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Wireless PHY – MAC

Multiple Access Principles

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Aim

- **Review/overview of multiple access techniques, incl. duplexing, for wireless communication**
  - **Familiarise with the main characteristics of these (pros and cons)**
  - **Relate these to existing wireless communication standards**

MAC is Medium Access Control and hence tightly coupled to Multiple Access principles

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Multiple Access

- Multiple access (MA) is to permit the communication resources to be shared among a large number of users seeking to communicate
- This sharing should ideally be accomplished without interference between the users' communication signals
- Multiple access is tightly coupled to air interface modulation
  - designed together to handle spectral containment, need for guard bands, detection performance, …
- The choice of multiple access is influenced by
  - spectral efficiency
  - complexity (for detection, interference cancellation, etc.)
  - flexibility (to traffic, resource allocation, etc.)

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Terminology

- Some terminology (strictly speaking)
  - *Multiplexing* is the combining of multiple signals from the same source (broadcasting – wireless downlink), whereas
  - *Multiple access* is the combining of signals from multiple sources (multiple access – wireless uplink)
- Multiple access is different between the downlink (*broadcast* – one to many) and uplink (*multiple access* – many to one)
  - In broadcast, resources to share are ”bandwidth” and power – *multiplexing and no access*
  - In multiple access, resources are bandwidth – *multiple access*

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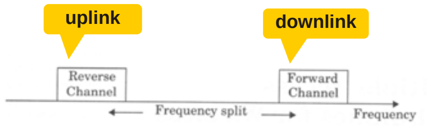
Duplexing



- **FDD**
  - **"full" duplex**
  - **requires paired frequencies**
  - **not efficient for assymmetric traffic**
  - **Usually duplex directions are offset in time (and freq.) to allow handshaking and processing time**

- **TDD**
  - **half duplex (simplex)**
  - **support of assymmetric traffic**
  - **potential for reduced channel feedback**
  - **synchronization and delay**

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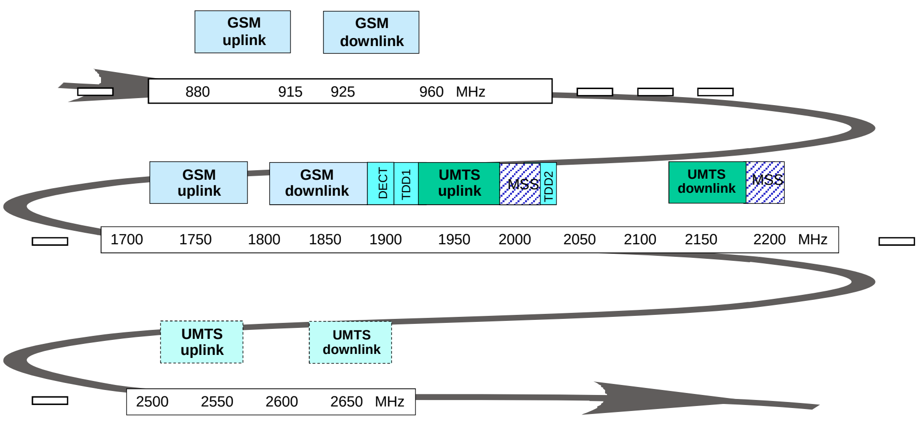
Example FDD



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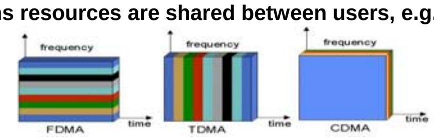
Multiple Access

- Basic forms (narrowband/wideband)
  - Frequency Division Multiple Access (FDMA) – resource is frequency
  - Time Division Multiple Access (TDMA) - resource is time
  - Code Division Multiple Access (CDMA) - resource is code/power
  - Spatial Division Multiple Access (SDMA) – resource is spatial
- In their basic forms these refer to *scheduled* MA, with dedicated or shared resources, i.e. there is total coordination between the channels
  - dedicated (*circuit/channelisation mode*) means resources are dedicated to a user, e.g. based on FDMA/TDMA in combination
  - shared (*packet mode*) means resources are shared between users, e.g. based on CDMA/TDMA



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Scheduled MA ex.

- Dedicated resources
  - GSM: TDMA/FDMA, FDD (FD)
  - UMTS: WCDMA, FDD/TDD (FD/HD)
  - DECT: MC(FDMA)/TDMA, TDD (HD)
- Shared resources
  - GPRS: FDMA/(dynamic)TDMA, FDD (FD)
  - LTE: OFDMA/SC-FDMA, FDD/TDD (FD/HD)
  - HSPA: WCDMA/(dynamic)TDMA, FDD (FD)

Acronyms:

GSM	Global System for Mobiles
UMTS	Universal Terrestrial Radio Access
DECT	Digital European Cordless Technology
GPRS	General Packet Radio Service
LTE	Long Term Evolution
HSPA	High Speed Packet Access
MC	Multi-Carrier

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Random MA

- Random MA – technology specific (often referred as packet access mode)
  - requires a MA protocol, e.g. the most commonly used is some form of CSMA/CA (CSMA/CD)
  - and can have resource reservation (”scheduled”) variants, e.g. PRMA (TDMA + slotted ALOHA/Reservation ALOHA)
  - Examples:
    - WiFi: (FDMA/) CDMA (DS/FH) or OFDMA, TDD (HD) – DCF; CSMA/CA w. exp. backoff (ALOHA like)
    - BT: CDMA (FH), TDD (HD) – CSMA/CA or dynamic TDMA
  - also used for Random Access (connection setup) in scheduled systems – usually in some form of slotted-ALOHA (scheduling opportunities)

Acronyms:

PRMA	Packet Reservation Multiple AccessGlobal System for Mobiles
CSMA	Carrier Sense Multiple Access (/CA - Collision Avoidance)
DCF	Distributed Coordination Function
BT	Blueetooth

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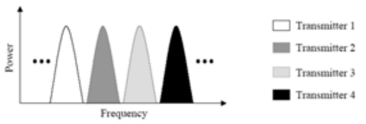
FDMA



- Intrinsically narrowband
  - freq. non-selective fading
  - no need for equalisation (simple signal processing)
  - low trunking efficiency in terms of equipment (and resources)
- Continuous transmission
  - dedicated channels
  - low signalling overhead for synchronisation and framing
  - challenging handovers
- Frequency duplexing
  - spectrum constraints (separation), component cost
- Spectral Efficiency (bps/Hz/km2)
  - guard bands
  - nonlinearity/distortion
    - interference between carriers in broadcast requires back-off (low power efficiency)
    - AM to PM (modulation transfer)

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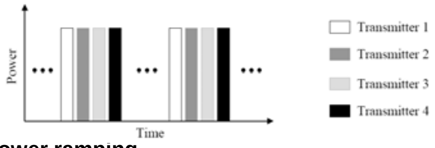
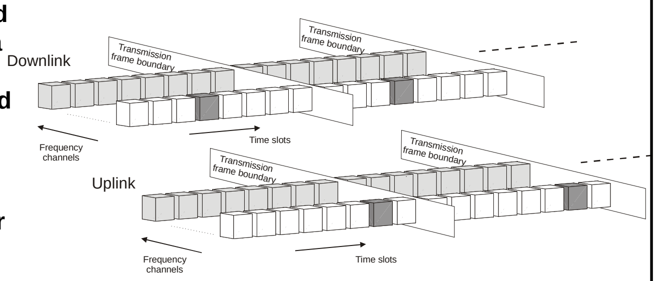
TDMA

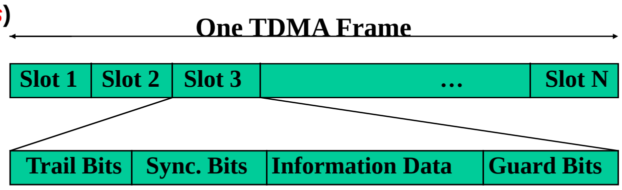
- Intrinsically wideband
  - need for equalisation due to higher signalling rate
- Discontinuous transmission
  - bursty transmission - need for power ramping
  - synchronous (framed)
    - need for guard and/or timing advance (Inter-Symbol Interference)
  - asynchronous as in random access (CSMA)
  - buffering
  - synchronisation (overhead)
  - better support for handover
- Spectral Efficiency
  - wider band or wideband (full spectrum is used), full power - only out of band considerations
  - switching (no duplexer)
  - trunking (e.g. dynamic TDMA)
  - guard times, synchronisation and framing



FDMA/TDMA

- A channel is allocated as a combination of a given frequency and time slot (dark shaded cubes) in following successive time intervals
- Users have each their own unique combination of frequency (narrowband) and time slot (*orthogonal channels*)





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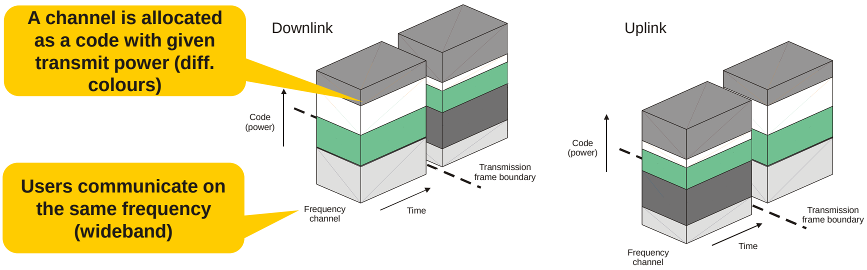
CDMA

- Different users are separated by a code which spreads the signal energy over a bandwidth much greater than the signal information bandwidth (spread spectrum)
- Intrinsically wideband
  - robustness to freq. selective fading (advantageous)
- Soft capacity (achieved with non-orthogonal codes in which case capacity is inferior to TDMA and FDMA (orthogonal))



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Implementations

- Two basic forms:
  - Frequency Hopping (FH) is a specific form of FDMA/TDMA – orthogonal or non-orthogonal, and fast or slow (symbol or frame)
  - Direct Sequence (DS) orthogonal or Pseudo Noise (PN) spreading (modulation); each ”bit” on the air interface is termed a chip
- Code-division implemented as direct sequence spread sprectrum is the most common:
  - Spreading code increases bandwidth by G (spreading gain or spreading factor)
  - Orthogonal codes, e.g. Walsh-Hadamard codes, leads to zero cross correlation, with a spreading gain of G for G orthogonal codes (see later)
  - Non-orthogonal codes, e.g. Maximum Length (ML) shift registers leads to cross-corr. of approx. 1/G (interference suppression)

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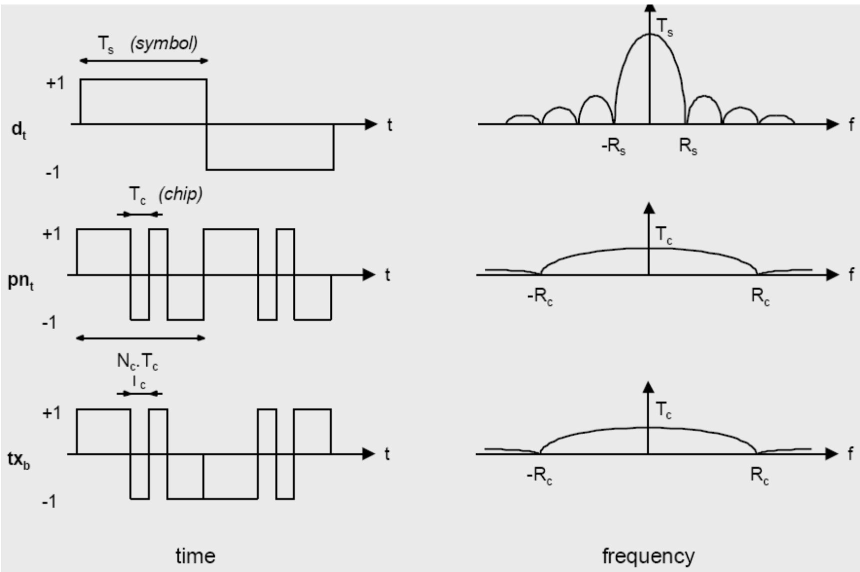
Direct Sequence



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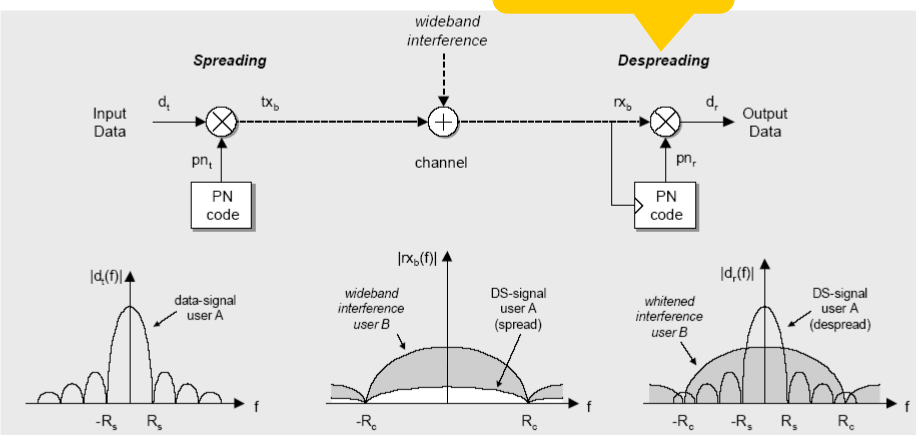
Direct Sequence

matched filtering / pulse compression



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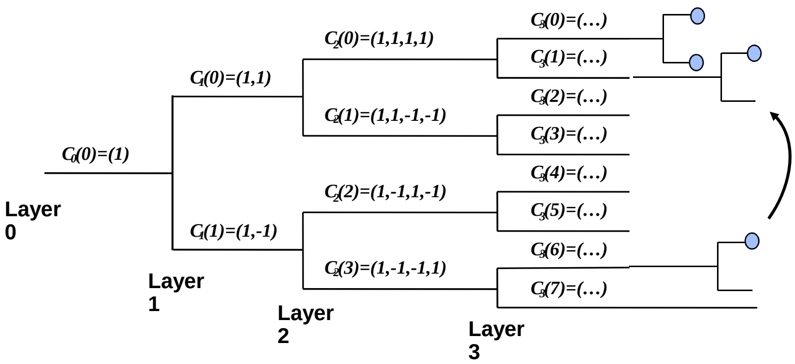
Channel Codes

- Orthogonal codes, e.g. Walsh-Hadamard code tree leads to zero cross correlation, with a spreading factor/gain of *G* for *G* orthogonal codes
- The codes are layered according to the code type



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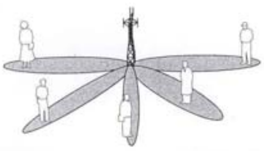
SDMA

- Controls radiated energy for each user in space using spot beam (beamforming) antennas



- Covers areas with same frequency in a TDMA or CDMA system
- Cover areas with different frequencies in FDMA systems
- Implemented using adaptive antennas or sectorised antennas with handover between beams or user tracking
- Basically a non-orthogonal access due to beam cross-coupling

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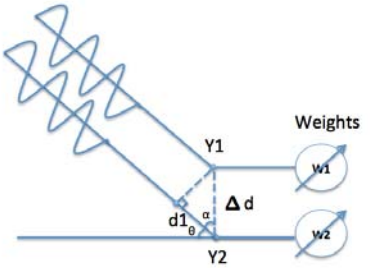
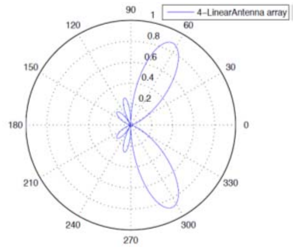
Beamforming





- Maximise the array response in the direction of the desired signal (measured)

$$\theta_{opt} = \underset{\|\mathbf{w}_{BF}\|^2=1}{\arg\max} \left| \mathbf{w}_{BF}^{H}(\theta)\mathbf{h}_{meas} \right|$$

- where the corresponding (optimum) weight is

$$\mathbf{w}_{BF}\left(\theta_{opt}\right) = \left[\ldots, \frac{1}{\sqrt{N}} e^{-j\frac{2\pi\Delta d}{\lambda}(n-1)\sin\left(\theta_{opt}\right)}, \ldots \right]^T$$

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Summary and Learnings

- Multiple Access versus Multiplexing
- FDD and TDD duplexing (full and half)
- Scheduled and Random Multiple Access
- Basic forms – FDMA, TDMA, CDMA and SDMA – pros and cons
- Orthogonal and non-orthogonal access

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