# Komunikasi Akses Wireless

# OFDM

Faculty of Electrical Engineering
Bandung – 2020

# 4G Approaches

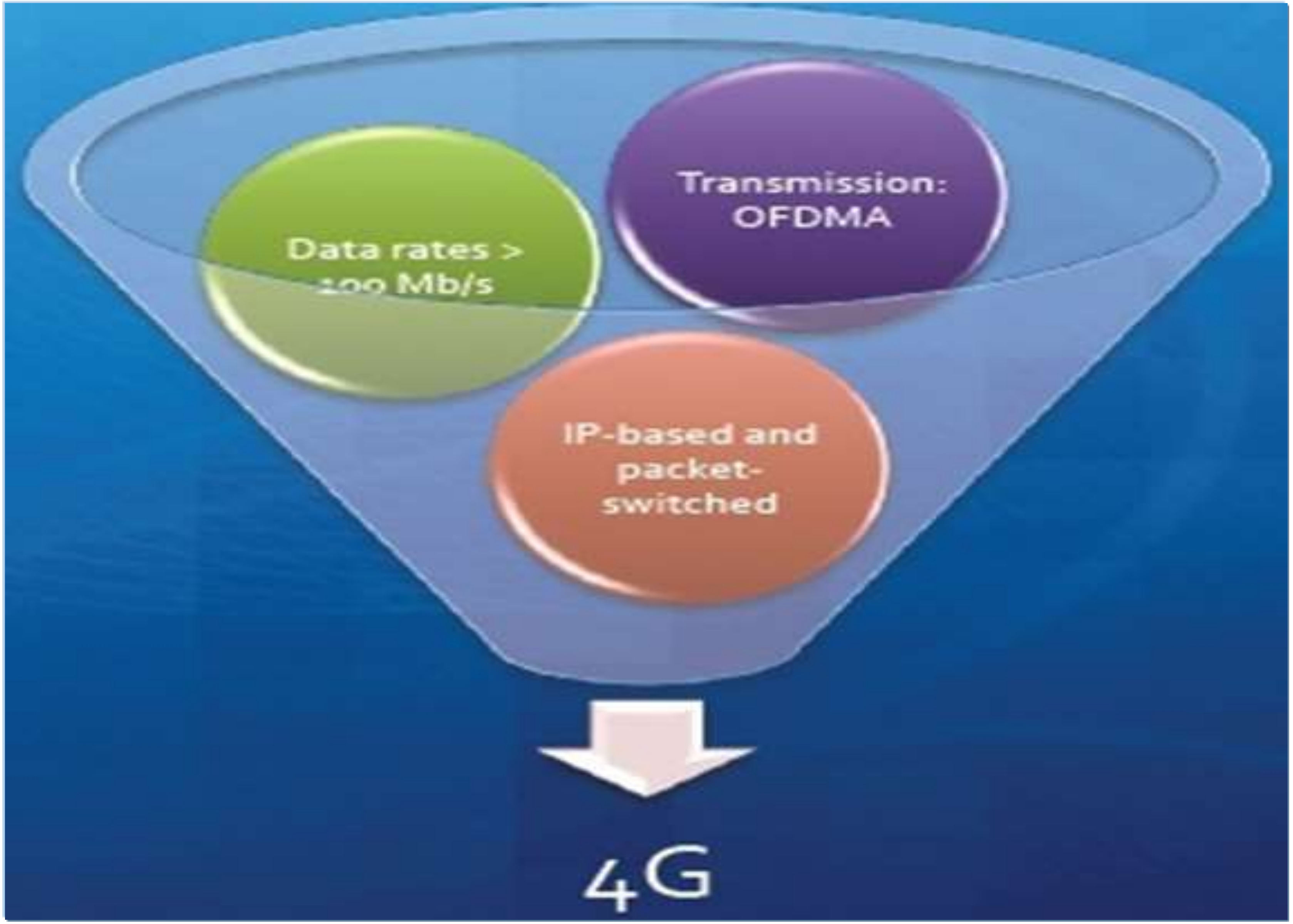
Access Scheme

All-IP Network

Advanced Antenna

Cognitive Radio

# ITU 4G Requirement



# Subject

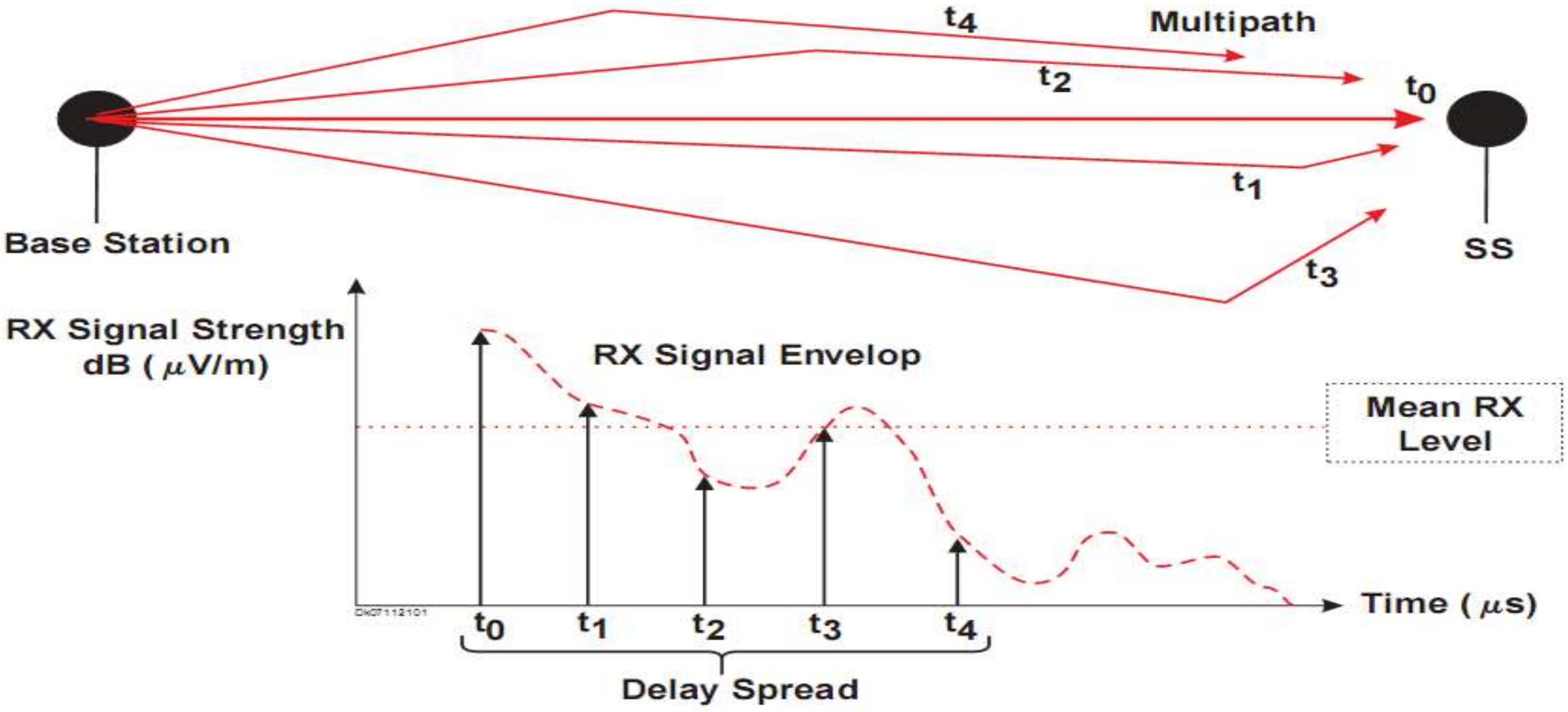
a. Konsep OFDM

b. Konsep OFDMA

c. Pengenalan SC-FDMA

# Konsep OFDM

# 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.

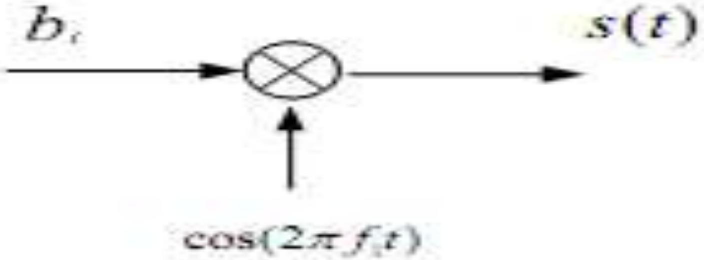
# Problems of
# Mutipath Propagation & High Data Rate

- 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

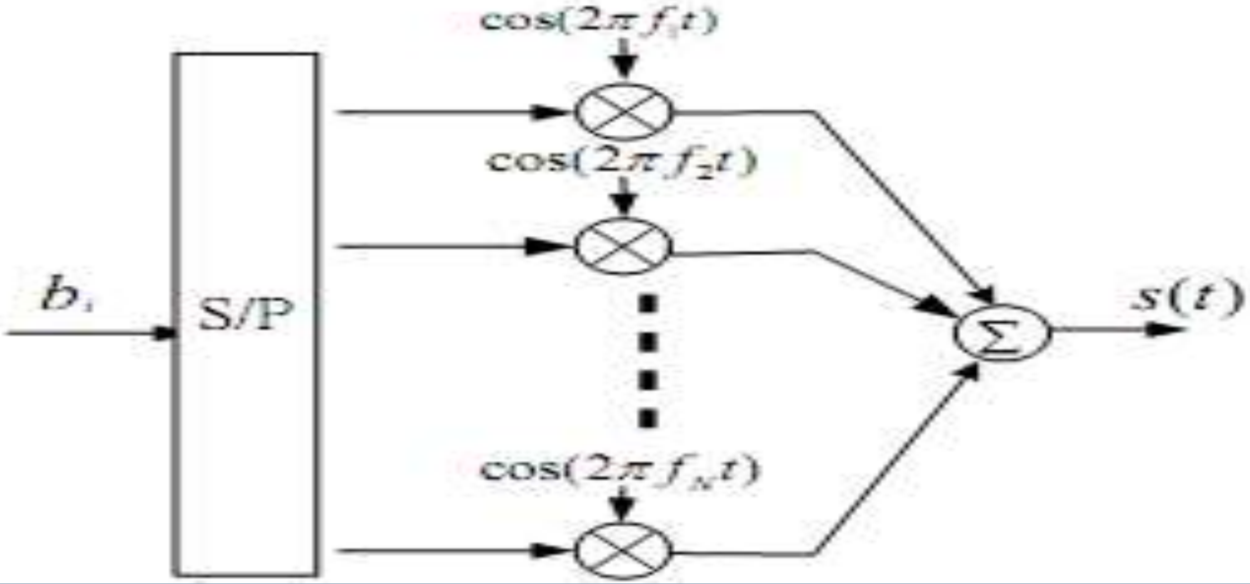
- Single carrier transmission
  - The concept of single-carrier is that each user transmits and receives data stream with only one carrier at any time.
- Multicarrier transmission
  - The concept of multi-carrier transmission is that a user can employ a number of carriers to transmit data simultaneously.

- Single and multicarrier transmission

Single carrier transmission

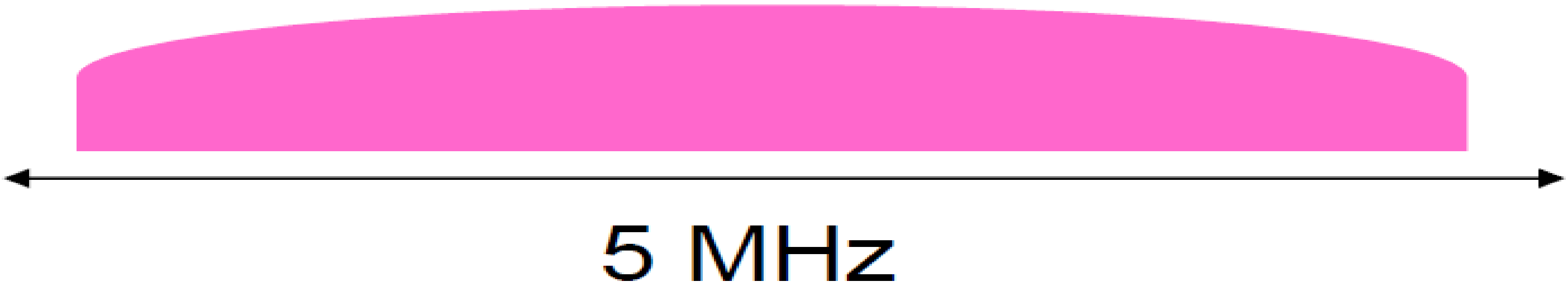



Multicarrier carrier transmission

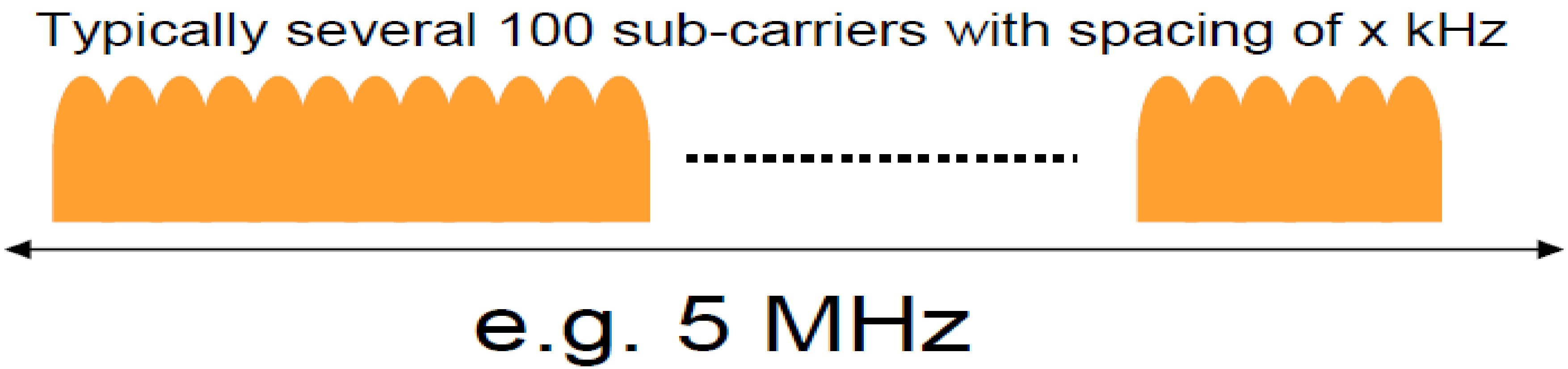


# Teknologi Pendukung LTE

- Single Carrier Transmission (e.g. WCDMA)




- Orthogonal Frequency Division Multiplexing



# Keterbatasan Modulasi Carrier Tunggal

- Penggunaan suatu carrier tunggal memiliki kelemahan mendasar : durasi cyclic prefix ditentukan oleh maximum expected delay spread .

$$delay_{\max} = T_{CP}$$

- Durasi simbol bisa dibuat seukuran dengan cyclic prefix, namun transmisi data menjadi tinggal setengahnya karena untuk cyclic prefix sehingga sistem menjadi tidak efisien (E kecil)

$$E = \frac{T_{SYMBOL}}{T_{SYMBOL} + T_{CP}}$$

- Selain itu, durasi simbol yang mengecil berarti juga menggunakan spektrum (fs) lebih besar.

$$f_S = \frac{1}{T_S} = \frac{1}{T_{SYMBOL} + T_{CP}}$$

- Untuk peningkatan efisiensi, durasi simbol harus panjang, namun laju simbol menjadi turun.

# 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*

# What is Multicarrier Modulation?

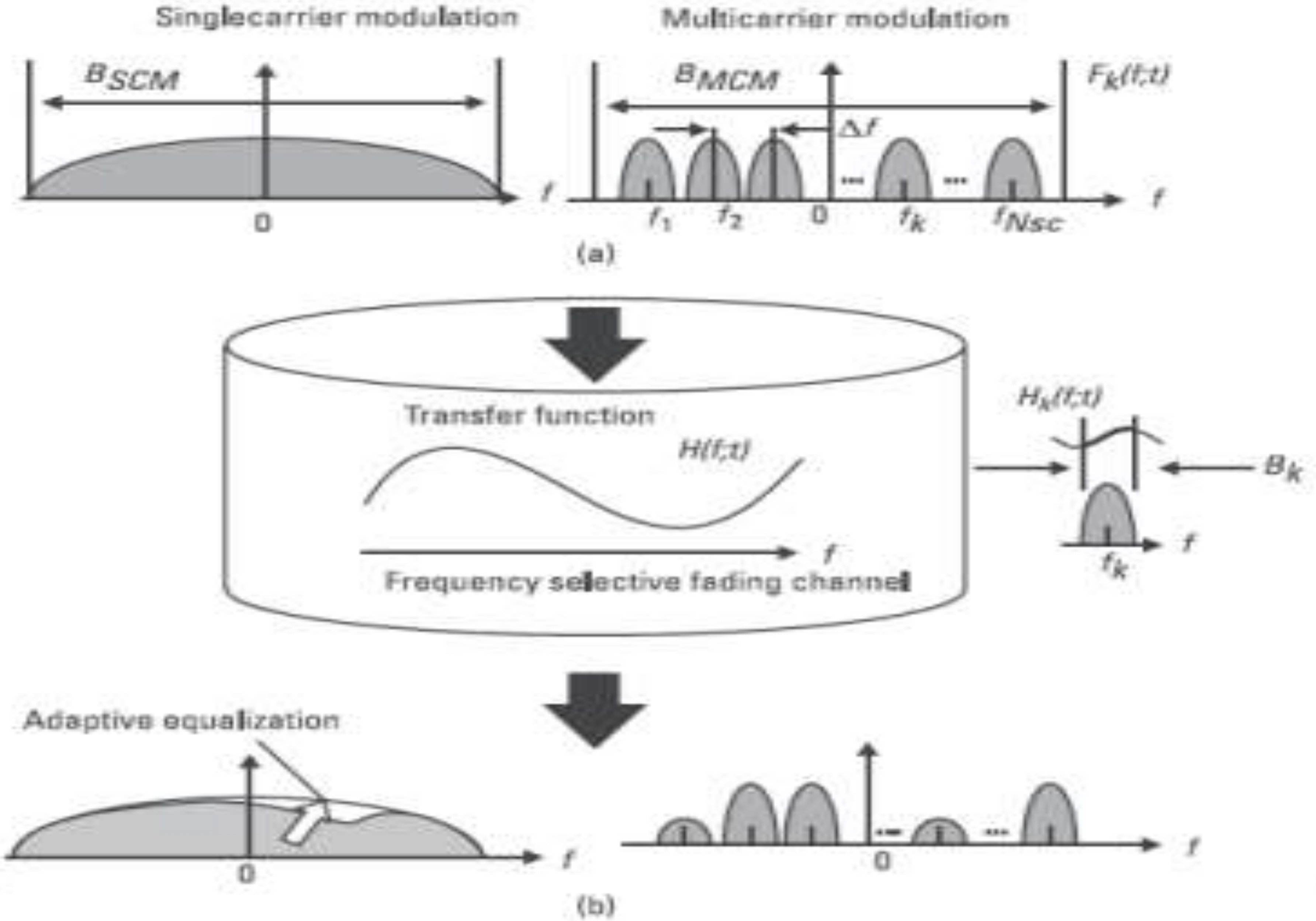
- Multicarrier modulation is the generic term used for any orthogonal pulse amplitude modulation (OPAM) where the orthogonal pulses are roughly localized in the frequency domain.

- It includes, as special cases, frequency division multiplexing (FDM) and orthogonal FDM (OFDM) and discrete multitone transmission (DMT)

- Now what is orthogonal pulse amplitude modulation (OPAM)?

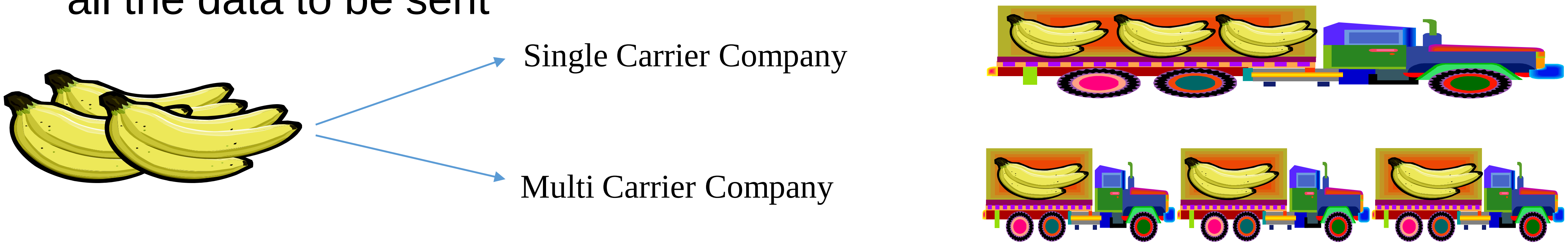
- Based on our knowledge of modulation, we should be able to understand OPAM very easily and then move on to MCM.

# The difference between MCM and SCM

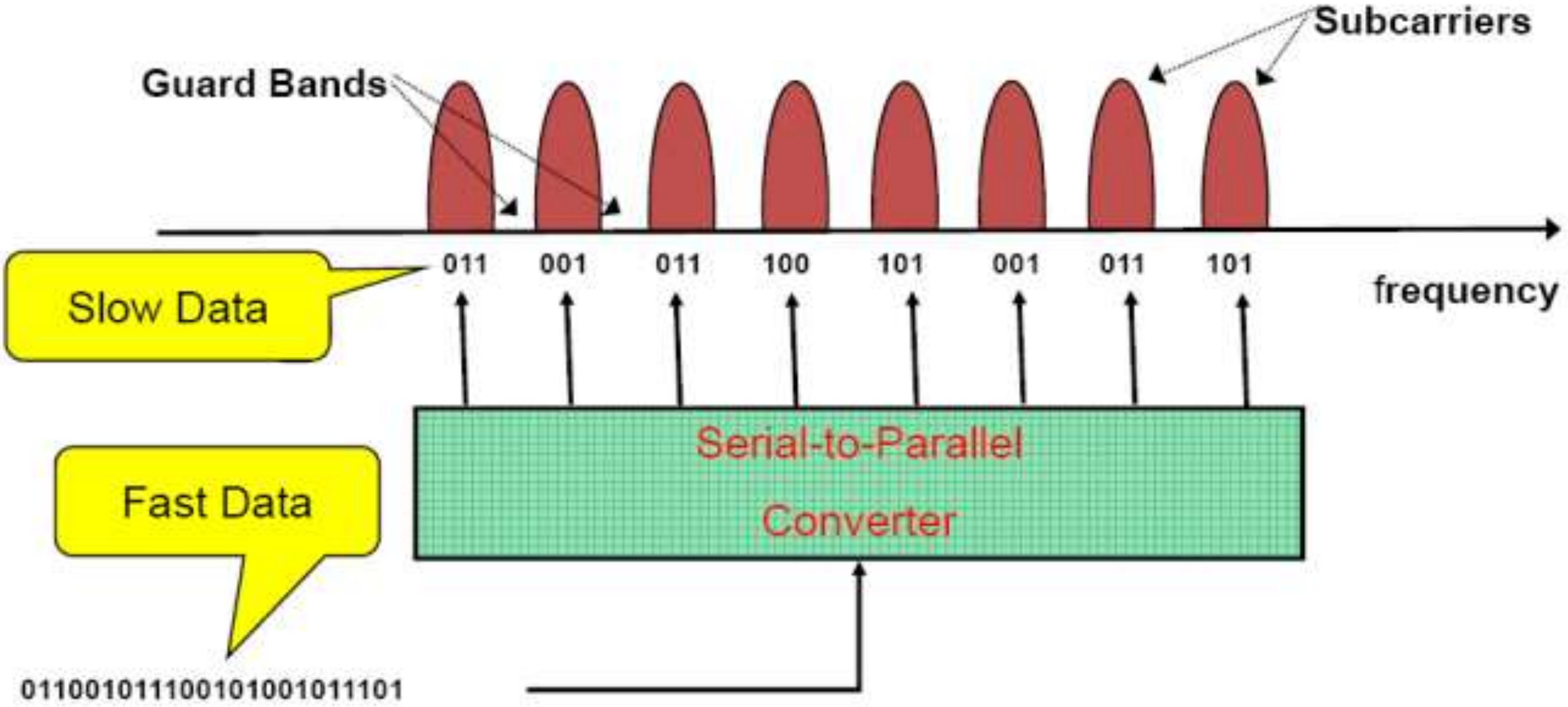


# Multicarrier Transmission - Basic Concept

- *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

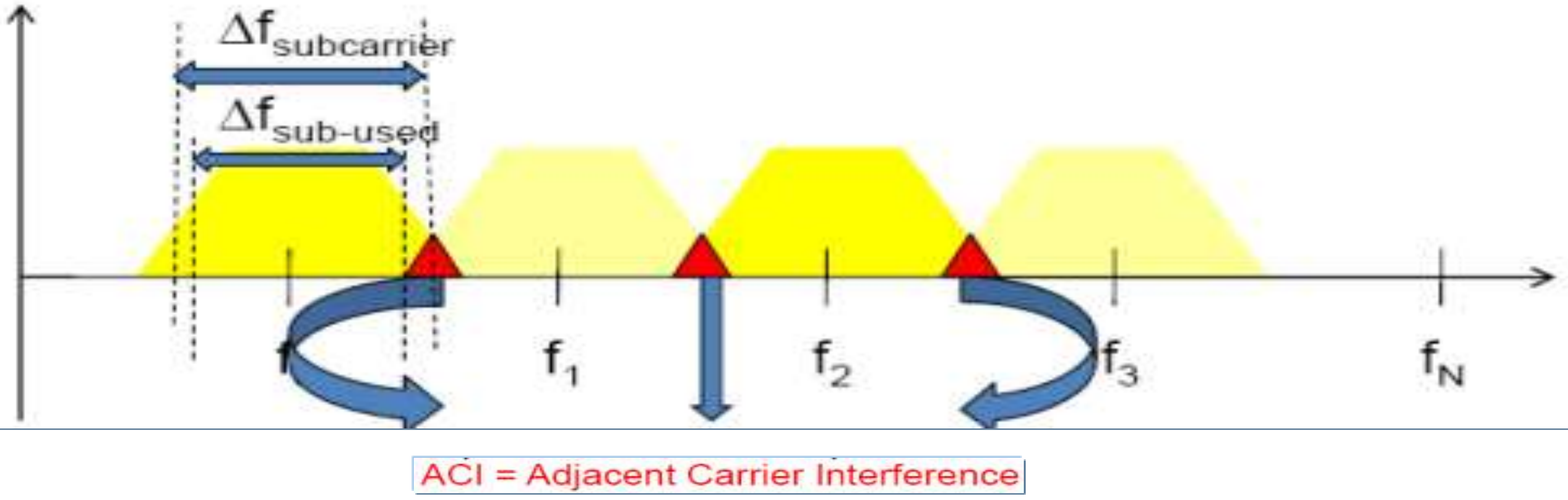


# Modulasi Multicarrier

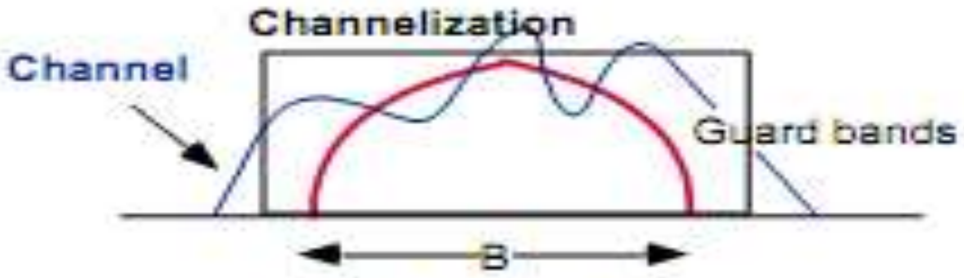


# Modulasi Multicarrier

- 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.

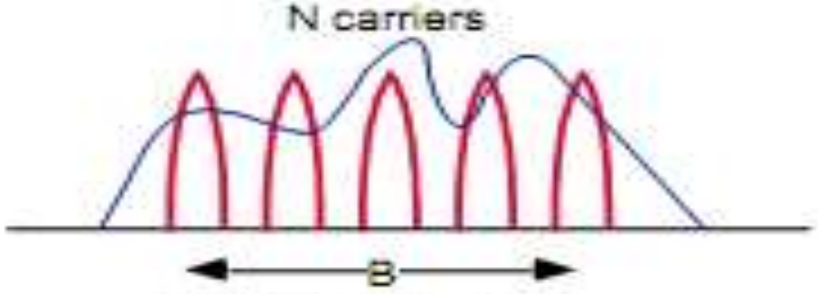


# Modulation techniques: monocarrier vs. multicarrier




Pulse length ~1/B

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




Pulse length ~ N/B

– 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:**

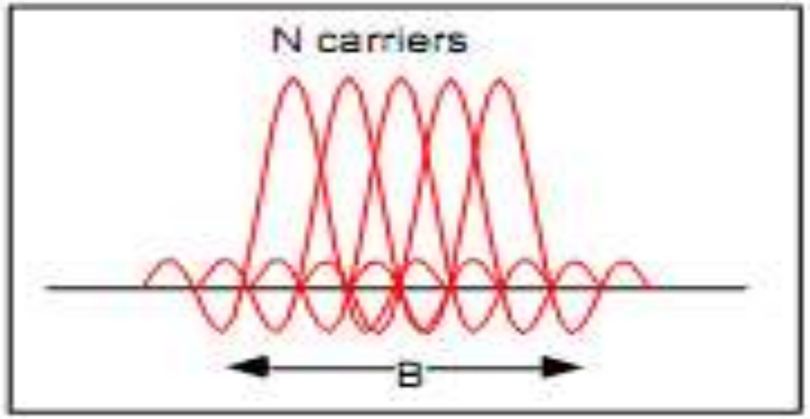
**Eliminate band guards between carriers**

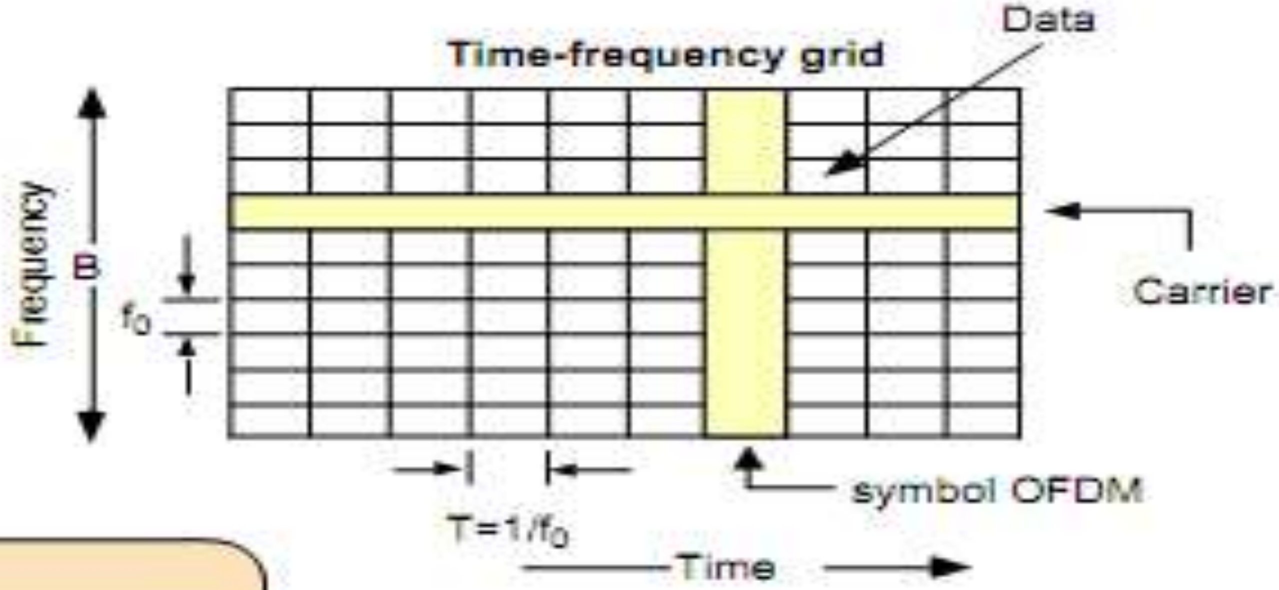
**To use orthogonal carriers (allowing spectrum overlapping)**

# 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

- Peak of spectrum for each sub-band must correspond to zero crossings for all other modulated sub-carriers.
- Interference now avoided in frequency-domain.
- Adjacent sub-carriers spaced exactly 1/T Hz apart when sub-band pulse-rate is 1/T pulses/second.
- Sub-carriers are as close together as they can possibly be without introducing spectral interference.
- Each modulated sub-carrier is ‘orthogonal’ to all others which means that they do not interfere with each other.

# The Multicarrier Modulation Idea (1)

- Suppose we have a fixed channel bandwidth $W$.
- We are free to increase signal dimensionality $N$ if we simultaneously increase symbol interval $T$.
- Intuitively we are compensating for reduced symbol rate by increasing the number of symbols per symbol interval.
- How do we choose the set of orthogonal pulses as we increase $T$?
- One solution: make the bandwidth of each pulse on the order of $1/2T$, satisfying Nyquist rate.
- Then place them at different non-overlapping centre frequencies.
- As $T$ and $N$ increase, this will make only a small portion of the channel transfer function over narrower and narrower bandwidth affect each pulse transmission.

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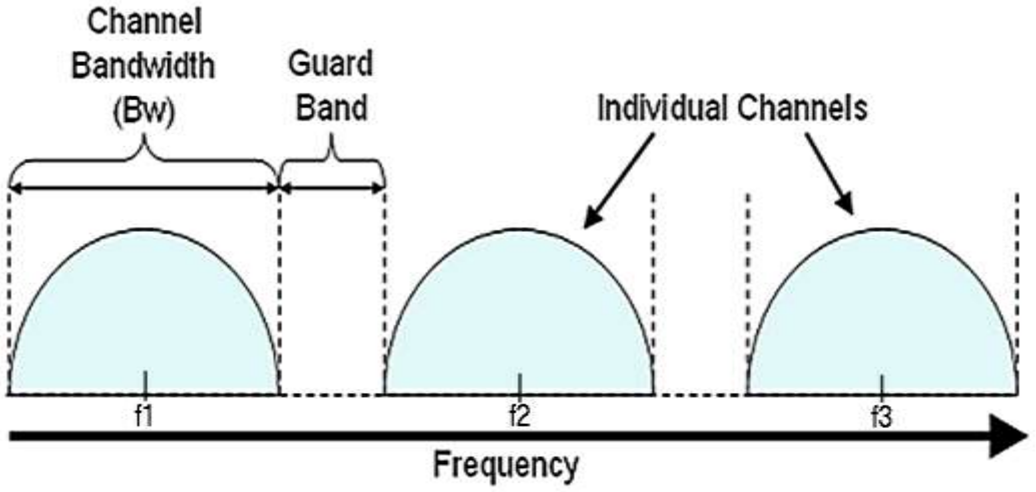
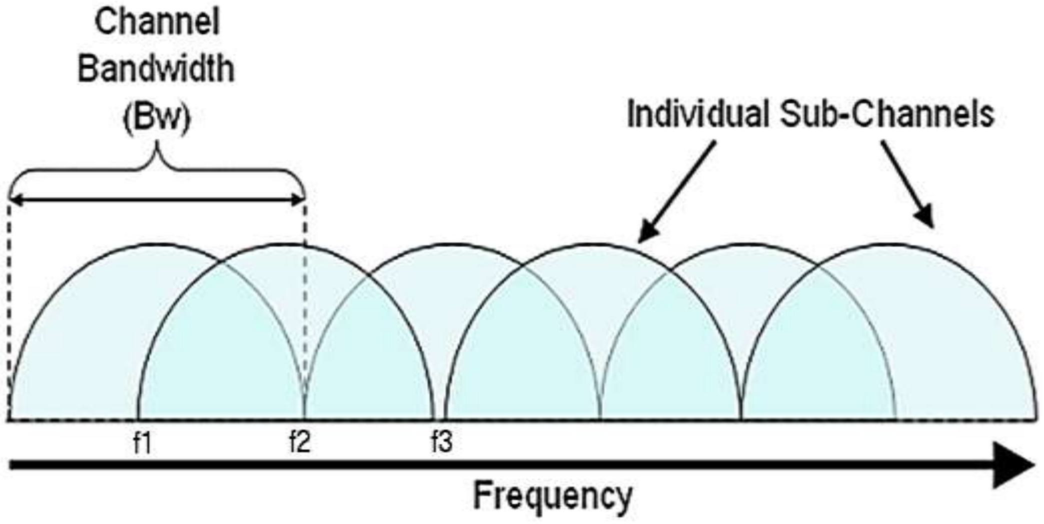
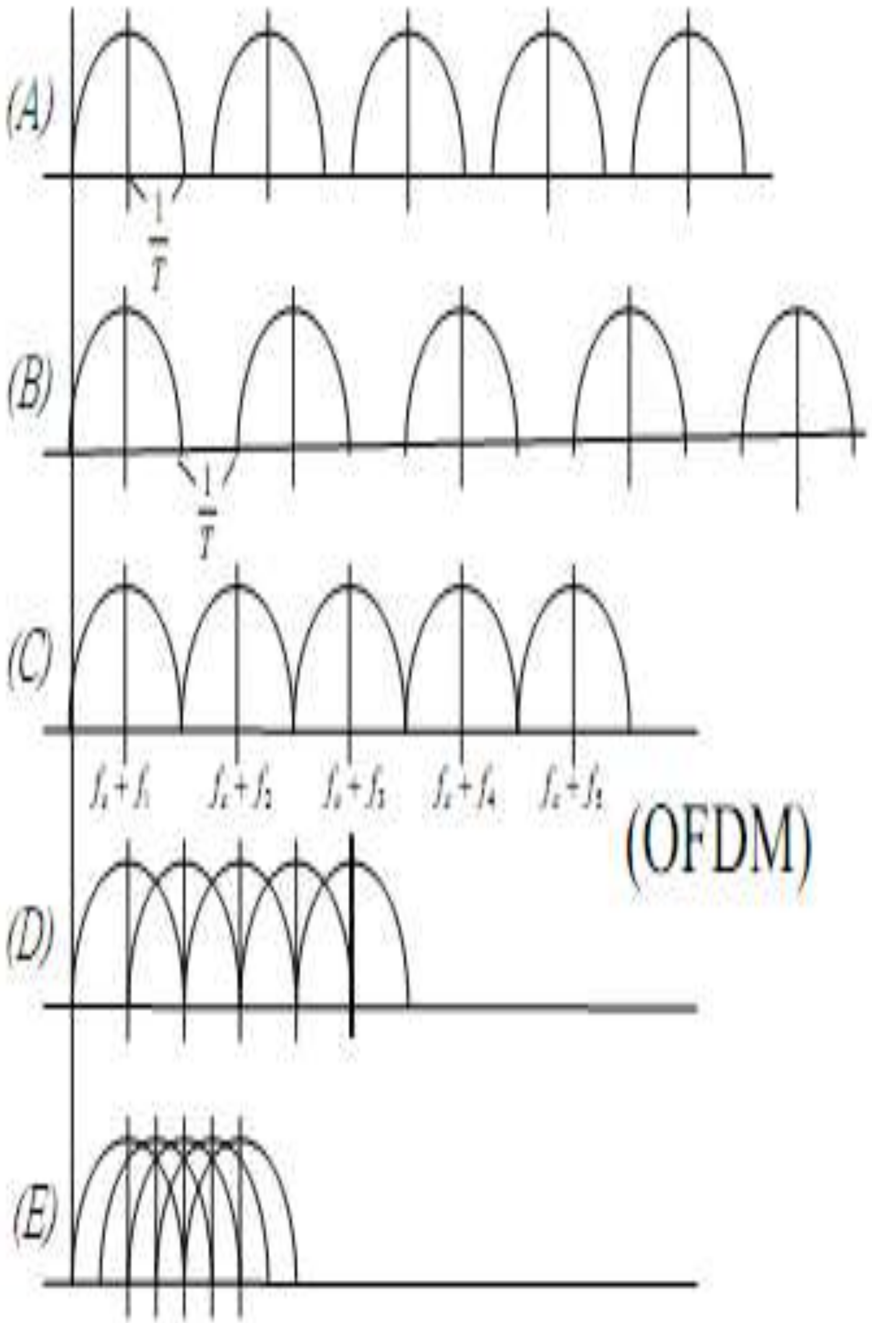
- Eventually, for sufficiently large $T$ the channel transfer function will be constant over the bandwidth of each pulse.
- Therefore, ISI for each pulse will be insignificant.
- By proper MCM system design, we can cleverly avoid ISI.

# 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**






Orthogonal

Orthogonal, $n$=3

Orthogonal, $n$=2

Orthogonal, $n$=1

Non-orthogonal

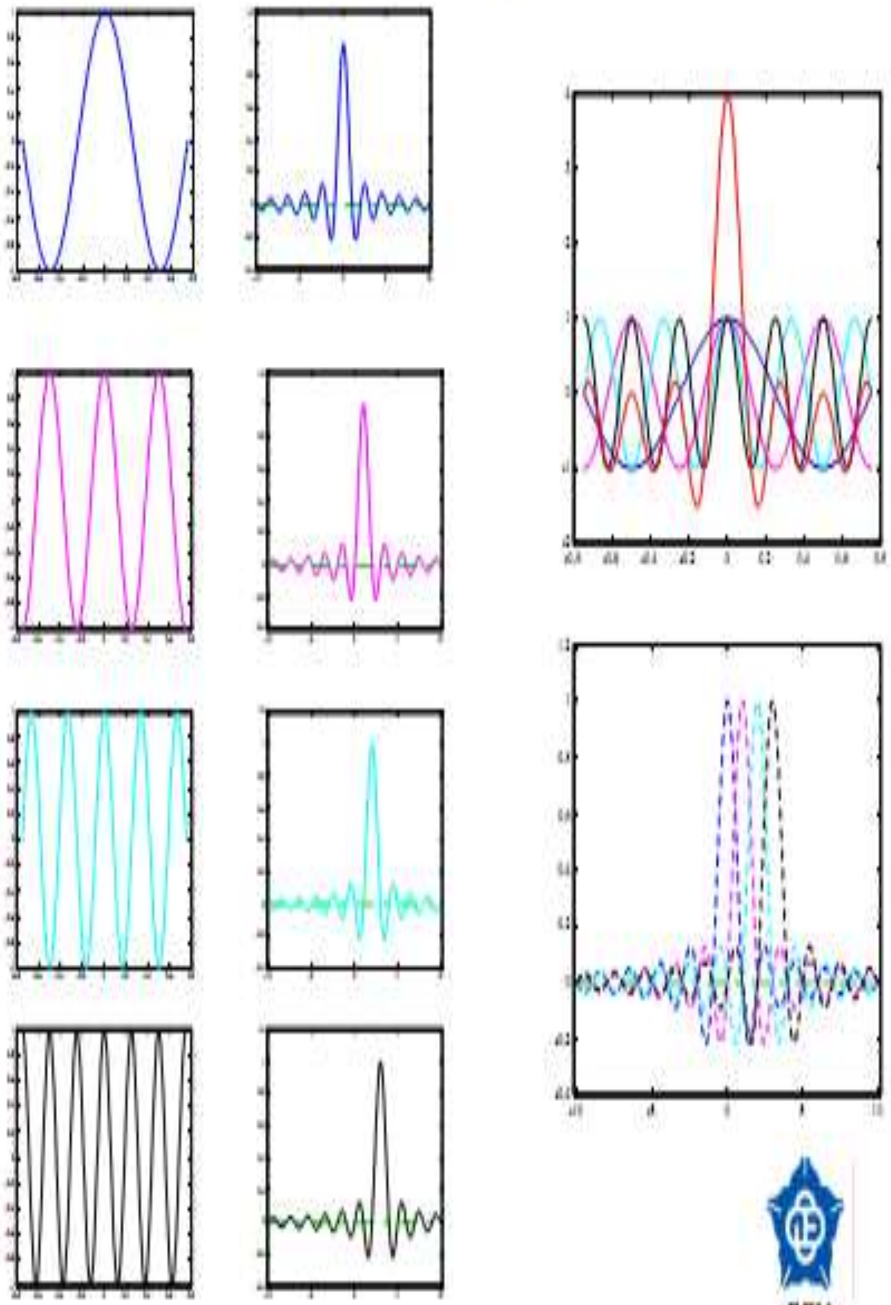
Time domain Frequency domain

subcarrier $f_1$

subcarrier $f_2$

subcarrier $f_3$

subcarrier $f_4$



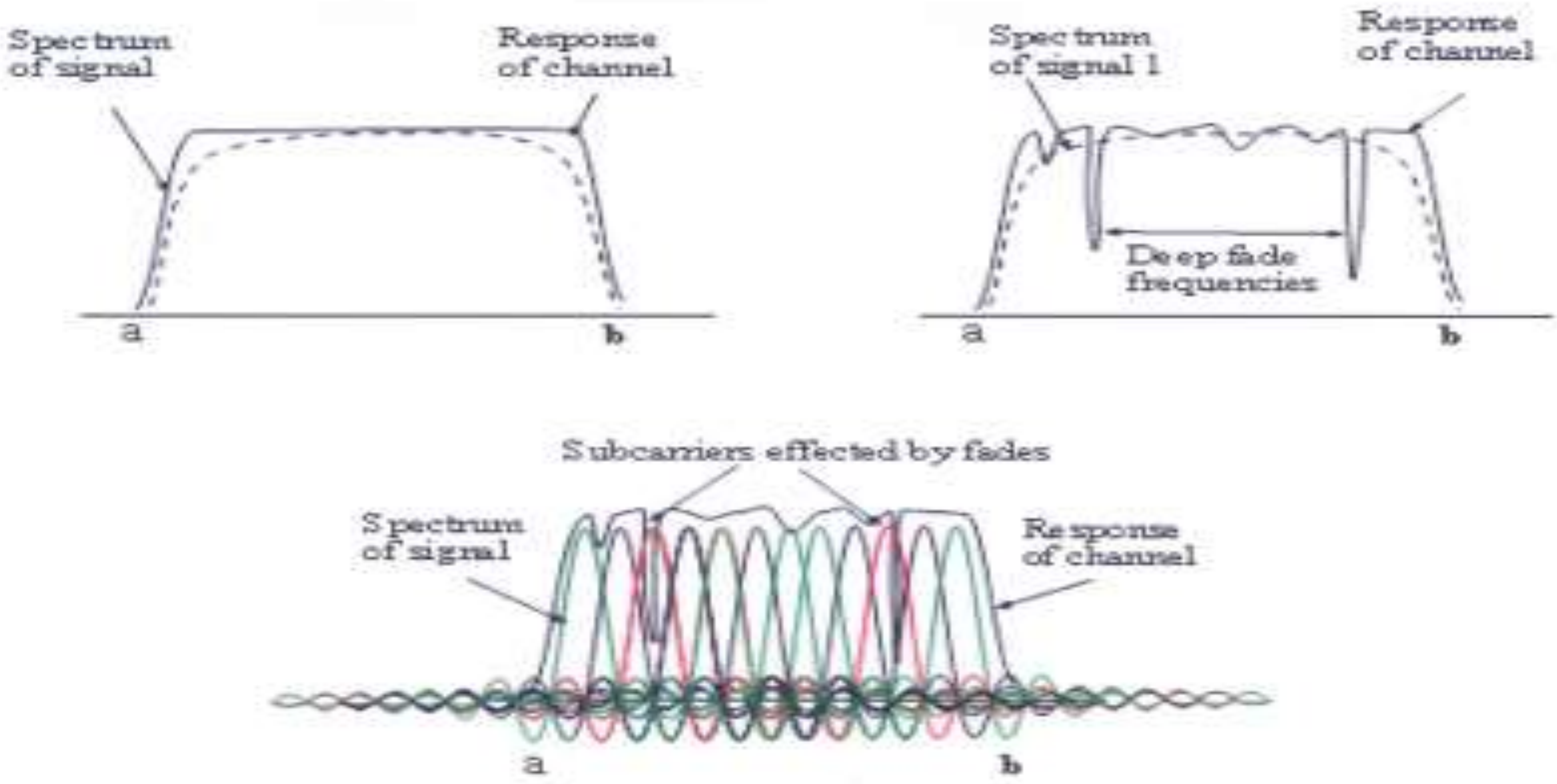
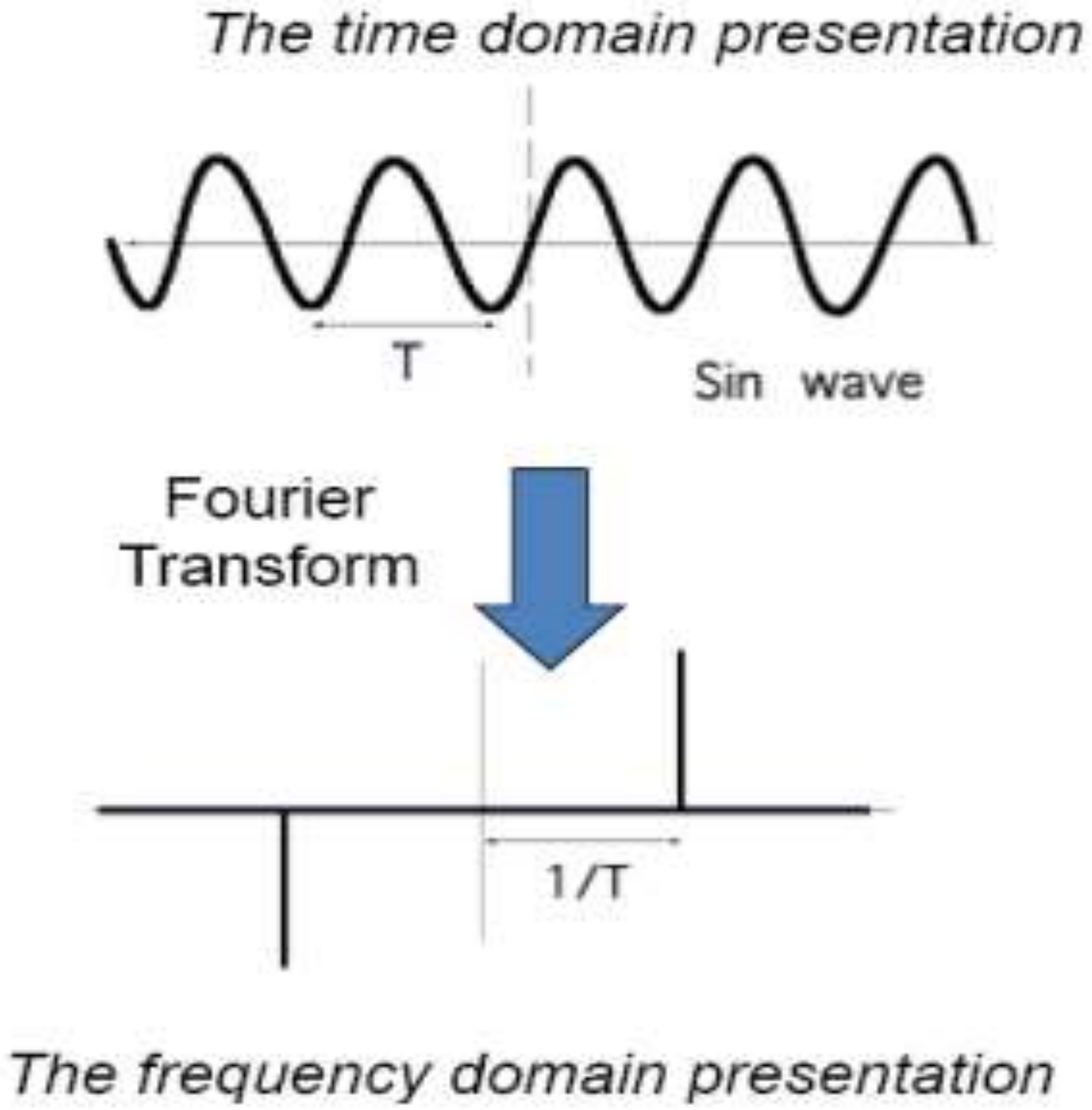



Fig. 20 – (a) The signal we want to send and the channel frequency response are well matched. (b) A fading channel has frequencies that do not allow anything to pass. Data is lost sporadically. (c) With OFDM, where we have many little sub-carriers, only a small sub-set of the data is lost due to fading.

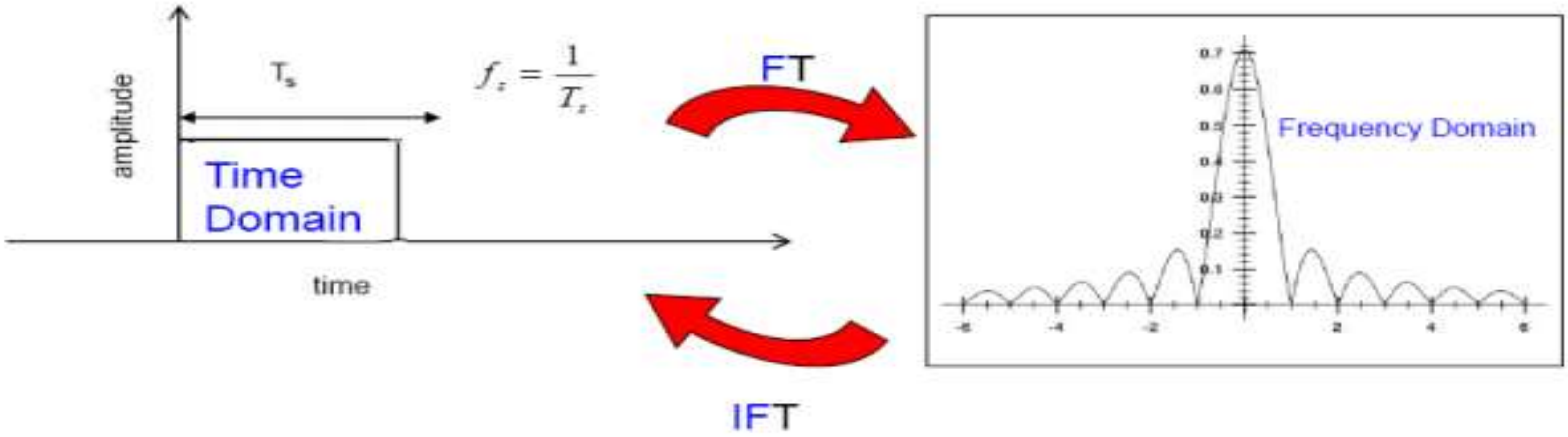
# Representasi Kawasan Waktu vs Frekuensi

- Dua penggambaran karakteristik sinyal :
  - Representasi kawasan waktu :
    - Membantu mengenali seberapa panjang durasi suatu simbol It helps
  - Representasi kawasan frekuensi :
    - Untuk memahami kebutuhan spektrum



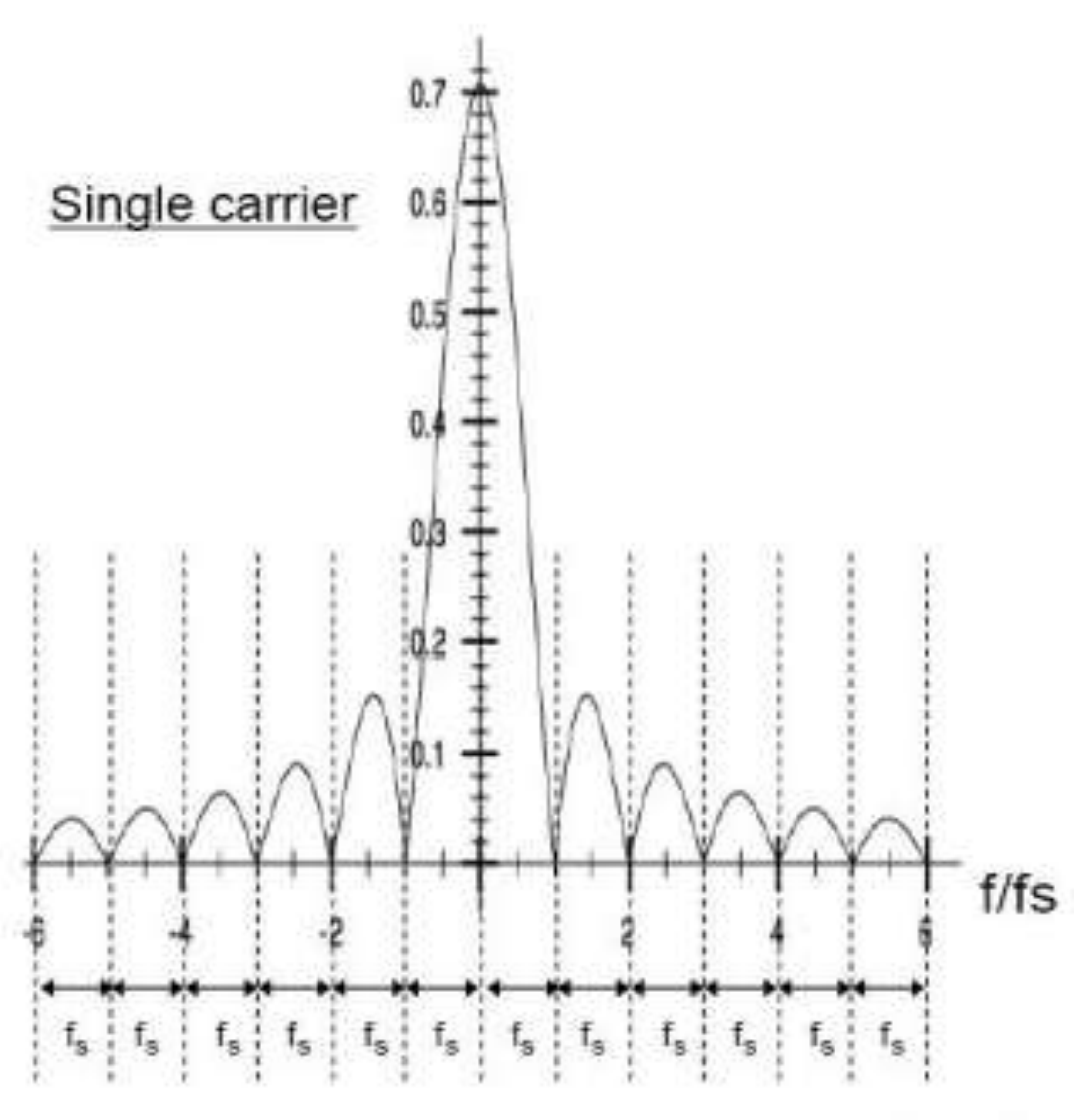
# Pulsa Kotak

- Pulsa kotak merupakan pulsa sederhana dalam kawasan waktu.
- Pulsa ini dibentuk dengan cara menaikkan amplituda pada saat t=0 ke maksimum dan setelah suatu durasi waktu Ts amplituda diturunkan kembali ke 0.



# OFDM

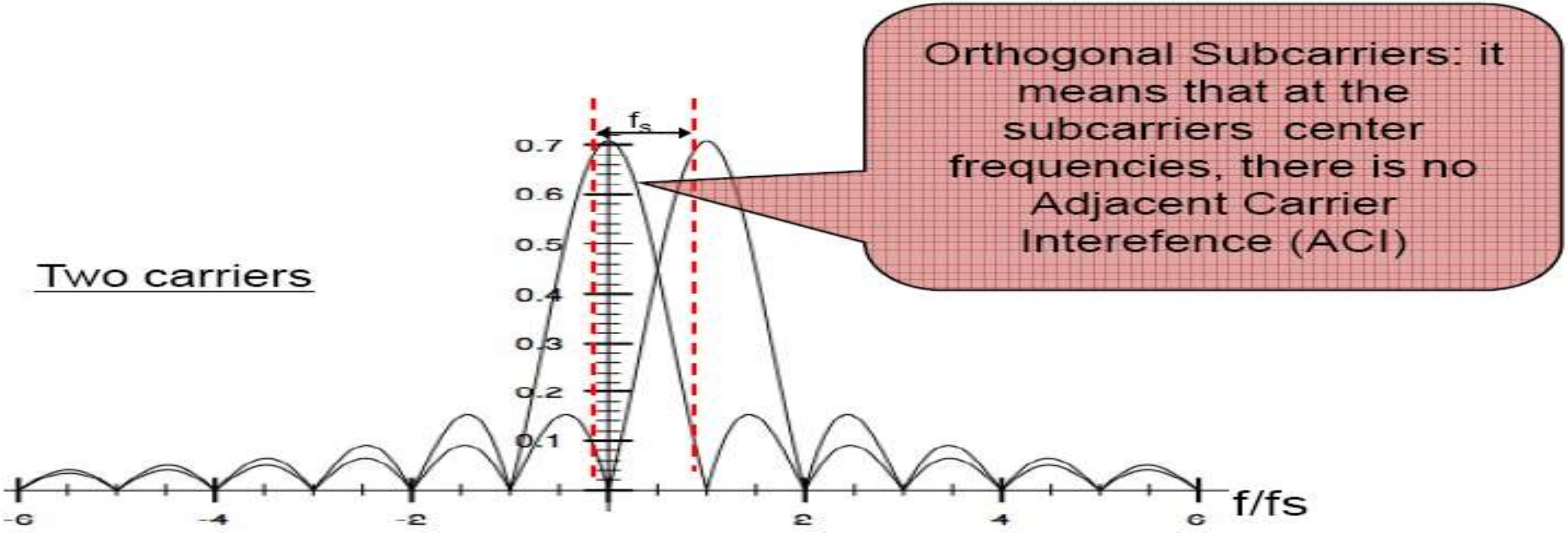
- Suatu pulsa kotak merupakan opsi sinyal yang baik dan mudah diimplementasikan.
- Pulsa kotak dalam kawasan frekuensi memiliki spektrum dengan null terletak pada kelipatan integer dari 1/durasi simbol.
- Puncak daya terletak pada center frequency .



# OFDM

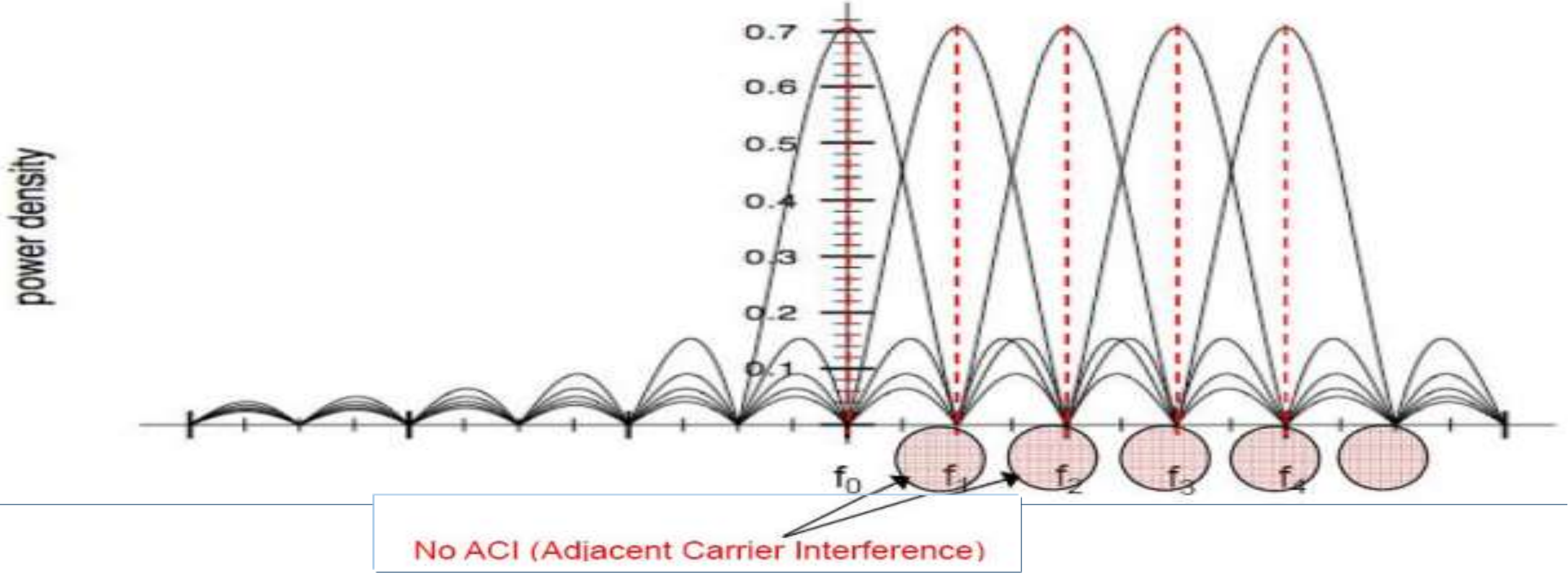
OFDM secara sederhana menempatkan next carrier persis di null pertama dari carrier sebelumnya.

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



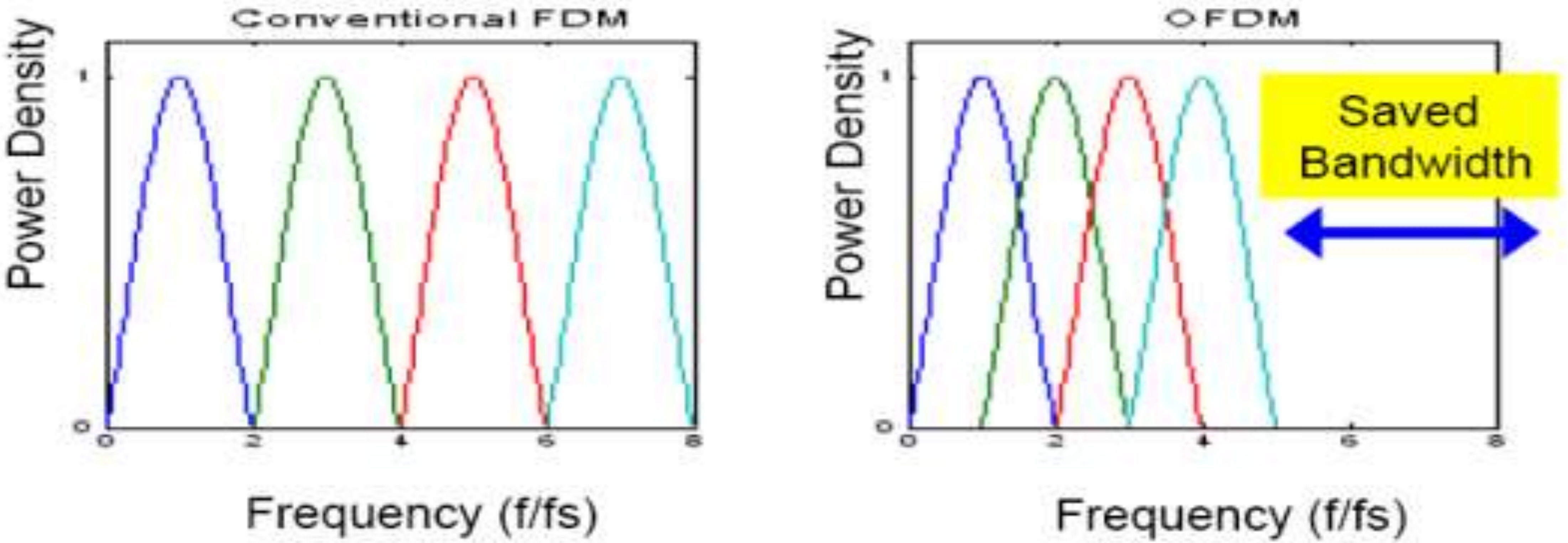
# Overlapping Spektrum pada OFDM

$$f_n = f_0 + nf_s = f_0 + n\frac{1}{T_s} \qquad n = \ldots -1, 0, 1, 2 \ldots$$

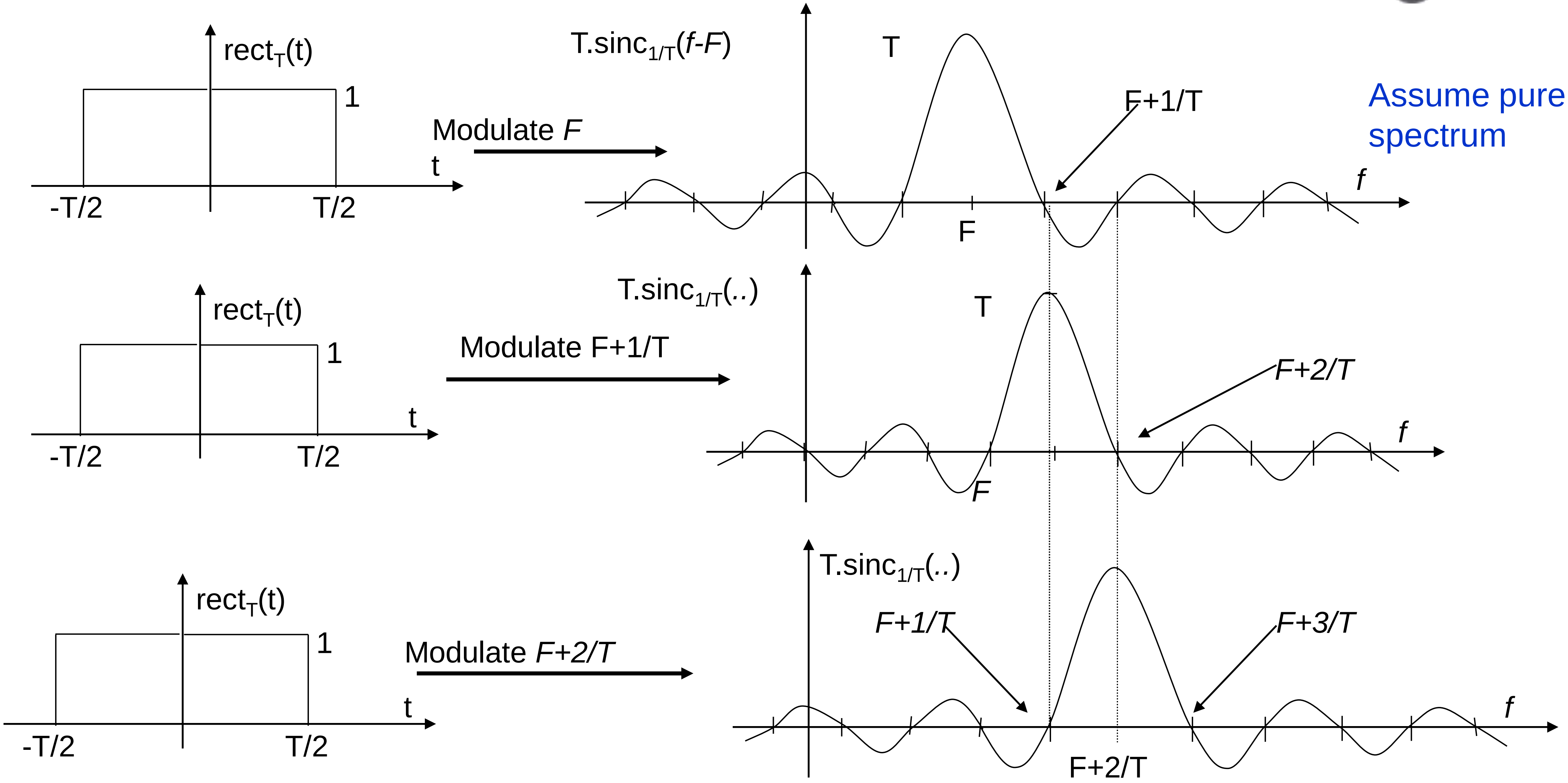


# OFDM

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



# Combining OFDM sub-bands



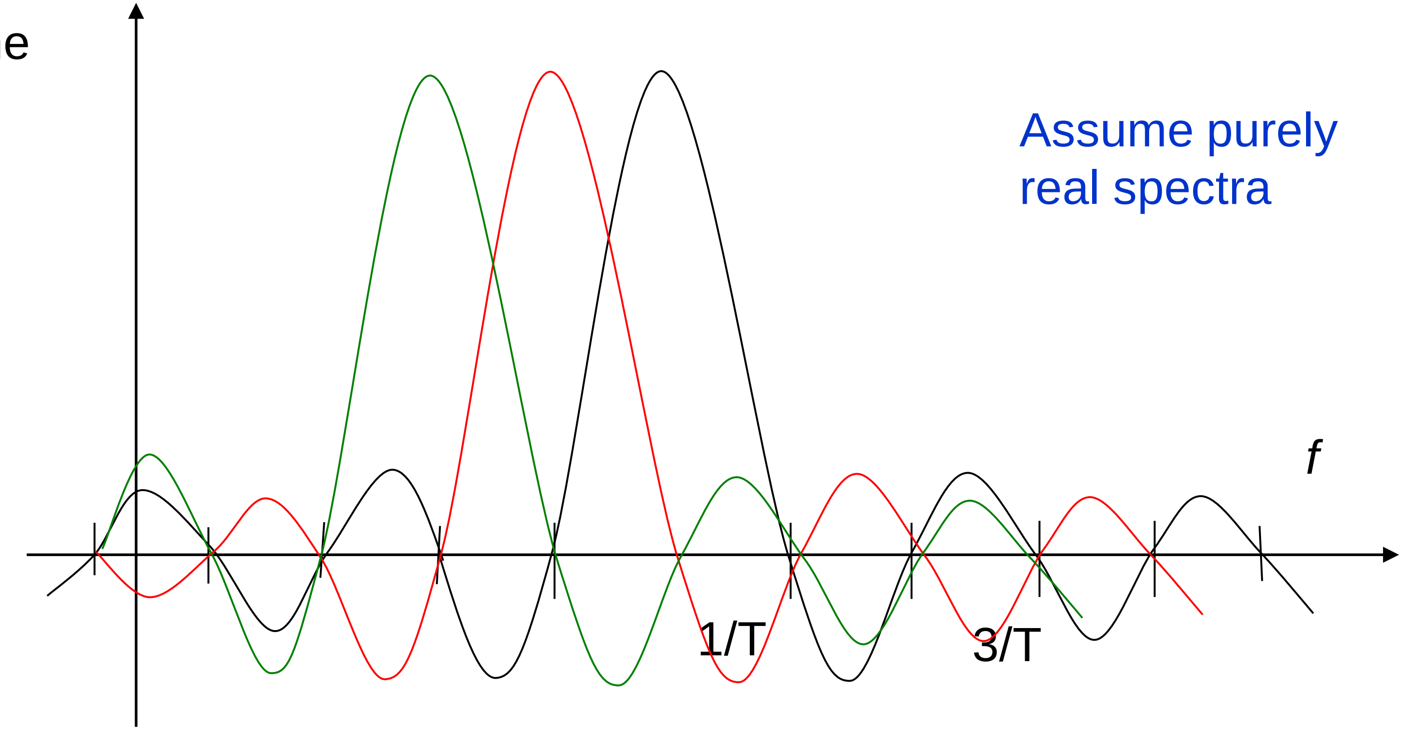

Assume purely real spectrum

# OFDM spectrum

SUM

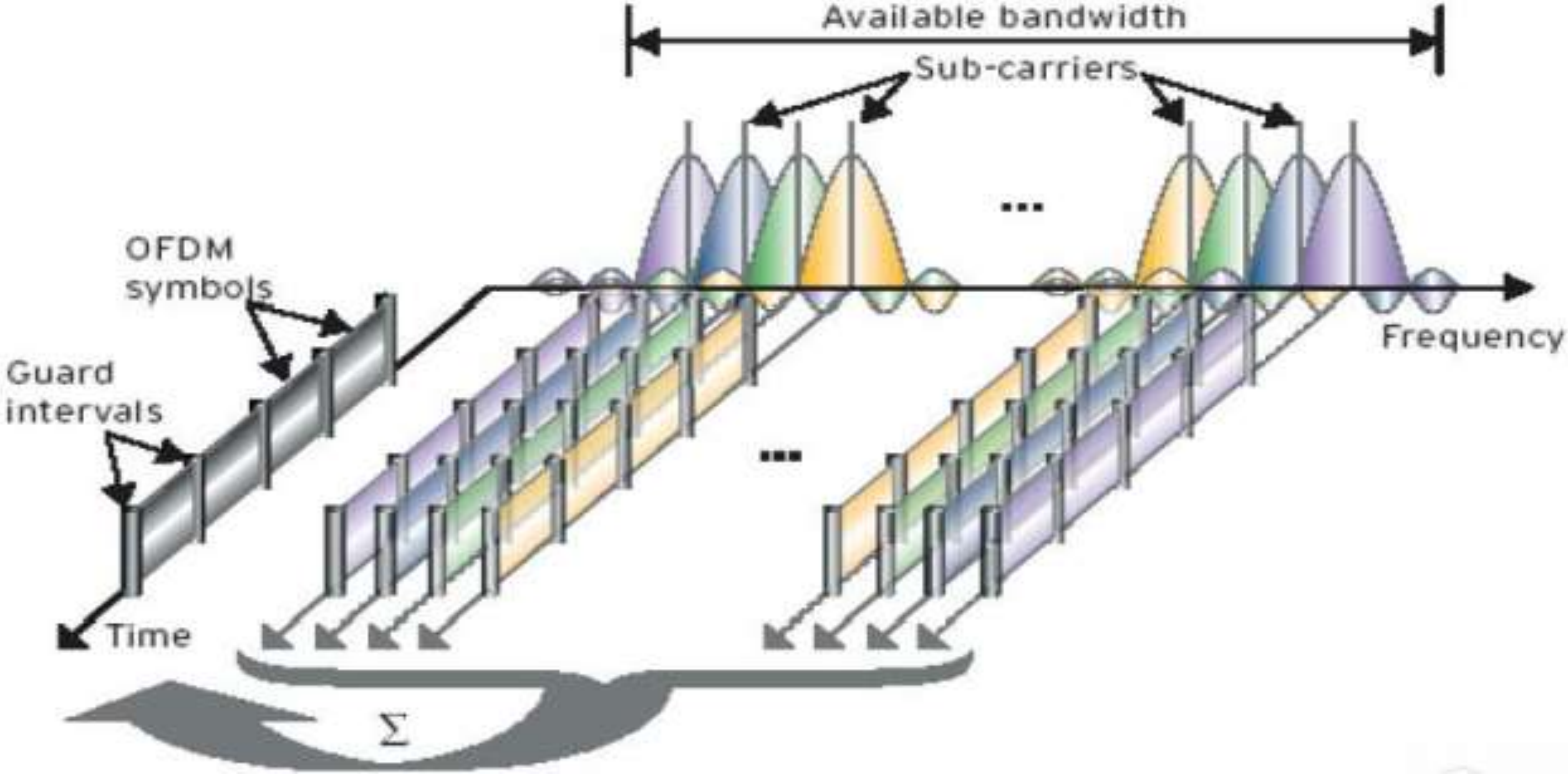
Fourier transform

Combine
real
spectra



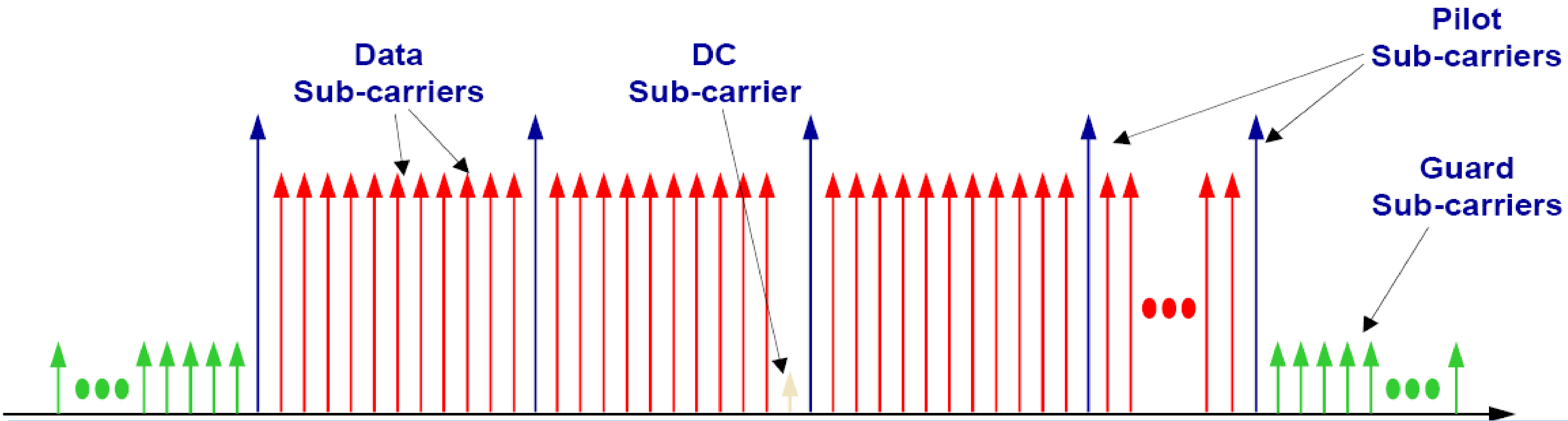

Assume purely
real spectra

# Sinyal OFDM



Available bandwidth
Sub-carriers
...
OFDM symbols
Guard intervals
Frequency
...
Time
Σ

# 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.

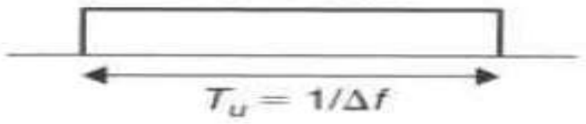
**Null Subcarrier**

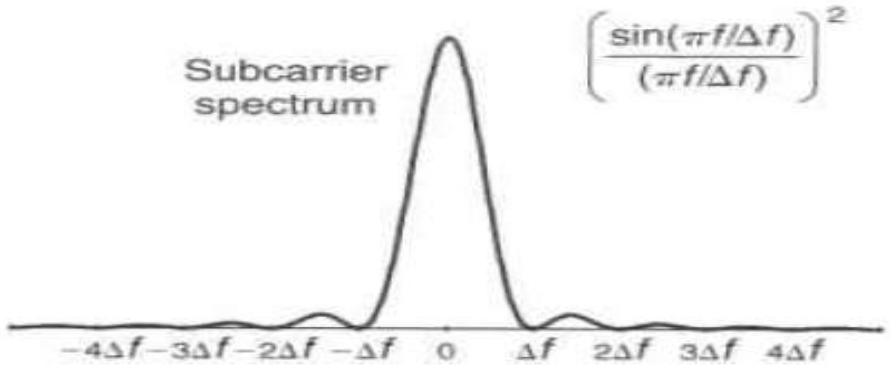
- Guard Sub-carriers
- DC Sub-carrier

# OFDM – Signal properties

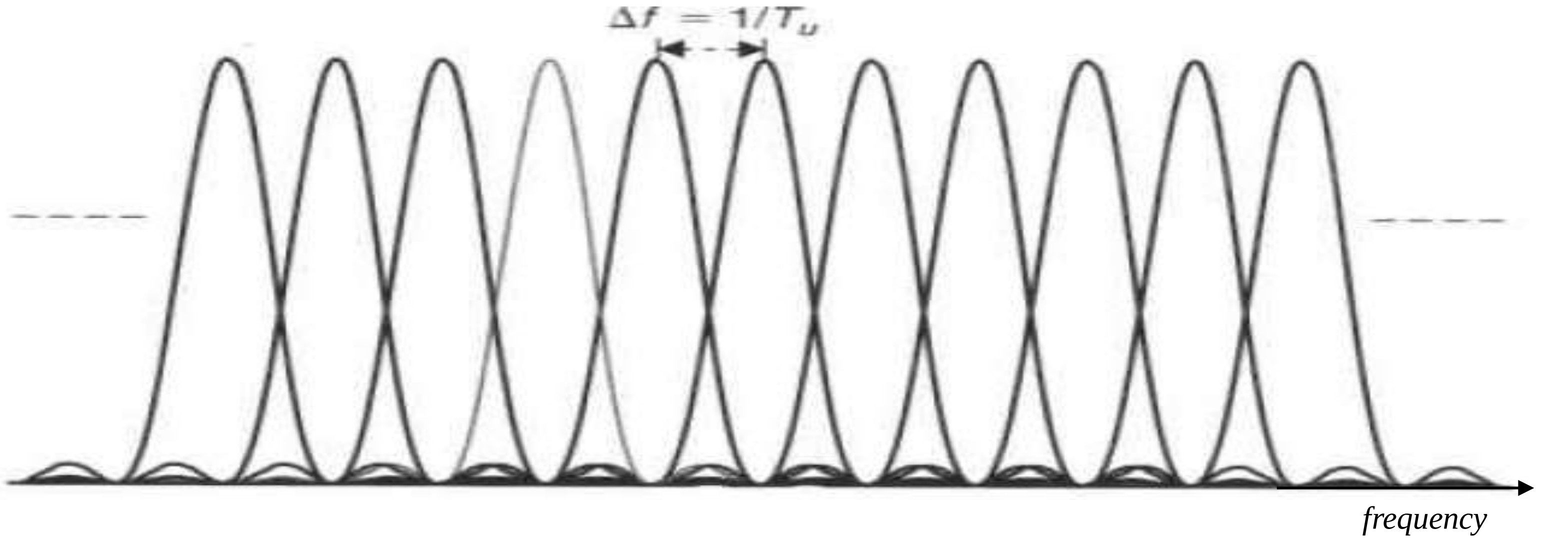
Frequency domain

Time domain



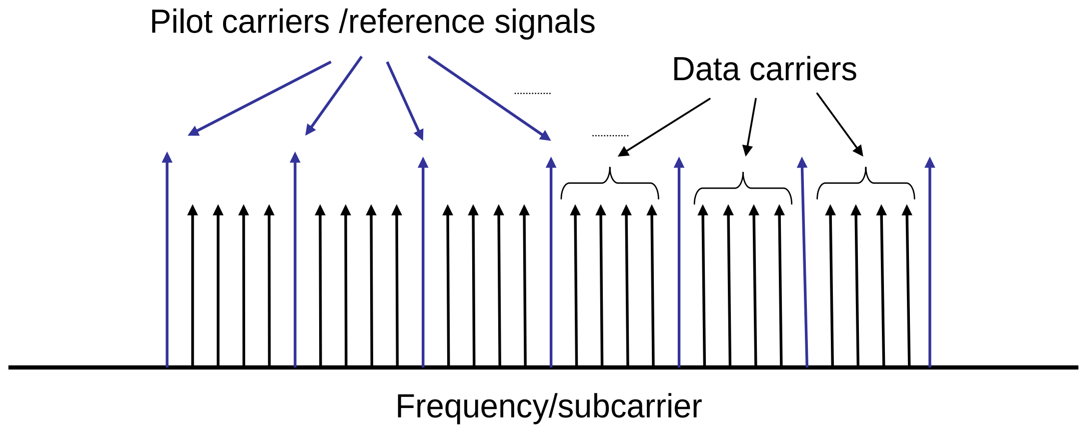



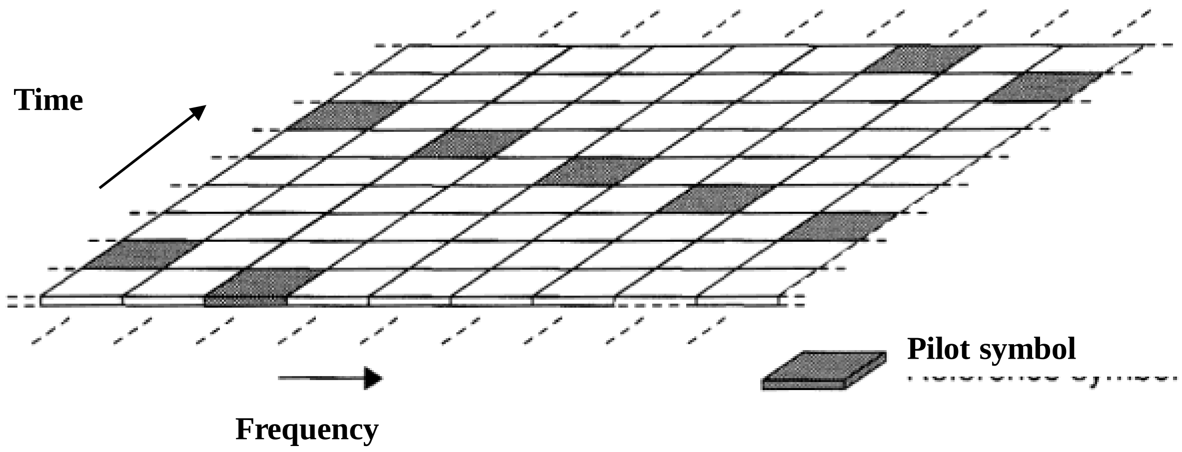

Power Spectrum for OFDM symbol



# Channel Estimation_pilot symbols

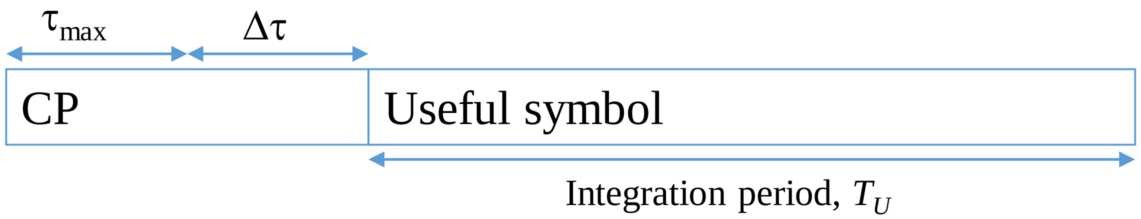
- The channel parameters can be estimated based on known symbols (pilot symbols)
- The pilot symbols should have sufficient density to provide estimates with good quality (tradeoff with efficiency)
- Different estimation methods exist
  - Averaging combined with interpolation
  - *Minimum-mean square error* (MMSE)



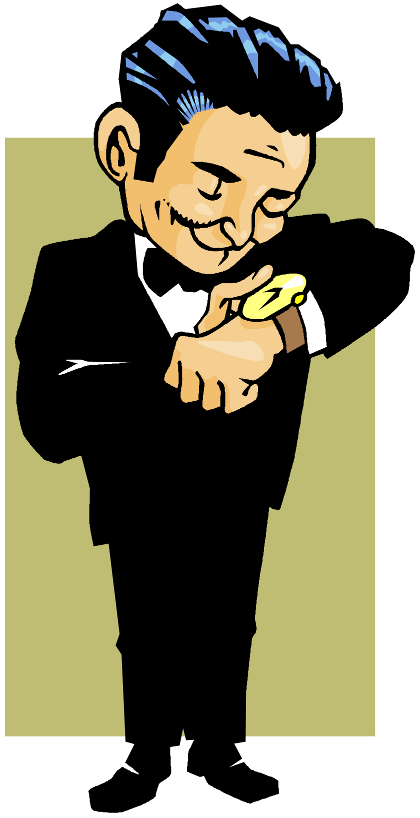



# OFDM Synchronization

- Timing recovery
  - No problem if offset is within $\Delta\tau$

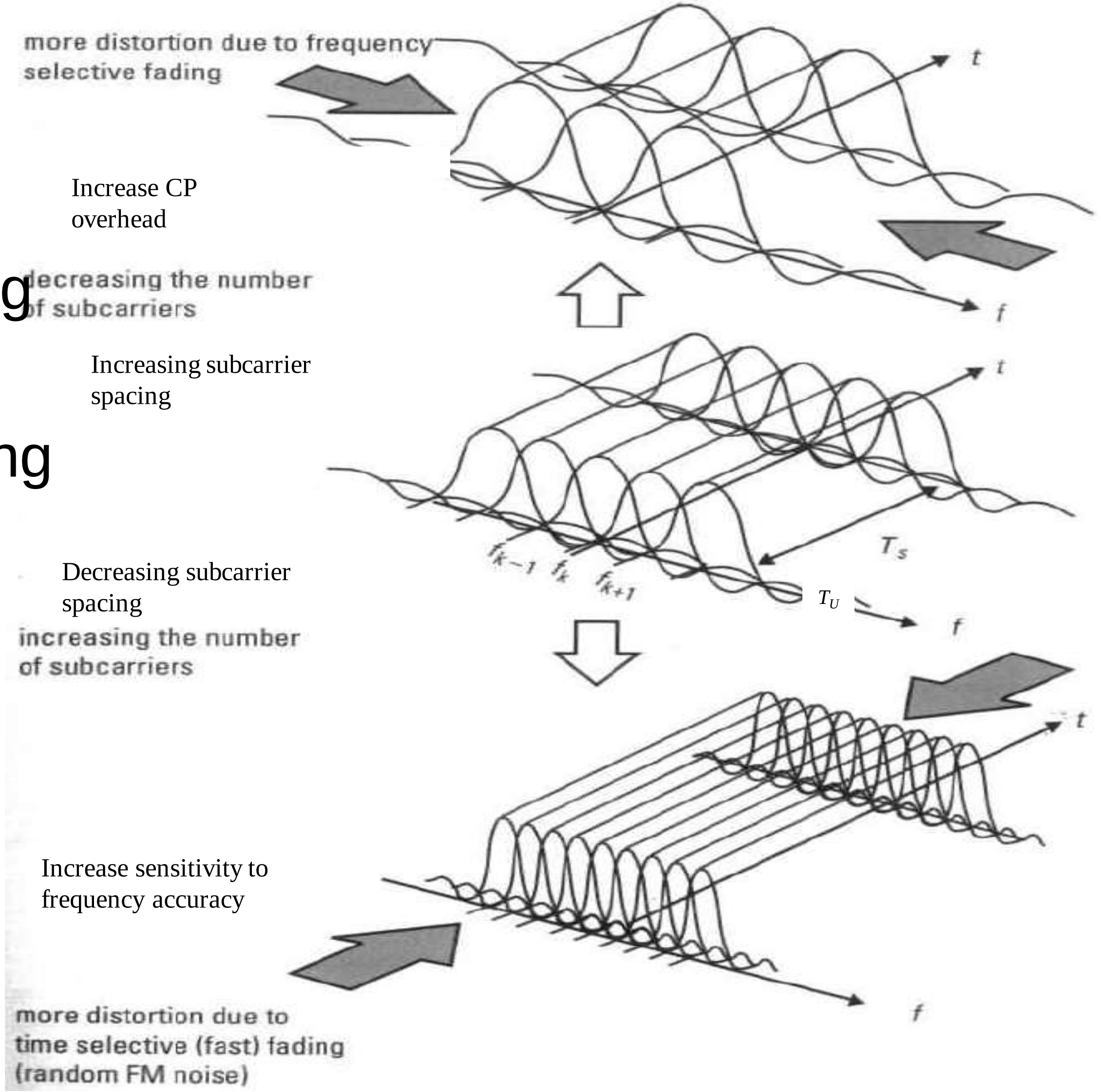



- Frequency synchronization
  - A carrier synchronization error will introduce phase rotation, amplitude reduction and ICI
  - Frequency offsets of up to 2 % of $\Delta f$ is negligible
  - Even offsets of 5 – 10 % can be tolerated in many situations

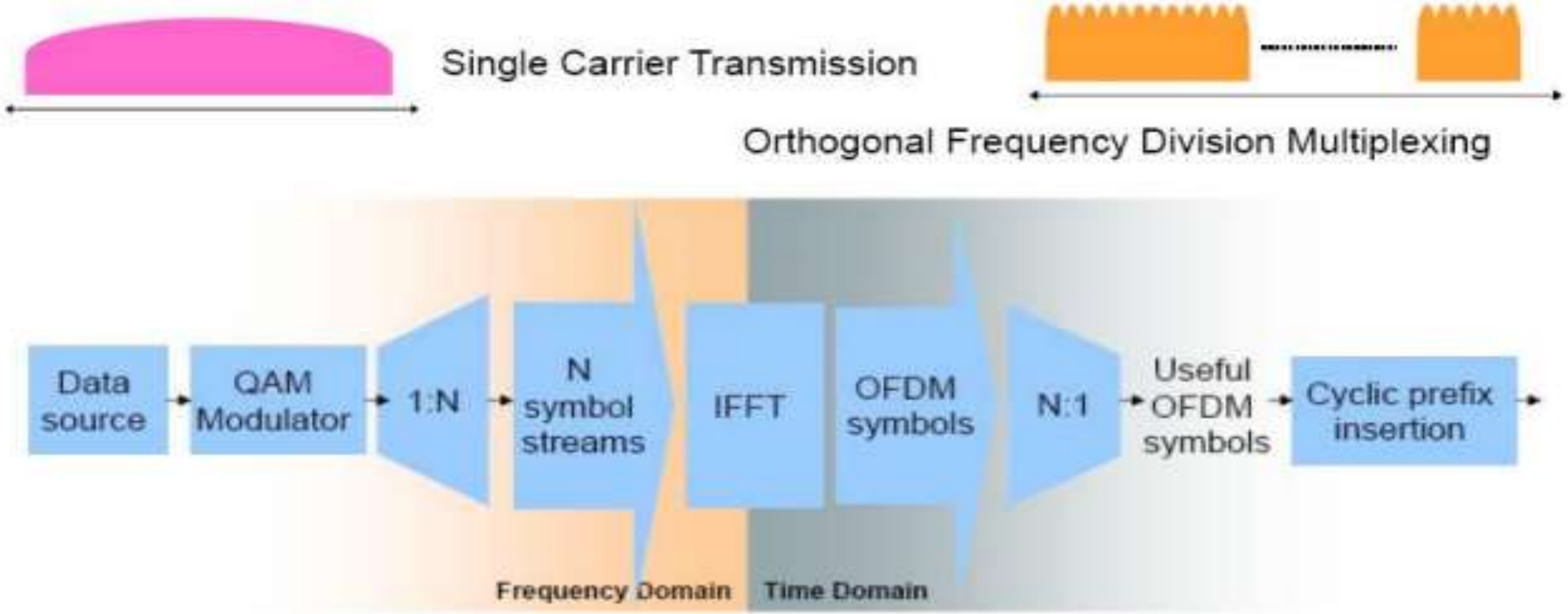


# Choosing the OFDM parameters

- Symbol time ($T_U$) and subcarrier spacing ($\Delta f$) are inverse
  - $T_U = 1/\Delta f$
- Consequences of increasing the subcarrier spacing
  - Increase cyclic prefix overhead
- Consequences of decreasing the subcarrier spacing
  - Increase sensitivity to frequency inaccuracy
  - Increasing number of subcarriers increases Tx and Rx complexity

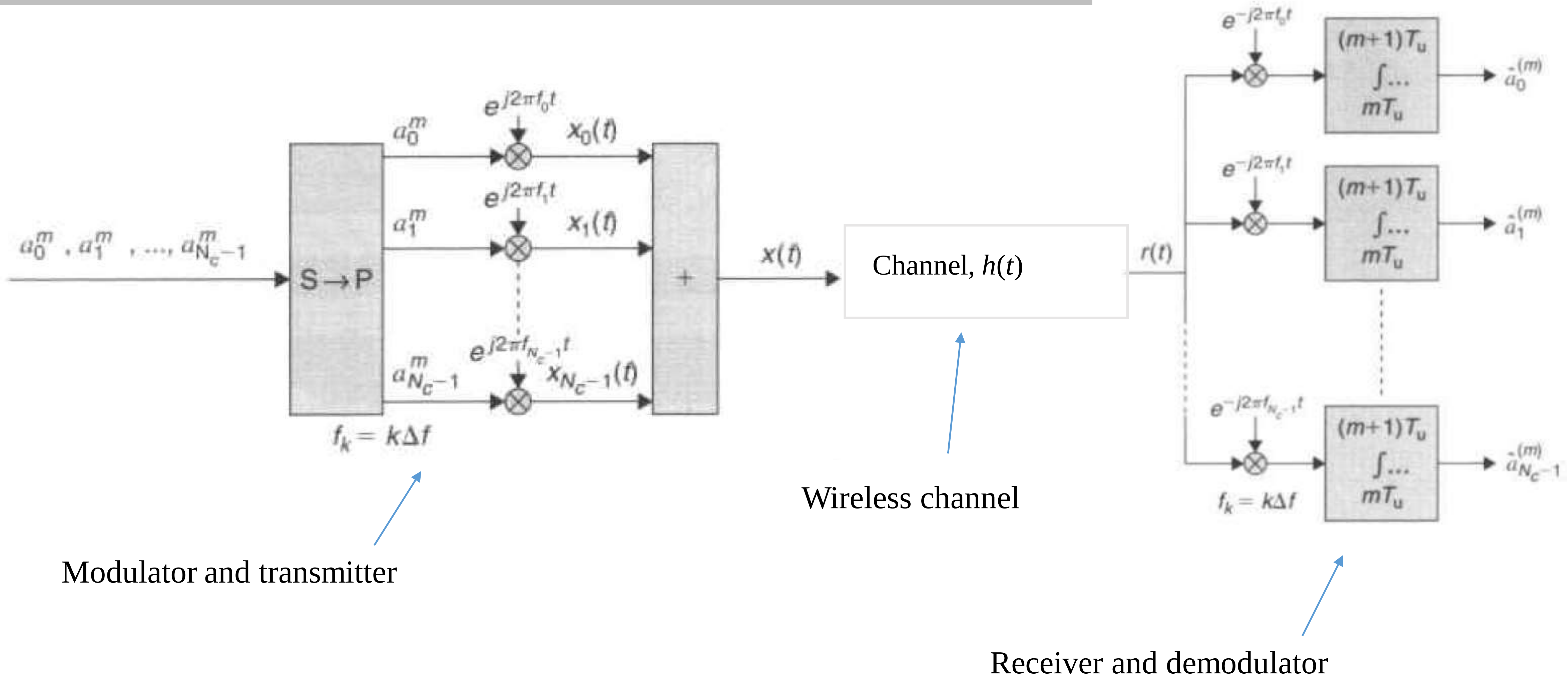


# OFDM

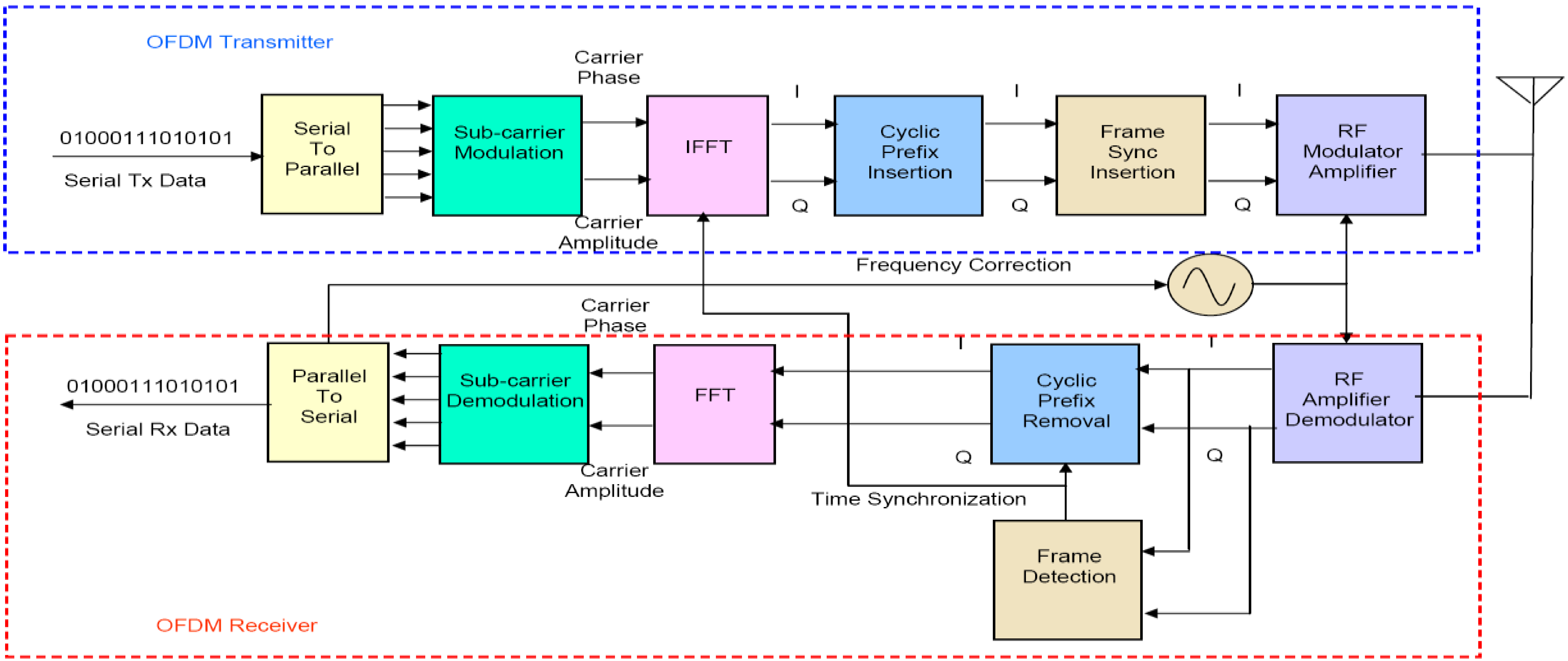



OFDM signal generation is based on Inverse Fast Fourier Transform (IFFT) operation on transmitter side. On receiver side, an FFT operation will be used.

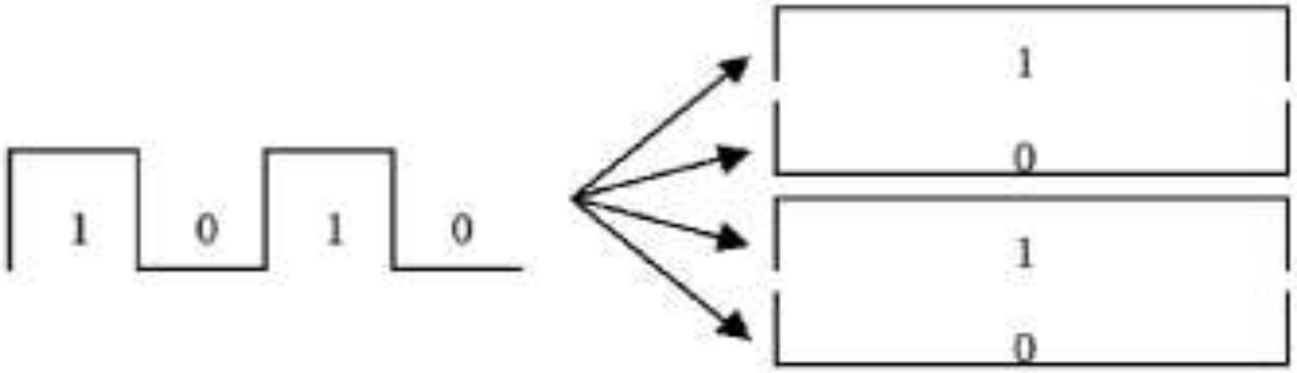
# OFDM Transmission model

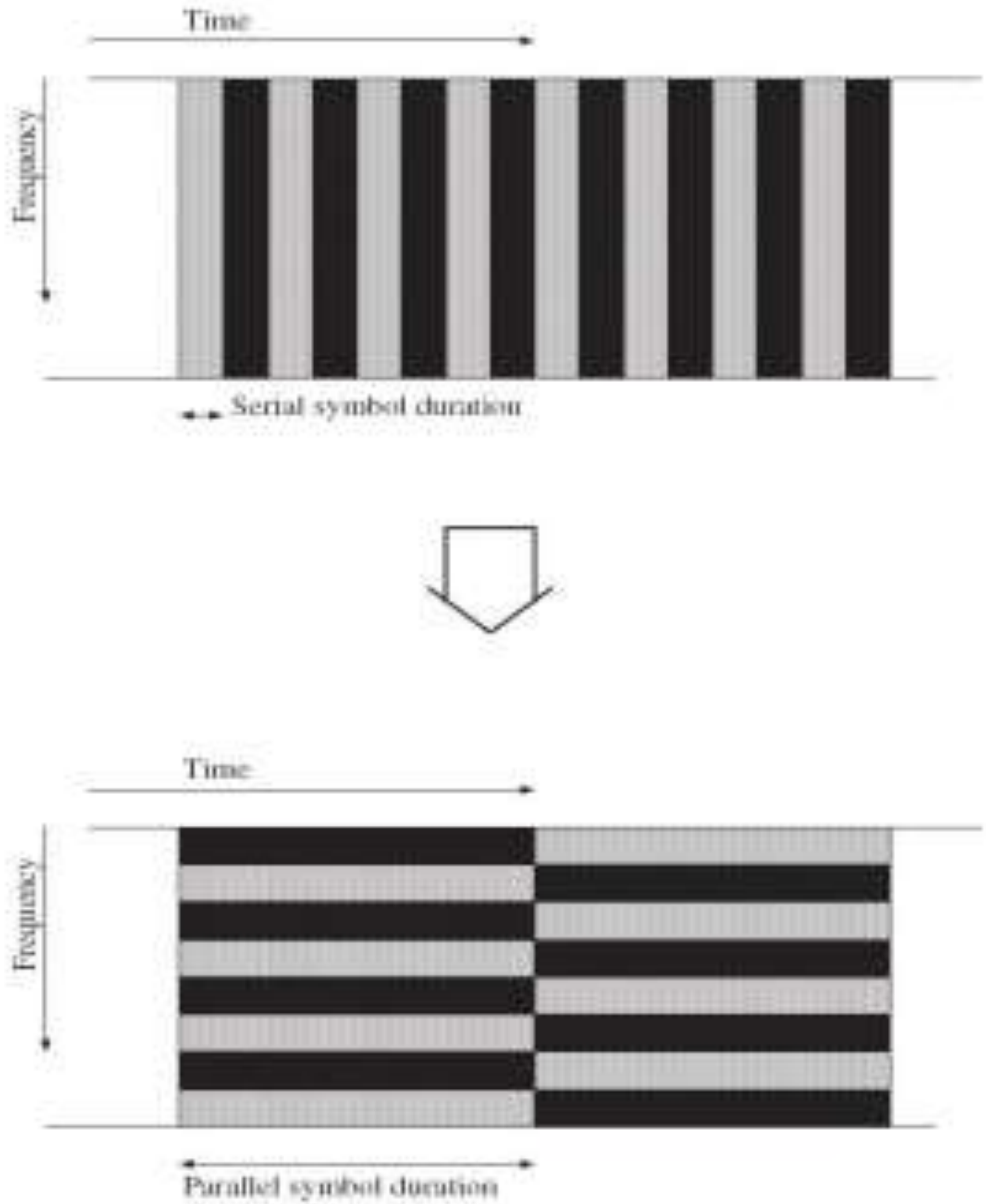


# OFDM Transceiver

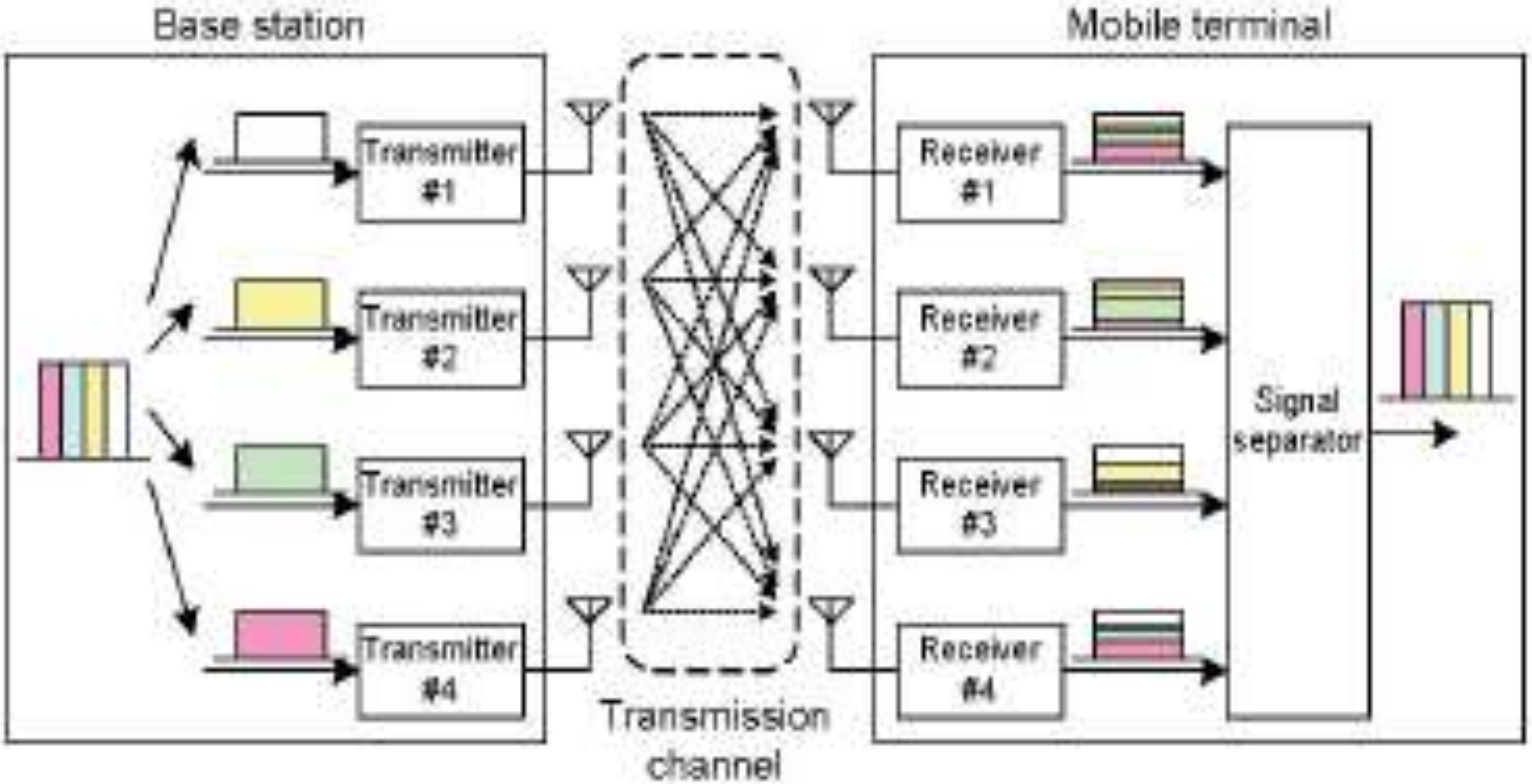


# The parallel principle

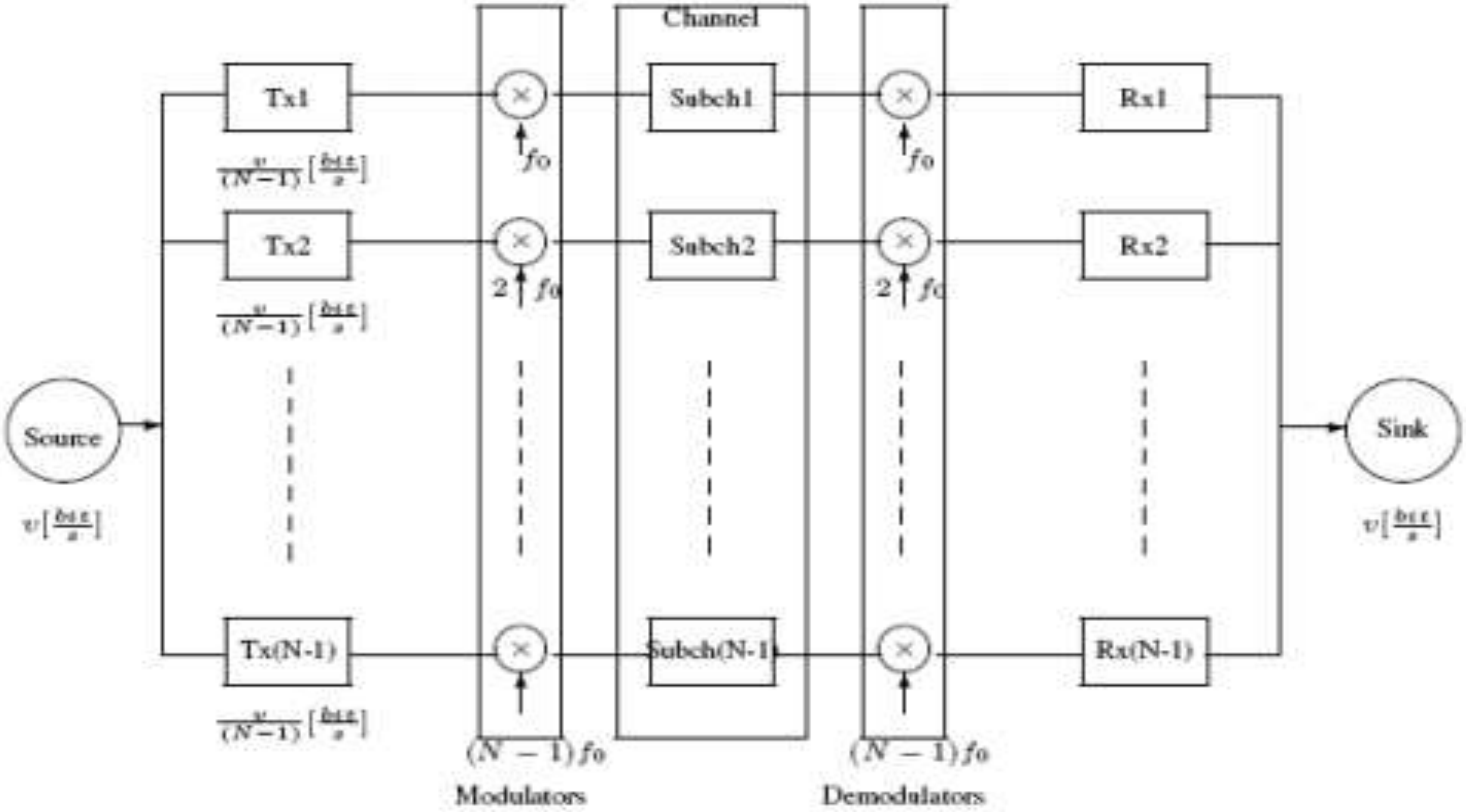


# LTE MIMO concept



# The modem parallel orthogonal

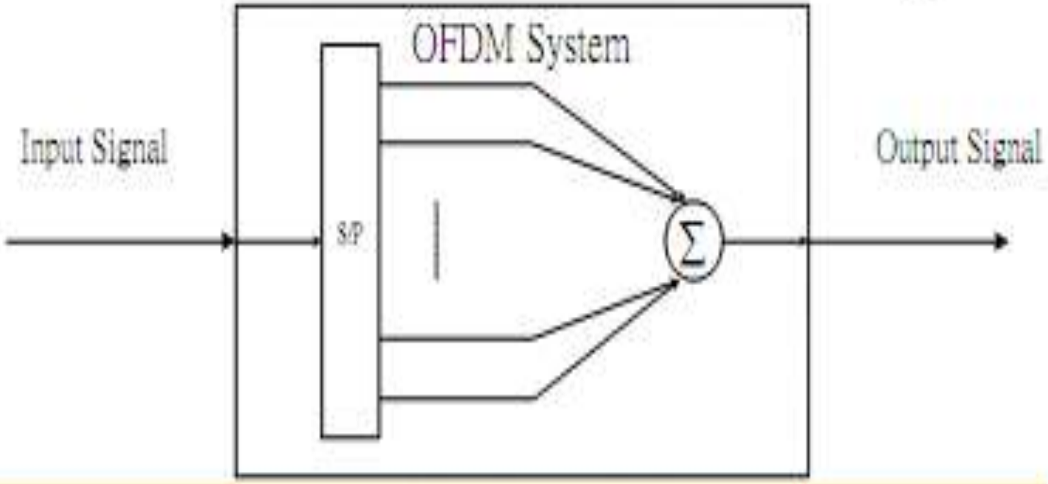


- Because of its high-speed data transmission and effectiveness in combating the frequency selective fading channel, OFDM technique is widely used in wireless communication nowadays.

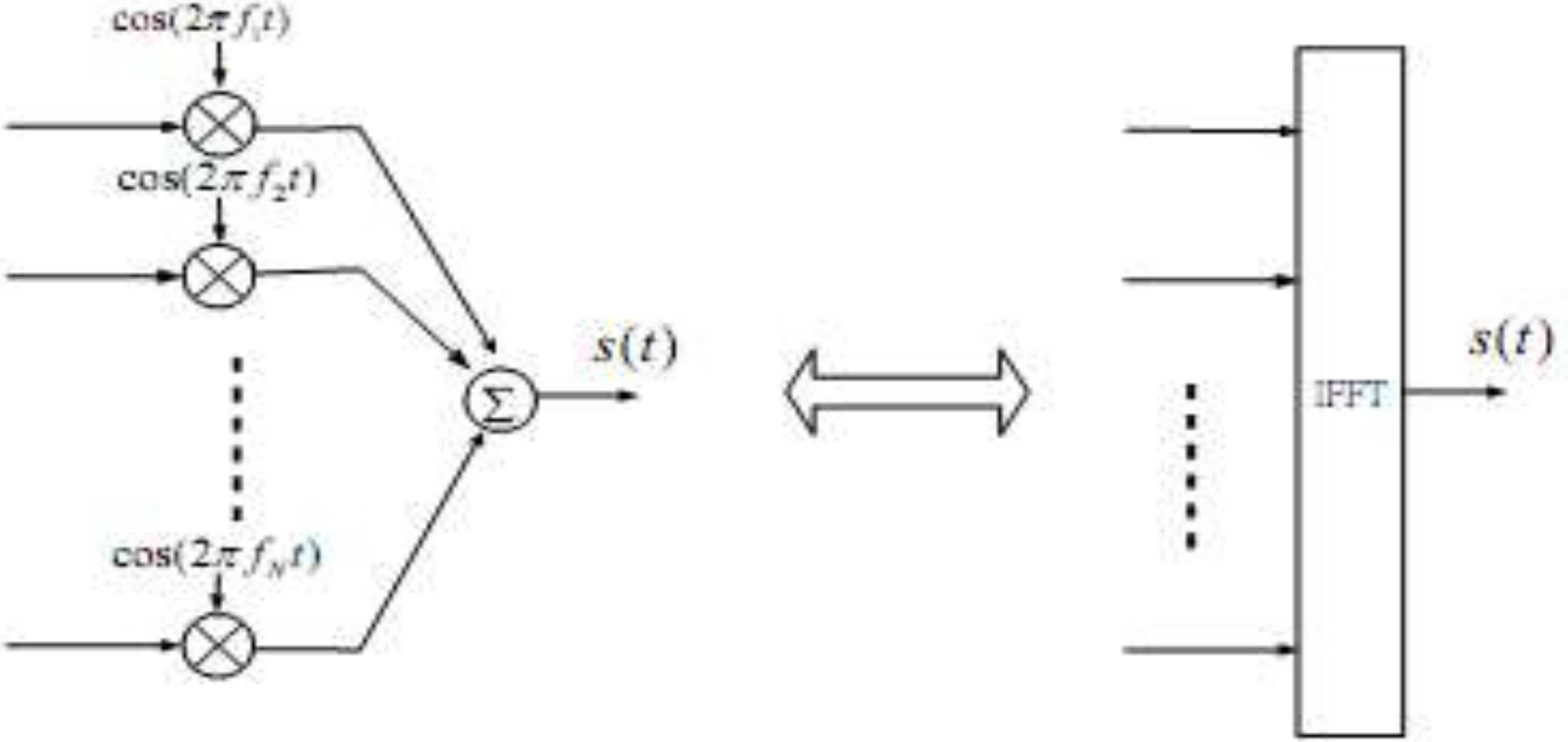
- Orthogonal frequency division multiplexing (OFDM) is a multi-carrier transmission technique, which divides the available spectrum into many subcarriers, each one being modulated by a low data rate stream.

- OFDM is a special case of multicarrier transmission , where a single data stream is transmitted over a number of lower rate subcarrier[1,4].

- OFDM can be viewed as either a modulation technique or a multiplex technique.
  - Modulation technique
    - Viewed by the relation between input and output signals
  - Multiplex technique
    - Viewed by the output signal which is the linear sum of the modulated signals



- The employment of discrete Fourier transform to replace the banks of sinusoidal generator and the demodulation significantly reduces the implementation complexity of OFDM modems.



# OFDM Modulation using FFTs

**On line signal**

$$x(t)=\sum_{k=0}^{N-1}\sum_{l} c_l^k \psi_k(t-lT)$$

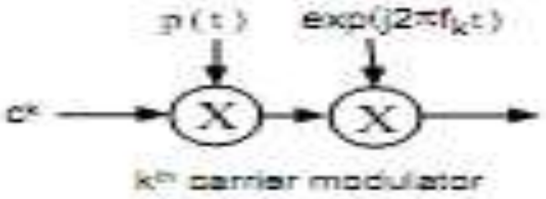
c: data
Ψ: pulse

**Orthogonality principle**

$$\int_0^T \psi_k(t)\psi_i^*(t)dt=\begin{cases}1\ ;\ if\ i=k\\ 0\ ;\ if\ i\neq k\end{cases}$$

Let us assume $\psi_k(t)=p(t)e^{j2\pi f_k t}$ and $f_k=k/T$ ⇒ $x(t)=\sum_{k=0}^{N-1}\sum_{l} c_l^k p(t-lT)e^{j2\pi f_k t}$

Modulator bank of type




Sampling at $T_s=T/N$

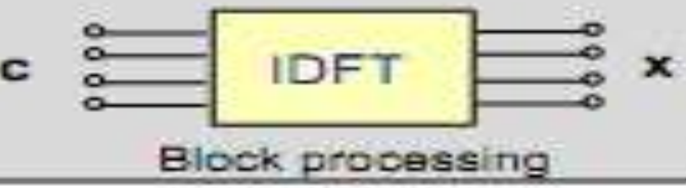
$$x[n]=\sum_{k=0}^{N-1}\sum_{l} c_l^k\,\mathrm{rect}(nT_s-lNT_s)e^{j2\pi knT_s/NT_s}=\sum_{k=0}^{N-1}\sum_{l} c_l^k\,\mathrm{rect}(n-lN)e^{j2\pi kn/N}$$

where $\mathrm{rect}[n-lN]=\begin{cases}1;\ lN<n\leq(l+1)N\\ 0;\quad else\end{cases}$ It can be expressed as

$$x[n]=\sum_{l}\mathrm{rect}[n-lN]\sum_{k=0}^{N-1}c_l^k e^{j2\pi kn/N}=\sum_{l}\mathrm{rect}[n-lN]IDFT(\mathbf{c}_l,n)$$

1 OFDM symbol carries N data c

$$x[n]=IDFT(\mathbf{c}_l,n)\ ;\ lN<n\leq(l+1)N$$



# 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.

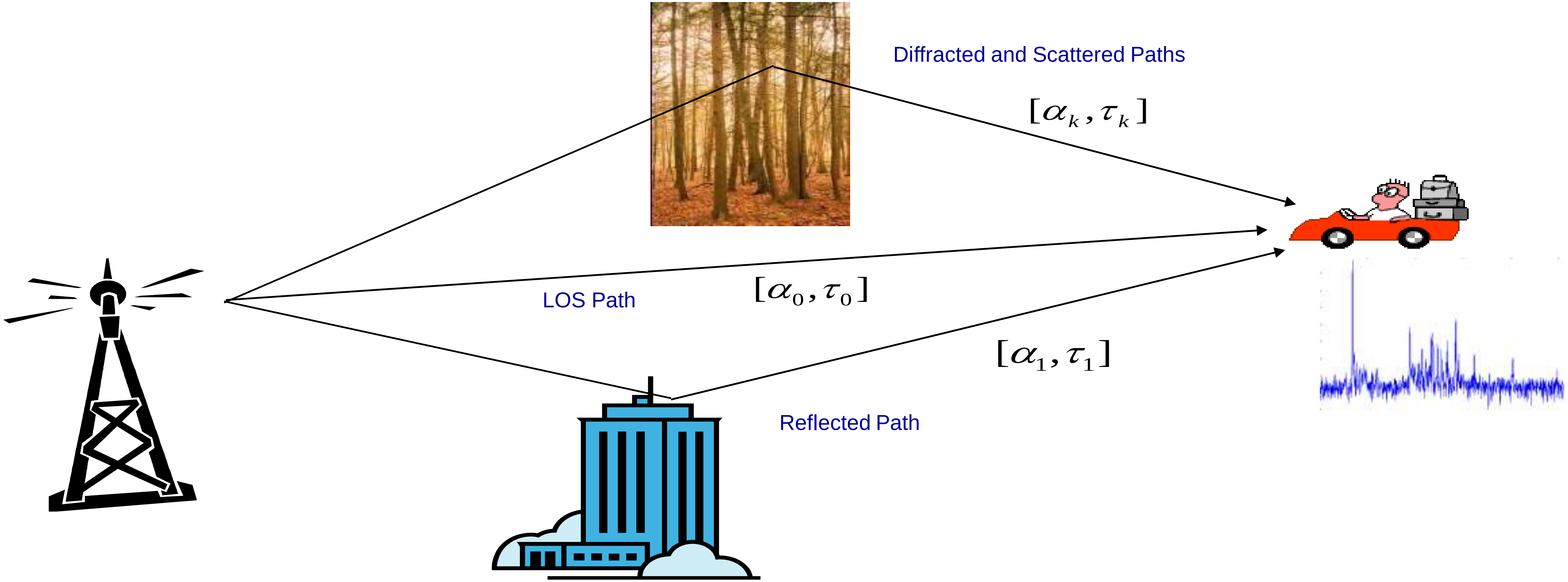
(iii) Equalisation is easier than with single carrier systems which use adaptive filtering. OFDM receiver can amplify real & imag parts of FFT outputs such that they have same amplitudes.

Possible because of the cyclic extension as explained earlier.

# Disadvantages of OFDM

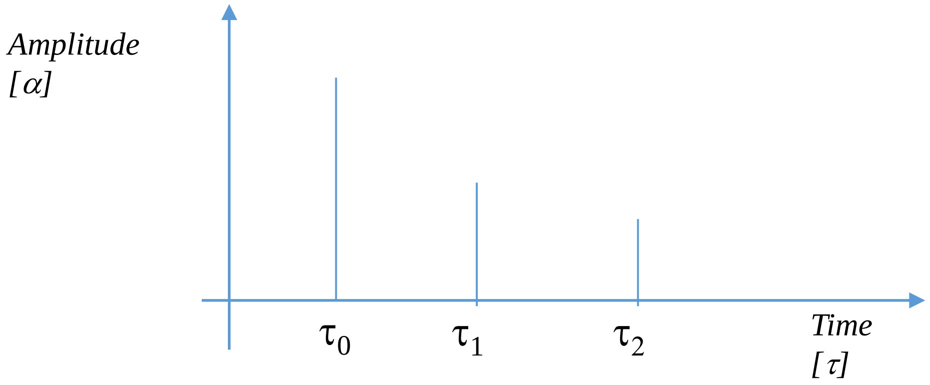
- 'Peak to mean' ratio of symbols can be very large by nature of FFT & Inv-FFT. (Amplitudes can become very large in comparison to the mean)
- Shapes OFDM symbols very complex & must be sent & received accurately.
- With QPSK on each sub-carrier, $\approx 10^{29}$ shapes & even more with 64-QAM
- Transmitter & 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.

# Effect of Multipath channel

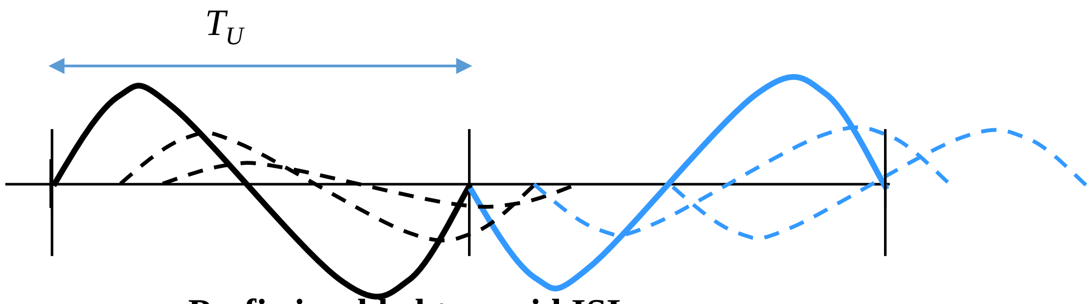


# Multipath Channel (Cyclic Prefix)

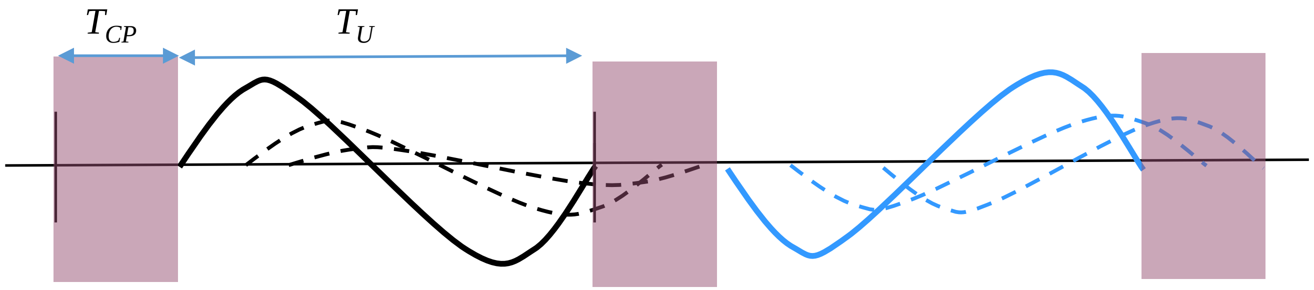
Example multipath profile



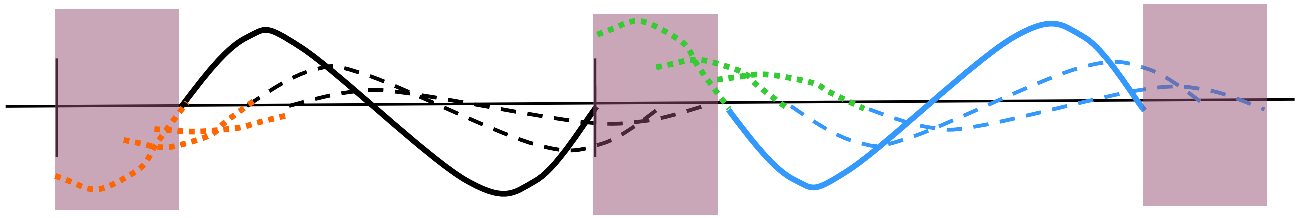

**Multipath introduces *inter-symbol-interference* (ISI)**




**Prefix is added to avoid ISI**

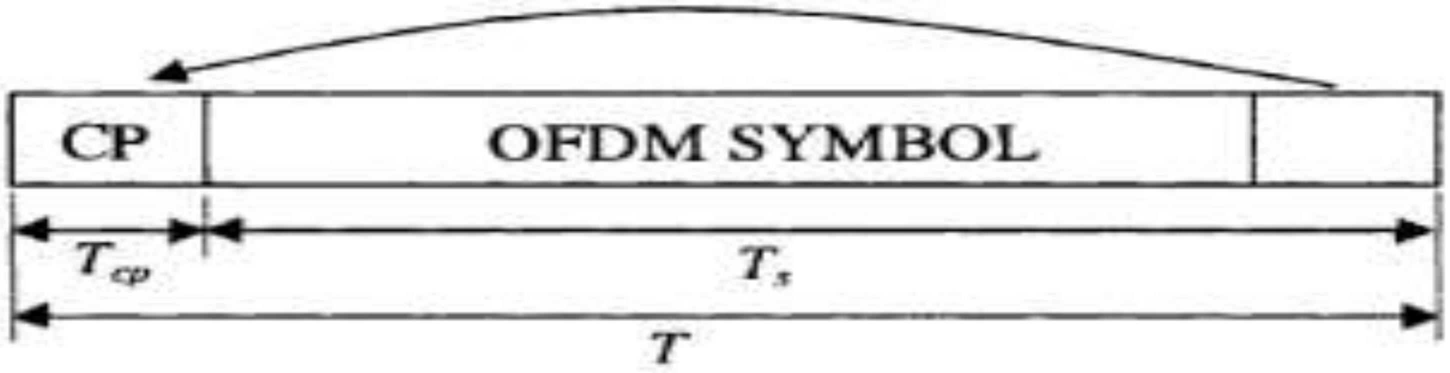


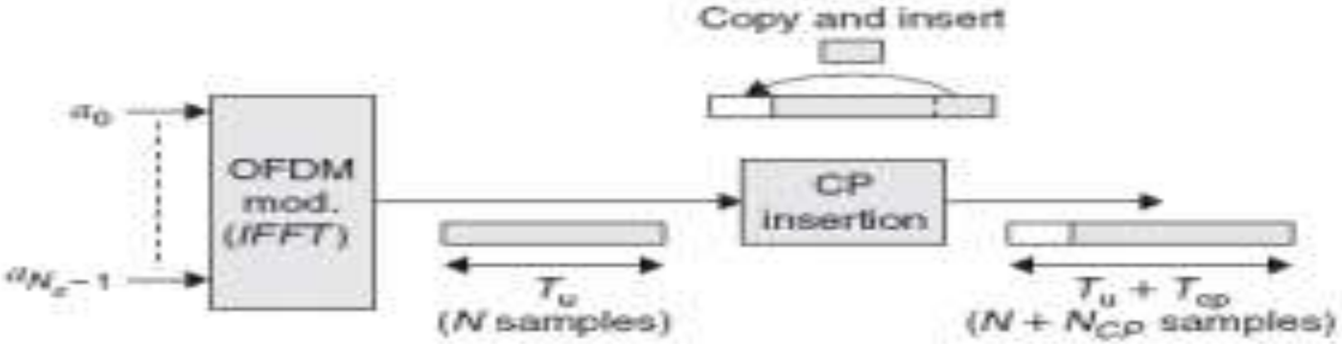

**The prefix is made cyclic to avoid *inter-carrier-interference* (ICI) (maintain orthogonality)**

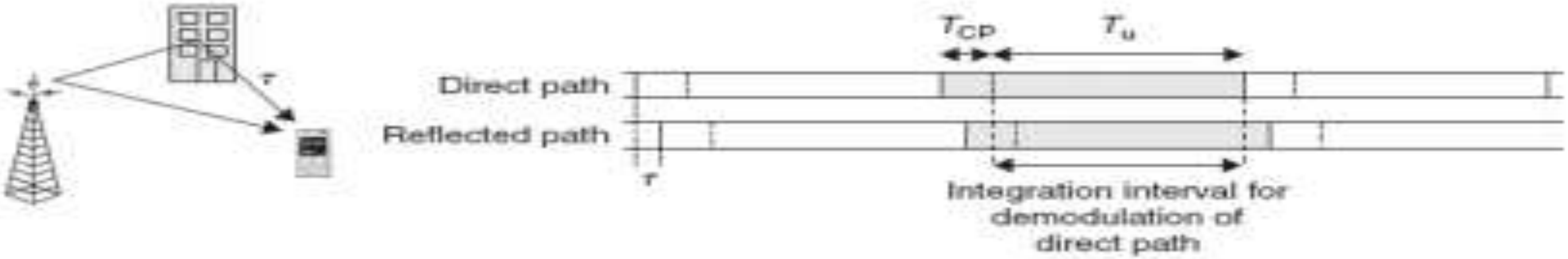


# Cyclic Prefix

- Principle

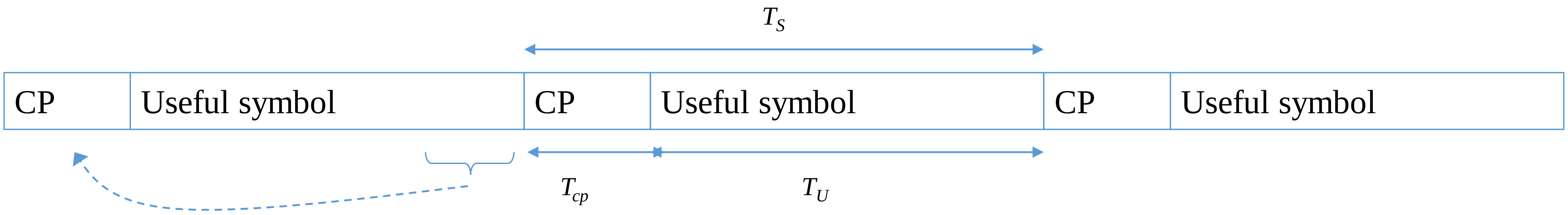


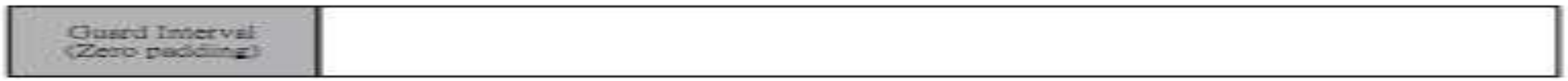
# Cyclic Prefix for Multipath channel

- $T_{cp}$ should cover the maximum length of the time dispersion
- Increasing $T_{cp}$ implies increased overhead in power and bandwidth ($T_{cp}/T_S$)
- For large transmission distances there is a trade-off between power loss and time dispersion



- Intersymbol interference is eliminated almost completely by introducing a guard interval with zero padding in every OFDM symbol.

  - Guard interval with zero padding

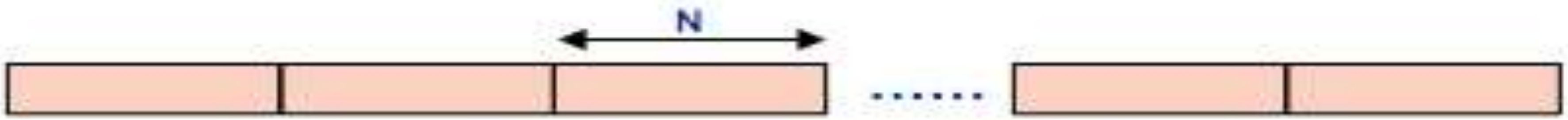



  - The way to eliminate ISI

- In the guard time , the OFDM symbol is cyclically extended to avoid intercarrier interference.

  - Guard interval with cyclic extension (cyclic prefix)

# Robustness against the channel and ACI improvement




**Virtual** OFDM symbols within the slot

- With guards (Cyclic prefixes), the channel's time dispersion is avoided

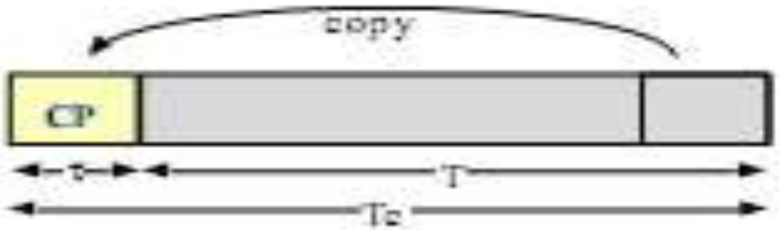

OFDM symbols with time guards (CPs)

- With smooth transitions between symbols, the Adjacent Channel Interference is minimized


OFDM symbols with time guards and shaping (extra time guard)

**Drawback**: it is implemented by using the **TIME** resource

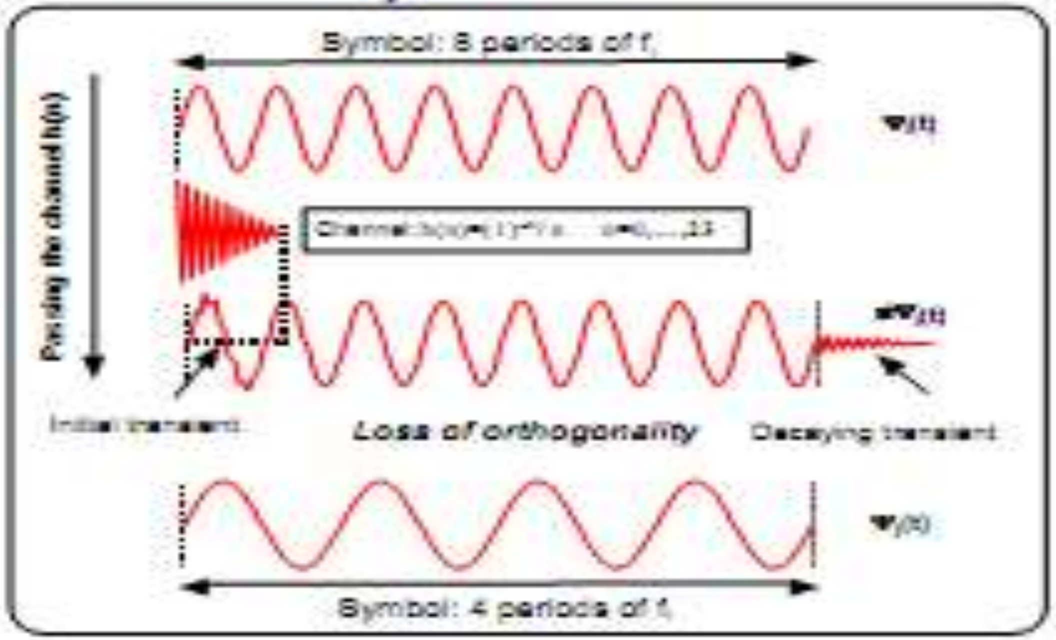
## Including a cyclic prefix to the OFDM symbol: 'special' time guards in the symbol transitions



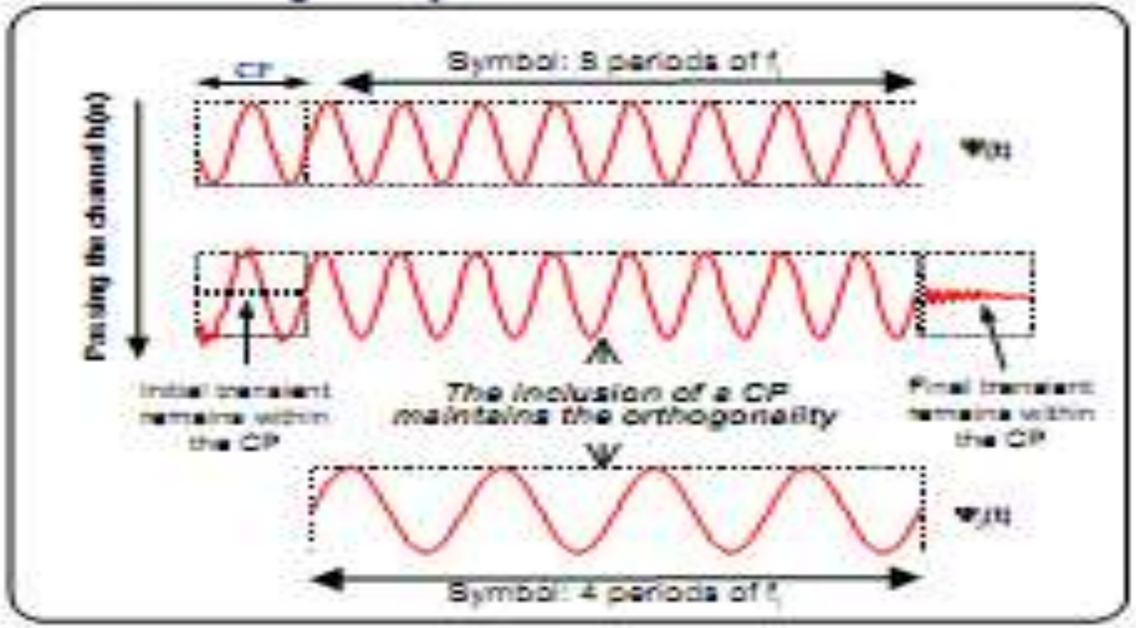

Furthermore, it converts **Lineal conv. = Cyclic conv.**

*(Method: overlap-save)*

*Without the Cyclic Prefix*



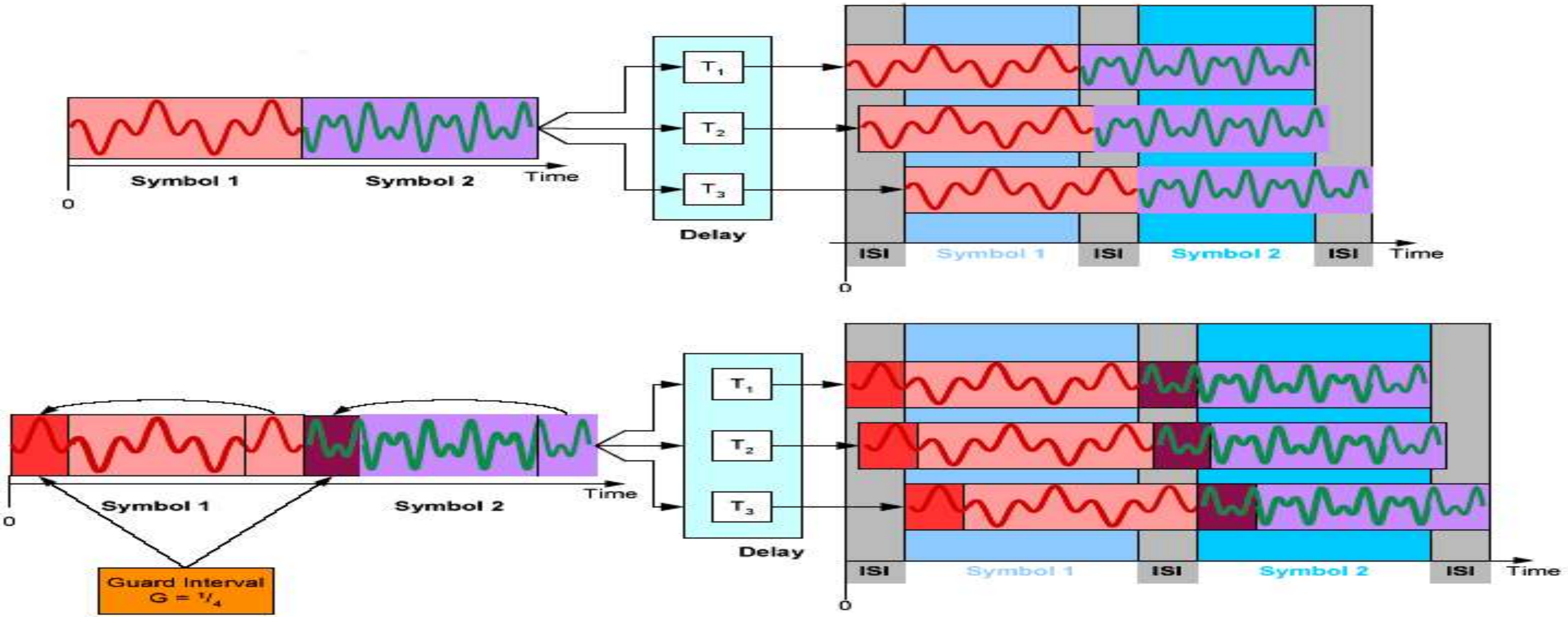

*Including the Cyclic Prefix*




CP functions:

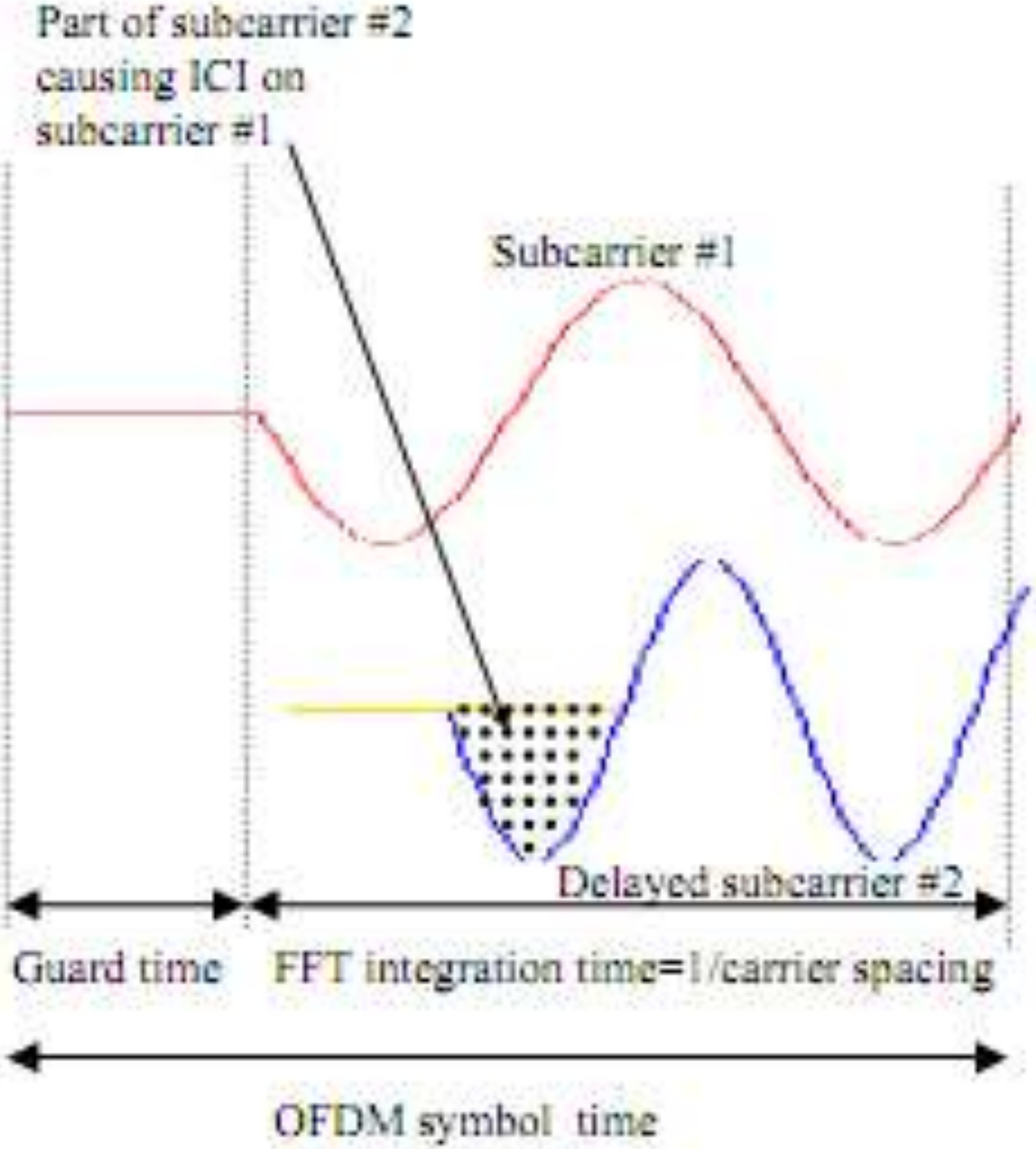
- It **accommodates** the decaying transient of the previous symbol (ISI)
- It **avoids** the initial transient reaches the current symbol (ICI)

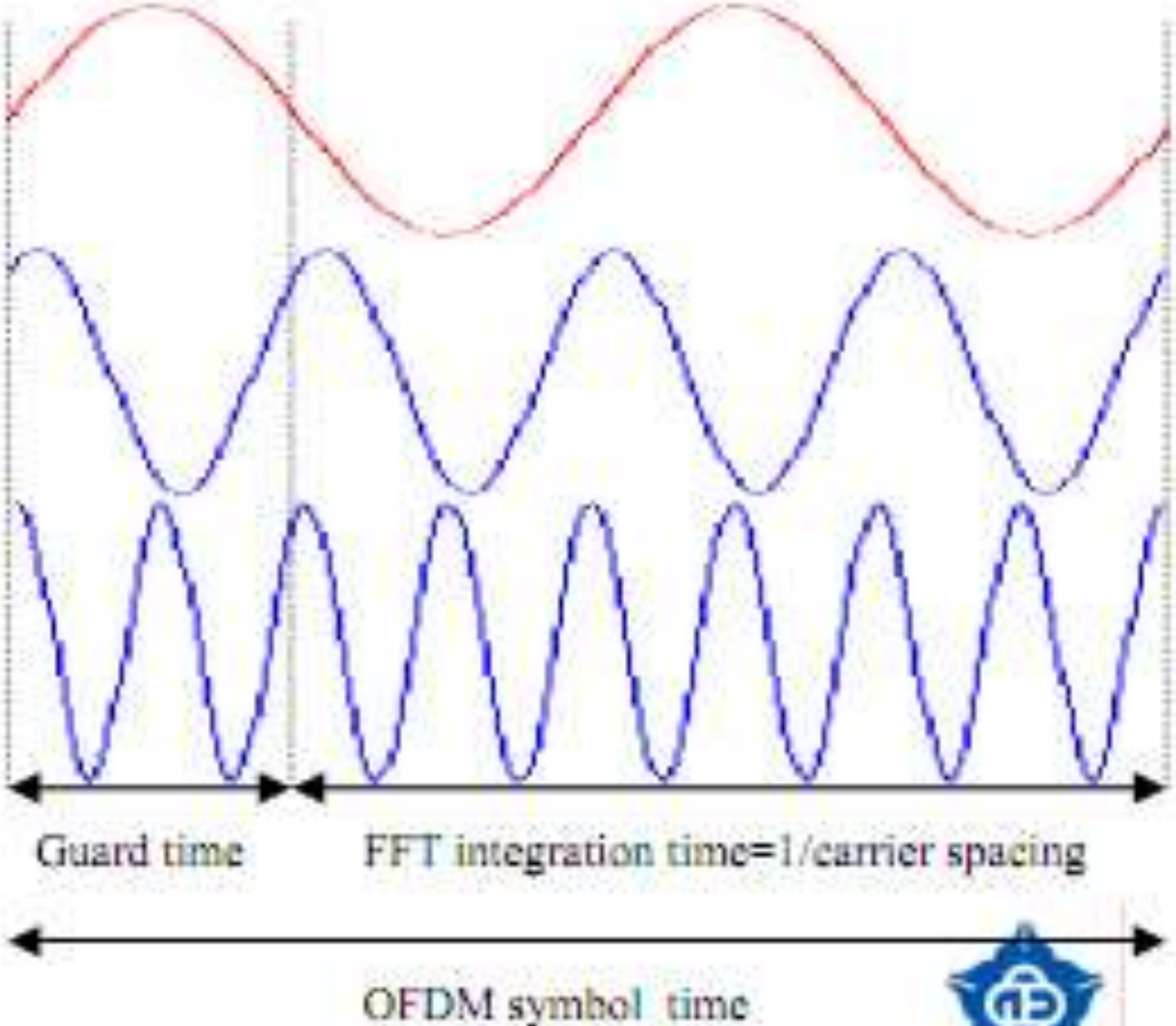
# Guard Interval (Cyclic Prefix)




- Untuk mengatasi multipath delay spread
- Guard Interval (cyclic prefix) : 1/4, 1/8, 1/16 or 1/32

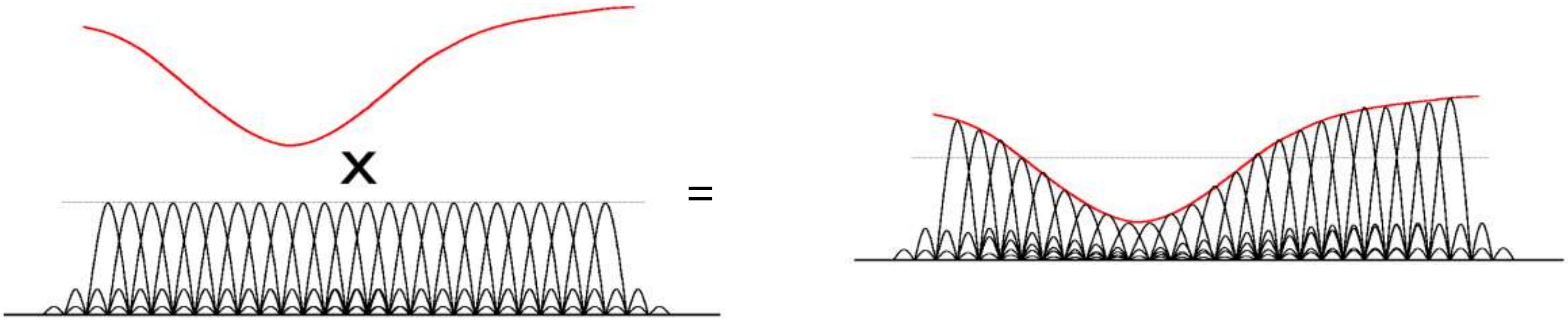
## ➢ The way to avoid ICI



# Multipath channel (frequency diversity)

- The OFDM symbol can be exposed to a frequency selective channel
- The attenuation for each subcarrier can be viewed as “flat”
  - Due to the cyclic prefix there is no need for a complex equalizer
- Possible transmission techniques
  - *Forward error correction* (FEC) over the frequency band
  - Adaptive coding and modulation per carrier

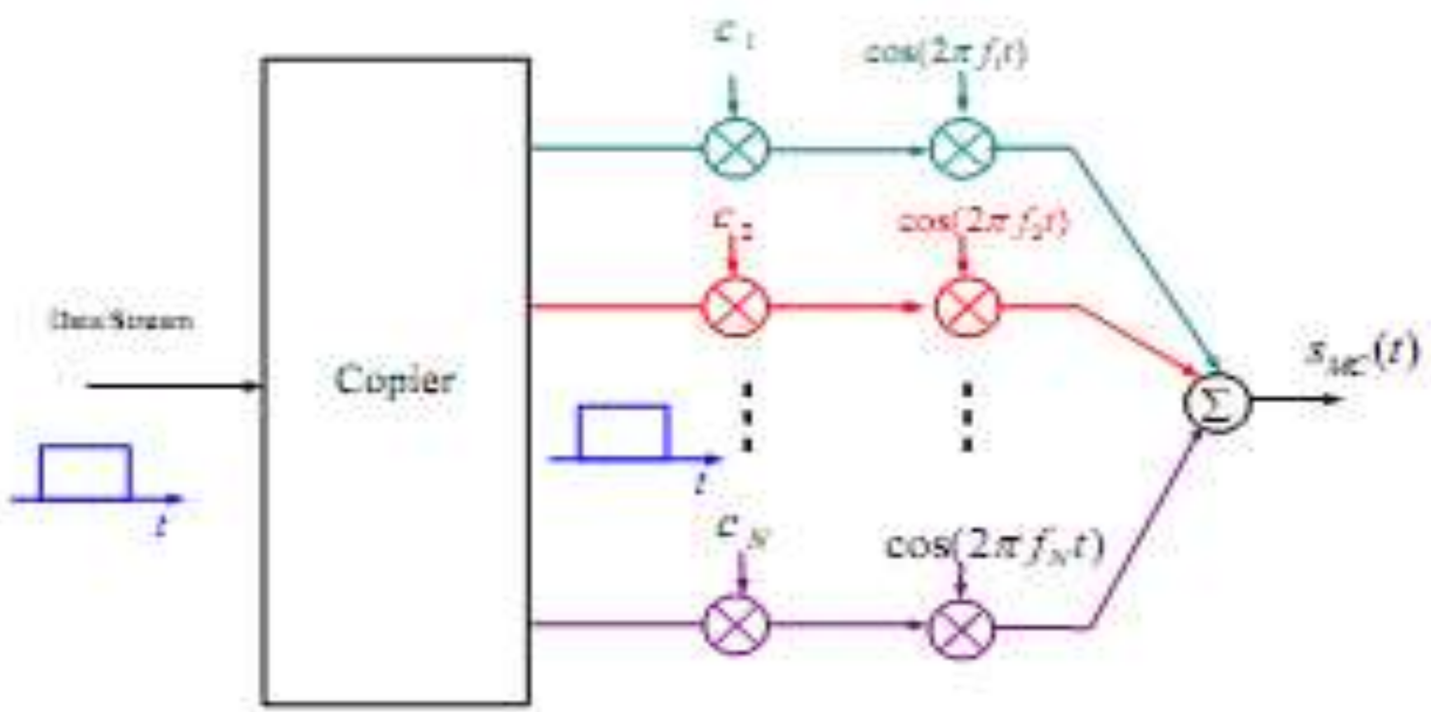


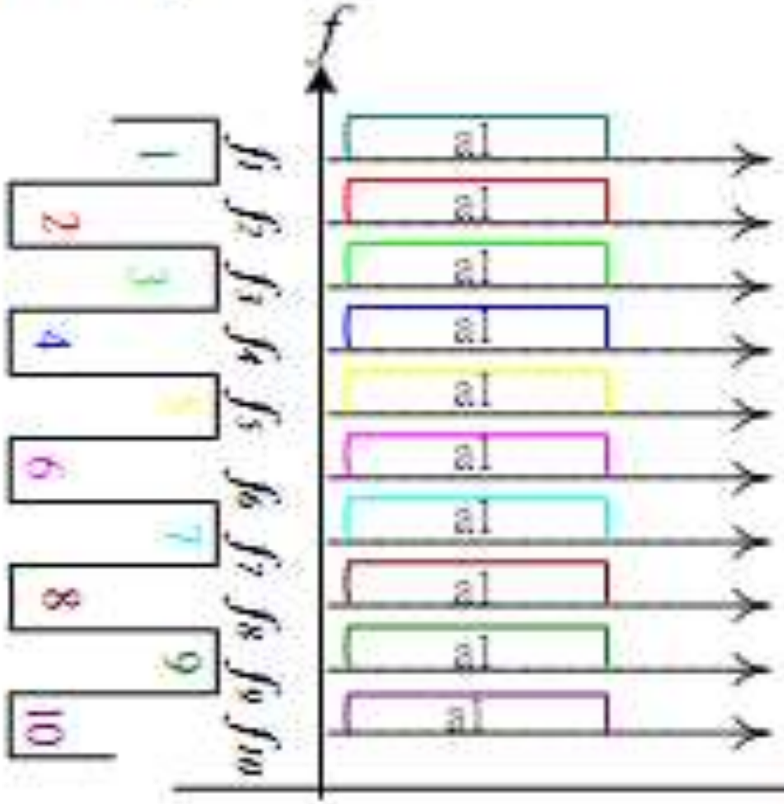
# Multicarrier CDMA system

## Frequency domain spreading

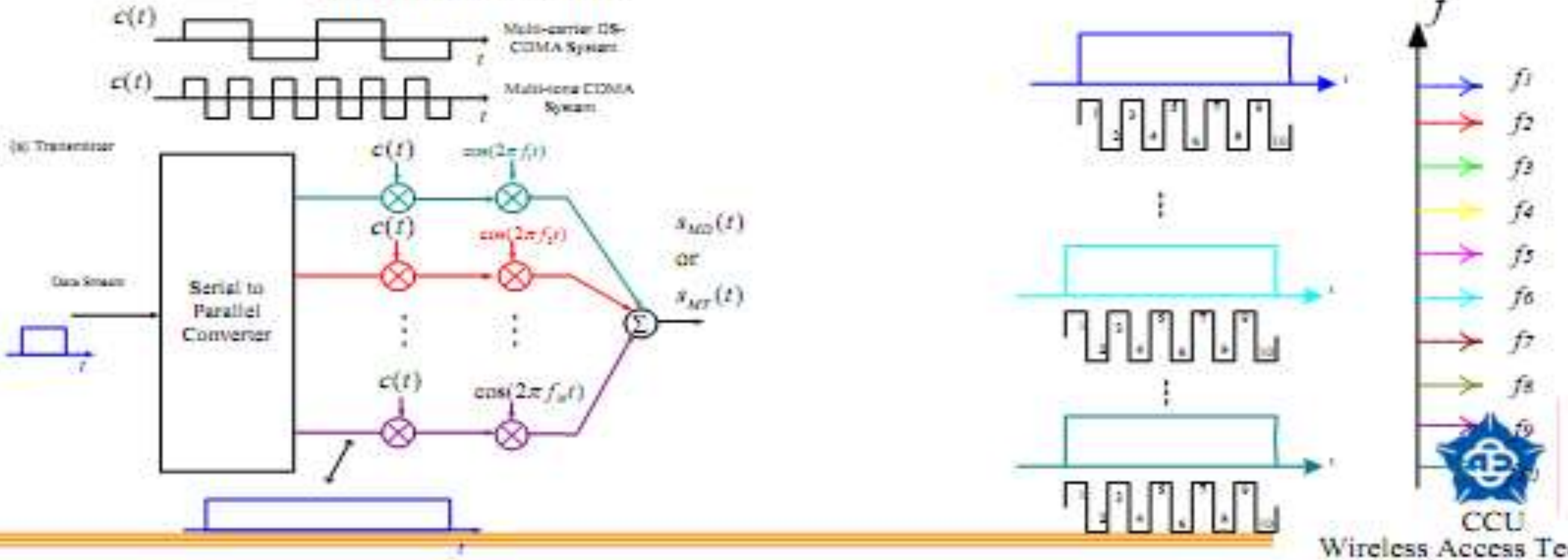
### MC-CDMA system

- The spreading operation in the frequency domain
- It spreads the original data streams using a given spreading code, and then modulates a different subcarriers with each chip

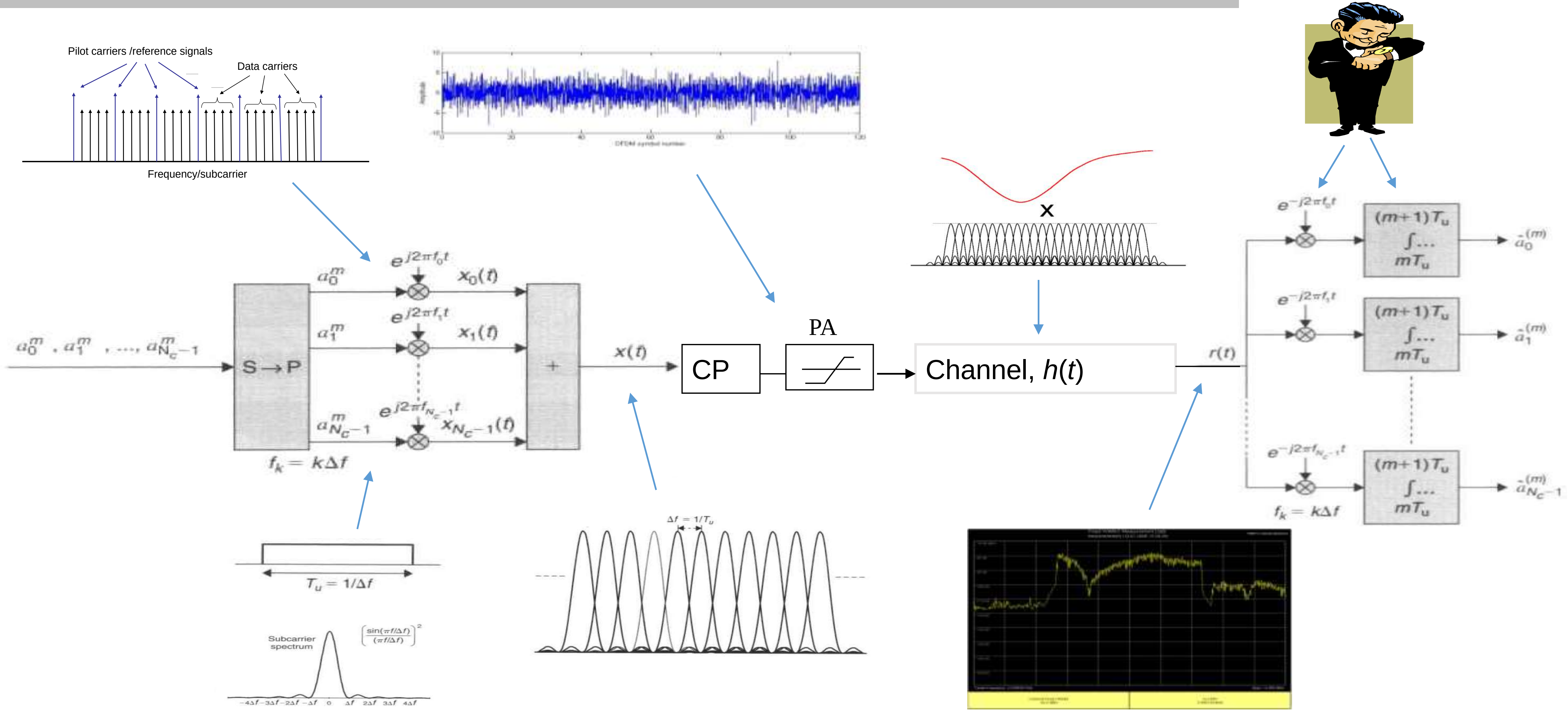


- Time domain spreading
  - Multi-carrier DS-CDMA system
  - Multi-tone CDMA system
    - The spreading operation in the time domain
    - It spreads the serial-to-parallel (s/p) converted data streams using a given spreading code, and then modulates a different subcarrier with each data stream.



# Summary



Pilot carriers /reference signals
Data carriers
Frequency/subcarrier
x
$e^{j2\pi f_0 t}$
$e^{j2\pi f_1 t}$
$e^{j2\pi f_{N_c-1} t}$
$a_0^m , a_1^m , \ldots, a_{N_c-1}^m$
S→P
$a_0^m$
$a_1^m$
$a_{N_c-1}^m$
$x_0(t)$
$x_1(t)$
$x_{N_c-1}(t)$
+
$x(t)$
$f_k = k\Delta f$
CP
PA
Channel, $h(t)$
$r(t)$
$e^{-j2\pi f_0 t}$
$e^{-j2\pi f_1 t}$
$e^{-j2\pi f_{N_c-1} t}$
$\int_{mT_u}^{(m+1)T_u} \ldots$
$\hat{a}_0^{(m)}$
$\hat{a}_1^{(m)}$
$\hat{a}_{N_c-1}^{(m)}$
$f_k = k\Delta f$
$T_u = 1/\Delta f$
Subcarrier spectrum
$\left(\frac{\sin(\pi f/\Delta f)}{(\pi f/\Delta f)}\right)^2$
$\Delta f = 1/T_u$

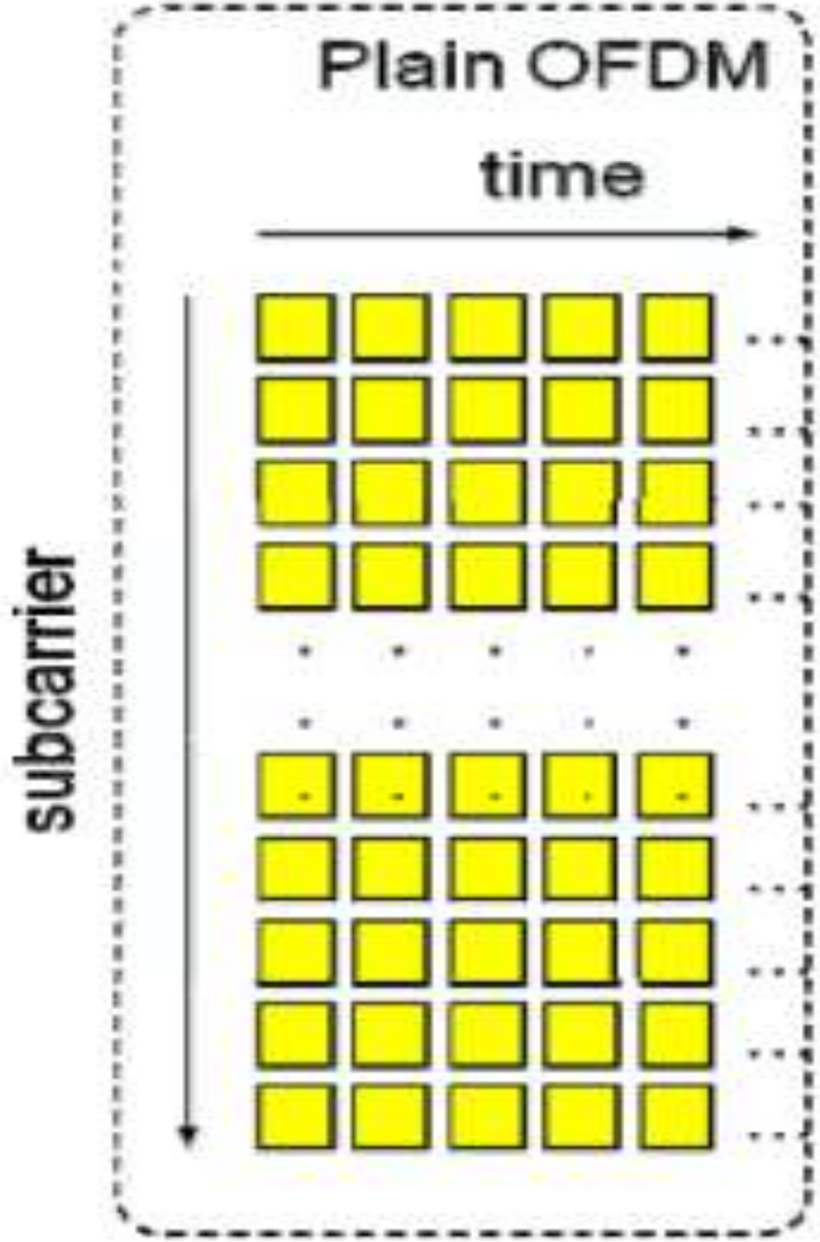
# Konsep OFDMA

# OFDM dan Multiple Access

- Sampai saat ini, kita baru bicara tentang simple point-to-point atau broadcast OFDM.
- Bagaimana dengan penanganan multi user dimana masing-masing user menggunakan sinyal OFDM ?
- Secara teknis, OFDM dapat dikombinasikan dengan beberapa metode multiple access untuk mendukung layanan multi user:
  - Plain OFDM
  - FDMA/OFDM, TDMA/OFDM, CDMA/OFDM

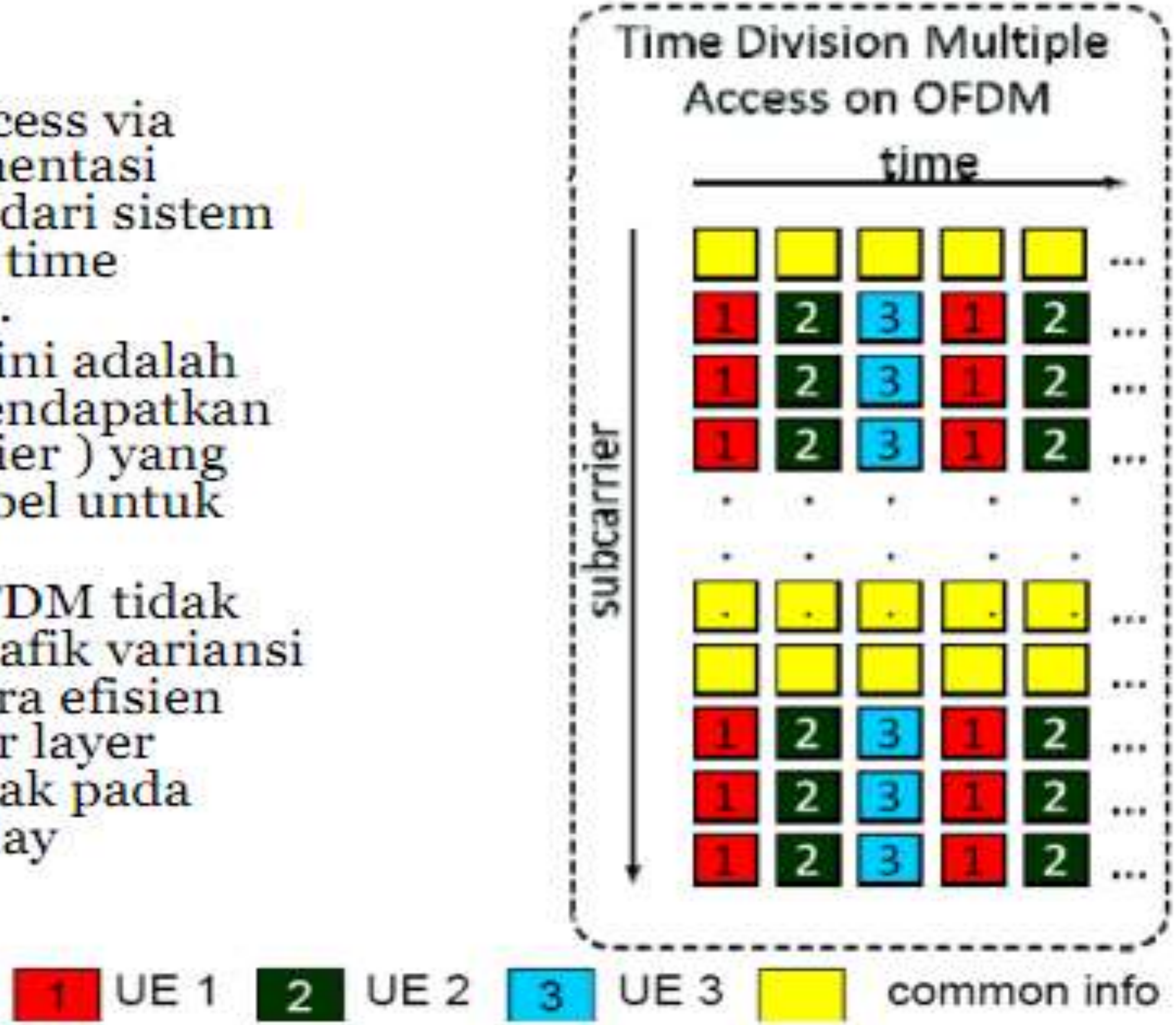
# Plain OFDM

- 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



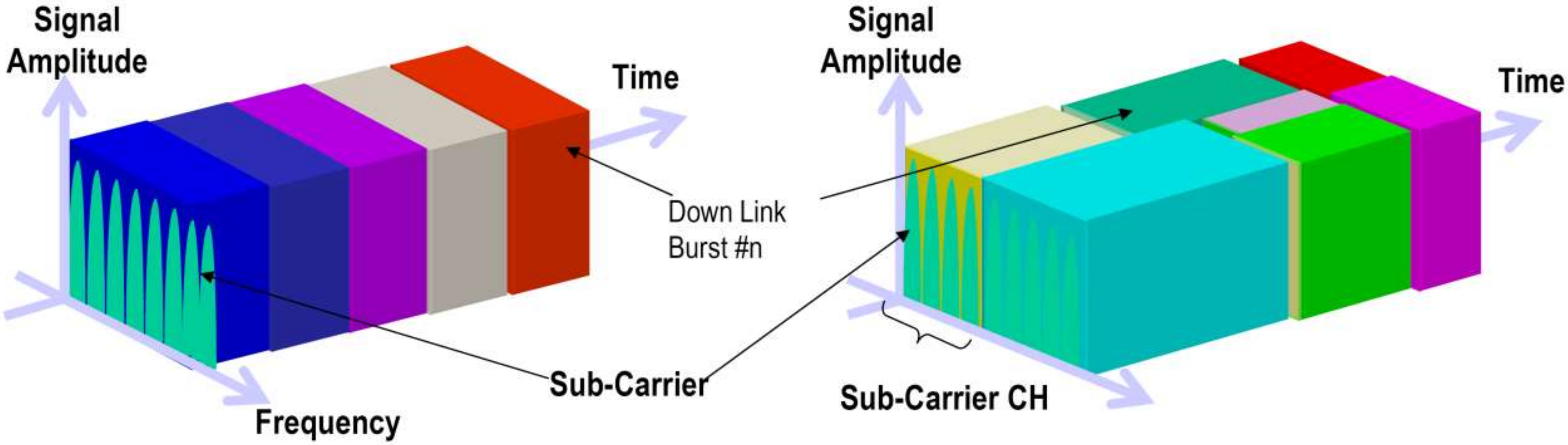
# OFDM & OFDMA

**OFDM**

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

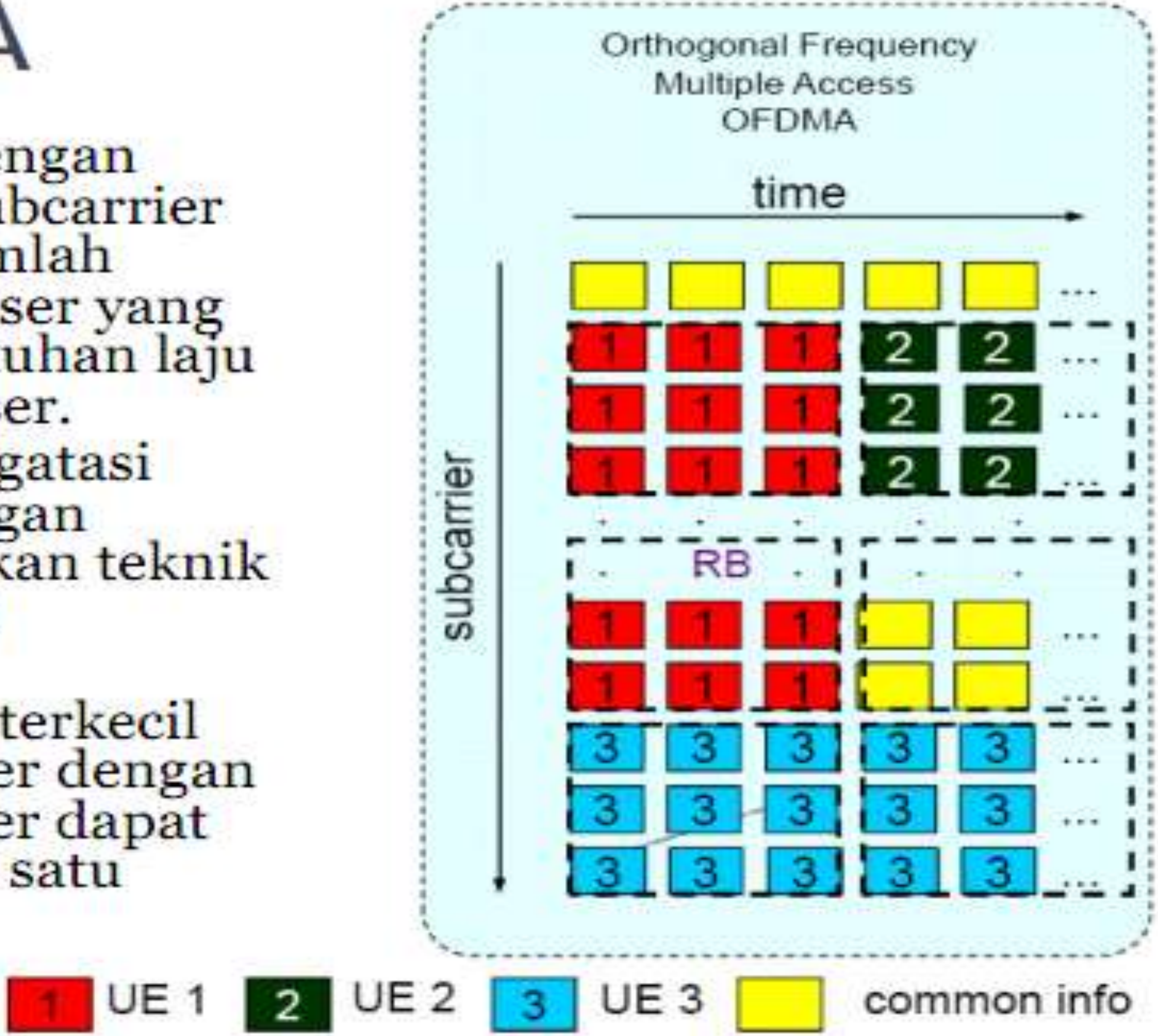
**OFDMA**

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



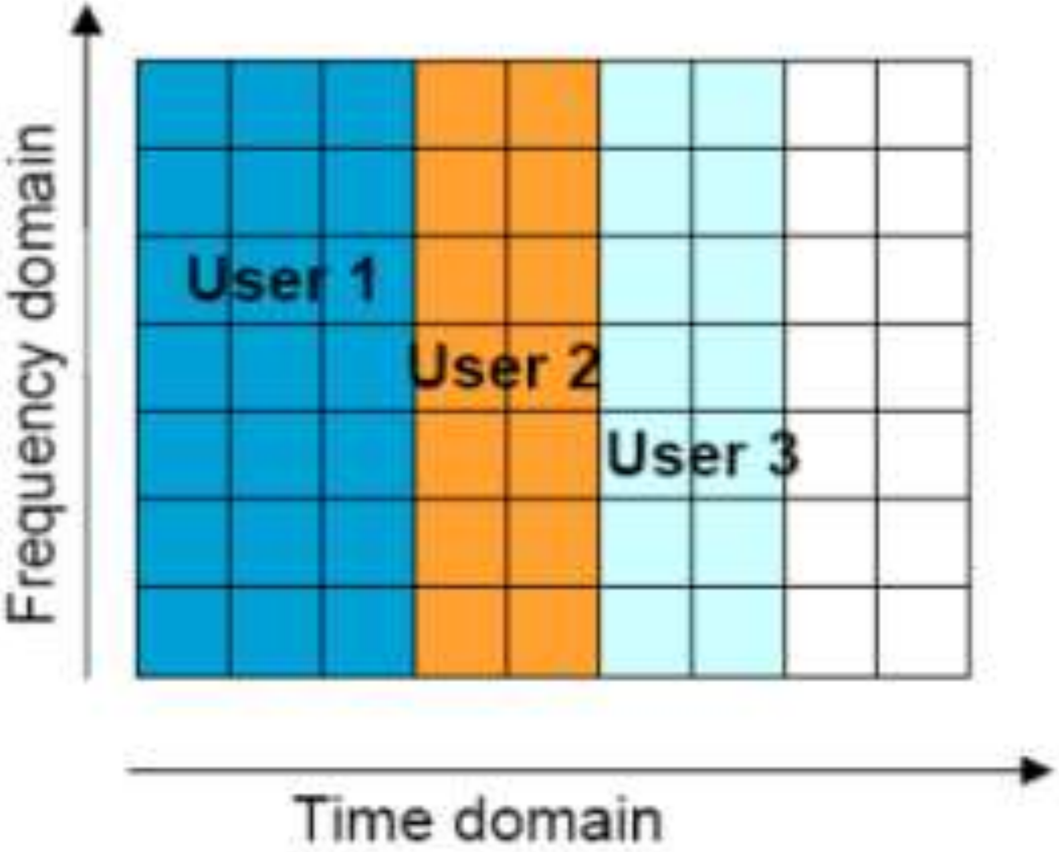
# FDMA/OFDMA

- 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.

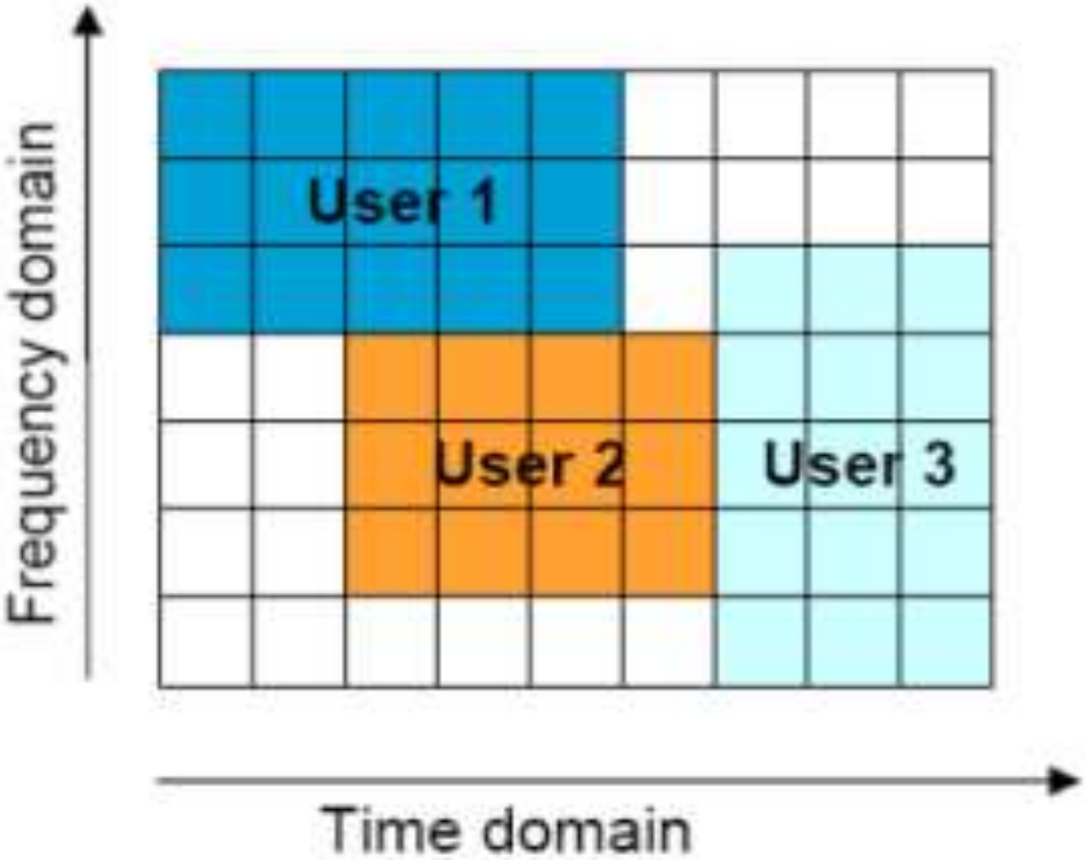


# Perbedaan OFDM dan OFDMA

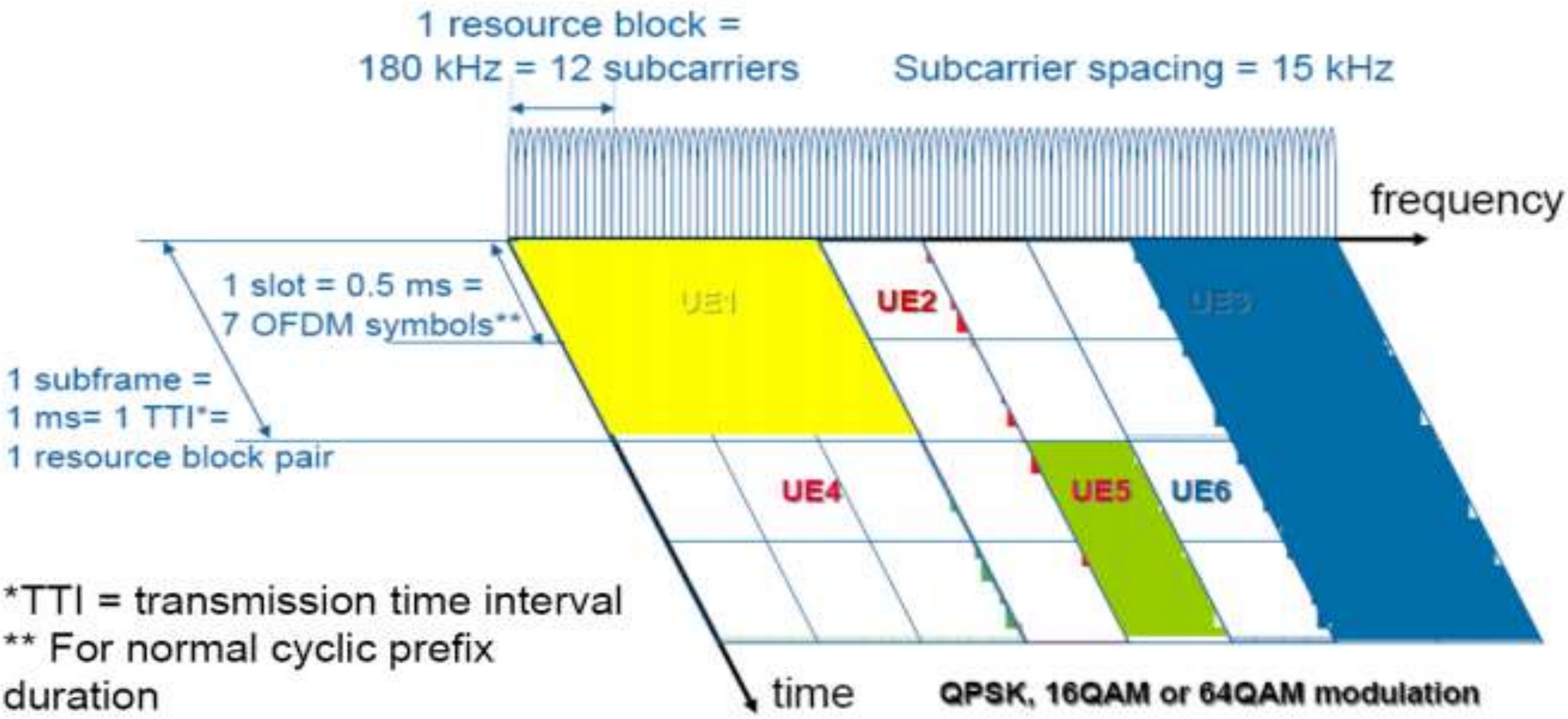
**OFDM allocates users in time domain only**




**OFDMA allocates users in time and frequency domain**

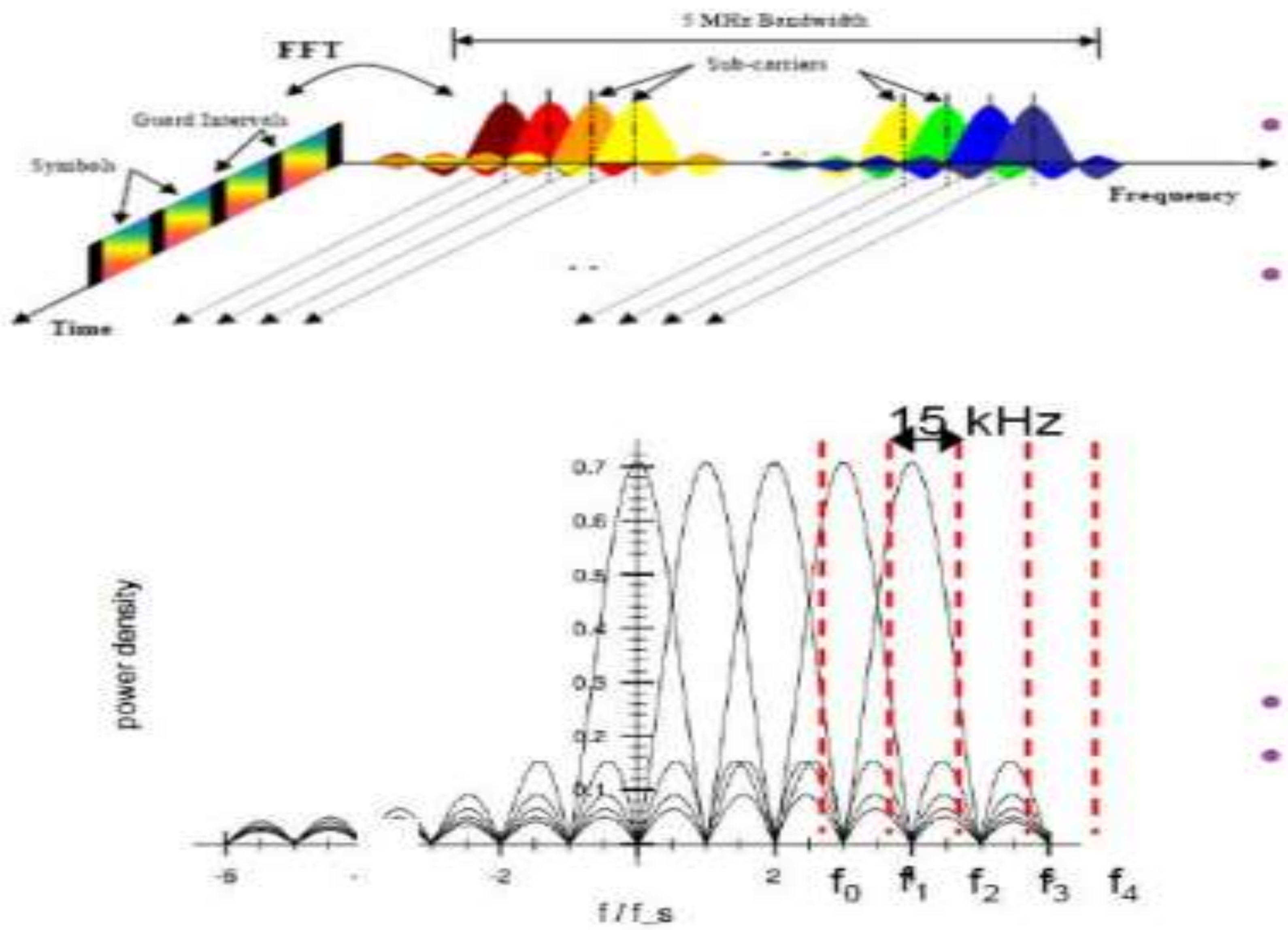


# OFDMA Time-Frequency Multiplexing



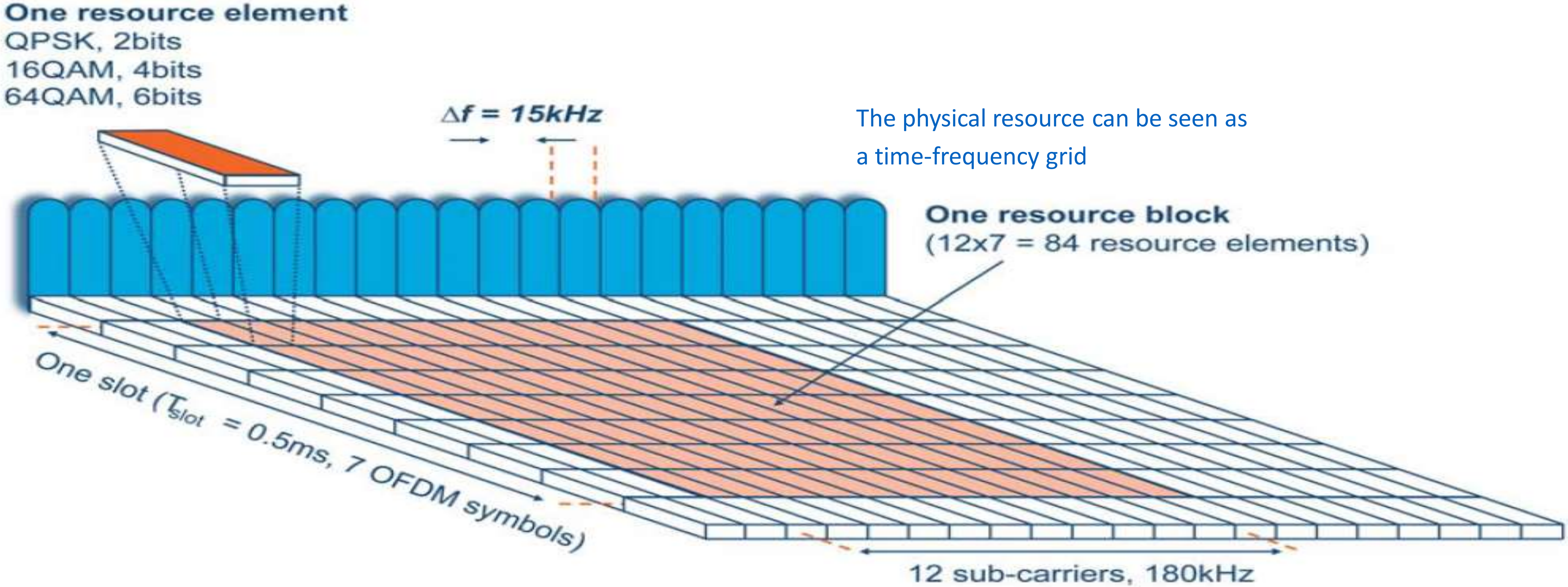
# LTE Downlink : OFDMA Konvensional






- LTE menyediakan modulasi QPSK, 16QAM, 64QAM pada arah downlink
- Cyclic prefix digunakan untuk guard interval, dengan beberapa konfigurasi yang berbeda :
  - Normal cyclic prefix dengan 5.2 µs (symbol pertama) / 4.7 µs (symbol lainnya)
  - Extended cyclic prefix dengan 16.7 µs
- 15 kHz subcarrier spacing
- Scalable bandwidth

# 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

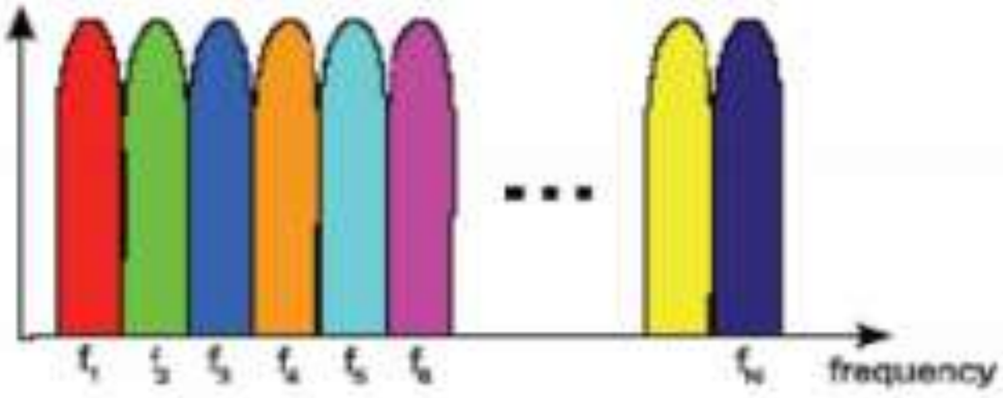
# Pengenalan SC FDMA

# SC-FDMA

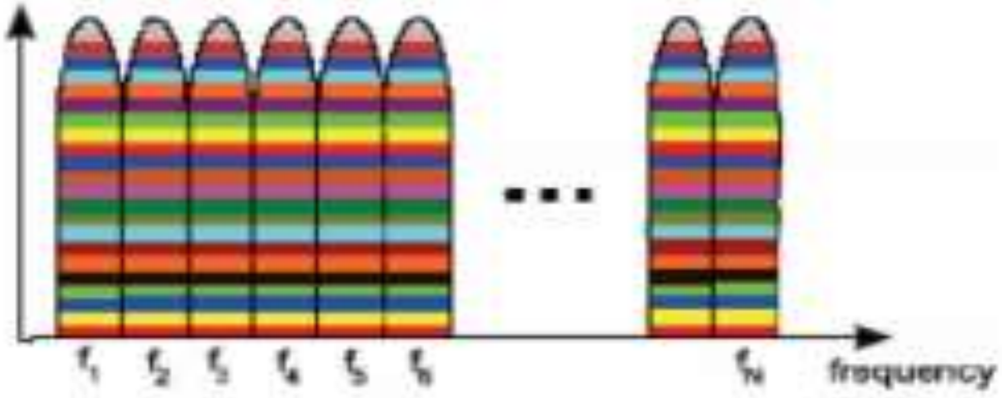
- SC-FDMA :Single Carrier Frequency Division Multiple Access
- SC-FDMA merupakn skema modulasi hybrid yang menggabungkan low PAPR dari sistem single-carrier dengan sifat multipath resistance dan alokasi flexible subcarrier yang diberikan oleh OFDM
- SC menyelesaikan problem PAPR dengan melakukan grouping 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.

# 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