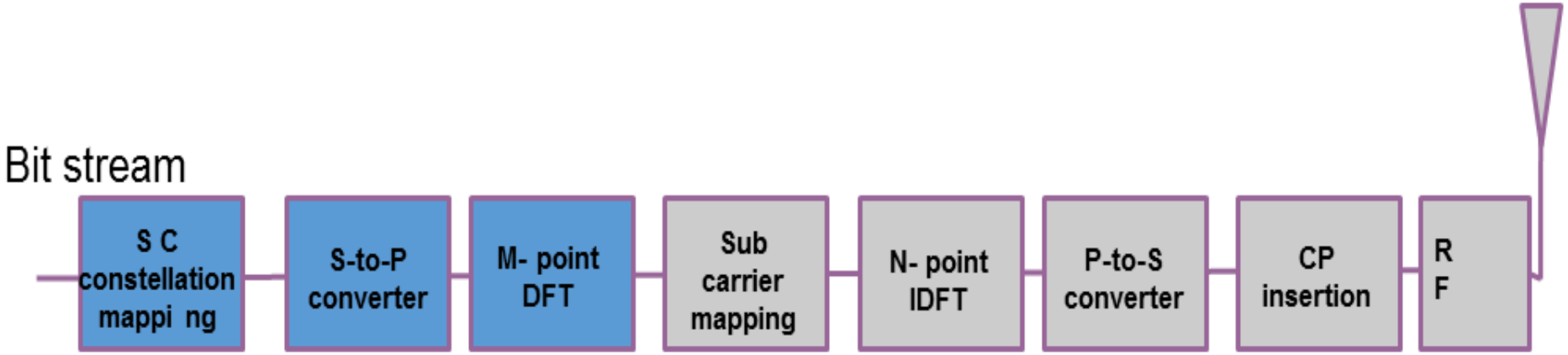
- **LTE uses OFDM (Orthogonal Frequency Division Multiplexing) as its radio technology in downlink**
- **In the uplink LTE uses a pre=coded version of OFDM, SC-FDMA (Single Carrier Frequency Division Multiple Access) to reduced power consumption**

Pengenalan SC FDMA

SC-FDMA

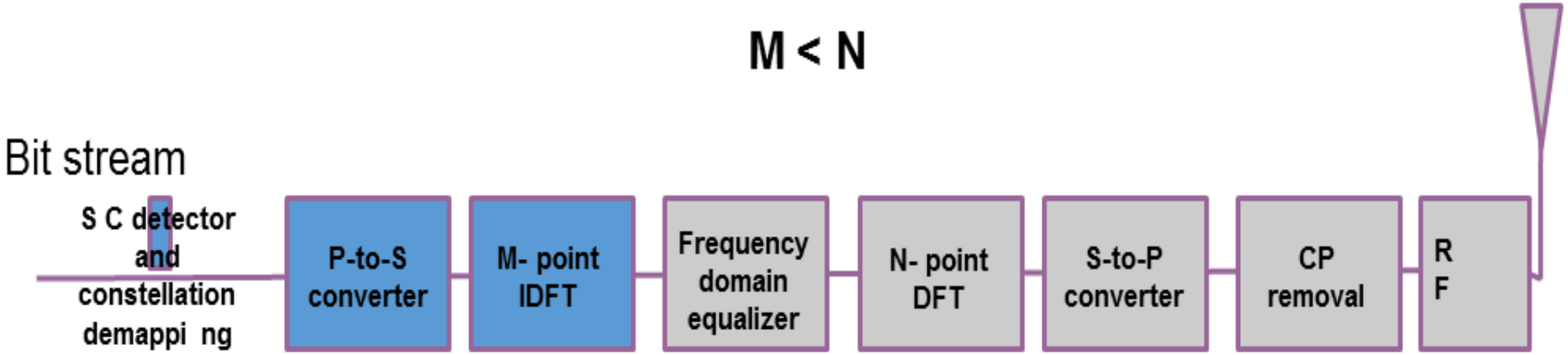
- SC-FDMA :Single Carrier Frequency Division Multiple Access
- SC-FDMA merupakn skema modulasi hybrid yang menggabungkan low PAPR dari sistem single-carrier dengan sifat multipath resistance dan alokasi flexible subcarrier yang diberikan oleh OFDM
- SC menyelesaikan problem PAPR dengan melakukan grouping resouce block untuk mengurangi kebutuhan linearitas penguatan dan konsumis daya sehingga terjadi peningkatan coverage dan kinerja di pinggir sel.
- SC-FDMA menjadi salahsatu opsi WiMAX (802.16d) dan dipakai pada LTE untuk arah uplink.

SC FDMA Functional blocks



SC-FDMA Transmitter

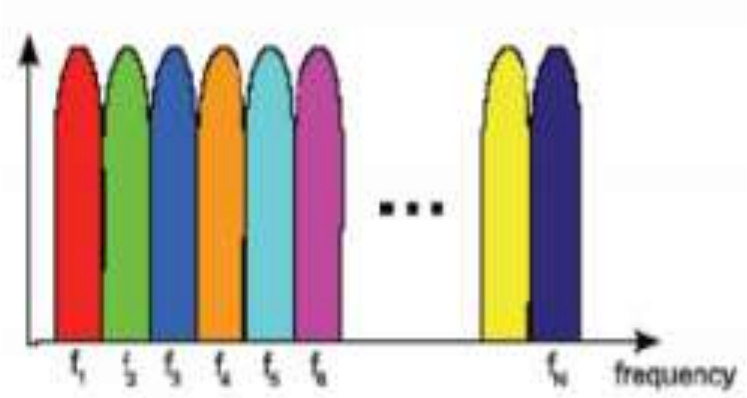
M < N



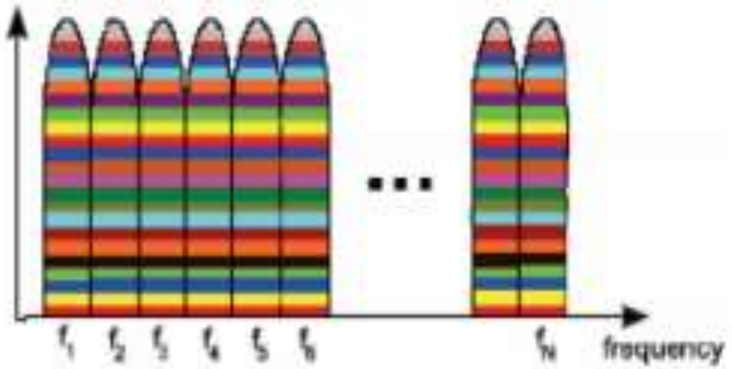
SC-FDMA receiver

Bentuk Sinyal SC-FDMA

- Sama seperti sinyal OFDMA, tetapi :
  - Pada OFDMA, tiap sub-carrier hanya membawa informasi yang terkait dengan satu simbol spesifik
  - Pada SC-FDMA, tiap sub-carrier mengandung semua informasi simbol yang terkirim

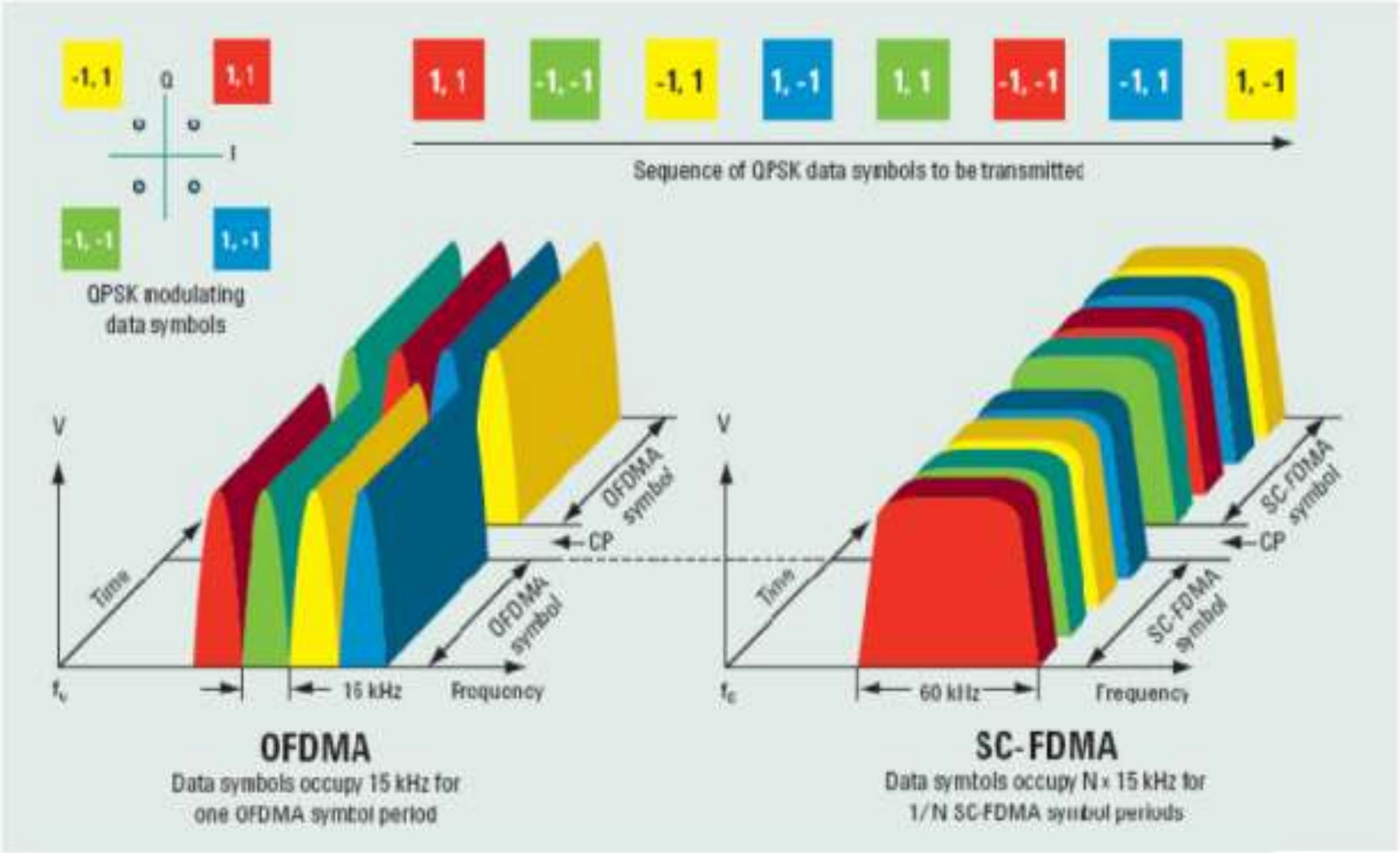


(a) OFDM subcarriers



(b) DFT-s-OFDM subcarriers

Perbandingan OFDMA dan SC-FDMA



OFDMA

Data symbols occupy 15 kHz for one OFDMA symbol period

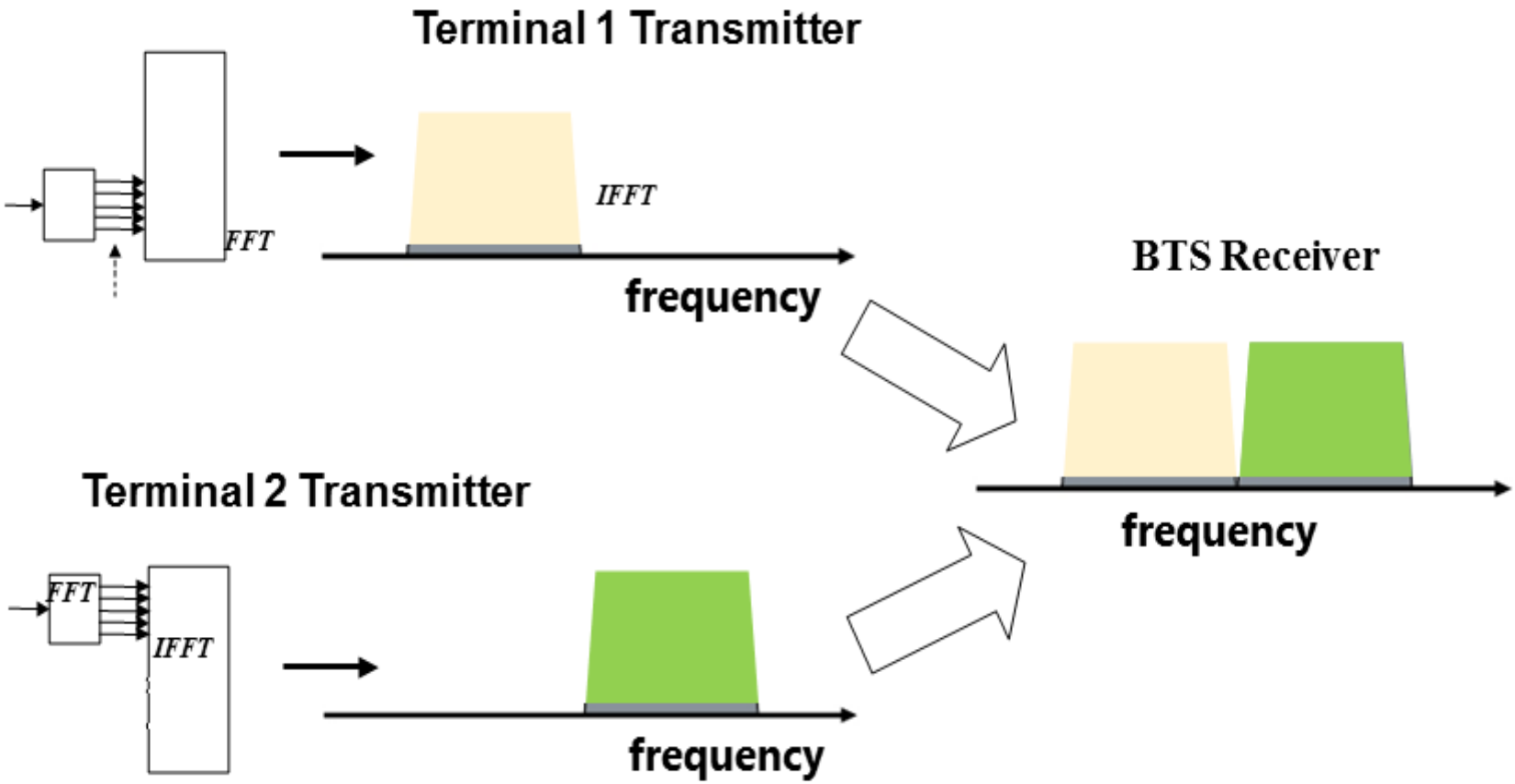
SC-FDMA

Data symbols occupy N × 15 kHz for 1/N SC-FDMA symbol periods

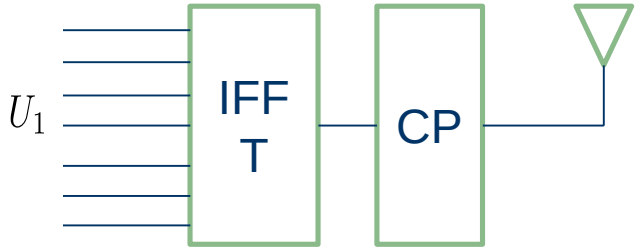
Uplink Multiple Access – SC-FDMA

User multiplexing in frequency domain

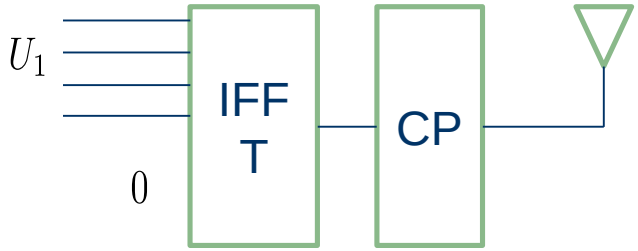
- Smallest uplink bandwidth 180 kHz.
- Largest 20 MHz (terminal are required to able to receive & transmit up to 20 MHz, depending on the frequency band though.)

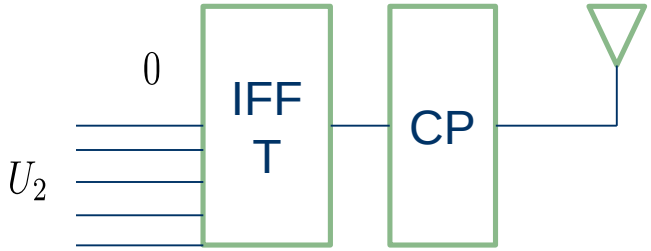


OFDM, OFDMA, dan SC-FDMA

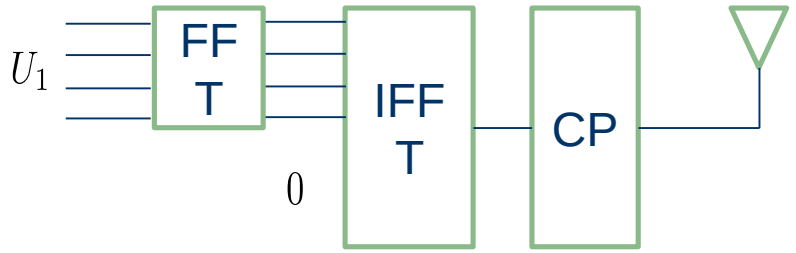


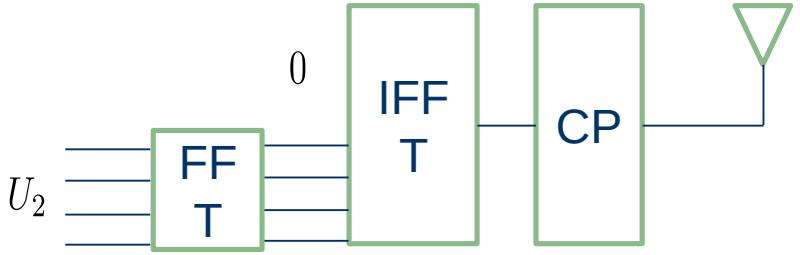
OFDM





OFDMA





SC-FDMA

- **OFDM dan OFDMA memiliki peak-to-average Power (PAPR) yang besar (buruk) → boros power**
- **SC-FDMA memiliki PAPR yang rendah (baik)**
- **SC-FDMA dipakai pada Uplink 4G**