Mobile Communication Networks

V

Multi-carrier Modulation
OFDM

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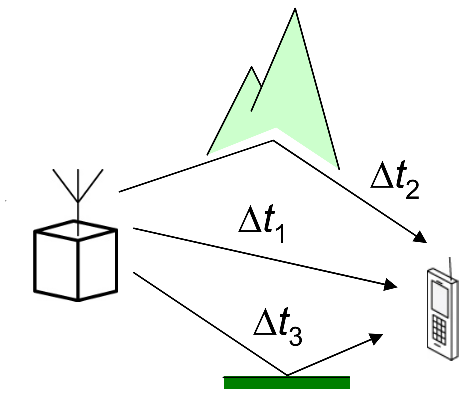
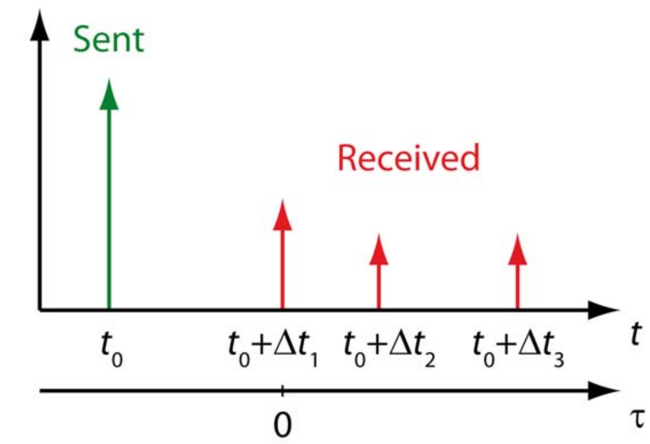
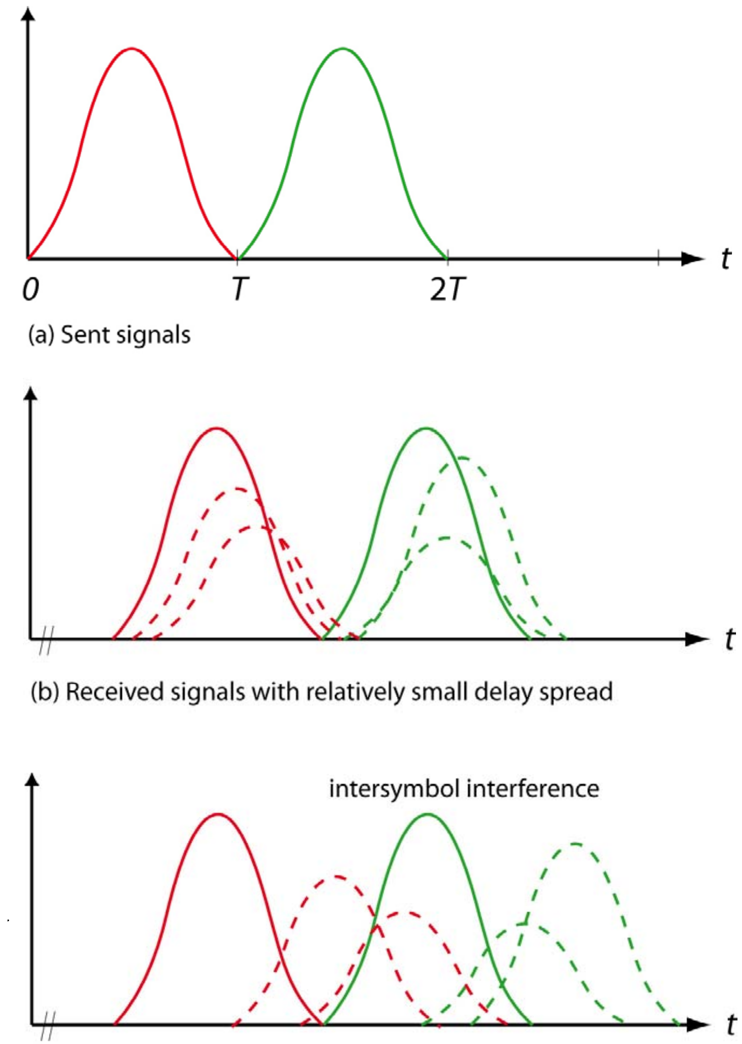
Inter-Symbol-Interference





Power delay profile

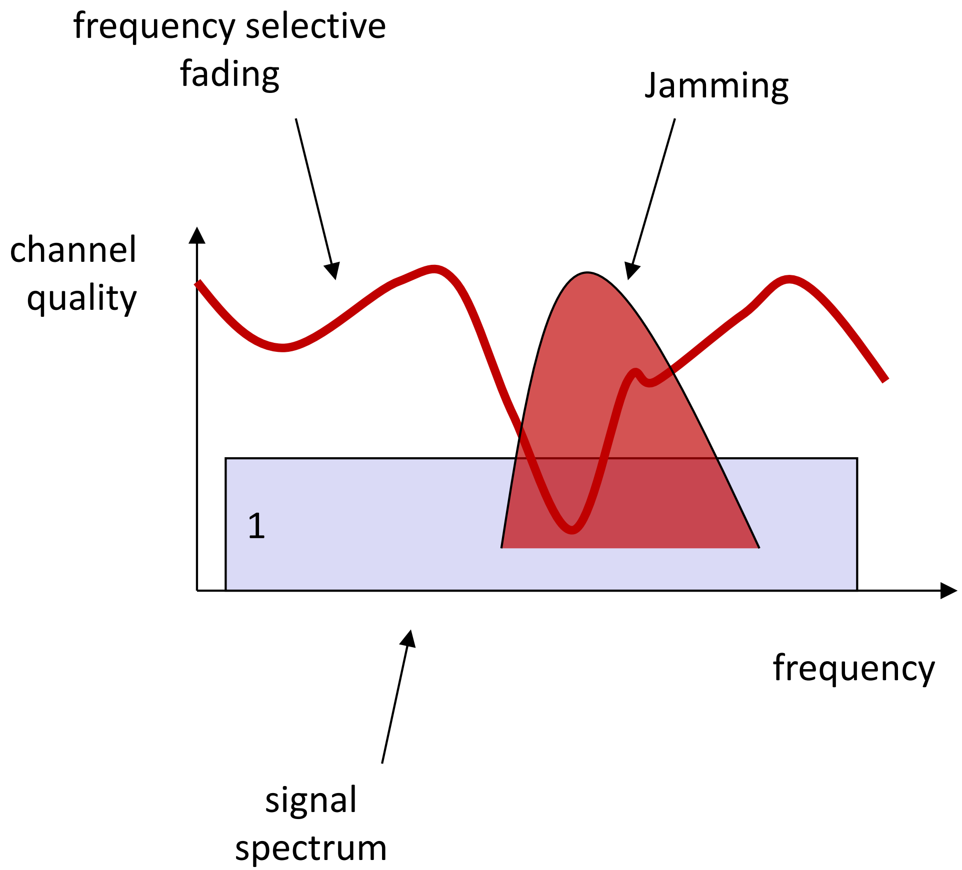


(a) Sent signals

(b) Received signals with relatively small delay spread

(c) Received signals with relatively large delay spread

frequency selective fading and Jamming



Questions:

- How to overcome **data rate limitation** due to **ISI**?
- How to cope with (time varying) **frequency selective fading**?
- How to cope with narrow-band **interference**?
  (unintentional or jamming)
- Can **multiple users** transmit simultaneously in the same frequency band?

Multi-carrier Modulation

Single-carrier Modulation

- In a **single carrier** modulation scheme each data **symbol** is transmitted **sequentially** on a single carrier → signaling interval equal to data symbol duration

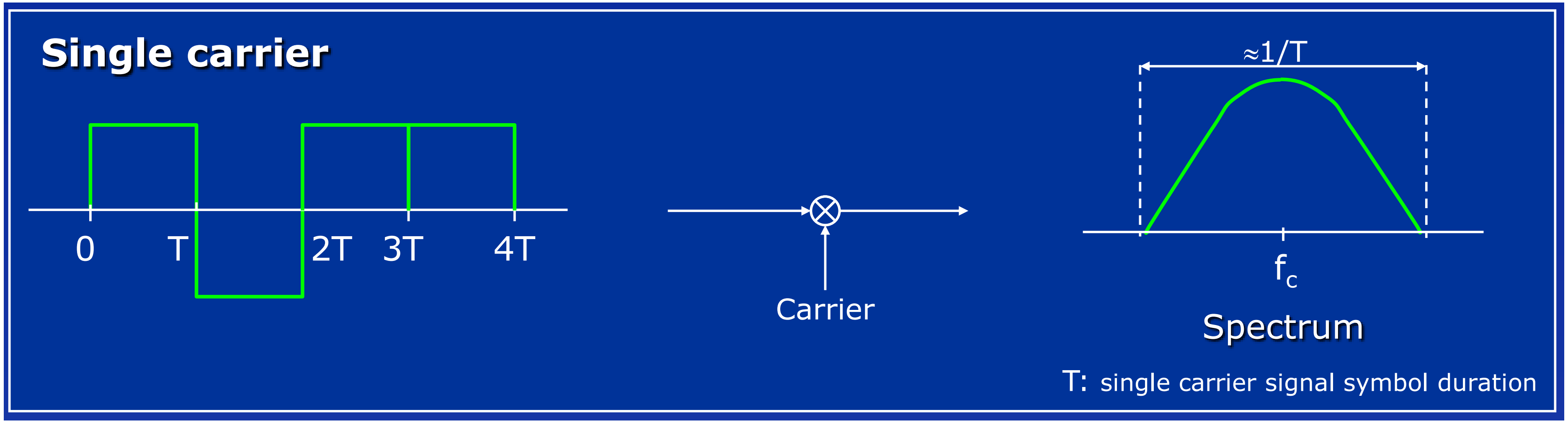
- In a **single carrier** modulation scheme the modulated carrier occupies the **entire available bandwidth**

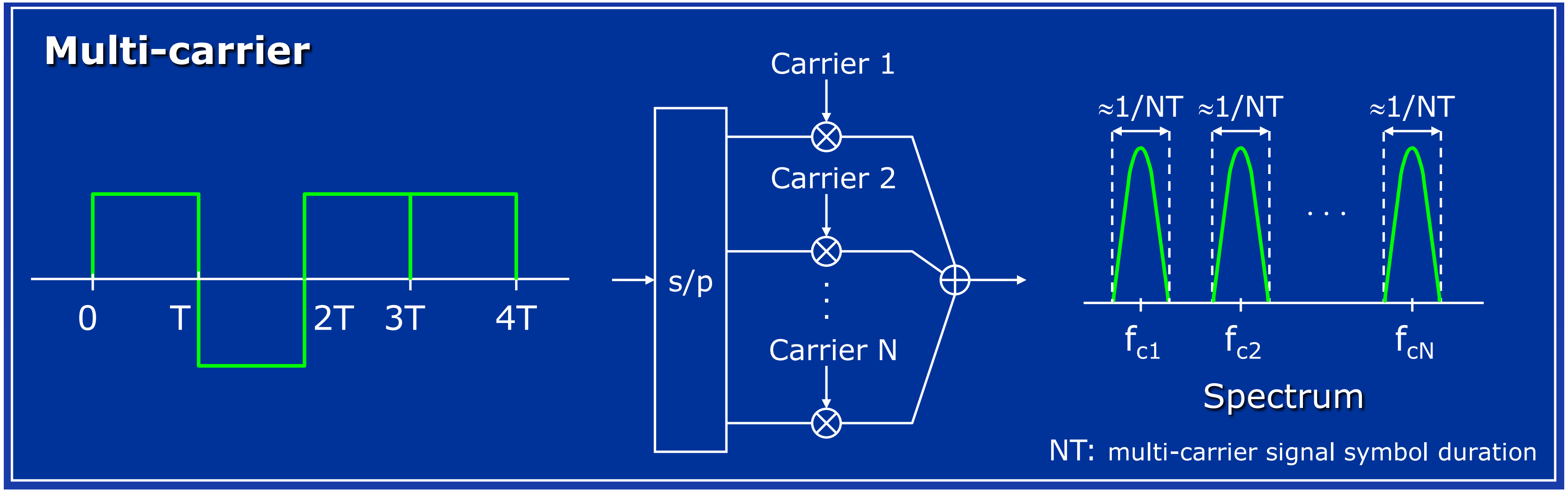
Multi-carrier Modulation (MCM)

- In a **multi-carrier** modulation (MCM) scheme, **N** sequential **data symbols** are transmitted **simultaneously** (in parallel) on **N multiple carriers** → signaling interval equal to N times data symbol duration

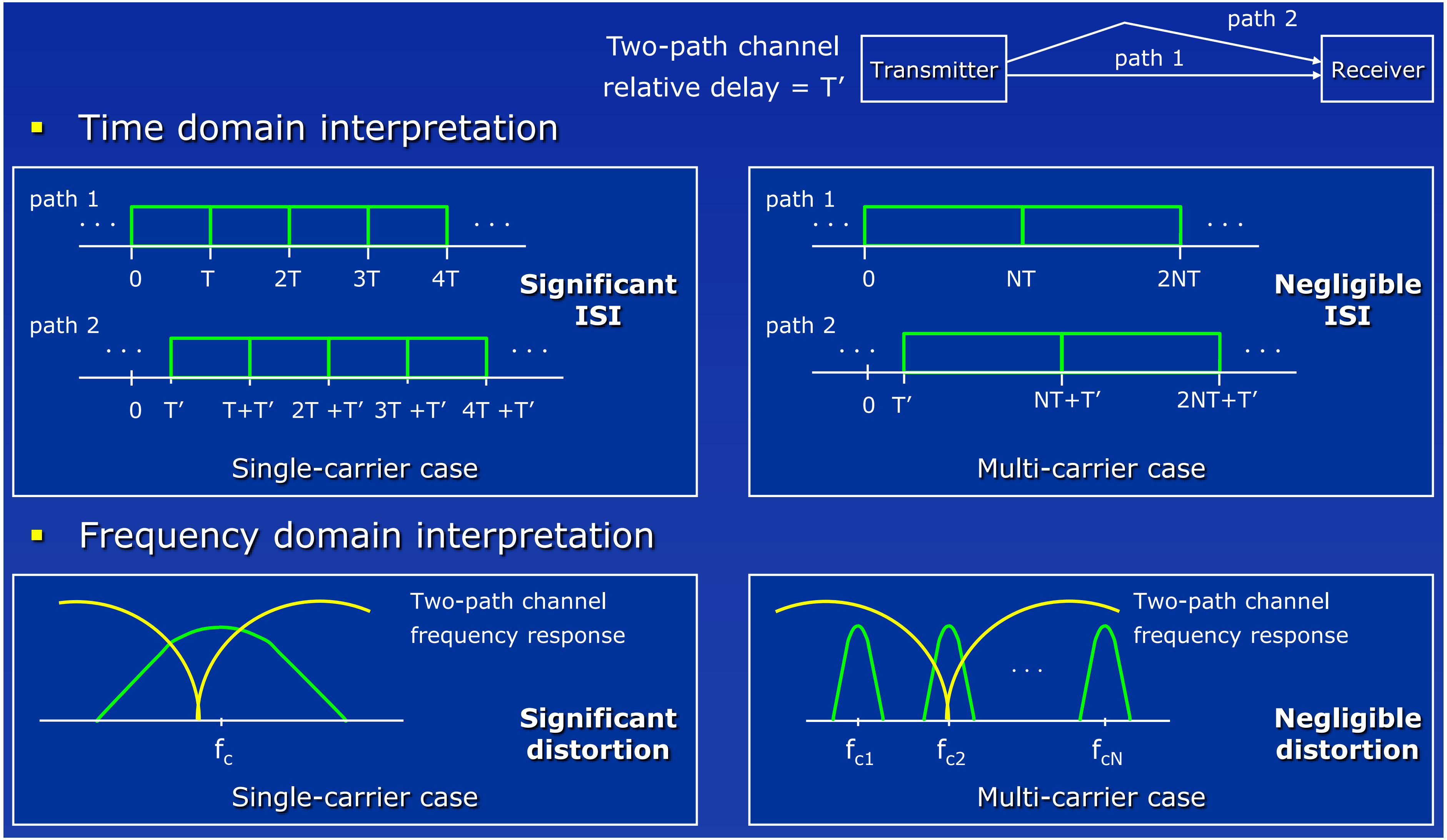
- In a **multi-carrier** modulation scheme each modulated carrier occupies only a **small part** of the entire available **bandwidth**

Multi-carrier Modulation





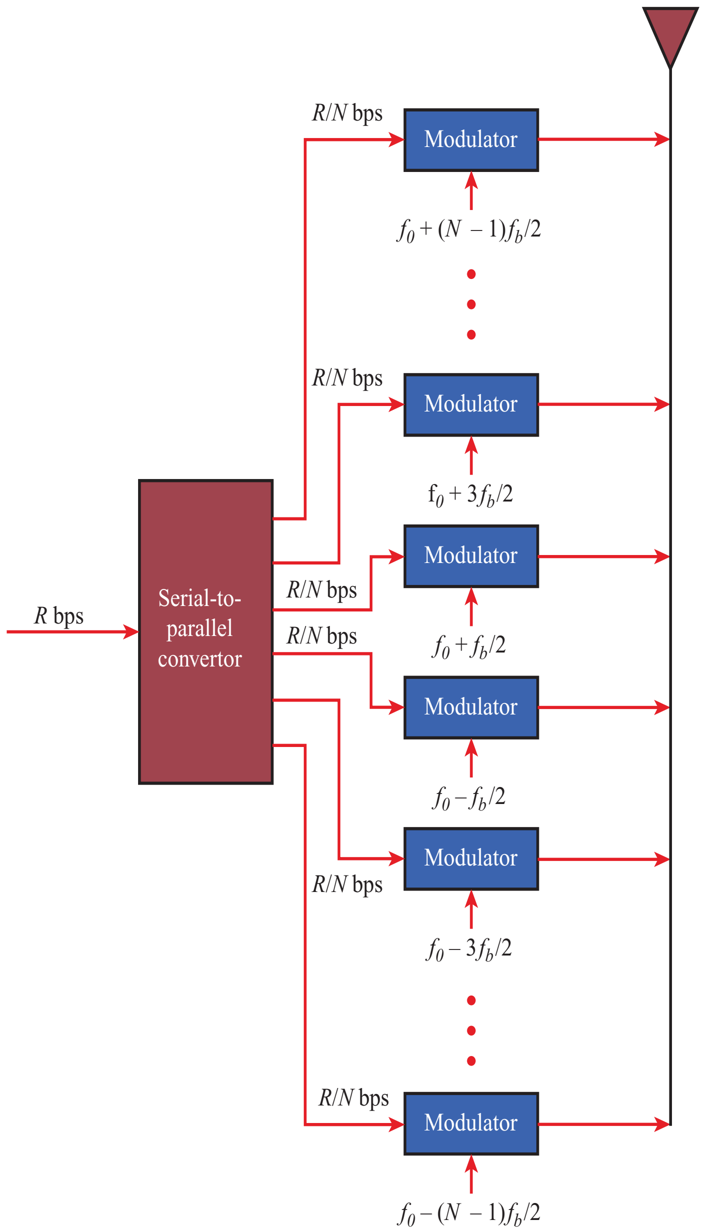
MCM on Multipath Channels



How OFDM works

- Start with a data stream of *R* bps
  - Could be sent with bandwidth *B*
  - With bit duration $T_b = 1/R$
- OFDM splits into *N* parallel data streams
  - Called *subcarriers*
  - Each with bandwidth $B' = B/N = f_b$
  - And data rate $R' = R/N$
  - Bit duration $T_b' = 1/R' = N/R = N*T_b$

Conceptual Understanding of Orthogonal Frequency Division Multiplexing



Orthogonal Frequency Division Multiplexing (OFDM)

- **OFDM** is a **multi-carrier** modulation scheme

- In OFDM the **frequency spacing** between adjacent subcarriers is f_b**=1/(NT)**

- f_b=1/(NT) is the **minimum frequency separation** that is necessary to ensure **orthogonality** between the sub-carriers over the signaling interval of length **NT**

- In OFDM the frequency spectrum of each sub-carrier overlaps the frequency spectrum of adjacent sub-carriers

Orthogonality

- The spacing of the f_b frequencies allows tight packing of signals
  - Actually with overlap between the signals
  - Signals at spacing of f_b , $2f_b$, $3f_b$,etc.

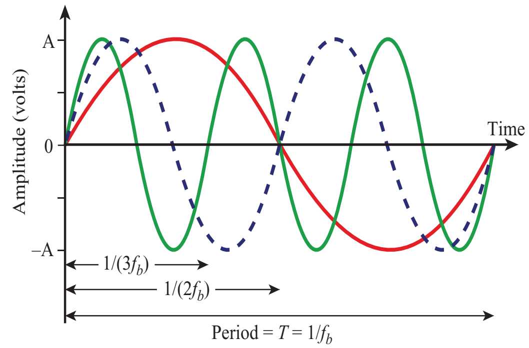
Orthogonality

- The choice of f_b is related to the bit rate to make the signals *orthogonal*
  - Average over bit time of $s_1(t) \times s_2(t) = 0$
  - Receiver is able to extract only the $s_1(t)$ signal
    - If there is no corruption in the frequency spacing

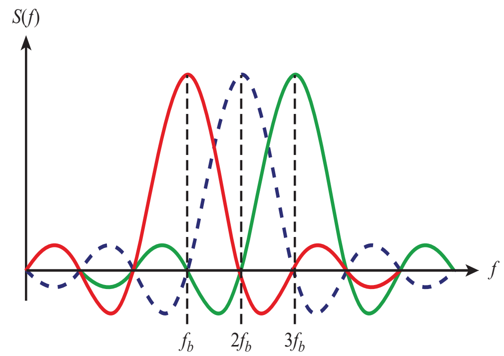
Orthogonality

- Traditional **FDM** makes signals completely **avoid** frequency **overlap**
  - **OFDM** allows **overlap** which greatly **increases capacity**

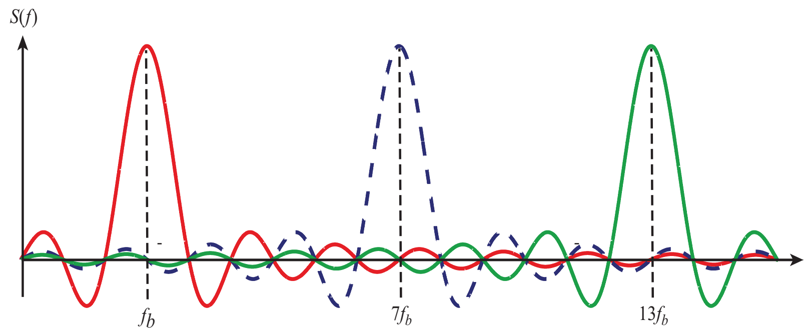
Illustration of Orthogonality of OFDM



(a) Three subcarriers in time domain



(b) Three orthogonal subcarriers in frequency domain



(c) Three carriers using traditional FDM

Orthogonality

- Given an OFDM subcarrier bit time of T
  - f_b must be a multiple of $1/T$

- Example: IEEE 802.11n wireless LAN
  - 20 MHz total bandwidth
    - Only 15 MHz can be used
  - 48 subcarriers
  - $f_b = 0.3125$ MHz
  - Signal is translated to 2.4 GHz or 5 GHz bands

Benefits of OFDM

- **Frequency selective fading** only affects **some subcarriers**
  - Can easily be **handled** with a **forward error-correcting** code
  - Easier to equalize

Benefits of OFDM

- More importantly, OFDM **overcomes** intersymbol interference (**ISI**)
  - ISI is a caused by multipath signals arriving in later bits
  - OFDM bit times are much, much longer (by a factor of *N*)
    - ISI is dramatically reduced
  - *N* is chosen so the root-mean-square delay spread is significantly smaller than the OFDM bit time
  - It may not be necessary to deploy equalizers to overcome ISI
    - Eliminates the use of these complex and expensive devices.

Benefits of OFDM

- Bandwidth efficiency
- Possible use of Adaptive Modulation and Coding (AMC) in each of the subcarriers

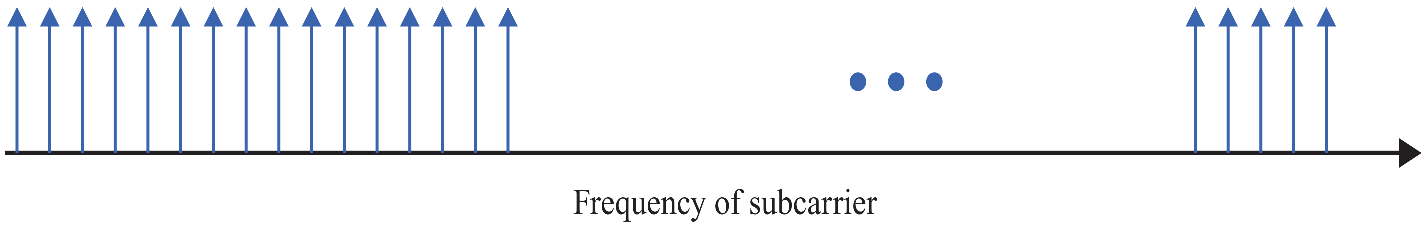
OFDMA

- Orthogonal Frequency Division Multiple Access (**OFDMA**) uses OFDM to share the wireless channel
  - **Different users** can have **different slices** of **time** and different **groups of subcarriers**
  - Subcarriers are allocated in groups
    - Called subchannels or resource blocks
    - Too much computation to allocate every subcarrier separately

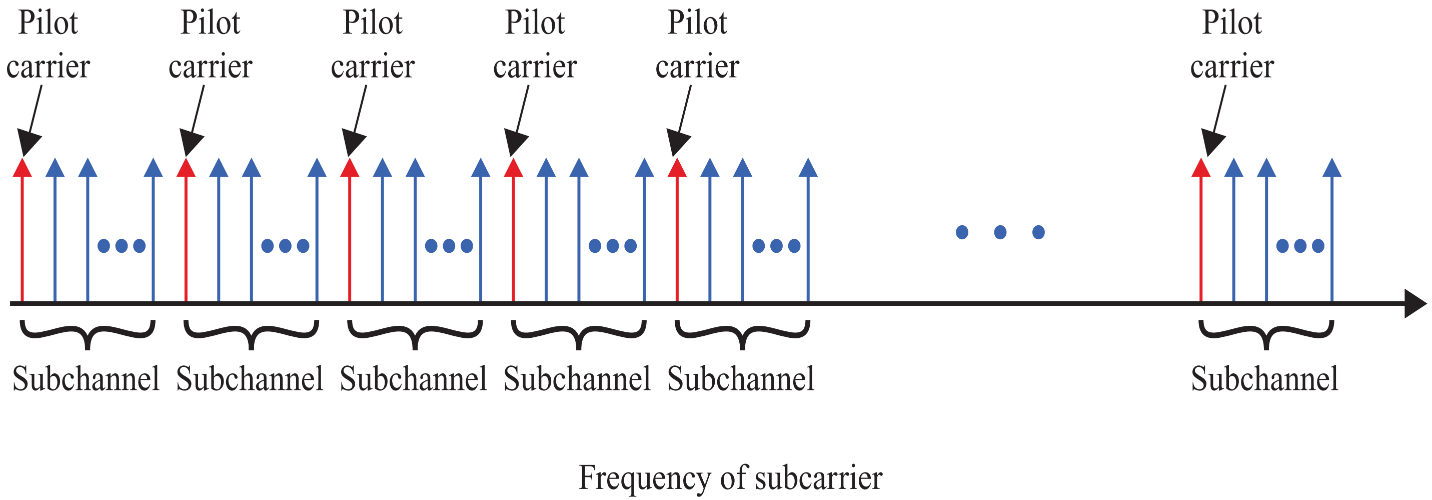
OFDMA

- Subchannel allocation
  - Adjacent subcarriers – similar SINR
    - Must measure to find the best subchannel
  - Regularly spaced subcarriers – diverse SINR
  - Randomly space subcarriers – diverse SINR and reduced adjacent-cell interference

OFDM and OFDMA



(a) OFDM



(b) OFDMA (adjacent subcarriers)

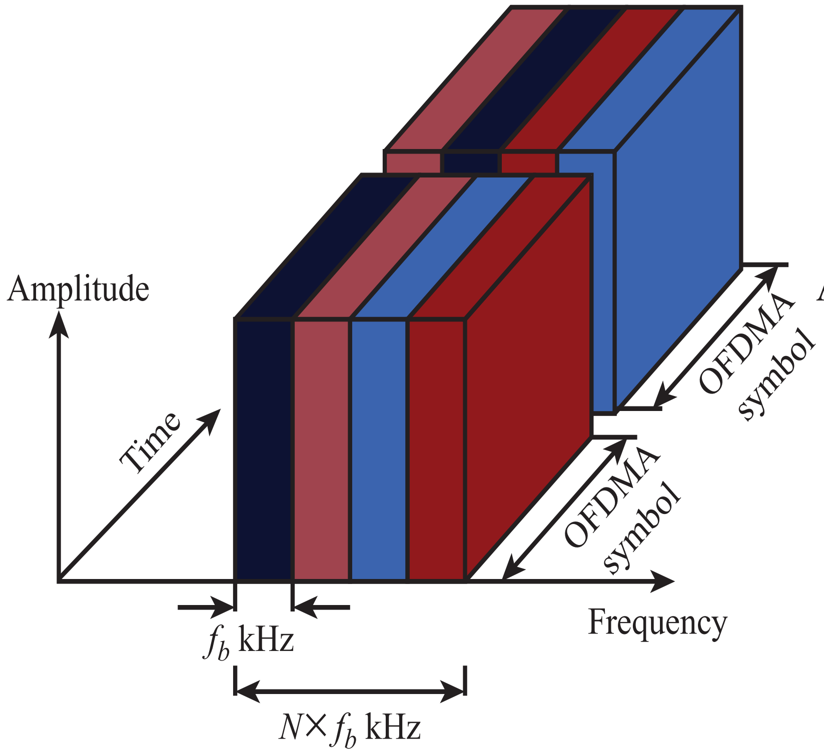
Opportunistic scheduling

- Schedule subchannels and power levels based on
  - Channel conditions
  - Data requirements
- Adjust in a dynamic fashion
  - Use channel variations as an opportunity to schedule the best choice in users
    - Hence the term *opportunistic scheduling*
  - Criteria (maybe more than one used simultaneously)
    - System efficiency – pick users with best throughput
    - Fairness – proportional fairness considers the ratio of users' current rates to the users' average rates to know when a channel is best *for them*
    - Requirements – audio, video
    - Priority – public safety, emergency, or priority customers

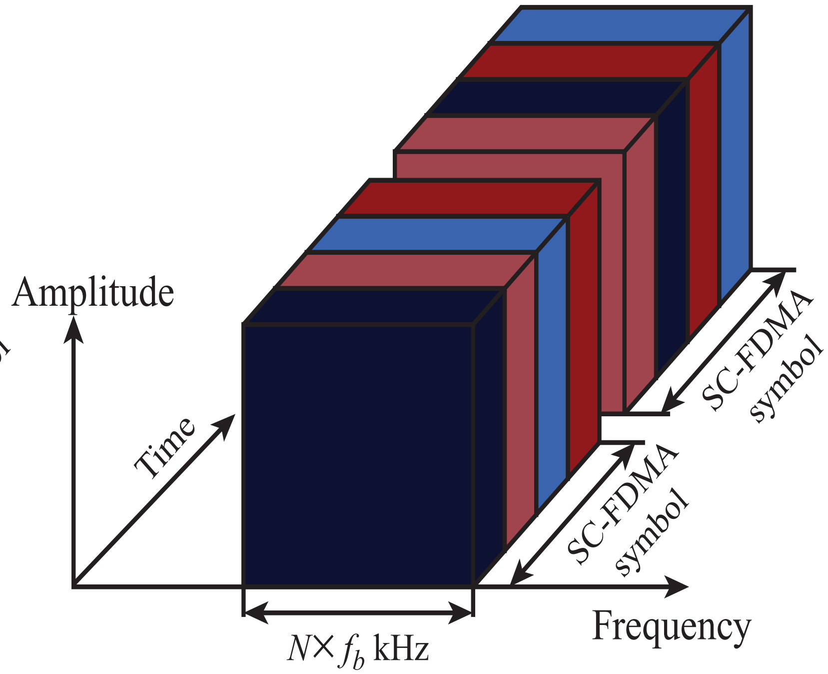
Single-carrier FDMA

- SC-FDMA has similar structure and performance to OFDMA
  - Mobile user benefits – battery life, power efficiency, lower cost
  - Good for uplinks
- However:
  - Spreads data symbols over all subcarriers
  - Every data symbol is carried by every subcarrier
- Multiple access is not possible
  - At one time, all subcarriers must be dedicated to one user
  - Multiple access is provided by using different time slots

Example of OFDMA and SC-FDMA



(a) OFDMA: Data symbols occupy f_b kHz for one OFDMA symbol period



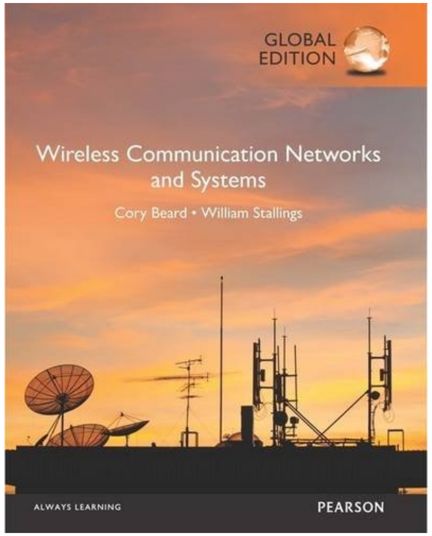
(b) SC-FDMA: Data symbols occupy $N \times f_b$ kHz for 1/N SC-FDMA symbol period

Example: LTE networks

- OFDMA for downlink

- SC-FDMA for uplink

Literature



Wireless Communication Networks and Systems,

C. Beard and W. Stallings, Prentice Hall

- Chap 8