DC2

Radio Systems
Description of the Course

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A.Y. 2016-17
Credits: 6

Outline

1. Mobile Radio Networks
2. Reference Standards
3. Background on Radio Networks
4. The Course

1. Mobile Radio Networks

Radio Networks (RN)

RN = *Networks of Communication Networks* made of *Nodes* connected through *Radio* links.

Why *Radio, not *Wireless*?**

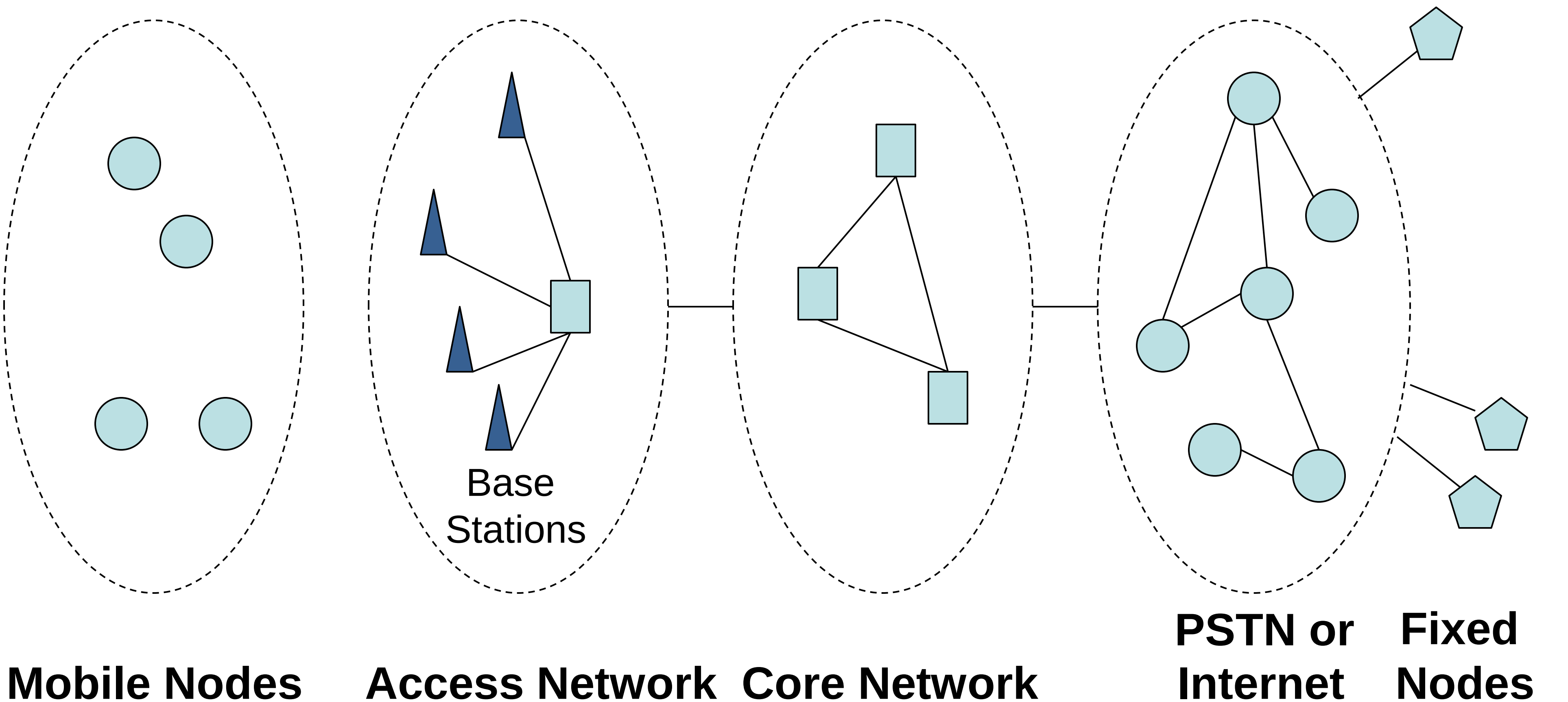
***Wireless* just says “with no wires”, neglecting the essence of the radio channel.**

***Radio* reflects the relevance of the transmission medium on the network ability to exchange data.
The word stresses the implications of the physical on the digital world.**

** Etymology of Radio: Radius [lat] = ray of light*

Mobile Radio Networks (MRN)

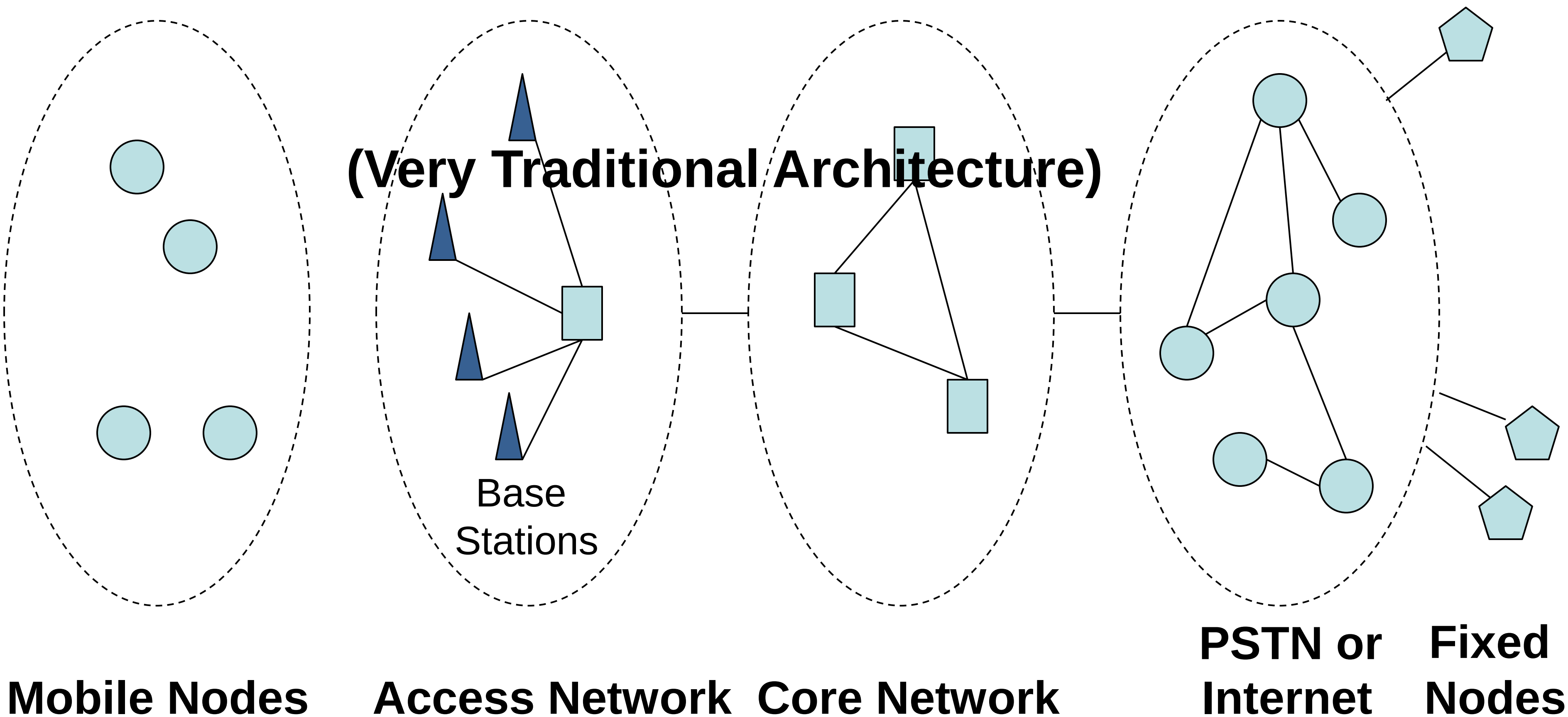
Radio Networks ensuring node *Mobility*.



Mobile Radio Networks (MRN)

Radio Networks ensuring node *Mobility*.

(Very Traditional Architecture)



Mobile Radio Networks

How are mobile radio networks evolving since the dawn of mobile radio communications?

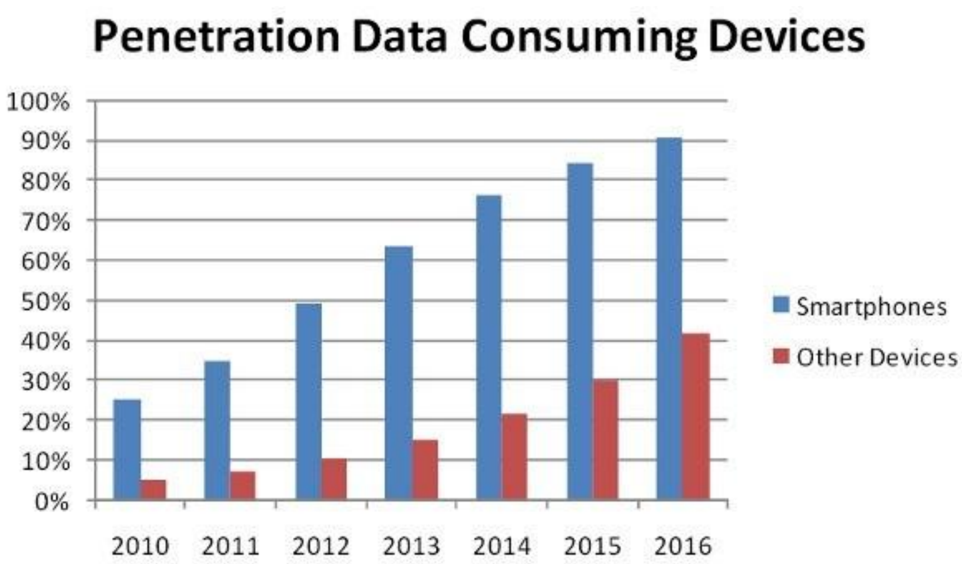
1G, 2G, 3G, 4G, 5G ...

1980  2015

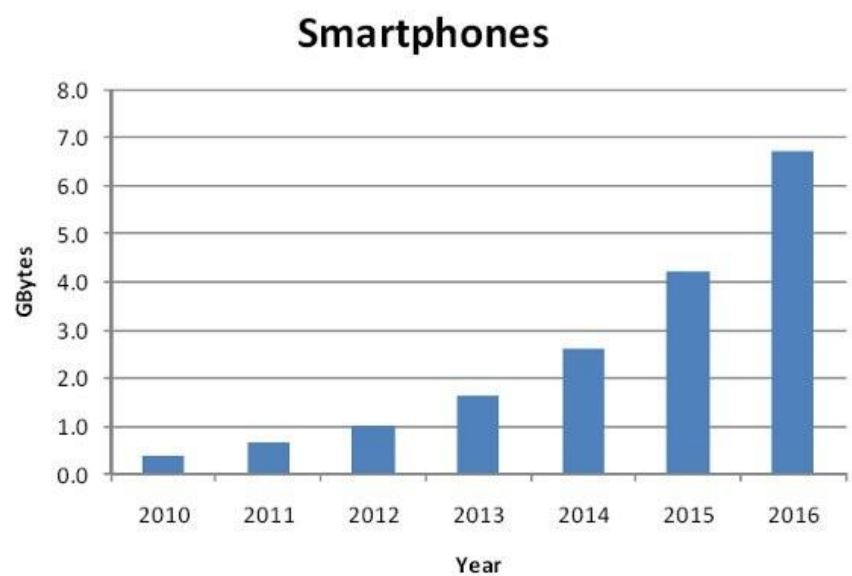
Smaller sizes
From voice to data

Mobile Radio Networks

Mobile Radio Networks and Data Traffic



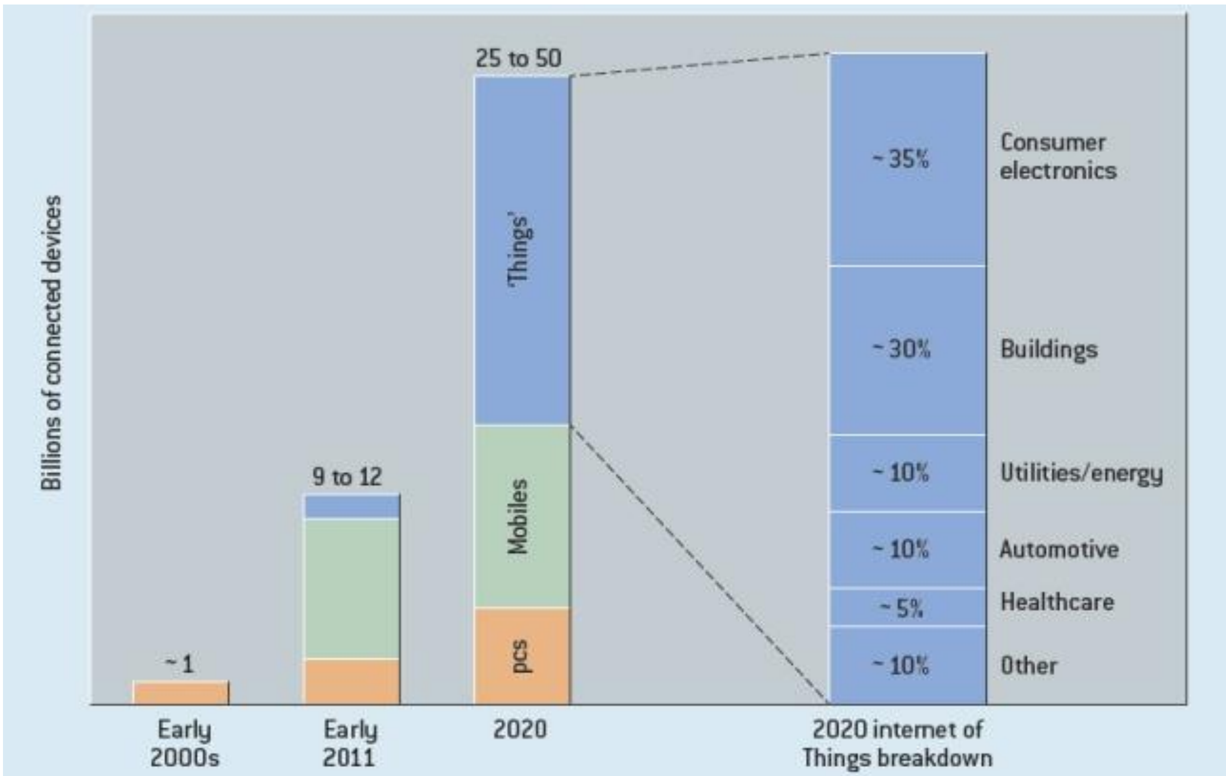
Fonte: Research In Motion – Digital Economy Strategy Consultation Submission: Mobile Broadband Capacity Constraints And the Need for Optimization



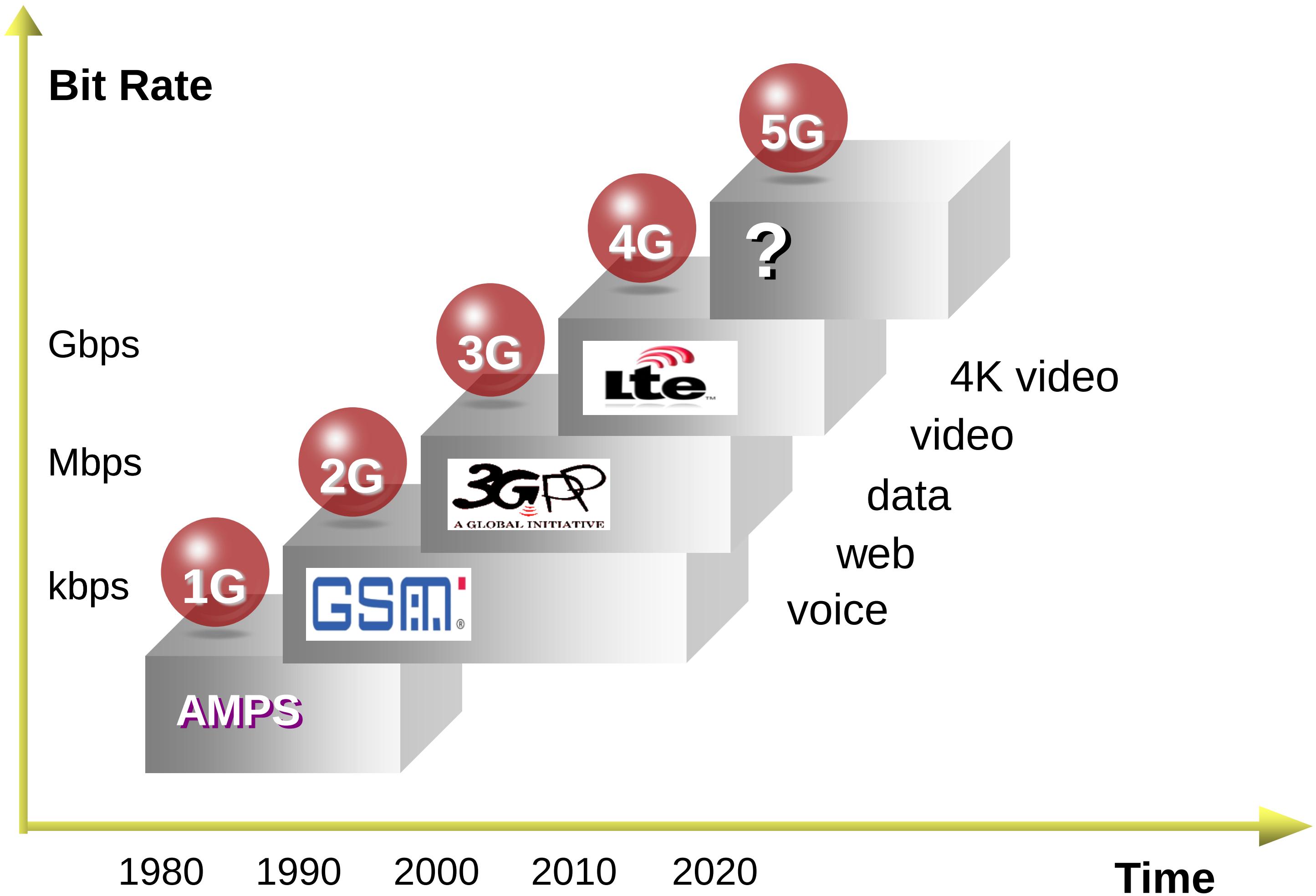
Fonte: Research In Motion – Digital Economy Strategy Consultation Submission: Mobile Broadband Capacity Constraints And the Need for Optimization

Mobile Radio Networks

Mobile Radio Networks: Number and Type of Connected Devices

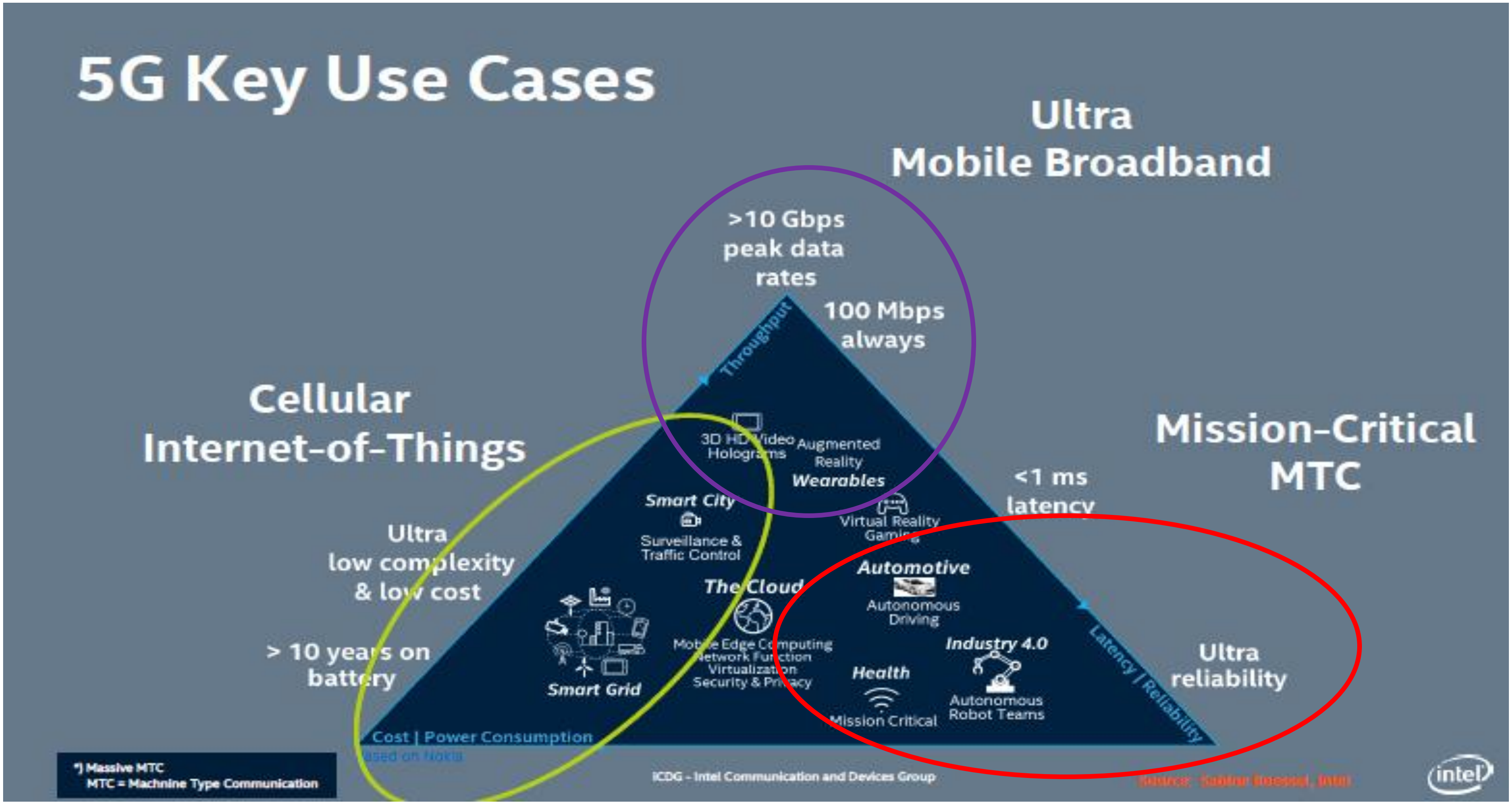


Mobile Radio Networks



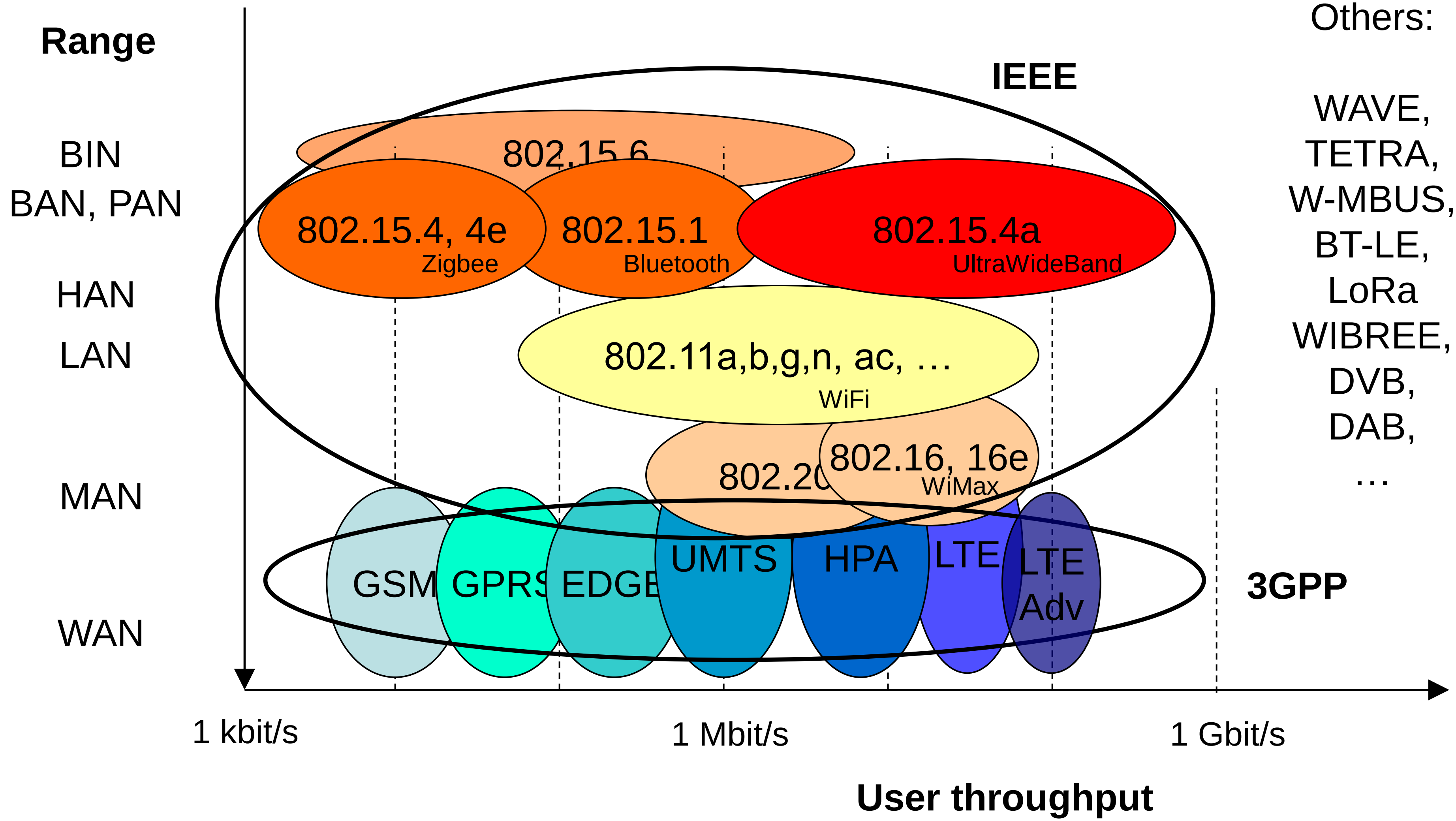
Source: Huawei

Mobile Radio Networks



2. Reference Standards

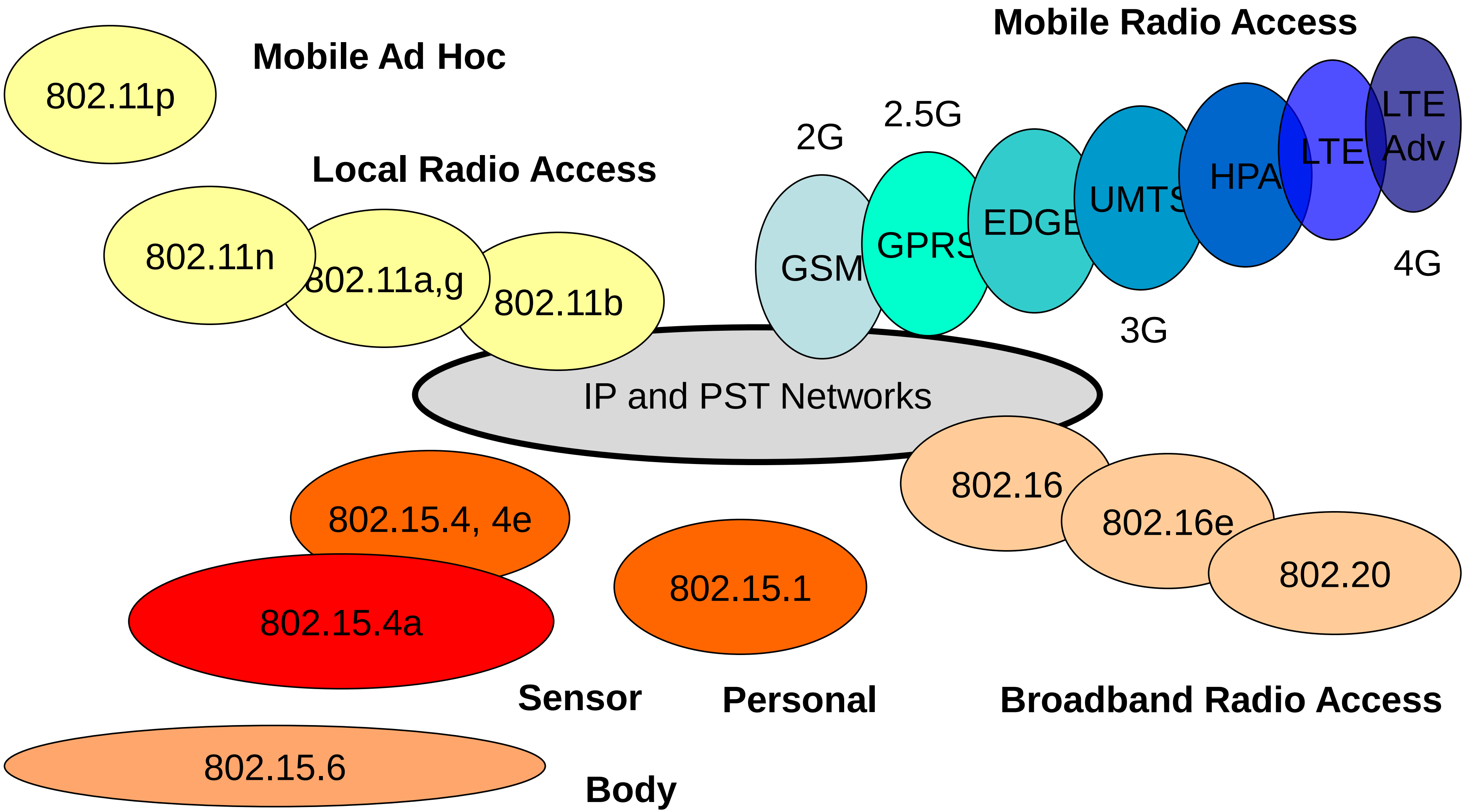
Radio Communication Standards



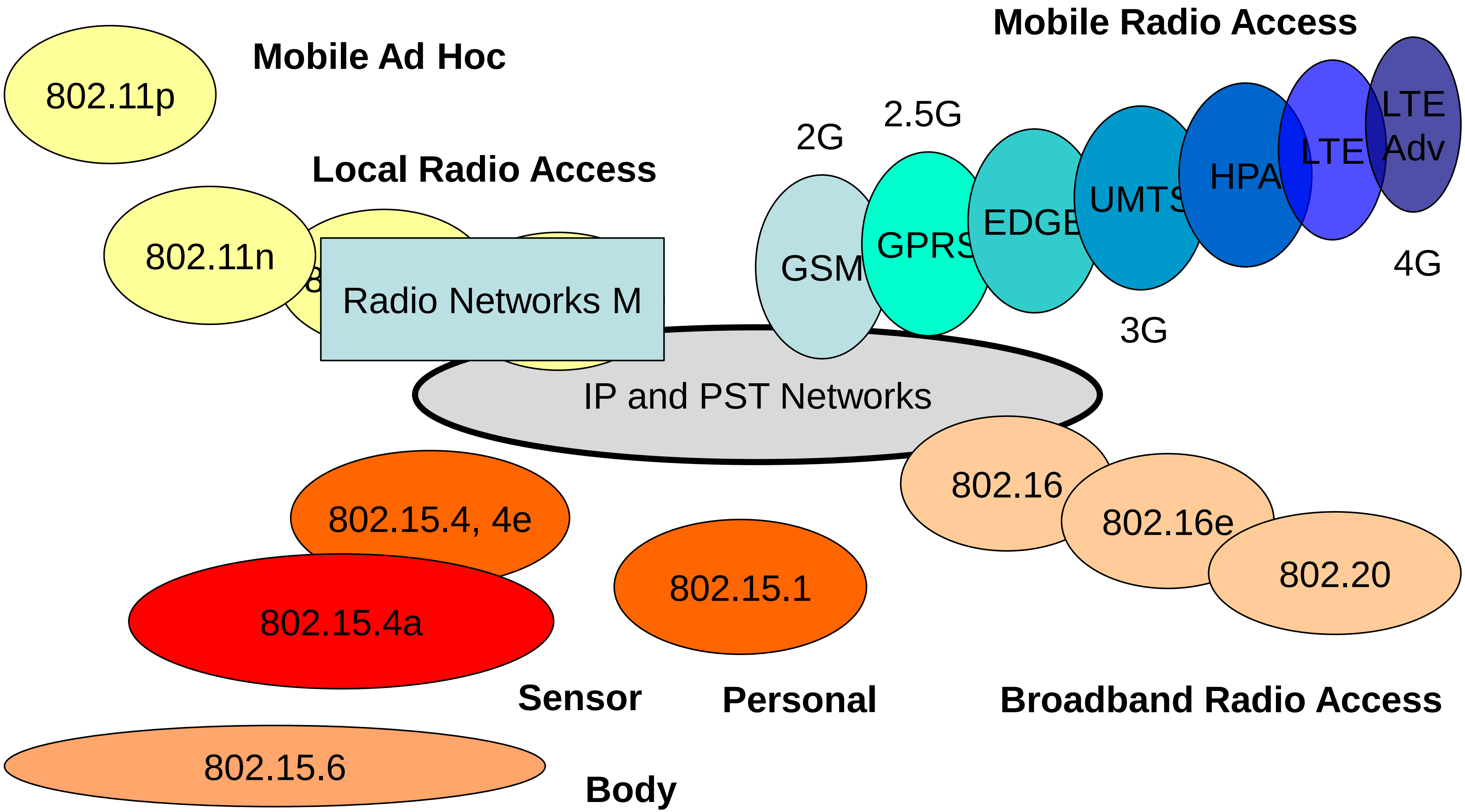
Others:

WAVE,
TETRA,
W-MBUS,
BT-LE,
LoRa
WIBREE,
DVB,
DAB,
…

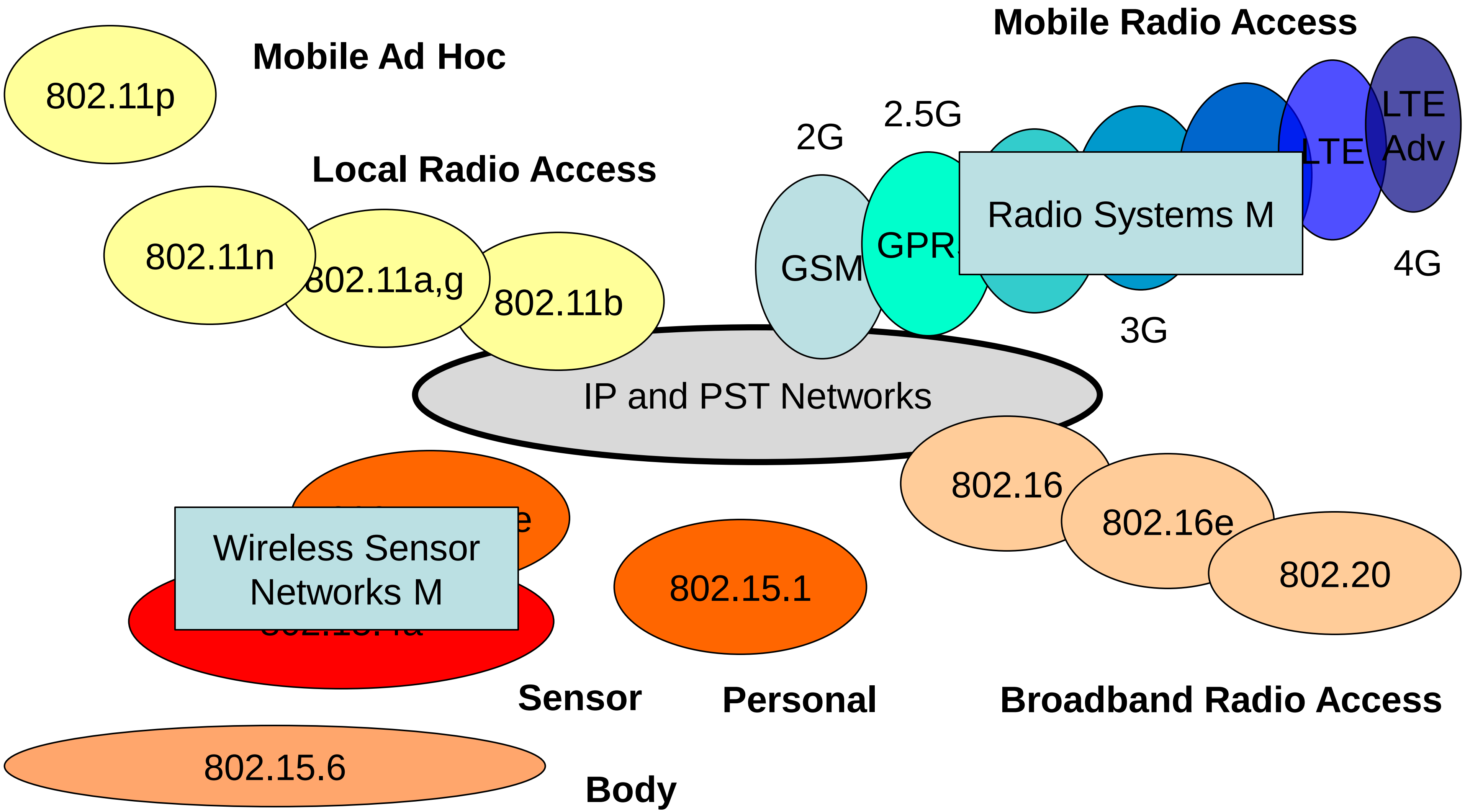
Radio Communication Standards



Radio Communication Standards



Radio Communication Standards



3. Background on RNs

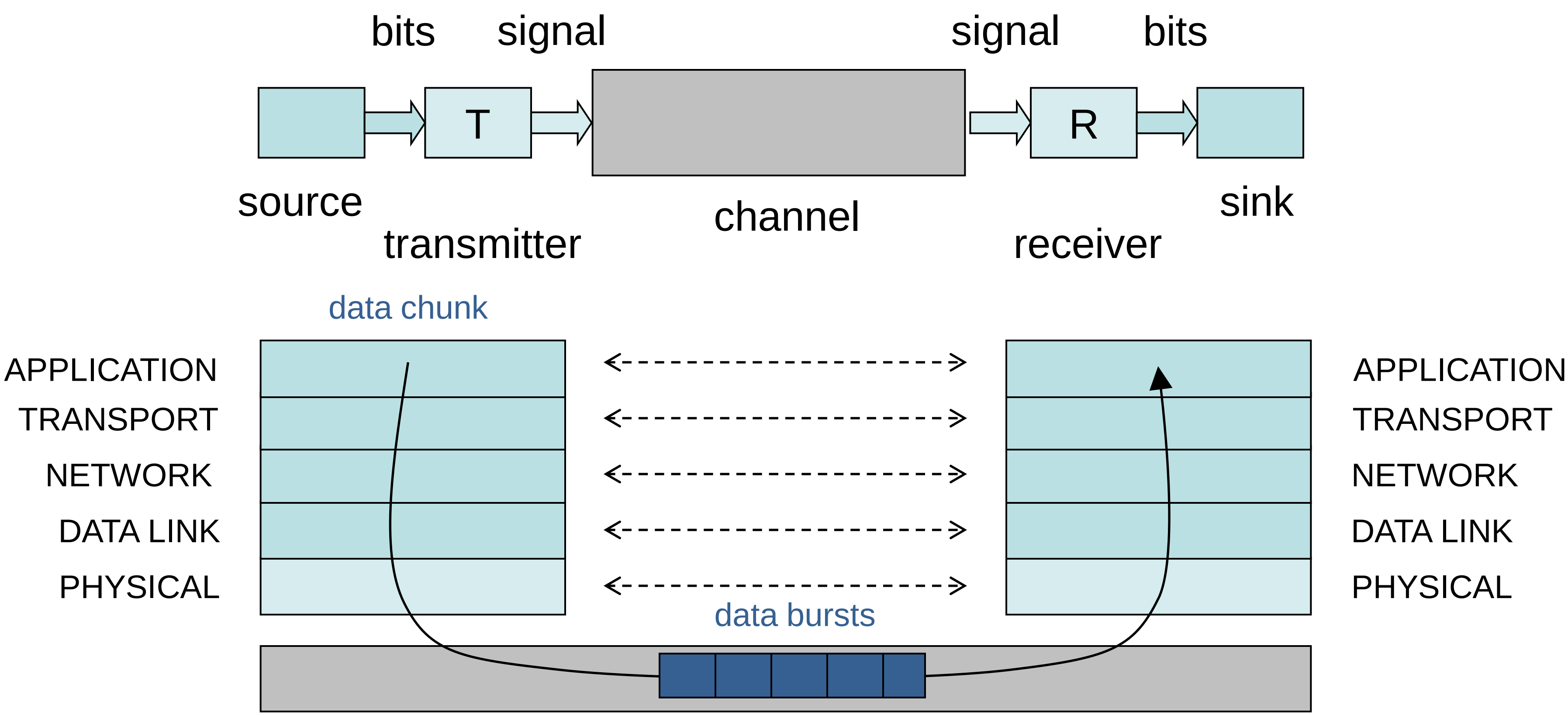
Introduction to RNs

Three fundamental keywords:

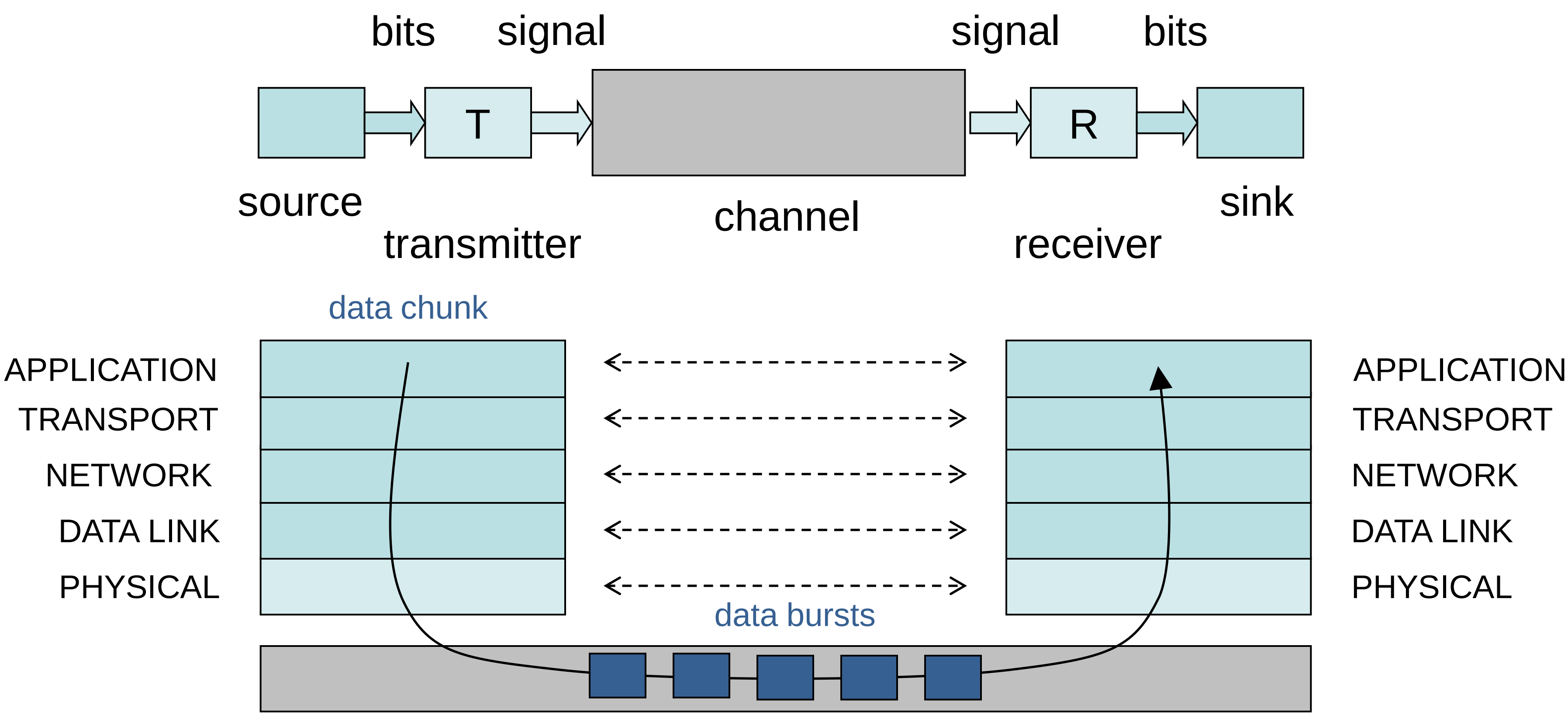
1) Digital Communications
2) Radio
3) Networks

Introduction to RNs: 1) Digital Communications

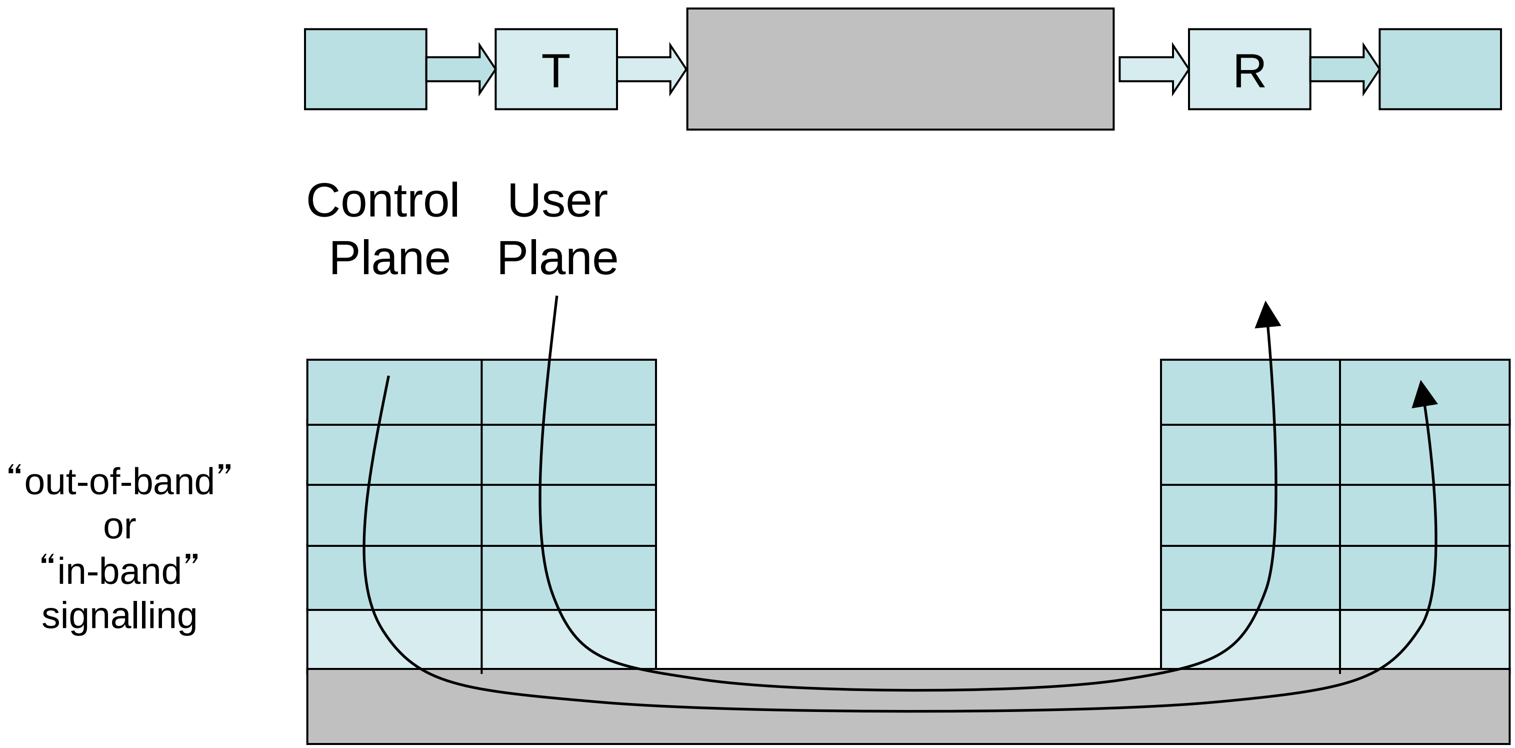
Link Level View



Introduction to RNs: 1) Digital Communications



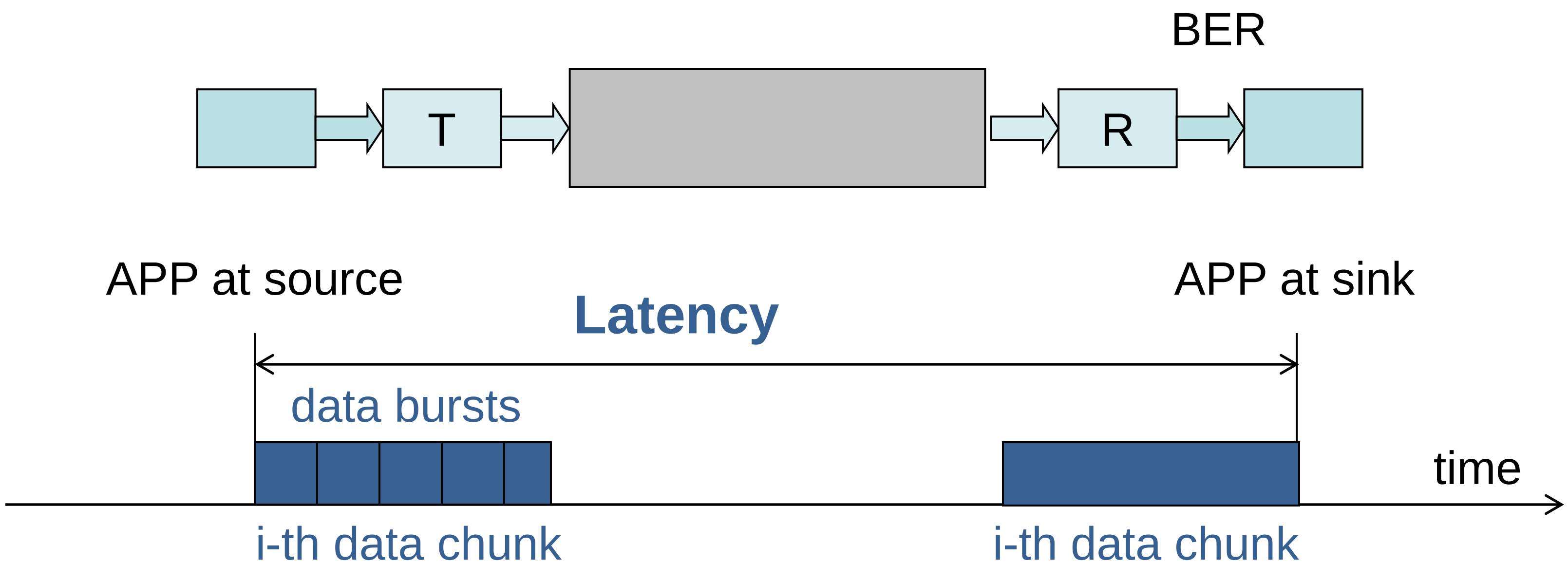
Introduction to RNs: 1) Digital Communications



Introduction to RNs: 1) Digital Communications

1) Digital Communications → A) Application Requirements

User Plane



U = User Throughput = Number of information bits per second received

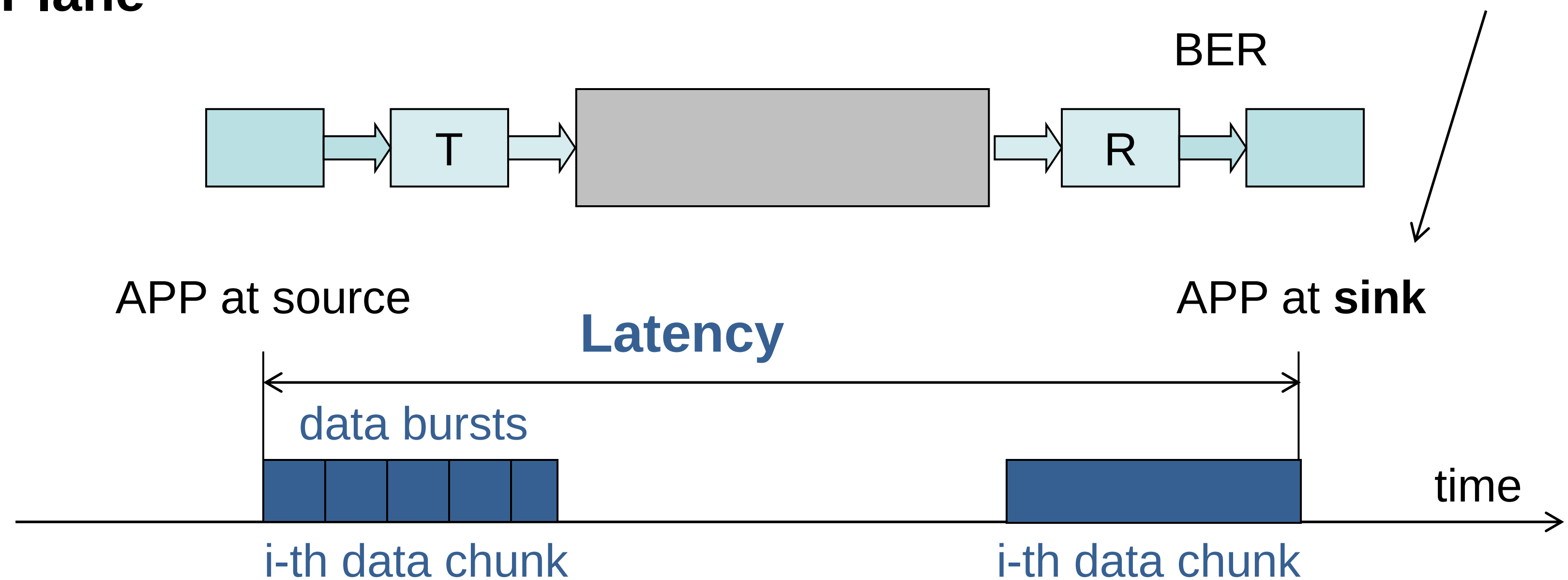
BER = Bit Error Rate = Percentage of erroneous bits

Introduction to RNs: 1) Digital Communications

1) Digital Communications → A) Application Requirements

What & Where?

User Plane



U = User Throughput = Number of information bits per second received

BER = Bit Error Rate = Percentage of erroneous bits

Introduction to RNs: 1) Digital Communications

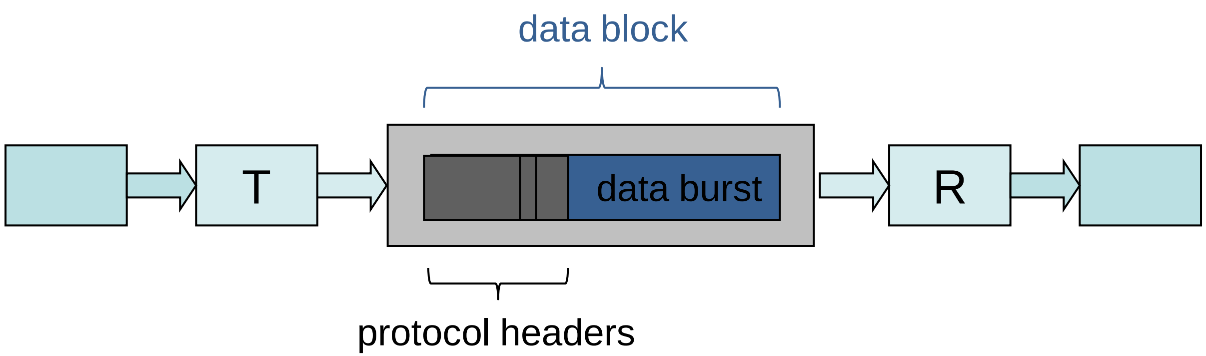
1) Digital Communications → A) Application Requirements

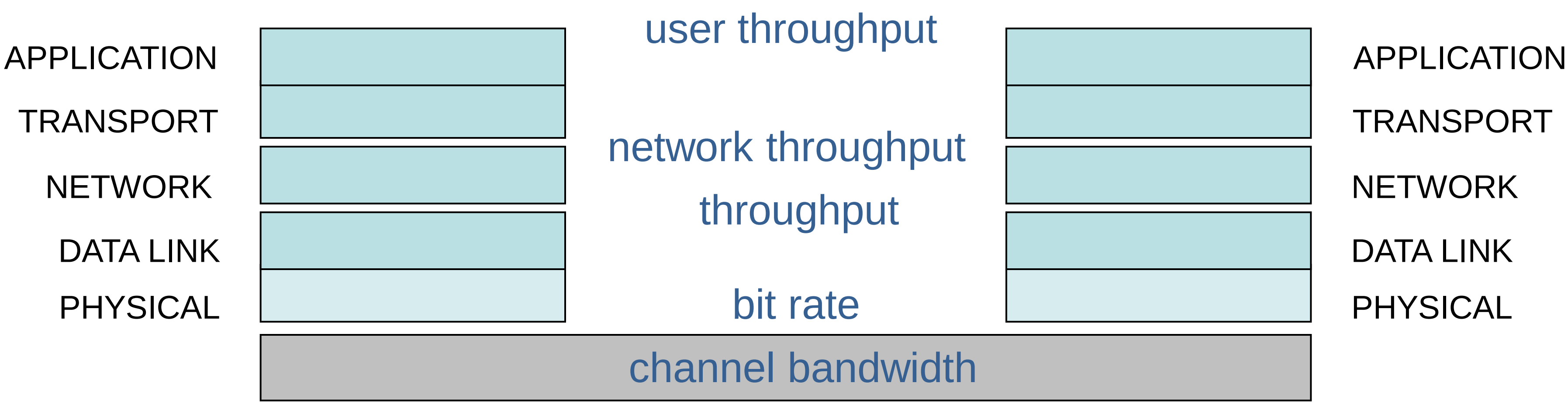
Some examples

	Interactive audio	Interactive video	web browsing	control
user throughput	10 Kbit/s	100 Kbit/s	n. a.	n. a.
latency	300 ms	500 ms	n. a.	1-10 ms
bit errors	0.01	0.001	zero	zero

Introduction to RNs: 1) Digital Communications

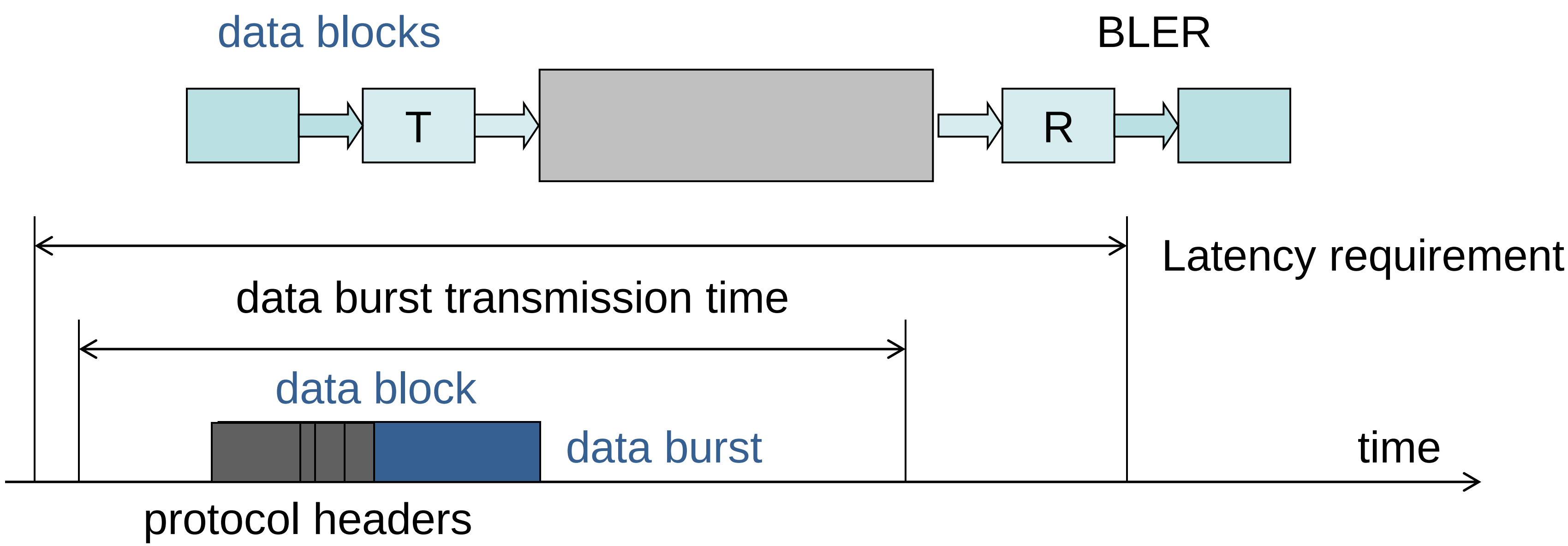
1) Digital Communications → B) Protocol Overhead





Introduction to RNs: 1) Digital Communications

1) Digital Communications → B) Protocol Overhead

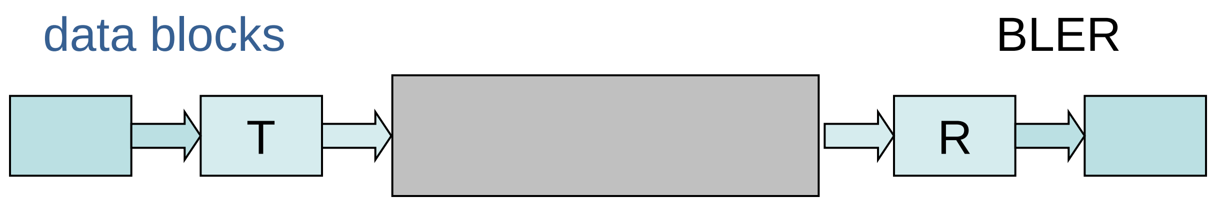


BLER = BLock Error Rate

User Throughput = bit rate * protocol efficiency * (1 – BLER) < bit rate

Introduction to RNs: 1) Digital Communications

1) Digital Communications → B) Protocol Overhead

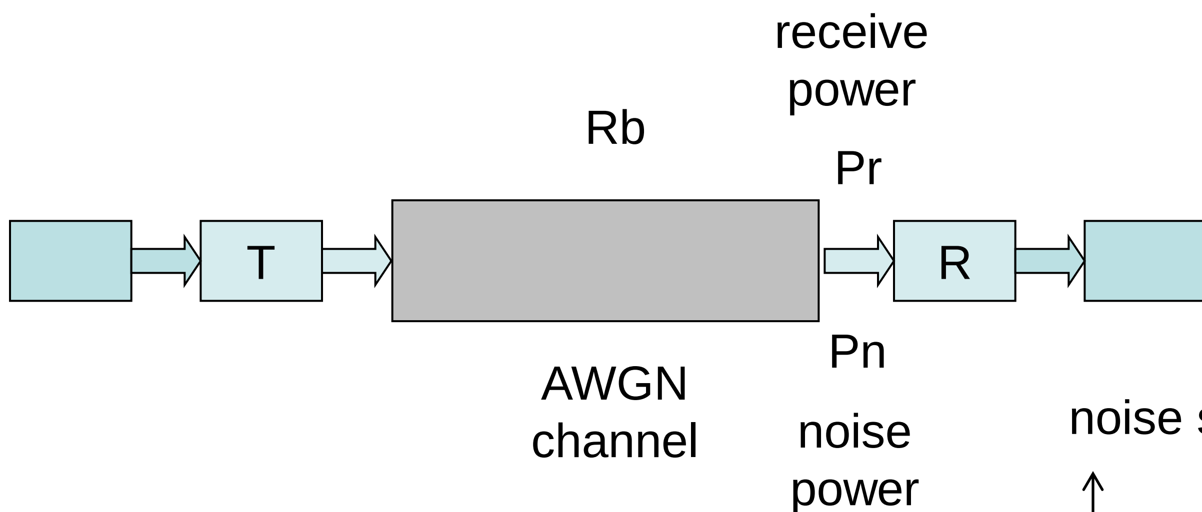


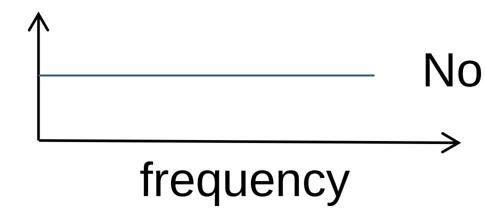
Higher user throughputs require:

Larger bit rates
More efficient protocols
Reliable channels

Introduction to RNs: 1) Digital Communications

1) Digital Communications → C) Channel Constraints





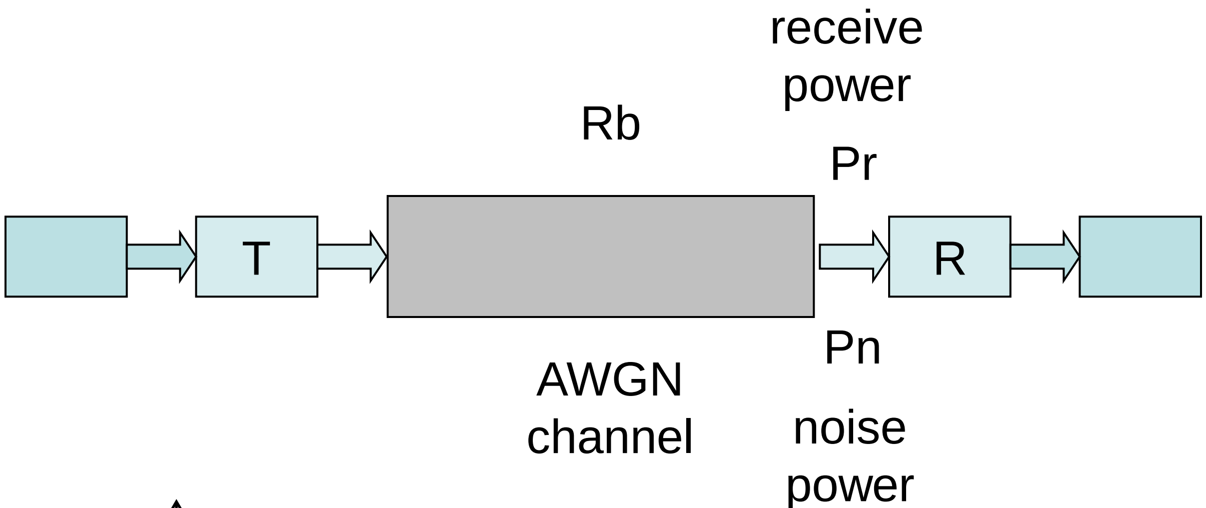
Channel Capacity:
Maximum bit rate that can be transmitted
over the AWGN channel with Bit Error Rate (BER) zero.

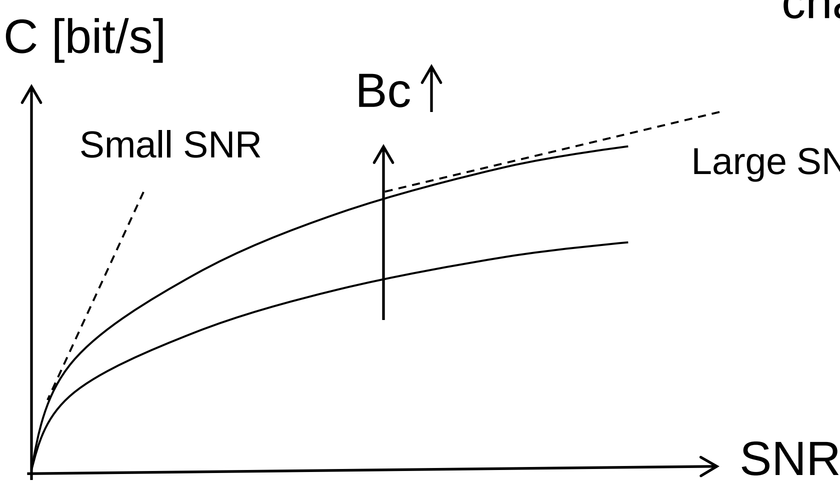
$C = Bc * \log_2 [1 + SNR]$ **[Shannon, 1949]**

SNR = average Signal power / Noise power = Pr / Pn **Pn = No * Beq**

Introduction to RNs: 1) Digital Communications

1) Digital Communications → C) Channel Constraints





Introduction to RNs: 1) Digital Communications

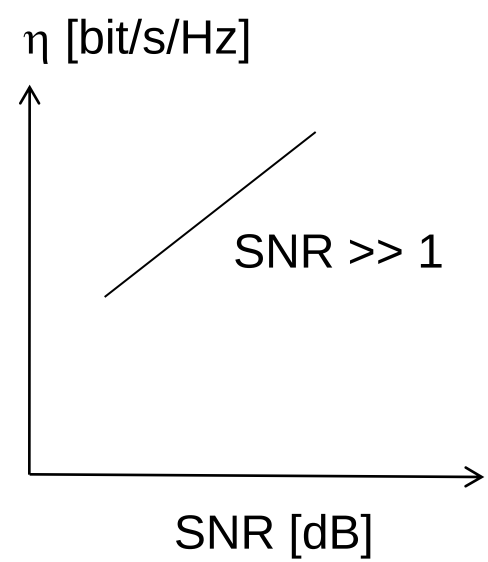
1) Digital Communications → C) Channel Constraints

Larger bit rates require:

Larger bandwidth
Higher received powers (reduced link distances)
Smaller noise power

Introduction to RNs: 1) Digital Communications

1) Digital Communications → D) Transmission Techniques



Link Spectrum Efficiency:

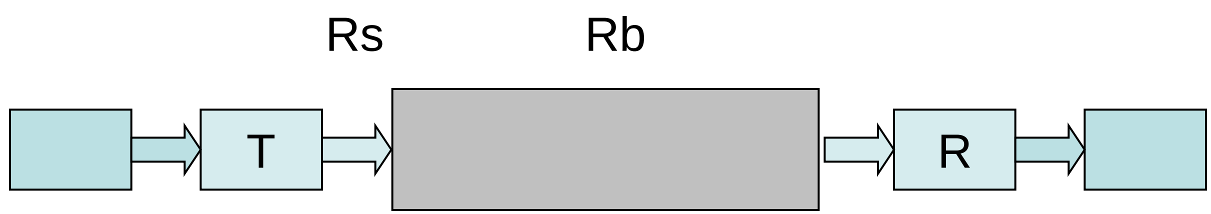
Bit rate transmitted per spectrum unit

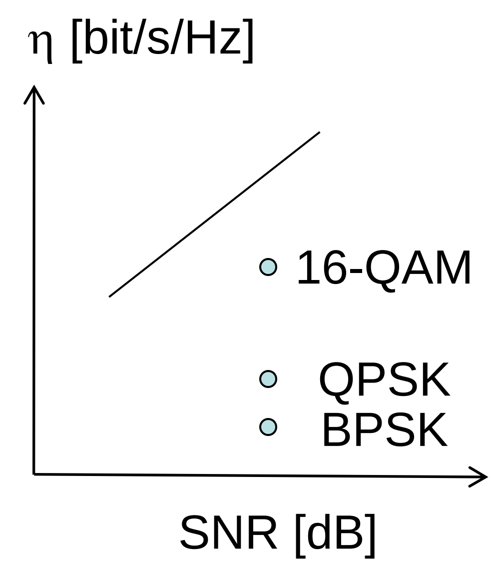
η = Rb / Bc [bit/s/Hz]

$$\eta < C / Bc = \log_2 [\ 1 + SNR\ ] = k * 10\log_{10} [\ 1 + SNR\ ]$$

Introduction to RNs: 1) Digital Communications

1) Digital Communications → D) Transmission Techniques





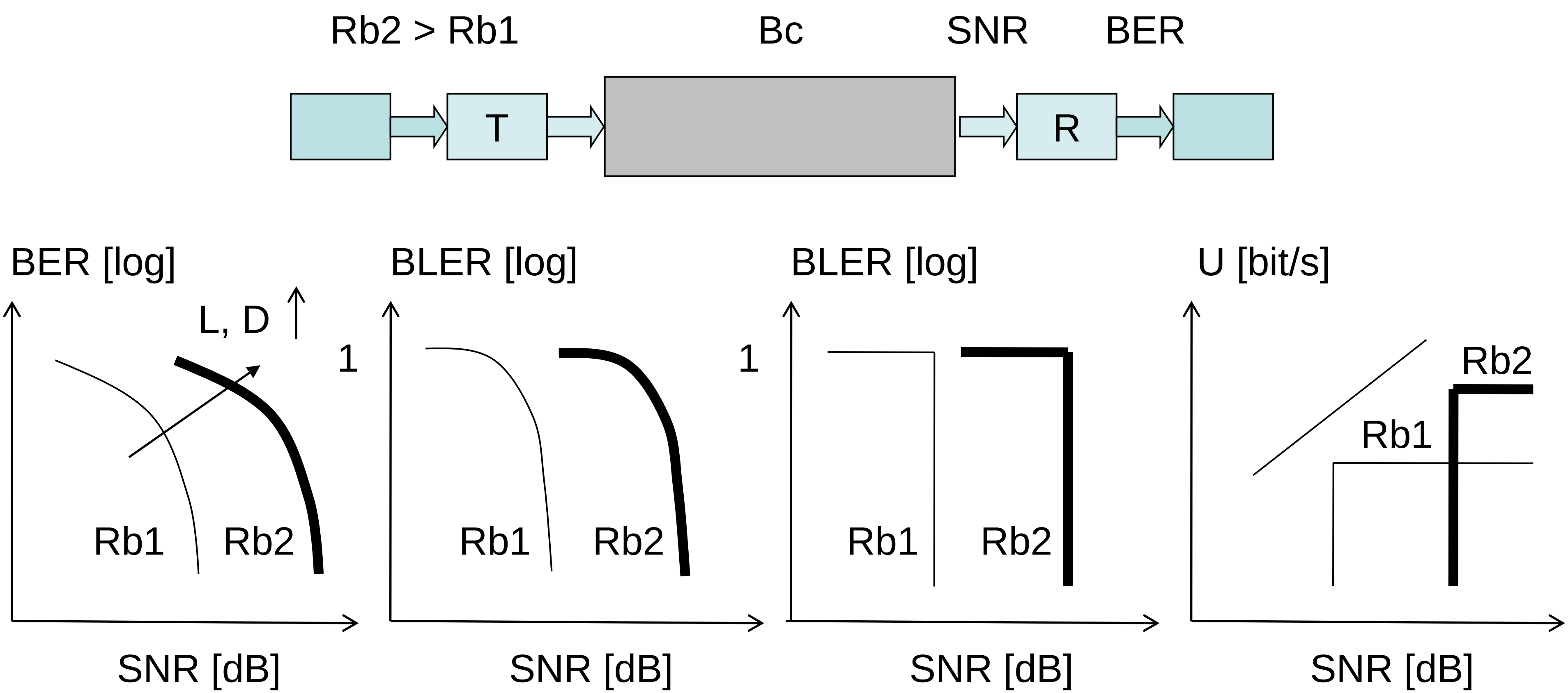
Multi-Level/Dimensional Modulation Formats:
bits mapped onto multi-level symbols (L levels),
multi-dimensional signals (D dimensions)

$Bc > Rs = Rb / D * \log_2 (L)$ **[Nyquist, 1928]**

$\eta < D * \log_2 (L)$

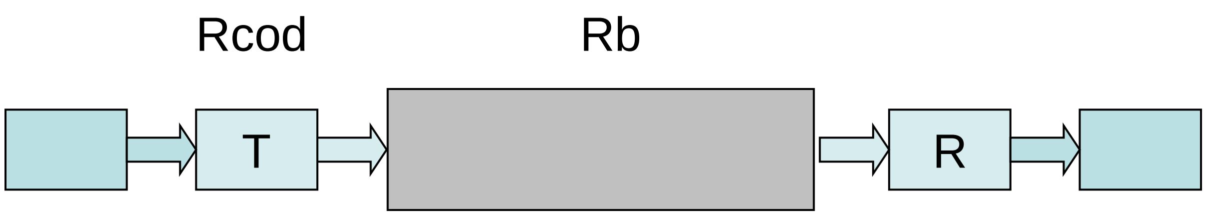
Introduction to RNs: 1) Digital Communications

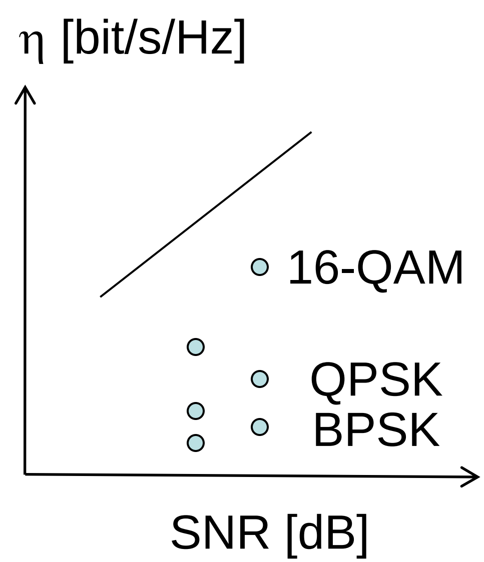
1) Digital Communications → D) Transmission Techniques



Introduction to RNs: 1) Digital Communications

1) Digital Communications → D) Transmission Techniques





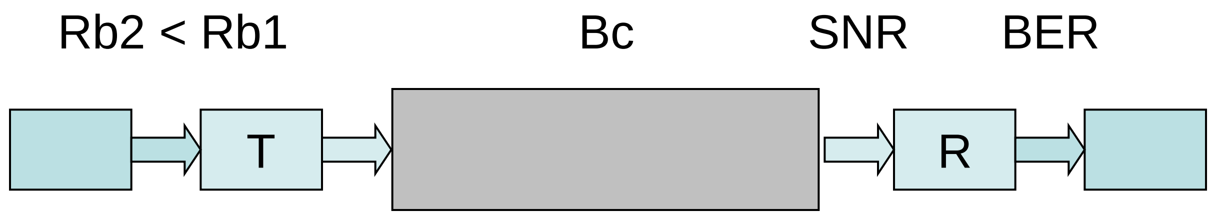
Error Correction Codes:
Redundancy bits added to protect information bits
R is the bit rate before redundancy is added

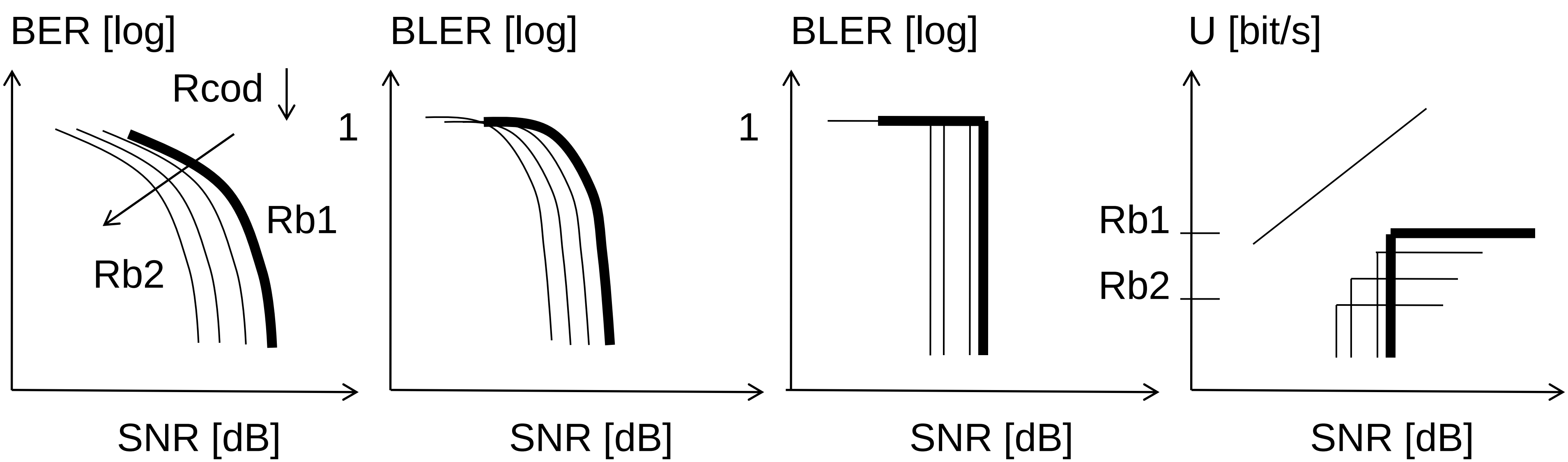
$Rcod = R / Rb < 1$ **Coding Rate**

$\eta < D * \log_2(L) * Rcod$

Introduction to RNs: 1) Digital Communications

1) Digital Communications → D) Transmission Techniques





Introduction to RNs: 1) Digital Communications

1) Digital Communications → D) Transmission Techniques

Larger bit rates also require:

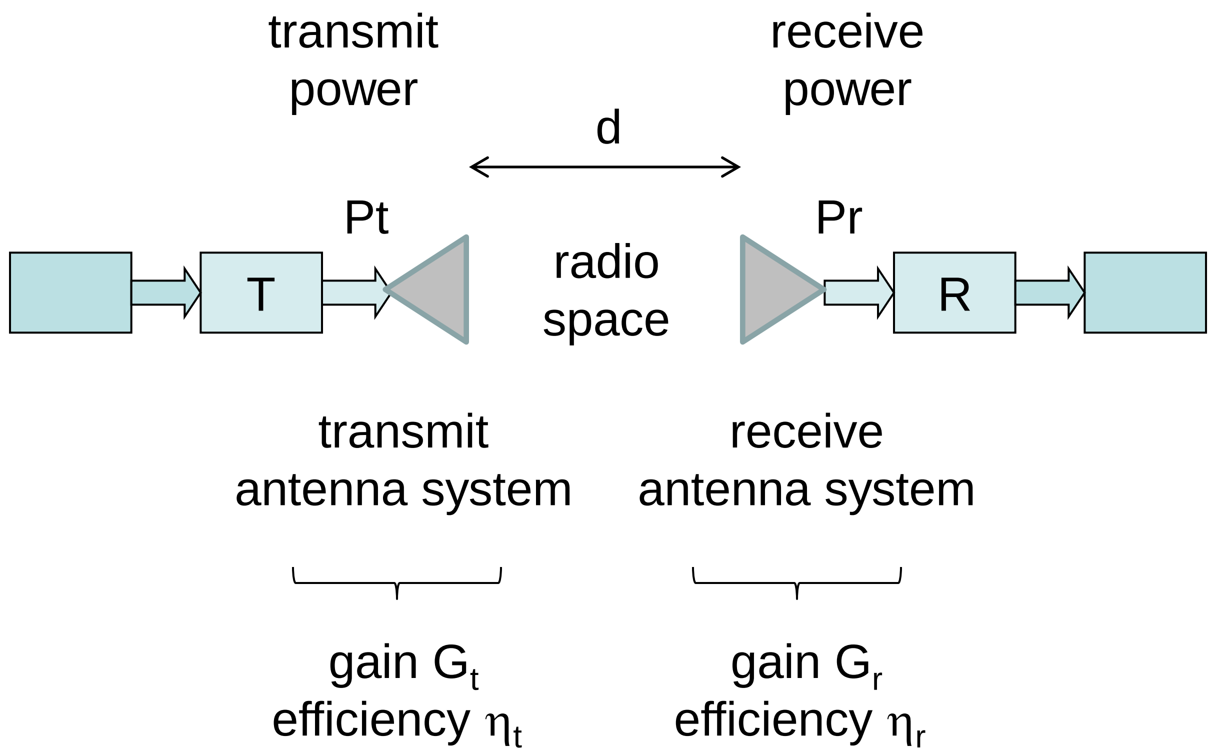
Efficient (i.e. complex) transmission techniques
Adaptation to channel conditions

Introduction to RNs: 1) Digital Communications

Background concepts from RN course:

Digital Transmission in Noise Limited Systems
Link Adaptation
Power Control
FEC, ARQ
Link Spectrum Efficiency

Introduction to RNs: 2) Radio

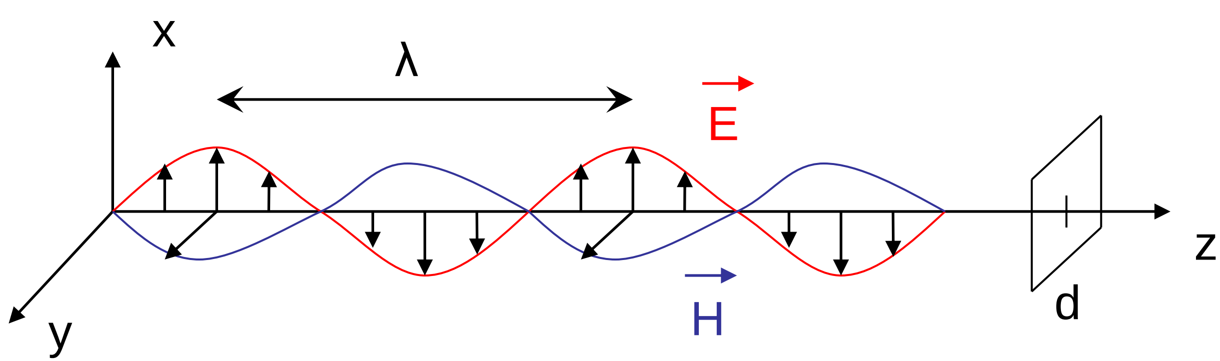


Introduction to RNs: 2) Radio

2) Radio → E) Waves

Radio Communication is*

**the transmission, emission, reception
of signs, signals, writings, images, sounds or information
of whatever nature,
making use of *electromagnetic waves***



*** MIN. SV. EC – DIP. COM. IT. – Piano Naz. di ripartiz. delle frequenze – Glossario**

Introduction to RNs: 2) Radio

2) Radio → E) Waves

Phase speed in clear sky
$c = 3\ 10^{8}$ m/s $= f\ \lambda$

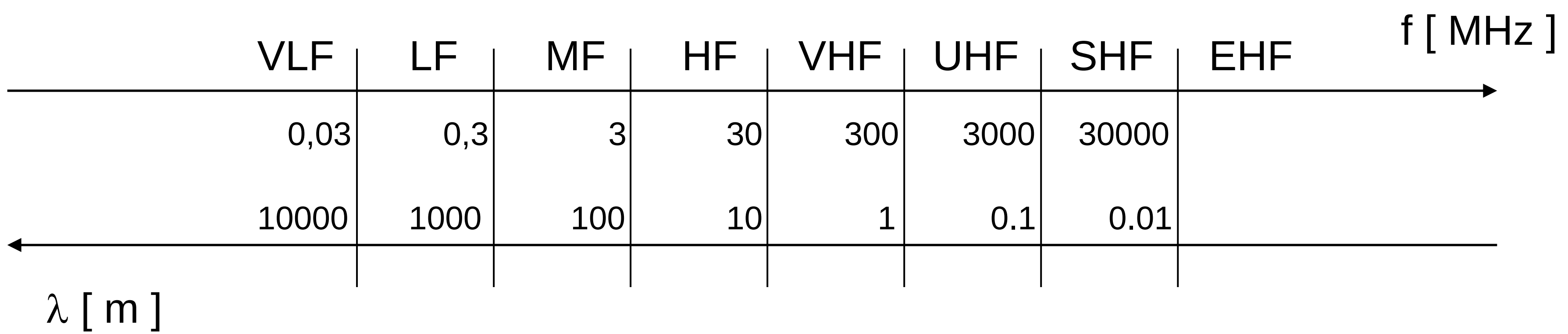
Power density in free space
$p(d) = 0.5\ E_m^{\ 2} / 377$
$= Pt\ Gt\ \eta_t / 4\ \pi\ d^2$ W/m^2

Received power is
$Pr = p(d)\ Gr\ \eta_r / 4\ \pi / \lambda^2$ W

Waves tend to interact with objects of size equal to or larger than λ

Efficient antennas have size close to λ

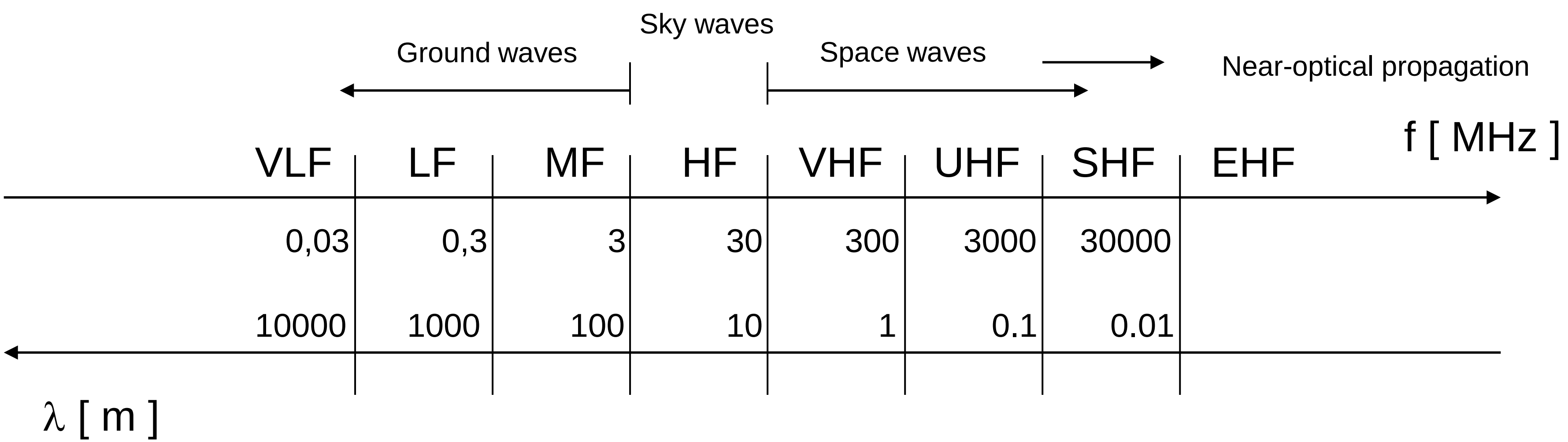
Antenna gains depend on directivity



Introduction to RNs: 2) Radio

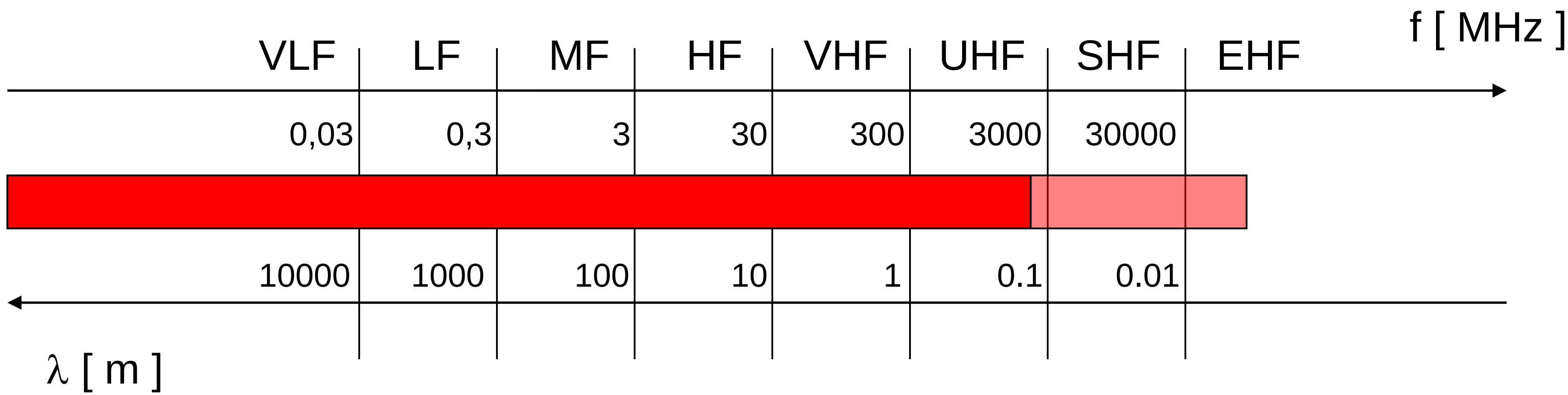
2) Radio → E) Waves

3 > f [MHz]	**λ [m] > 100**	**Ground Waves**
3 < f [MHz] < 30	**10 < λ [m] < 100**	**Sky Waves**
30 < f [MHz]	**10 > λ [m]**	**Space Waves**



Introduction to RNs: 2) Radio

2) Radio → F) Frequency Spectrum

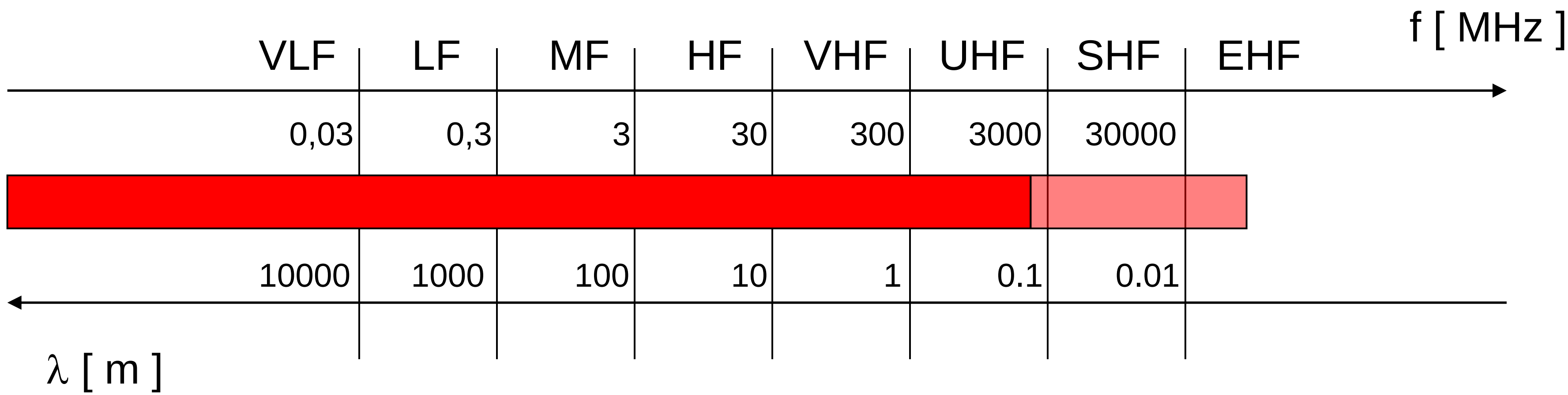


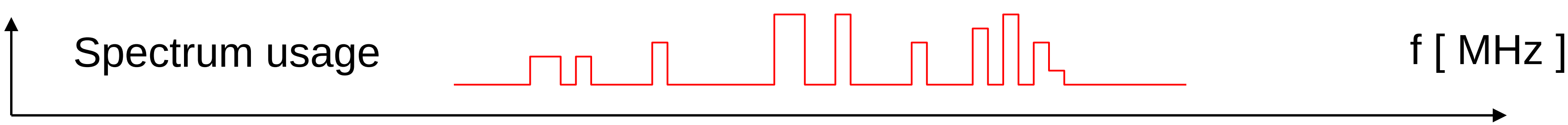
Frequency band assignments to services are:

1) Requested by industry alliances, standardisation bodies
2) Negotiated within and recommended by ITU-R
3) Regulated on a country basis by National Authorities
4) Released to operators / users

Introduction to RNs: 2) Radio

2) Radio → F) Frequency Spectrum





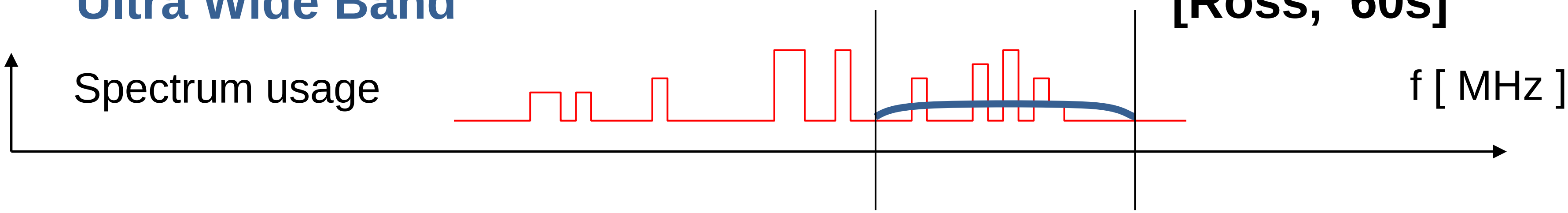
More than 90% is actually unutilised!

Introduction to RNs: 2) Radio

2) Radio → F) Frequency Spectrum

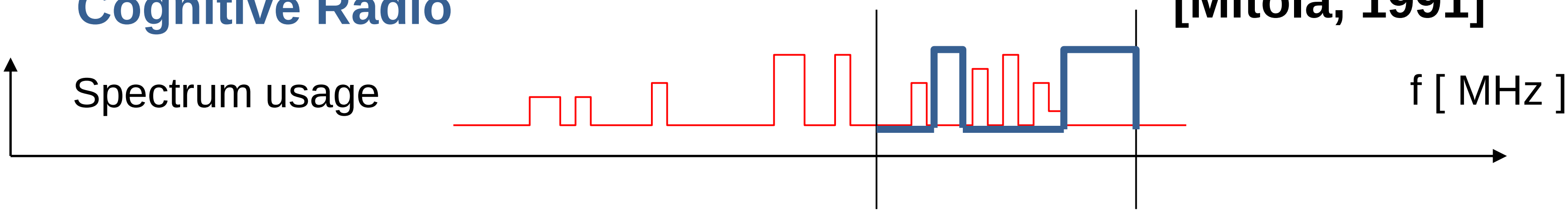
Ultra Wide Band

[Ross, '60s]



Cognitive Radio

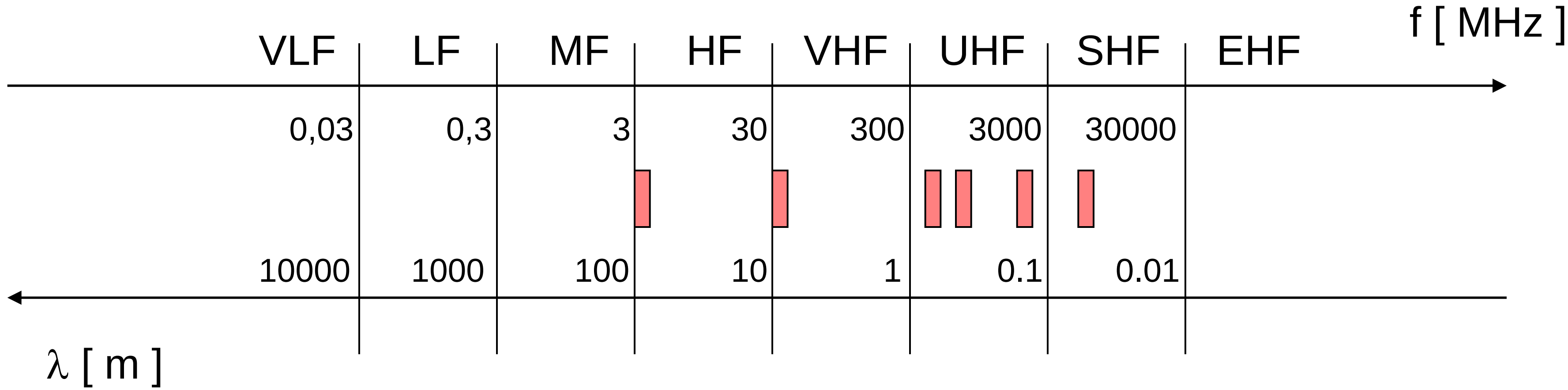
[Mitola, 1991]



Introduction to RNs: 2) Radio

2) Radio → F) Frequency Spectrum

ISM Bands: Licence - Exempt in Most Countries



13.553 – 13.567 MHz **RFid**
40.66 – 40.70 MHz **RFid**
433 – 464 MHz **Proprietary Radios**
902 – 928 MHz **Proprietary Radios**
2.4 – 2.48 GHz **Bleutooth, WiFi, Zigbee, …**
5.725 – 5.875 GHz **WiFi, …**

Introduction to RNs: 2) Radio

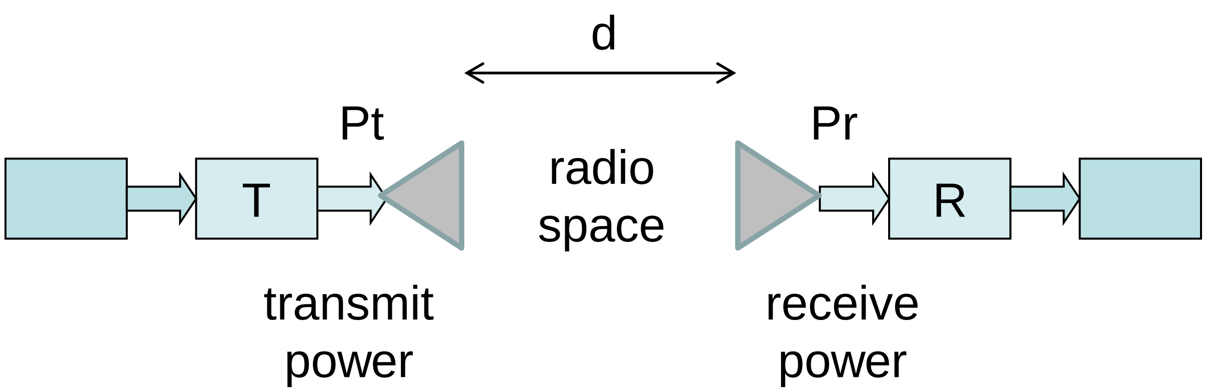
2) Radio → F) Frequency Spectrum

To cope with spectrum scarcity:

Higher Frequencies
Ultra Wide Band Techniques
Cognitive Radio
Spectrum Sharing

Introduction to RNs: 2) Radio

2) Radio → G) Unpredictable Channel



If radio space is uniform, isotropic, perfect dielectric, without obstacles,

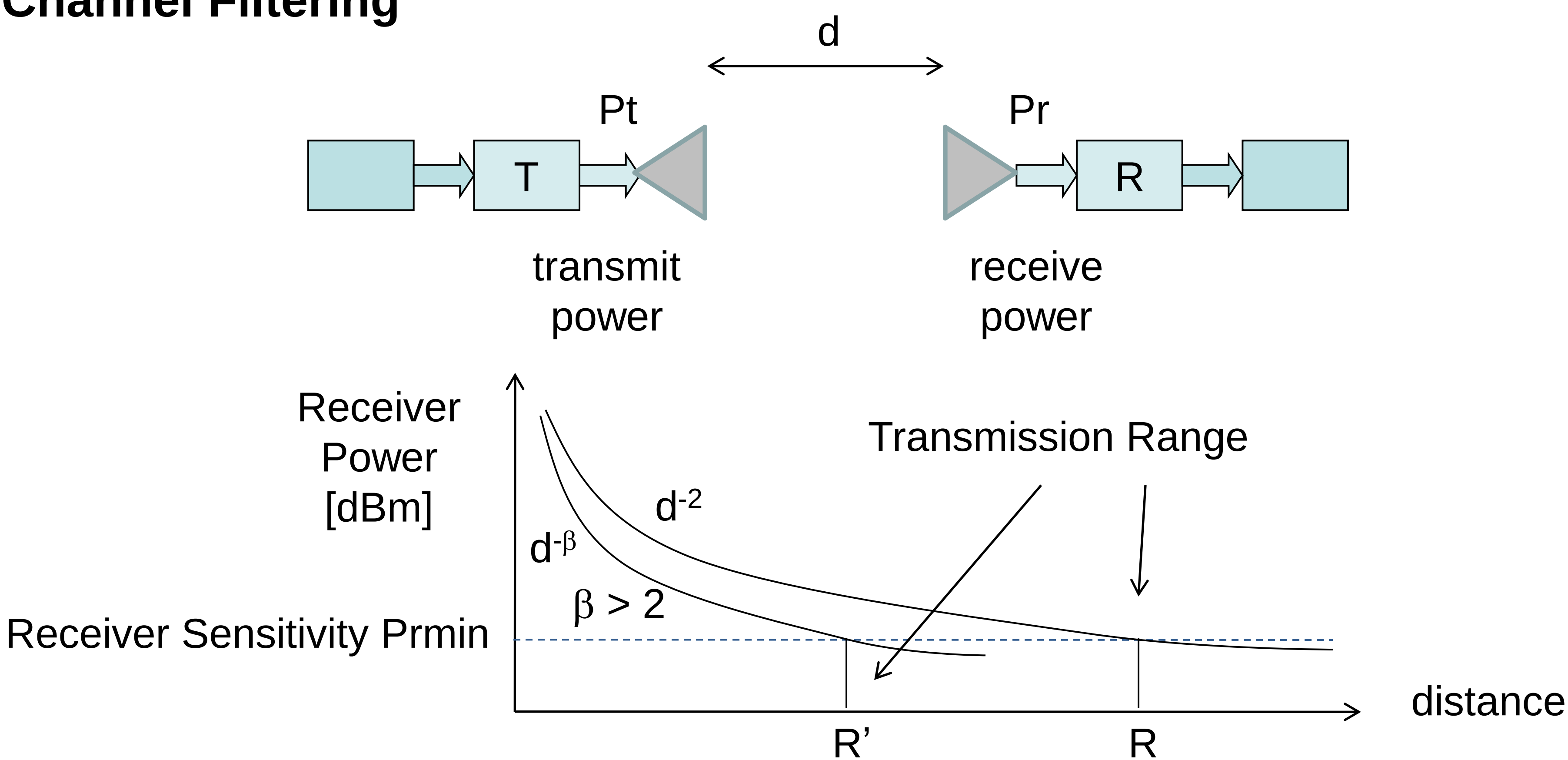
Pr = Pt Gt Gr / Aio **Aio = $(4 \pi d / \lambda)^2$** **[Friis, 1945]**

Otherwise…

Introduction to RNs: 2) Radio

2) Radio → G) Unpredictable Channel

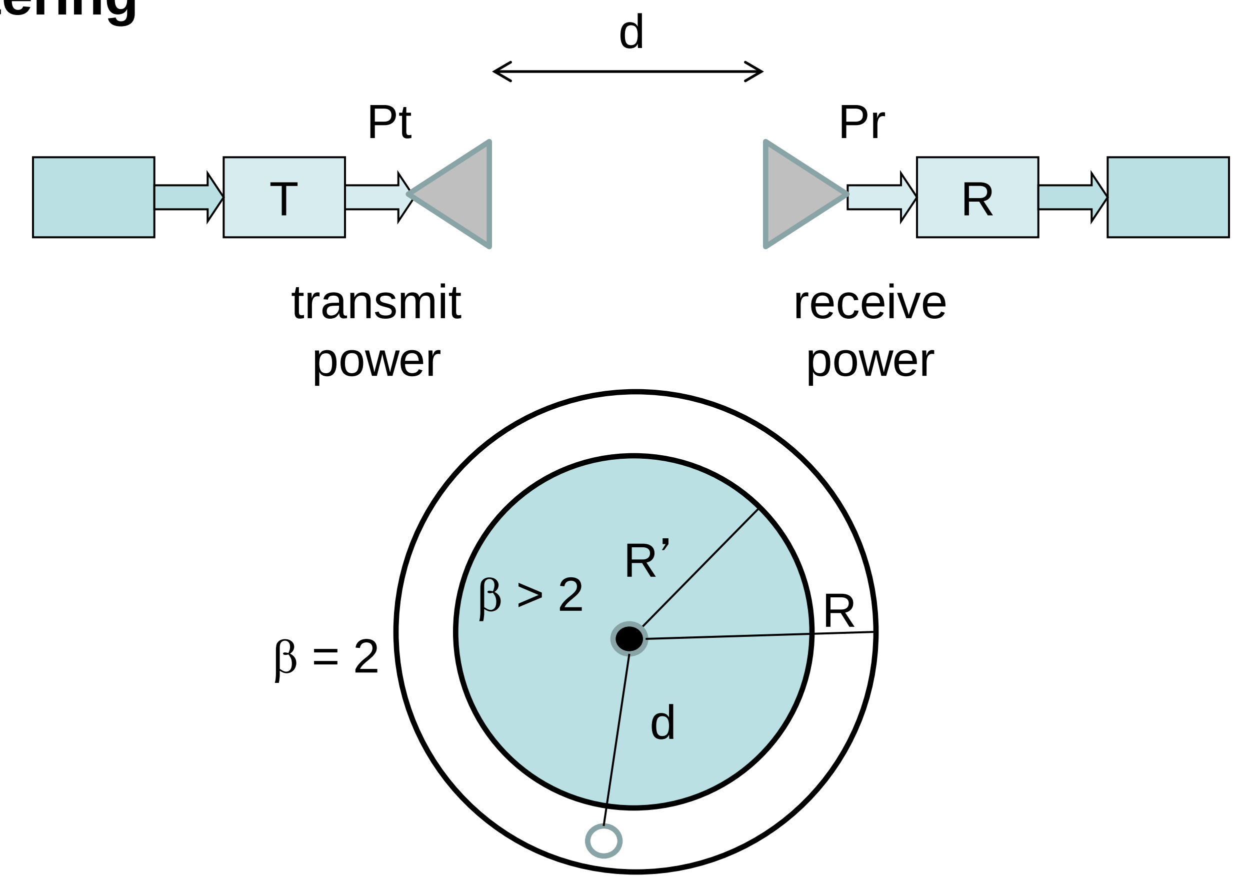
Channel Filtering



Introduction to RNs: 2) Radio

2) Radio → G) Unpredictable Channel

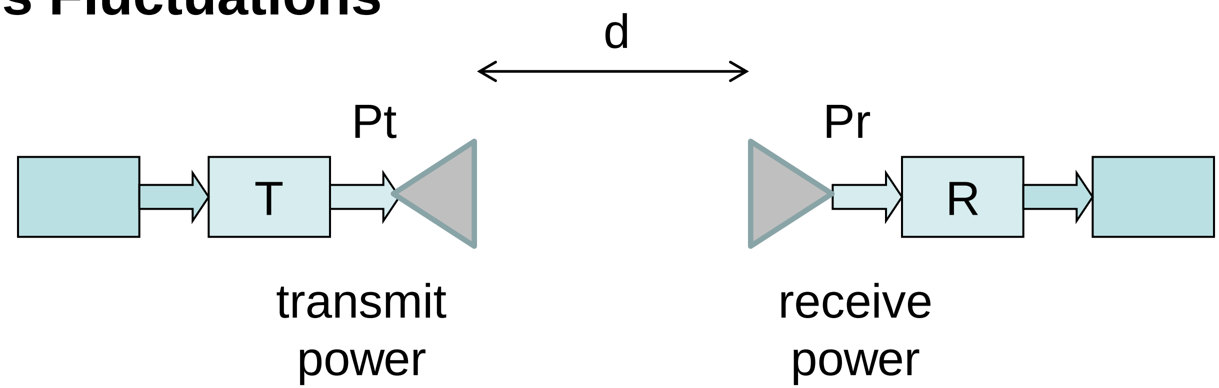
Channel Filtering

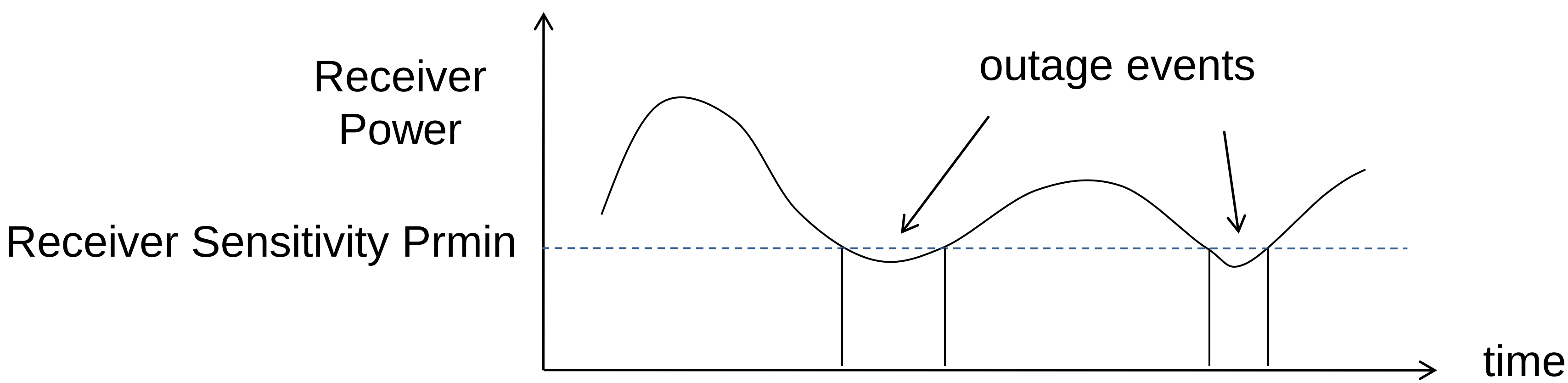


Introduction to RNs: 2) Radio

2) Radio → G) Unpredictable Channel

Channel Loss Fluctuations

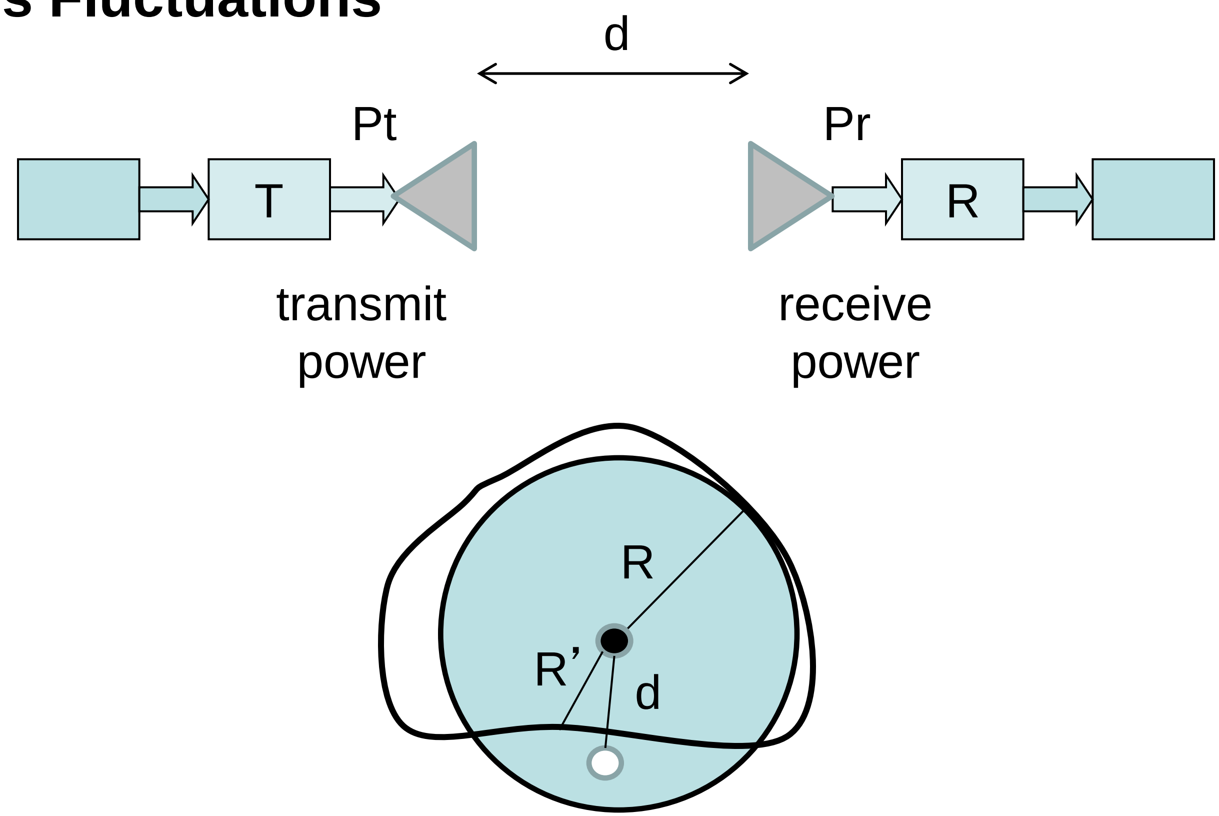




Introduction to RNs: 2) Radio

2) Radio → G) Unpredictable Channel

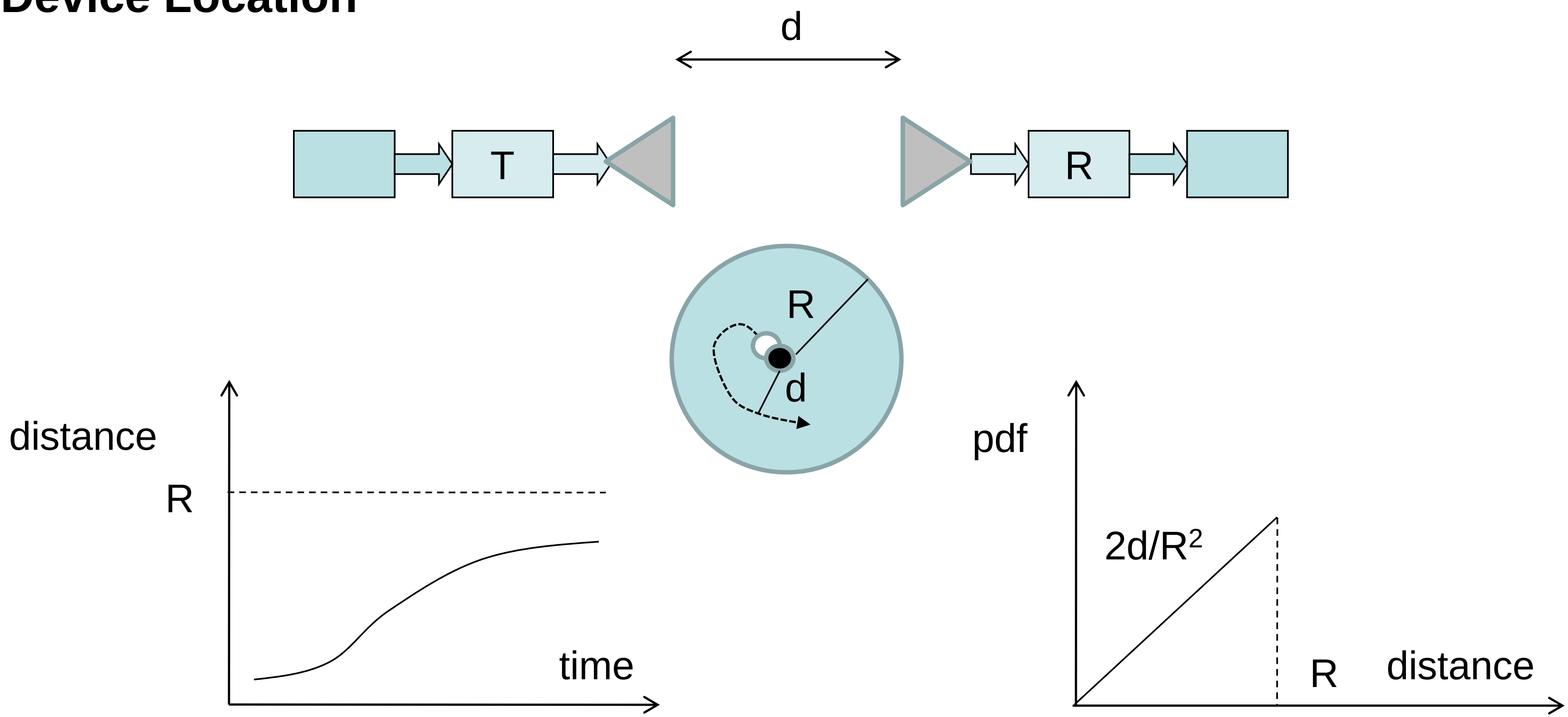
Channel Loss Fluctuations



Introduction to RNs: 2) Radio

2) Radio → G) Unpredictable Channel

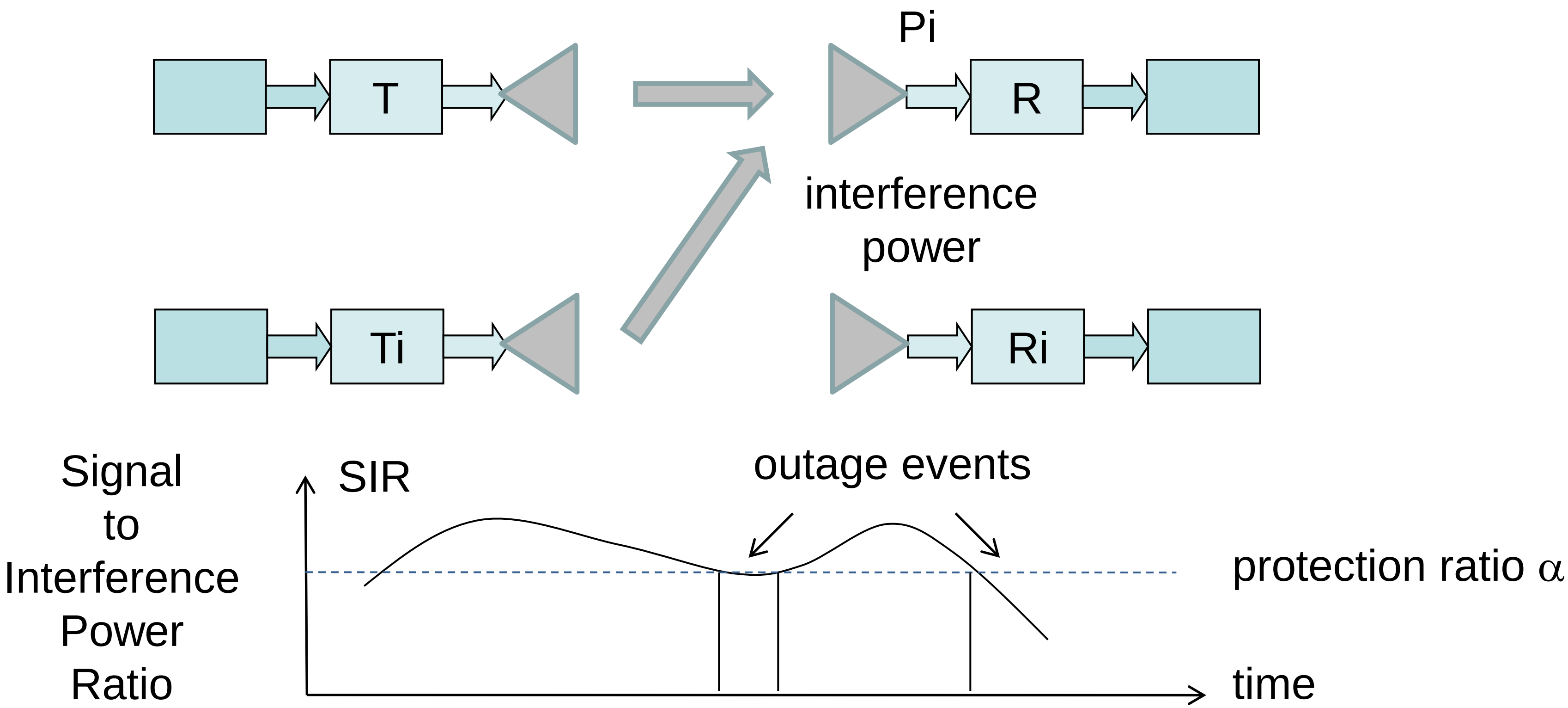
Device Location



Introduction to RNs: 2) Radio

2) Radio → G) Unpredictable Channel

Interference



Introduction to RNs: 2) Radio

2) Radio → G) Unpredictable Channel

Unreliable Links

Countermeasures to unreliable channels needed at link level

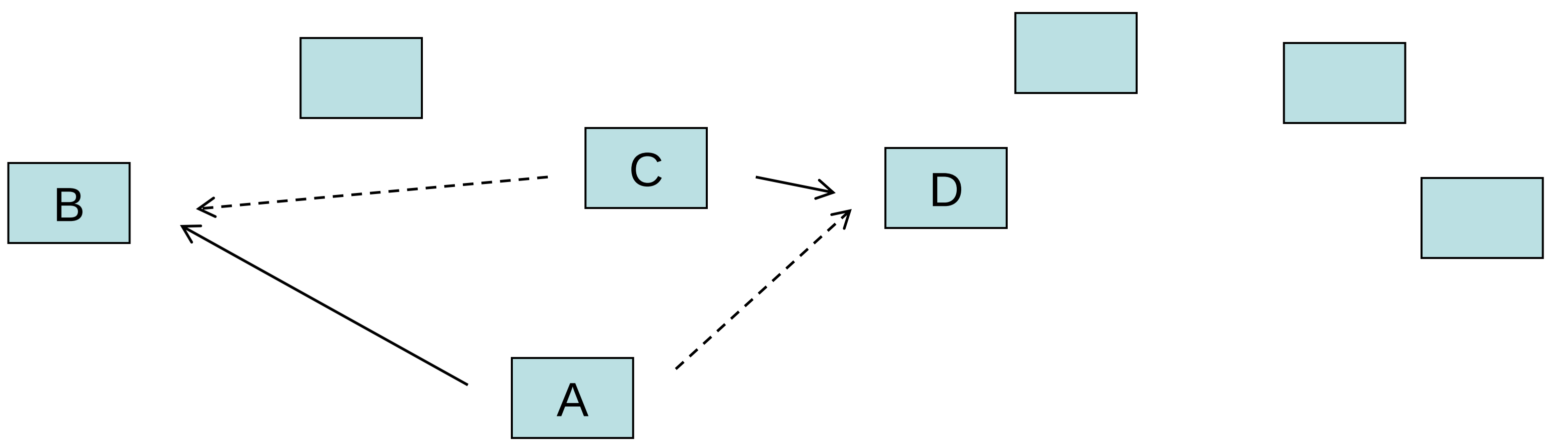
Introduction to RNs: 2) Radio

Background concepts from RN course:

Radio Channel Characterisation
Area Coverage
Interleaving
Diversity
Link Performance in the presence of Fading

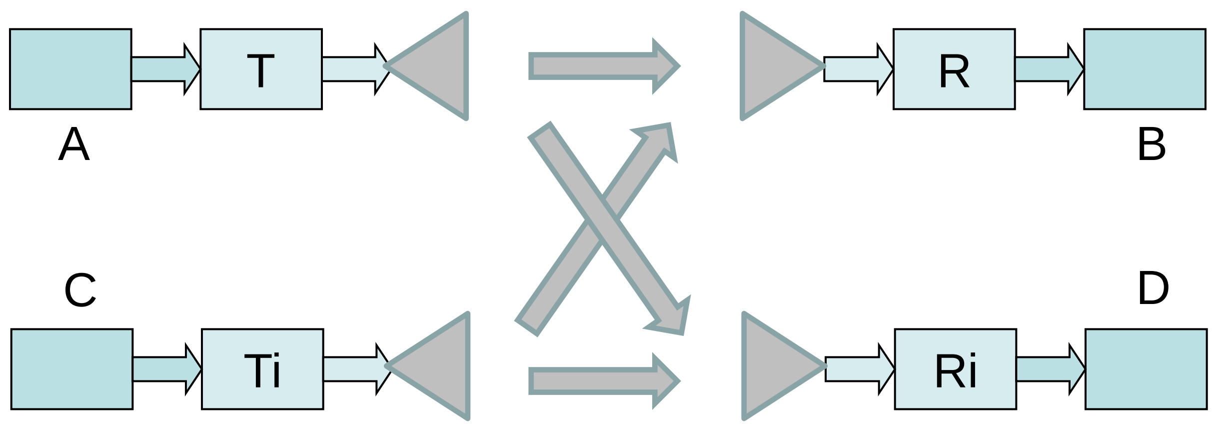
Introduction to RNs: 3) Networks

Network Level View



Introduction to RNs: 3) Networks

3) Networks → H) Mutual Interactions

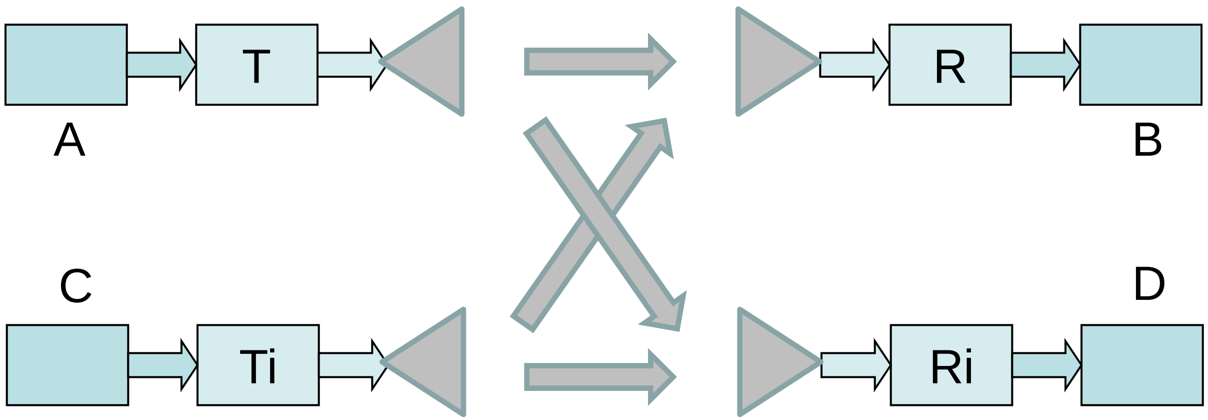


Interference Management is a key Issue:

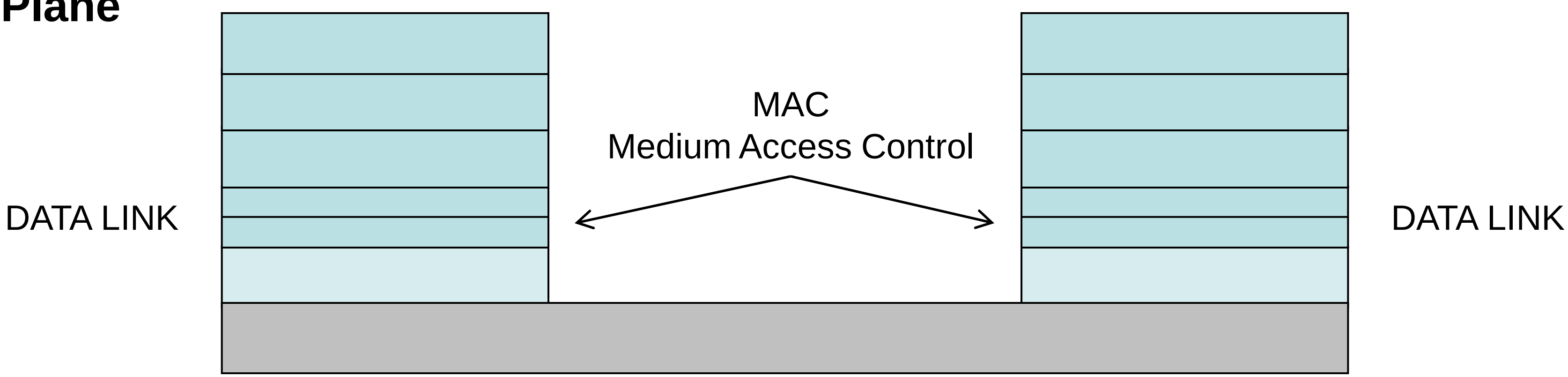
- Interference Avoidance → PHY or DATA LINK or NETWORK Layer
- Interference Averaging → PHY or DATA LINK Layer
- Interference Rejection → PHY Layer
- Collision Resolution → DATA LINK Layer

Introduction to RNs: 3) Networks

3) Networks → H) Mutual Interactions

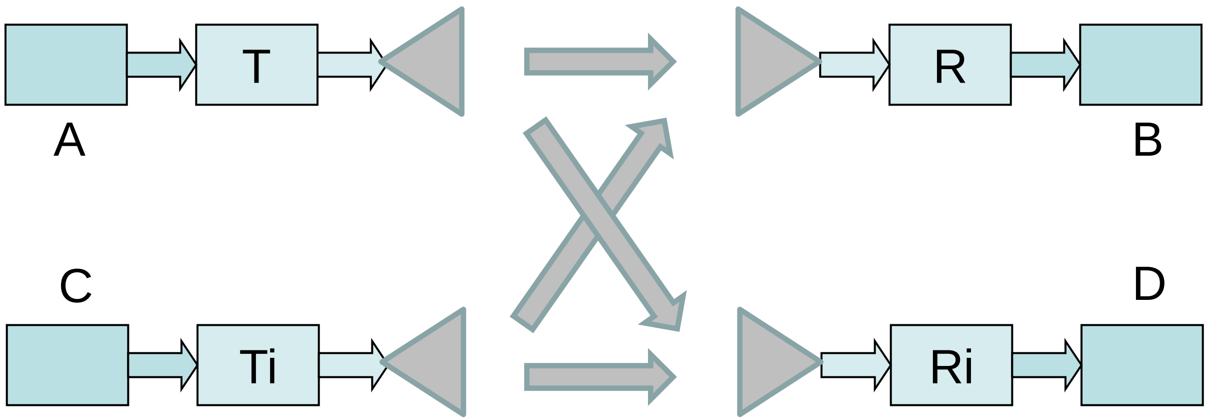


User Plane

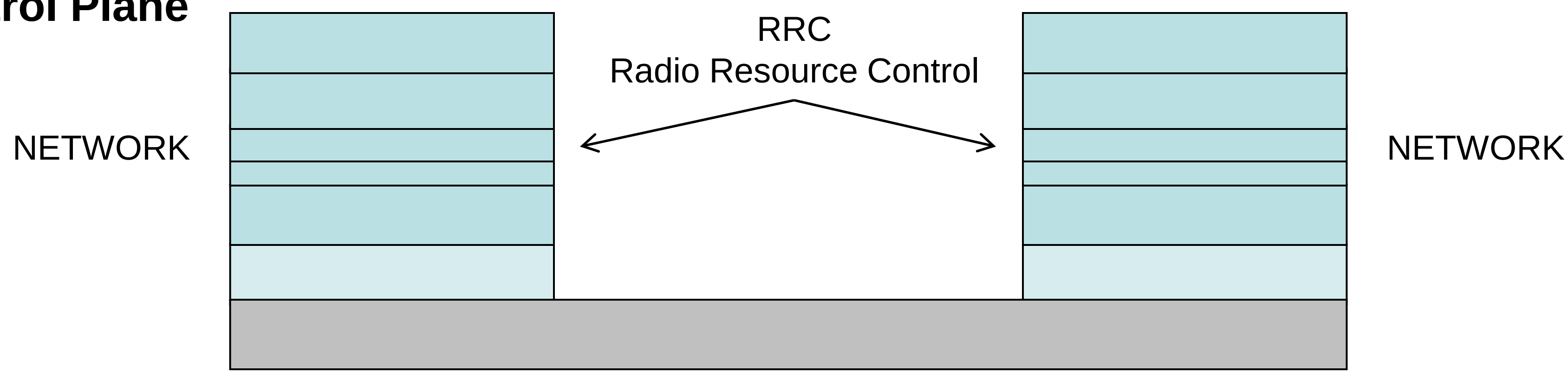


Introduction to RNs: 3) Networks

3) Networks → H) Mutual Interactions

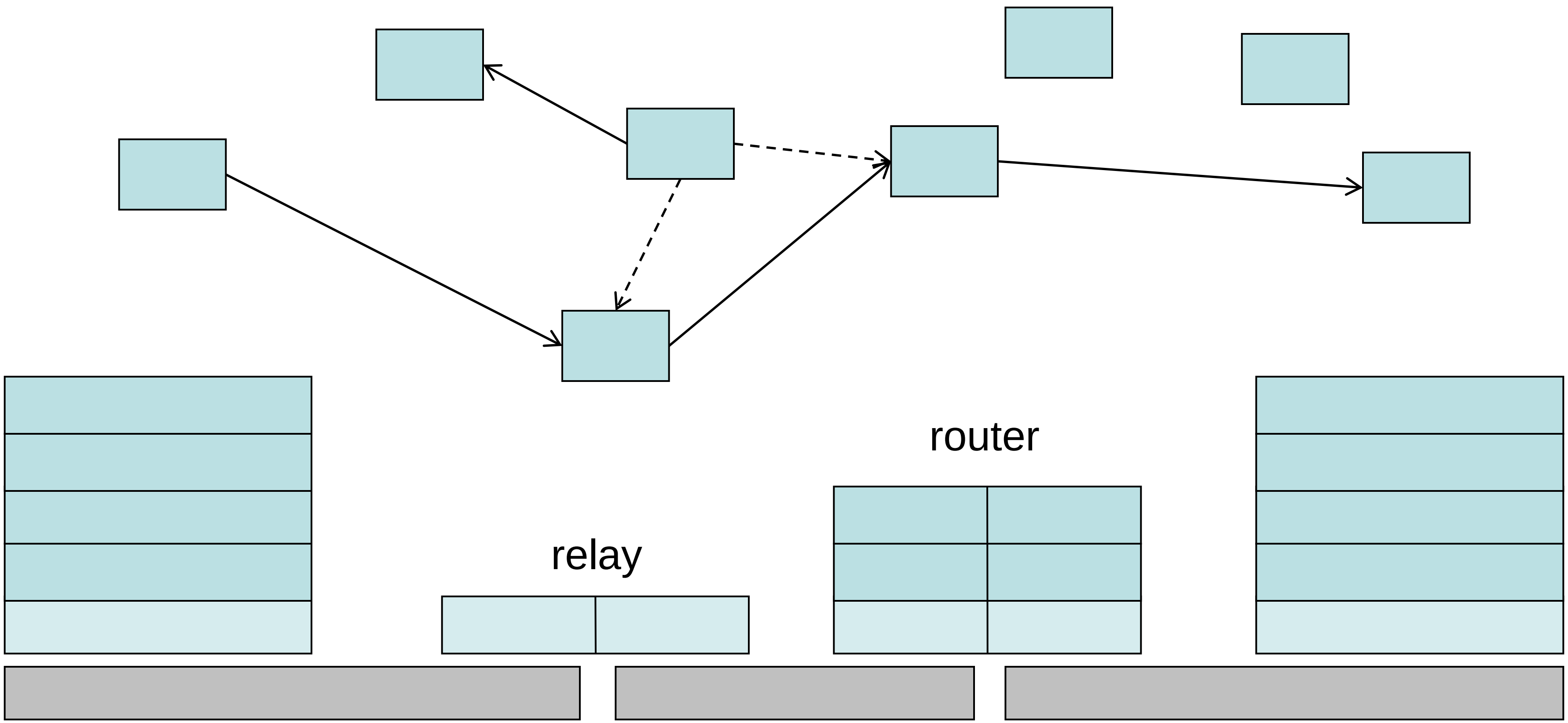


Control Plane



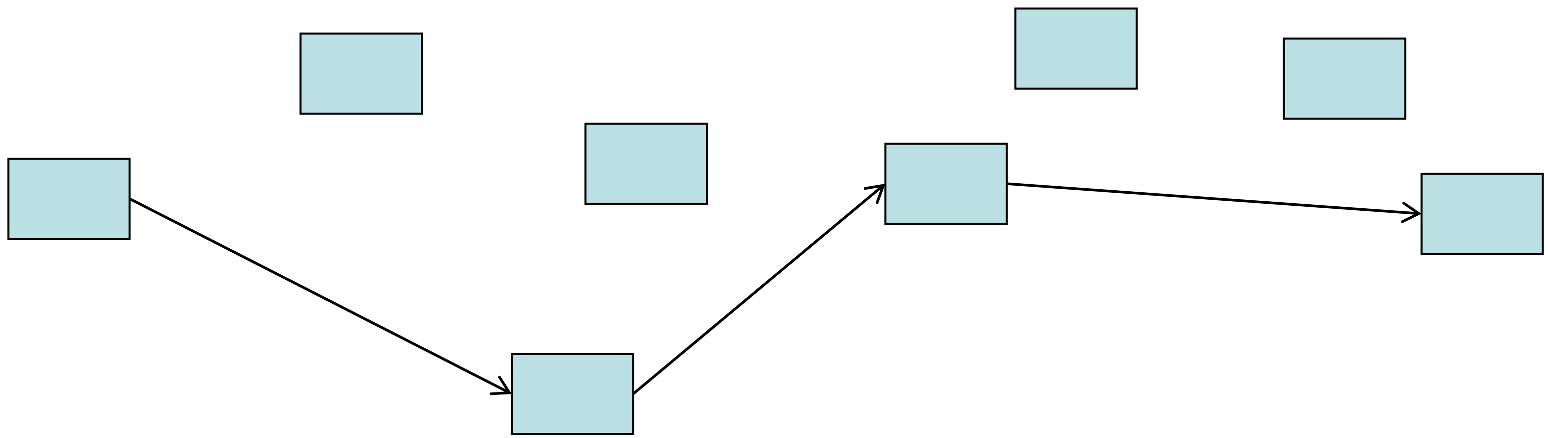
Introduction to RNs: 3) Networks

3) Networks → I) Protocol Complexity



Introduction to RNs: 3) Networks

3) Networks → I) Protocol Complexity



Complexity is Against Efficiency!

Introduction to RNs: 3) Networks

3) Networks → L) Topologies & Architectures

Mobile Radio Access
Broadband Radio Access
Local Radio Access
} **Area Coverage → Cellular Networks**

Mobile Ad Hoc — **Device Centric → Peer-to-Peer Networks**

Personal
Sensor
Body
} **Data Centric → Coordinator Based Networks**

Introduction to RNs: 3) Networks

3) Networks → L) Topologies & Architectures

Mobile Radio Access

Broadband Radio Access

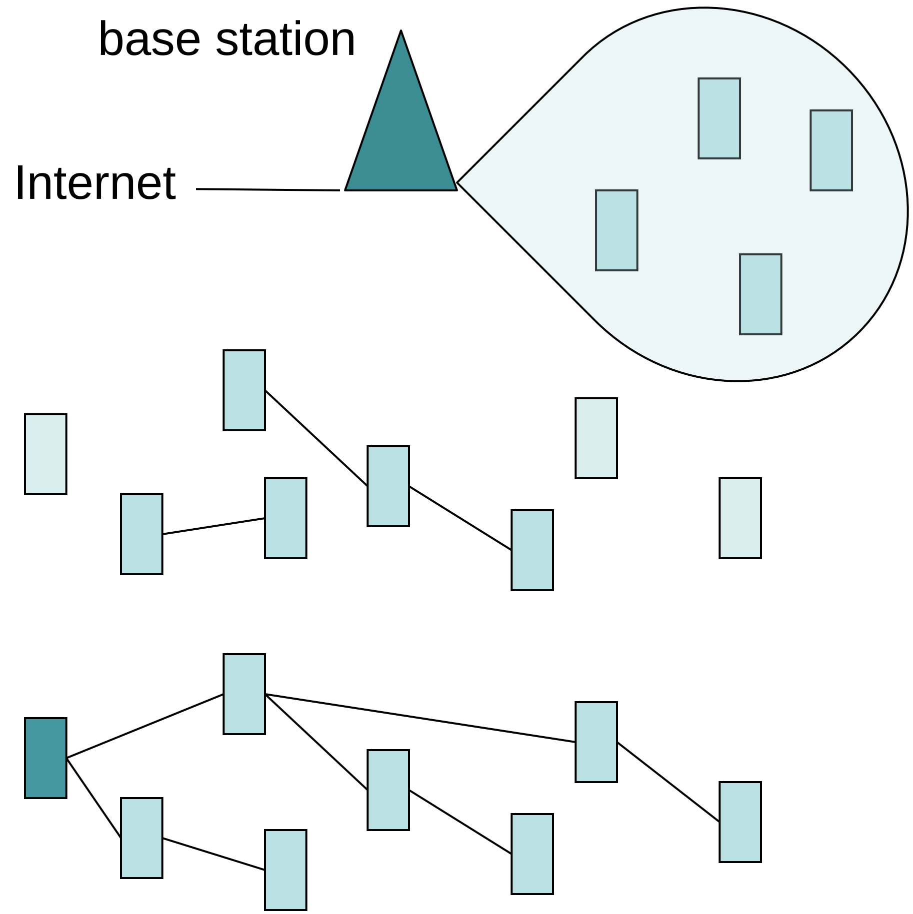
Local Radio Access

Mobile Ad Hoc

Personal

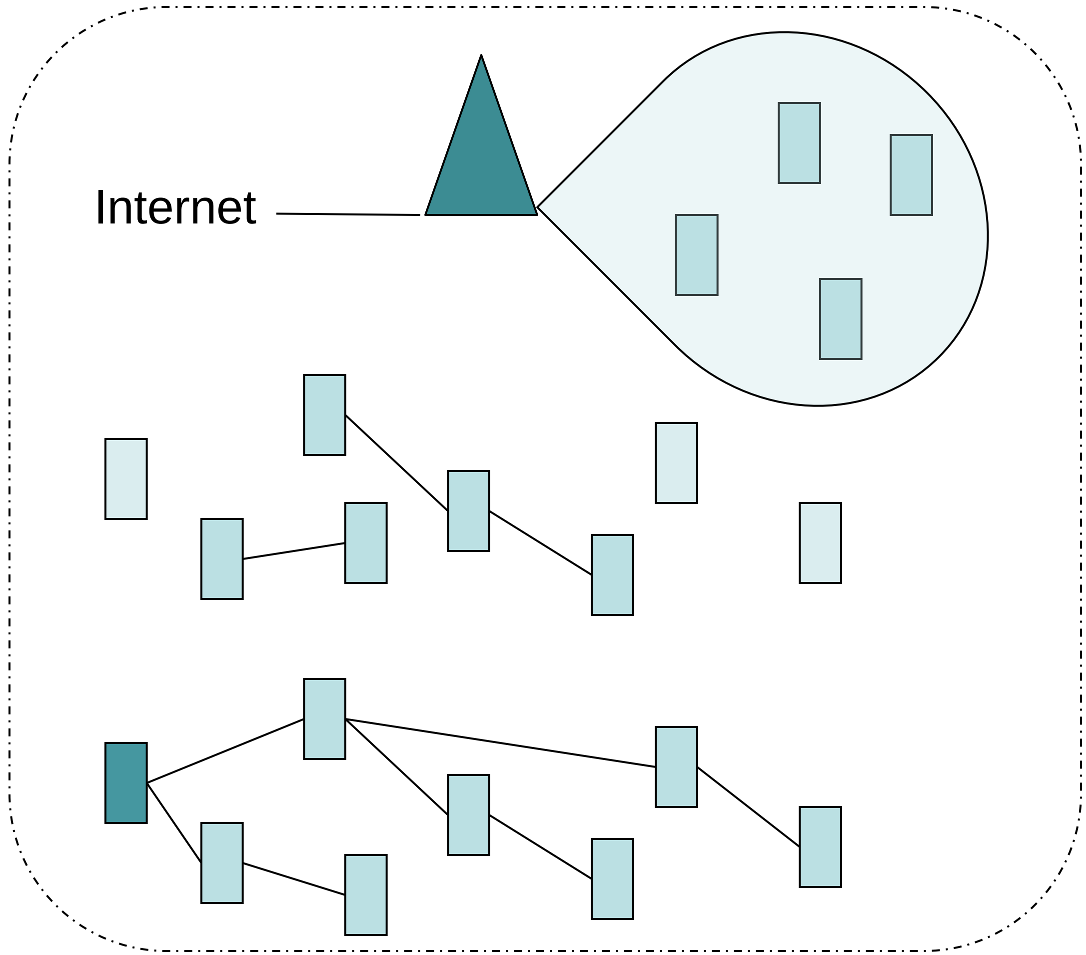
Sensor

Body



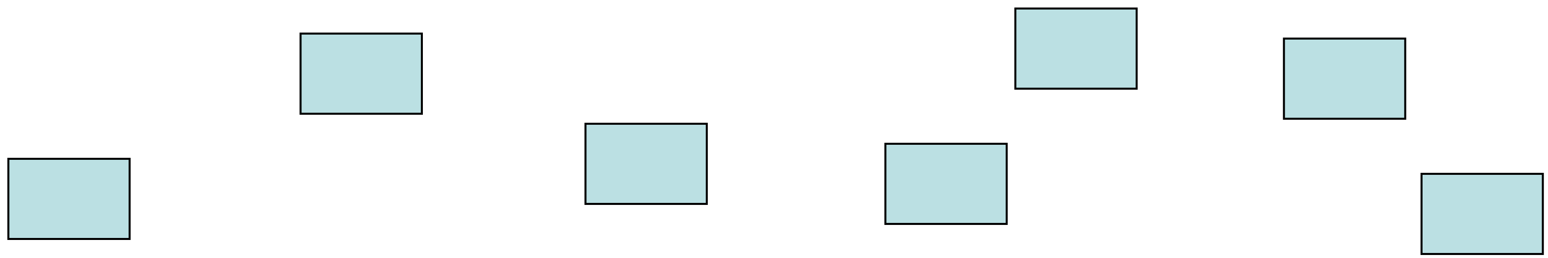
Introduction to RNs: 3) Networks

3) Networks → **L) Topologies & Architectures**



**Efficient
Network Architectures
are required**

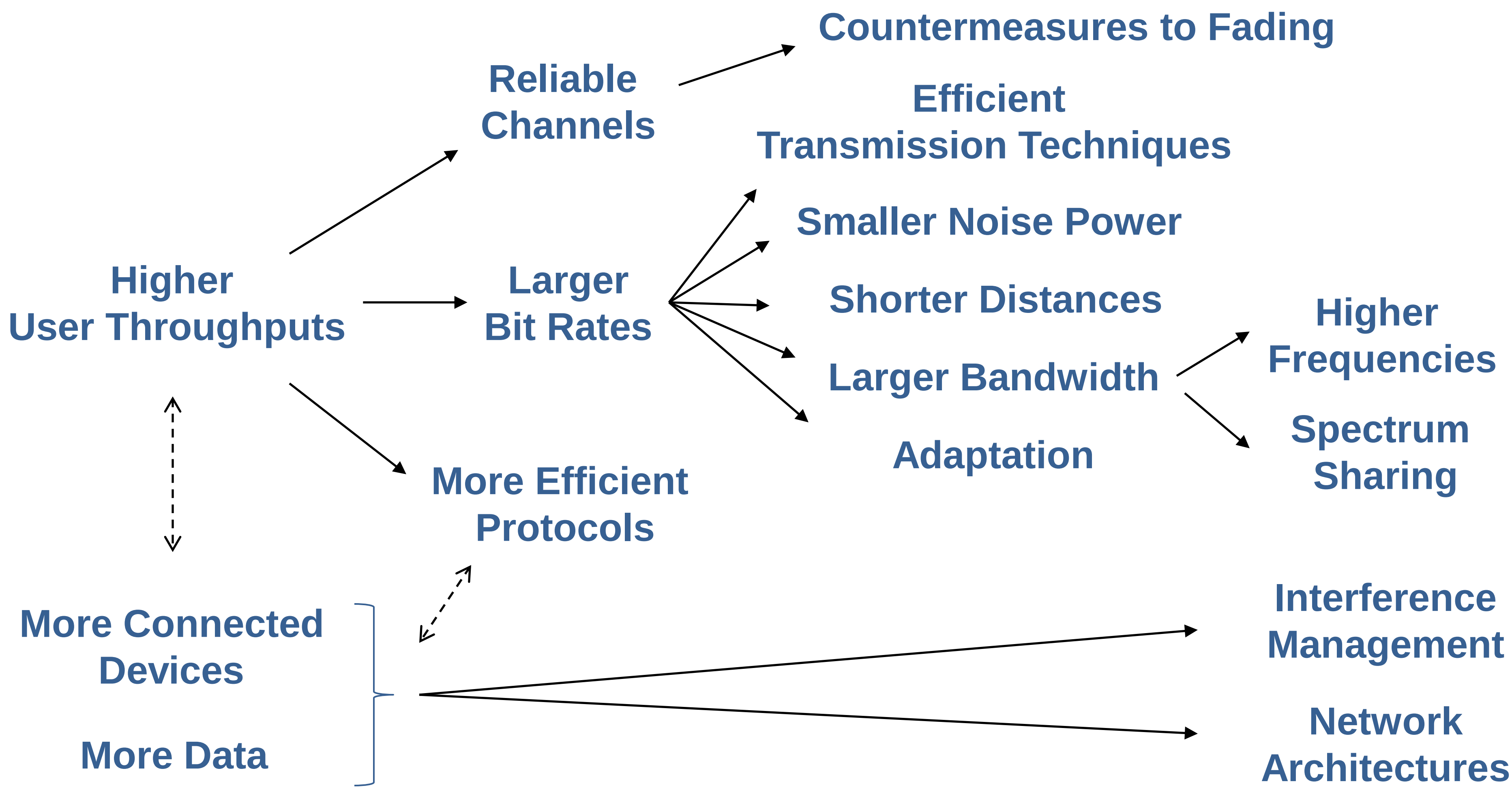
Introduction to RNs: 3) Networks



Background concepts from RN course:

Digital Transmission in Interference Limited Systems
Capture Effect
Link Performance in the Presence of Interference

Introduction to RNs: Summary

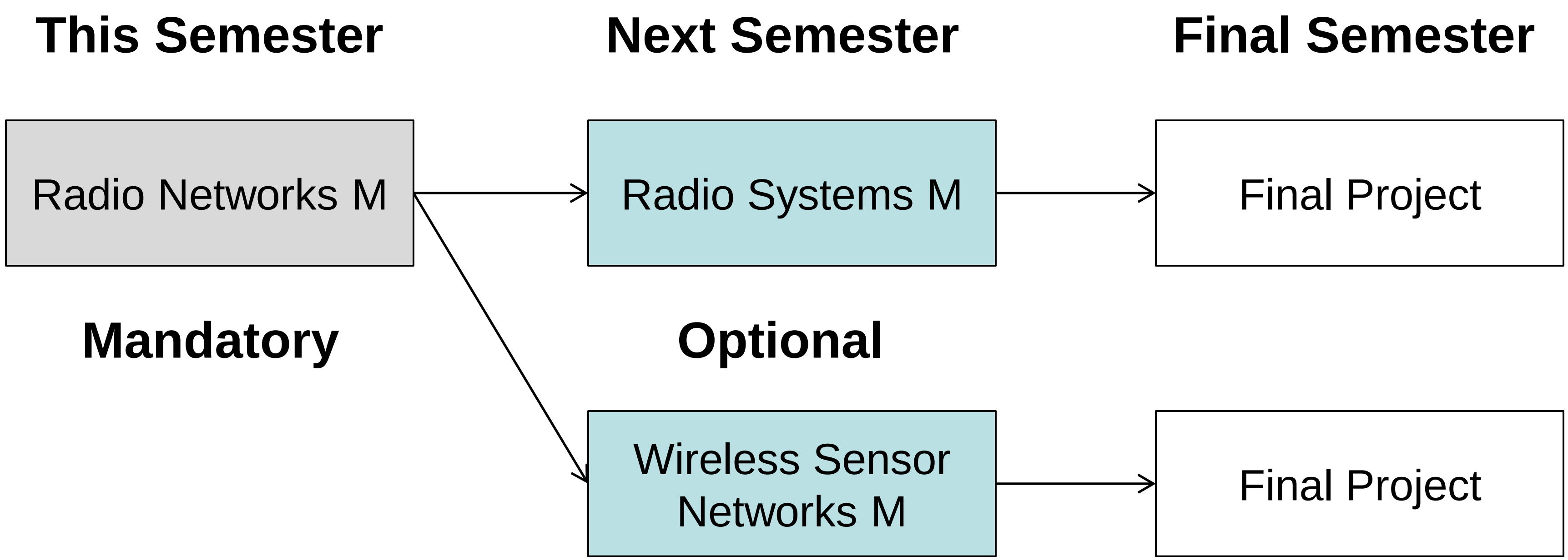


4. The Course

Modelling and Design of Radio Networks:

Fundamental Techniques, Algorithms and Protocols

From the Radio Channel to the Network Layer



The Course: Lecture Blocks (RN + RS = 120 hours)

INT	**Introduction**
DTN	**Digital Transmission in Noise Limited Systems**
LRC	**Link Level: Radio Channel**
LCF	**Link Level: Countermeasures to Fading**
LMA	**Link Level: Multiple Antennas**
DTI	**Digital Transmission in Interference Limited Systems**
LMS	**Link Level: Modulation Schemes**
MSG	**Methods: Stochastic Geometry**
MNG	**Methods: Network Graphs**
MAS	**Methods: Access Level Simulation**
NRA	**Network Level: Radio Resource Assignment in Cellular Networks**
NRM	**Network Level: Radio Resource Management**
MLS	**Methods: Link Level Simulation**
NMA	**Network Level: Medium Access Control**
MNS	**Methods: Network Level Simulation**
NMH	**Network Level: Multi-Hop Networks**
MRN	**Mobile Radio Networks**
IOT	**Internet of Things**
CON	**Conclusions**

The Course: Lecture Blocks (RS = 60 hours)

INT	Introduction
DTN	Digital Transmission in Noise Limited Systems
LRC	Link Level: Radio Channel
LCF	Link Level: Countermeasures to Fading
LMA	**Link Level: Multiple Antennas**
DTI	Digital Transmission in Interference Limited Systems
LMS	**Link Level: Modulation Schemes**
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NMH	Network Level: Multi-Hop Networks
MRN	**Mobile Radio Networks**
IOT	Internet of Things
CON	**Conclusions**

The Course

Instructor:	**Roberto Verdone** **roberto.verdone@unibo.it ***
Teaching Assistant:	
Website:	**www.robertoverdone.org → courses**
Teaching Material:	**Handouts will be available as pdf files**
Exam:	**Single step: after the end of the course.**
Additional Material:	**Handwritten notes plus references to books** **Audio recording of lectures** **Homework, further reading** **Books available in my office for daily use**

*** Clear e-mails no longer than three lines, requiring answers that can be given in three lines.**

The Course: Assessment Rules

A (30L) B (28-30) C (25-27) D (22-24) E (19-21)
F (failed)

Written exercise: if you fail → F; if you complete it, you start with B

Then, two questions plus discussion of the simulation blocks:
each time, either you confirm or you go down by one or two steps

If you answer all questions correctly → B
If you tell me more than what I told → A

***Concepts*, first of all**
***Description* of techniques, algorithms and protocols**
***Formalisation* of problems through diagrams, equations, formulae, etc**
Precise description through *analytical* models

The Course: Tips – secrets to succeed

Take *notes* during the lectures!

Look for *details*; be precise

Engineers do not use adjectives and adverbs. They use *numbers*.

Try to find *connections* between separate lecture blocks

Try to find out what's the *philosophy* behind the course

Assess yourself through the *self-assessment tools* we will provide

Try the *intermediate exam* to check the status of your preparation

Be *interactive* during the lectures!