Wireless Access Channels

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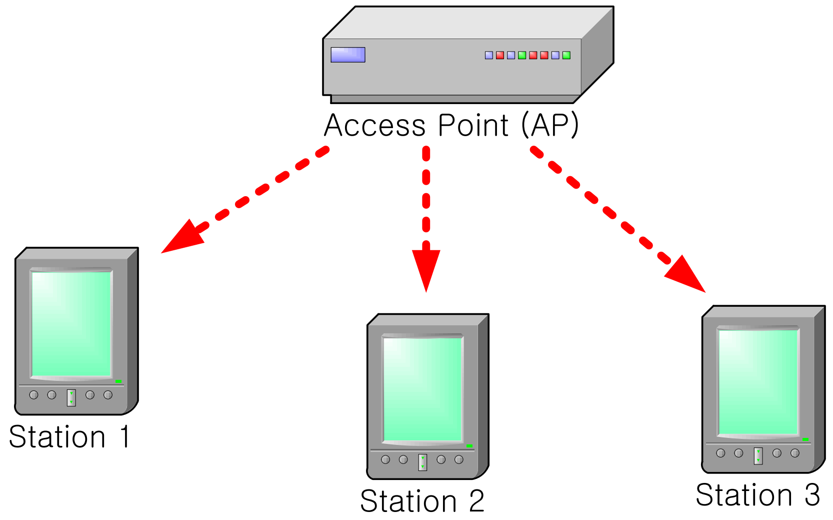
Adapted from Prof. Sunghyun Choi's slides

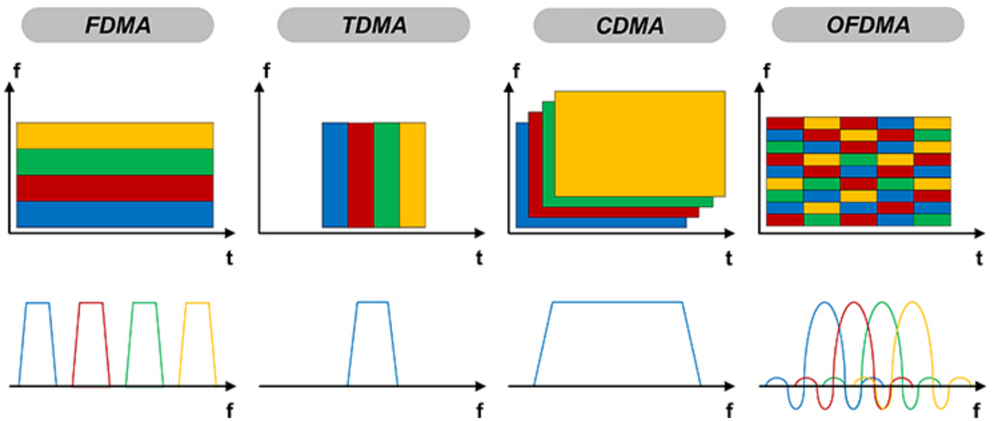
Broadcast Channel

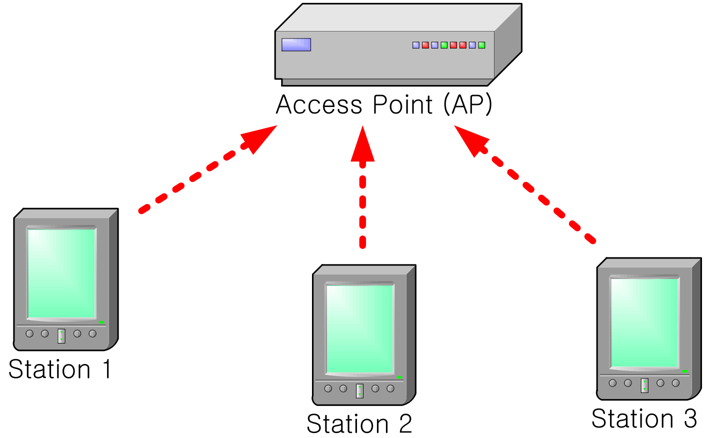
- From AP to stations
  - i.e., downlink (DL) or forward link (FL)
- Multiplexing schemes used
  - e.g., FDM, TDM, CDM, OFDM, WDM …
- Complexity and power at the transmitter is less limited than at the receivers



Multiple Access Channel

- From stations to AP
  - i.e., uplink (UL) or reserve link (RL)
- Multiple access schemes used
  - e.g., FDMA, TDMA, CDMA, OFDMA, …
- Complexity and power at the receiver (i.e., AP) is less limited than at the transmitters (i.e., stations)

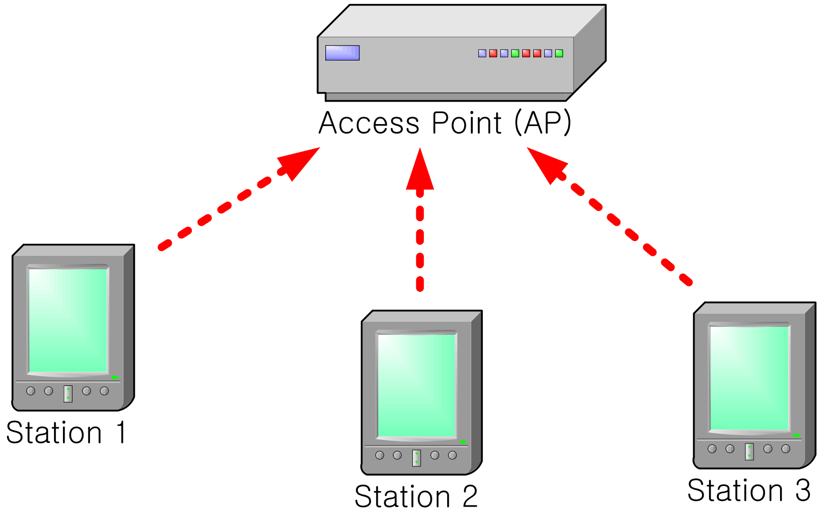


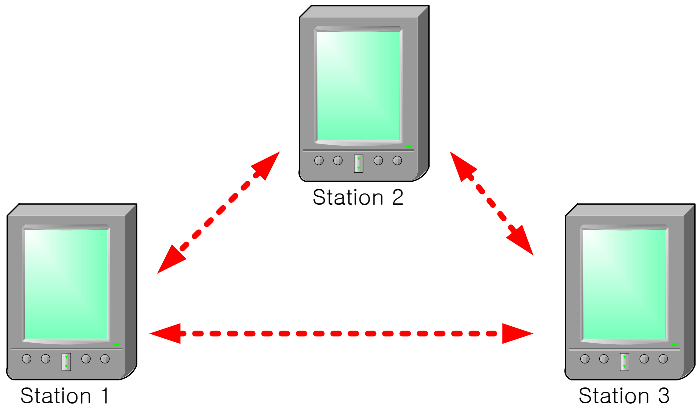


Source: The future 5th generation (5G) of mobile networks: Challenges and opportunities of an impelling scenario

Random Access Channel

- For UL in infrastructure and peer-to-peer in ad-hoc networks
- A form of multiple access channels without the control by the AP
- Any wireless system includes RA channel





Facts

- More utilized DL broadcast channel
  - Typical client/server scenario
  - DL allocated more bandwidth
- More costly UL multiple/random access channels
  - More technical challenges involving more communication overheads
  - Less complexity and power available with stations
  - Less efficient UL transmissions
  - More money is there with UL technologies?

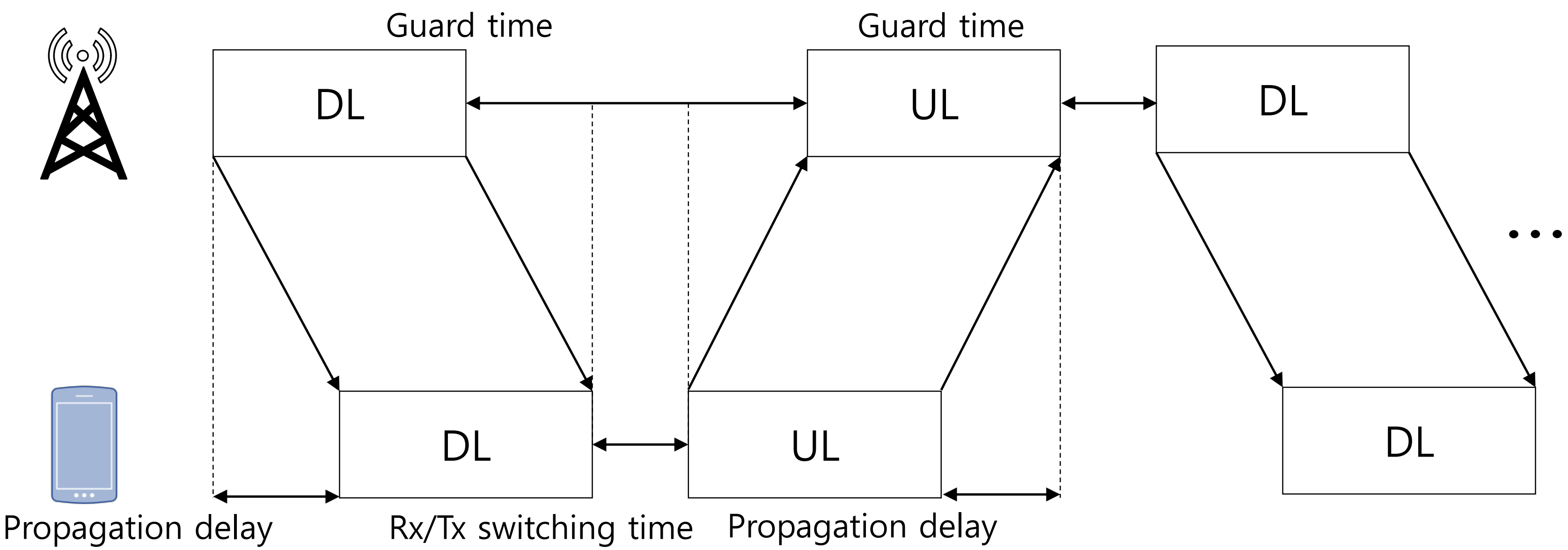
Duplexing Schemes

- Frequency Division Duplexing (FDD)
  - UL/DL in well separated frequency bands
  - No synchronization issue
  - Used for most commercial cellular systems

- Time Division Duplexing (TDD)
  - UL/DL shares the same frequency band in different time slots
  - Need a guard time between UL and DL boundary
  - Flexible UL/DL time sharing → not really!
  - Easy channel estimation due to channel reciprocity

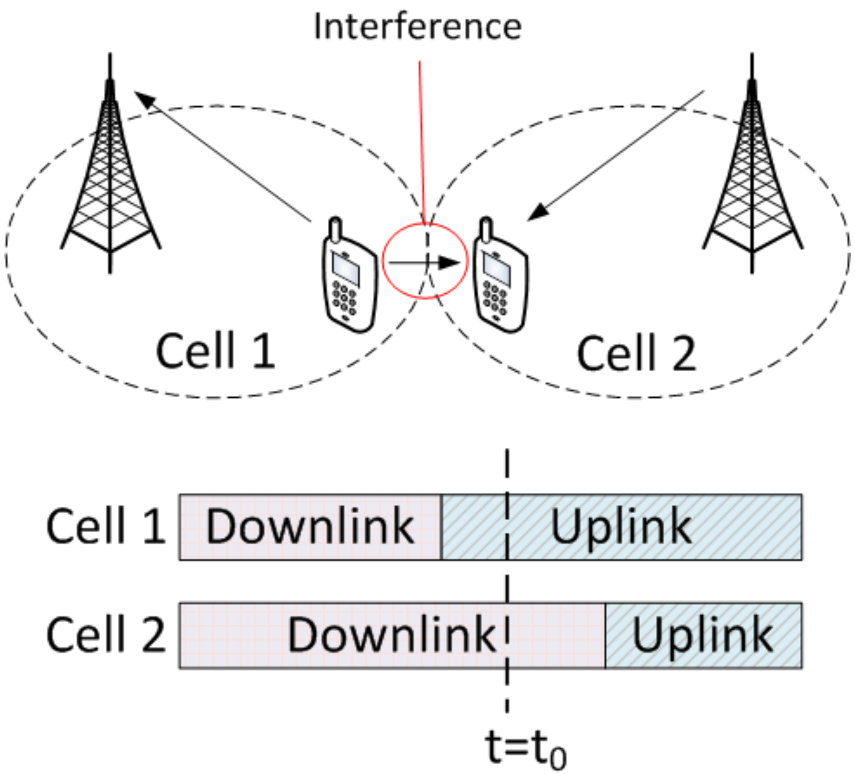
Guard Time in TDD

- Different guard time is needed between DL to UL and UL to DL
- Min. Guard time for DL to UL
  - 2 * Max. propagation delay + Rx/Tx switching time
- Min. Guard time for UL to DL
  - Rx/Tx switching time



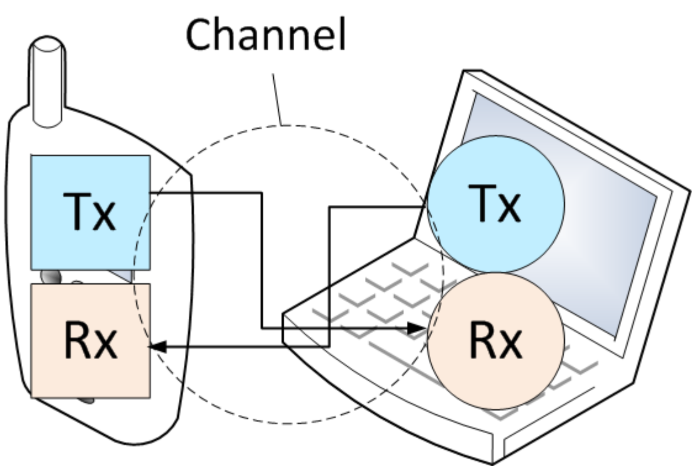
Multi-Cellular TDD Network

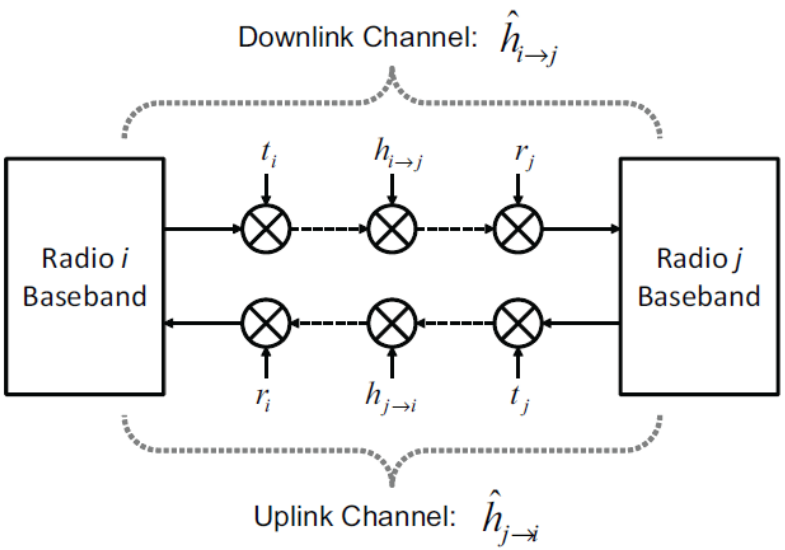
- Why isn't flexible UL/DL sharing possible?



Channel Reciprocity

- Physical channels for UL & DL are reciprocal
- Due to the differences of transceiver hardware, real channels are not reciprocal, and hence, calibration is needed



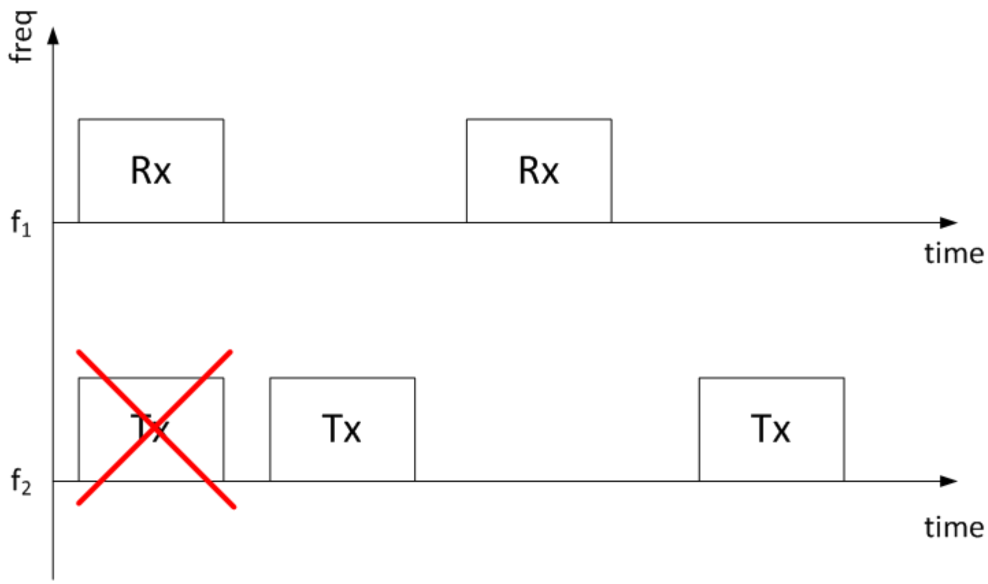


$$h_{i\to j} = h_{j\to i}.$$

Source: C. Shepard et al., "Argos: practical many-antenna base stations," in Proc. ACM MobiCom 2012.

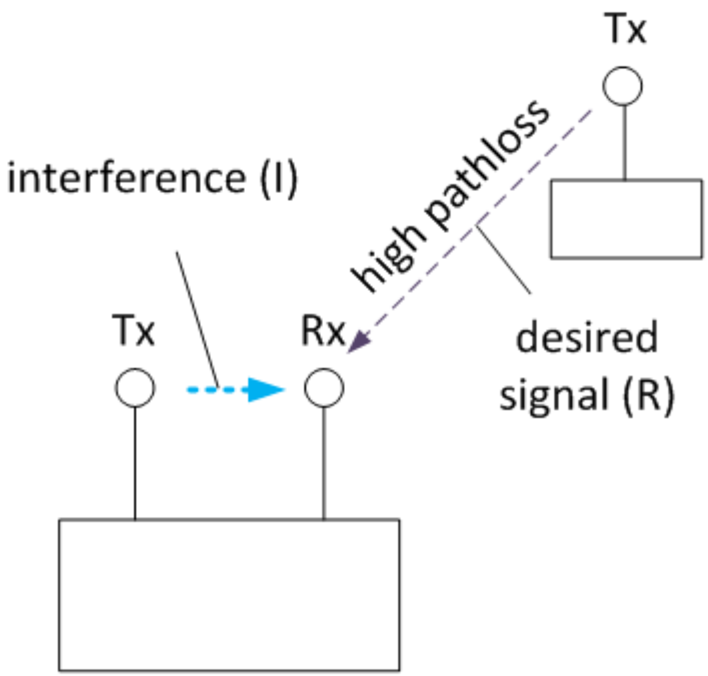
Half-Duplex FDD

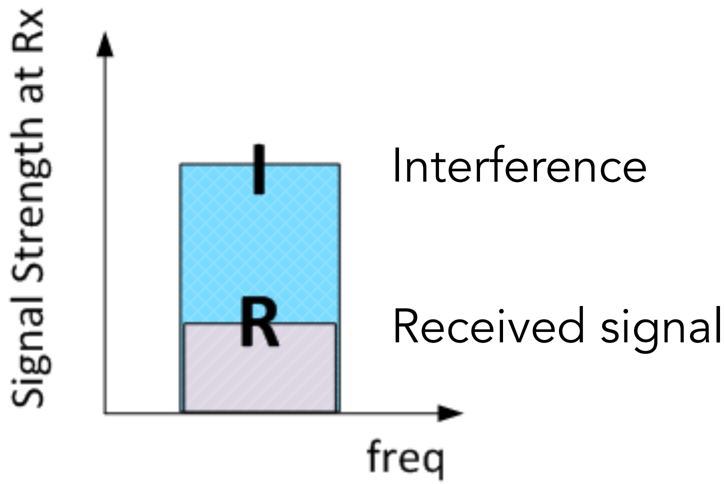
- For a given mobile terminal, either Tx or Rx (not both) is scheduled at a given time
- Advantage: TDD baseband implementation can be used



Full Duplex

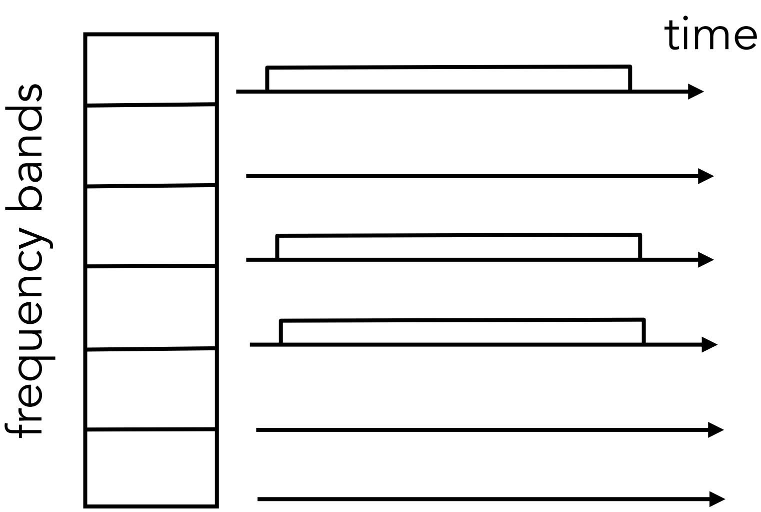
- In general, full duplex in a single frequency band is difficult
- But, even in a single frequency band, Tx and Rx can occur simultaneously (with separate antennas) by cancelling self-interference





FDM/FDMA (Frequency Division)

- Channel spectrum divided into frequency bands
- Each station assigned fixed frequency band
- Unused transmission time in frequency bands go idle
- Example: 6 stations, 1,3,4 have pkt, frequency bands 2,5,6 idle

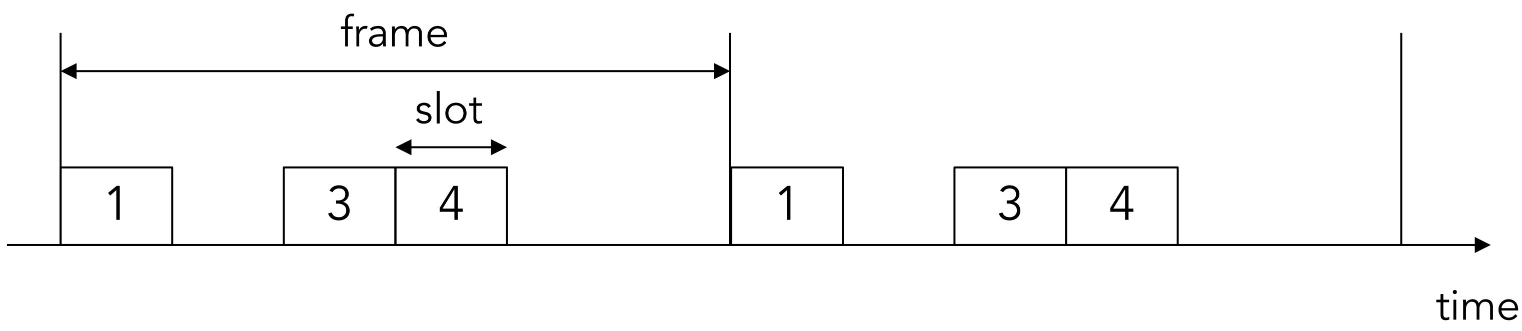


FDM/FDMA (Frequency Division)

- Advantages
  - Narrowband signal → no ISI (inter-symbol interference)
- Disadvantages
  - Difficult to allocate multiple channels
  - Waste of time
- Well suited for analog transmissions
  - FM, AM broadcast …
- Used in combination with other MAs today

TDM/TDMA (Time Division)

- Access to channel in "rounds"
- Each station gets fixed length slot (length = pkt trans time) in each round
- Unused slots go idle
- Example: 6 stations, 1,3,4 have pkt, slots 2,5,6 idle



TDM/TDMA (Time Division)

- Advantages
  - Non-continuous transmission → good for handoff support and power save
  - Easy to allocate multiple channels using dynamic allocation and dynamic TDMA

- Disadvantages
  - Tight synchronization needed among users
  - Multipath destroys orthogonality → equalization needed to handle ISI

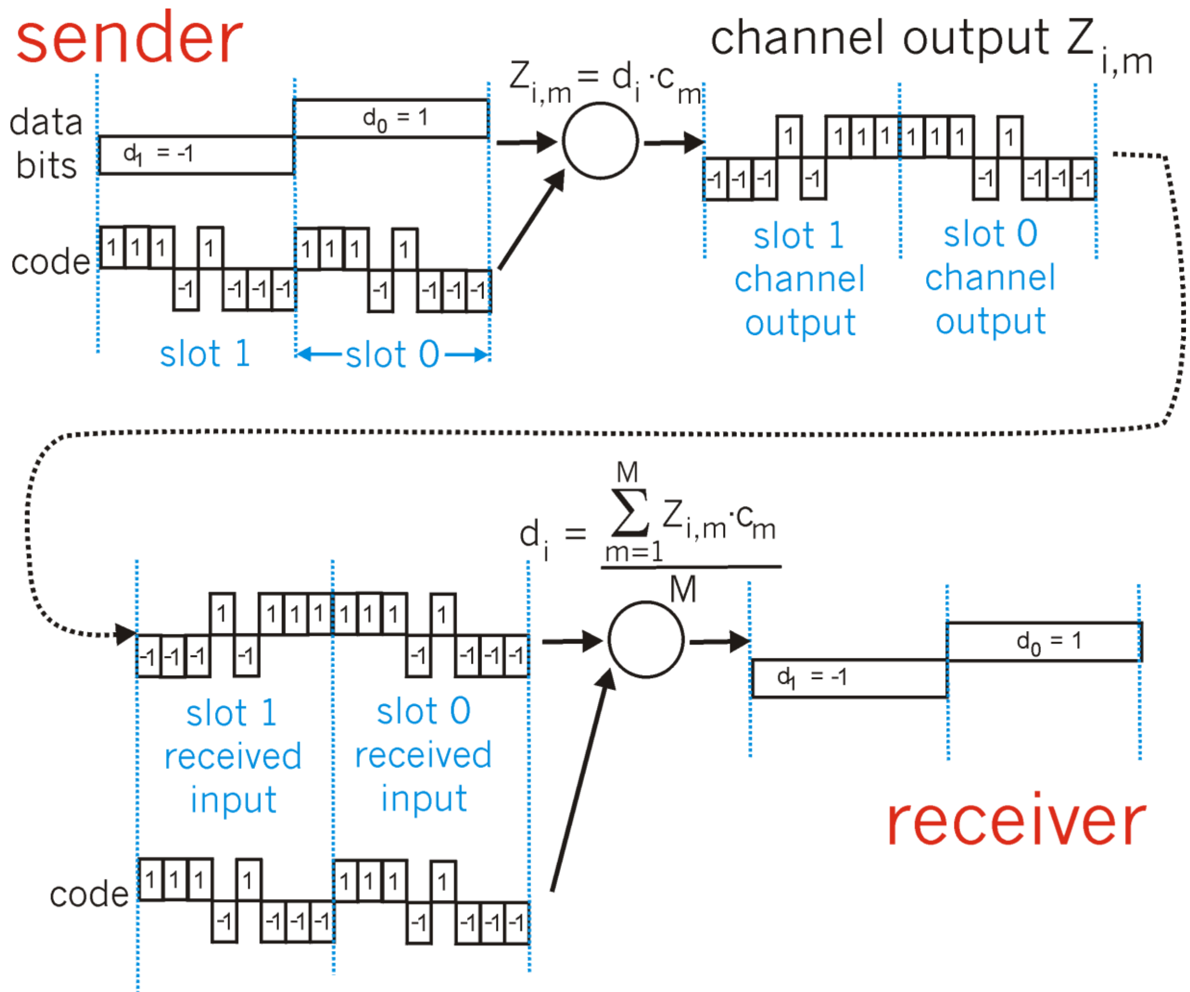
CDM/CDMA (Code Division)

- Unique "code" assigned to each user
- All users share same frequency, but each user has own "chipping" sequence (i.e., code) to encode data

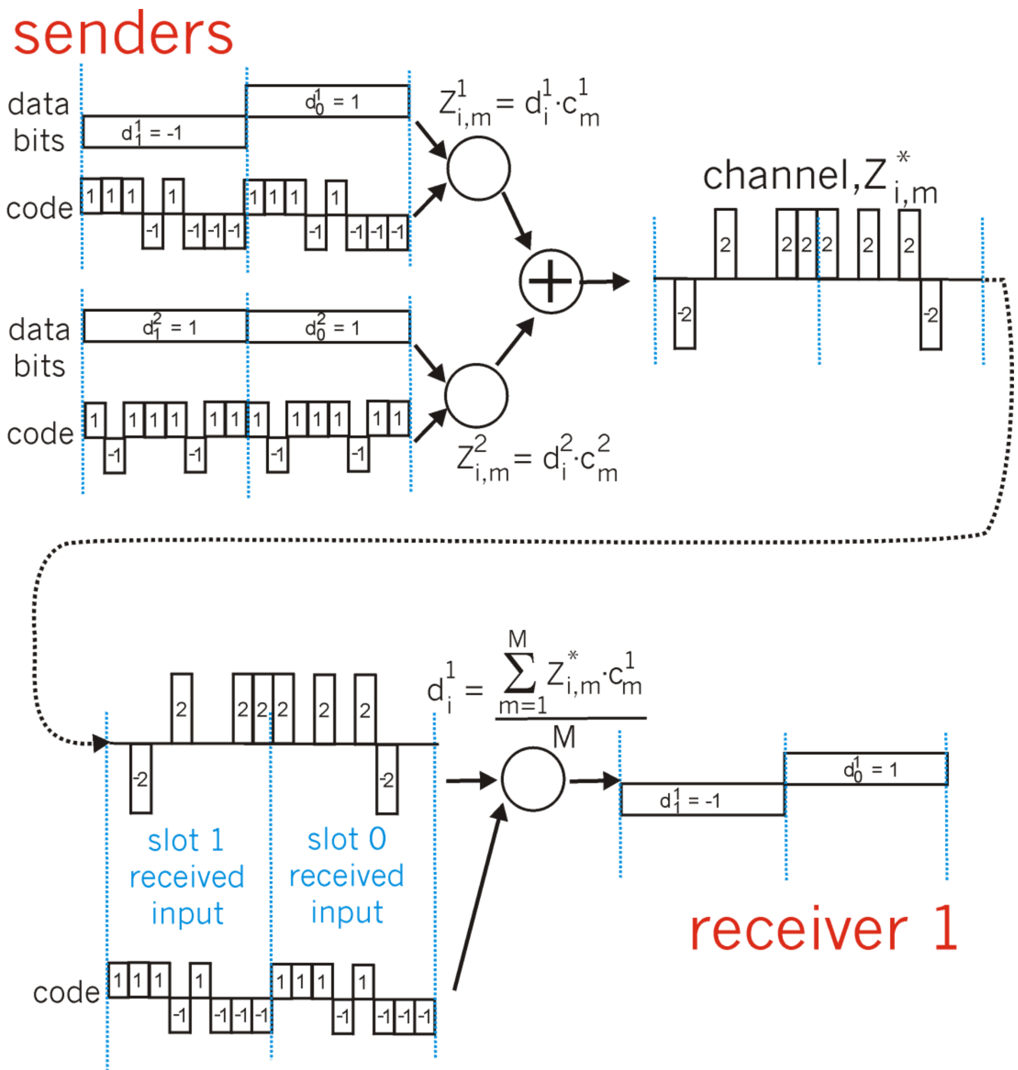
- *encoded signal* = (original data) X (chipping sequence)
- *decoding*: inner-product of encoded signal and chipping sequence

- Allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes have good "cross-correlation")

CDMA Encode/Decode

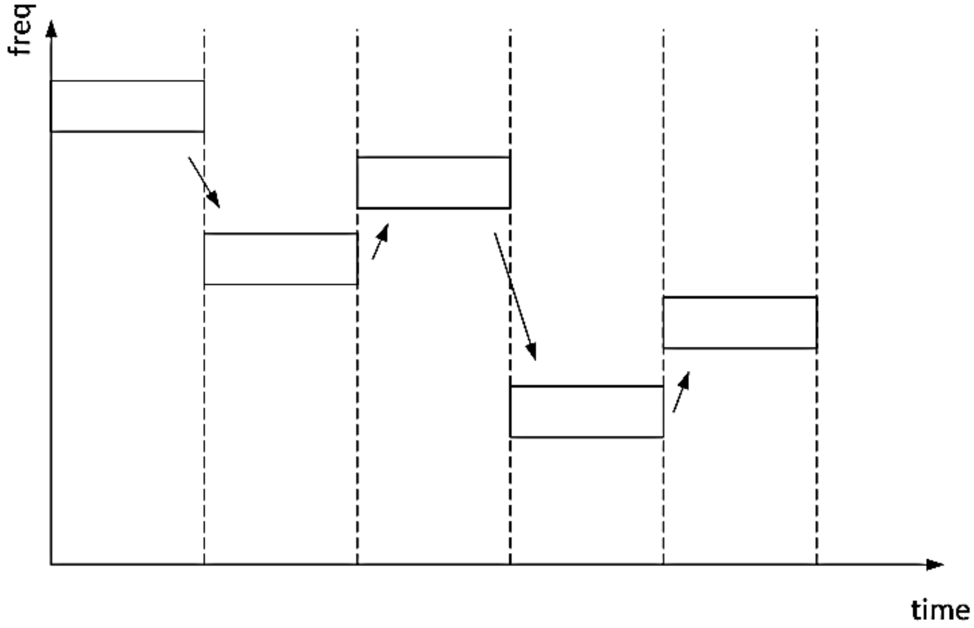


CDMA: Two-sender Interference



Frequency Hopping Spread Spectrum (FHSS)

- Tx frequency band hops over time according to a pseudo random sequence
  - Cf. Direct Sequence Spread Spectrum (DSSS), explained above
- FHSS-based CDMA is also possible



CDM/CDMA (Code Division)

- Advantages
  - Soft capacity (as interference limited)
  - Frequency reuse factor = 1 possible
  - Easy to allocate multiple channels

- Disadvantages
  - Near-far problem → UL power control needed
  - Cell breathing (due to interference limited)

- The winner of 3G !!!
  - Mostly based on Direct Sequence Spread Spectrum (DSSS), but could be with Frequency Hopping Spread Spectrum (FHSS)

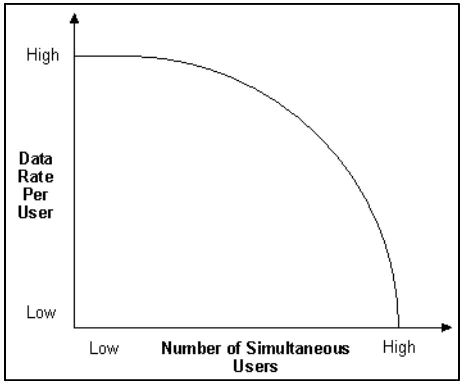
Soft Capacity & Cell Breathing

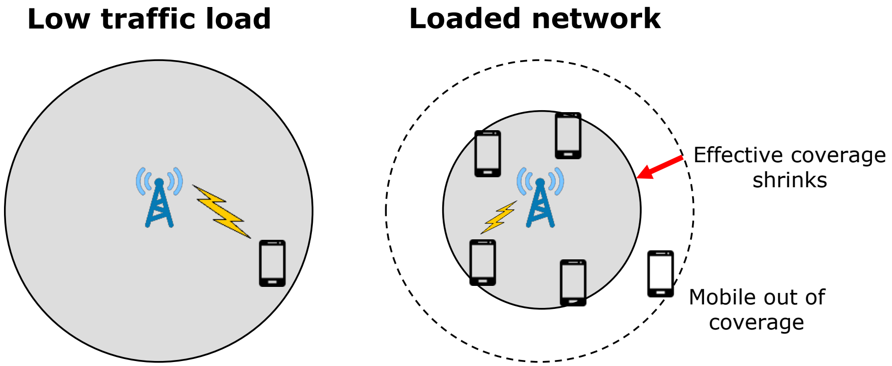
- Soft capacity in CDMA
  - Non-orthogonal, but "good" cross-correlation codes used in practice
  - Signal-to-interference-plus-noise ratio (SINR) can be expressed as:

$$\mathrm{SINR}_r = \frac{S_r}{N + \sum_{i \neq r} \frac{S_i}{PG}}$$

S_r: Received signal strength for desired signal
S_i: Received signal strength for interference signal from i
N: Noise level
PG: Processing gain

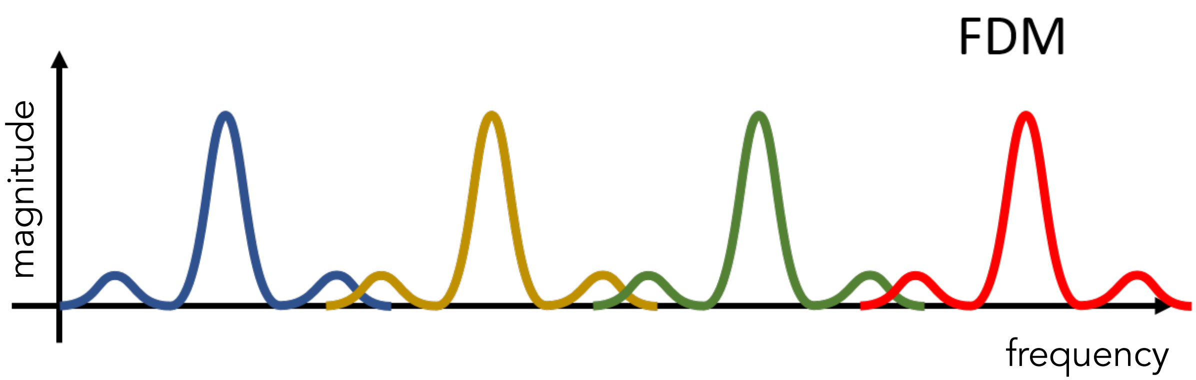
  - Network capacity is soft-limited by # of simultaneous users
- Cell breathing
  - Shrink of effective coverage when a base station becomes overloaded
  - It supports load-balancing, but uncontrolled cell size is not desirable

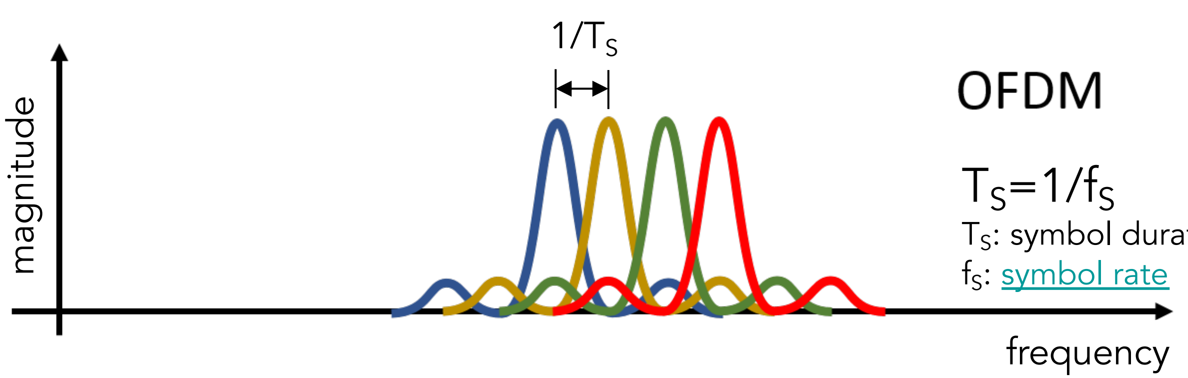




OFDM/OFDMA

- Transmission of different user data in multiple overlapping orthogonal subcarriers
  - Similar to FDM/FDMA?





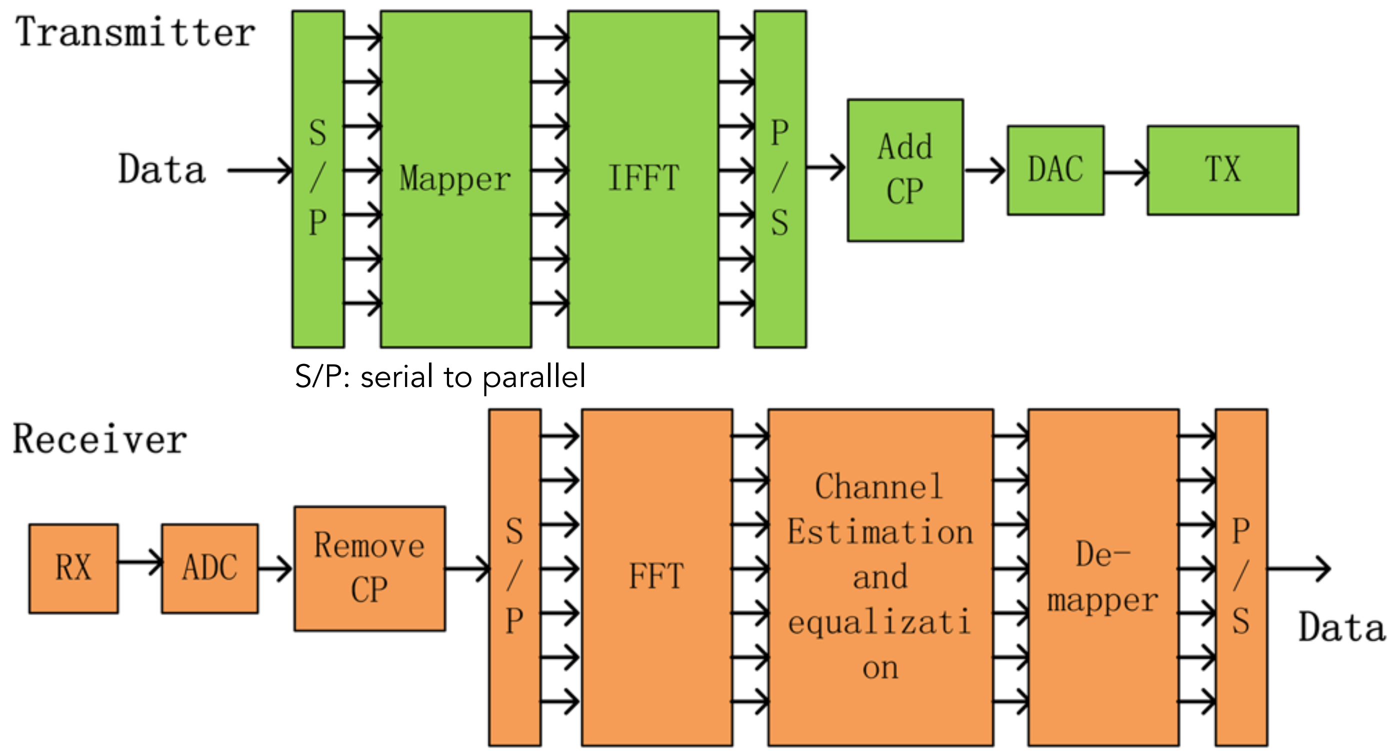
$T_S = 1/f_S$

T_S: symbol duration

f_S: symbol rate

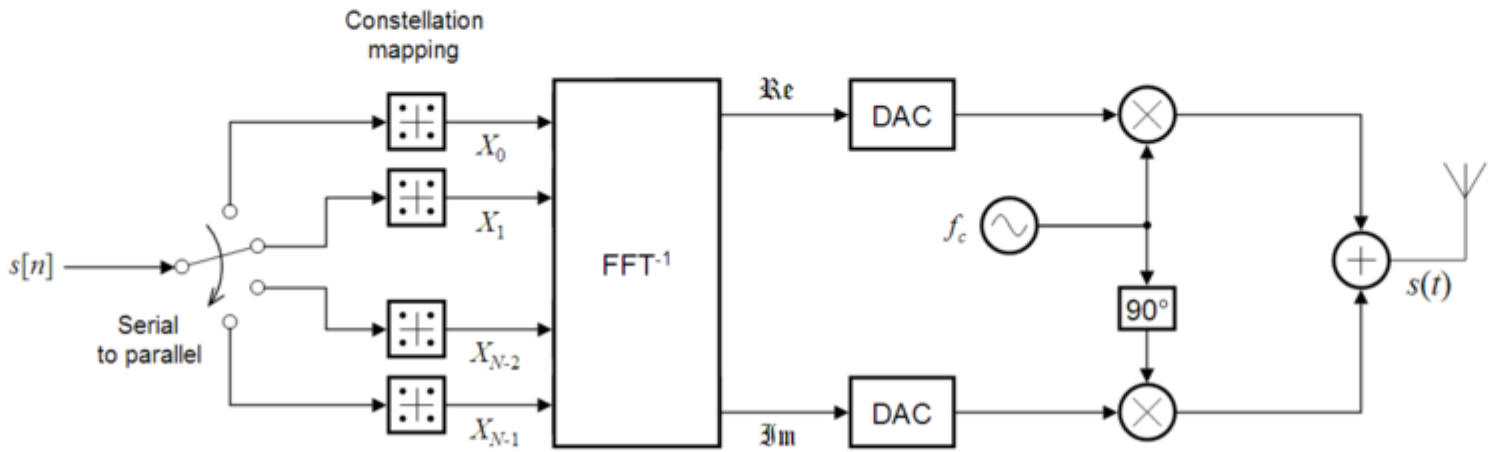
OFDM/OFDMA

- Block diagram of Tx and Rx

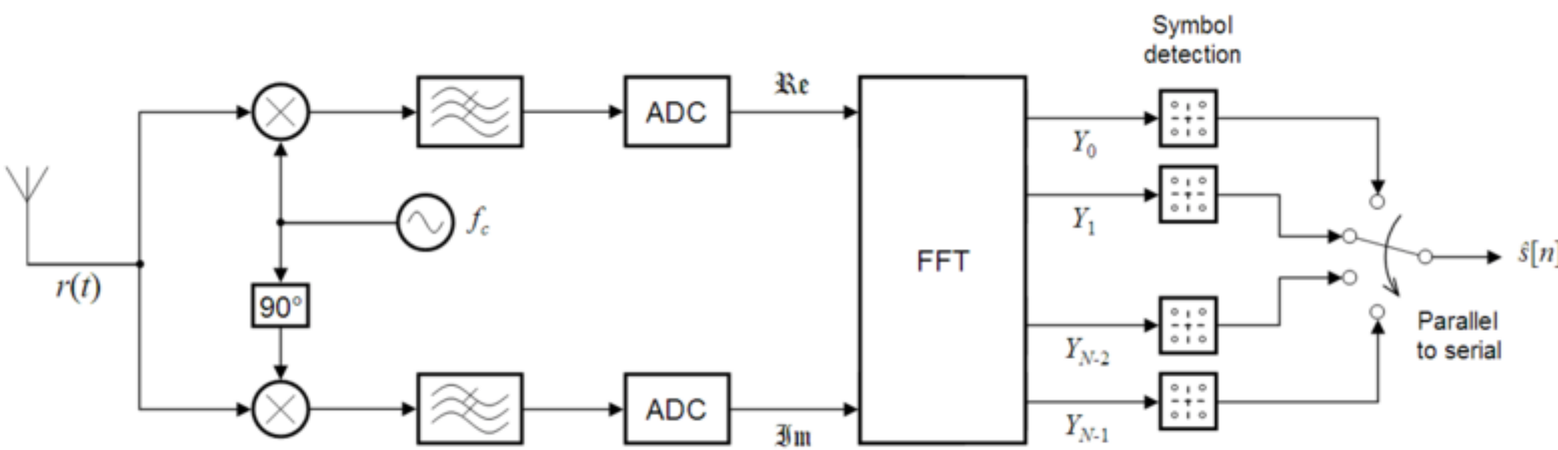


OFDM/OFDMA

- Transmitter

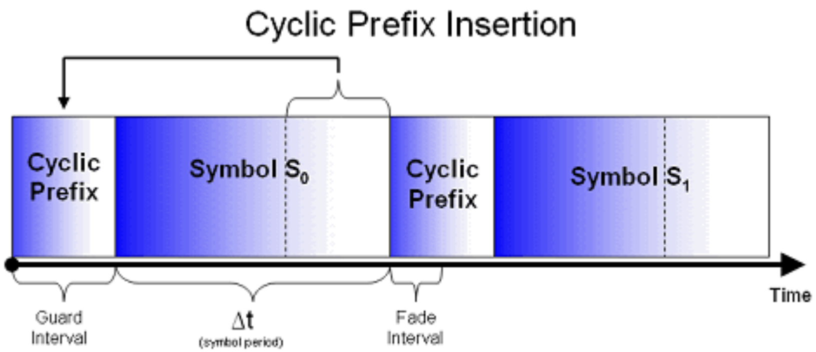


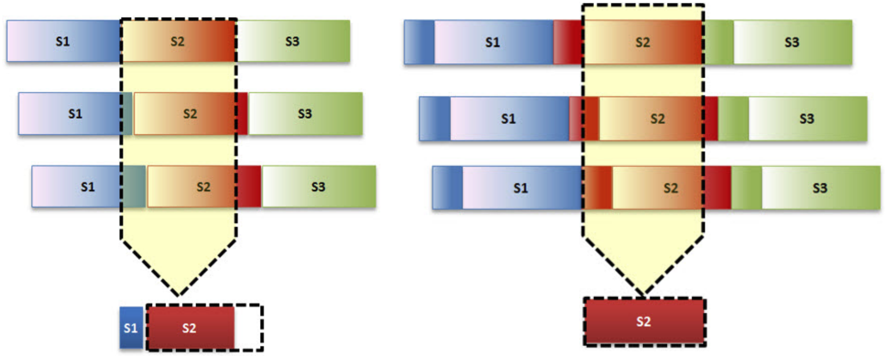
- Receiver



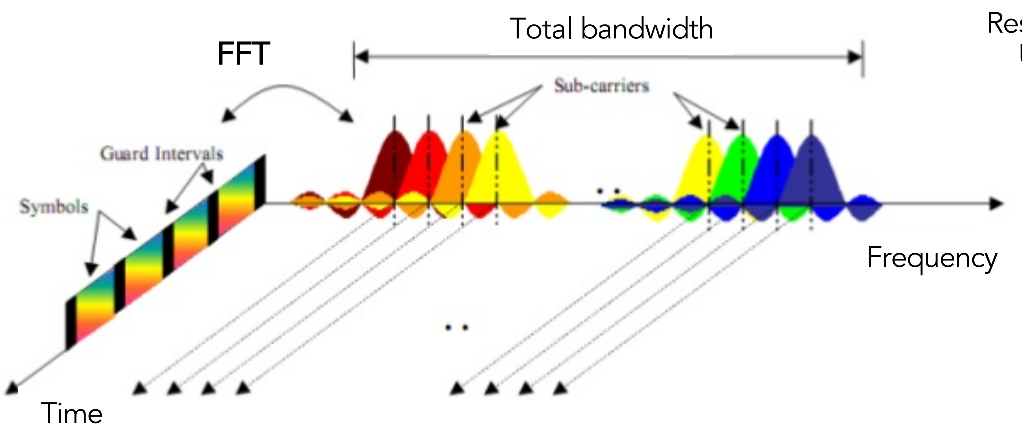
OFDM/OFDMA

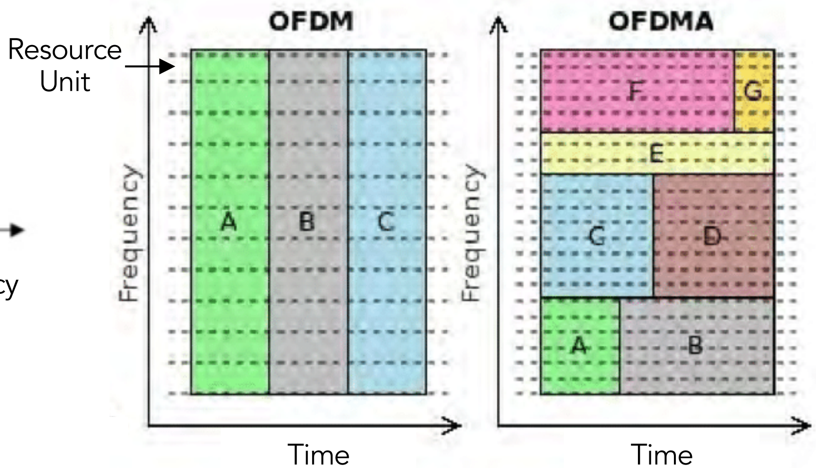
- Cyclic Prefix (CP) to eliminate ISI due to fading





- OFDM vs. OFDMA





OFDM/OFDMA

- Dara rate
  - $\boldsymbol{R}\ (\boldsymbol{bps}) = \frac{N_C \cdot B}{\Delta T + T}$
    - N_C: # of data subcarriers in an OFDM symbol (excluding pilot subcarriers)
    - B: # of information bits per subcarrier
    - T: OFDM symbol duration (w/o cyclic prefix)
    - ΔT: Cyclic prefix duration
  - B depends on modulation and coding scheme (MCS)
    - e.g., 16-QAM and ½ code rate: B = 4x1/2 = 2

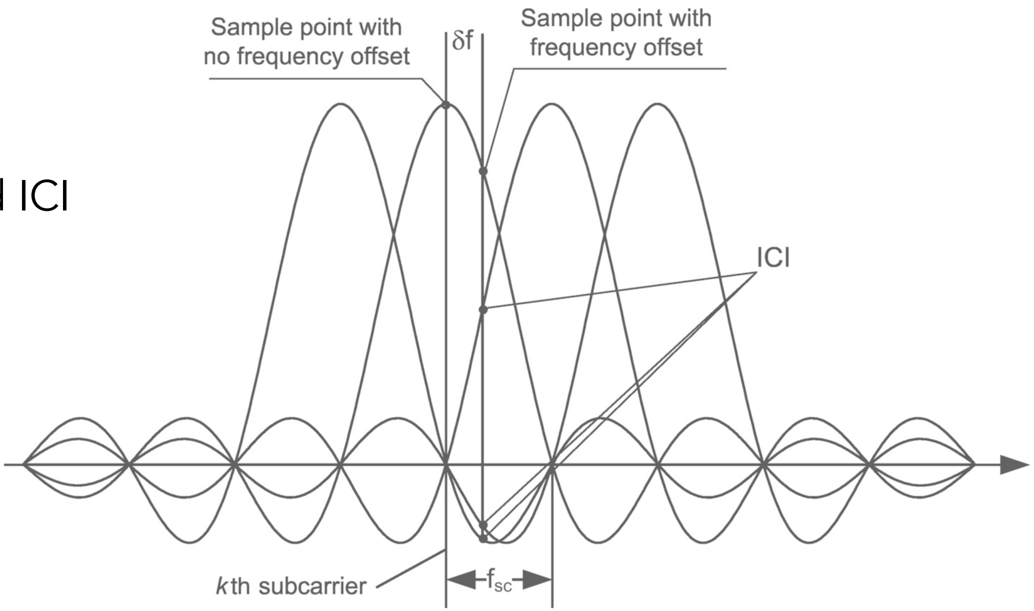
- OFDM symbol design
  - ΔT is set depending on target environment (> maximum delay spread)
  - $T \uparrow$ → fraction of CP in an OFDM symbol (i.e., overhead) ↓ → efficiency ↑
  - But, there are some downsides with large T
    - 1) Complexity increases due to large FFT size
    - 2) More vulnerable to inter-carrier interference (ICI)

OFDM/OFDMA

- Advantages
  - Long duration symbol → no worry about ISI
  - Good for high speed transmission in heavily multipath environments
  - Relatively easy to implement using FFT compared to CDMA
  - Many variations, e.g., TDMA, DSSS in frequency domain, FH-OFDMA, ...

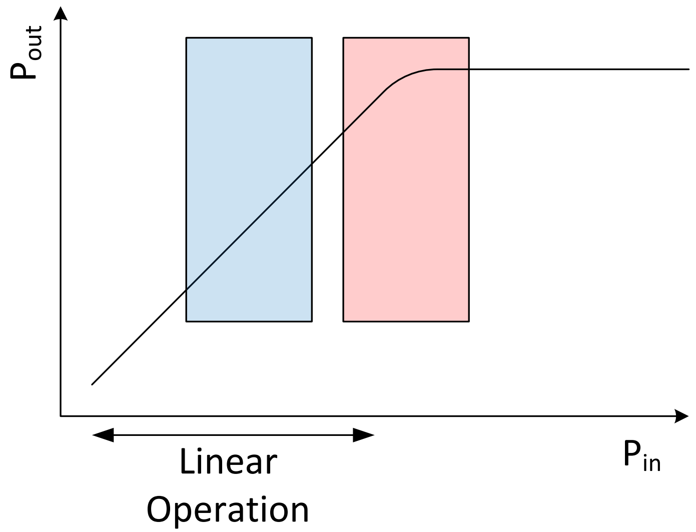
- Disadvantages
  - Complexity ...
    - e.g., frequency offset and ICI

- The winner of 4G !!!



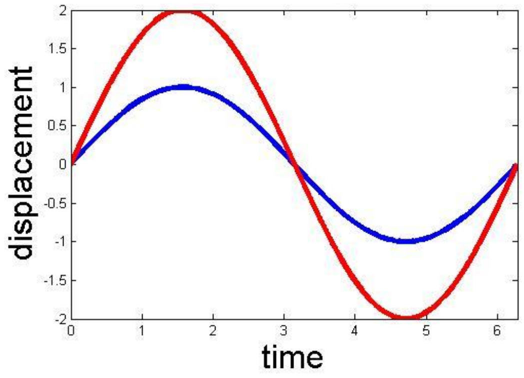
PAPR (Peak to Average Power Ratio)

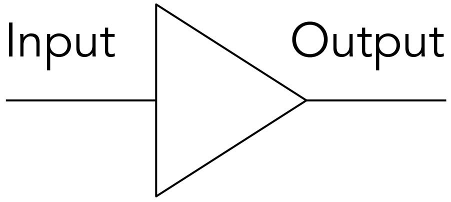
- PAPR = $\frac{|x|^2_{peak}}{x^2_{rms}}$

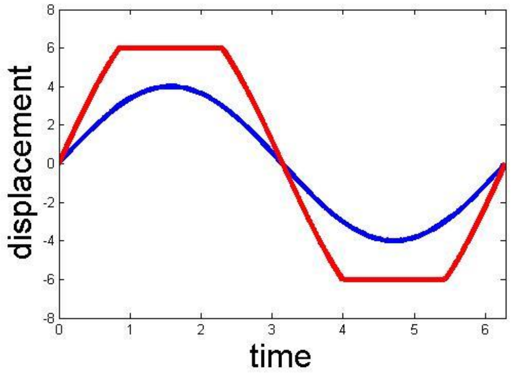


Input signal

Output signal

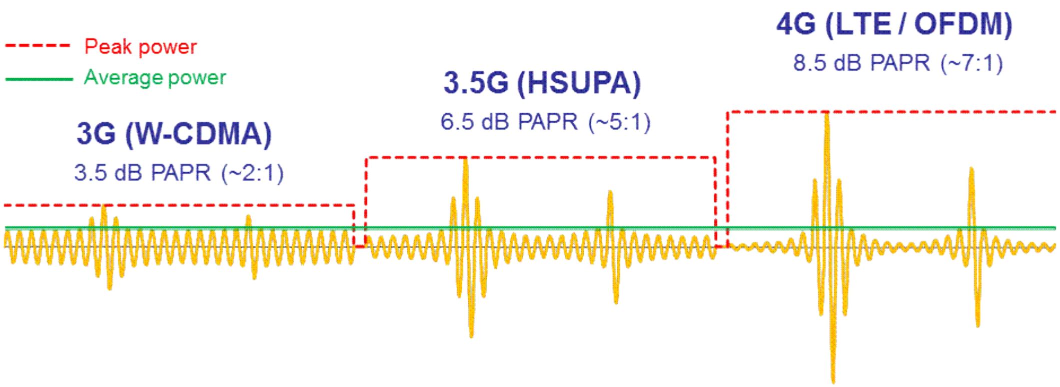


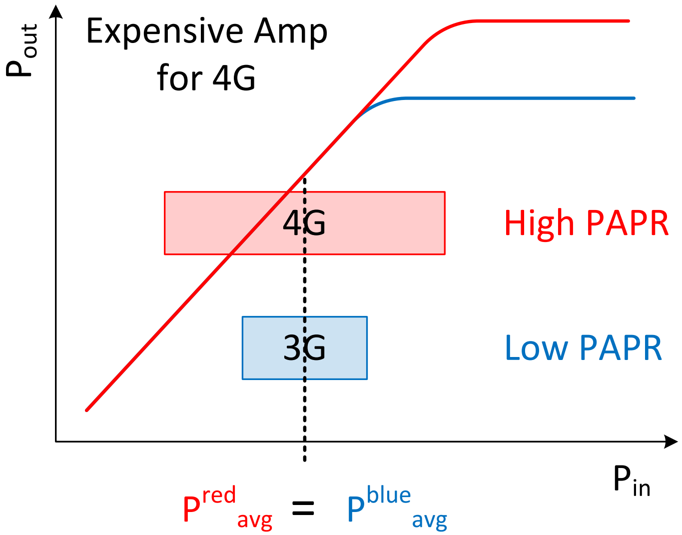




PAPR (Peak to Average Power Ratio)

- Higher data rates lead to "peakier" waveforms





- Avg. tx power determines the transmission range
  - High PAPR is not desirable
- BPSK/QPSK: Amplitude is not important

Examples

- AMPS US 1G – Analog FDMA/FDD
- GSM EU 2G – TDMA/FDD
- IS-95 US 2G – CDMA/FDD
- W-CDMA EU 3G – CDMA/FDD(/TDD)
- DECT EU CT – TDMA/TDD
- HIPERLAN/2 EU WLAN – D-TDMA/TDD
- IEEE 802.11 US WLAN – kind of TDMA/TDD? But,..
- WiMAX/WiBro – OFDMA/TDD + MIMO
- LTE – OFDMA/FDD(/TDD) + MIMO

Paper Reading for a Presentation Session

- Presentation template is provided in eTL
- Emphasize the novelty in the perspective of at least one of the followings: 1) New problem, 2) New technique, 3) Outstanding results or new observations

Paper ID	Wireless Networks Reading List - Sign up sheet (by 11:59pm, 04/05 Sunday) [PDF search - dl.acm.org]	Venue	Student ID	Name	(waiting list) Student ID	(waiting list) Name
1	Gentle Flow Control: Avoiding Deadlock in Lossless Networks	ACM SIGCOMM 2019				
2	Pluginizing QUIC	ACM SIGCOMM 2019				
3	HPCC: High Precision Congestion Control	ACM SIGCOMM 2019				
4	RF-based Inertial Measurement	ACM SIGCOMM 2019				
5	A Millimeter Wave Network for Billions of Things	ACM SIGCOMM 2019				
6	Neural Packet Classification	ACM SIGCOMM 2019				
7	Vantage: Optimizing video upload for time-shifted viewing of social live streams	ACM SIGCOMM 2019				
8	End-to-End Transport for Video QOE Fairness	ACM SIGCOMM 2019				
9	Veni Vidi Dixi: Reliable Wireless Communication with Depth Images	ACM CoNEXT 2019				
10	EasyPass: Combating IoT Delay with Multiple Access Wireless Side Channels	ACM CoNEXT 2019				
11	Smartphone Positioning with Radio Measurements from a Single WiFi Access Point	ACM CoNEXT 2019				
12	ADS: Accurate Decoding of RFID tags at Scale	ACM CoNEXT 2019				
13	Reducing Tail Latency using Duplication: A Multi-Layered Approach	ACM CoNEXT 2019				
14	AViC: A Cache for Adaptive Bitrate Video	ACM CoNEXT 2019				
15	MuSher: An Agile Multipath-TCP Scheduler for Dual-Band 802.11ad/ac Wireless LANs	ACM MOBICOM 2019				
16	ClientMarshal: Regaining Control from Wireless Clients for Better Experience in Enterprise WLANs	ACM MOBICOM 2019				
17	Systematic way to LTE Testing	ACM MOBICOM 2019				
18	Detecting if LTE is the Bottleneck with BurstTracker	ACM MOBICOM 2019				
19	Living IoT: A Flying Wireless Platform on Live Insects	ACM MOBICOM 2019				
20	Wideband Full-Duplex Wireless via Frequency-Domain Equalization: Design and Experimentation	ACM MOBICOM 2019				
21	Blind Distributed MU-MIMO for IoT Networking over VHF Narrowband Spectrum	ACM MOBICOM 2019				
22	On-Off Noise Power Communication	ACM MOBICOM 2019				
23	OFDMA-Enabled Wi-Fi Backscatter	ACM MOBICOM 2019				
24	RNN-based Room Scale Hand Motion Tracking	ACM MOBICOM 2019				
25	Rebooting Ultrasonic Positioning Systems for Ultrasound-incapable Smart Devices	ACM MOBICOM 2019				
26	Canceling Inaudible Voice Commands Against Voice Control Systems	ACM MOBICOM 2019				
27	mQRCode: Secure QR Code Using Nonlinearity of Spatial Frequency in Light	ACM MOBICOM 2019				
28	On the Feasibility of Wi-Fi Based Material Sensing	ACM MOBICOM 2019				
29	mD-Track: Leveraging Multi-Dimensionality for Passive Indoor Wi-Fi Tracking	ACM MOBICOM 2019				
30	Proximity detection with single-antenna IoT devices	ACM MOBICOM 2019				
31	vrAIn: A Deep Learning Approach Tailoring Computing and Radio Resources in Virtualized RANs	ACM MOBICOM 2019				
32	Fast and Efficient Cross Band Channel Prediction Using Machine Learning	ACM MOBICOM 2019				
33	A Framework for Analyzing Spectrum Characteristics in Large Spatio-temporal Scales	ACM MOBICOM 2019				