COMPUTER ENGINEERING

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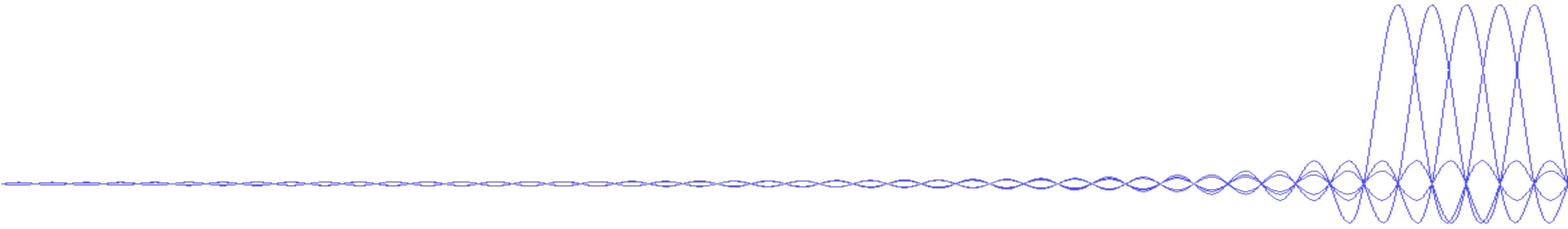
ADVANCED DIGITAL SIGNAL PROCESSING
Chapter 4: OFDM Modulation/Demodulation

28/10/2017



Content

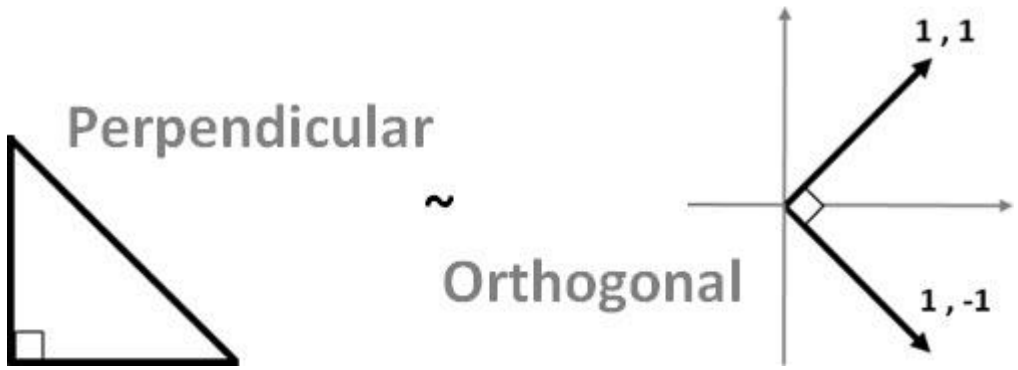
- Orthogonality
- Orthogonality – CDMA
- Orthogonality - OFDM
- OFDM Modulation - IFFT
- OFDM Demodulation - FFT

Orthogonality

- Orthogonality is property that allows multiple information signals to be transmitted perfectly over a common channel with the successful detection
- Two functions or signals are said to be orthogonal if they are mutually independent of each other
- Two vectors are said to be orthogonal if dot product is zero. Sine and cosine are best example of orthogonal signal and integration of protect of the two orthogonal is zero.

Orthogonality

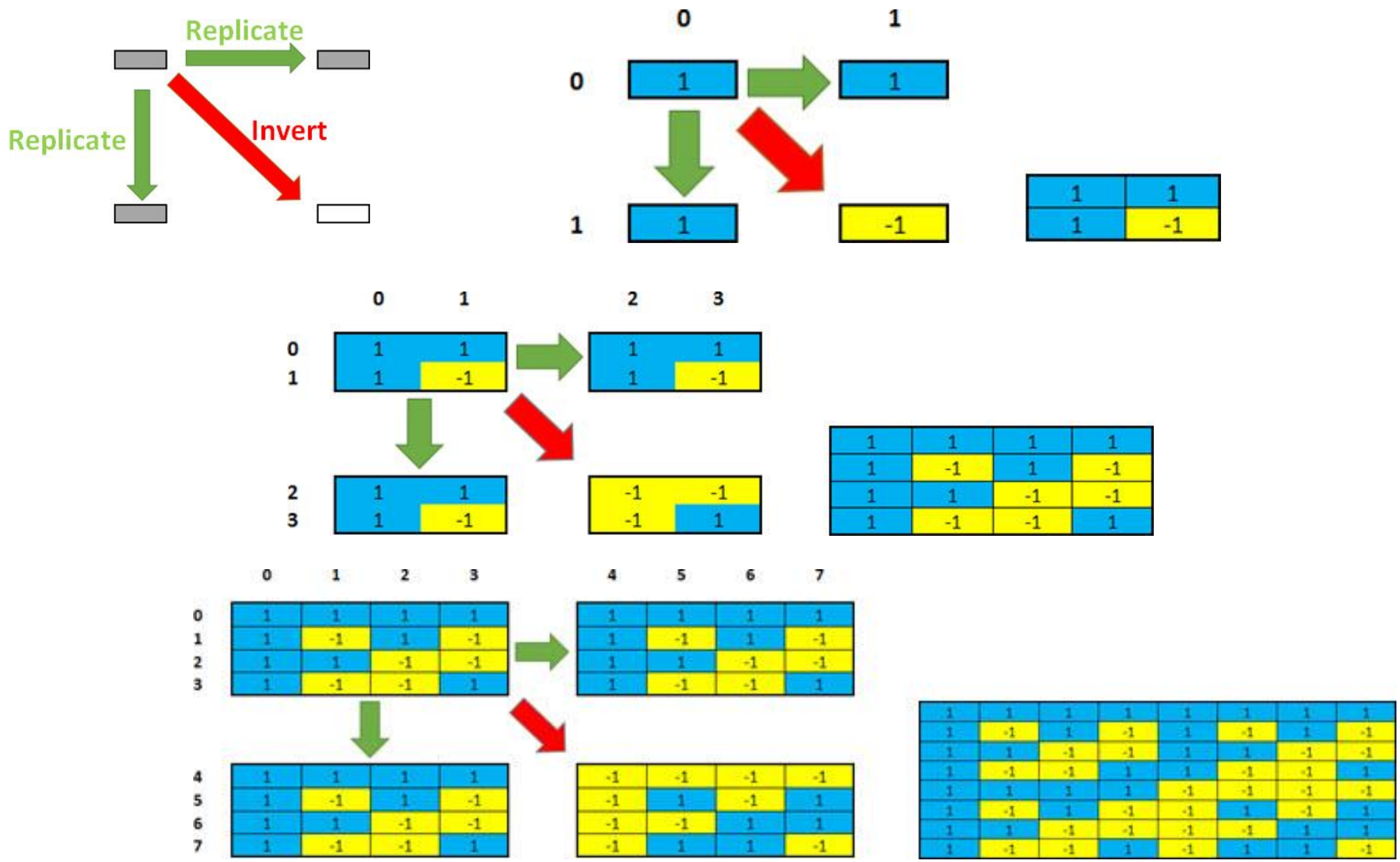
- Perpendicular Vs Orthogonality



  - u = (1,1)   v = (1,-1)
  - u.v = u1*v1 + u2*v2 = 1*1 + 1*(-1) = 0
  - Then, u and v are orthogonal
- Hence, if two vectors has an angle X of 90 degrees to each other - ie they are orthogonal - their Dot Product is equal to zero

Orthogonality - CDMA

- CDMA: Code-division multiple access



Orthogonality - CDMA

i.e. code 2	1	1	-1	-1	1	1	-1	-1
	X	X	X	X	X	X	X	X
i.e. code 5	1	-1	1	-1	-1	1	-1	1
	=	=	=	=	=	=	=	=
	1	-1	-1	1	-1	1	1	-1

$\sum = 0$

Orthogonality - CDMA

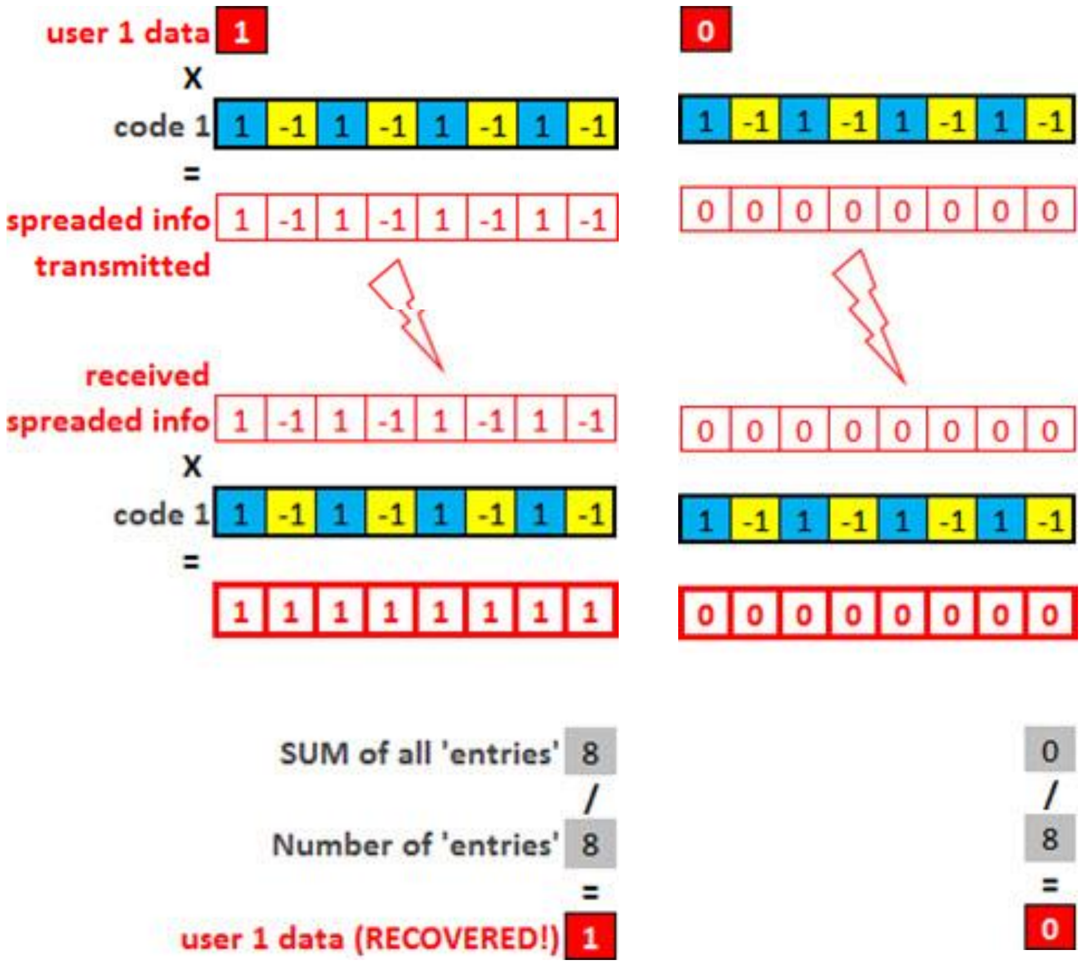
- Orthogonal code matrix

8 x 8

	0	1	2	3	4	5	6	7
0	1	1	1	1	1	1	1	1
1	1	-1	1	-1	1	-1	1	-1
2	1	1	-1	-1	1	1	-1	-1
3	1	-1	-1	1	1	-1	-1	1
4	1	1	1	1	-1	-1	-1	-1
5	1	-1	1	-1	-1	1	-1	1
6	1	1	-1	-1	-1	-1	1	1
7	1	-1	-1	1	-1	1	1	-1

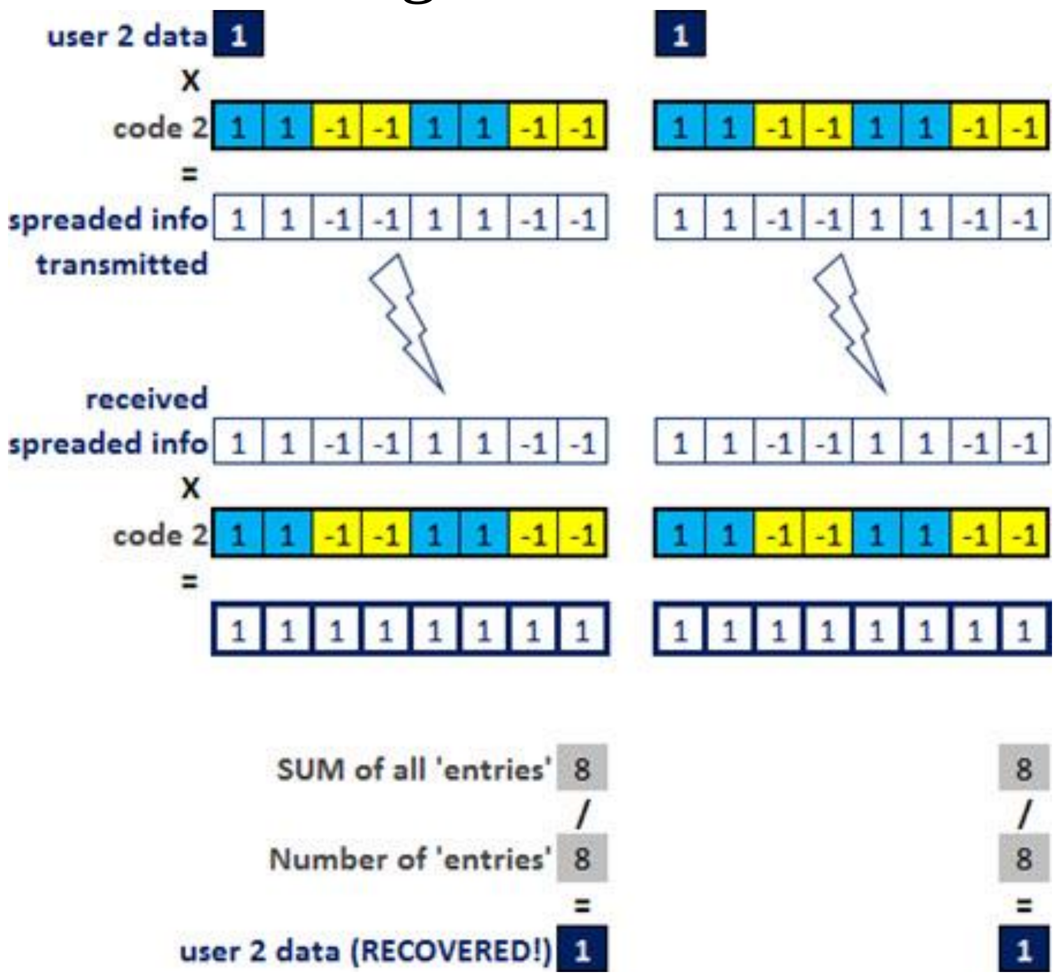
Orthogonality - CDMA

- Spreaded code – Single User1



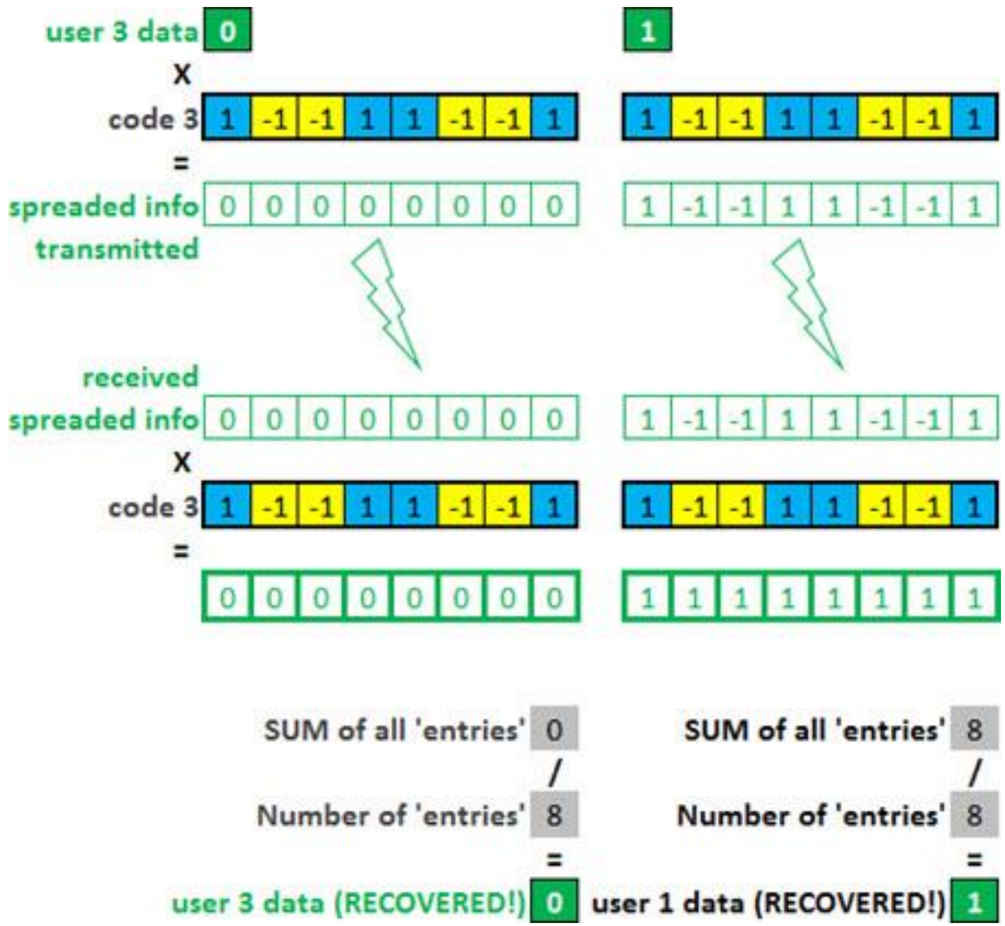
Orthogonality - CDMA

- Spreaded code – Single User2



Orthogonality - CDMA

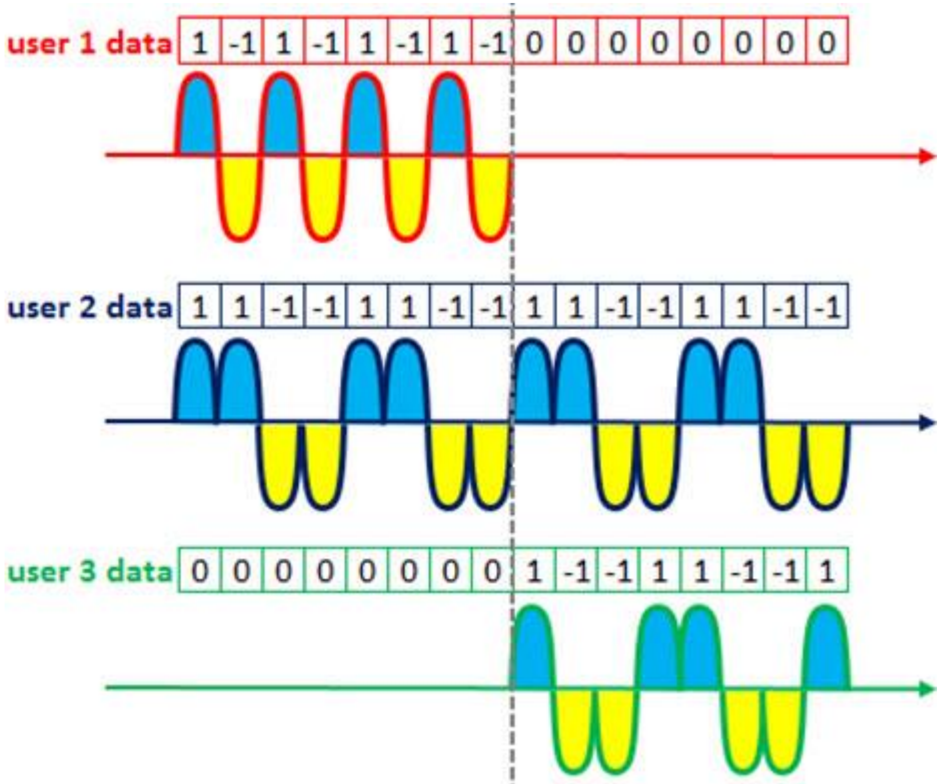
- Spreaded code – Single User3



Orthogonality - CDMA

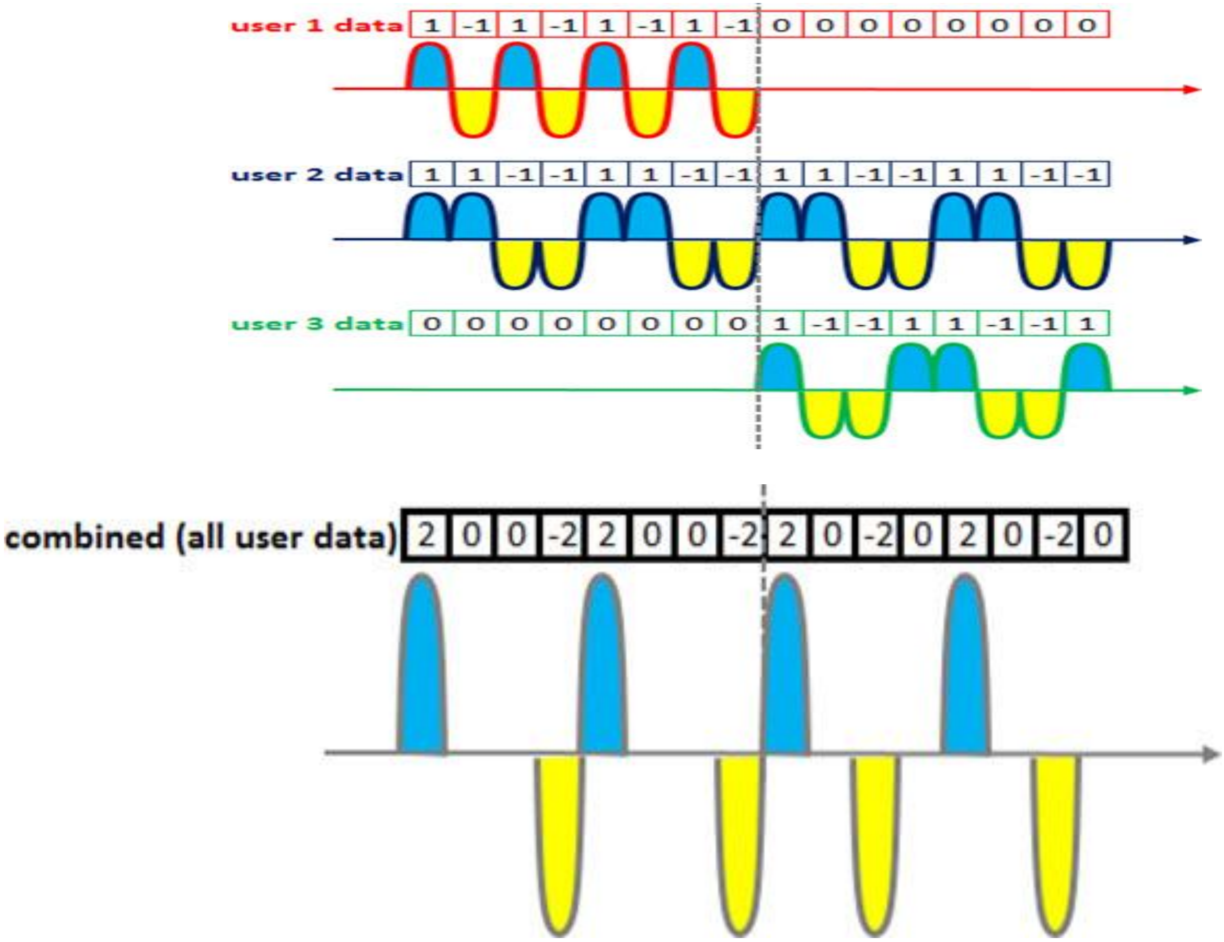
- Spreaded code – Multiple User {1, 2, 3}

user 1 data	1	-1	1	-1	1	-1	1	-1	0	0	0	0	0	0	0	0
user 2 data	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1
user 3 data	0	0	0	0	0	0	0	0	1	-1	-1	1	1	-1	-1	1



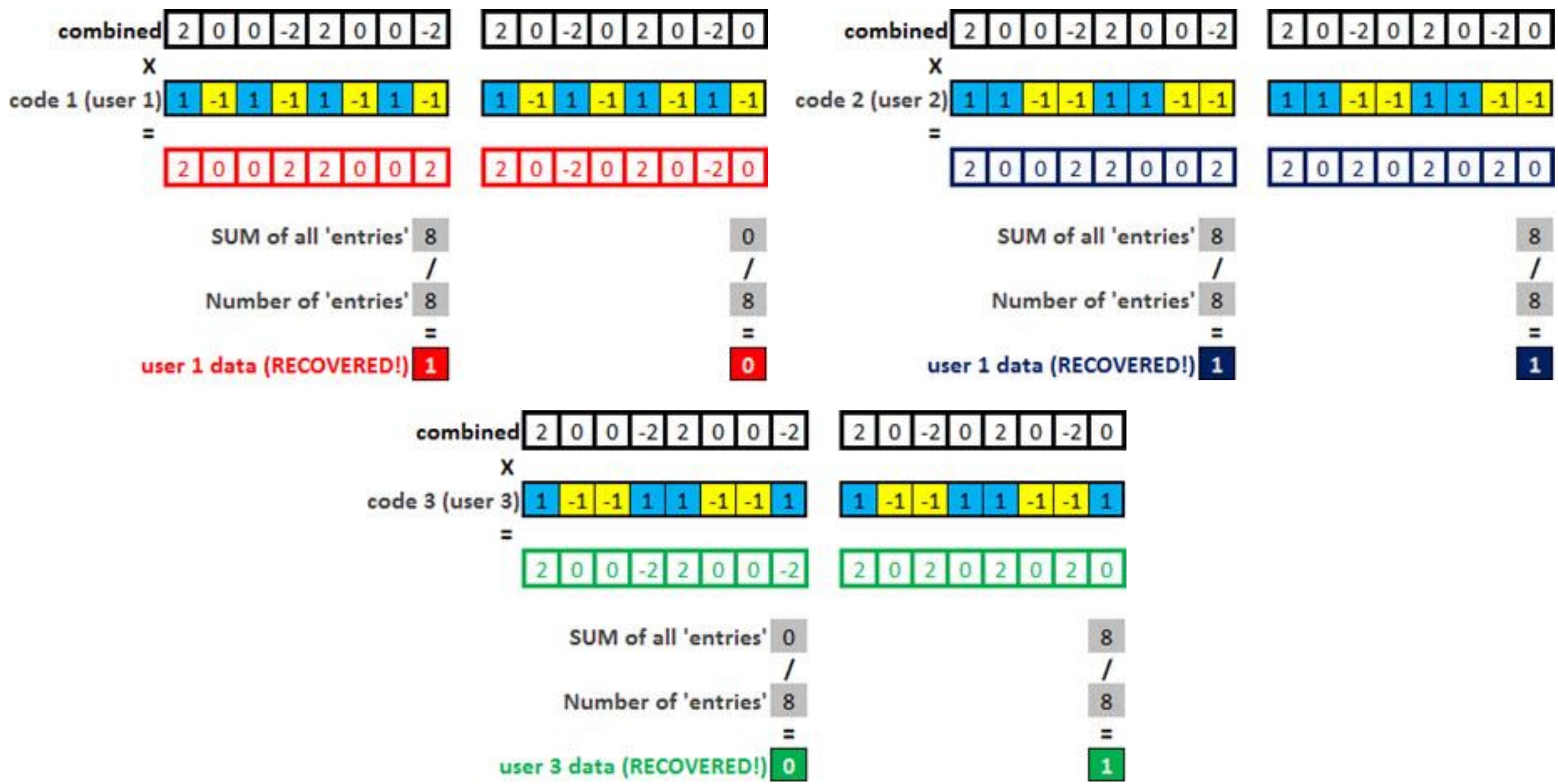
Orthogonality - CDMA

- Spreaded code – Multiple User {1, 2, 3}



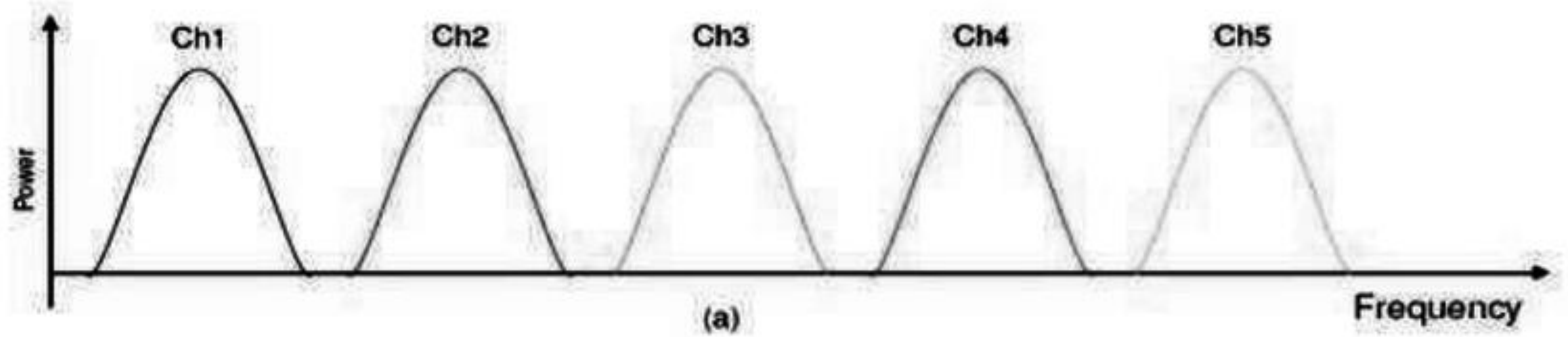
Orthogonality - CDMA

- Spreaded code – Multiple User {1, 2, 3}

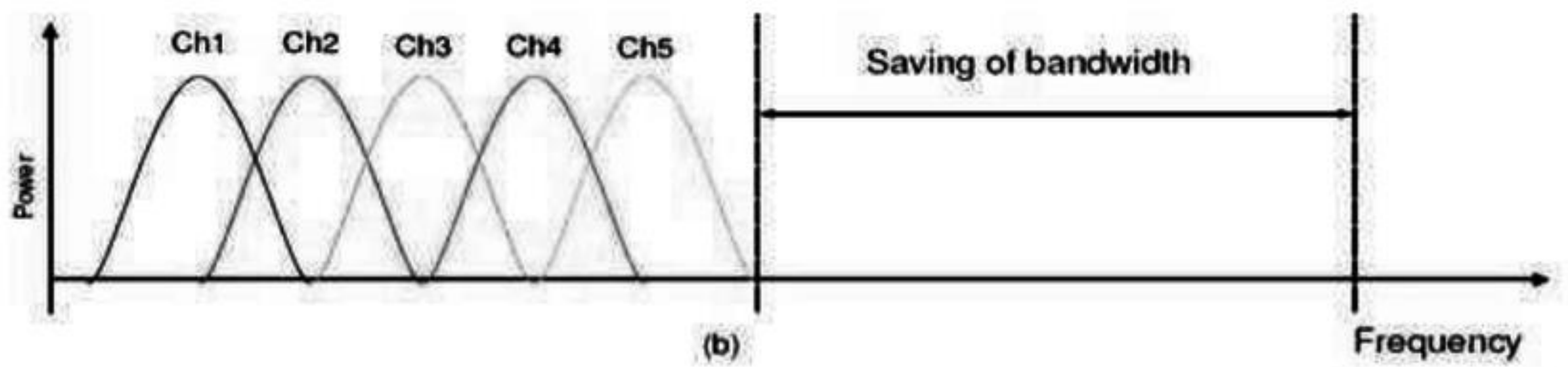


Orthogonality - OFDM

- Conventional FDM



- Orthogonal FDM



Orthogonality - OFDM

- OFDM: Orthogonal Frequency Division Multiplexing

$$x(t) = \sum_{k=0}^{N-1} X_k e^{j2\pi f_k t}$$

- where,
  - X_k, k=0:N-1, transmitted data (complex number I, Q) is given constellation modulation (Mapper)
  - f_k, k=0:N-1, carrier frequency
  - N: Number of subcarriers, Number of samples per OFDM symbol duration

Orthogonality - OFDM

$$x(t) = \sum_{k=0}^{N-1} X_k e^{j2\pi k f_s t}$$

- where,
  - f_s: frequency spacing
- To keep orthogonality among signals on different frequency, the minimum frequency spacing must be:

$$f_s = \frac{1}{T_s}$$

- where,
  - T_s: OFDM symbol duration

Orthogonality - OFDM

- Proven:

$$x_q(t) = X_q e^{j2\pi q f_s t}$$

$$x_p(t) = X_p e^{j2\pi p f_s t}$$

$$< x_p\ (t). < x_q\ (t) >$$

$$= \int_0^{T_s} X_q e^{j2\pi q f_s t} . X_p e^{j2\pi p f_s t}\ dt$$

$$= \frac{X_q . X_p}{e^{j2\pi(q+p) f_s}} \left(e^{j2\pi(q+p) f_s T_s} - 1\right)$$

$$= 0 \qquad \text{if } f_s = 1/T_s$$

Reminder: IDFT/DFT – IFFT/FFT

- IDFT: The mathematical computation is used to convert frequency domain signal into a same-length time domain signal

$$x_n = \sum_{k=0}^{N-1} X_k e^{j2\pi kn/N}, \qquad k = 0, \ldots, N\text{-}1$$

- IFFT: An algorithm to rapidly compute and reduce the complexity of IDFT if N is power of 2

- DFT: The mathematical computation is used to convert time domain signal into a same-length frequency domain signal

$$X_k = \sum_{n=0}^{N-1} x_n e^{-j2\pi kn/N}, \qquad k = 0, \ldots., N\text{-}1$$

- FFT: An algorithm to rapidly compute and reduce the complexity of DFT if N is power of 2

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OFDM Modulation/Demodulation

- OFDM Modulation

$$x_n = \sum_{k=0}^{N-1} X_k e^{j2\pi k f_s n T_s / N} \qquad n = 0, \ldots, N\text{-}1 \text{ (IFFT)}$$

$$= \sum_{k=0}^{N-1} X_k e^{j2\pi kn/N}$$

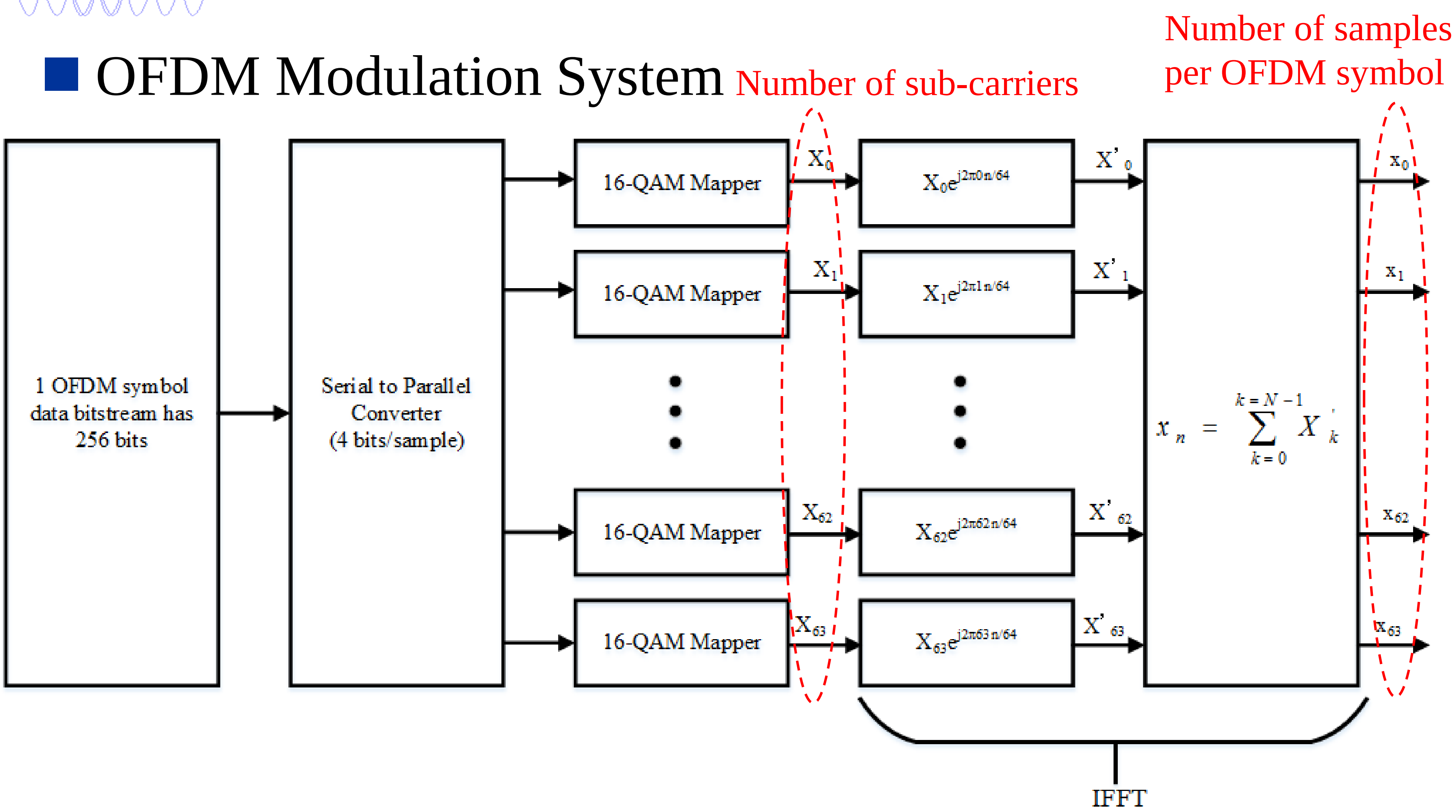
- OFDM Demodulation

$$X_k = \sum_{k=0}^{N-1} x_n e^{-j2\pi k f_s n T_s / N} \qquad k = 0, \ldots, N\text{-}1 \text{ (FFT)}$$

$$= \sum_{k=0}^{N-1} x_n e^{-j2\pi kn/N}$$

OFDM Modulation System

- OFDM Modulation System



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