RRA

Mobile Radio Networks
Introduction

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Credits: 6

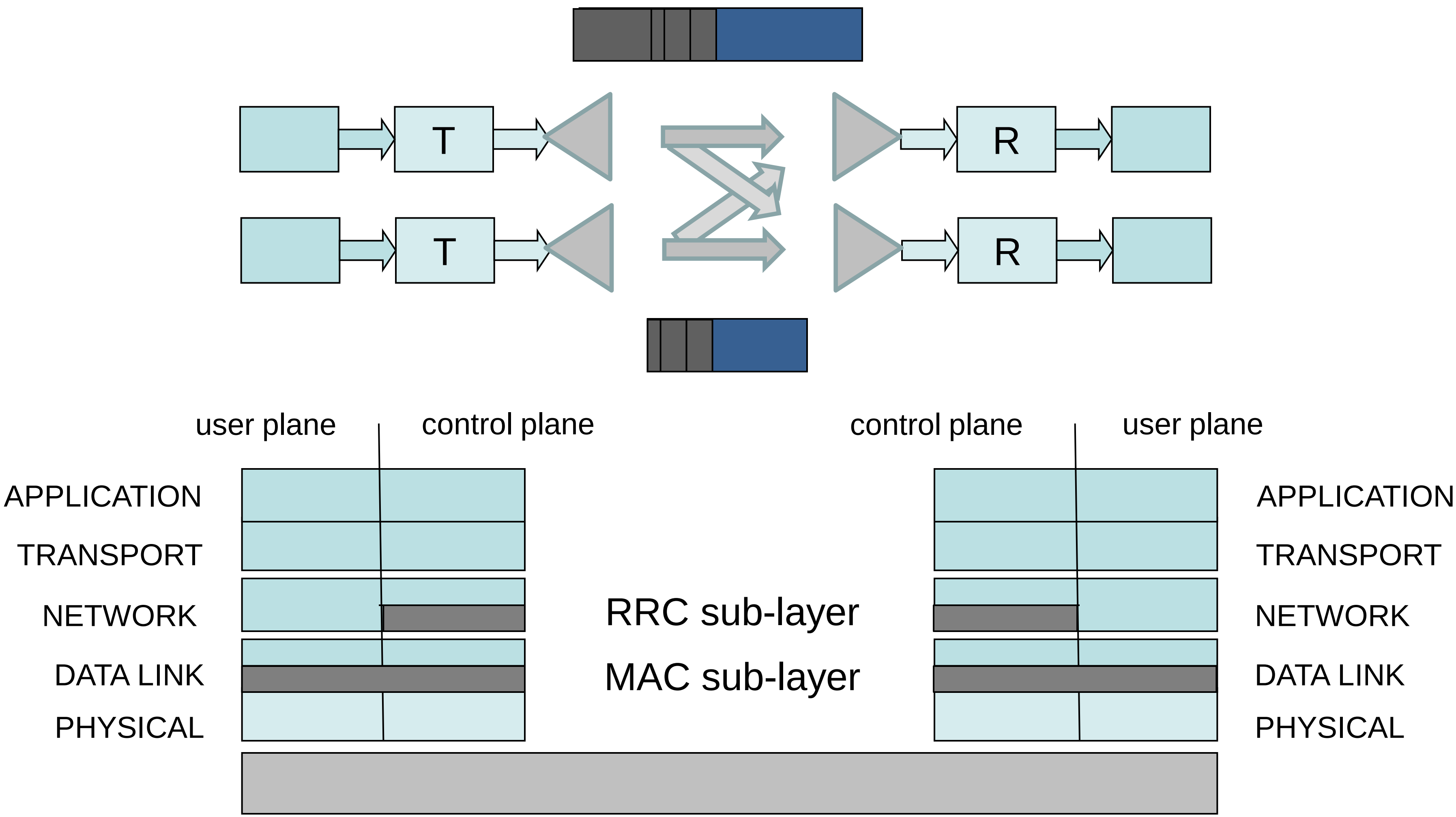
Slides are provided as supporting tool, they are not a textbook!

Outline

1. Radio Resources
2. Assignment of Radio Resources

This lecture block will introduce the notion of radio resource, and the techniques to access the shared radio channel.

Sharing the Radio Channel



1. Radio Resources

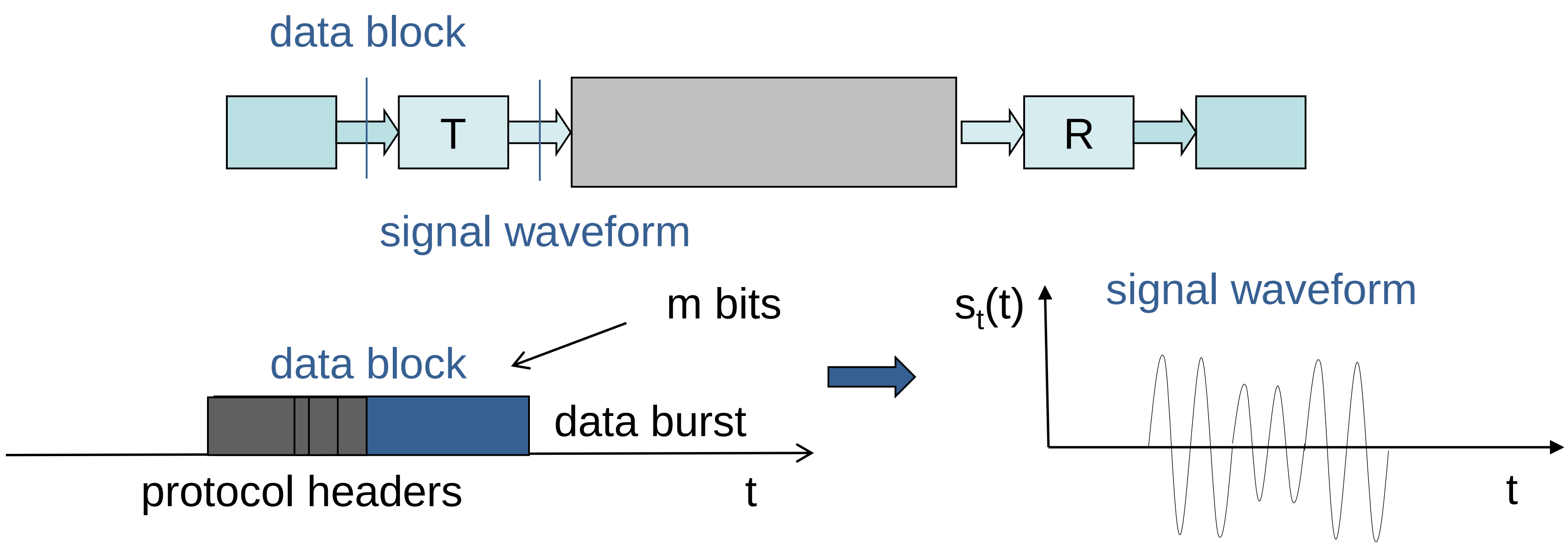
Radio Resources

Medium Access Control (MAC) and Radio Resource Control (RRC)

Both MAC and RRC address the problem of assigning ***radio resource units*** to data blocks in a shared radio environment, at a different pace

Radio Resource (RR)

A *radio waveform* allowing the transmission of a given data block (m bits)



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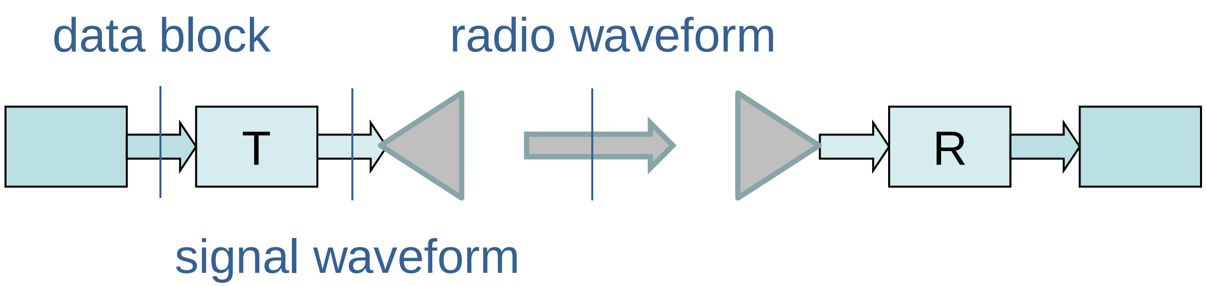

The radio waveform is an e.m. wave, whose electrical field component E(t) has amplitude which is proportional to the amplitude $s_t(t)$ of the signal waveform; however, it also includes the spatial dimension of radiation (directional behaviours) described by the antenna diagram.

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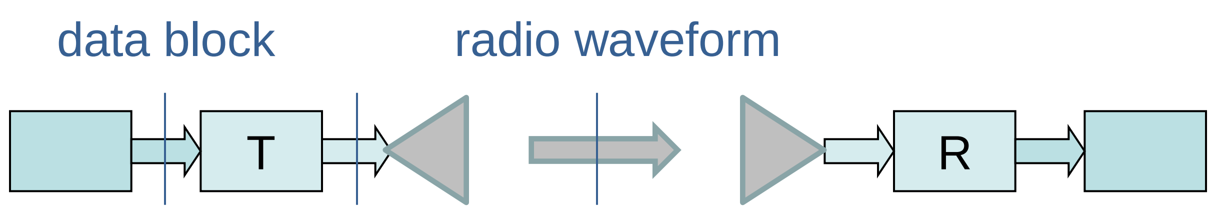


Radio Resource Assignment (RRA)

The process of assigning RRs to data blocks in a given area, for a given time frame.

Radio Resources

Radio Resource Payload

Amount of information bits (as seen by data link layer) carried by the RR

Radio Resource Unit (RU)

A RR carrying the minimum value of Radio Resource Payload that can be assigned

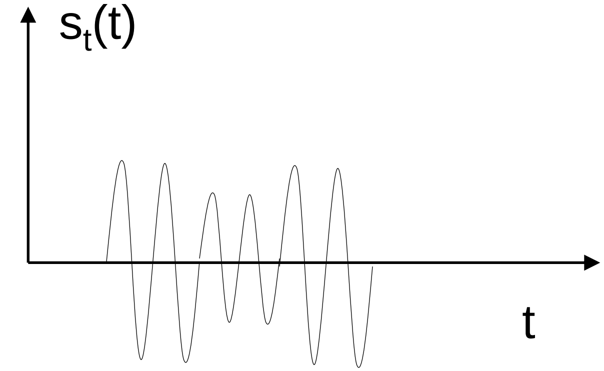
The scope of RR Assignment is to maximise the exploitation of the available RUs while fulfilling Quality of Experience (QoE) requirements:

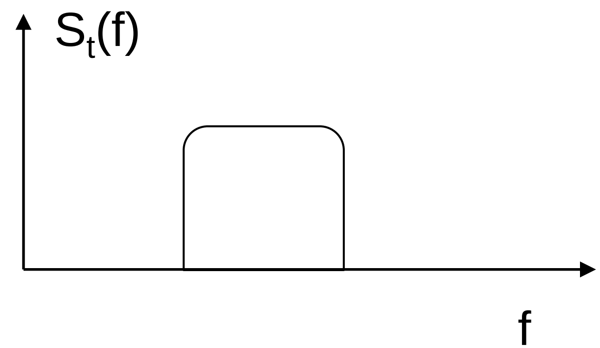
tradeoff **between**
network spectrum efficiency
and
QoE of the largest possible number of users

Radio Resources

The RU assignment implies the definition of all characteristics of the radio waveform.

From the signal waveform viewpoint:





RU = [?]

Radio Resources

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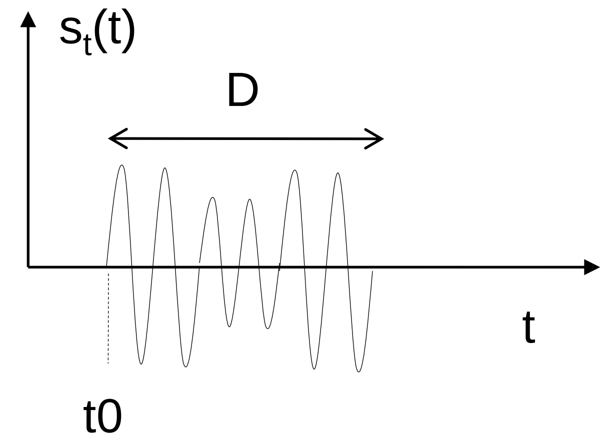
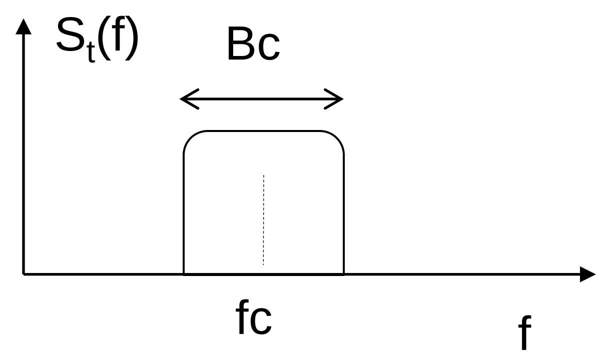
From the signal waveform viewpoint:



- energy level (E),
- modulation and coding scheme (MCS),
- carrier frequency (fc),
- start time (t0),
- duration (D),
- bandwidth (Bc).



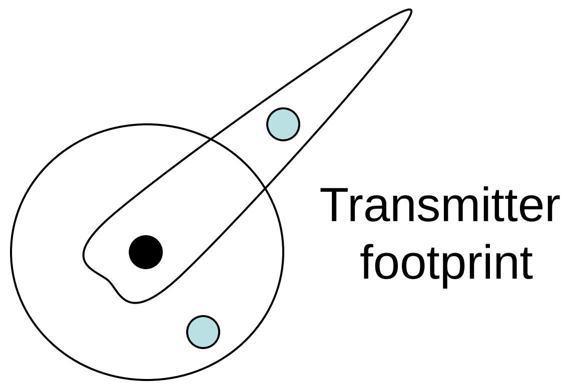
RU = [E, MCS, fc, t0, D, Bc]

Radio Resources

The RU assignment implies the definition of all characteristics of the radio waveform.

From the *radio* waveform viewpoint:

- energy level (E),
- modulation and coding scheme (MCS),
- carrier frequency (fc),
- start time (t0),
- duration (D),
- bandwidth (Bc),
- radiation pattern (Ga)



RU = [E, MCS, fc, t0, D, Bc, Ga]

Radio Resources: Bi-directionality

FDD (Frequency Division Duplexing)

The two links use different frequency bands

RU = [E, MCS, fc, t0, D, Bc, Ga]

TDD (Time Division Duplexing)

The time axis is divided in two, and fast alternate transmissions occur on the same band

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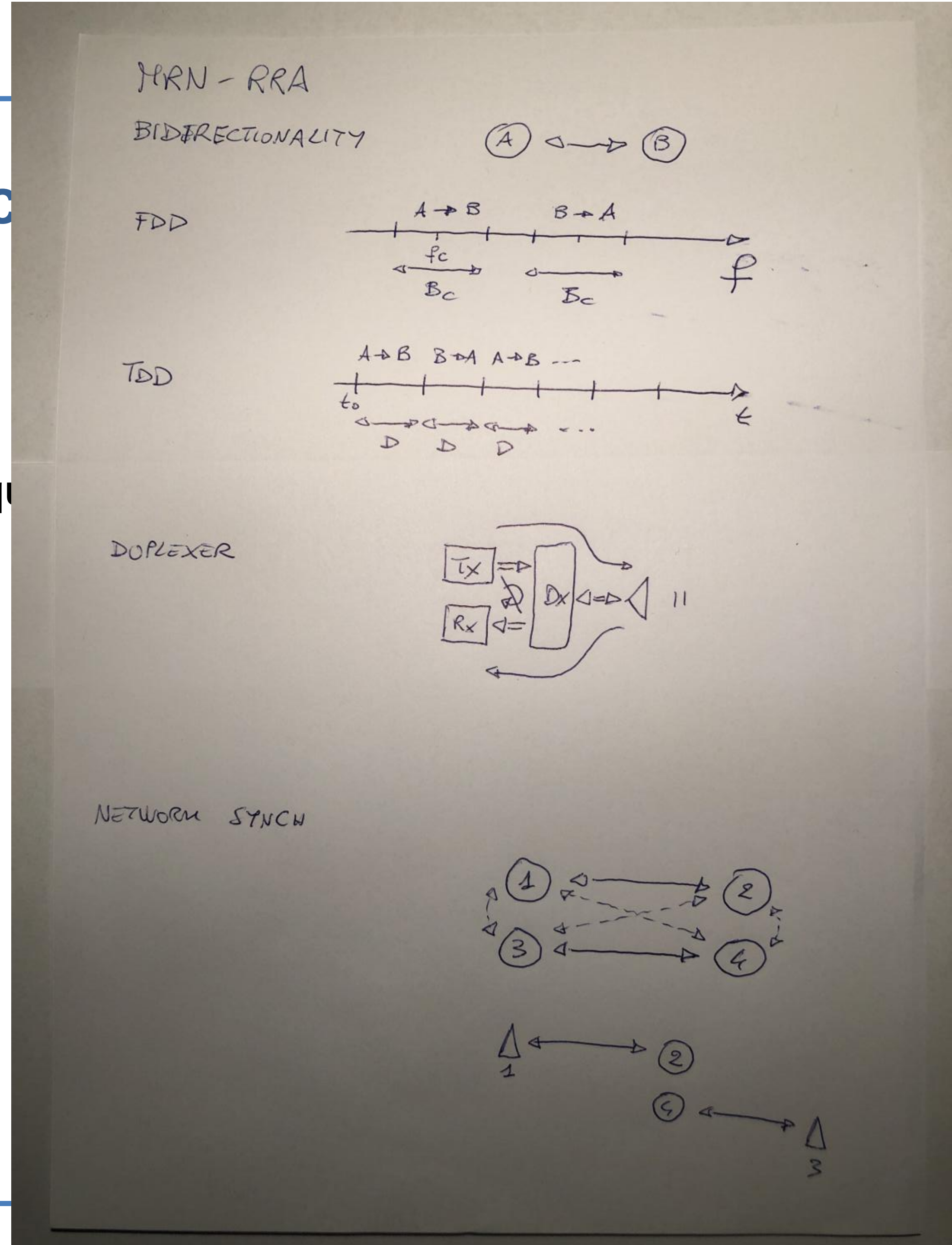


Radio Resources: Bi-directionality

Duplexing Technique	Duplexing Duty Cycle, η_d: fraction of time transmitter is on.
FDD	$\eta_d = 1$
TDD	$\eta_d = 0.5$

Be careful:
the definition accounts for the exploitation of the radio channel in the given direction,
but it does not account for the fact that for the opposite direction,
other resources are needed (other time slot with TDD, other band with FDD).

Radio Resources: Bi-directionality

Duplexing Technique	Advantages	Disadvantages
FDD	simple	good duplexer needed to avoid transmitter-to-receiver interference
TDD	cheaper	synchronisation at link level bit rate needs to be doubled

In both cases synchronisation at network level can be an issue; simpler with FDD
In cellular networks

2. Assignment of Radio Resources

Radio Resource Assignment

Radio Resource Set

It is the set of RUs available to the users in a given area.

Radio Resource Set Capacity

It is the number of RUs that can be assigned to the users in a given area under some QoE constraints.

Hard Capacity: in some cases the maximum number of RUs available is known

Soft Capacity: in some other cases this number has no fixed maximum value

Radio Resource Assignment

Radio Resources can be assigned to users *orthogonally* within a given area.

Two RRs x(t) and y(t) are orthogonal if:

Int [x(t) y(t)] = 0

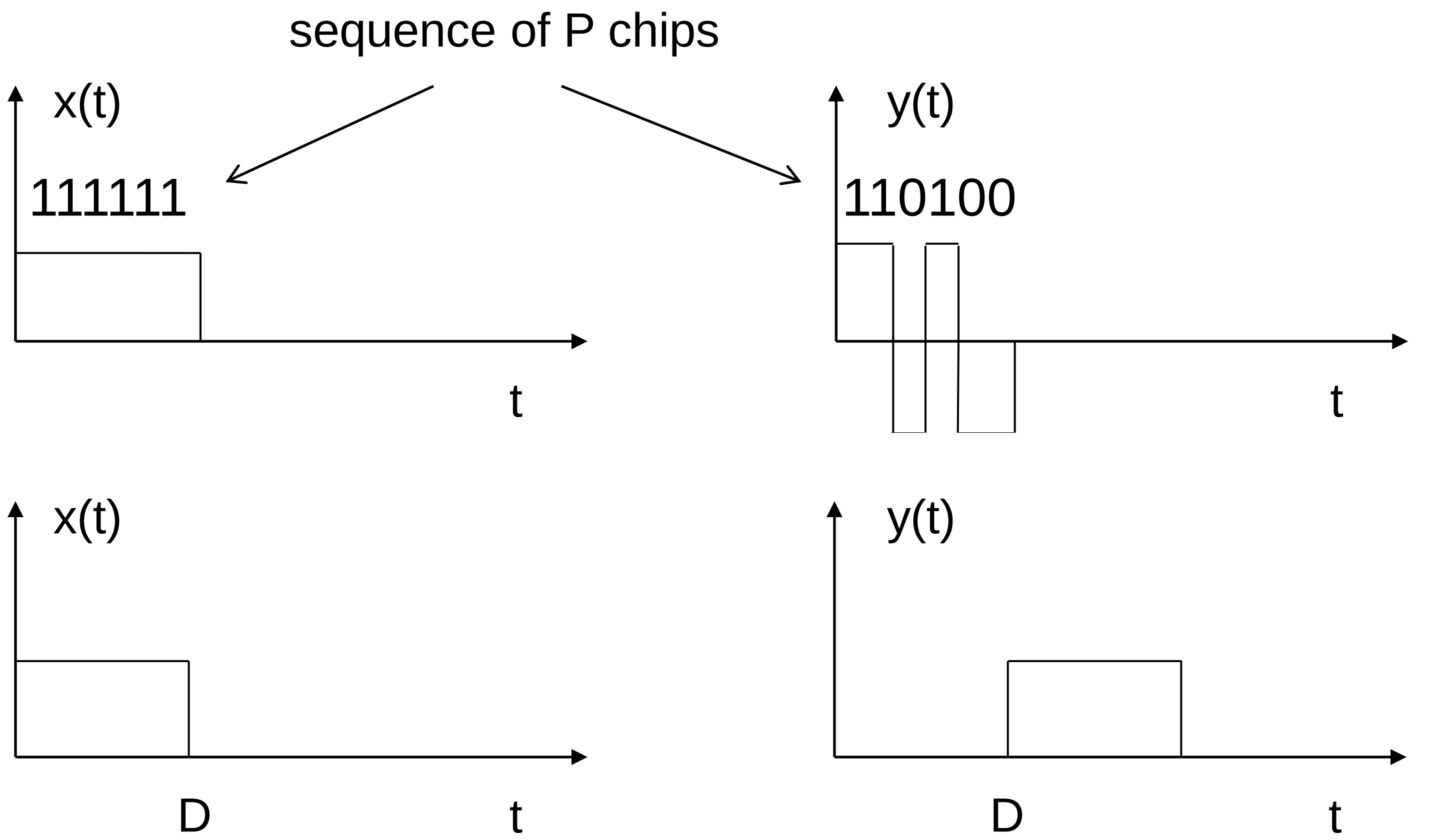
If they are orthogonal, it is possible to avoid interference (somehow).
Otherwise, *collision resolution* or *interference rejection* techniques must be used

2G and 4G networks use orthogonal RUs.
3G is based on almost-orthogonal RUs.

It is foreseen that 5G-NR will use as an option
NOMA: Non Orthogonal Multiple Access.

Note: *Int* means the integral over the entire time axis, with respect to time

Radio Resource Assignment: Orthogonality



CDMA

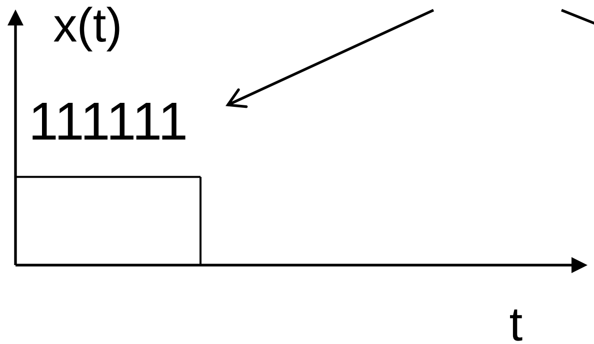
TDMA

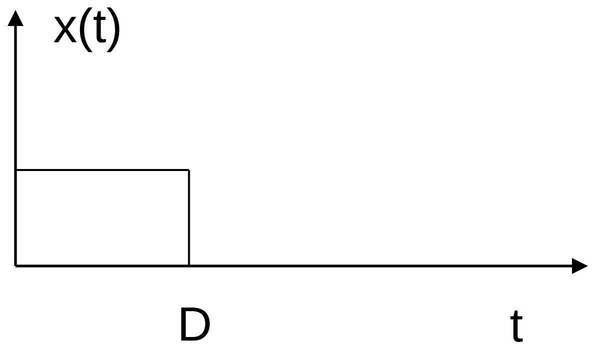
$x(t) = X \cos(2\pi f_1 t)\, \mathrm{rect}(t/T)$ $y(t) = Y \cos(2\pi f_2 t)\, \mathrm{rect}(t/T)$ FDMA

$f_1 = f_2 + k/T$

Radio Resource Assignme

sequence of P chips



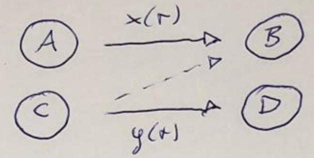


$$x(t) = X \cos(2 \pi f_1 t) \,\mathrm{rect}\,(t/T)$$

$f_1 = f_2$

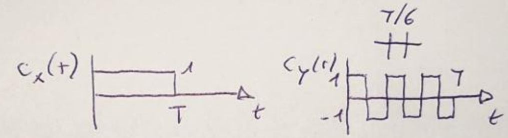
MRN - RRA

ORTHOGONALITY



$$\int_{-\infty}^{+\infty} x(t)\, y(t)\, dt = 0$$

CDMA



$$\int_{-\infty}^{+\infty} c_x(t)\, c_y(t)\, dt =$$

$$\int_0^T 1 \; c_y(t)\, dt =$$

$$\int_0^{T/6} 1\, dt + \int_{T/6}^{2T/6} (-1)\, dt + \dots =$$

$$T/6 - T/6 + T/6 - \dots = 0$$

$x(t) = x_0(t) \cdot c_x(t)$ $\quad x_0(t) = X_0$ in $[0,T[$

$y(t) = y_0(t) \cdot c_y(t)$ $\quad y_0(t) = Y_0$ in $[0,T[$

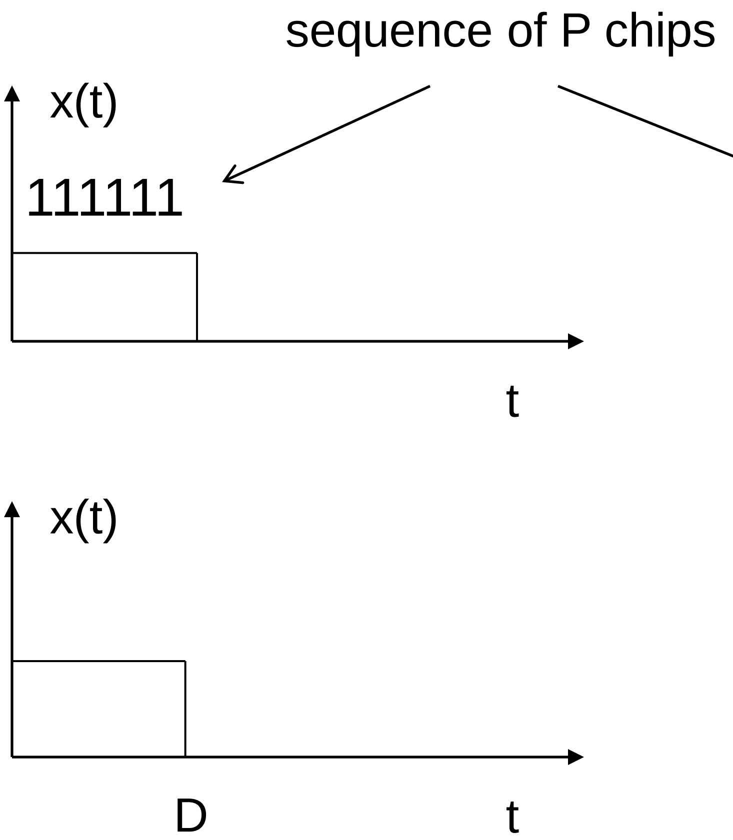
$$S_B(t) = \int_0^T x(t)\, y(t)\, dt =$$

$$= \int_0^T X_0\, c_x(t)\, Y_0\, c_y(t)\, dt =$$

$$= X_0 Y_0 \underbrace{\int_0^T c_x(t)\, c_y(t)\, dt}_{0} = 0$$

$x(t)$ and $y(t)$ are orthogonal

Radio Resource Assignme



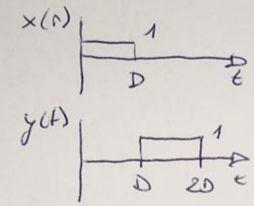
$x(t) = X \cos(2\pi f_1 t)\ \mathrm{rect}(t/T)$

$f_1 = f_2$

MRN – RRA

ORTHOGONALITY /2

TDMA



$$s_B(\tau) = \int_0^{2D} x(\tau)\, y(\tau)\, d\tau =$$

$$= \int_0^{D} 1 \cdot 0 \, d\tau + \int_D^{2D} 0 \cdot 1 \, d\tau = 0$$

FDMA

$x(\tau) = X \cos(2\pi f_1 t)$ in $[-T/2, T/2[$

$y(\tau) = Y \cos(2\pi f_2 t)$ in $[-T/2, T/2[$

$$s_B(\tau) = \int_{-T/2}^{T/2} x(\tau)\, y(\tau)\, d\tau =$$

$$= \int_{-T/2}^{T/2} X \cos(2\pi f_1 t)\, Y \cos(2\pi f_2 t)\, d\tau =$$

$$= XY \int_{-T/2}^{T/2} \frac{1}{2} \left[\cos(2\pi (f_1+f_2) t) + \cos(2\pi \underbrace{(f_1 - f_2)}_{K/T} t) \right] d\tau$$

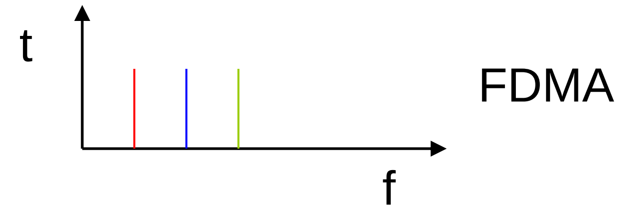
$$= XY \underbrace{[\sim 0]}_{\text{integral of cosine over many periods}} + XY \underbrace{[0]}_{\text{integral of cosine over } 2\pi K} = 0$$

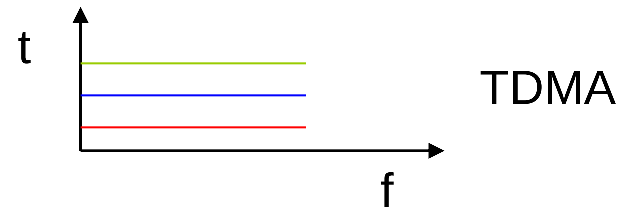
Radio Resource Assignment

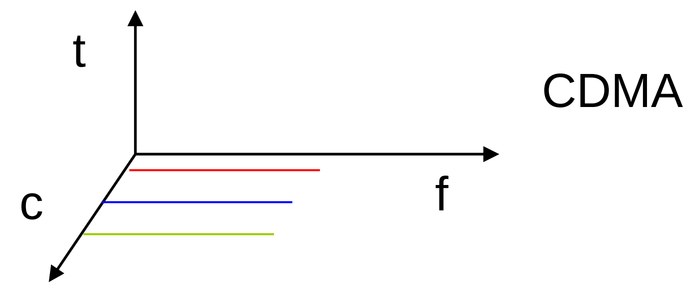
Orthogonality can be reached via:

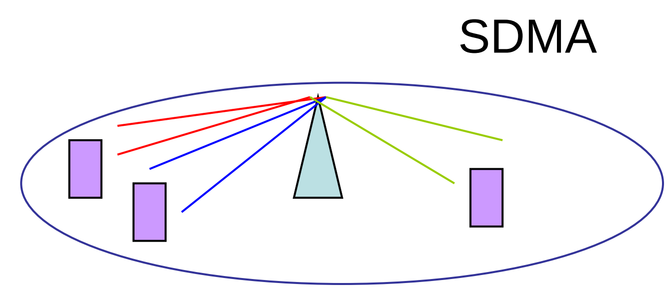
- Frequency (FDMA),
- Time (TDMA),
- Code (CDMA),
- Space Division (SDMA), or

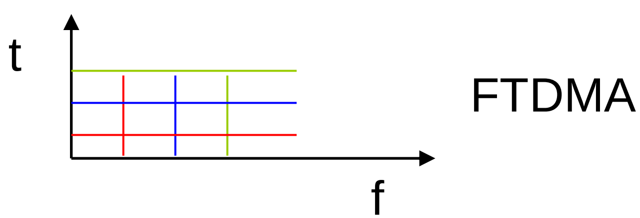
a mixture of them (e.g. FTDMA)











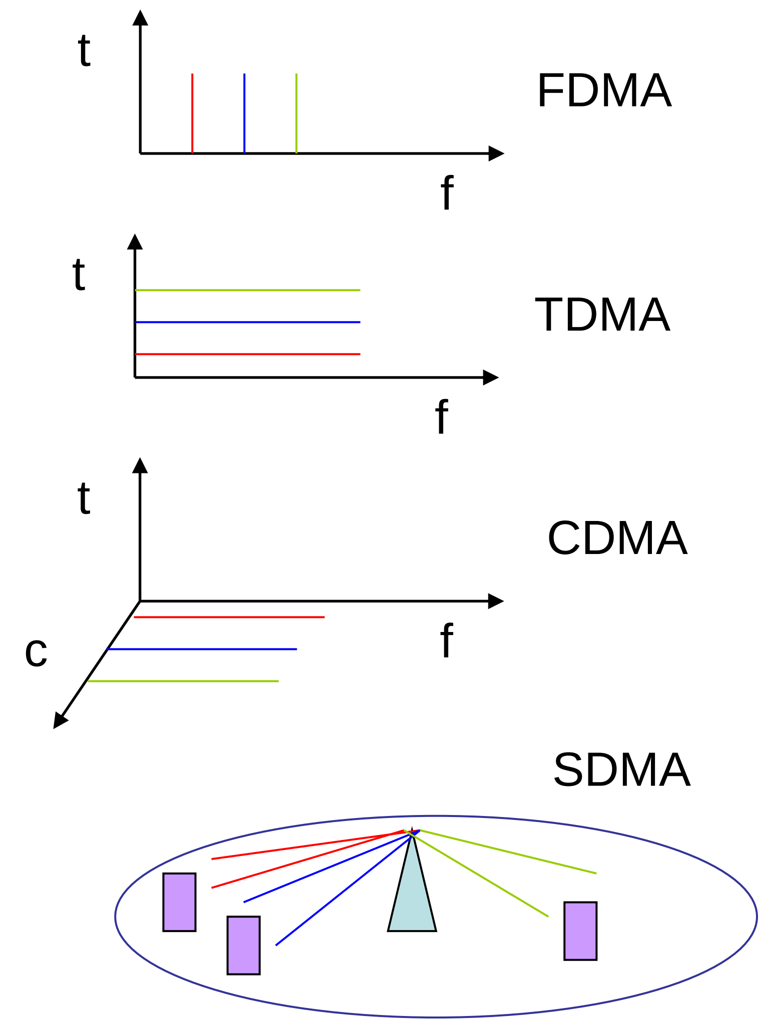
Radio Resource Assignment

FDMA: Bc = Bt / P
P is the number of frequency channels

TDMA: Rbu = Rb / P
P is the number of slots/frame

CDMA: Rs = Rc / P
P is the number of chips/symbol

Bc	channel bandwidth
Bt	total bandwidth shared
Rb	bit rate
Rbu	user bit rate
Rs	symbol rate
Rc	chip rate



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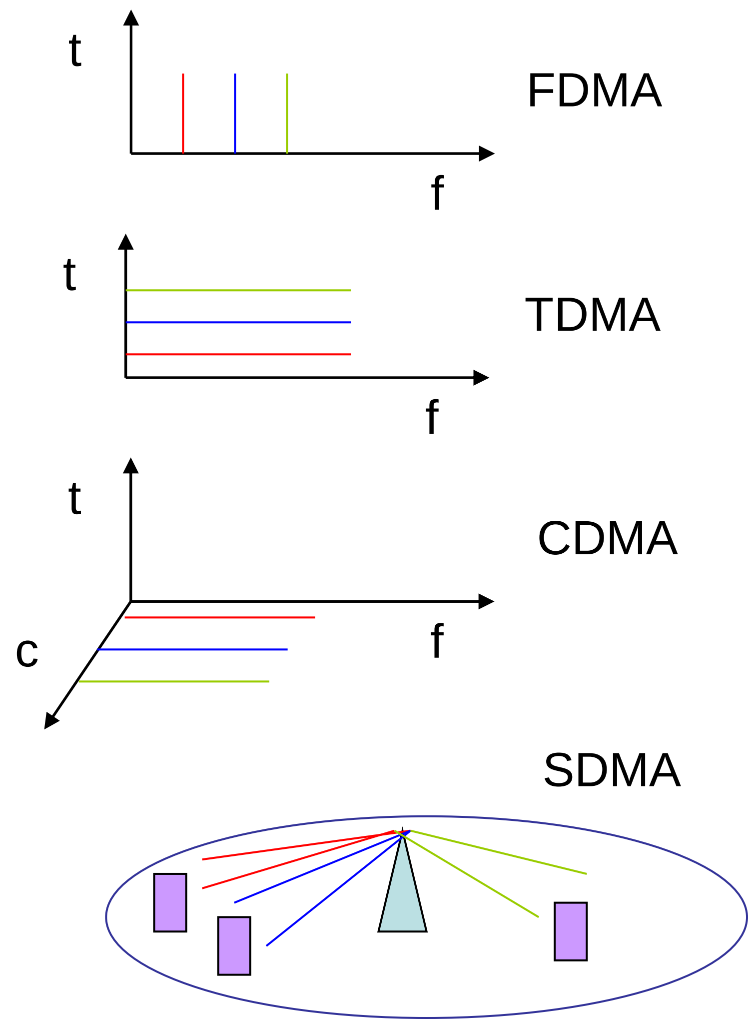
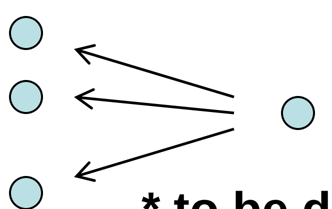


Radio Resource Assignment

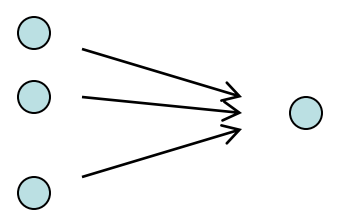
MA Technique	Access Duty Cycle: fraction of time the transmitter is on.	
FDMA	$\eta_a = 1$	
TDMA	$\eta_a = 1/P$	P = number of slots/frame
CDMA	$\eta_a = 1$	
SDMA	$\eta_a = 1$	

Radio Resource Assignment

MA Technique	Advantages	Disadvantages
FDMA	simple	# of receivers in MPtoP non linear effects in PtoMP
TDMA	cheaper in MPtoP slots for measurements*	synchronisation higher bit rate
CDMA	inherent encryption time resolution*	code orthogonality larger bandwidth
SDMA	protection against interference space is not limited resource	technological complexity



PtoMP



MPtoP

* to be discussed further later

Radio Resource Assignment

(Centralised) Fixed RR Assignment

A centralised network entity assigns RUs to nodes based on pre-defined schemes

(Centralised) Dynamic RR Assignment

A centralised network entity assigns RUs to nodes based on dynamic schemes [scheduling]

(Distributed) Controlled RR Assignment

Nodes self-assign RUs based on concerted policies

(Distributed) Random RR Assignment

Nodes self-assign RUs without concerted policies

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Exercise RRA#1

Consider the transmission from a base station towards a mobile user.
Assume a binary transmission (symbol rate = bit rate)
Assume the system can use an overall band of width Bt [MHz].
Assume a frame has duration Tf [ms].
Assume signals have bit/chip rate [Mb/s or Mchip/s] equal to the channel bandwidth.
Assume the system has to assign one RU per user.

1. **With FDMA, the overall band is split into P bands, each of width Bc = Bt / P.**
2. **With TDMA, the frame is split into P slots, each of duration D = Tf / P.**
3. **With CDMA, chips have duration equal to a bit time divided by P (P chips / bit).**
4. **With SDMA, each user is assigned a separate radiation beam.**

Assuming User Throughput U is a fixed fraction x of the user bit rate, compare U in the four cases.

1. 2. 3. U = x * Bt / P
4. U = x * Bt

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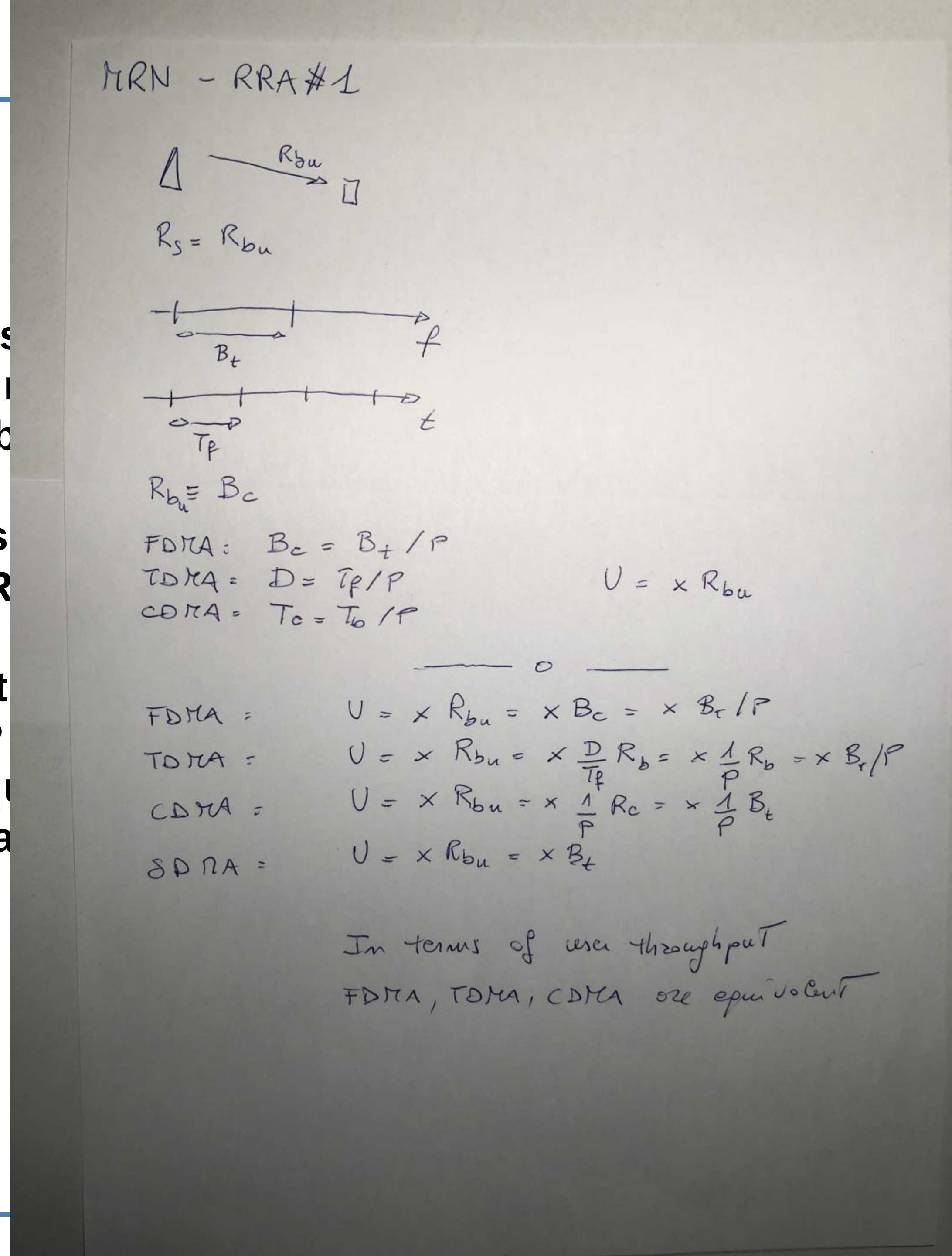

RRA

Mobile Radio Networks

Radio Resource Assignment: Fundamentals

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