

Técnicas de acceso multiusuario basadas en OFDM (OFDMA)

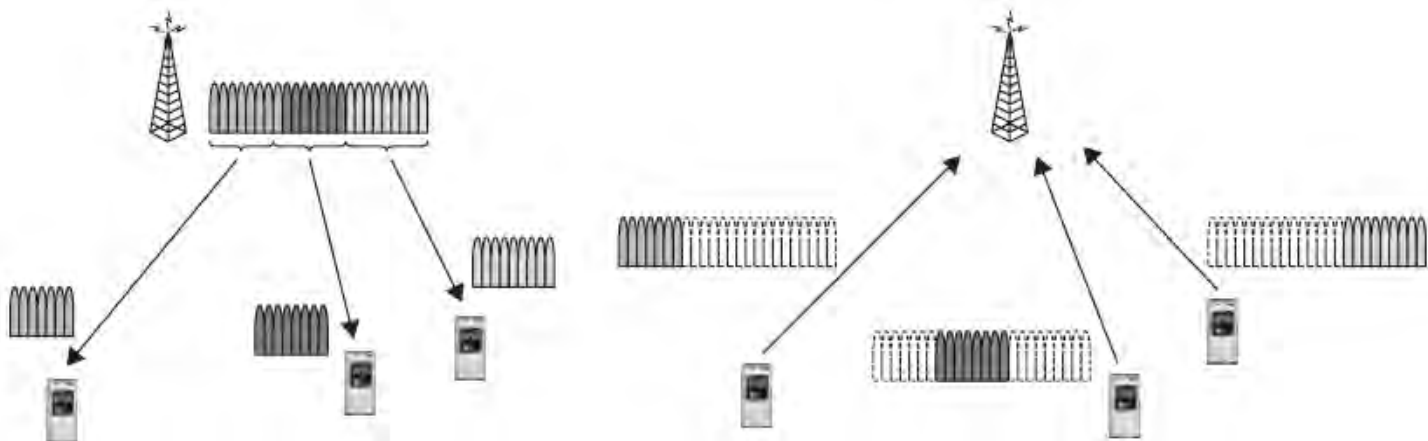
Fernando Gregorio

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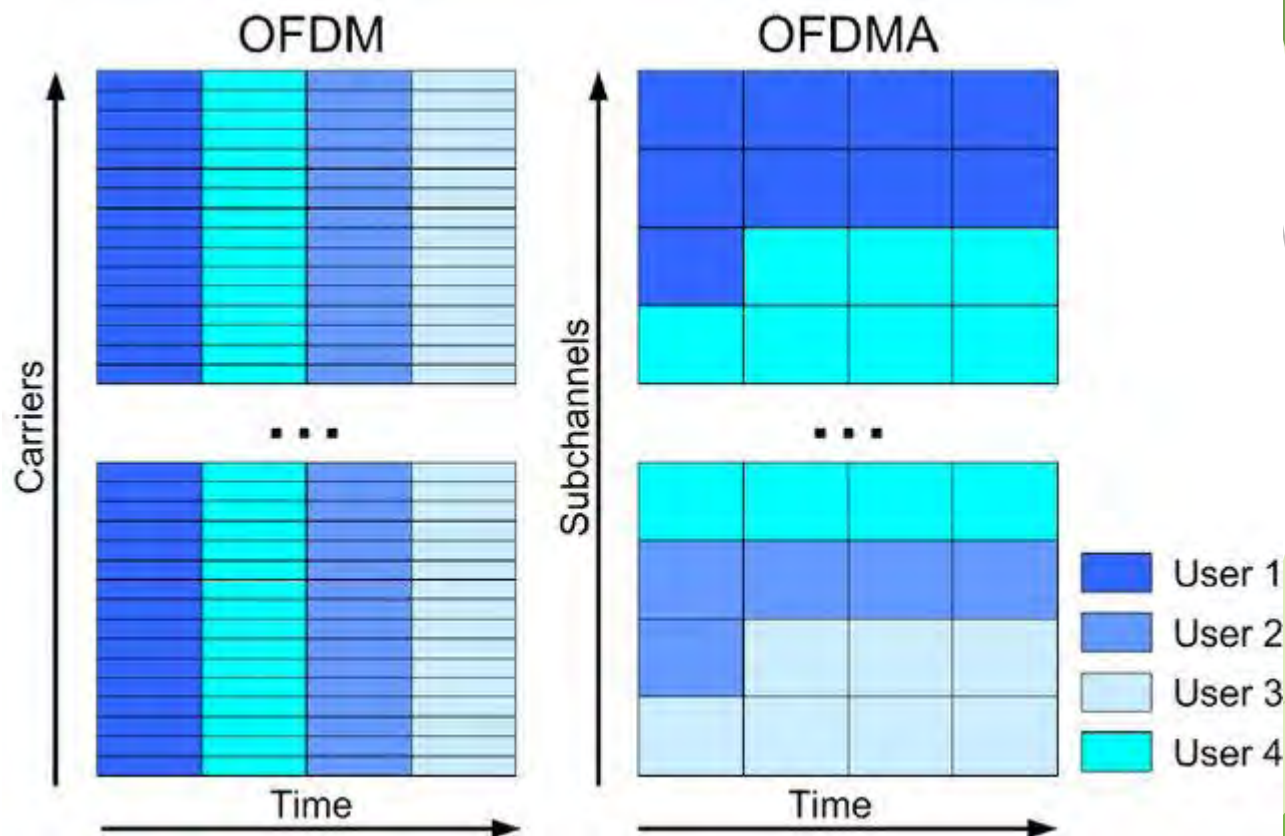


OFDMA

- ▶ El sistema de un único usuario, OFDM, puede extenderse directamente al caso multiusuario.
- ▶ Para el caso multiusuario las portadoras útiles se dividen en K subcanales de $N = N/K$ subportadoras, cada uno correspondiente a un usuario diferente.

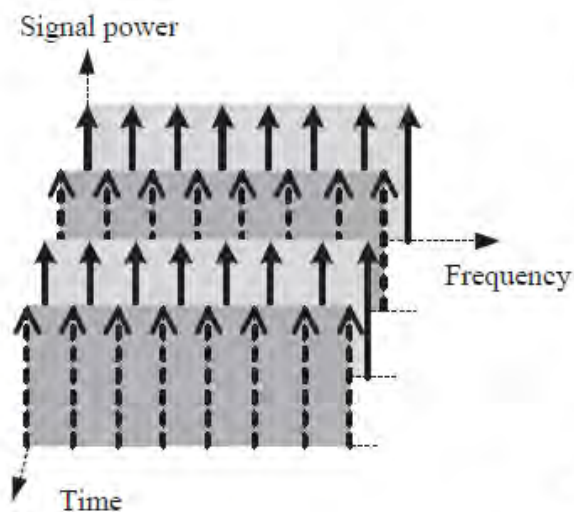


OFDMA

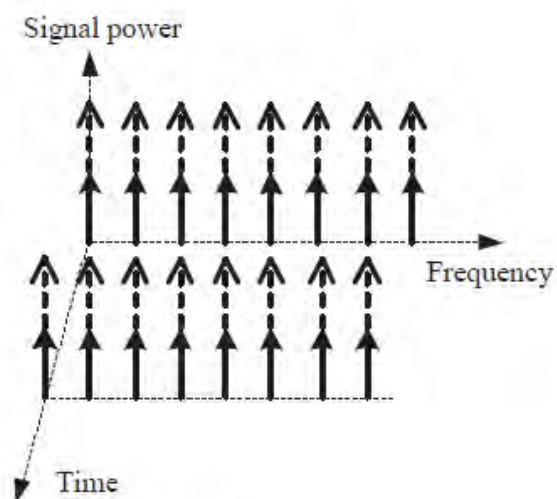


OFDMA vs TDMA

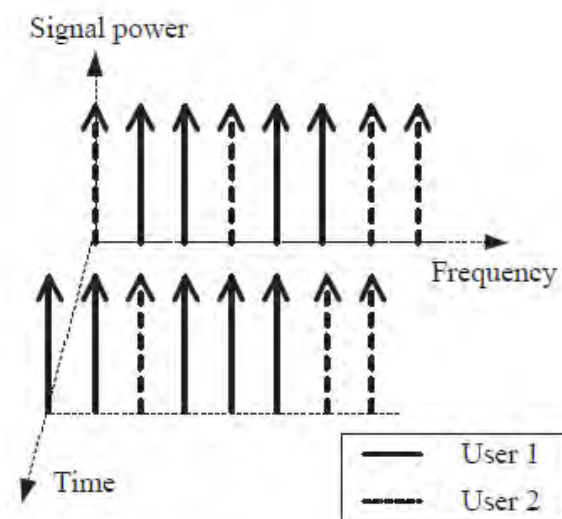
- ▶ Existen otras técnicas multiusuario
 - ▶ OFDM-TDMA
 - ▶ MC-CDMA
 - ▶ OFDMA



(a) OFDM-TDMA



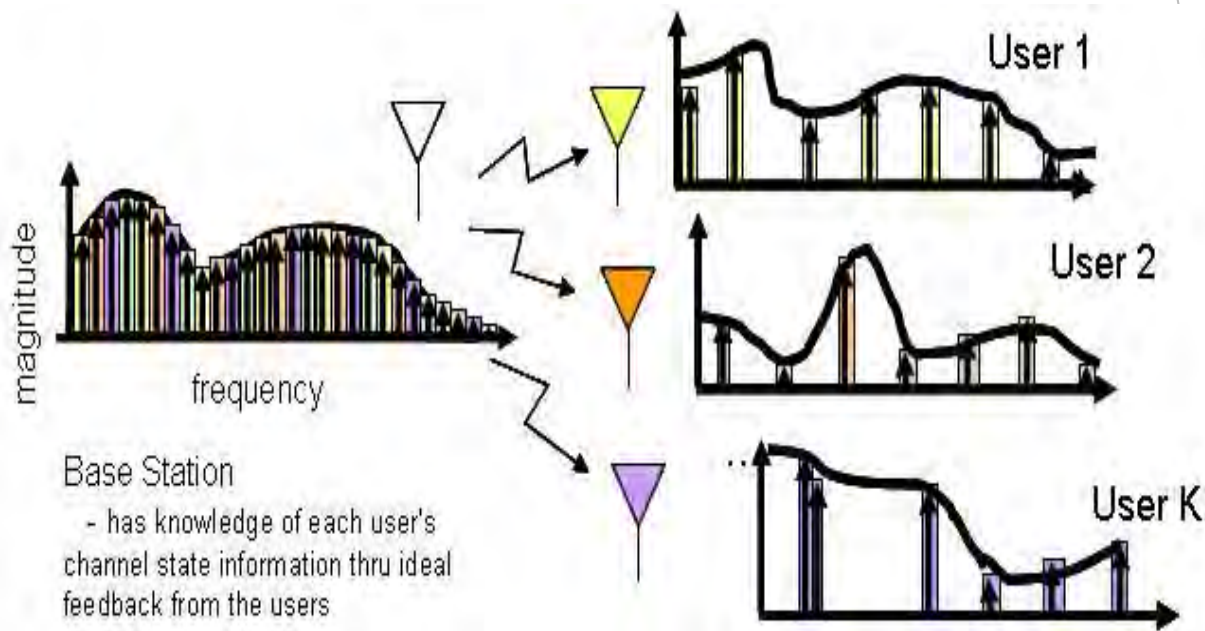
(b) MC-CDMA



(c) OFDMA

OFDMA

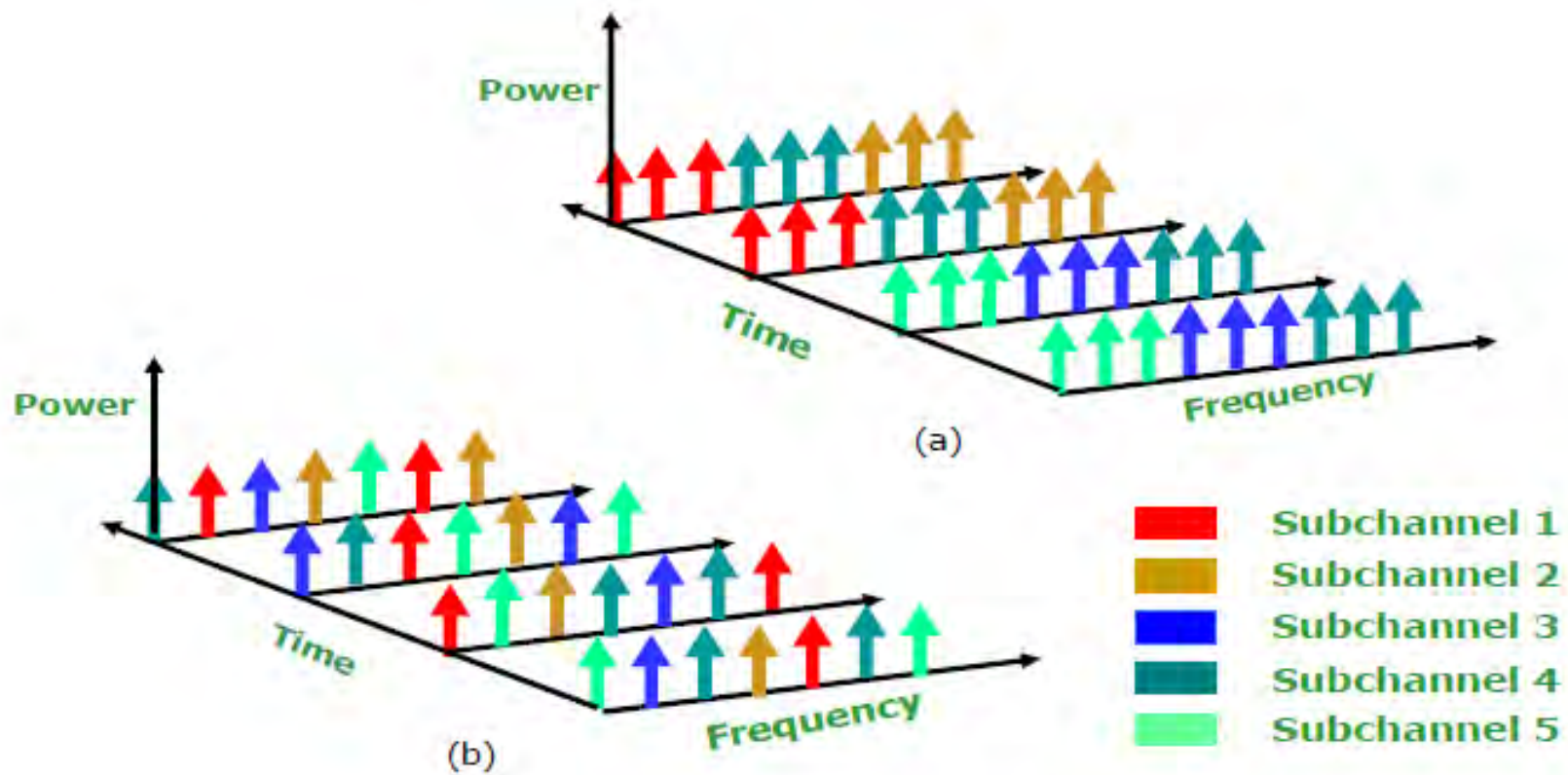
- ▶ Permite una asignación **dinamica** de las subportadoras asignadas a cada usuario.
- ▶ Subportadoras que presentan una elevada atenuación para un usuario, exhibe niveles bajos de atenuación para otros usuarios.
- ▶ La capacidad del sistema puede ser maximizada



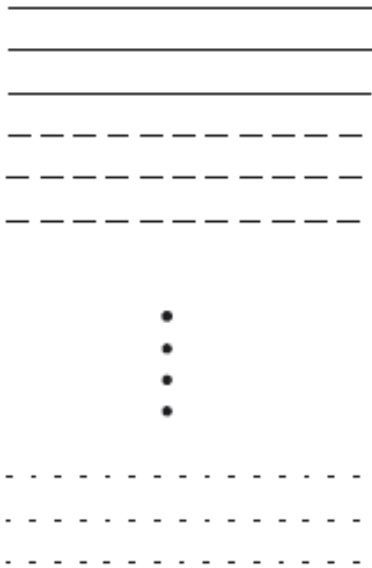
OFDMA

- ▶ Métodos de asignación de subportadoras:
 - ▶ La asignación NO se realiza a nivel de subportadoras.
 - ▶ La unidad mínima es un subcanal donde un set de subportadoras son agrupadas → canalización (bloques de recursos en LTE)
 - ▶ Existen dos métodos de canalización:
 - ▶ **ASM: portadoras adyacentes son agrupadas**
 - ▶ **DCM: portadoras disjuntas son agrupadas**

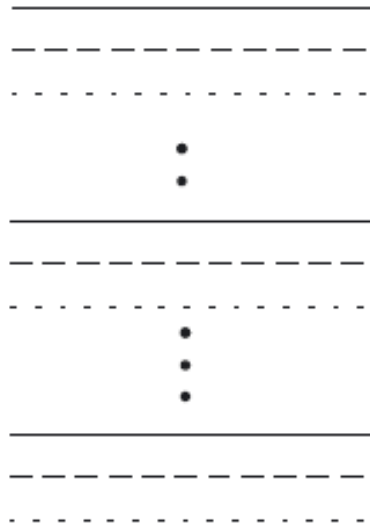
OFDMA



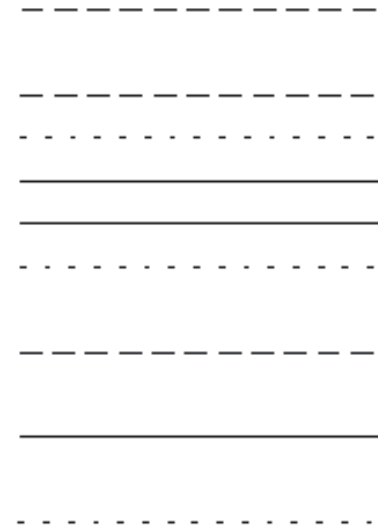
OFDMA - asignación



Contiguous
subcarriers



Regular
spacing



Pseudorandom
spacing

Ventajas y desventajas de cada método ?

Cual es la mejor opción ?

OFDMA - portadoras contiguas

- ▶ La estimación de canal es simplificada dado que las portadoras contiguas están correlacionadas.
- ▶ Se puede realizar un “intelligent scheduling” donde cada usuario es asignado a las portadoras con mejor calidad de canal.
- ▶ Se requiere que la estación base conozca la respuesta del canal en el ancho de banda de transmisión completo. Esta estimación de canal debe ser además actualizada.
- ▶ **Es adoptada en LTE**
- ▶ Wimax lo incluye como opcional

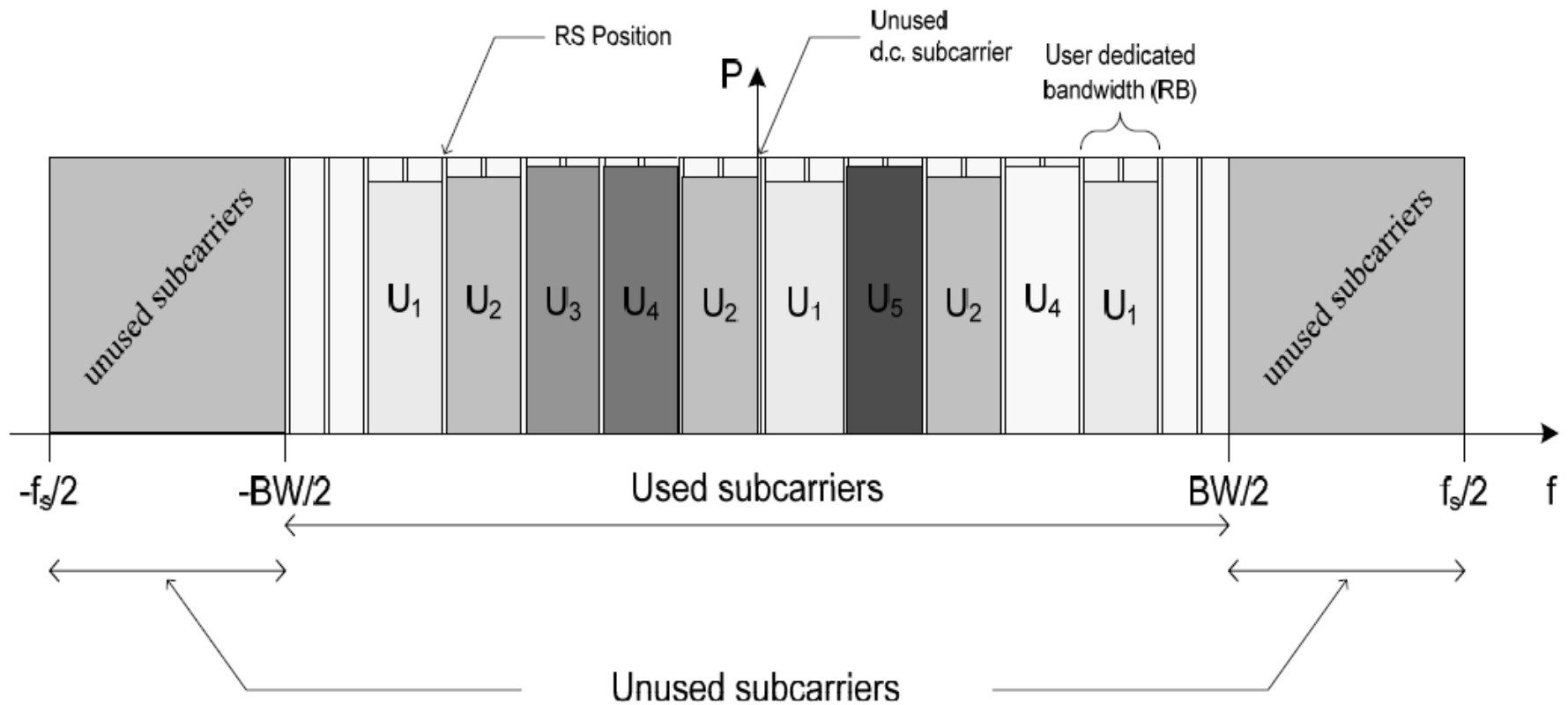
OFDMA - Portadoras espaciadas regularmente

- ▶ Alto nivel de diversidad en frecuencia (similar a OFDM).
- ▶ El problema del PAPR es reducido.
- ▶ NO se requiere conocimiento del canal en la estación base. Cada usuario es siempre asignado al mismo grupo de subportadoras.
- ▶ **NO** presenta diversidad multiusuario.
- ▶ Cada portadora asignada puede tener una atenuación severa.

Portadoras-Asignación pseudo aleatoria

- ▶ Similares pros and cons que el metodo anterior.
- ▶ Los efectos de interferencia de celdas vecinas son reducidos.
- ▶ Adoptado en WiMAX.

OFDMA en LTE



OFDMA-UPLINK

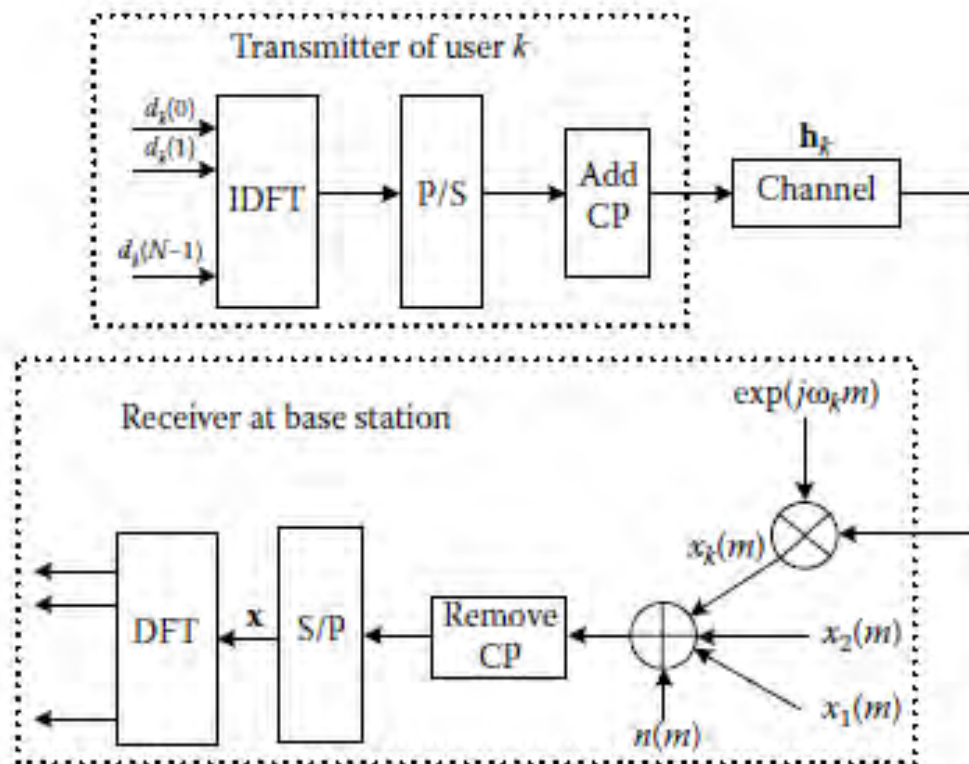


Figure 15.1 Baseband system diagram for OFDMA uplink. (From J. Chen, Y.-C. Wu, S. C. Chan, and T.-S. Ng, *IEEE Trans. Veh. Technol.*, 57 (6), 3462–3470, 2008. © 2008 IEEE. With permission.)

OFDMA Downlink Transmitter

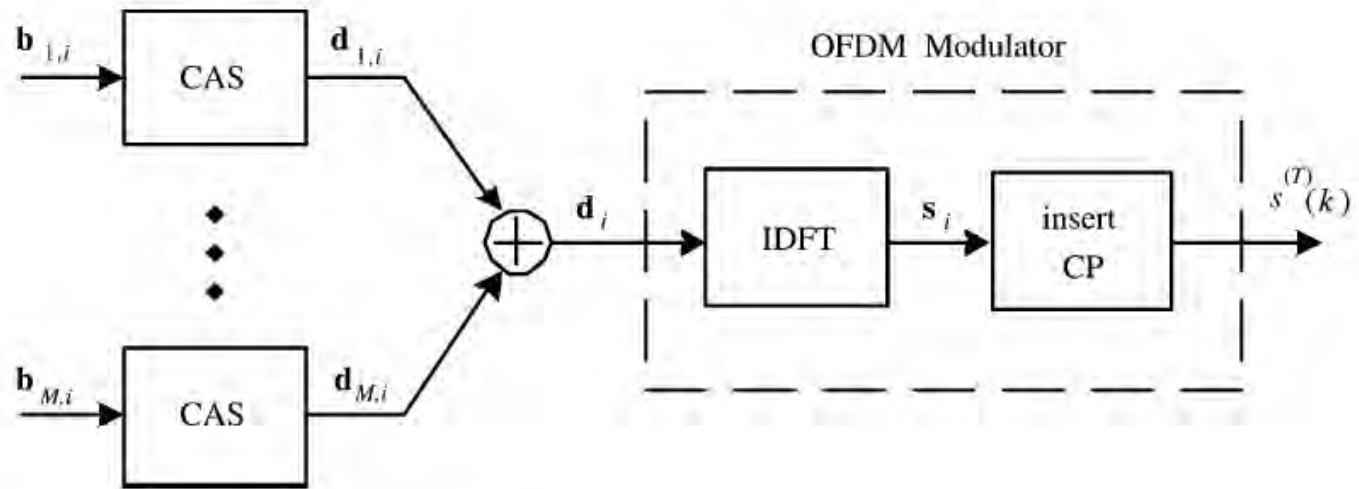


Fig. 2. Block diagram of OFDMA downlink transmitter.

OFDMA DOWNLINK Receiver

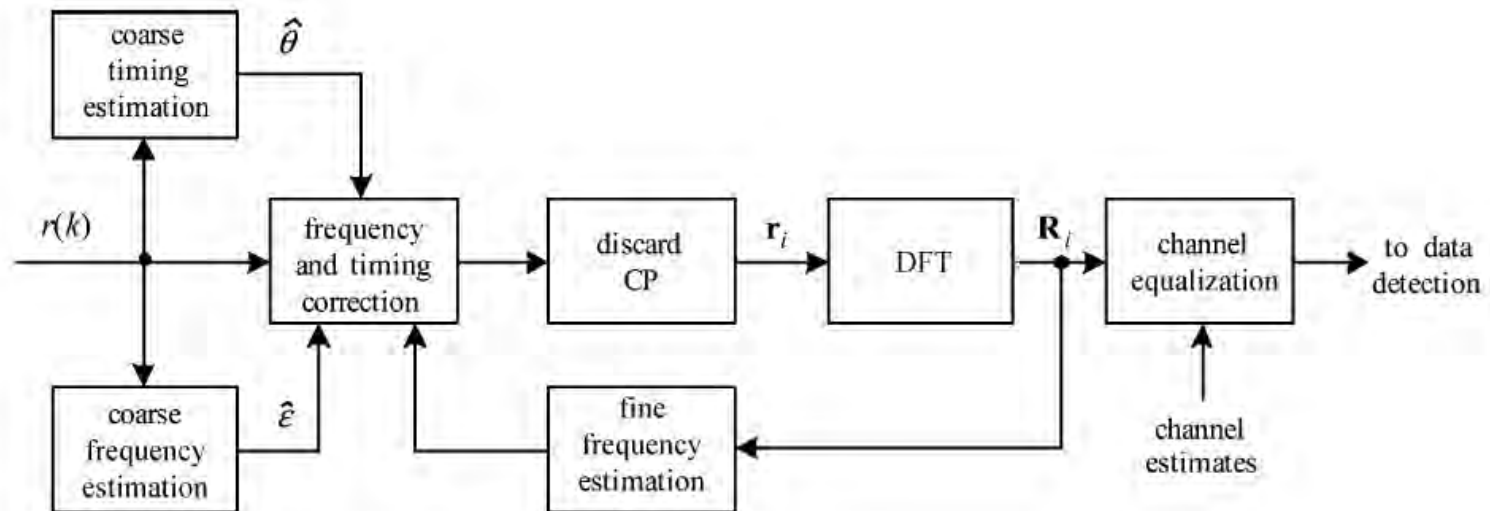


Fig. 3. Block diagram of OFDMA downlink receiver.

Generalmente cada usuario esta solamente interesado en los datos transmitidos en las suportadoras asignadas. Unicamente, las salidas de la DFT correspondientes con los indices asignados son utilizadas.

Ofdma UPLINK tx

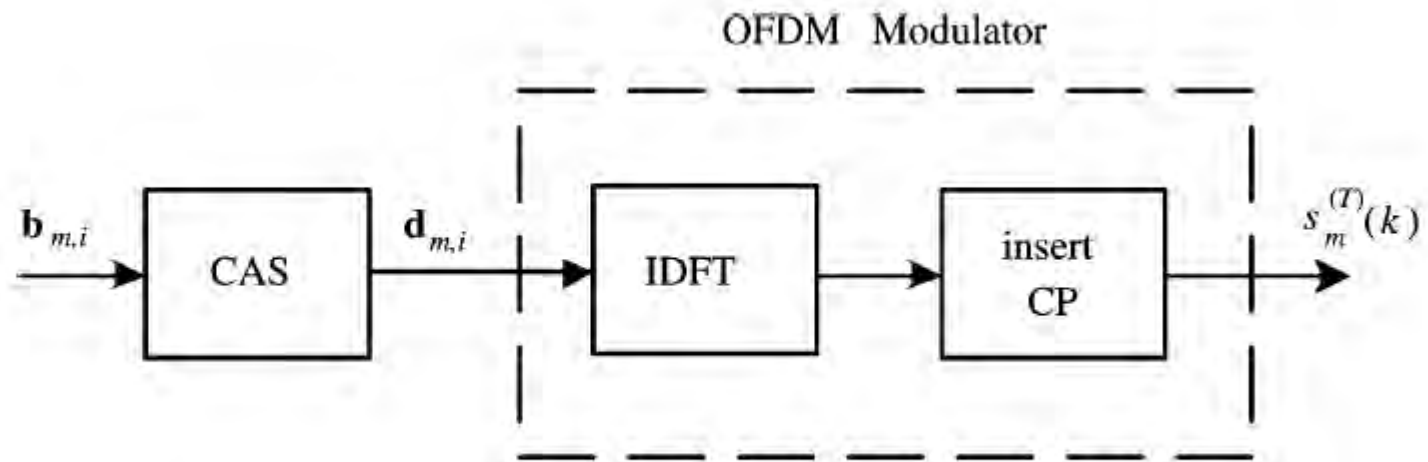
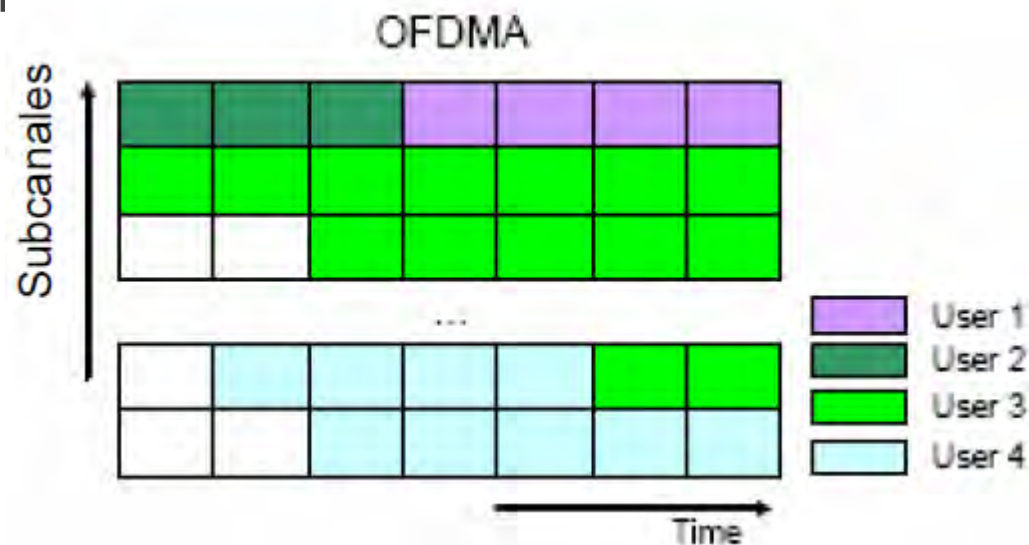


Fig. 14. Block diagram of m th OFDMA uplink transmitter.

The main difference is that, while the downlink signal conveys information for all active users, in the uplink each terminal only transmits its own data. Transmission occurs in a block-wise fashion, where each block $\mathbf{b}_{m,i}$ of P information symbols is fed to the CAS unit and mapped over the P subcarriers assigned to the considered user.

Un símbolo OFDMA

- ▶ Durante el tiempo de duración de símbolo las subportadoras se asignan a usuarios diferentes.
- ▶ Se requiere una representación tiempo-frecuencia para ubicar los recursos que se asignan a cada usuario.
- ▶ Las subportadoras se agrupan para formar lo que se denomina un subcanal (tamaño variable).



Un símbolo OFDMA - subcanales

- ▶ El ancho de banda se divide en subcanales lógicos con el fin de soportar escalabilidad y acceso múltiple
- ▶ Un subcanal es un conjunto de sub-portadoras físicas activas que pueden o no ser adyacentes. Es la menor estructura lógica que puede asignarse en el dominio de la frecuencia.

OFDMA - Slot

- ▶ Para su completa definición se requiere su ubicación en el tiempo (Símbolo OFDMA) y en la frecuencia (dimensión subcanal)
- ▶ Es la unidad de datos más pequeña que se puede asignar
- ▶ Sus dimensiones dependen de la estructura del símbolo OFDMA (función de UL y del DL)

OFDMA en LTE

- ▶ En el downlink, la menor unidad tiempo/frecuencia para transmisión es definida como resource element.
- ▶ Cada resource element es representado por una frecuencia y un símbolo OFDM en un slot.
- ▶ Resource blocks son definidos como N_{sc}^{RB} subcarriers consecutivas en dominio frecuencia y N_{symb}^{DL} símbolos OFDM consecutivos.

Table 21.6 Physical Resource Blocks
Parameters for Downlink

Configuration	N_{sc}^{RB}	N_{symb}^{DL}
Normal CP $\Delta F = 15$ kHz	12	7
Extended CP $\Delta F = 15$ kHz	12	6
Extended CP $\Delta F = 7.5$ kHz	24	6

OFDMA-LTE

- ▶ LA interface entre la MAC y la capa física.
 - ▶ LTE contiene un único canal de transporte (no existen canales dedicados).
 - ▶ Los canales de transporte hacen de interface entre la MAC y la capa física.
 - ▶ Los siguientes canales de transporte son definidos en LTE:
 - ▶ BCH - broadcast channel (BCH)
 - ▶ Downlink Shared channel (DL-SCH)
 - ▶ Paging channel (PCH)
 - ▶ Multicast channel (MCH)
 - ▶ Uplink shared channel (UL-SCH)
 - ▶ Random access channel (RACH)

**Mapeado
por el
PDSCH**

**Mapeado
por el
PUSCH**

OFDMA-LTE

Downlink Shared Channel (DL-SCH)

- Supports Hybrid ARQ (HARQ)
- Supports dynamic link adaption by varying modulation, coding and transmit power
- Suitable for transmission over entire cell coverage area
- Suitable for use with beamforming
- Support for dynamic and semi-static resource allocation
- Support for discontinuous receive (DRX) for power save

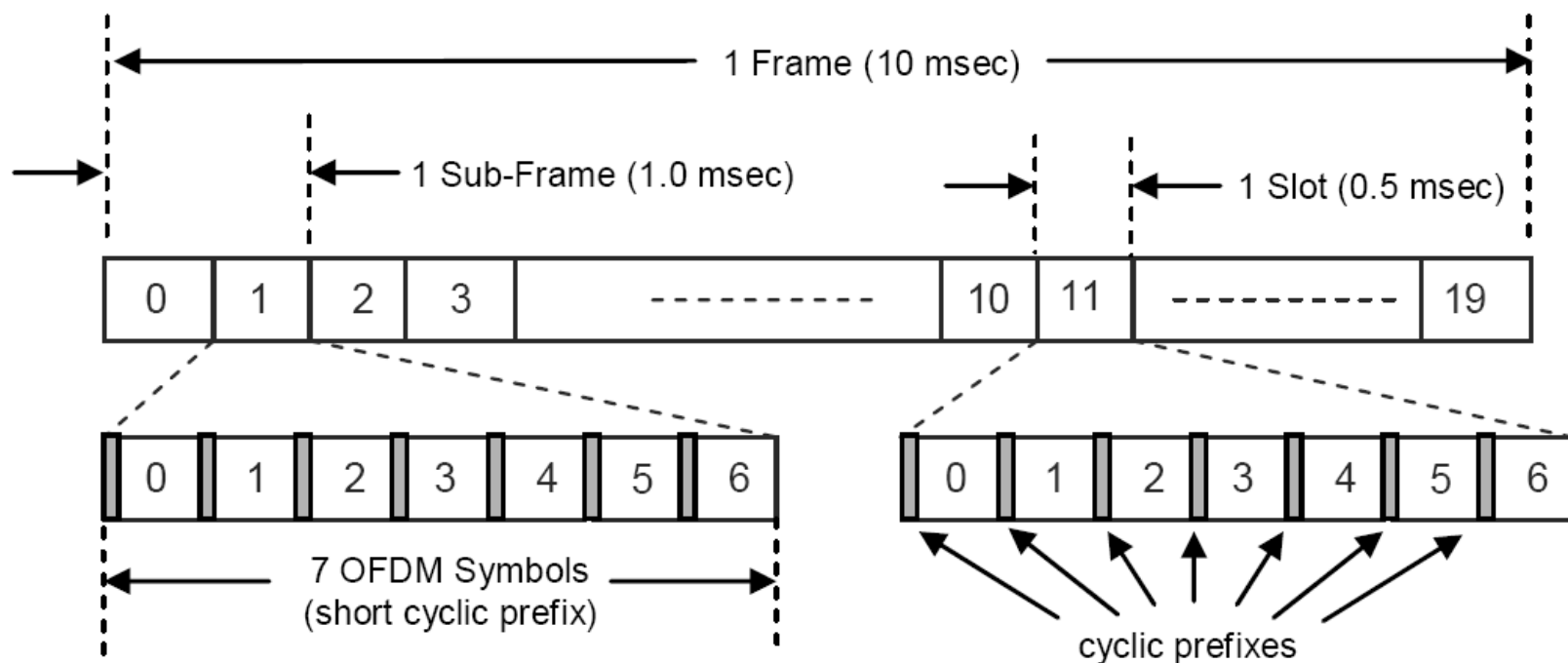
Uplink – Shared Channel (UL-SCH)

- Support possible use of beam forming
- Support dynamic link adaption (varying modulation, coding and/or Tx power)
- Support for HARQ
- Support for dynamic and semi-static resource allocation

OFDMA en LTE

- ▶ En OFDMA, los usuarios son allocados en subportadoras específicas durante una determinada cantidad de tiempo (physical resource blocks (PRBs)).
- ▶ La asignación de los PRBs es controlada por una función de scheduling de la **estación base 3gpp**

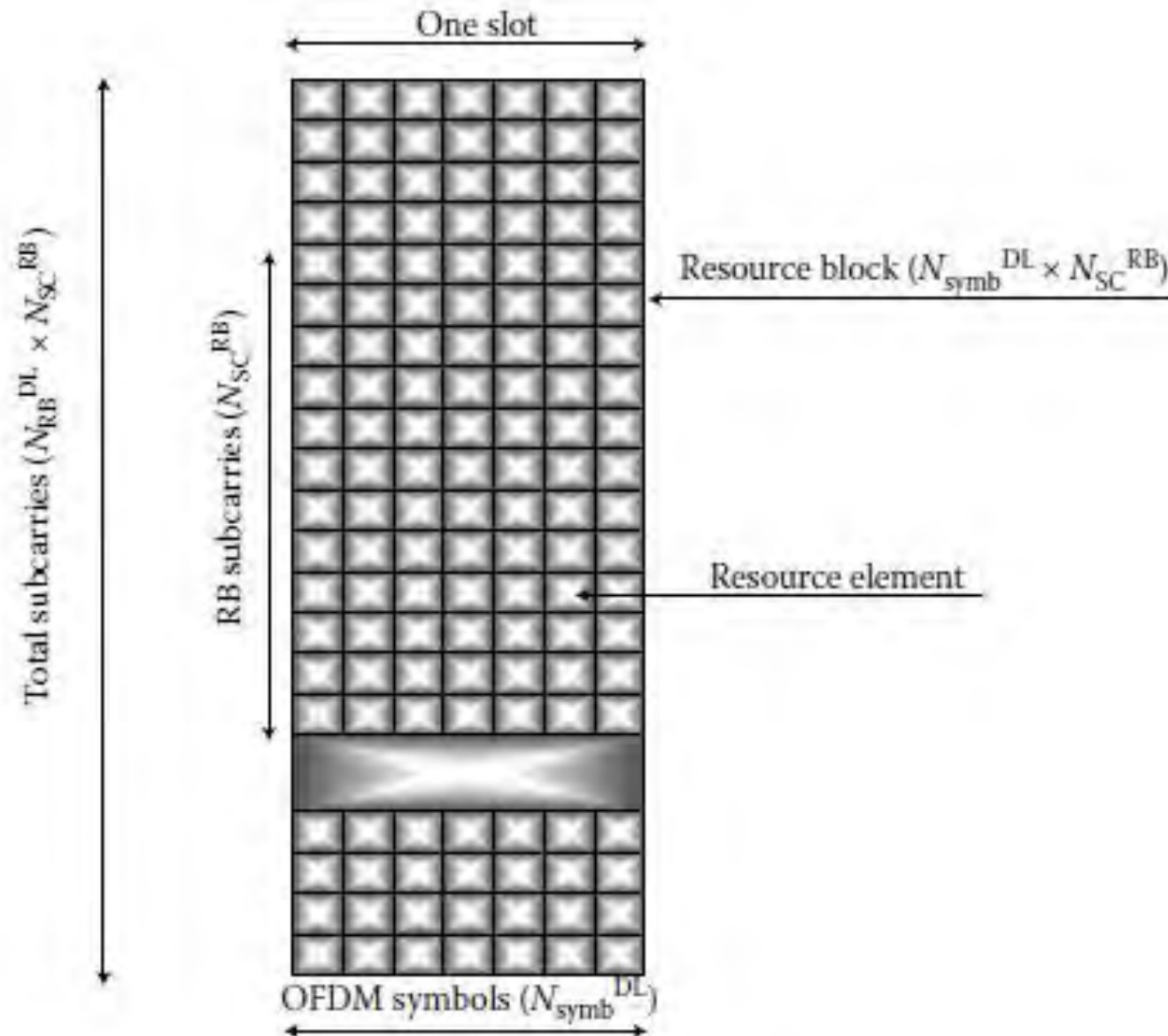
OFDMA en LTE



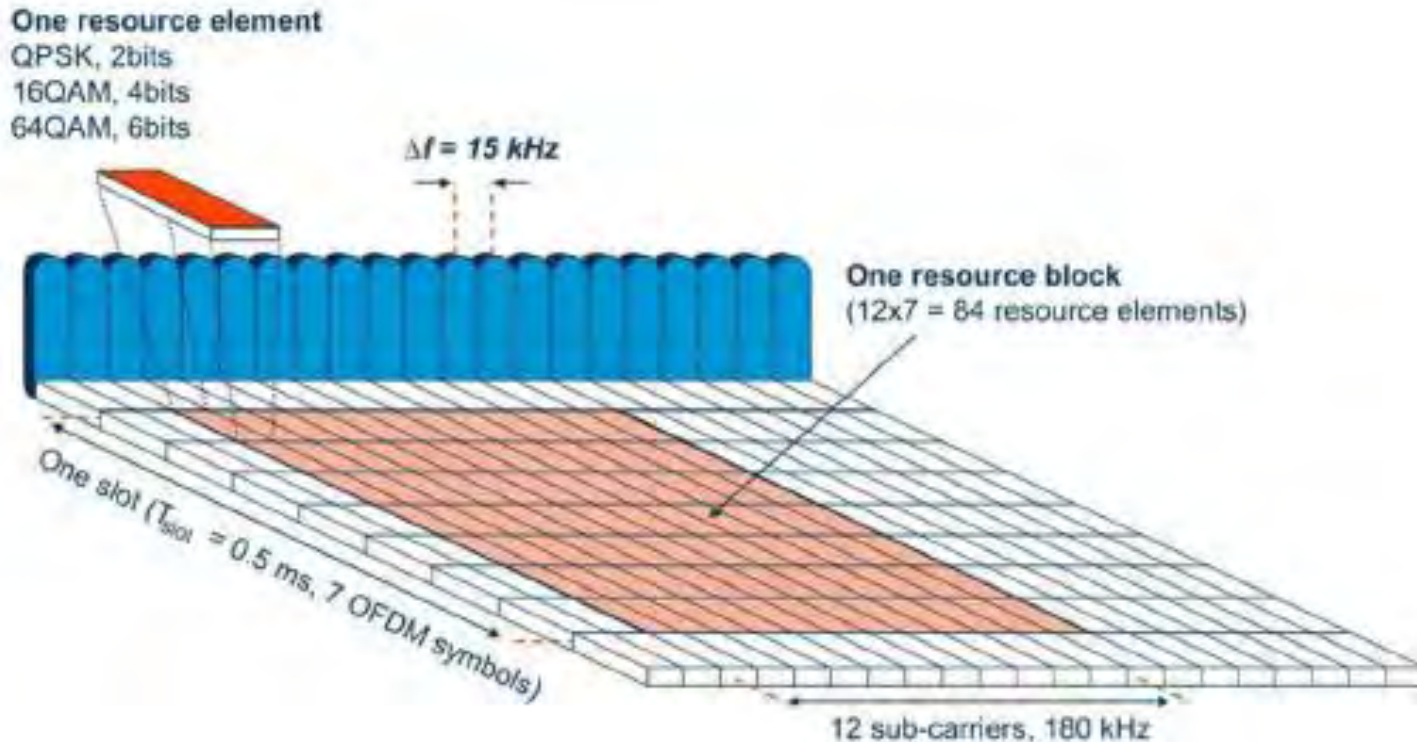
LTE no incluye un preamble específico.

La información esta embebida en los PRBs

OFDMA en LTE - Downlink



OFDMA - LTE



Los símbolos OFDM son agrupados en resources blocks (RB)

EL RB ocupa un total de 180KHz con 12 subportadoras y 0.5ms que equivalen a 7 símbolos OFDM.

OFDMA-LTE

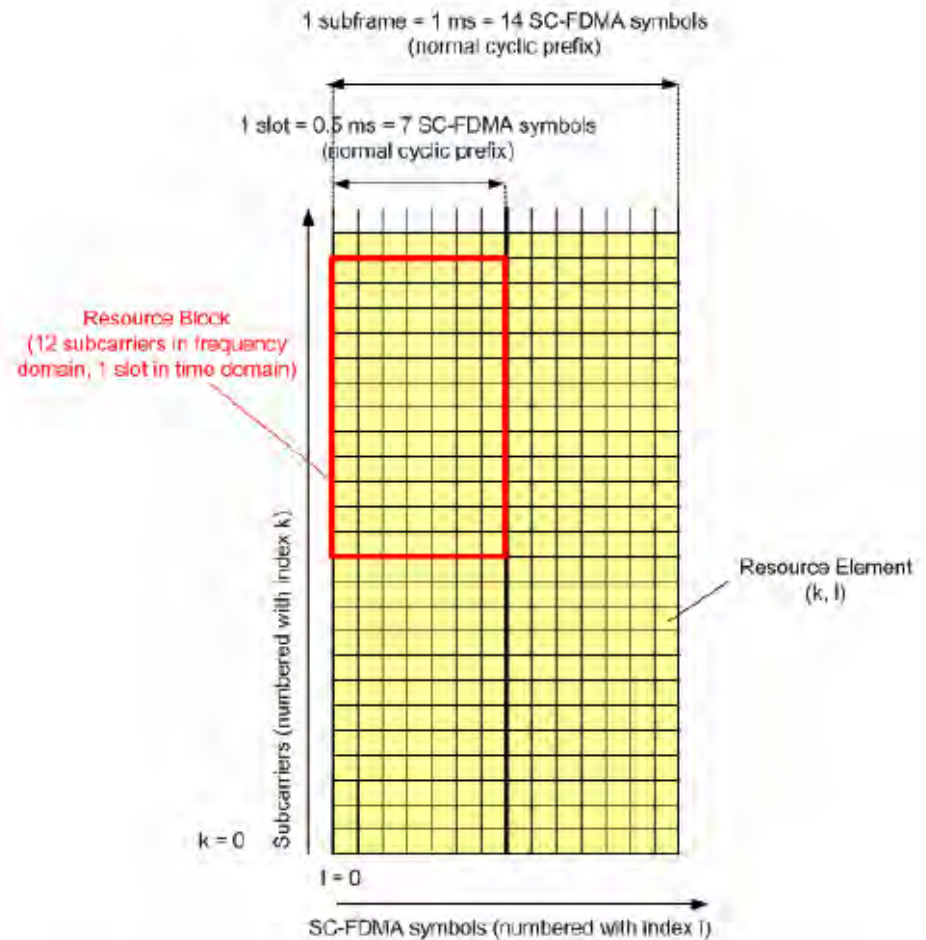
Nro de RB en función del ancho de banda

Channel bandwidth [MHz]	1.4	3	5	10	15	20
Number of resource blocks	6	15	25	50	75	100

A cada usuario se le asigna un grupo de RB en la grilla tiempo-frecuencia

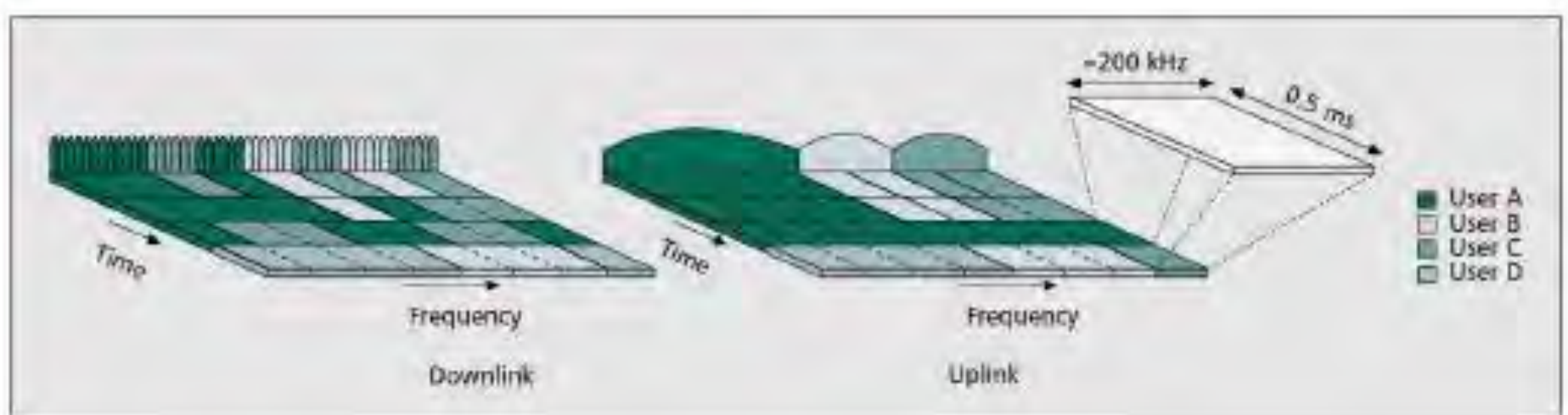
LTE uplink

- Similar al downlink (RBs)



LTE Uplink-downlink

- En el uplink siempre se asignan recursos contiguos



SC-FDMA

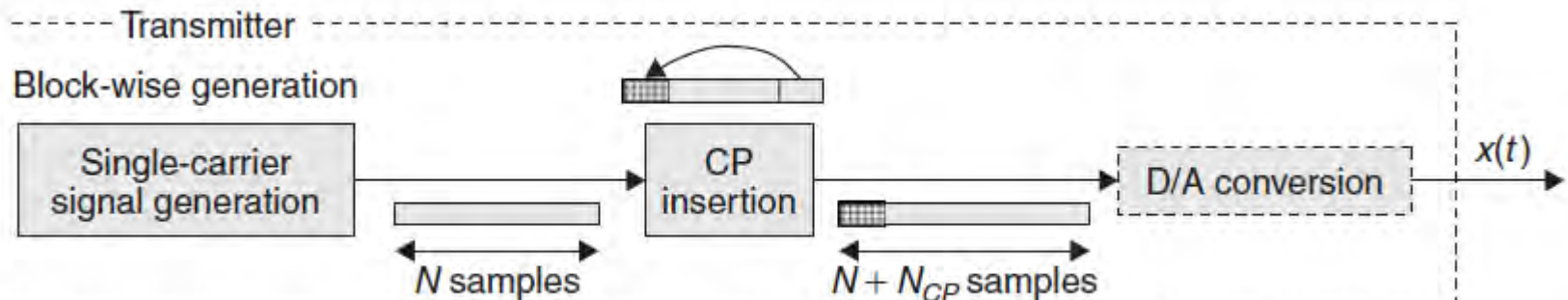
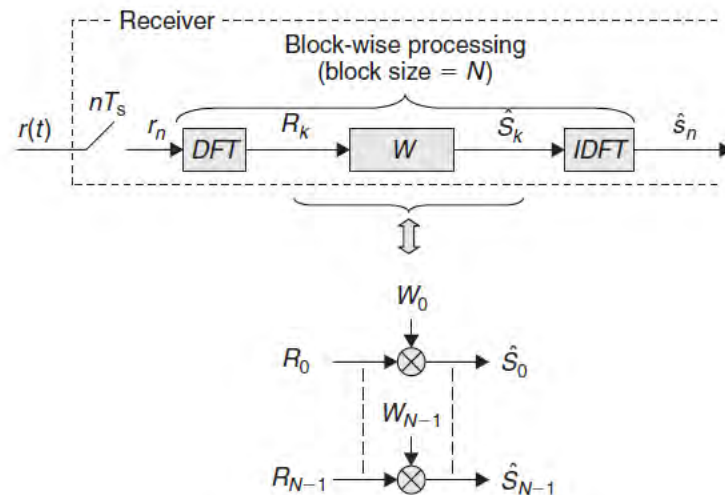
Single carrier frequency division multiple access

El UPLINK de LTE (cuarta generación)

FDE: frequency domain equalizer

- La convolución con el canal es una convolucional lineal \rightarrow el FDE corresponde a una convolución circular.

Solución \rightarrow prefijo cíclico !!

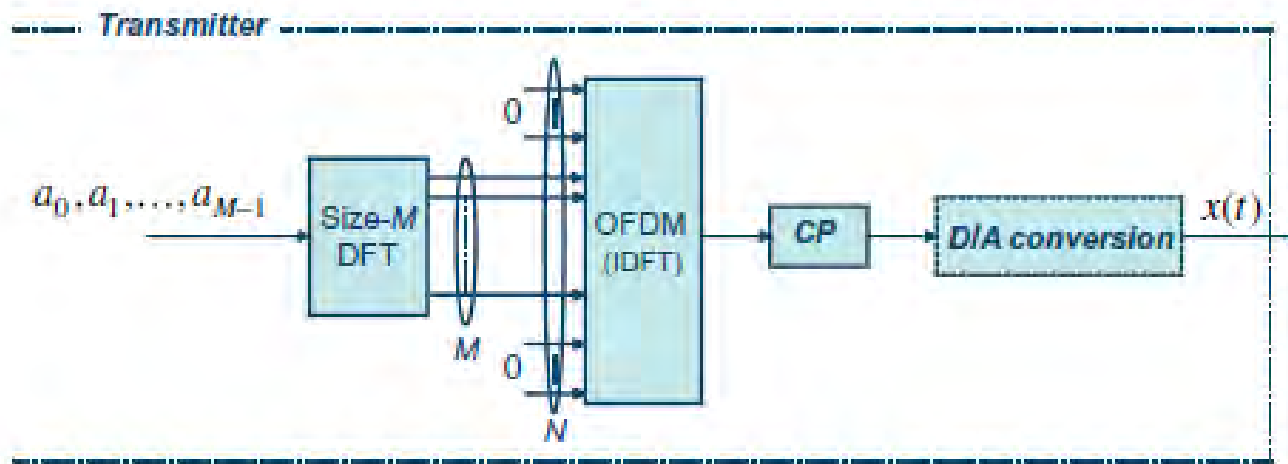


SC-FDMA

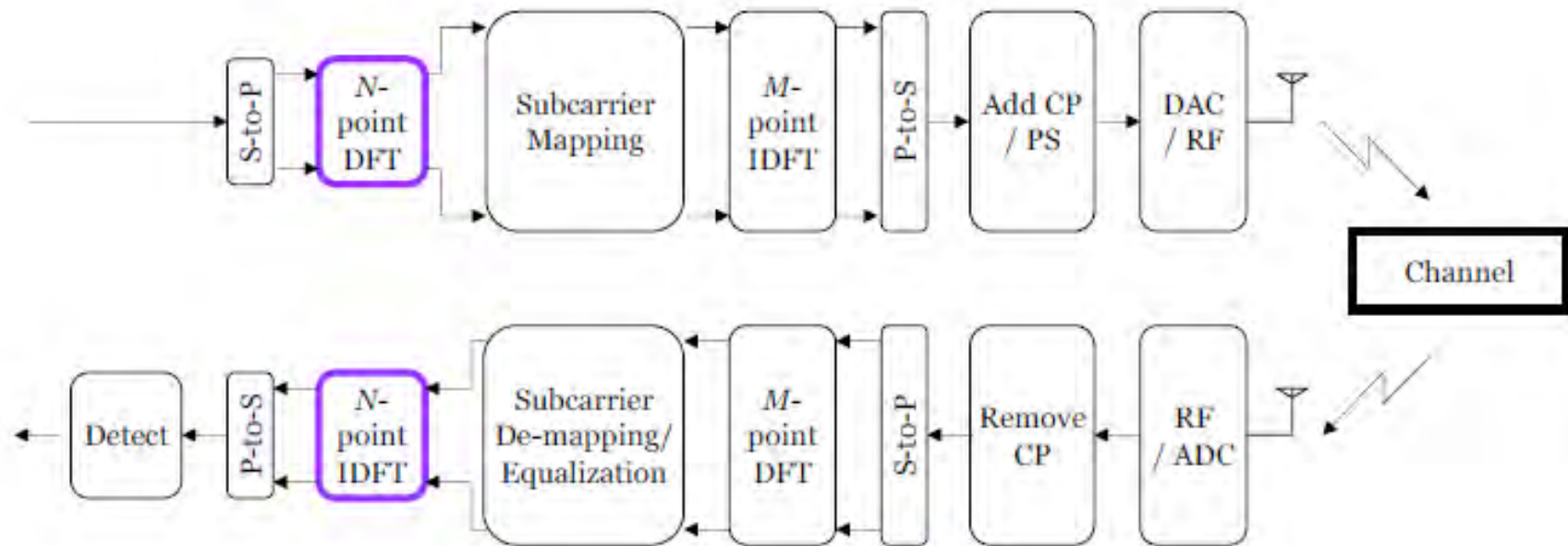
La modulacion de LTE UPLINK

SC-FDMA

- ▶ Utiliza single-carrier modulation, DFT spreading y ecualización en dominio frecuencia.
- ▶ Es adoptado por LTE (uplink)
- ▶ En SC-FDMA se transmiten “M” símbolos secuencialmente cada uno ocupando todo el ancho de banda disponible y con una duración igual a una parte del tiempo de símbolo.



SC-FDMA - diagrama en bloques



SC-FDMA: ☐ + ☒

OFDMA: ☐

* $N < M$

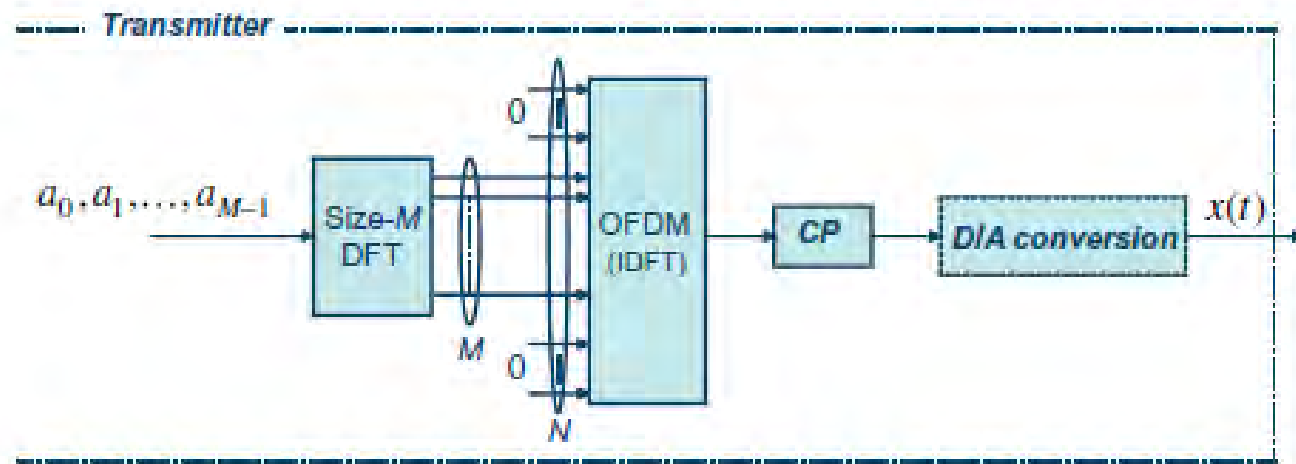
* S-to-P; Serial-to-Parallel

* P-to-S; Parallel-to-Serial

“One way to interpret DFTS-OFDM is as normal OFDM with a *DFT-based precoding*”
Libro Dahlman.

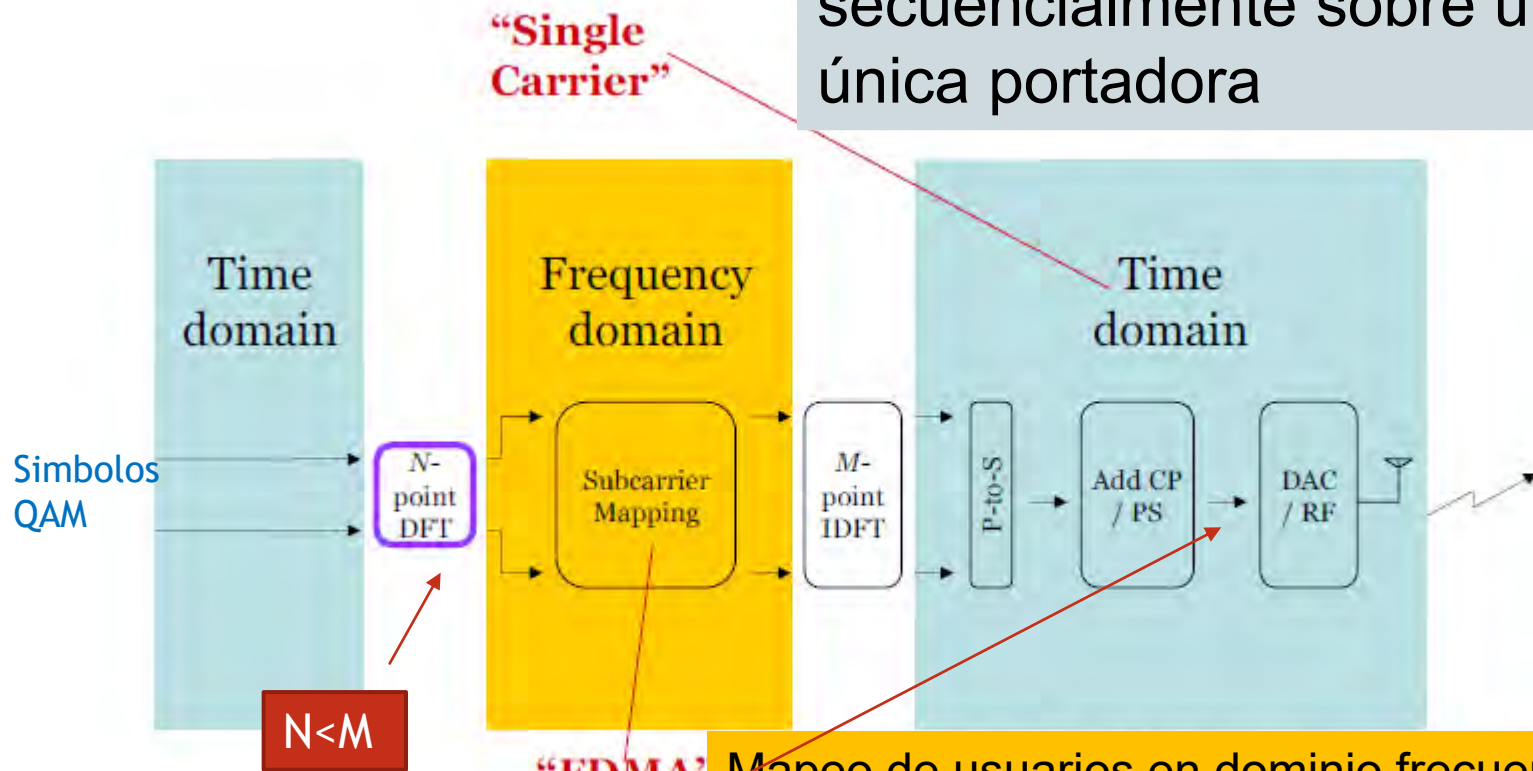
Es single carrier?

If the DFT size M equals the IDFT size N , the cascaded DFT/IDFT processing would obviously completely cancel each other out. However, if M is smaller than N and the remaining inputs to the IDFT are set to zero, the output of the IDFT will be a signal with “single-carrier” properties – that is, a signal with low power variations, and with a bandwidth that depends on M . More specifically, assuming a sampling rate f_s at the output of the IDFT, the nominal bandwidth of the transmitted signal will be $BW = M/N \cdot f_s$. Thus, by varying the block size M the instantaneous bandwidth of the transmitted signal can be varied, allowing for flexible-bandwidth assignment. Furthermore, by shifting the IDFT inputs to which the DFT outputs are mapped, the transmitted signal can be shifted in the frequency domain, as will be further discussed in Section 4.3.3.



Es Single-carrier?

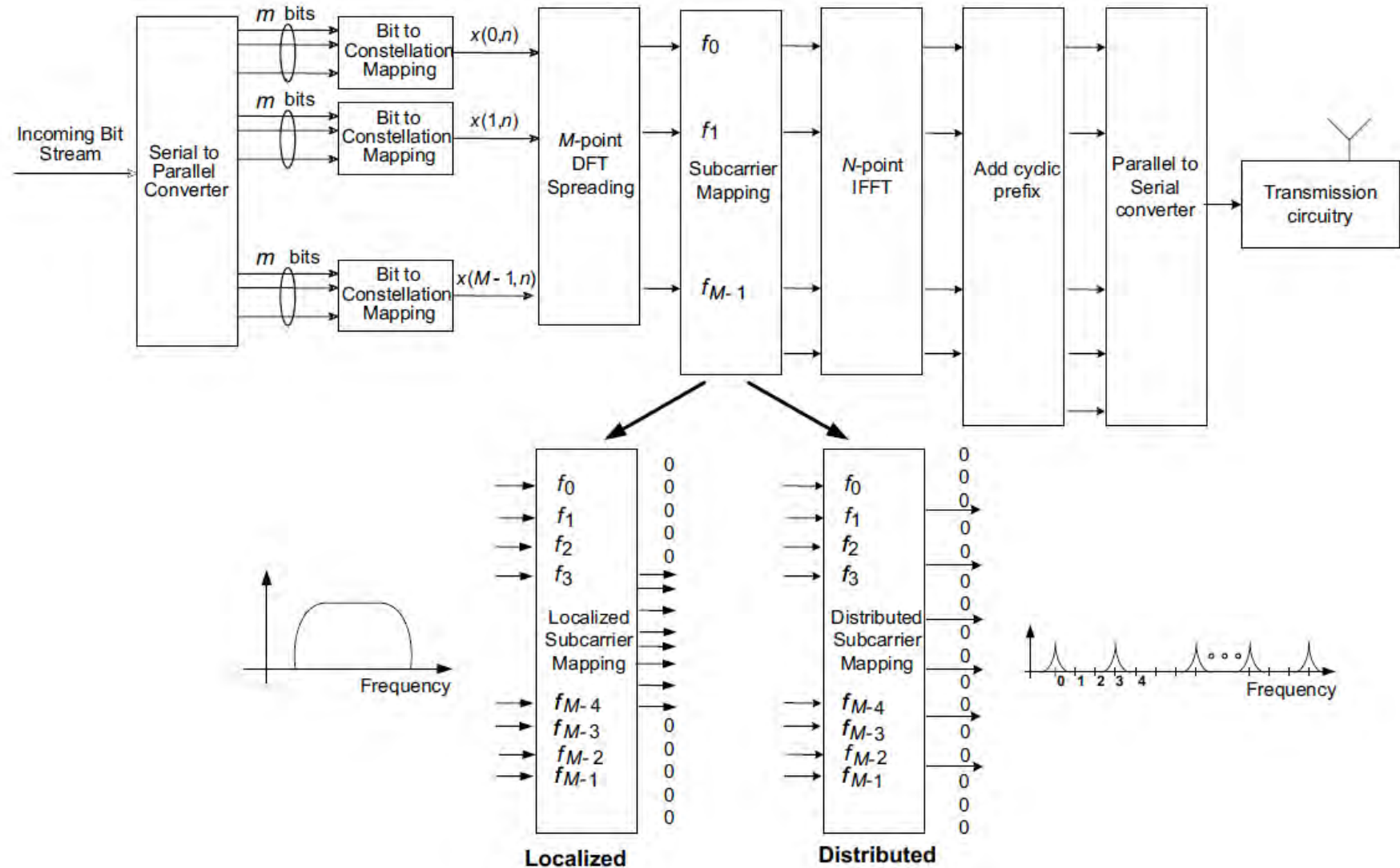
Los simbolos se transmiten secuencialmente sobre una única portadora



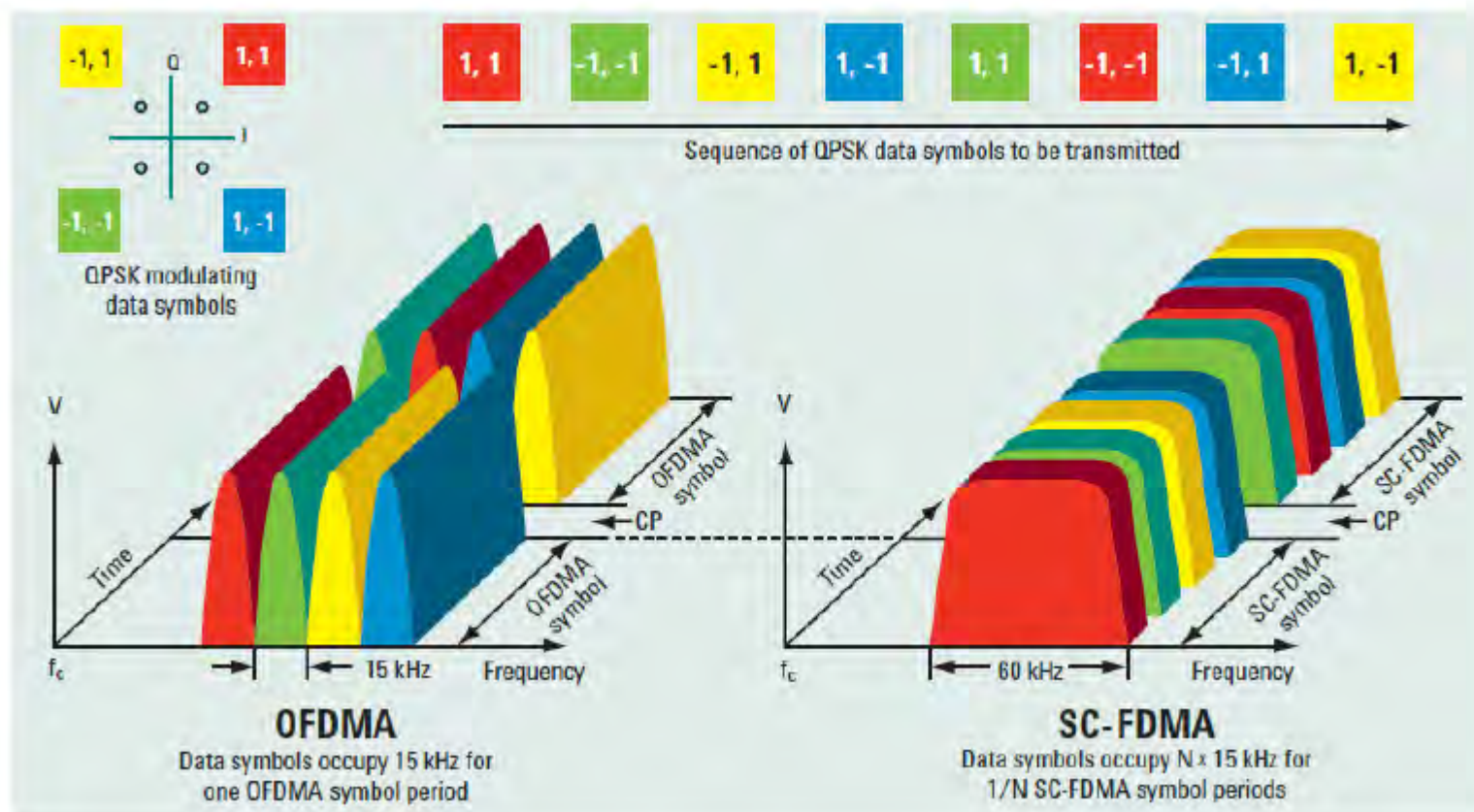
Mapeo de usuarios en dominio frecuencia

Paprr ?

SC-FDMA



SC-FDMA vs OFDMA



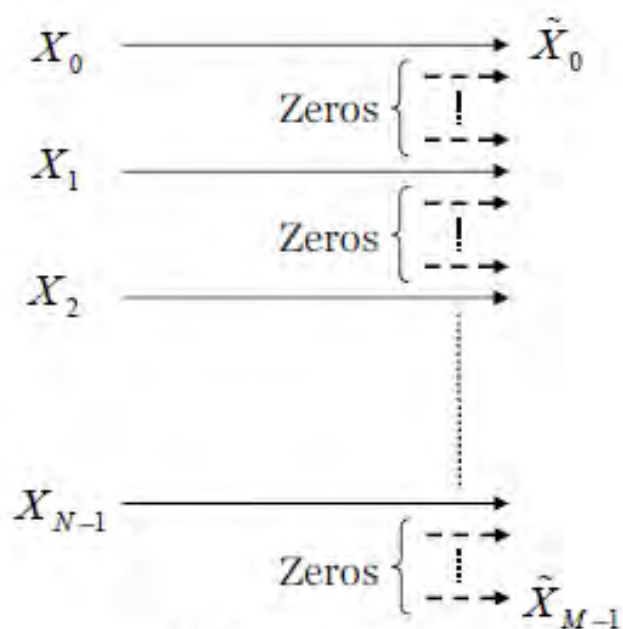
SC-FDMA

- ▶ En SC-FDMA una combinación lineal, vía DFT, de varios símbolos de datos se usa para modular varias sub-portadoras ortogonales → los símbolos de datos ocupan todo el ancho de banda, pero la duración de cada símbolo de datos representa sólo una porción del tiempo total del símbolo SC-FDMA.

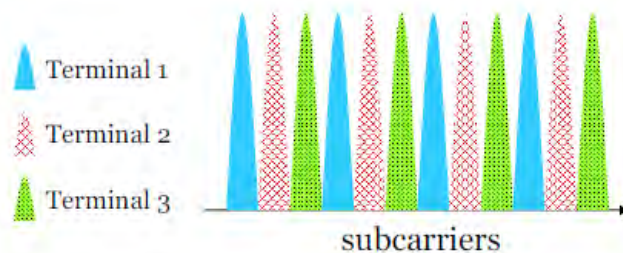
DFT-spread OFDM

SC-FDMA también es mencionada en varias referencias como DFTS-OFDM

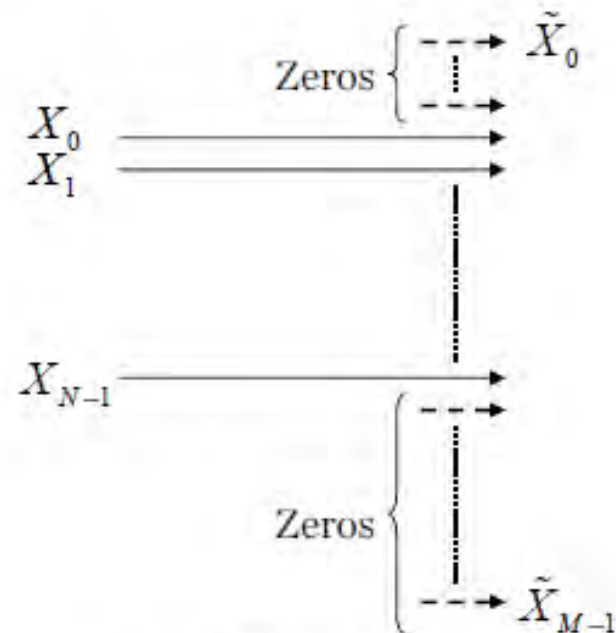
Mapeo de subportadoras



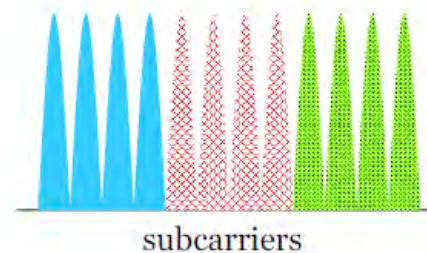
Distributed



Distributed Mode

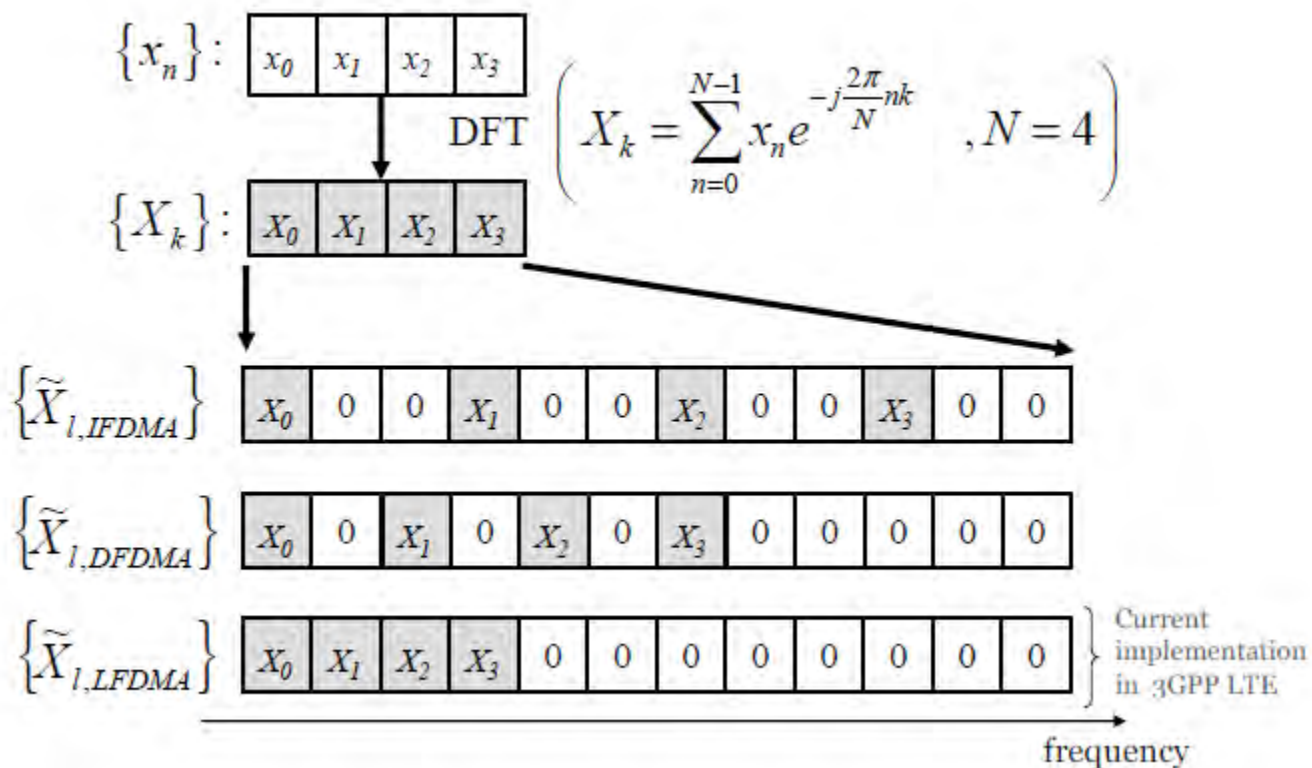


Localized



Localized Mode

Mapeo de subportadoras



Multiplexado de usuarios

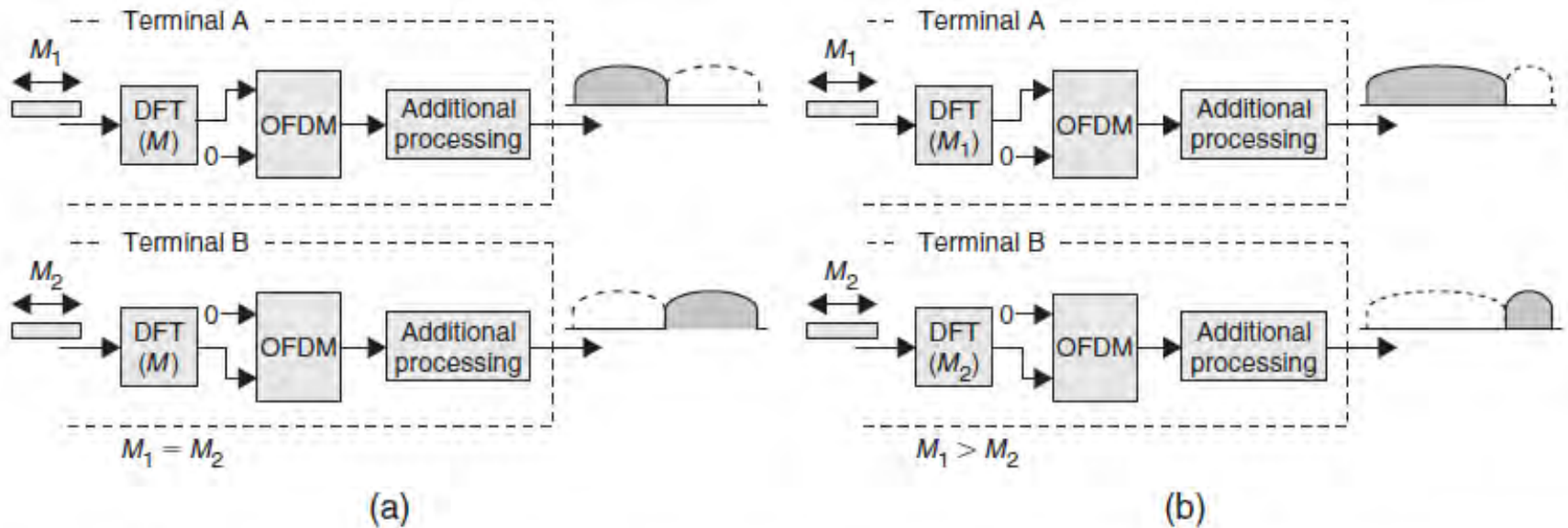


Figure 5.12 Uplink user multiplexing in case of DFTS-OFDM. (a) Equal-bandwidth assignment and (b) unequal-bandwidth assignment.

Asignación localizada o distribuida

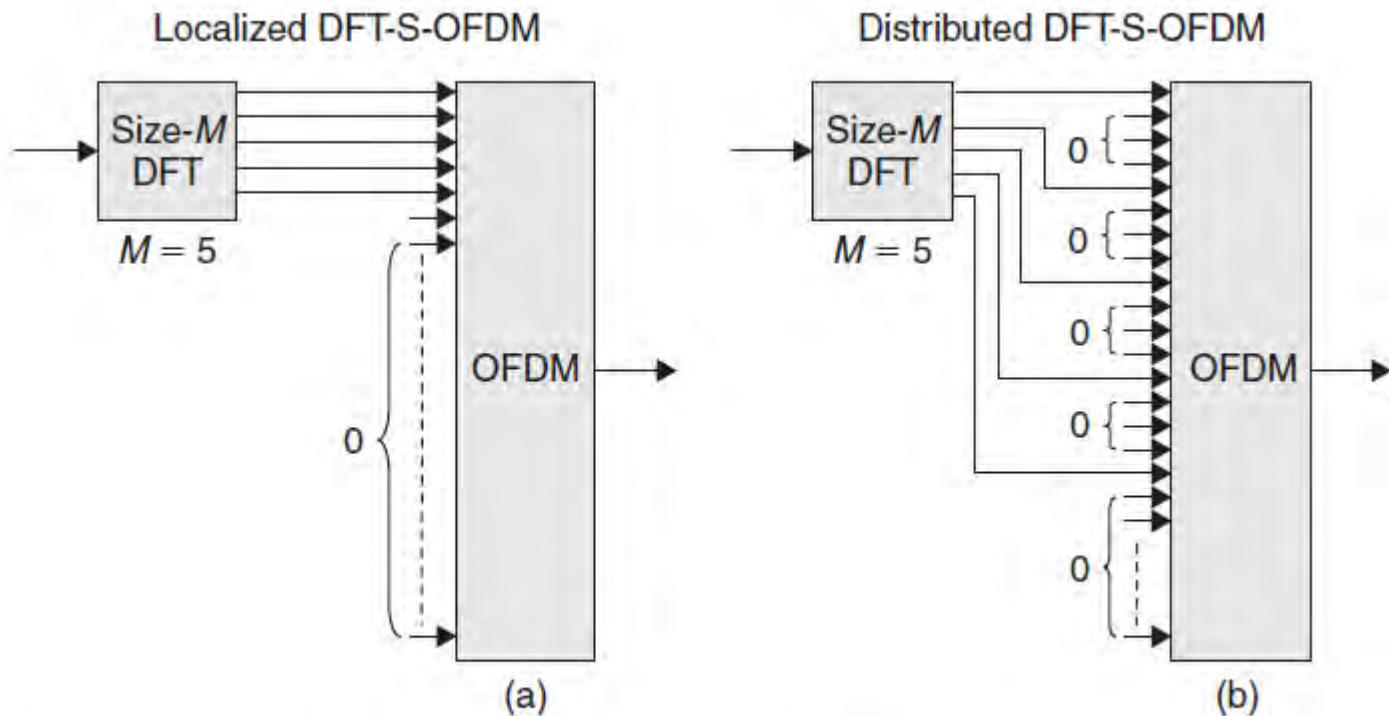
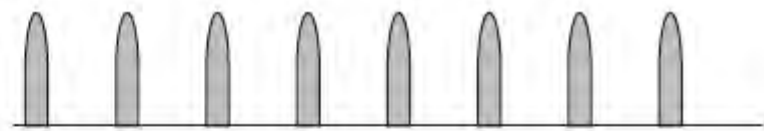


Figure 5.13 *Localized DFTS-OFDM vs. Distributed DFTS-OFDM.*



Localized transmission

(a)



Distributed transmission

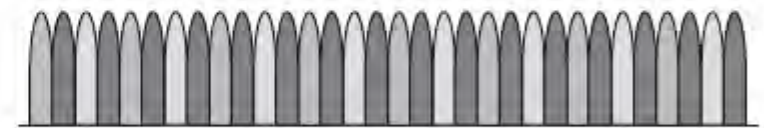
(b)

Figure 5.14 *Spectrum of localized and distributed DFTS-OFDM signals.*



Localized transmission

(a)



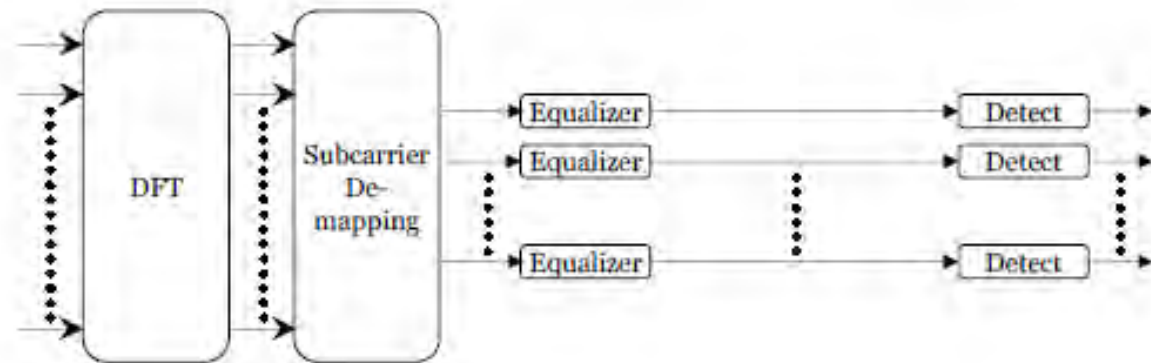
Distributed transmission

(b)

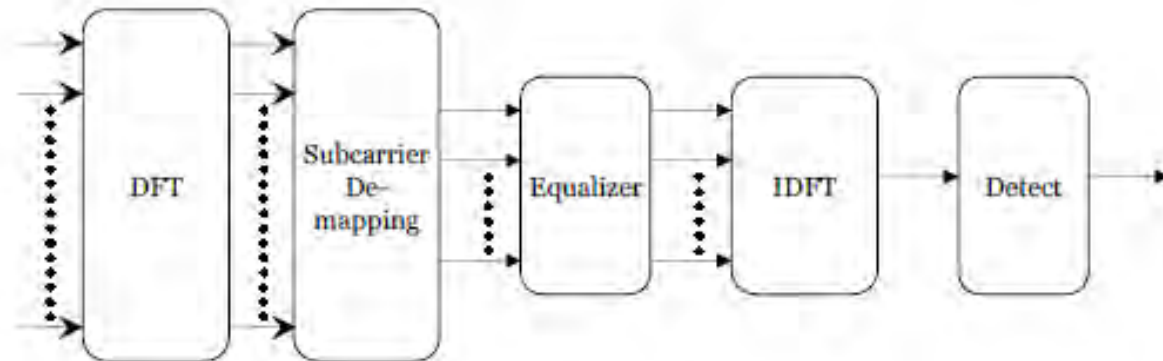
Figure 5.15 *User multiplexing in case of localized and distributed DFTS-OFDM.*

Ecualización

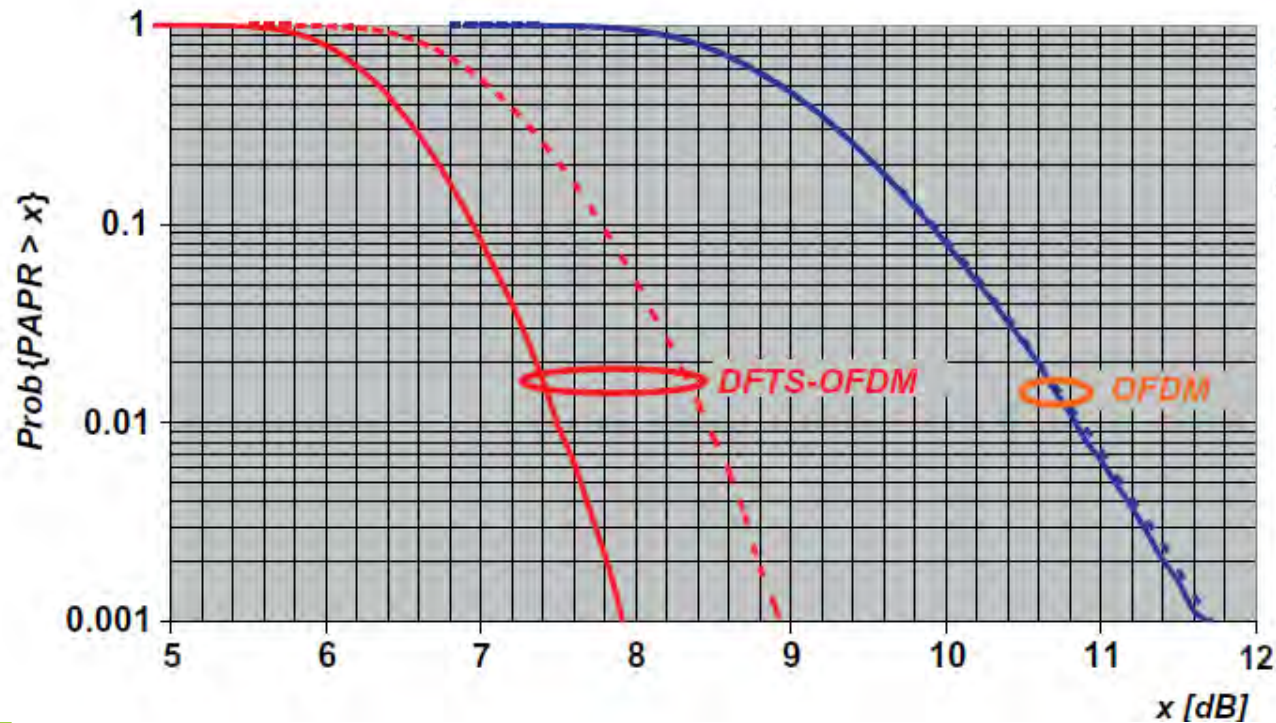
OFDMA



SC-FDMA



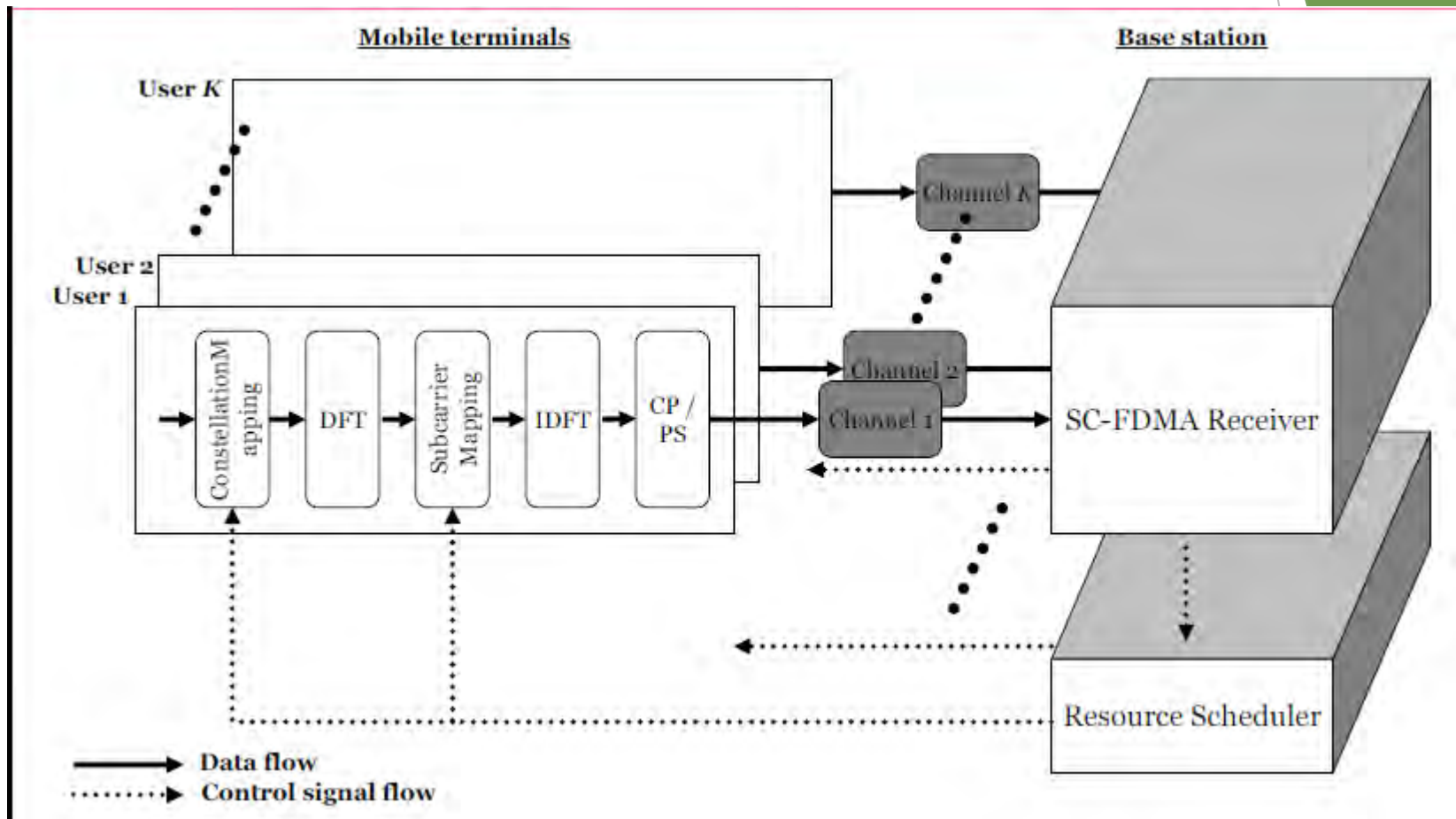
PAPR



Cubic metric:

- OFDM: 3.4 dB
- DFTS-OFDM (QPSK): 1.0 dB
- DFTS-OFDM (16QAM): 1.8 dB

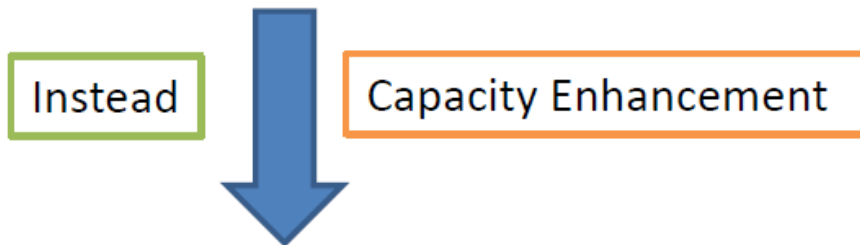
Uplink LTE block



Técnicas de acceso no-ortogonales - NOMA

From Noise to Interference Cancellation

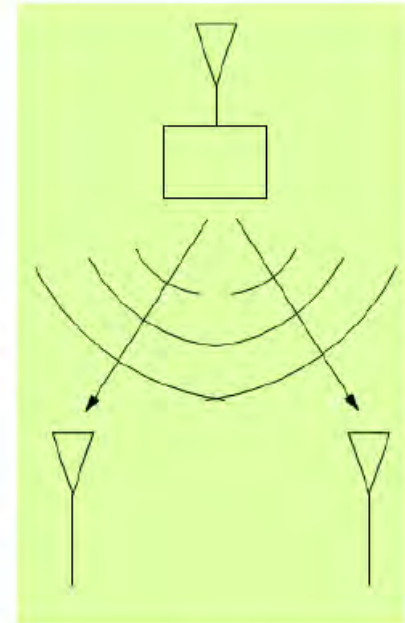
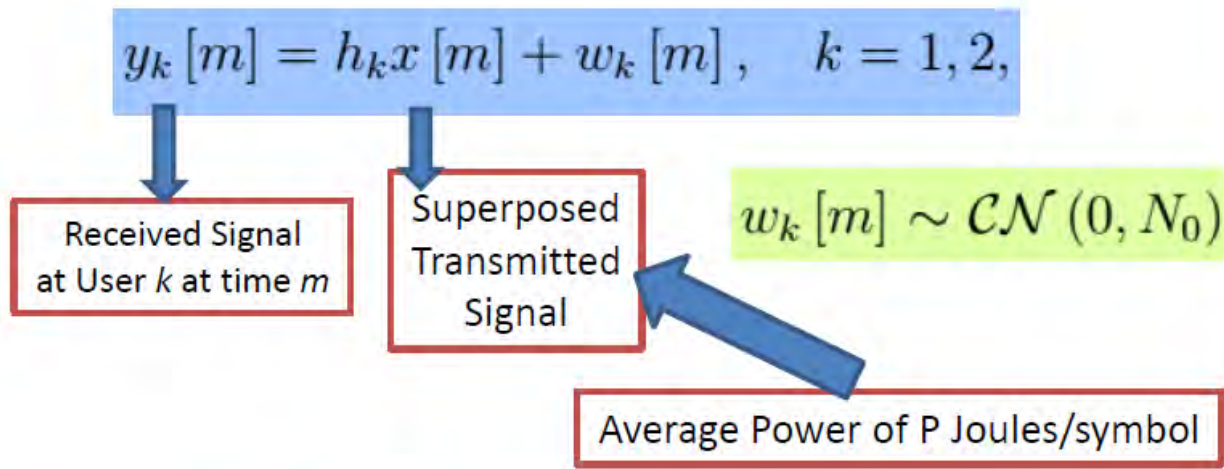
- **What happened in CDMA:** (say, uplink) an optimal multiple access strategy is for all users to **spread their signal across the entire bandwidth**. **Decoding every user treating the *interference from other users as noise***.



- **What happened if:** a *successive interference cancellation* (SIC) receiver is used. That is, **after one user is decoded, its signal is stripped away** from the aggregate received signal **before the next user is decoded**.
- In downlink, with signals for the users **superimposed** on top of each other and **SIC done** at the mobiles.

Downlink AWGN Channel

- Single Tx and multiple Rx



- At receiving side, users separately decode their data from the signals they receive.
- The regions of the rate (R_1, R_2) at which two users simultaneously can communicate

$$R_k < \log \left(1 + \frac{P|h_k|^2}{N_0} \right), \quad k = 1, 2.$$

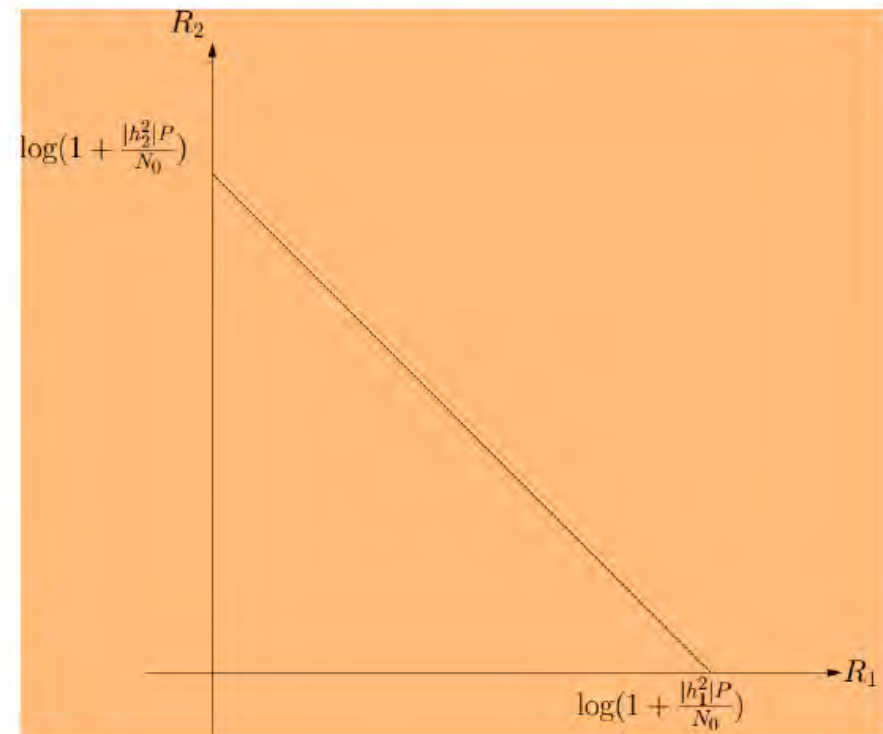
Downlink AWGN Channel

$$R_k < \log \left(1 + \frac{P|h_k|^2}{N_0} \right), \quad k = 1, 2.$$

- This **upper bound on R_k** can be attained by using all the power and degrees of freedom to communicate to user k (with the **other user getting zero rate**). Thus, we have the **two extreme points**:

- We can obtain any rate pair that is a combination of these two extreme points.
- Can we achieve a rate pair outside this triangle?
- Consider a symmetric case:

$$|h_1| = |h_2|$$



Downlink AWGN Channel

- Let us now think for another idea: if user 1 can successfully decode its data from y_1 , then user 2 which has the same SNR should also be able to decode the data of user 1 from y_2 . (Both y_1 and y_2 contains the superposed transmitted signal)
- Then, user 2 can *subtract* the codeword of user 1 from its received signal y_2 to better decode its own data, i.e., it can perform *successive interference cancellation*.
- Consider the superposed signal:

$$x[m] = x_1[m] + x_2[m],$$

- The transmitter encodes the information for each user over the entire bandwidth (and powers P_1 and P_2 with $P_1 + P_2 = P$)

Downlink AWGN Channel

- User 1 treats the signal for user 2 as noise and can hence be communicated to reliably at a rate of

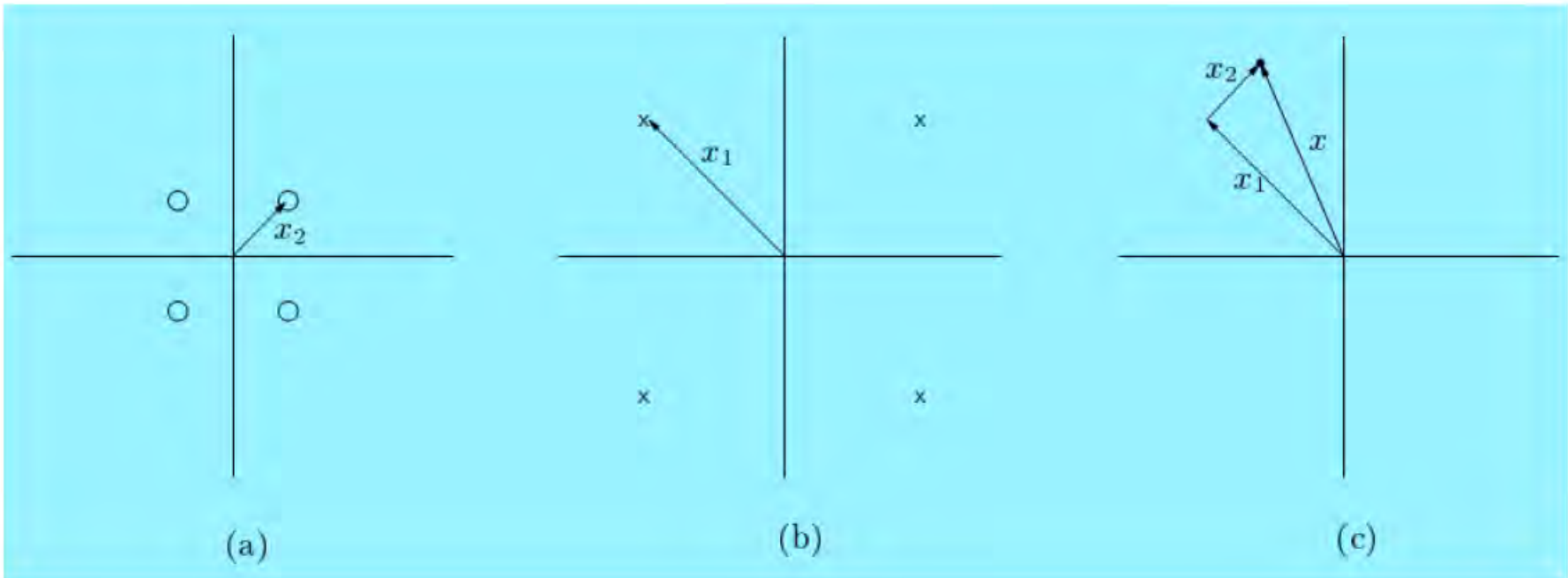
$$R_1 = \log \left(1 + \frac{P_1 |h_1|^2}{P_2 |h_1|^2 + N_0} \right) = \log \left(1 + \frac{(P_1 + P_2) |h_1|^2}{N_0} \right) - \log \left(1 + \frac{P_2 |h_1|^2}{N_0} \right)$$

- User 2 first decodes the data of user 1, subtracts the user 1 signal from y_2 and extracts its own data. Thus, user 2 can support reliably a rate

$$R_2 = \log \left(1 + \frac{P_2 |h_2|^2}{N_0} \right)$$

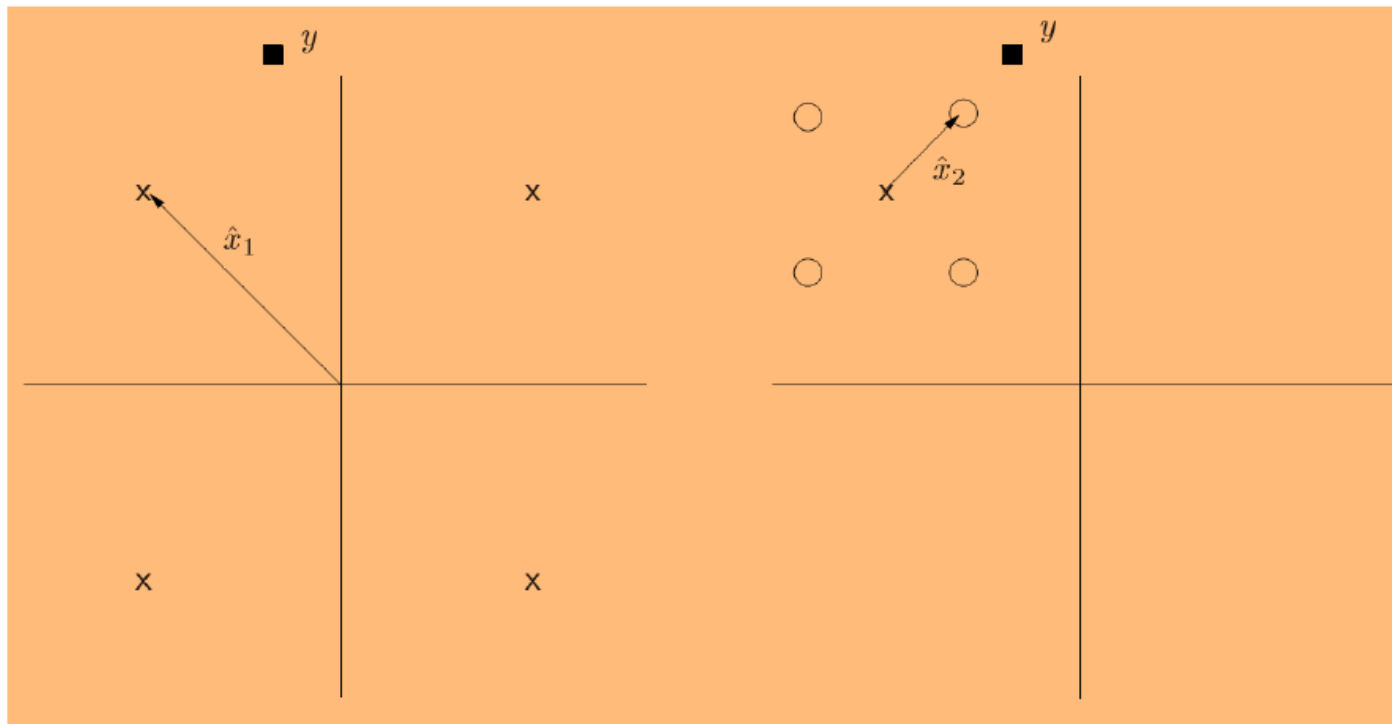
Downlink AWGN Channel

Superposition encoding example: The QPSK constellation of user 2 is superimposed on top of that of user 1.



Downlink AWGN Channel

Superposition decoding example: The transmitted constellation point of user 1 is decoded first, followed by decoding of the constellation point of user 2.

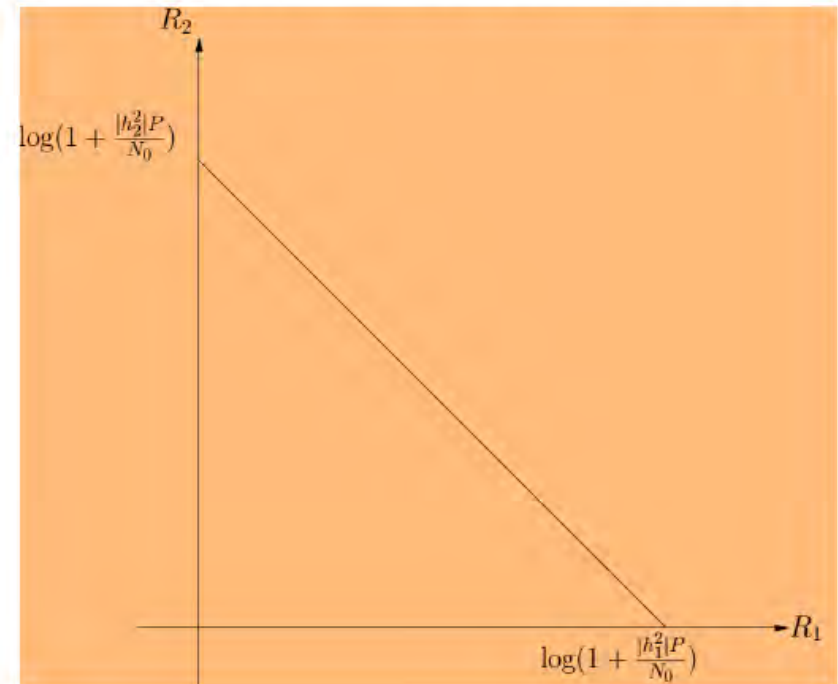


Downlink AWGN Channel

We see that the rate pair achieved in the figure (from slide 5) can also be achieved by the SIC strategy (Equations below)

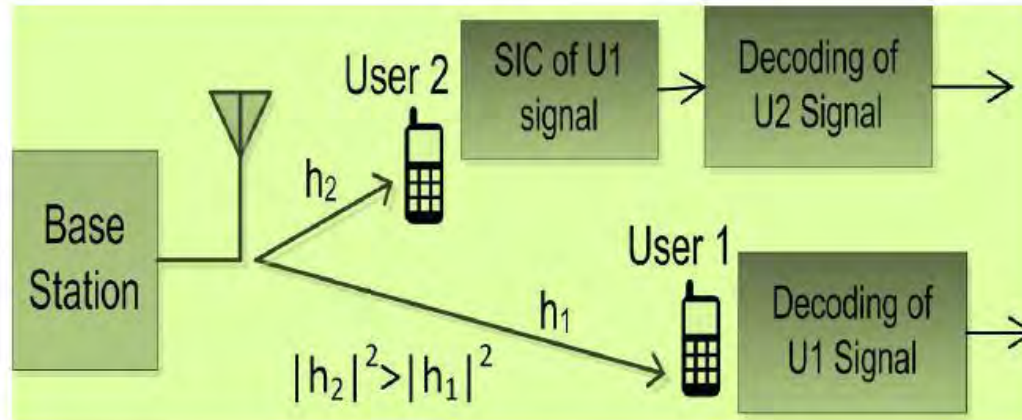
$$R_1 = \log \left(1 + \frac{P_1 |h_1|^2}{P_2 |h_1|^2 + N_0} \right)$$

$$R_2 = \log \left(1 + \frac{P_2 |h_2|^2}{N_0} \right)$$



Downlink AWGN Channel

Not symmetric channel: Let us consider the user 2 has better channel conditions than that of user 1



Non-Orthogonal Schemes

$$R_1 = \log \left(1 + \frac{P_1 |h_1|^2}{P_2 |h_1|^2 + N_0} \right) \quad \text{bits/s/Hz}$$

$$R_2 = \log \left(1 + \frac{P_2 |h_2|^2}{N_0} \right) \quad \text{bits/s/Hz.}$$

Orthogonal Schemes

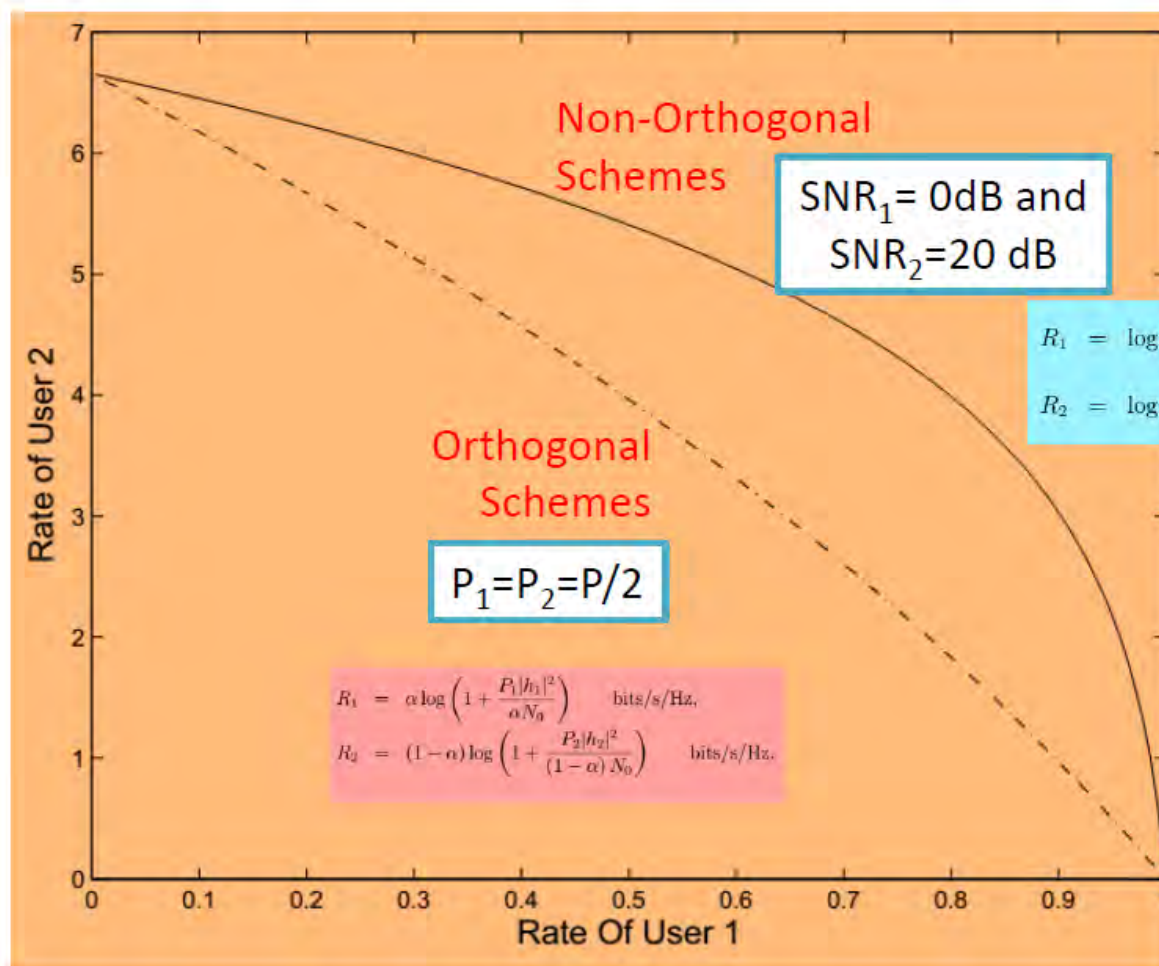
$$R_1 = \alpha \log \left(1 + \frac{P_1 |h_1|^2}{\alpha N_0} \right) \quad \text{bits/s/Hz,}$$

$$R_2 = (1 - \alpha) \log \left(1 + \frac{P_2 |h_2|^2}{(1 - \alpha) N_0} \right) \quad \text{bits/s/Hz.}$$



Note: α represents the fraction of the bandwidth devoted to user 1

Downlink AWGN: Orthogonal vs. Non-Orthogonal



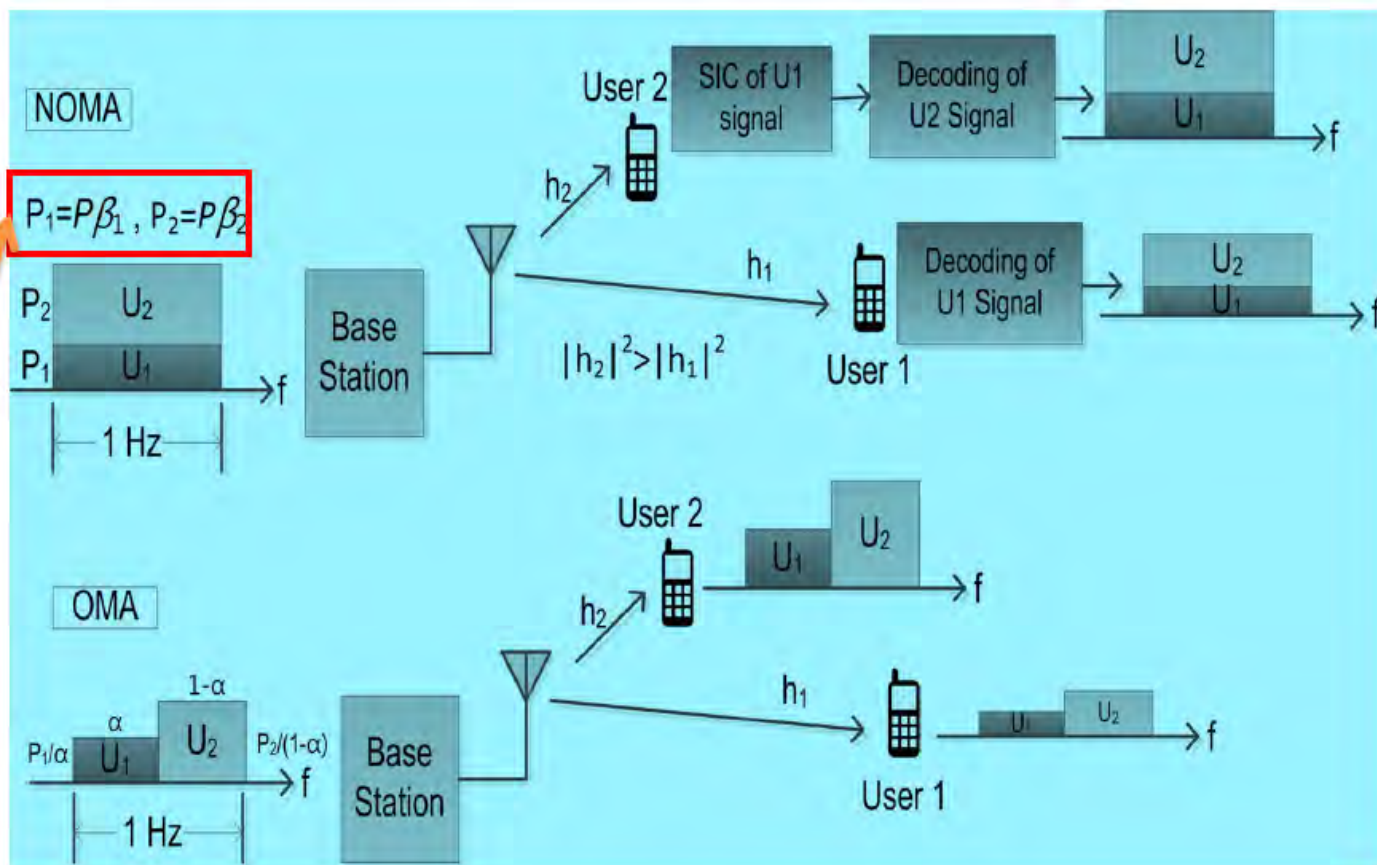
$$R_1 = \log \left(1 + \frac{P_1 |h_1|^2}{P_2 |h_1|^2 + N_0} \right) \quad \text{bits/s/Hz}$$

$$R_2 = \log \left(1 + \frac{P_2 |h_2|^2}{N_0} \right) \quad \text{bits/s/Hz}$$

$$R_1 = \alpha \log \left(1 + \frac{P_1 |h_1|^2}{\alpha N_0} \right) \quad \text{bits/s/Hz}$$

$$R_2 = (1 - \alpha) \log \left(1 + \frac{P_2 |h_2|^2}{(1 - \alpha) N_0} \right) \quad \text{bits/s/Hz}$$

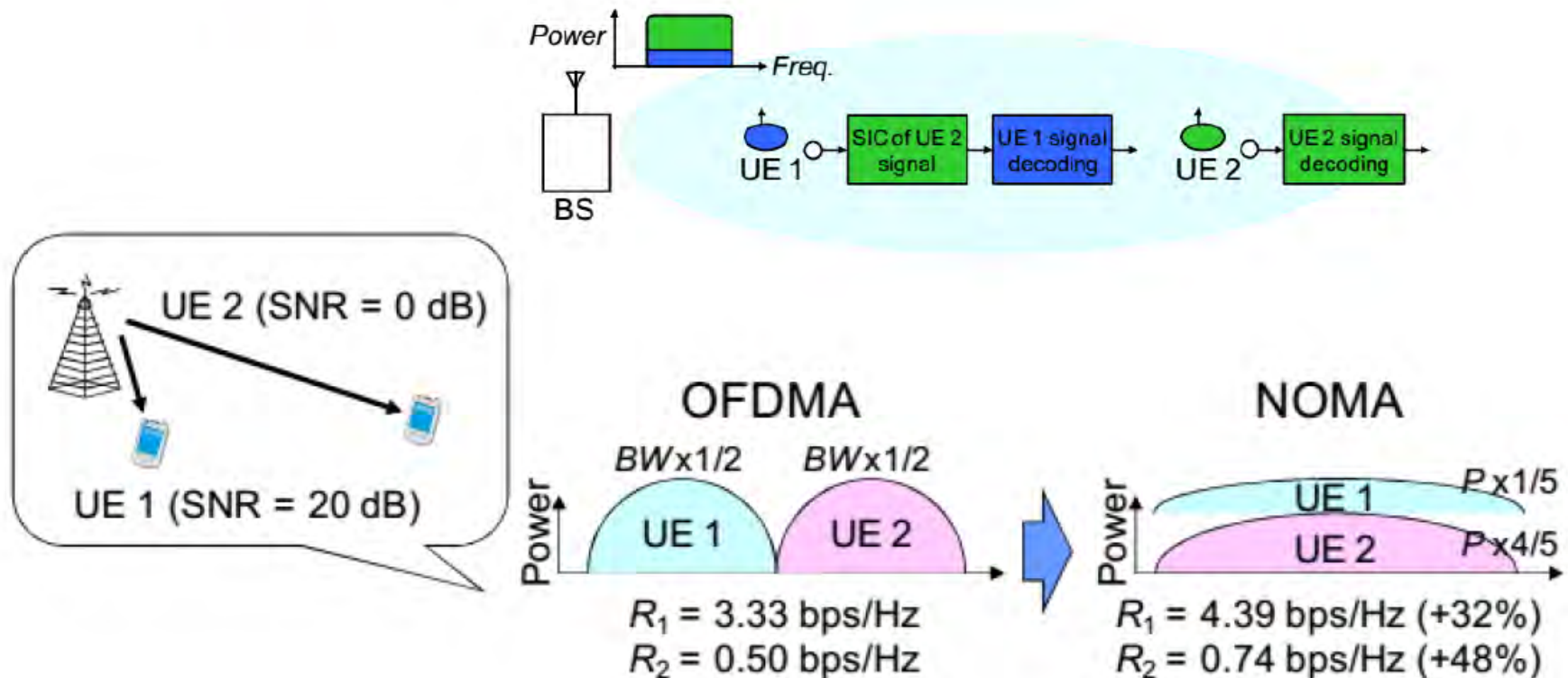
Orthogonal vs. Non-Orthogonal Schemes



Note: Capacity boundary of NOMA depends on the differences in channel gains and power allocation.

A Numerical Example

- Power allocation for each UE greatly affects the user throughput performance!



- NOMA achieves superior spectral efficiency compared to OMA.*

NOMA Basics Learned

- NOMA exploits power domain multiplexing.
- Superposition coding at Tx.
- Successive interference cancellation at Rx.
- A pair of users can be served by NOMA if their channel gains are considerably different.
- Power allocation strategies play an pivotal role in capacity enhancement.

Generalization: From Two Users to K Users

Consider a general case of K users and channels are sorted as

$$|h_1|^2 \leq |h_2|^2 \dots \leq |h_K|^2$$

note: h_k means the k th smallest instantaneous channel

Then, the capacity regions can be obtained by

$$R_k = \log \left(1 + \frac{P_k |h_k|^2}{N_0 + \underbrace{\left(\sum_{j=k+1}^K P_j \right) |h_k|^2}} \right), \quad k = 1 \dots K,$$

← $P = \sum_{k=1}^K P_k$

↗ Noise from other users after SIC

The cancellation order at every receiver is always to decode the weaker users before decoding its own data.

Técnicas no-ortogonales

- ▶ Pueden ofrecer mejoras en términos de eficiencia espectral
- ▶ Técnicas híbridas son consideradas en la futura 5G (OMA + NOMA)
- ▶ Estimación de canal requerido en los receptores SIC es fundamental para obtener un desempeño adecuado.
- ▶ Una buena herramienta para nodos IoT donde un gran número de usuarios requieren acceso al medio.
- ▶ NOMA en dominio potencia no es la única opción. Existe una gran variante de técnicas NOMA.
- ▶ NOMA esta incluido en 3GPP reléase 13 y en 5G novel ratio (NR) reléase 14/15 principalmente para el uplink en escenarios M2M, D2D.
- ▶ Huawei, DoCoMO, Qualcomm, Intel. Samsung están involucrados en el estudio