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Multiple Access Schemes for OFDM

S-72.4210 Post-Graduate Course
in Radio Communications

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Outline

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2. OFDM overview
3. OFDM-FDMA Techniques (Block, random, interleaved)
4. OFDM-TDMA Techniques
5. OFDM-CDMA Techniques (MC/MC-DS/MT-CDMA)
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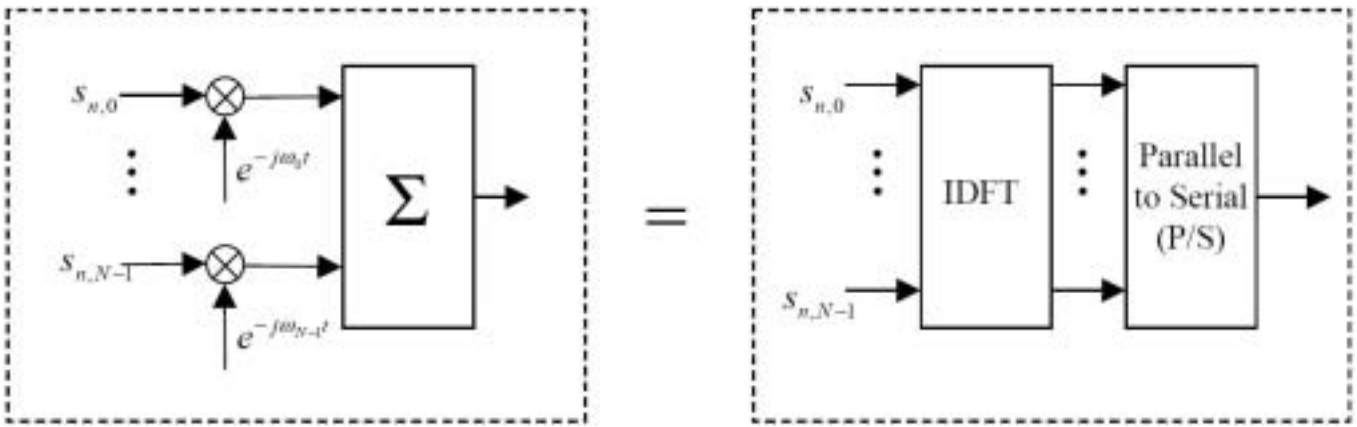
Introduction

- OFDM has wide acceptance in wireless communications as an appropriate broadband modulation scheme
- OFDM divides a wideband frequency-selective channel into narrowband flat fading sub-channels
- In multi-user systems, these sub-channels can be allocated among different users to provide multiple access schemes
- The use of adaptive techniques in these sub-channels can further increase the spectral efficiency of the wireless system
- Therefore, a main advantages of OFDM is the flexibility in combining adaptive modulation and multiple access techniques

OFDM Basics

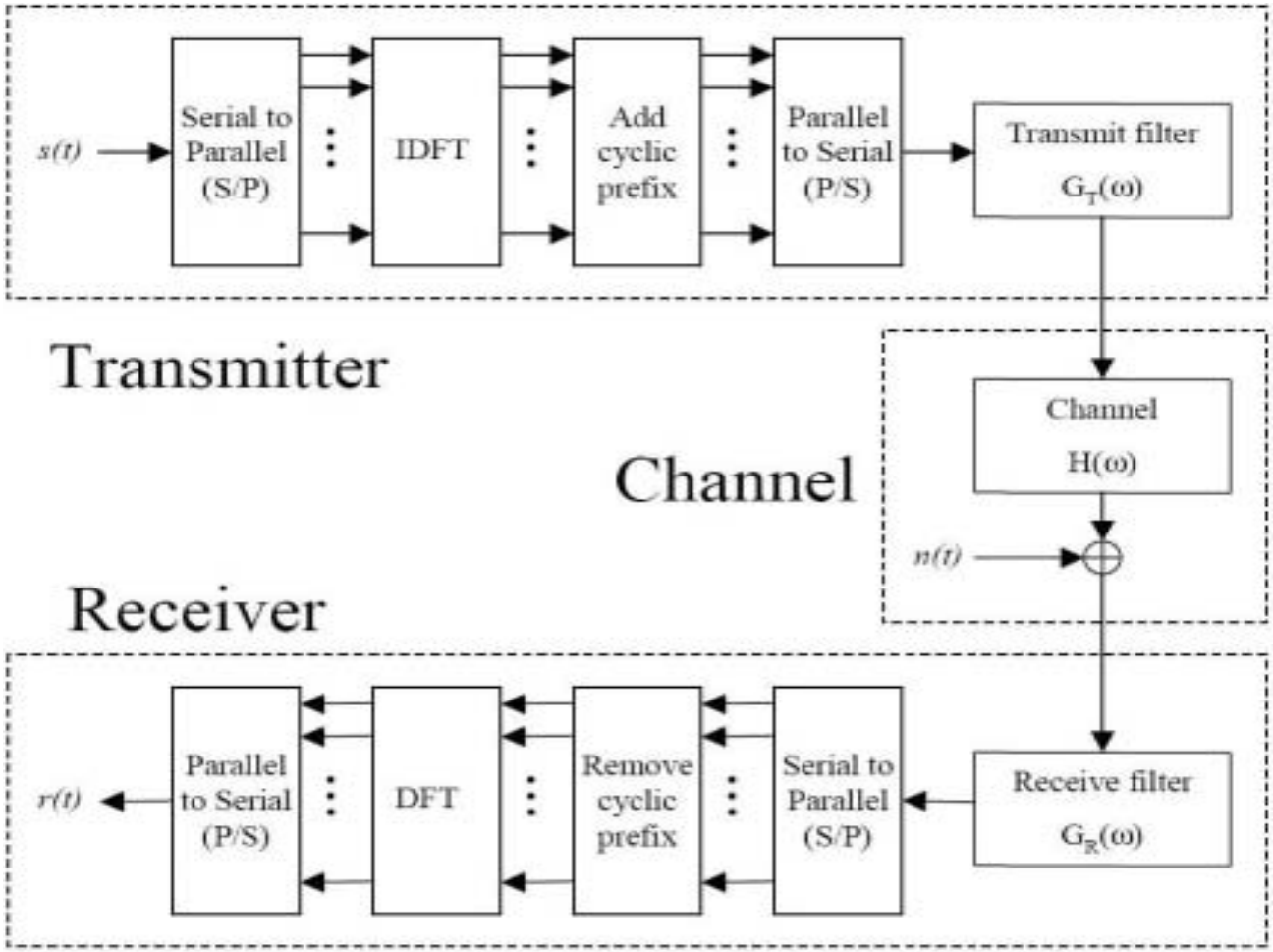
- Main idea: Split data stream into N parallel streams of reduced data rate and transmit each on a separate sub-carrie
- When the sub-carriers have appropriate spacing to satisfy orthogonality, their spectra will overlap
- OFDM modulation is equivalent to the IDFT:

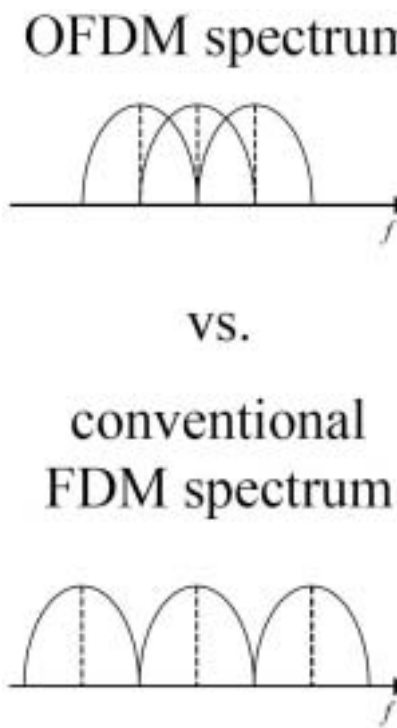


OFDM Basics

- Widely used in broadcast systems (DAB, DVB-T)
- High spectral efficiency and multi-path tolerance
- Easily generated using IFFT and received using FFT
- Sub-carrier orthogonality must be preserved (impaired by timing jitter and frequency offset)
- Carrier power and modulation scheme can be individually controlled for each carrier (not possible in broadcast systems due to one-way communication)
- In most communication systems two-way communication is required and multiple users must be supported

OFDM Overview





Adaptive Modulation

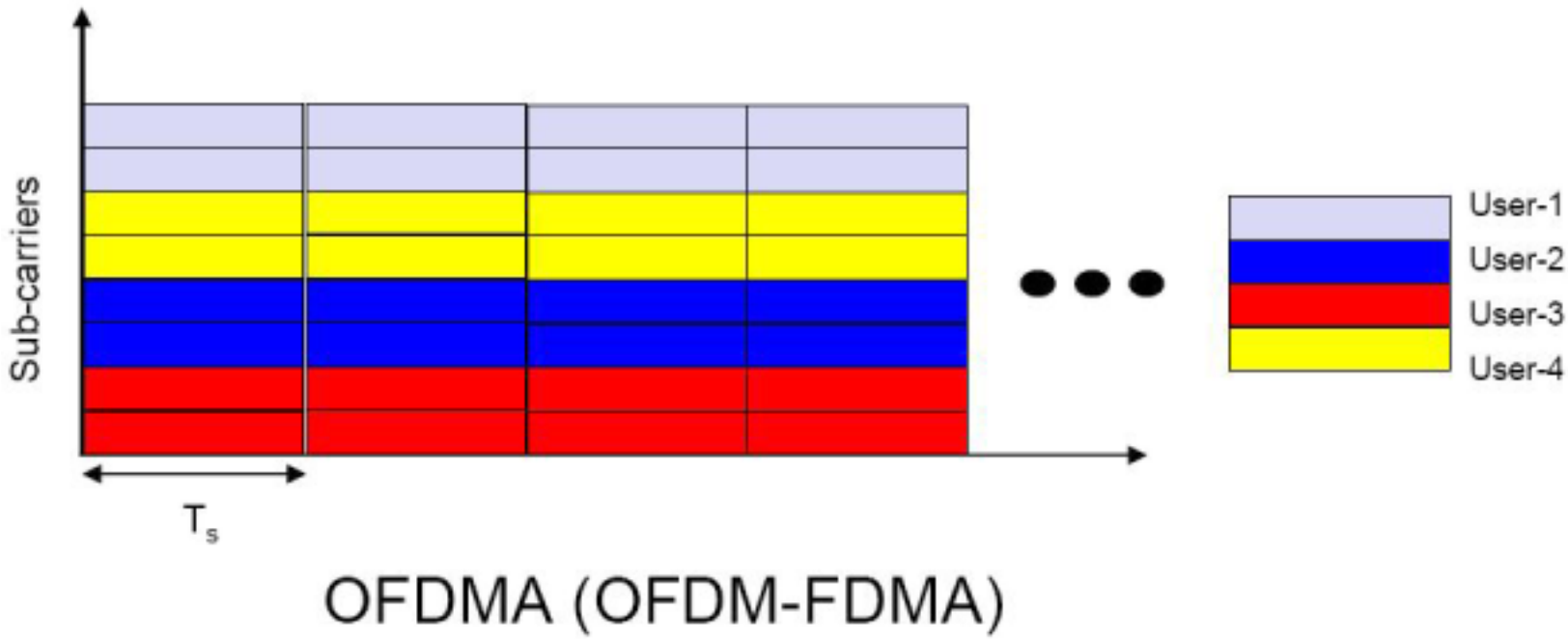
- Most OFDM systems use fixed modulation scheme over all sub-carriers for simplicity
- Each carrier in an OFDM system can potentially have a different modulation scheme (channel conditions)
- Spectral efficiency can be maximized choosing highest modulation scheme that give an acceptable BER
  - Fixed modulation scheme (1-2 bps/Hz) (BPSK or QPSK)
  - Adaptive modulation (up to 4-6 bps/Hz) (16QAM – 64QAM)
- Adaptive modulation requires transmission of overhead information to know accurately the radio channel

Multiple Access Schemes

- Multiple access schemes are used to allow many users to share simultaneously a finite amount of spectrum
- There are three fundamental multi-carrier based multiple access techniques for OFDM systems:
  - OFDM-FDMA
  - OFDM-TDMA
  - OFDM-CDMA
- Among three schemes, OFDM-FDMA is the most straightforward (a.k.a. OFDMA)

OFDM-FDMA

- Available sub-carriers are distributed among all the users for transmission at any time instant

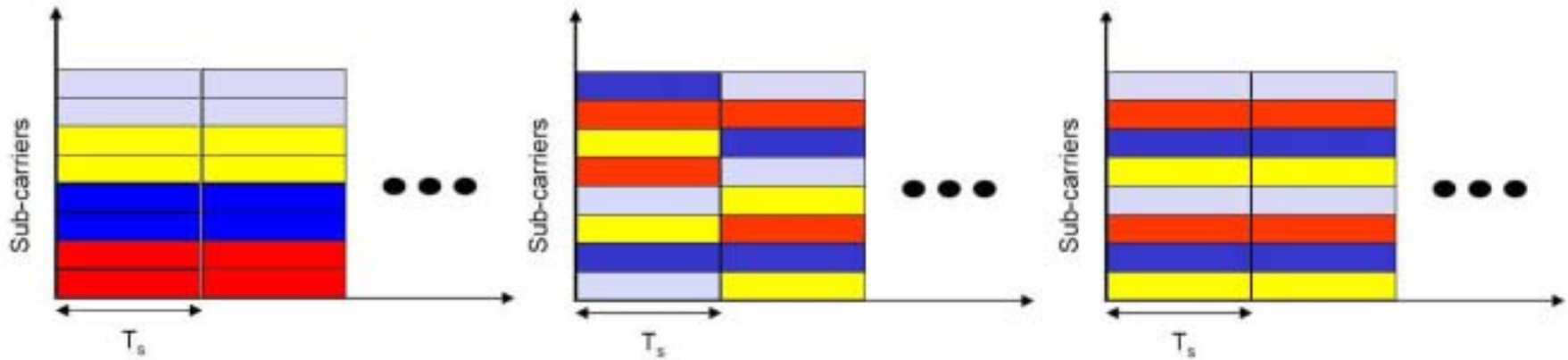


OFDM-FDMA

- Each user is allocated a pre-determined band of sub-carriers
- First proposed for CATV systems (used to send upstream data from subscriber to cable head-end)
- Later adopted for wireless communications systems
- Supports a number of identical down-streams, or different user data rates (different no. sub-carriers)
- Allows adaptive techniques per sub-carrier, based on sub-channel condition

OFDM-FDMA Variations

- Based on the allocation of sub-carriers to users, we can have the following variations:
  - Block FDMA (grouped carriers)
  - Random allocation (adaptive frequency hopping)
  - Interleaved FDMA (comb spread carriers)



Block FDMA | Random allocation | Interleaved FDMA

OFDM-FDMA Variations

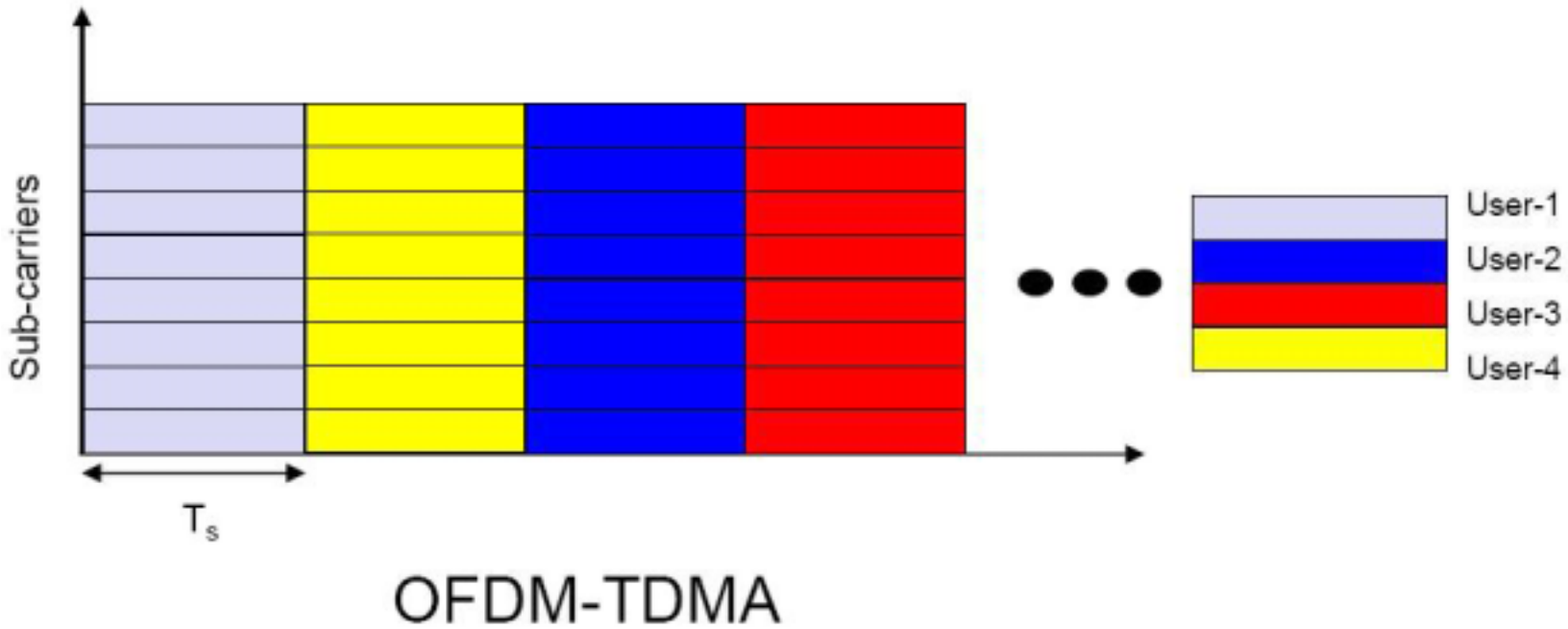
- Block FDMA:
  - Each user is allocated a bunch of adjacent sub-carriers
  - Bit-loading of the block can be considered together (adjacent sub-carrier gains are usually highly correlated)
  - Easy allocation of sub-carriers with very low computational complexity, but lacks in robustness
  - Minimizes inter-user interference due to distortion, power level variation and frequency errors
  - The transmission is susceptible to freq. selective fading (this problem can be partly overcome by FH the carriers)

OFDM-FDMA Variations

- Random Allocation:
  - Sub-carriers are randomly allocated (very low probability of having all sub-carriers in deep fade)
- Interleaved FDMA:
  - The sub-carriers assigned to a particular user are interlaced with other users' sub-carriers in the frequency domain
  - If deep fade occurs, only a single sub-carrier is affected and the data can be recovered using coding

OFDM-TDMA

- A particular user is given all the sub-carrier of the system for any particular symbol duration.



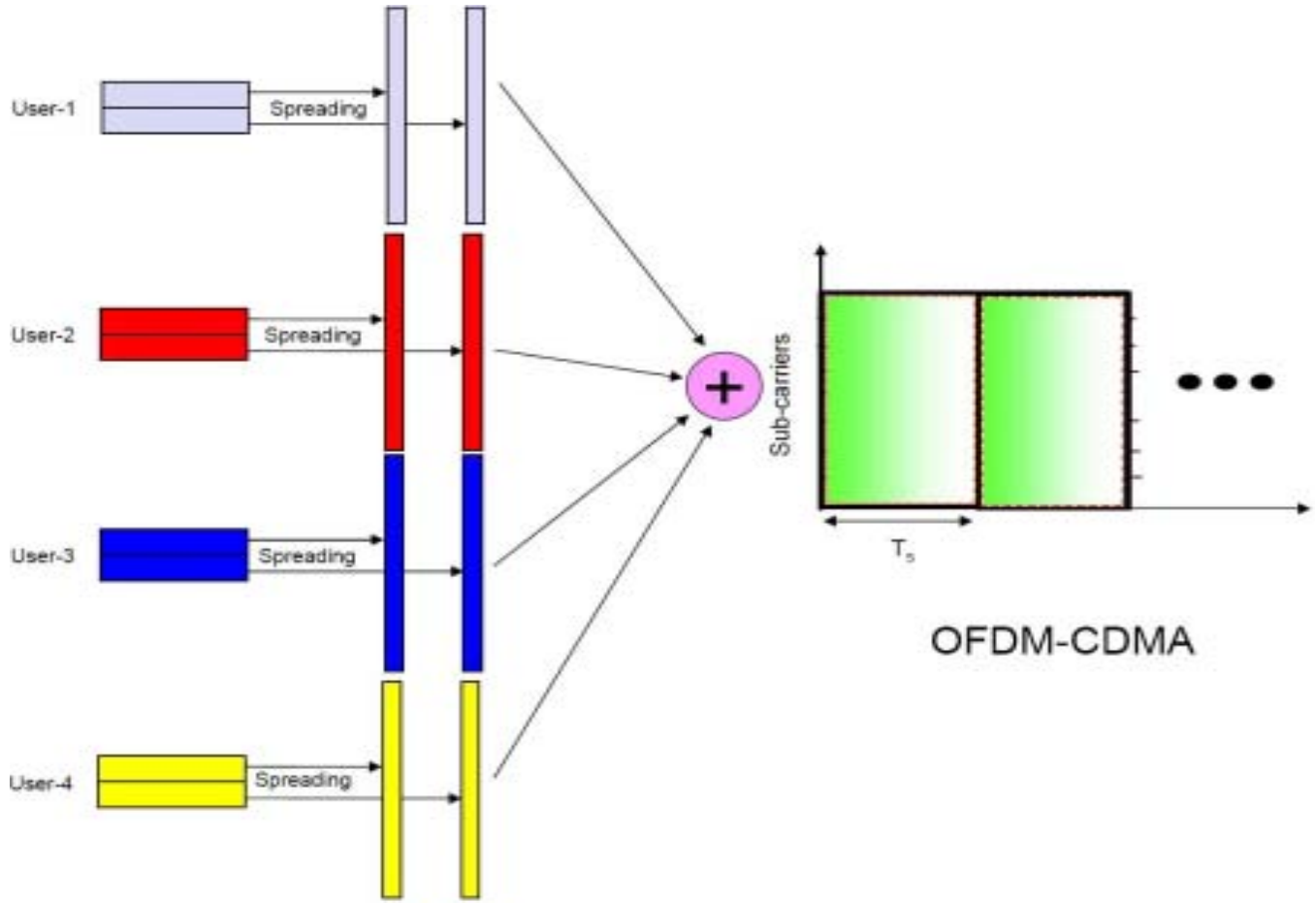
OFDM-TDMA

- Each user is assigned a time slot during which all the sub-carriers can be used for the particular user
- Adaptive loading can be performed on all the sub-carriers, depending on channel conditions
- The number of symbols per frame can be varied based on each users requirement
- Power consumption reduction (less activity)
- Degrading performance should be taken into account in delay constrained systems

OFDM-CDMA (Basics)

- User data is spread over several sub-carriers and/or OFDM symbols using spreading codes, and combined with signals from other users
- Hybrid access scheme that combines benefits:
  - OFDM: Provides a simple method to overcome the ISI effect of the multi-path frequency selective channel
  - CDMA: Provides frequency diversity and multi-user access scheme
- Several users transmit over the same sub-carriers

OFDM-CDMA (Basics)

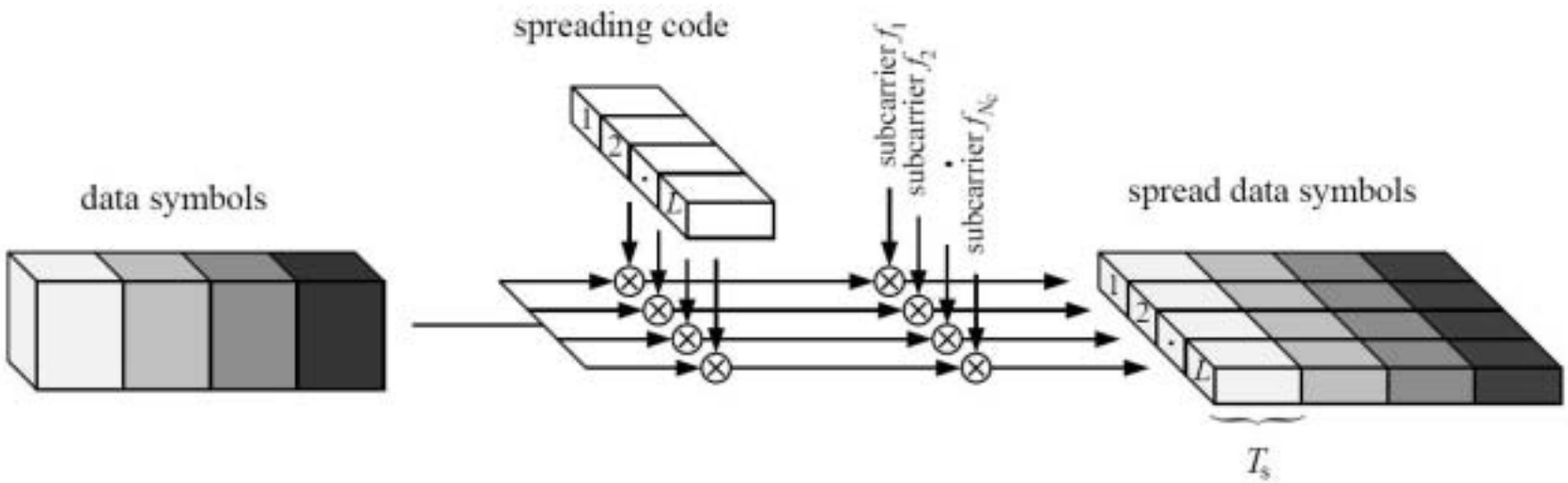


CDMA-based schemes

- First multiple access systems with MC modulation were based on DS-CDMA
- In 1993, three slightly different schemes were independently proposed:
  - MC-CDMA (Yee, Linnartz, Feetweis, and others)
  - MC-DS-CDMA (DaSilva and Sousa)
  - MT-CDMA (Vandendorpe)
- All users simultaneously share the available bandwidth and separation is carried out in the code domain

MC-CDMA

- Spreads the data and then modulates a different sub-carrier with each chip (can be thought of as spreading in frequency domain)

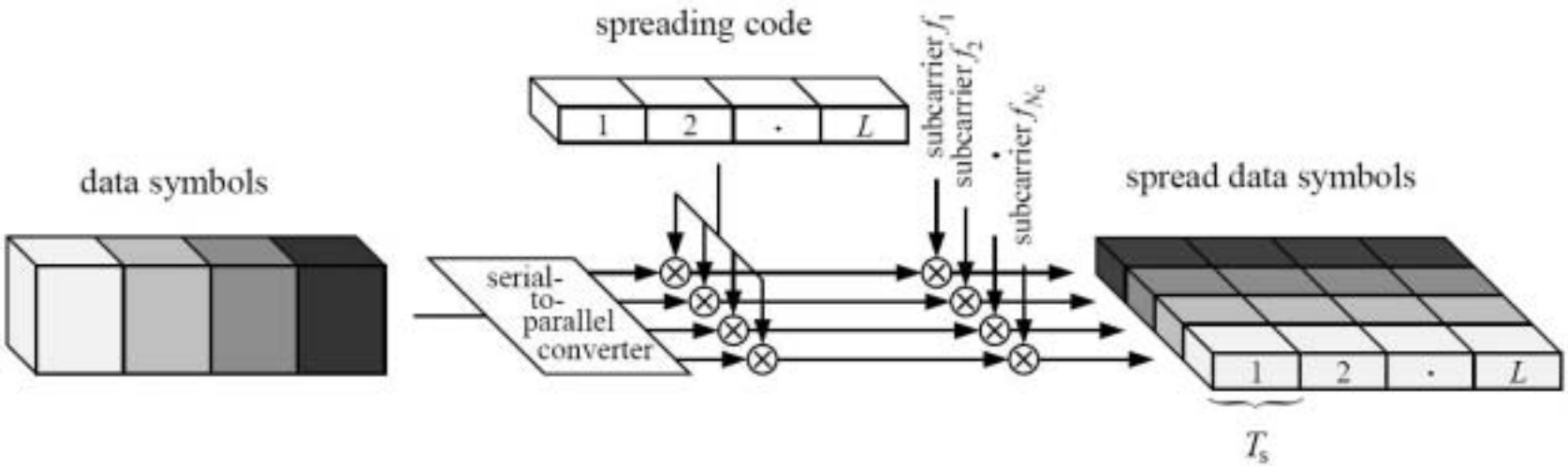


MC-CDMA

- Greatly reduces complexity of the SS system
  - FFT/IFFT replace synchronization and despreading
- More spectrally efficient than CDMA due to overlapped sub-carriers in OFDM
- Multiple users are assigned different spreading codes
  - Similar interference properties as in CDMA
- Most MC-CDMA systems were proposed for the downlink, where powerful receivers with low complexity are required

MC-DS-CDMA

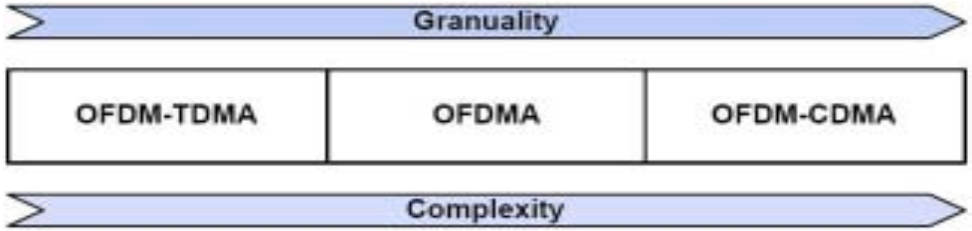
- Spreads the S/P converted data, then modulates a different sub-carrier with each stream (can be thought of as spreading in time domain)



MT-CDMA

- MC-DS-CDMA modulates the sub-streams on sub-carriers with a spacing of reciprocal of the chip duration to guarantee orthogonality after DS spreading
- In contrast to MC-DS-CDMA, in MT-CDMA sub-carrier spacing is smaller than reciprocal of chip duration
- The DS spreading per sub-carrier violates orthogonality requirements, introducing ICI
- However, tight sub-carrier spacing enables the use of longer spreading codes (more users at the expense of ICI)
- MT-CDMA was investigated for the asynchronous uplink

Multiple Access Schemes

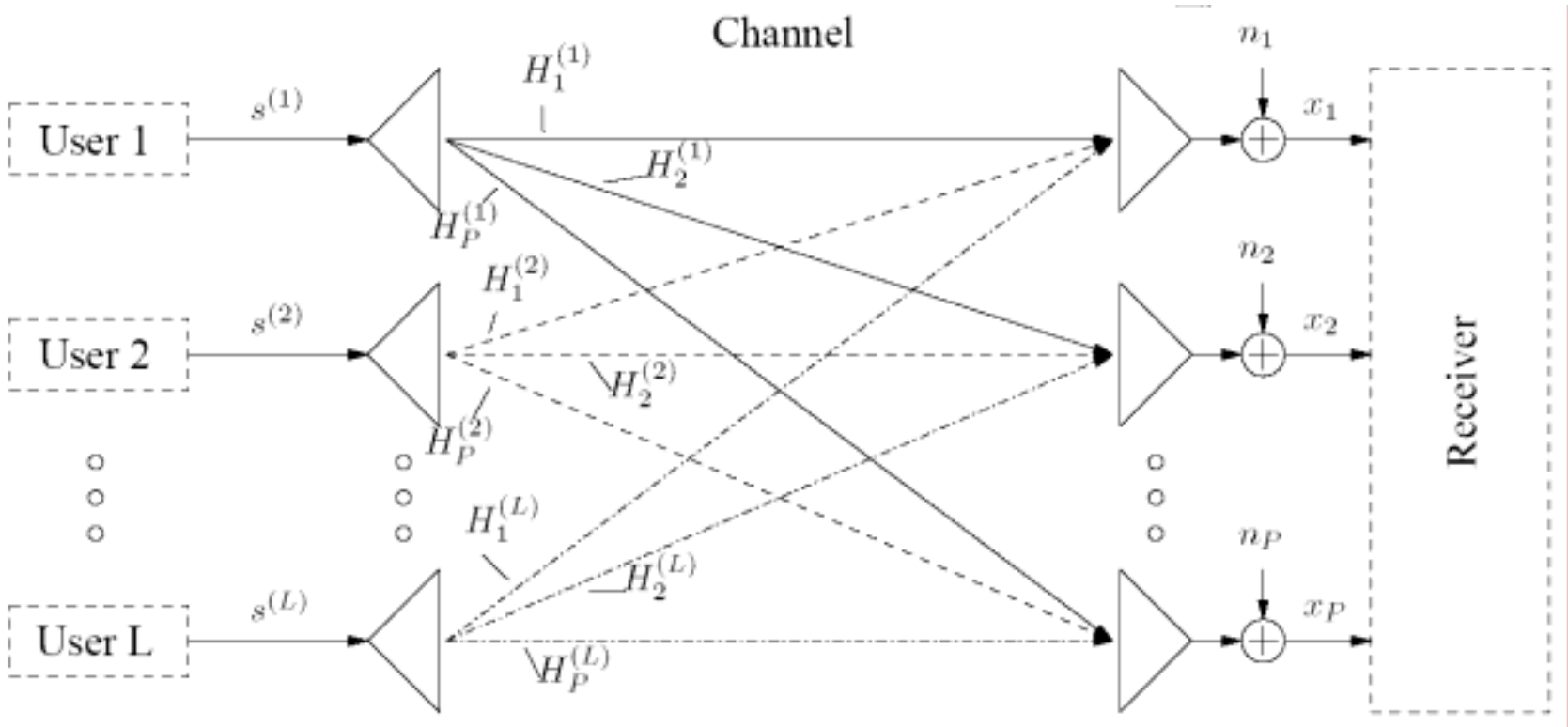


	Advantages	Disadvantages
OFDM-FDMA	Simple implementation Flexibility	Frequency-reuse factor ≥ 3
OFDM-TDMA	Power savings Simple resource allocation Easiest to implement	Relatively high latency Frequency-reuse factor ≥ 3 Lowest flexibility
OFDM-CDMA	Spectral efficiency Frequency diversity MAI and inter-cell interference resistance Frequency-reuse factor = 1 Highest flexibility	Requirement of power control Implementation complexity

SDMA-OFDM

- Antenna arrays can be used in an OFDM system for supporting multiple users in a SDMA scenario
- OFDM users are separated by a MUD based on their unique, user specific spatial signature
- The channel impulse response of each user should be accurately estimated
- Spatial signatures are typically not orthogonal
- Interference reduction is required (MUD, cancellation)

SDMA-OFDM



The SDMA-OFDM system is capable of differentiating L users' Tx signals at the BS invoking their unique, user specific signature created by the channel transfer functions

Summary

- OFDM is a well-known technique to combat ISI
- OFDM by itself is not a multi-access scheme, but a modulation scheme
- Existing multi-access schemes can be combined with OFDM (e.g., TDMA, FDMA, CDMA)
- Some forms of multi-user OFDM lend themselves well to adaptive techniques
- Due to this, many high-performance multi-user wireless systems today are based on OFDM techniques

References

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4. S. Kaiser, “Multi-Carrier CDMA Mobile Radio Systems - Analysis and Optimization of Detection, Decoding and Channel Estimation,” D usseldorf: VDI Verlag, Fortschritt-Berichte VDI, series 10, no. 531, 1998.
5. L. Hanzo, M. Münster, B.J. Choi and Thomas Keller, “OFDM and MC-CDMA for Broadband Multi-User Communications, WLANs and Broadcasting,” John Wiley & Sons, pp. 1014, 2003.

Homework

1. Explain the reason of using only low order constellations in broadcast systems based on OFDM.
2. What are the different multiple access schemes for OFDM? Explain briefly the difference among them.
3. Why is the implementation of OFDM-FDMA the most straightforward?
4. What are the main differences between MC-CDMA and MC-DS-CDMA?