Telecomunicazioni

Mobile Radio Networks

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Radio Networks @ WiLab
DEI, University of Bologna

Summary

1. Intro
2. Fundamentals
3. Steps
4. Access Network
5. Network Architecture
6. Radio Channel
7. 2G and 4G
8. Localisation and Tracking

Intro

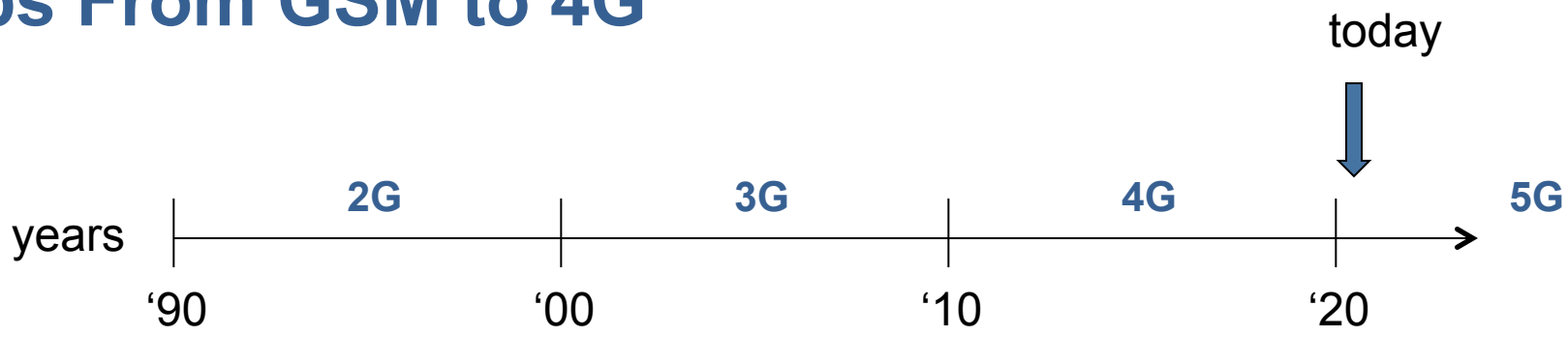
MRN

How are mobile services evolving since the dawn of digital era?

1G, 2G, 3G, 4G, 5G, …

(Smaller sizes)
From voice to data
Higher data rates
Lower latency
Pervasivity

Steps From GSM to 4G



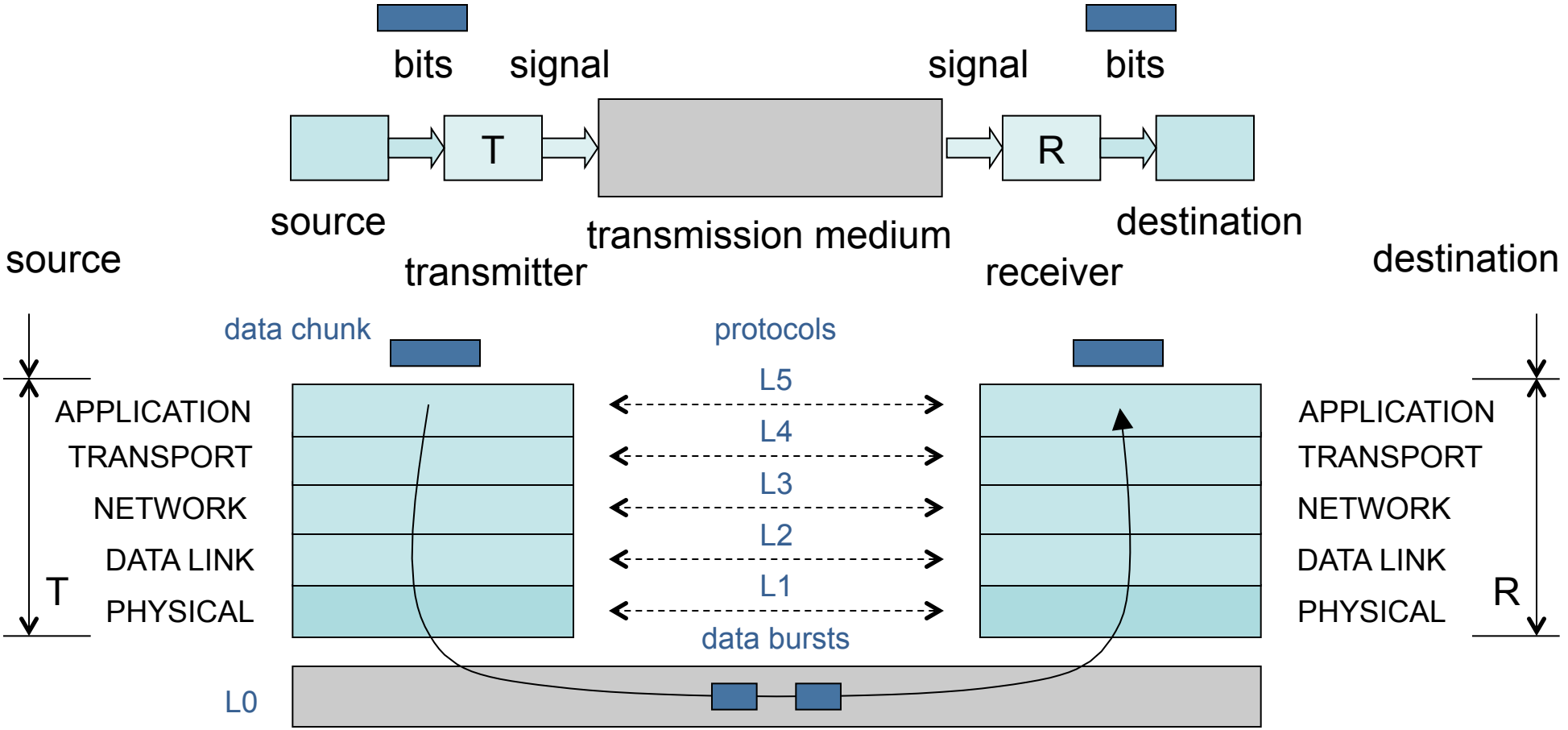
5G

IL PERICOLO INVISIBILE
PER LA VITA
STOP 5G
5 NOVEMBRE, ANCHE NOI A ROMA
PER DIRE STOP 5G
MARTEDÌ IN PROGRAMMA LA PRIMA MANIFESTAZIONE NAZIONALE UNITARIA
STOP 5G DENTRO E FUORI IL PARLAMENTO. AL CONVEGNO INTERNAZIONALE

Fundamentals

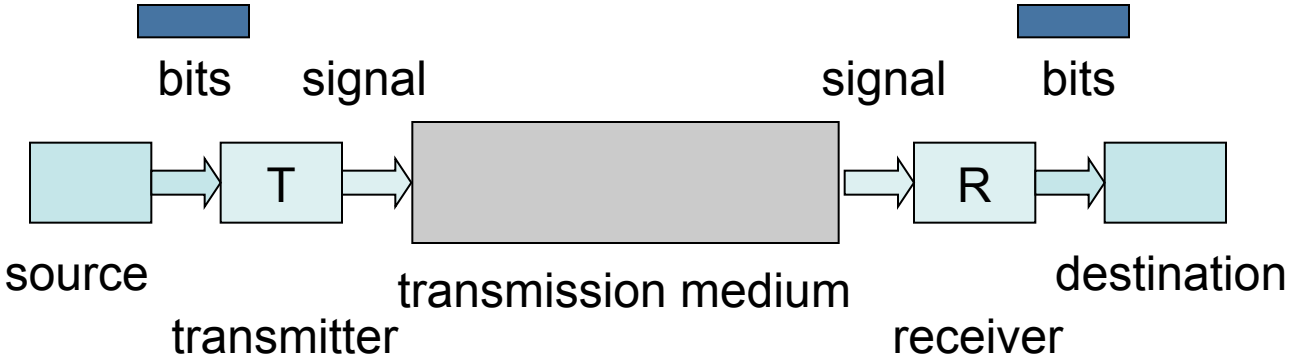
Fundamentals of Digital Communications

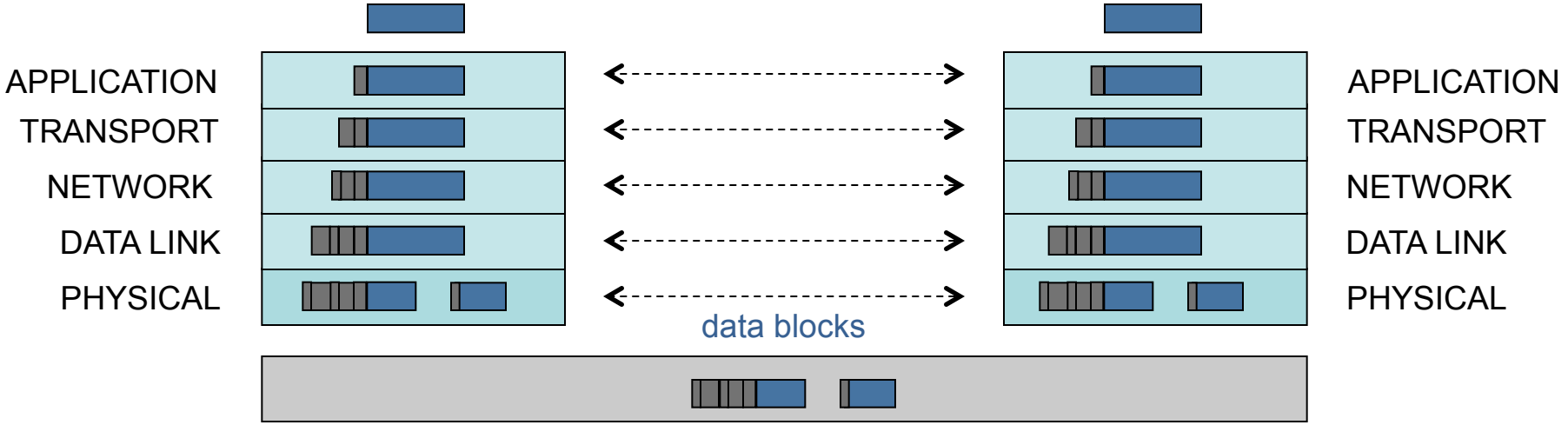
Digital Communications → Protocols



Fundamentals of Digital Communications

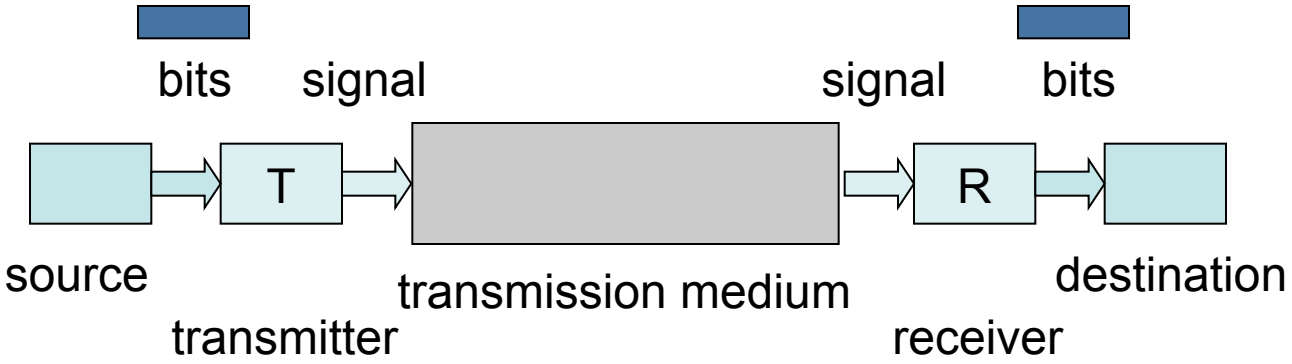
Digital Communications → Protocols

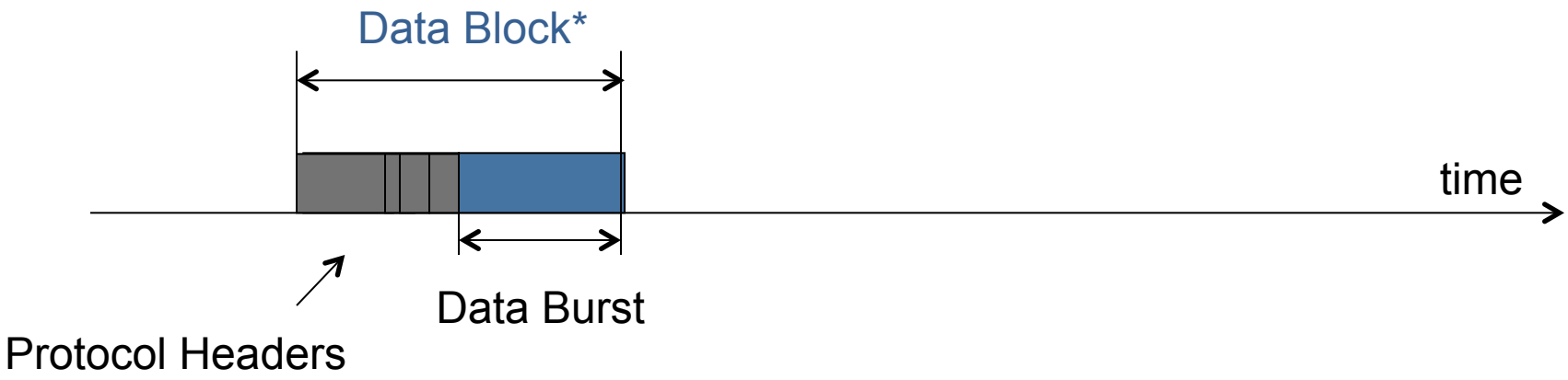




Fundamentals of Digital Communications

Digital Communications → Protocols

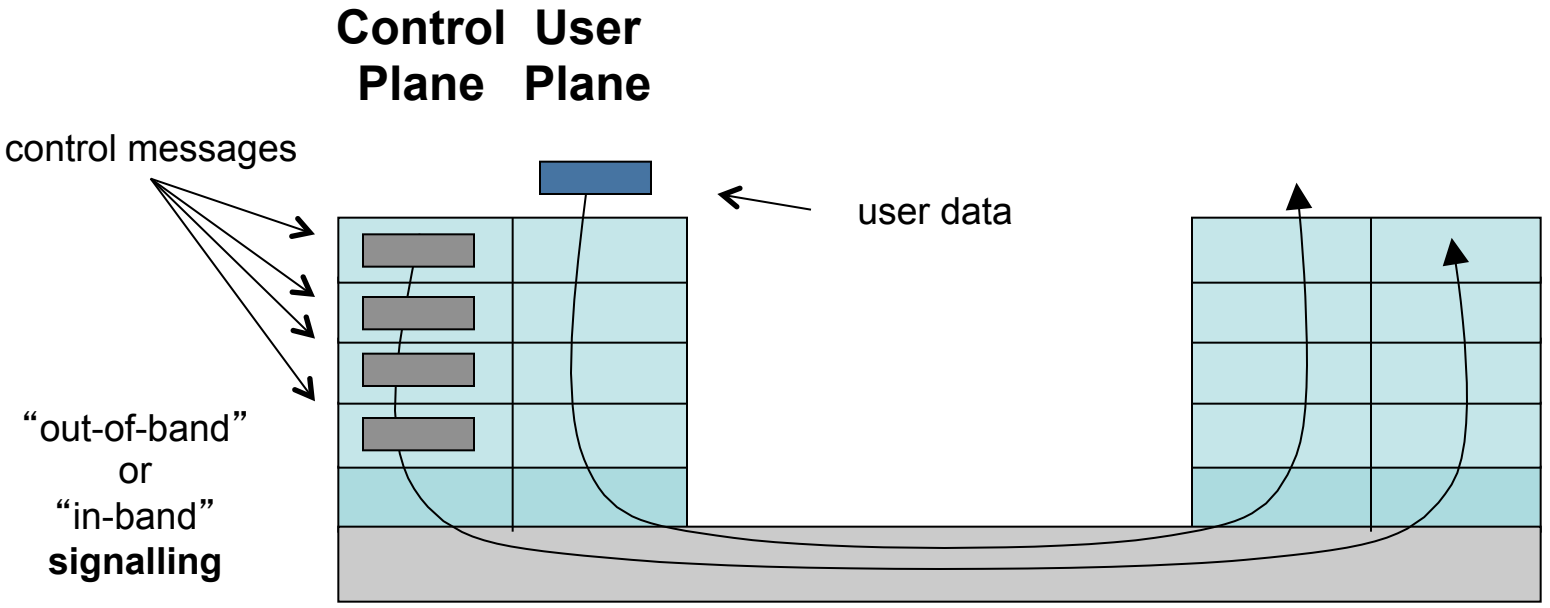




** Sometimes erroneously denoted as Packet. Packets are L3 entities.*

Fundamentals of Digital Communications

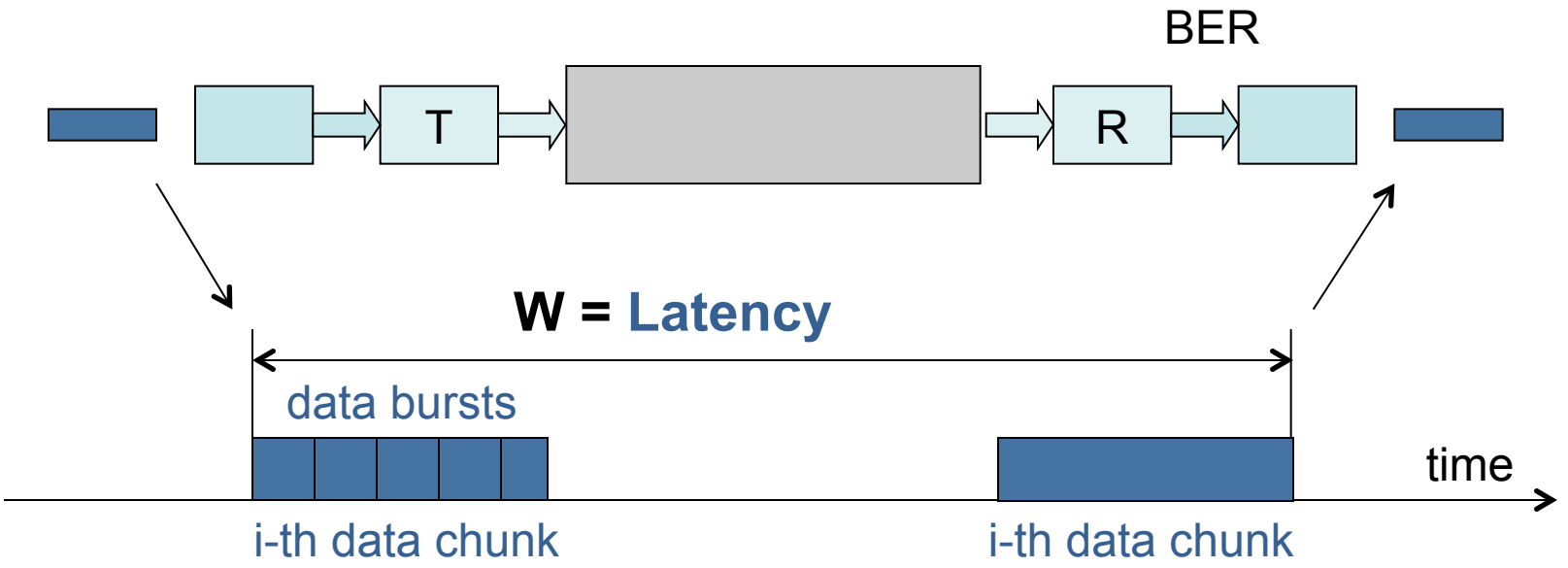
Digital Communications → Protocols



Fundamentals of Digital Communications

Digital Communications → Application Requirements

User Plane



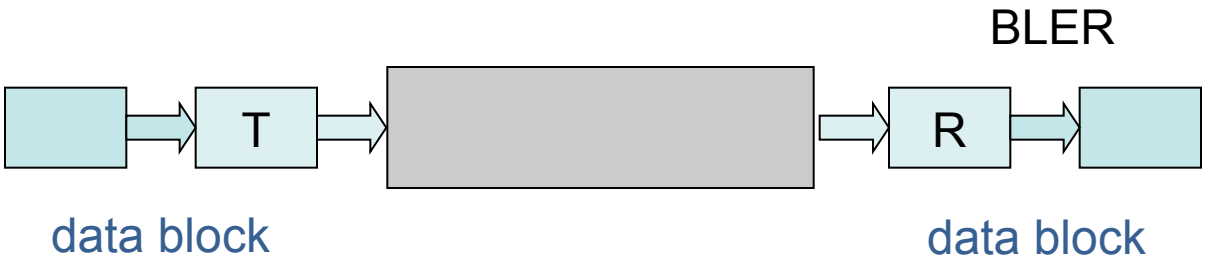
U = User Throughput = Number of information bits per second received

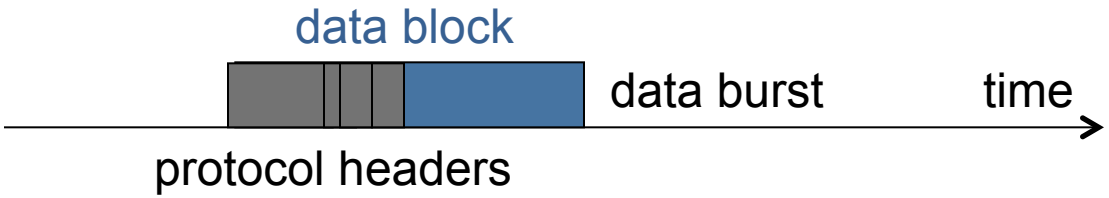
BER = Bit Error Rate = Percentage of erroneous bits

Fundamentals of Digital Communications

Digital Communications → Application Requirements

User Plane





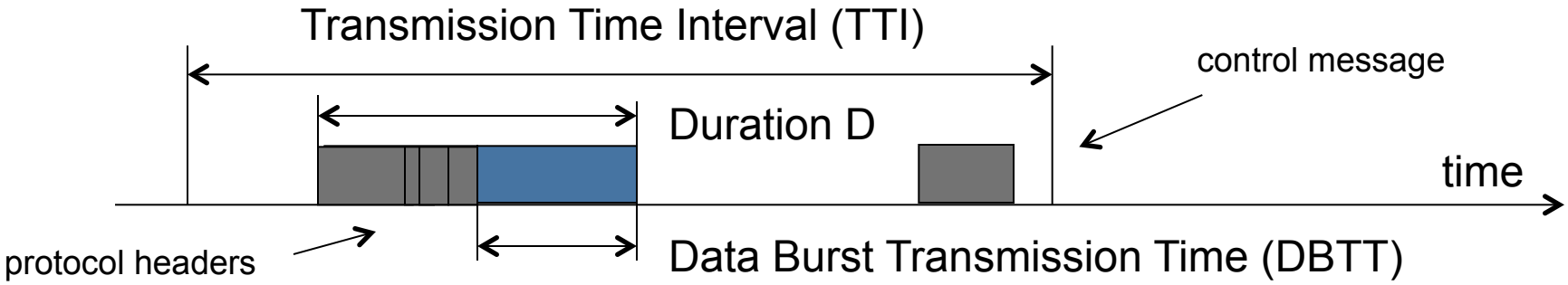
BLER = BLock Error Rate = Percentage of erroneous data blocks

Fundamentals of Digital Communications

Digital Communications → Protocol Efficiency

U < Rb for three reasons:

1. protocol headers (redundancy)
2. control messages (overhead)
3. silent intervals (overhead)



Protocol Efficiency = η_p = DBTT / TTI < 1

User Throughput = Rb * η_p < Rb **(ideal channel conditions)**

Fundamentals of Digital Communications

Digital Communications → Protocol Efficiency

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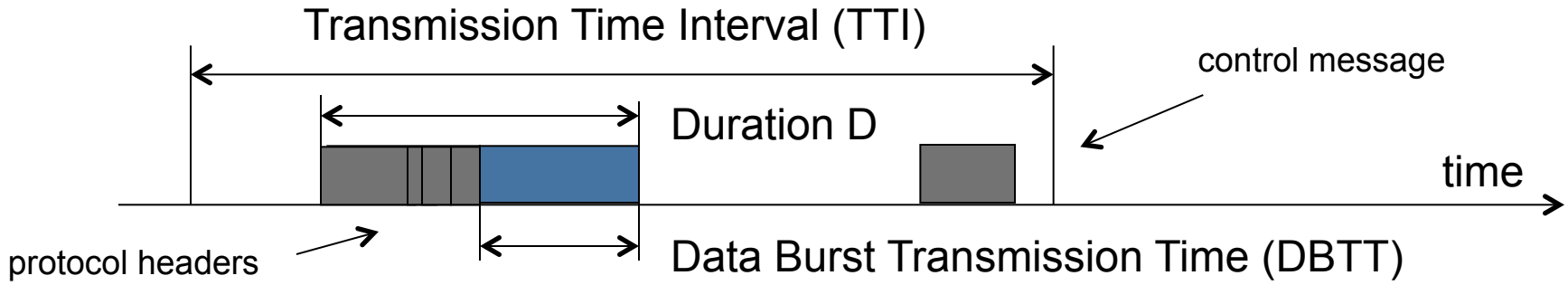

Redundancy Factor $= \eta_r = DBTT / D < 1$

Overhead Factor $= \eta_o = D / TTI < 1$

Fundamentals of Digital Communications

Digital Communications → Protocol Efficiency

U < Rb for three reasons:

1. protocol headers (redundancy)
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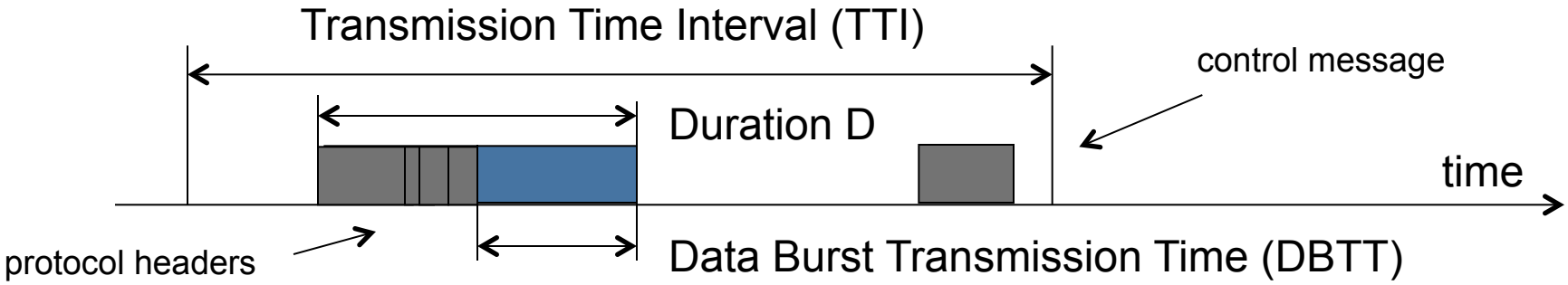


Protocol Efficiency = η_p = DBTT / TTI = η_r η_o

Fundamentals of Digital Communications

Digital Communications → Protocol Efficiency

$$\eta_p = \eta_r * \eta_o$$

η_r **Redundancy Factor**
η_o **Overhead Factor**

Fundamentals of Digital Communications

Digital Communications → Protocol Efficiency

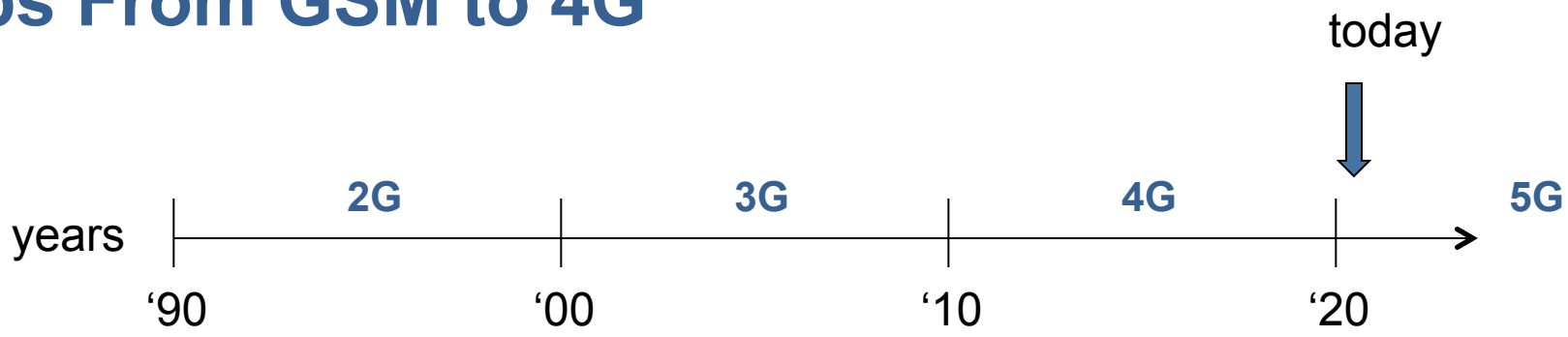
$$U = Rb * \eta_p * (1 - BLER)$$

Higher user throughputs require:

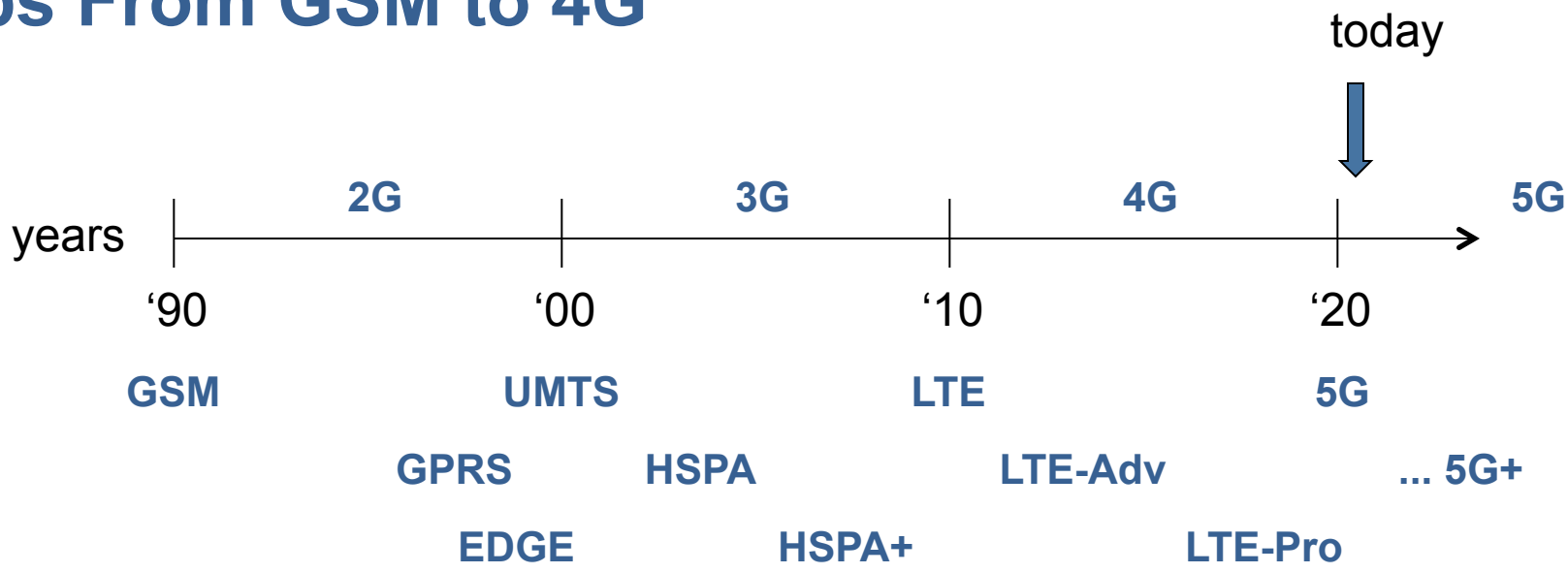
- Larger bit rates
- More efficient protocols
- Reliable channels

Steps

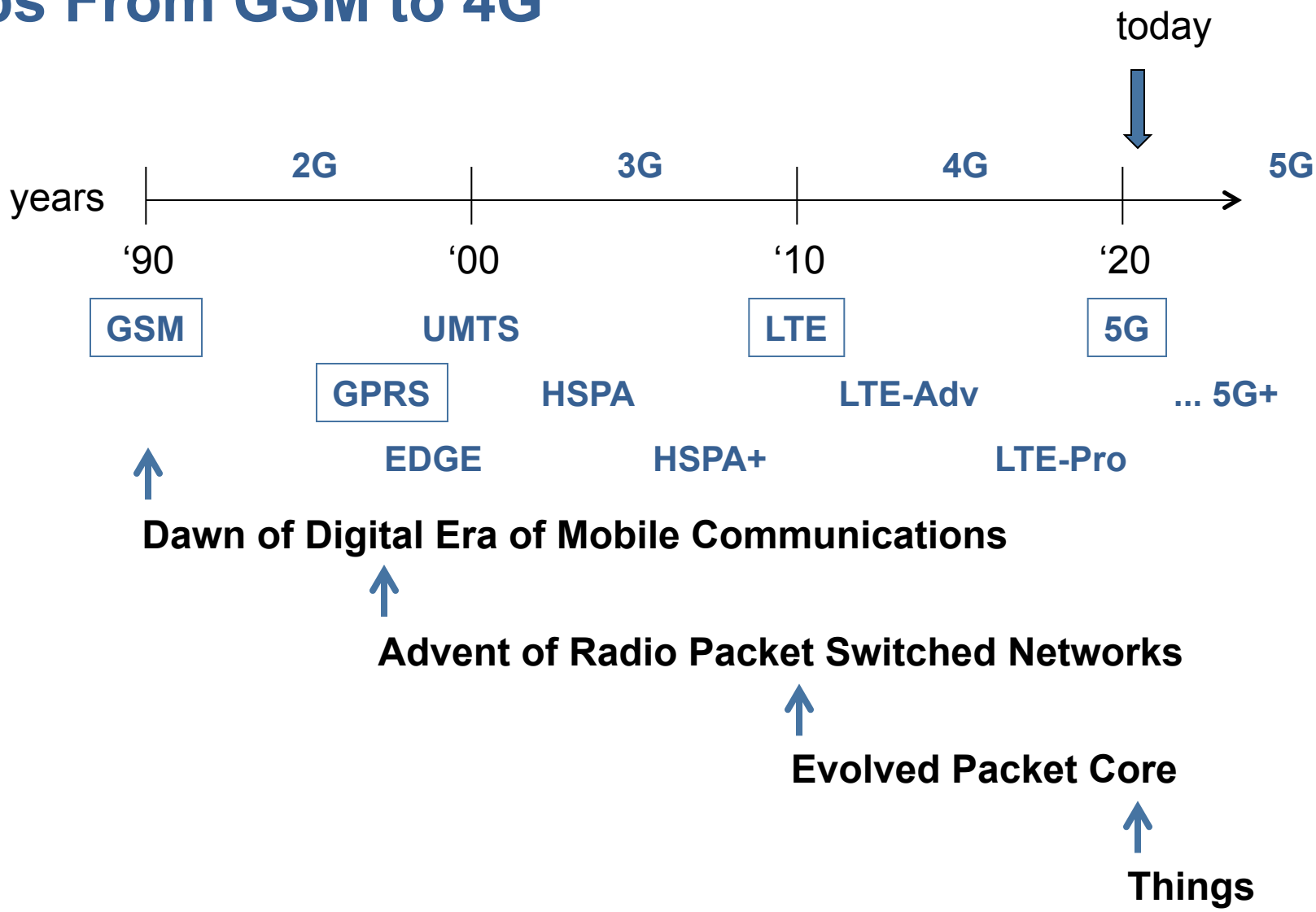
Steps From GSM to 4G



Steps From GSM to 4G

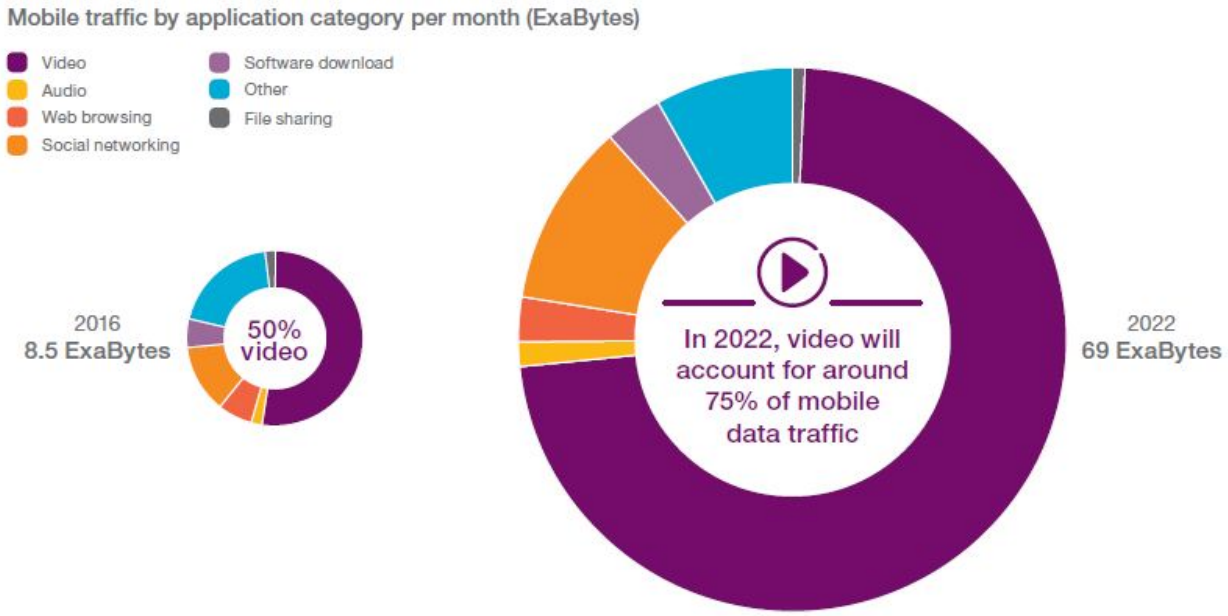


Steps From GSM to 4G



Trends: MRN

Data Traffic



[1] Video is likely to form a major part of file sharing traffic in addition to the identified application type 'video'
[2] Ericsson ConsumerLab, TV and Media (2016)

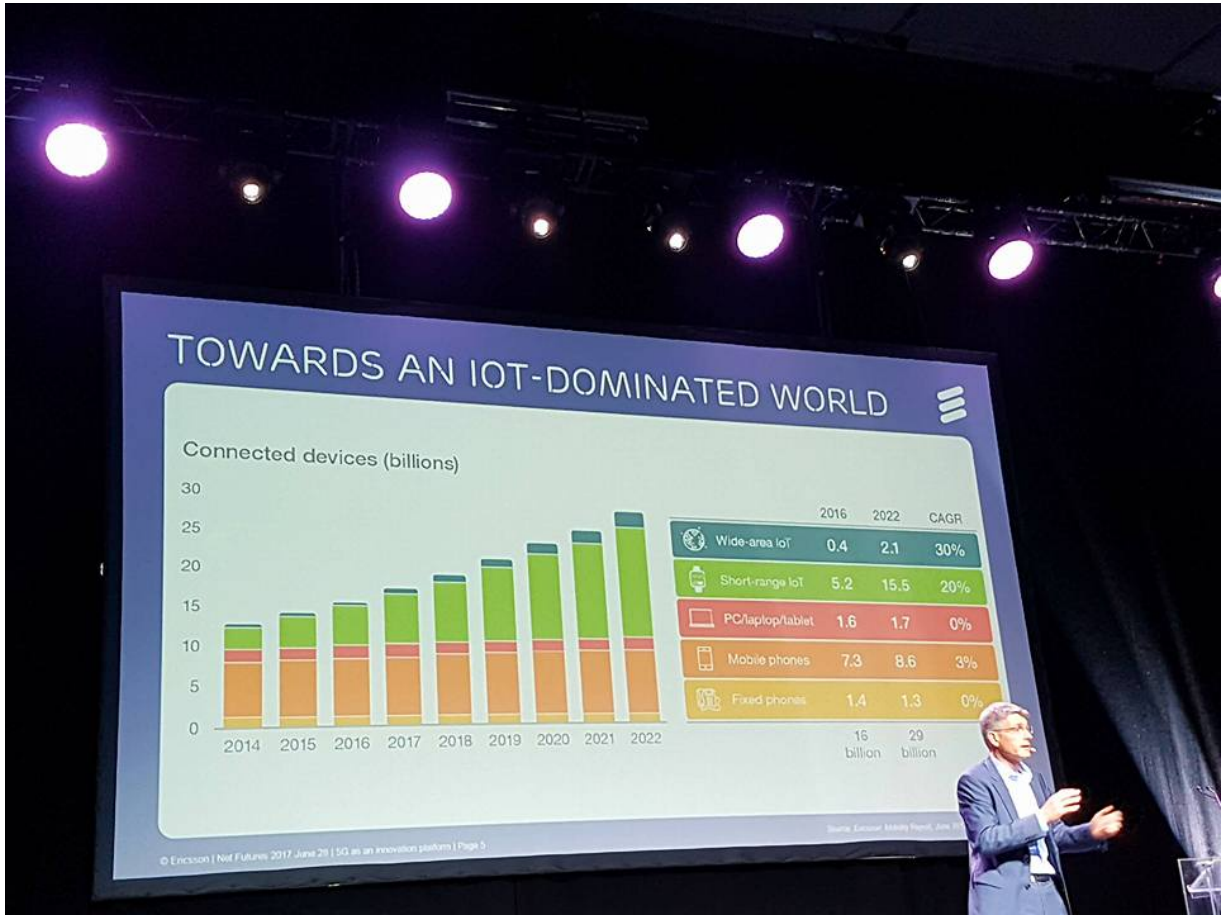
Trends: MRN

User Throughput

years	2G	3G	4G	5G
Bc [MHz]	0.200	5	5-100	5-1000
U (theoretical)	**500 Kbit/s**	**50 Mbit/s**	**4 Gbit/s**	**> 100 Gbit/s**
	x 100	**x 100**	**x 100**	

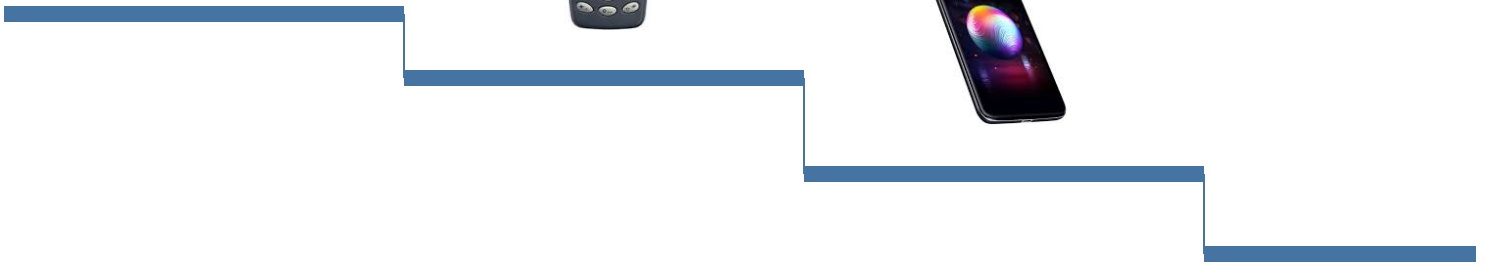
Trends: MRN

Number and Type of Connected Devices



Trends

Latency



	2G	3G	4G	5G
Bandwidth [MHz]	0.200	5	5-100	5-1000
Latency	**300 ms**	**100 ms**	**10 ms**	**1 ms**

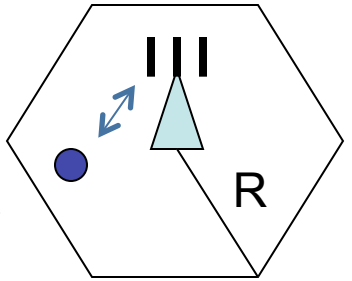
Access Network

Area Coverage Networks / Cellular Networks

Service Area

Scheduling

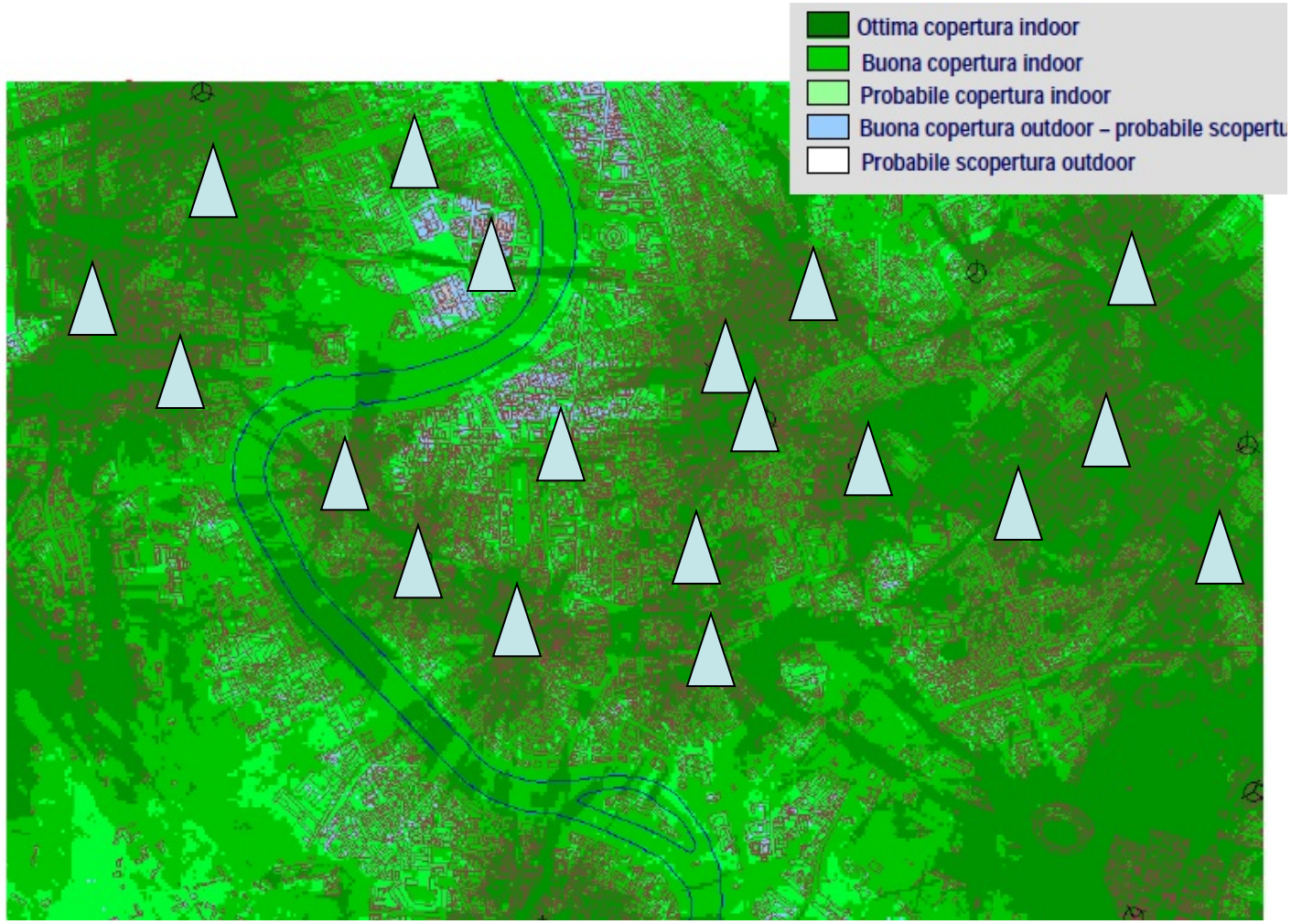
Power Control



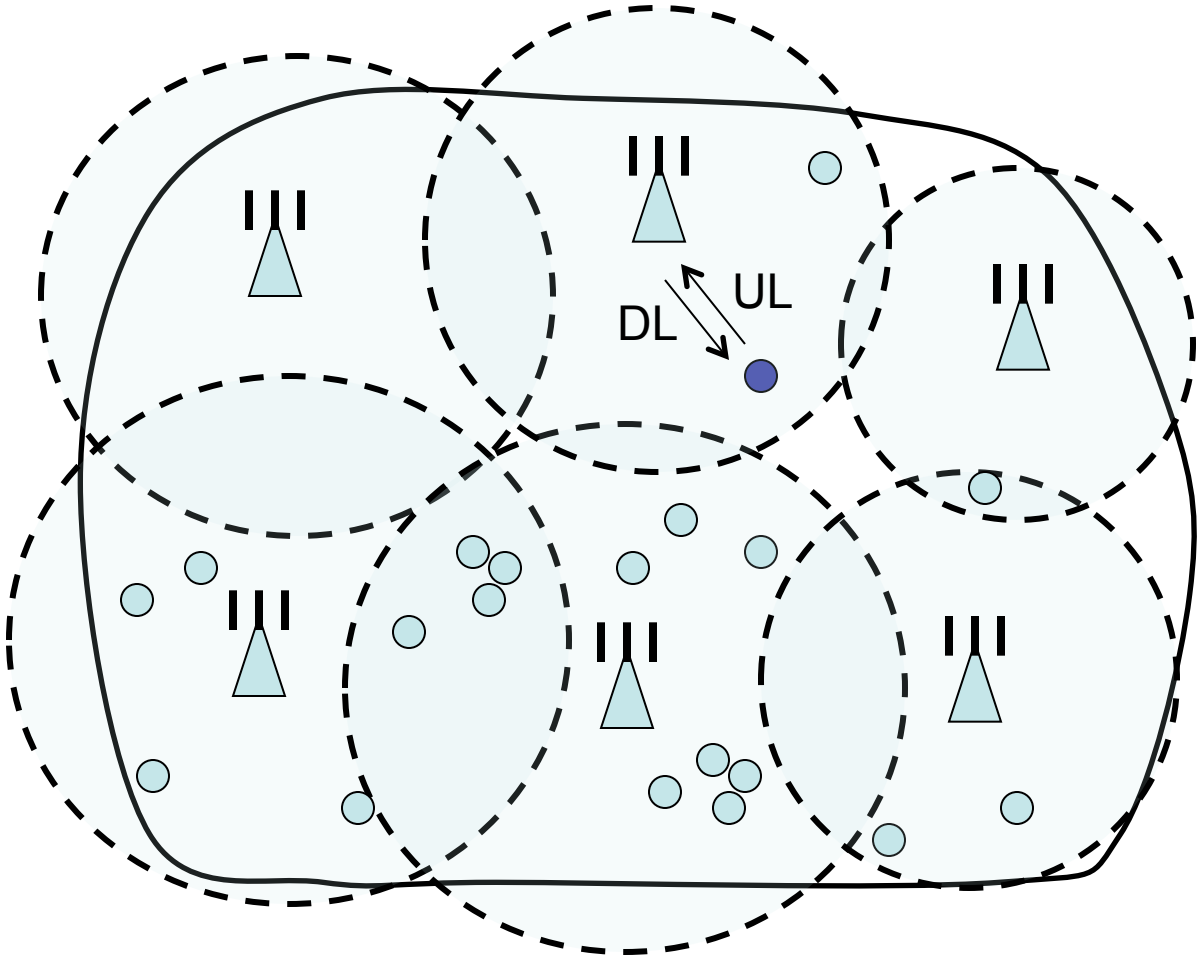
One base per cell with omnidirect. antenna system

Handover

Area Coverage Networks / Cellular Networks

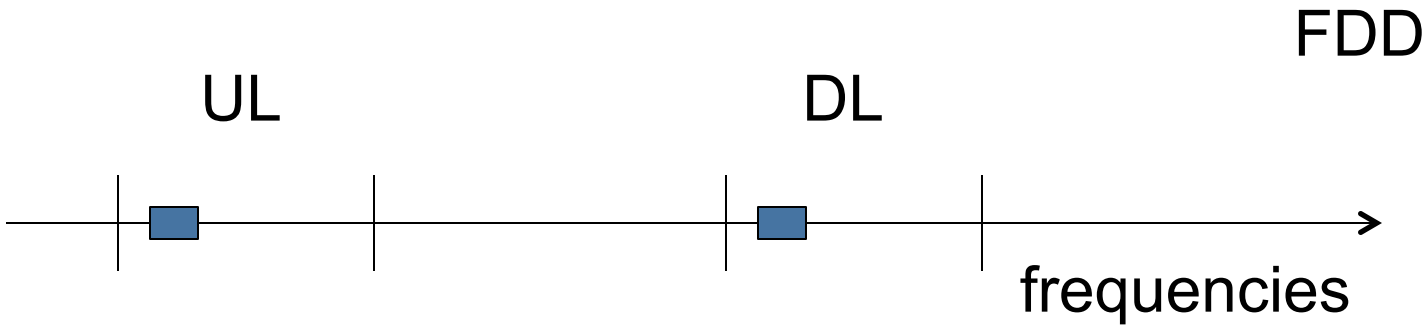


Area Coverage Networks / Cellular Networks



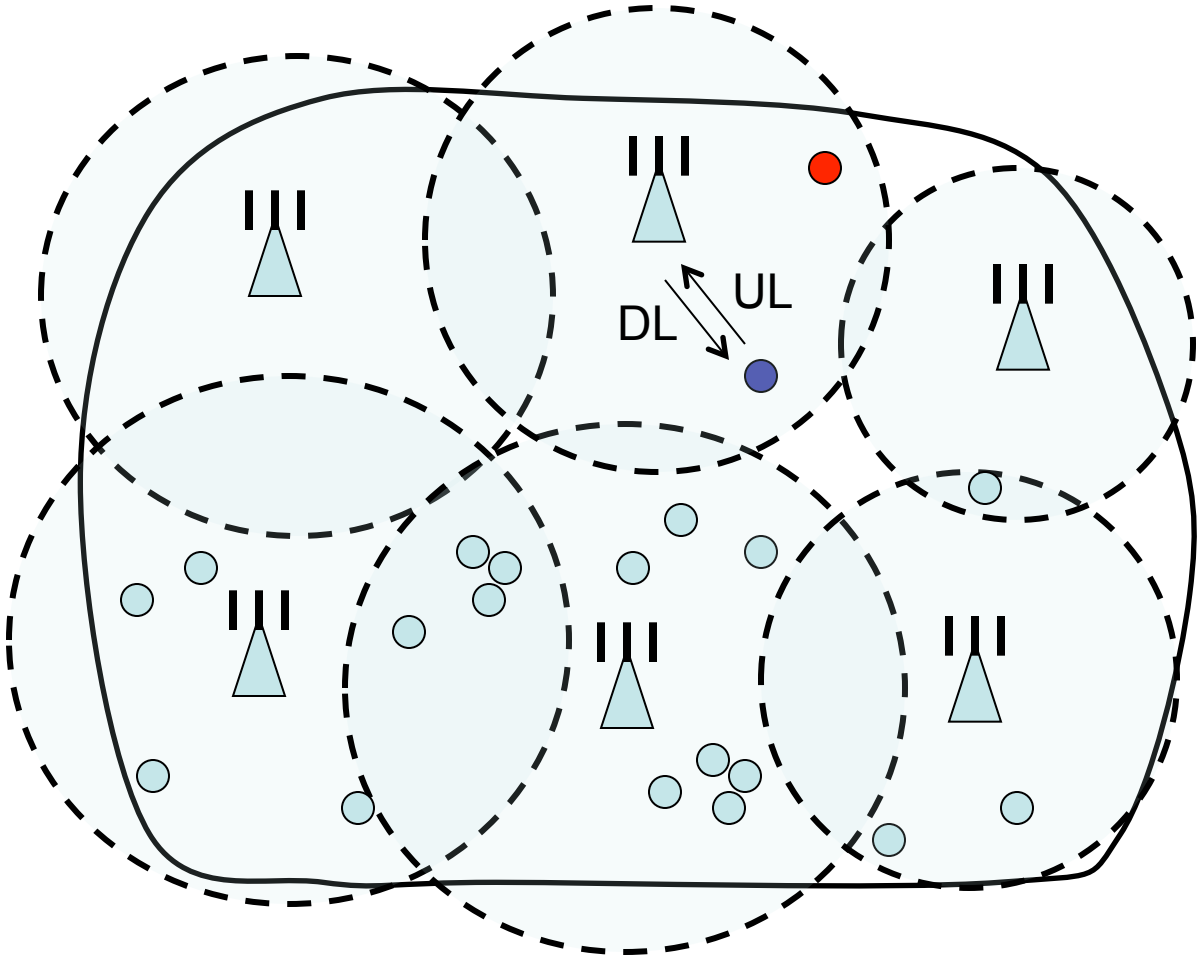
Downlink and Uplink

Area Coverage Networks / Cellular Networks



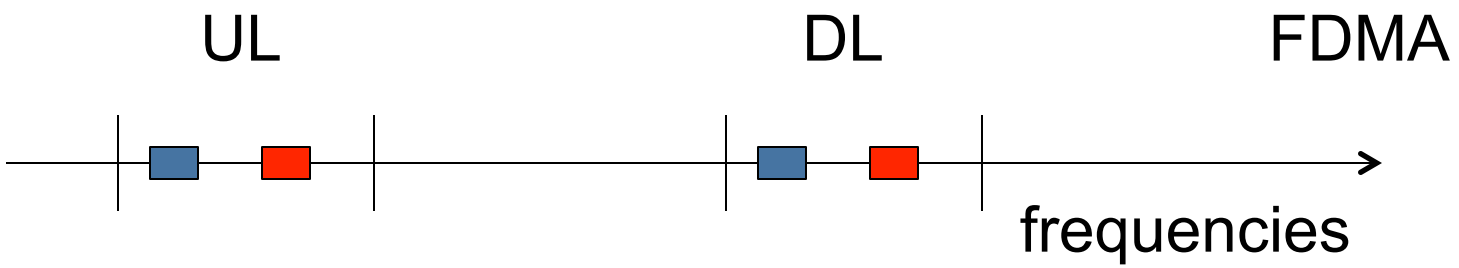
Downlink and Uplink

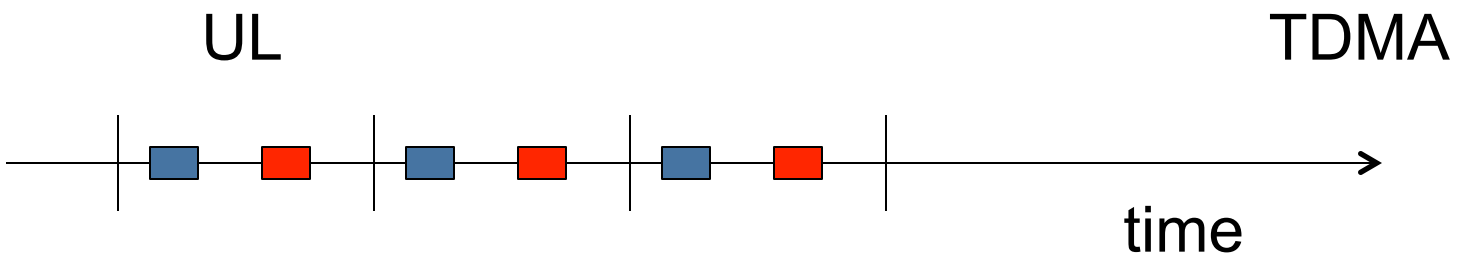
Area Coverage Networks / Cellular Networks



Intra-cell interference

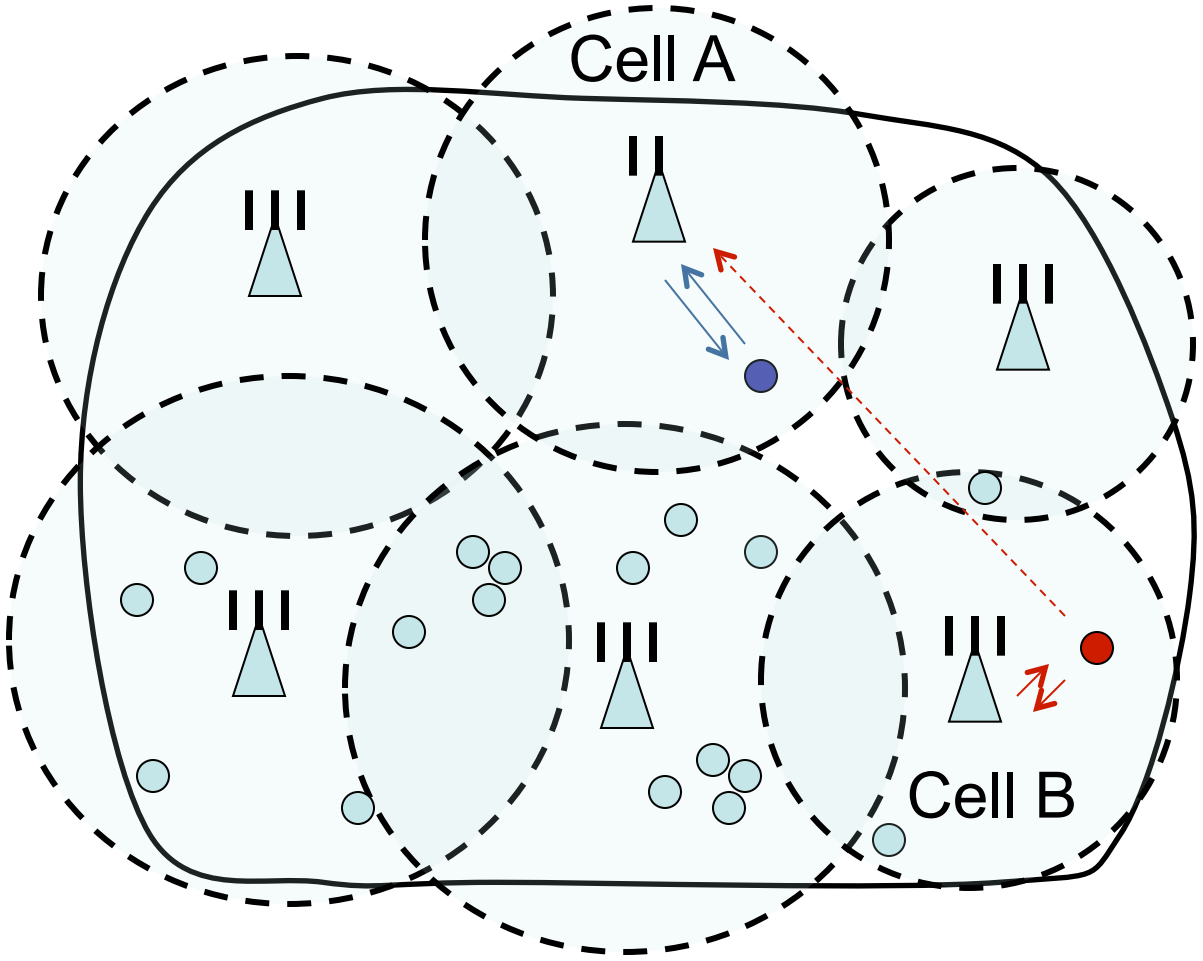
Area Coverage Networks / Cellular Networks





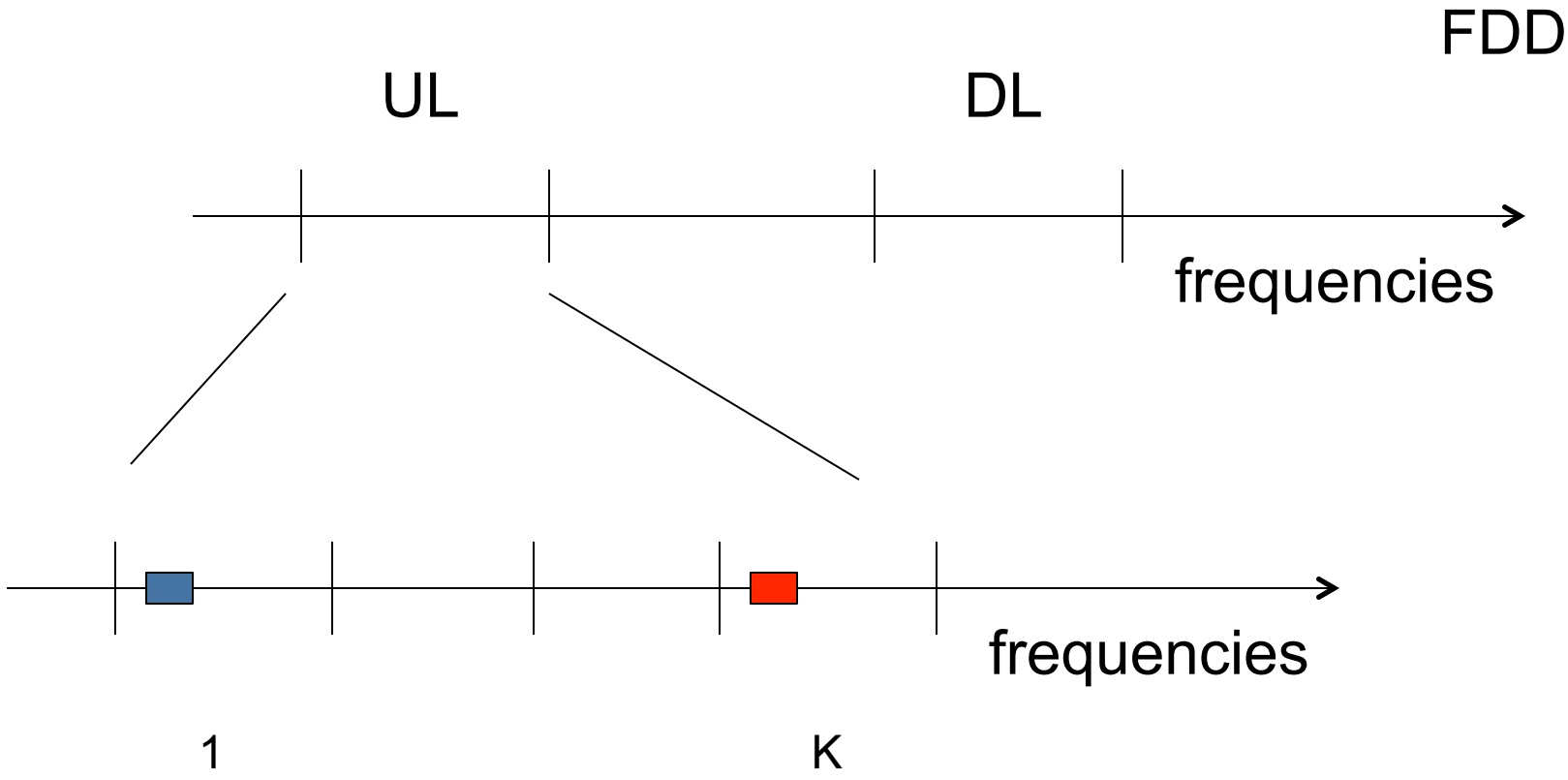
Intra-cell interference

Area Coverage Networks / Cellular Networks



Inter-cell interference

Area Coverage Networks / Cellular Networks

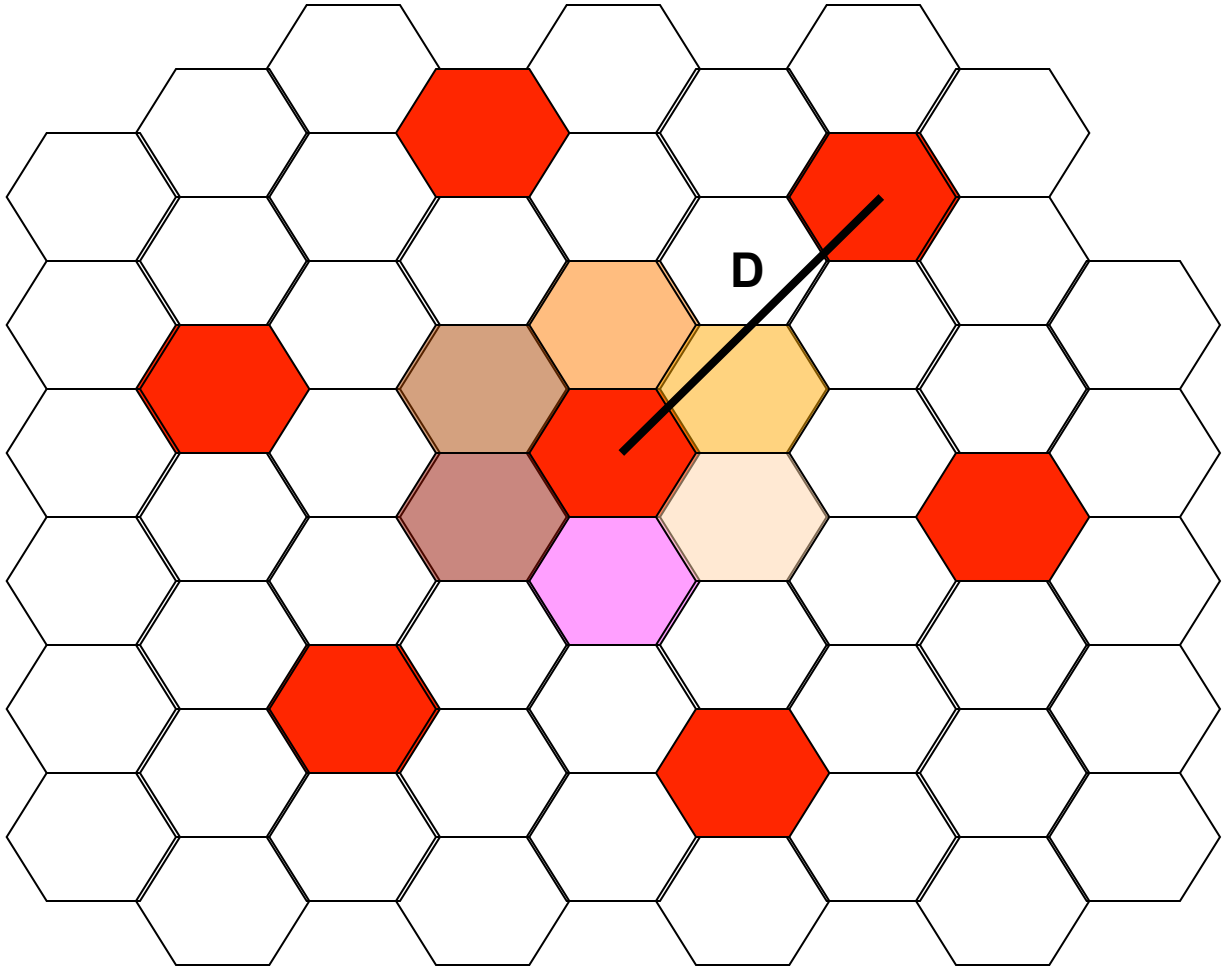


Inter-cell interference

Reuse

K = 7

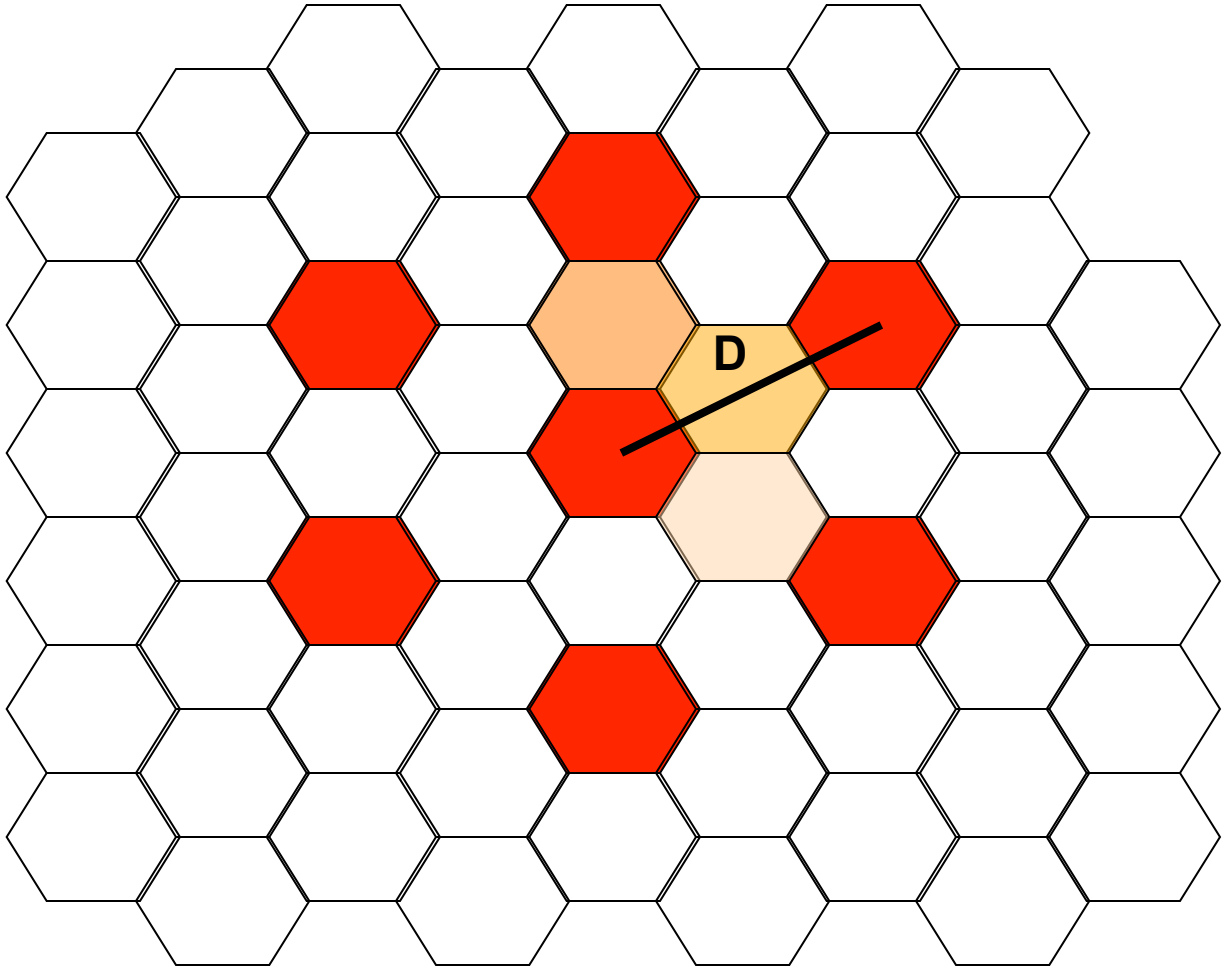
Six first – tier interferers



Reuse

K = 4

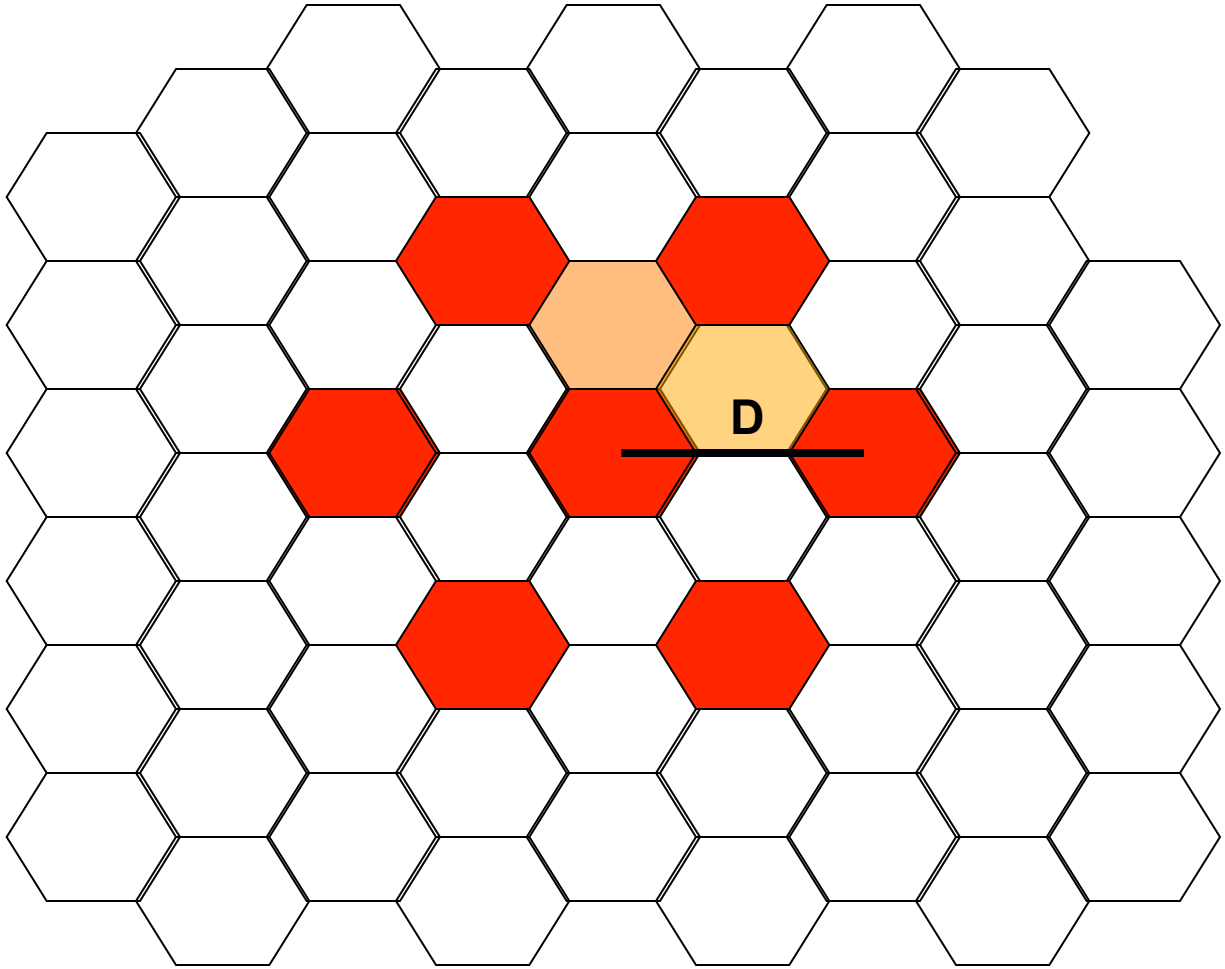
Six first – tier interferers



Reuse

K = 3

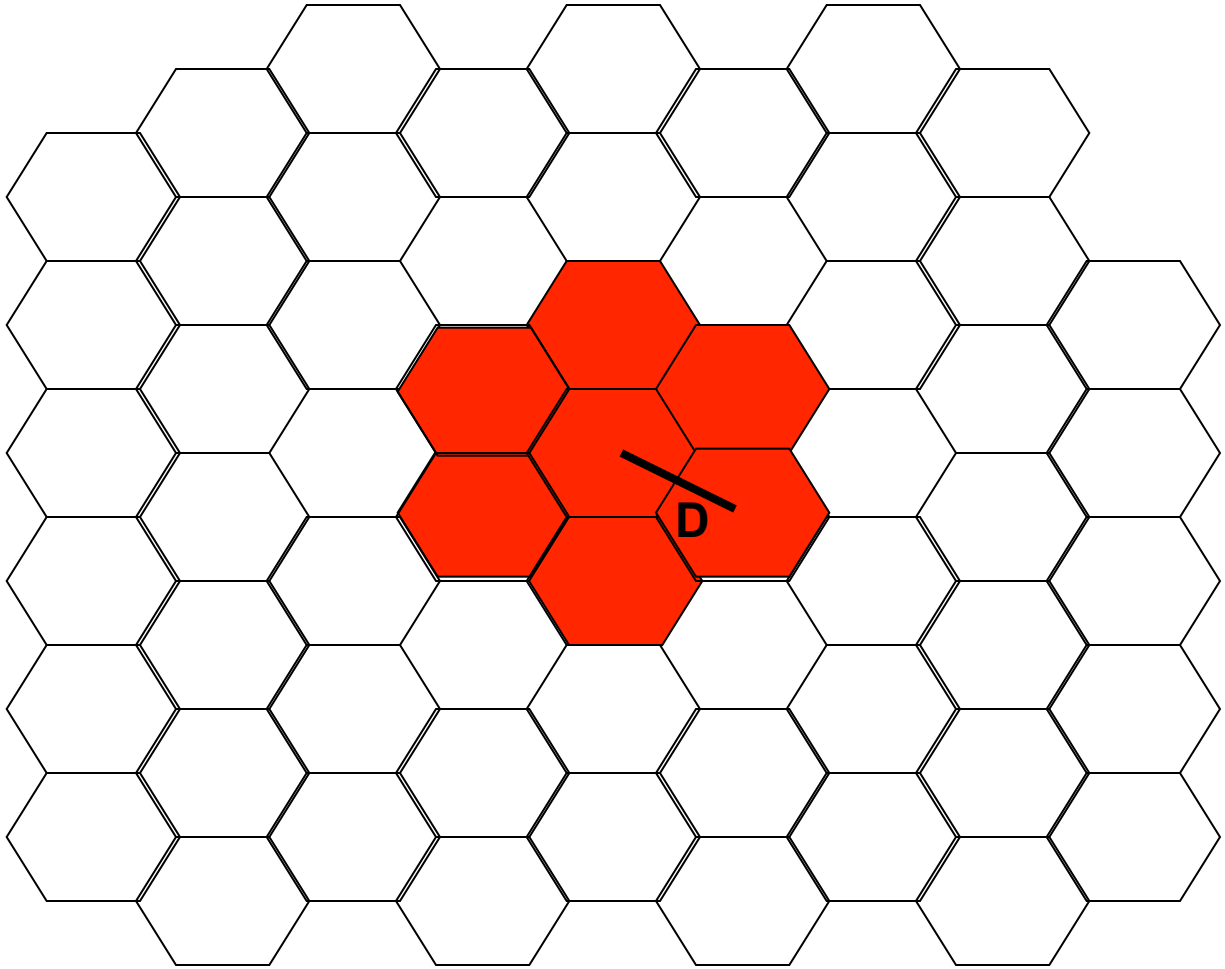
Six first – tier interferers



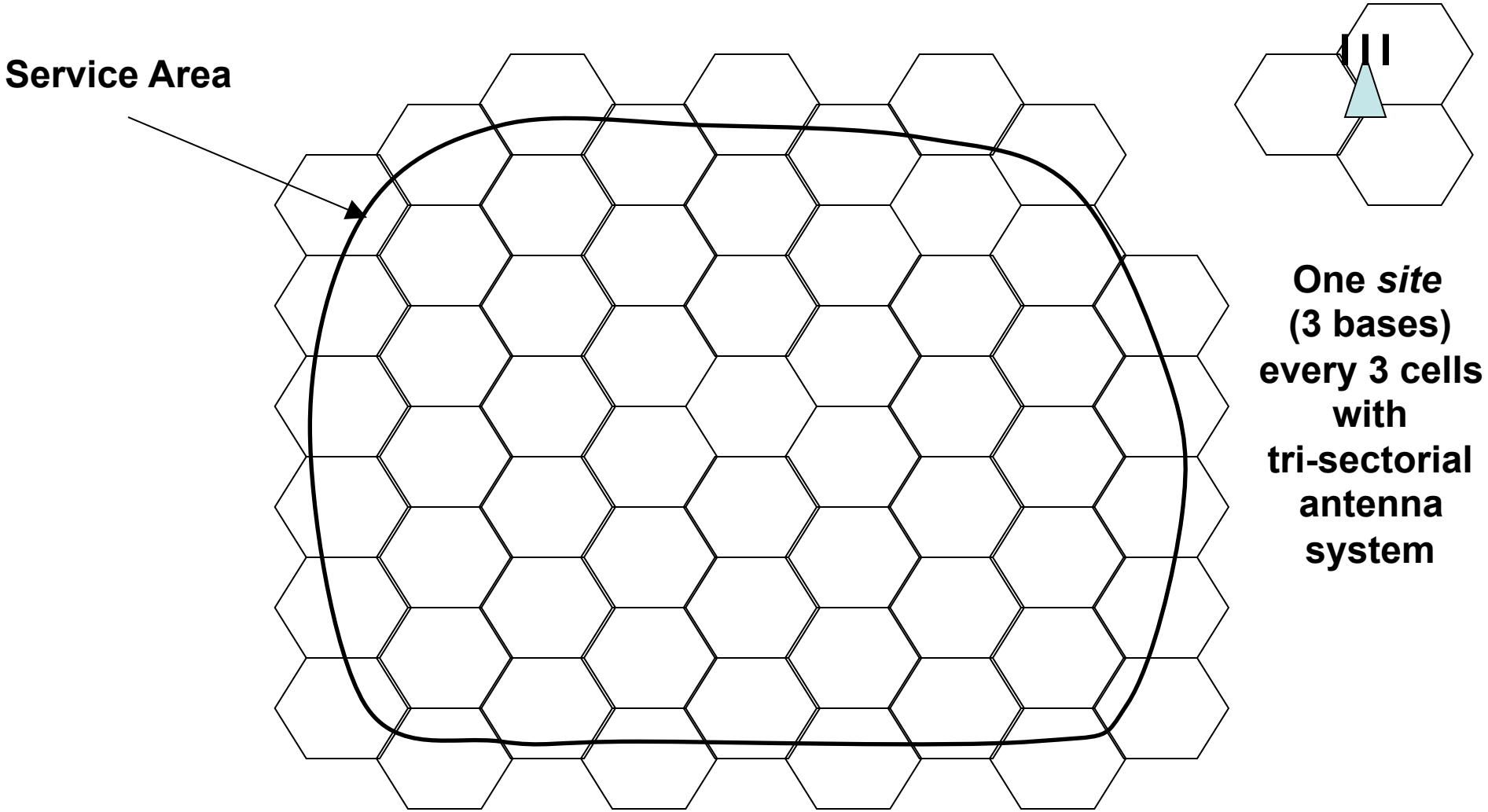
Reuse

K = 1

Six first – tier interferers

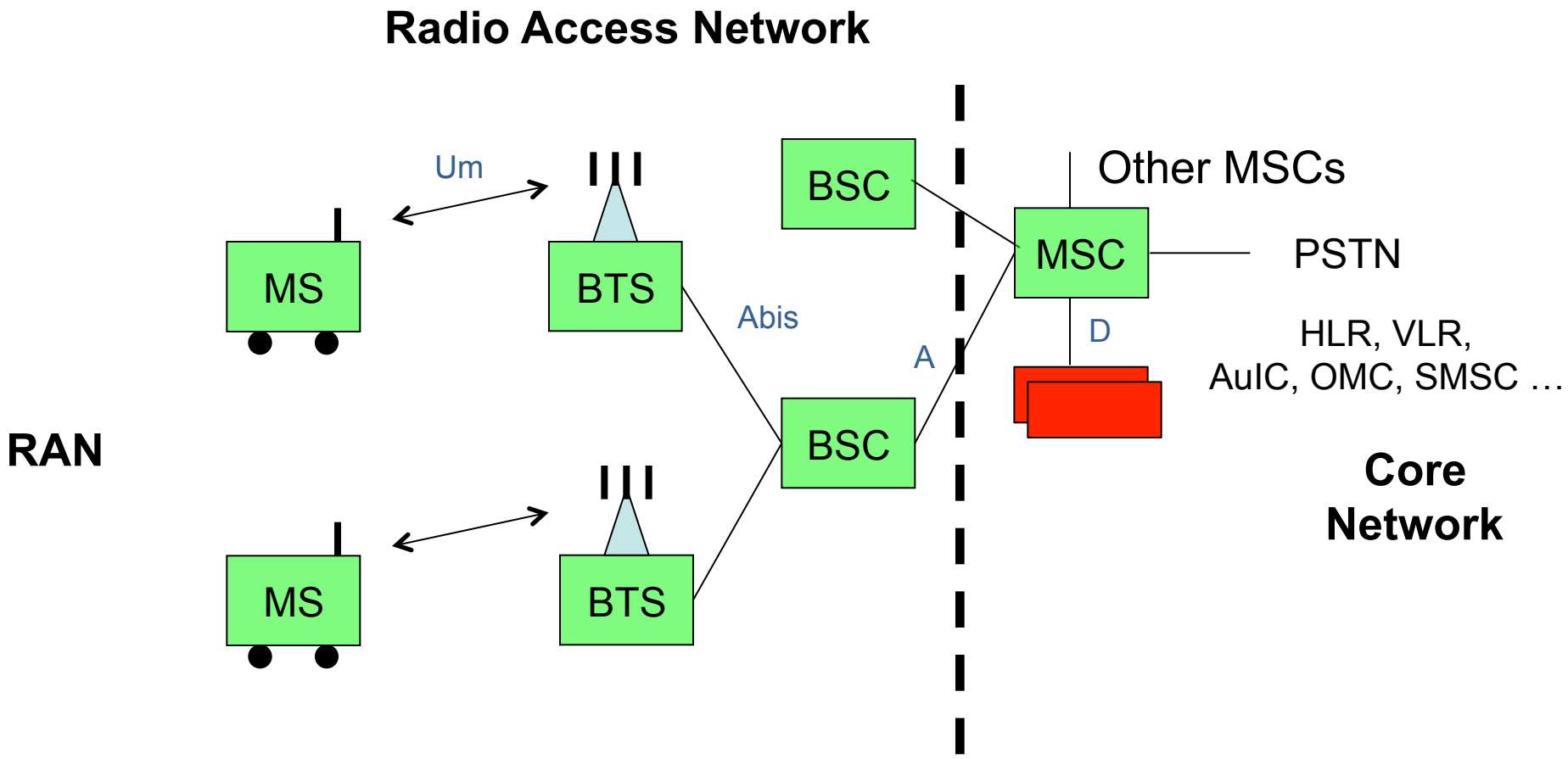


Area Coverage Networks / Cellular Networks

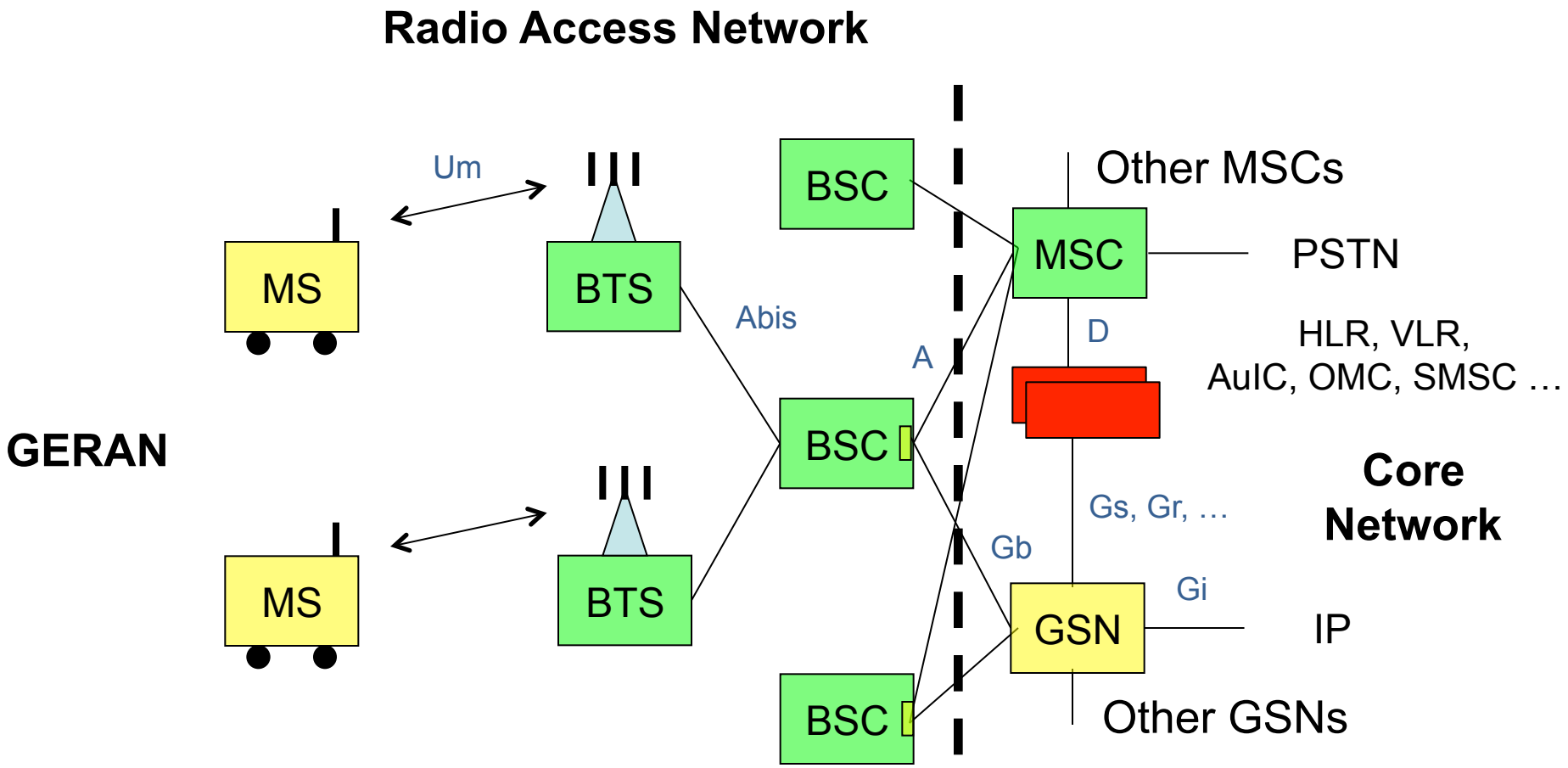


Network Architecture

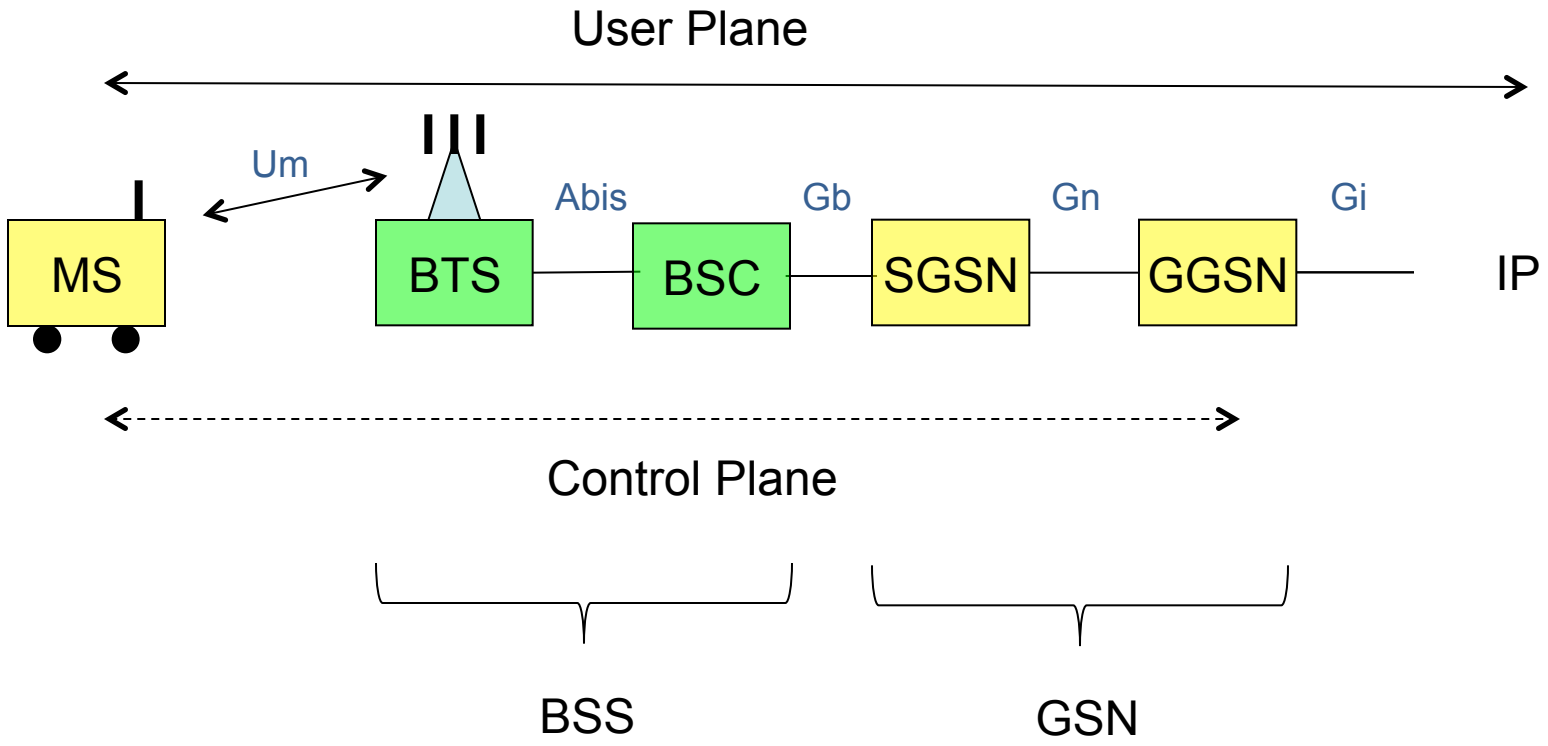
Network Architecture: 2G (GSM)



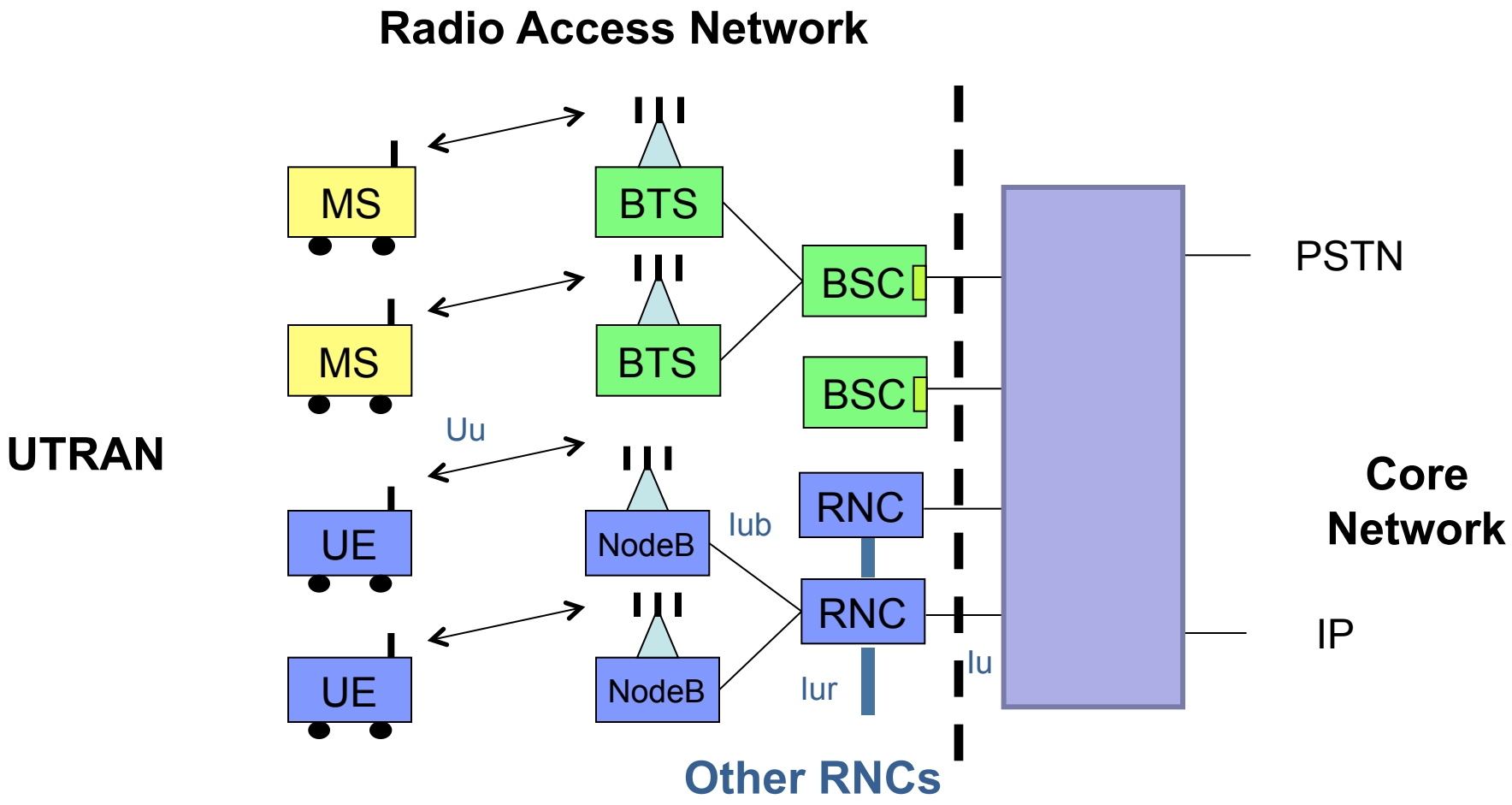
Network Architecture: 2.5G (Rel. 97)



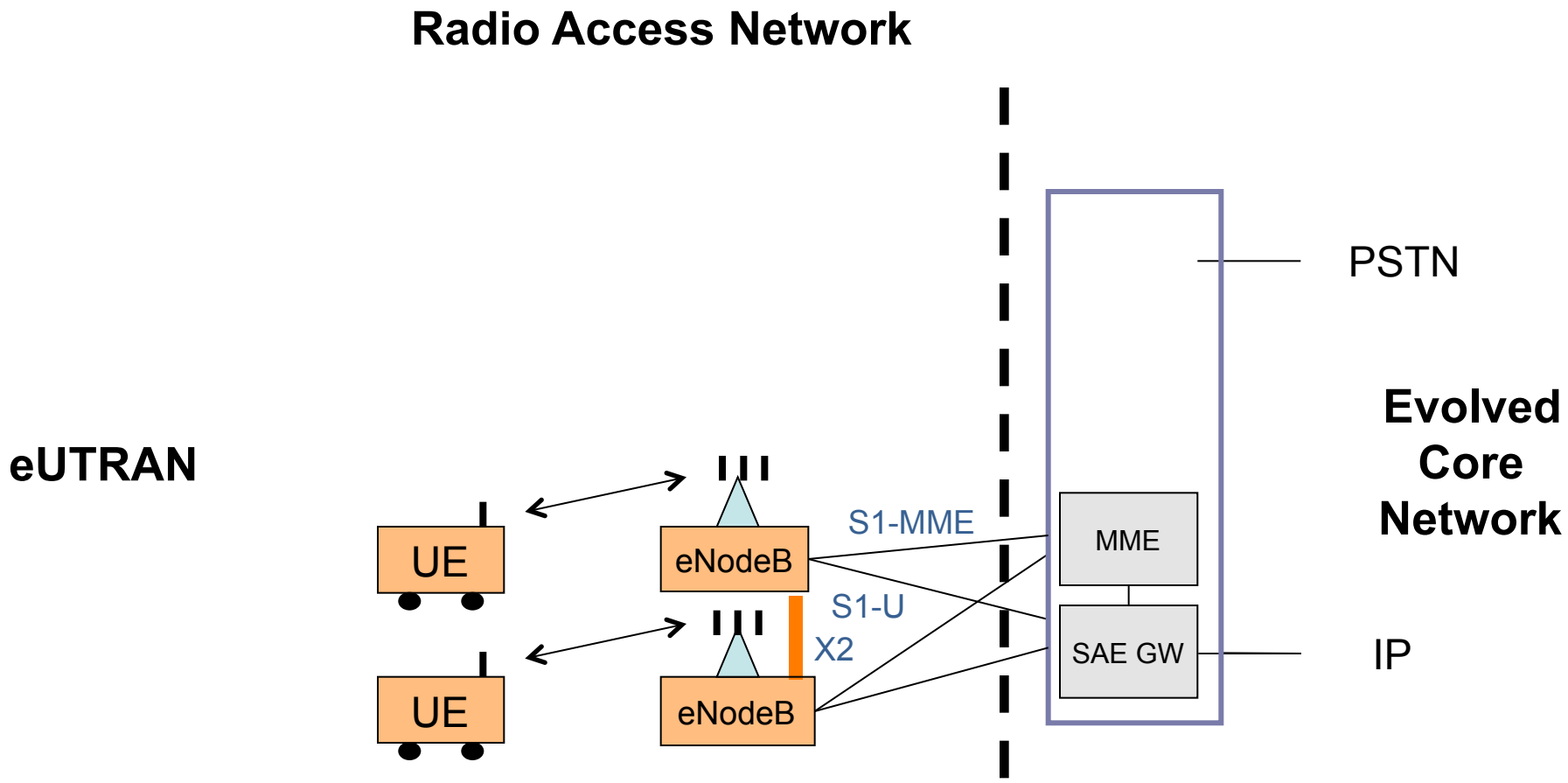
User / Control Plane (Rel. 97)



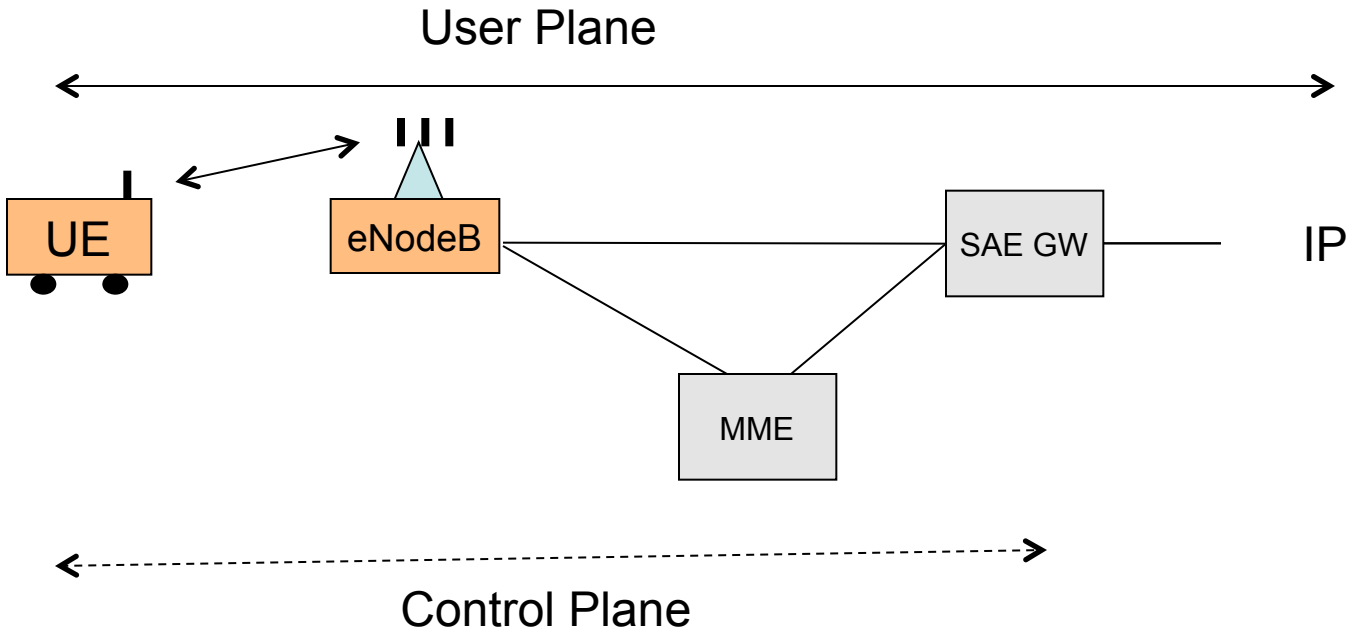
Network Architecture: UMTS (Rel. 99)



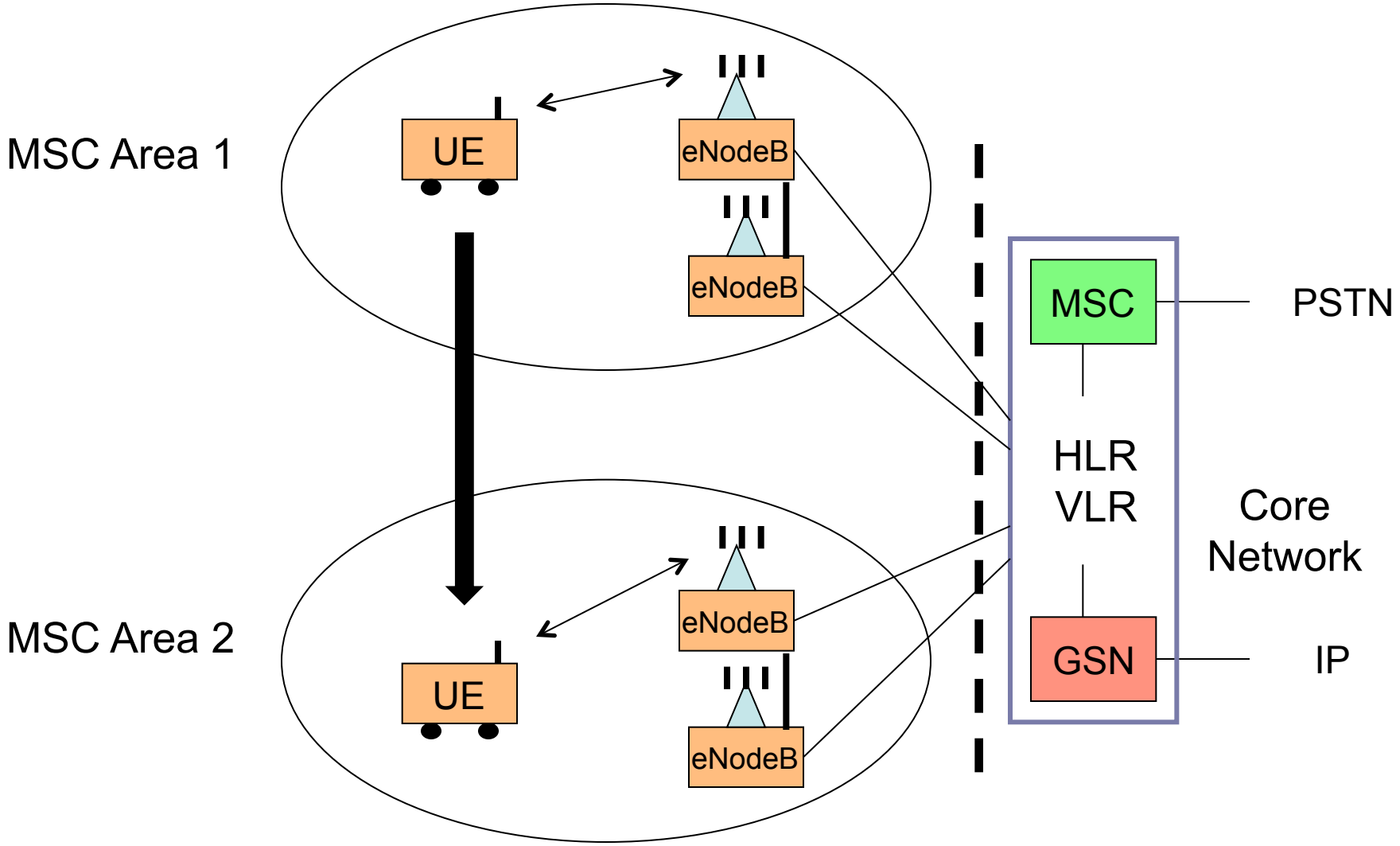
Network Architecture: LTE (Rel. 8)



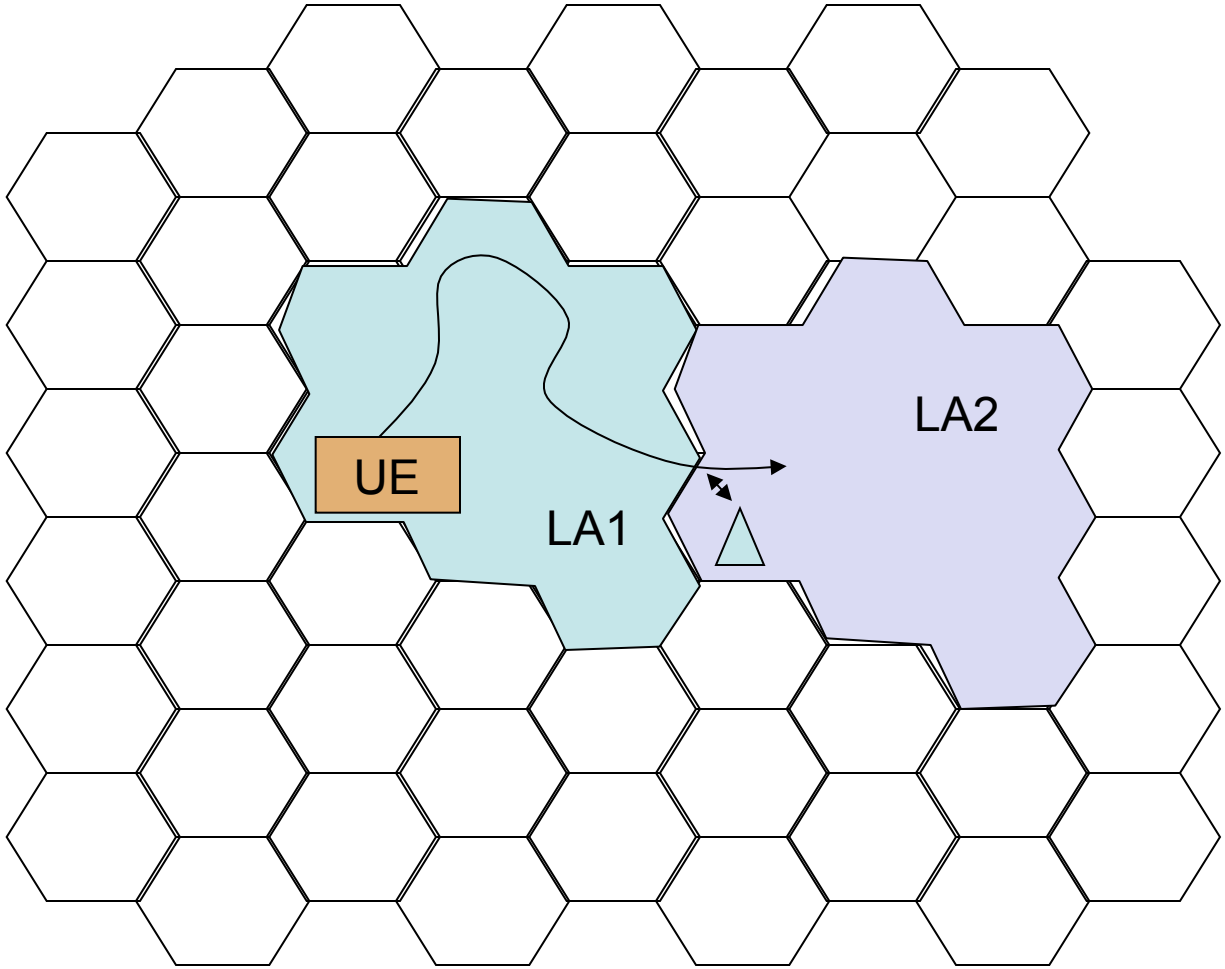
User / Control Plane (Rel. 8)



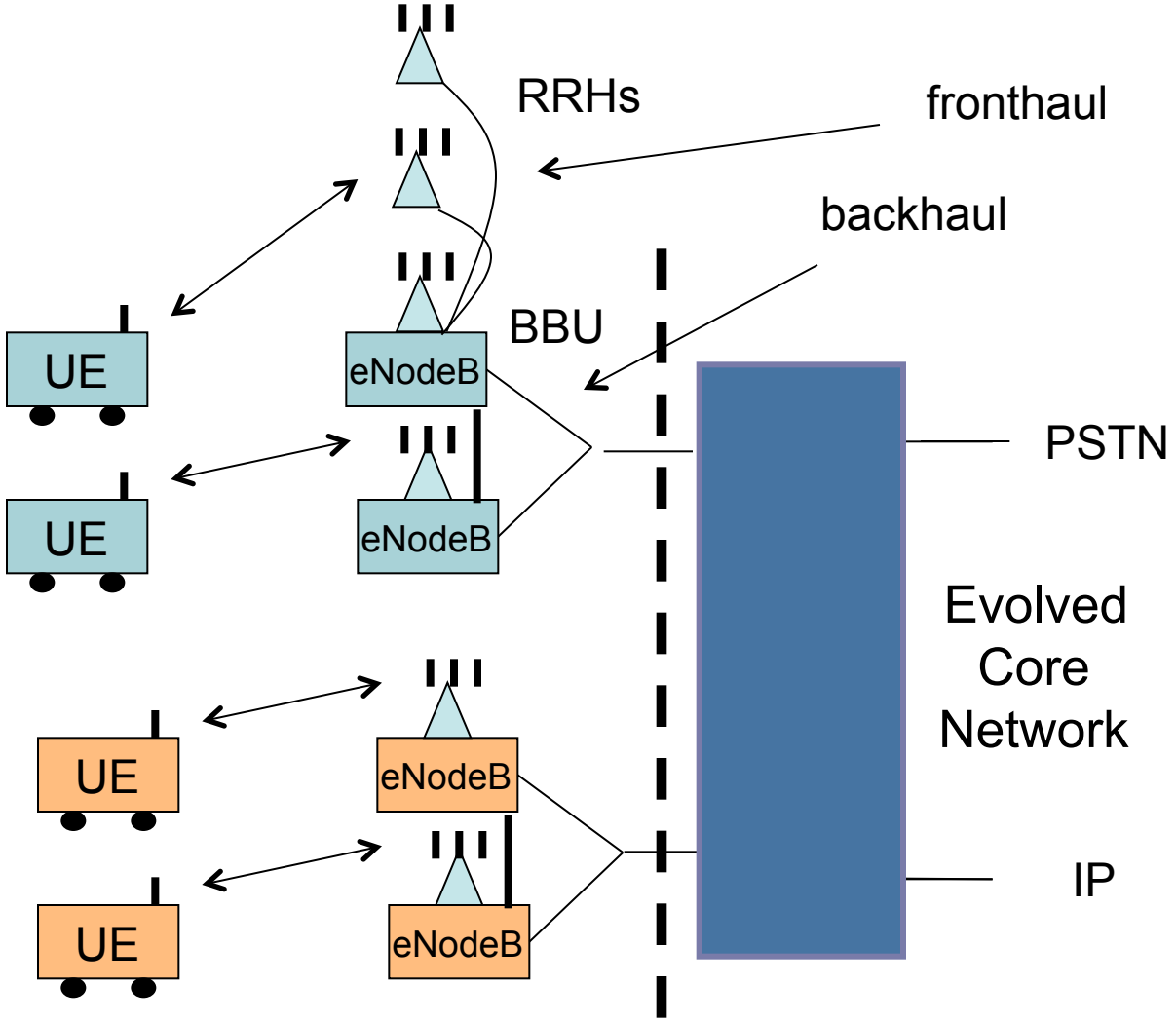
Mobility Management (Macro Level): HLR, VLR



Mobility Management (Micro Level): Location Areas



Network Architecture: 5G

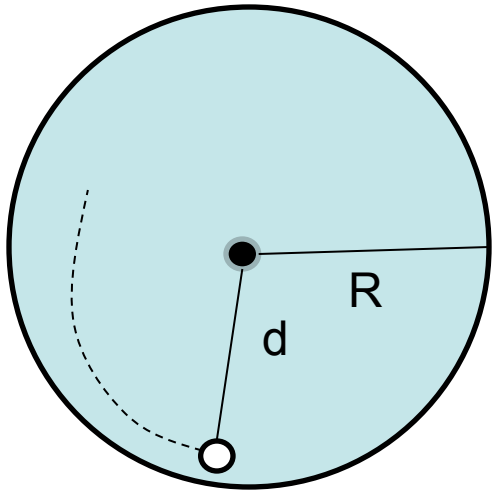


Radio Channel

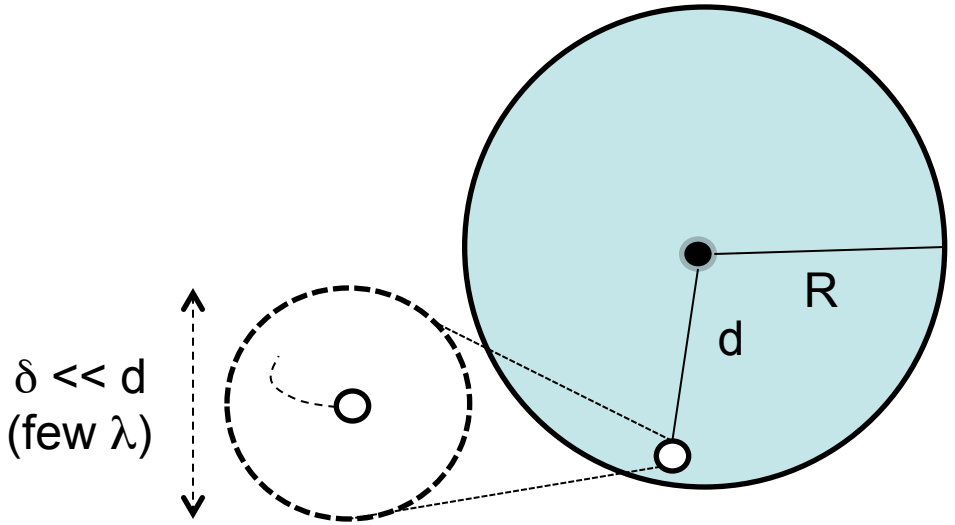
Radio Channel Characterisation

The main phenomena characterising the mobile channel can be categorised as:

1. **Large Scale** — **if observed only changing *significantly* the Tx-Rx relation**
2. **Small Scale** — **if observed with *small* changes of the Tx-Rx relation**

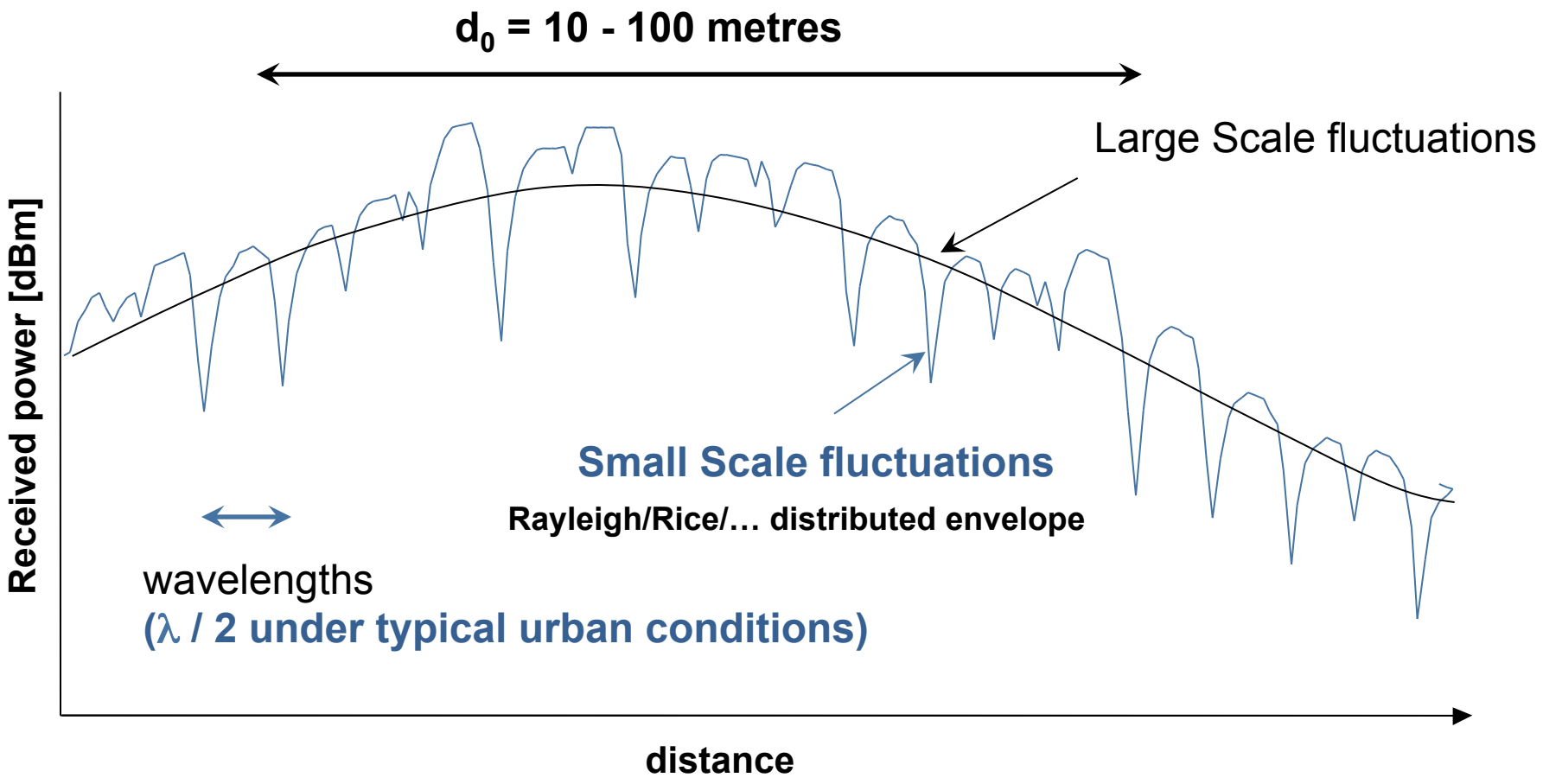


Large Scale



Small Scale

Small Scale: Narrowband (Mobile) Characterisation



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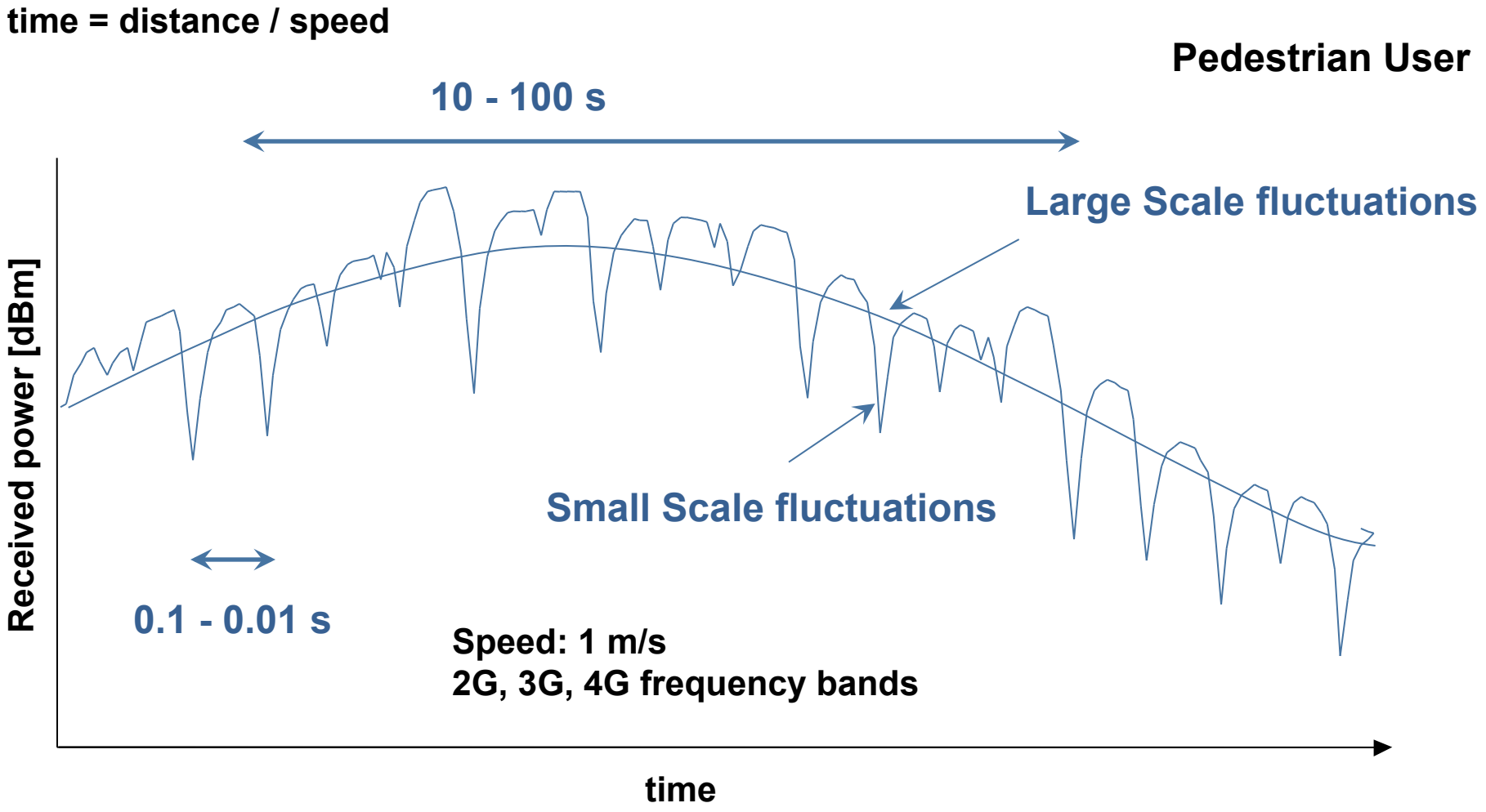
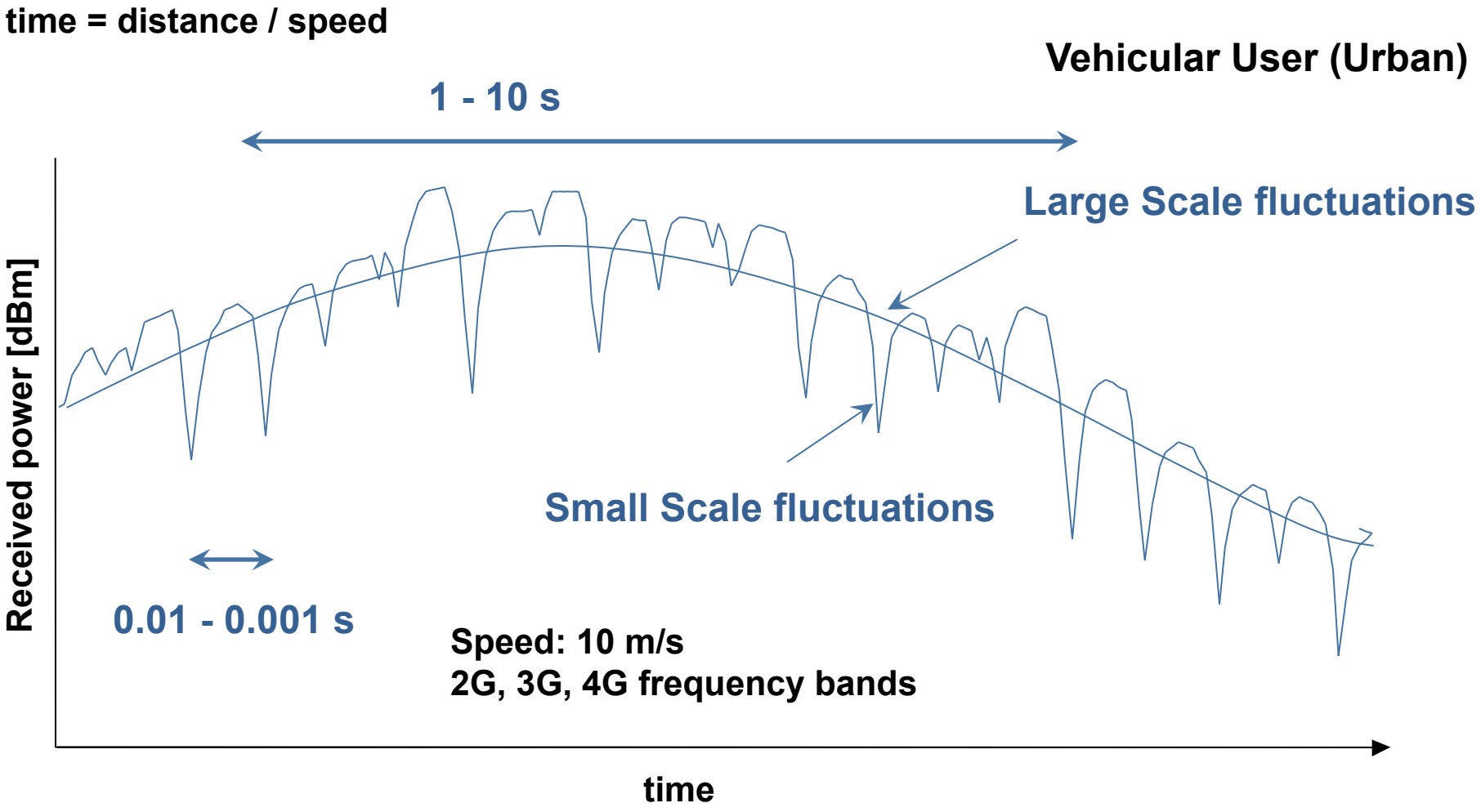
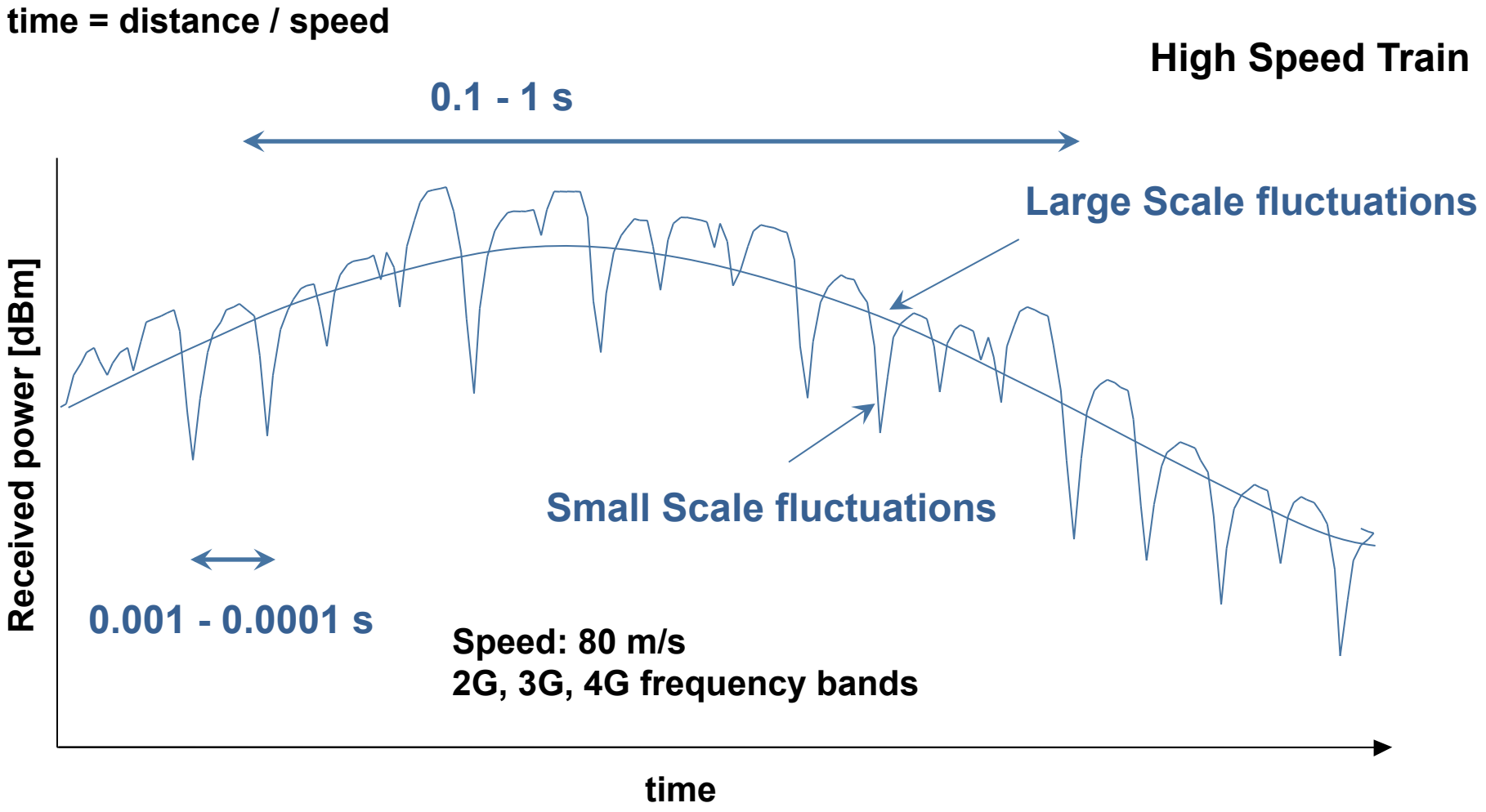


Small Scale: Narrowband (Mobile) Characterisation



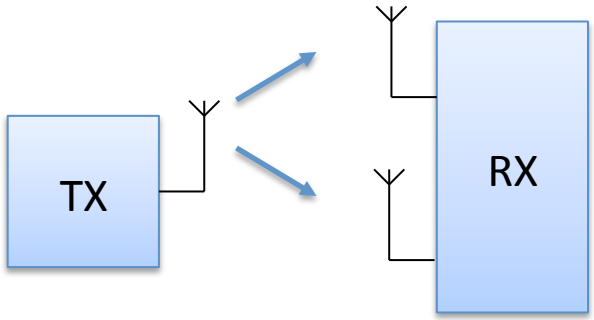
Small Scale: Narrowband (Mobile) Characterisation



2G and 4G

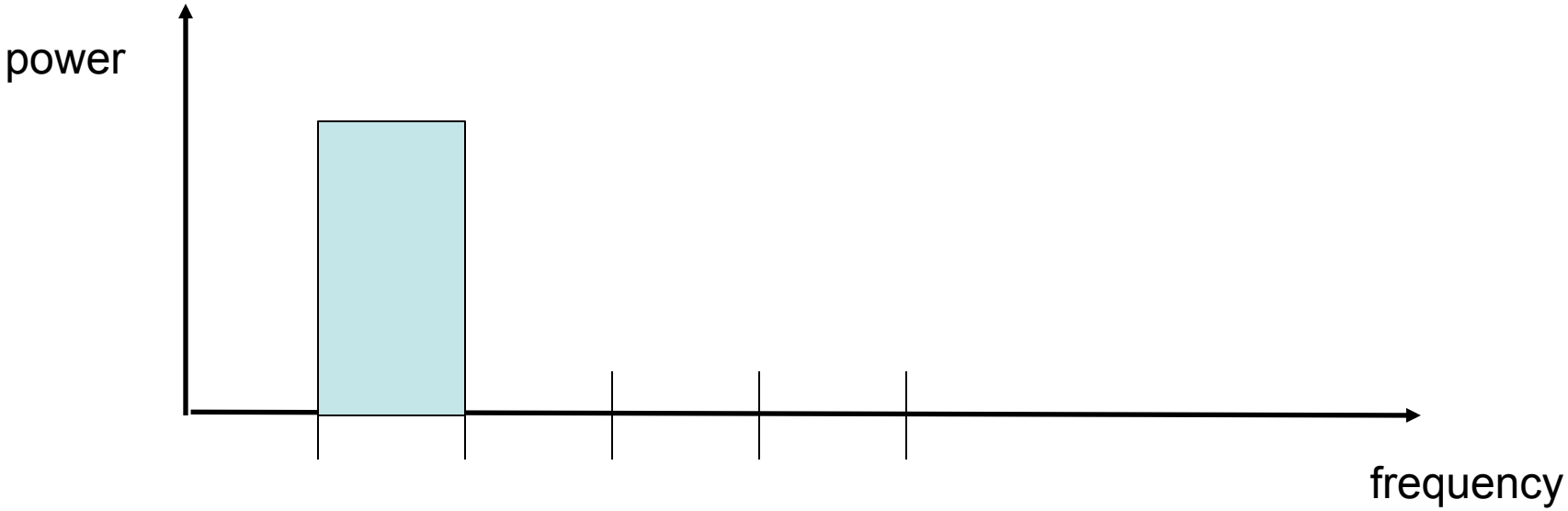
2G: GSM

Diversity

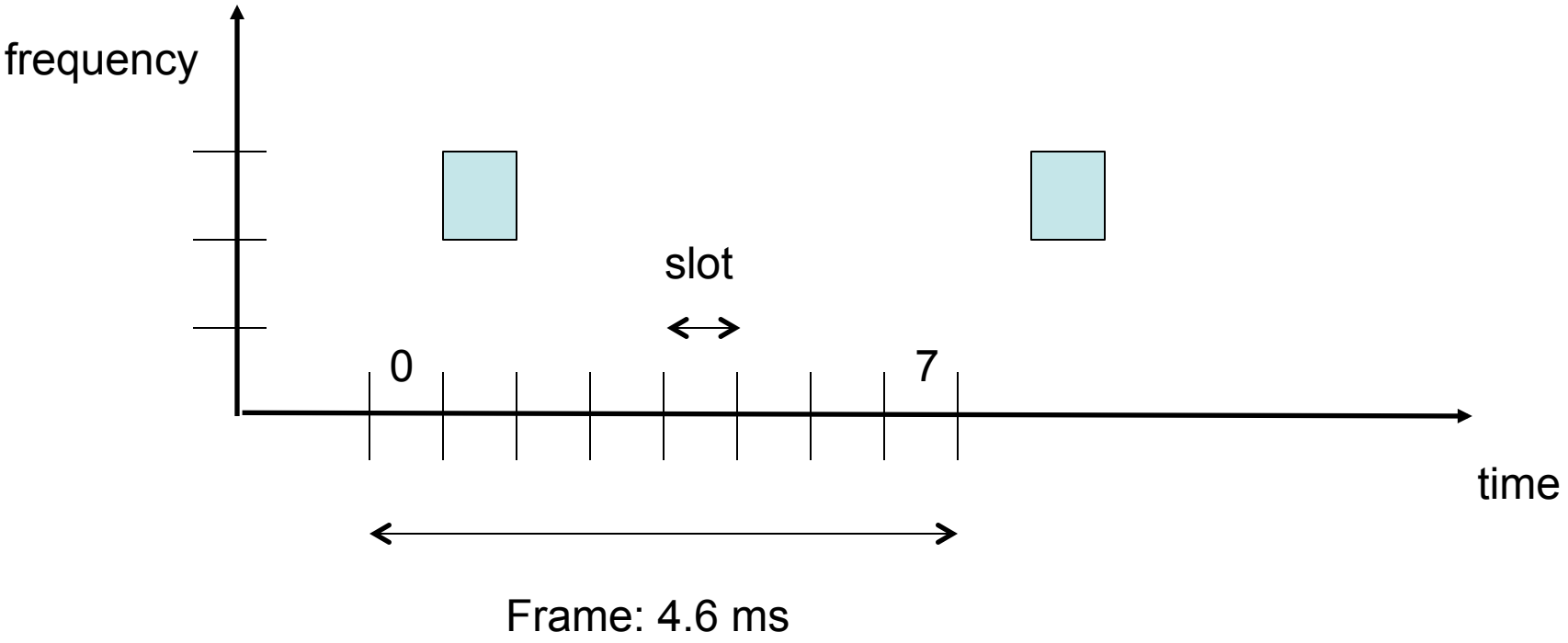


2G: FTDMA

Bc = 200 KHz

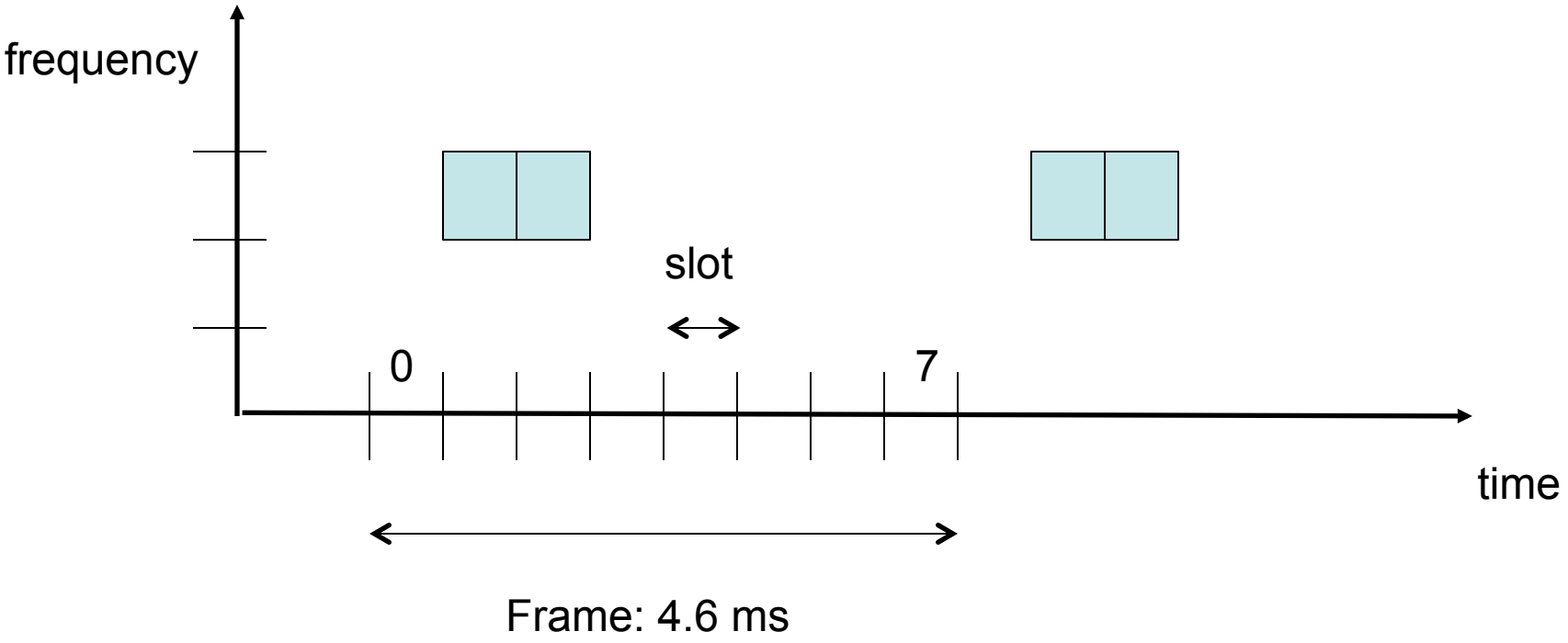


2G: FTDMA



2.5G (GPRS): FTDMA

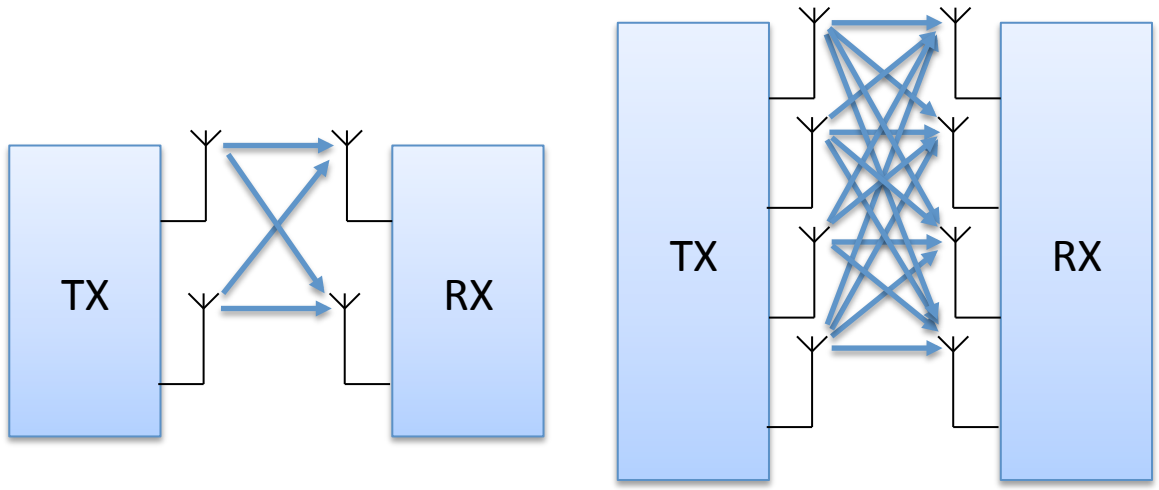
Bc = 200 KHz



4G: MIMO

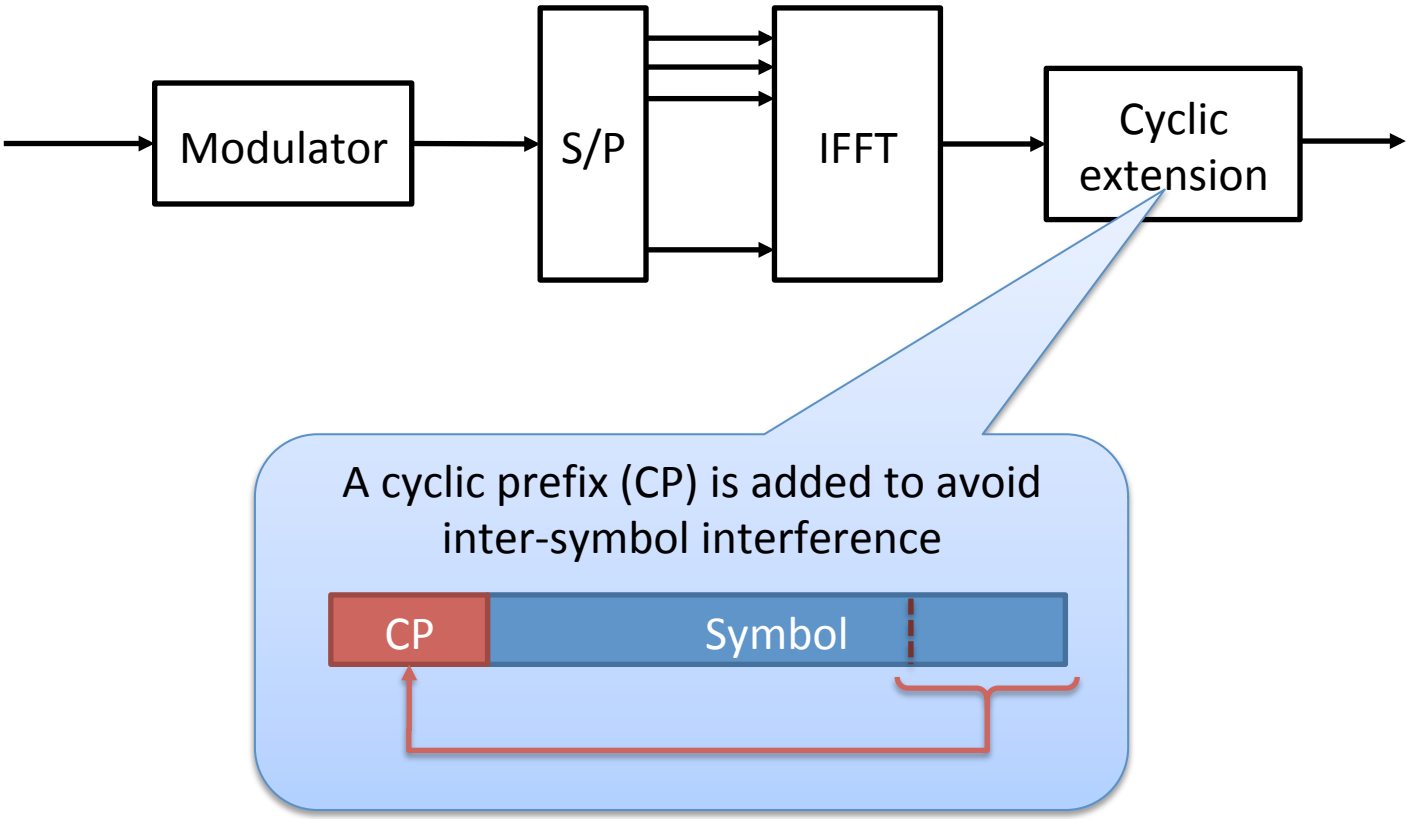
2 x 2

4 x 4



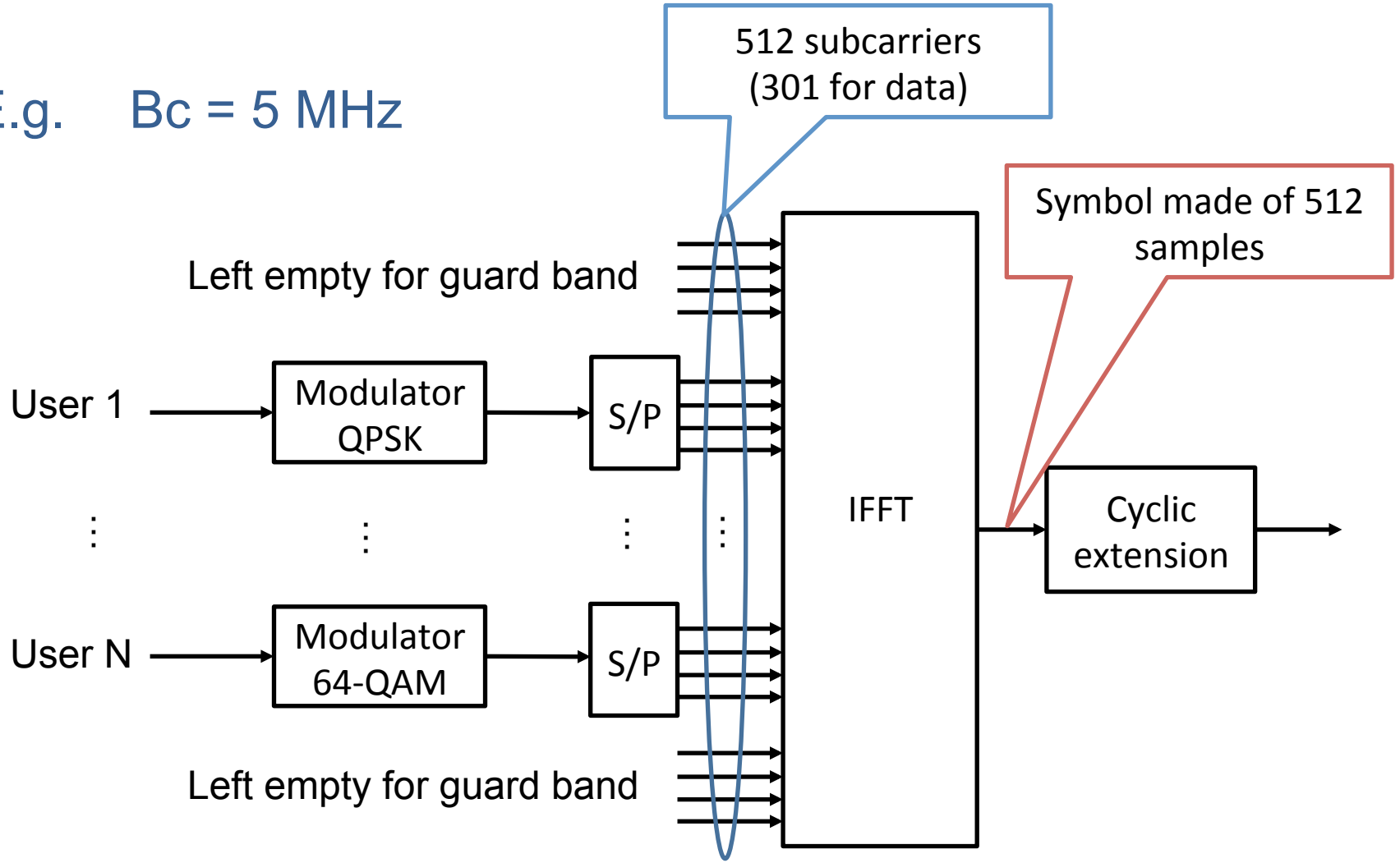
4G: OFTDMA

Bc = 1.4 MHz – 5 MHz – 10 MHz – 20 MHz



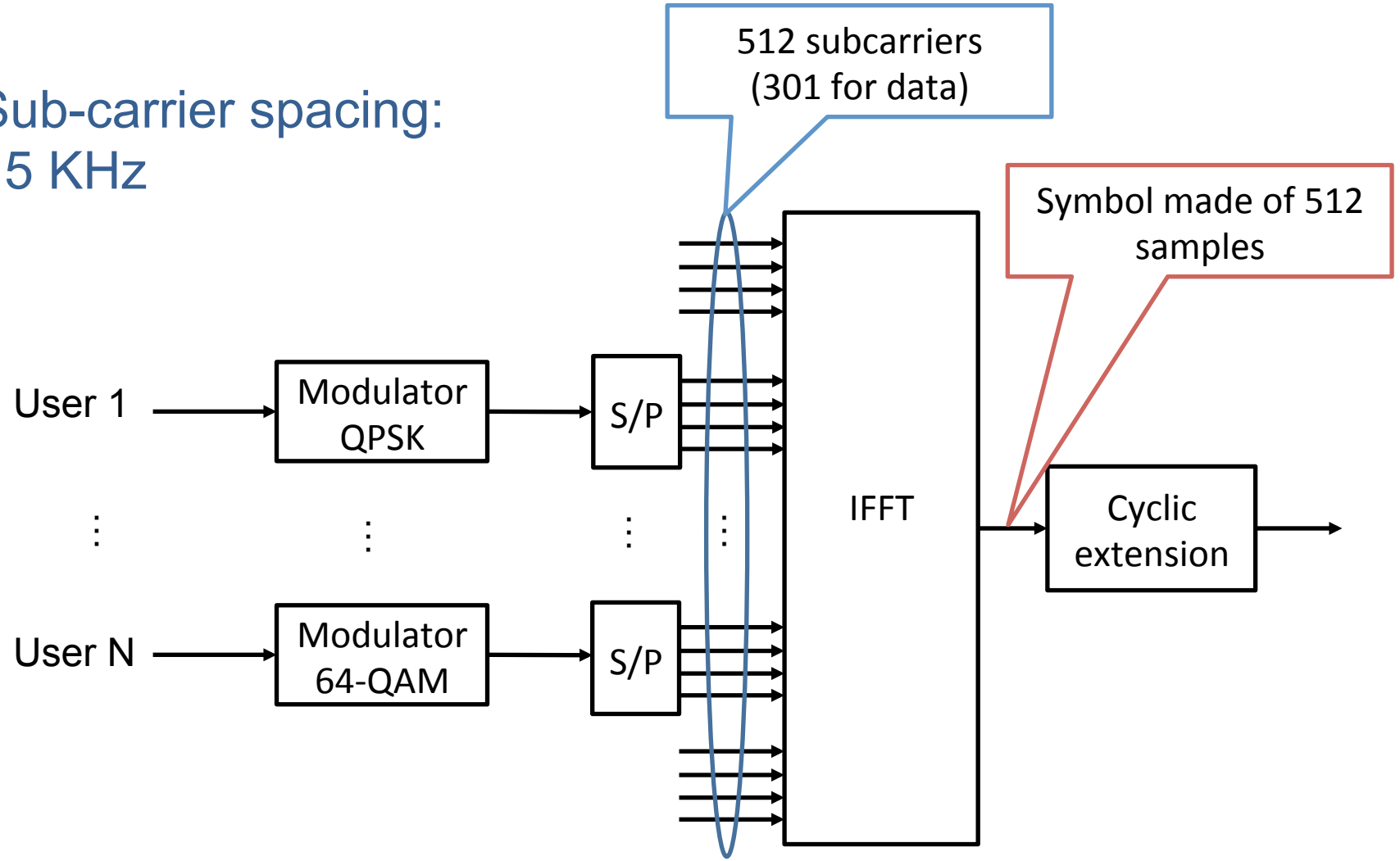
4G: OFTDMA

E.g. Bc = 5 MHz



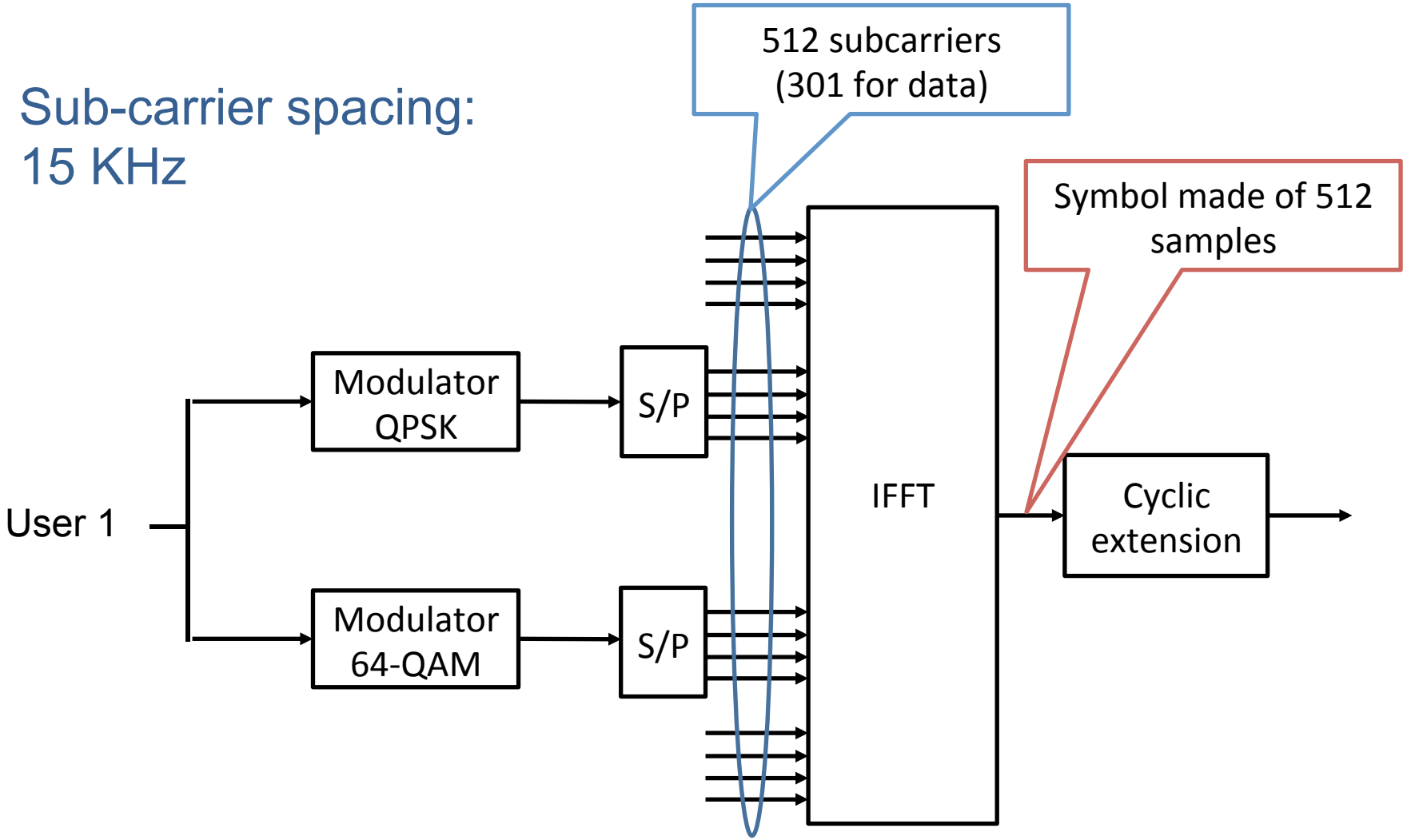
4G: OFTDMA

Sub-carrier spacing:
15 KHz



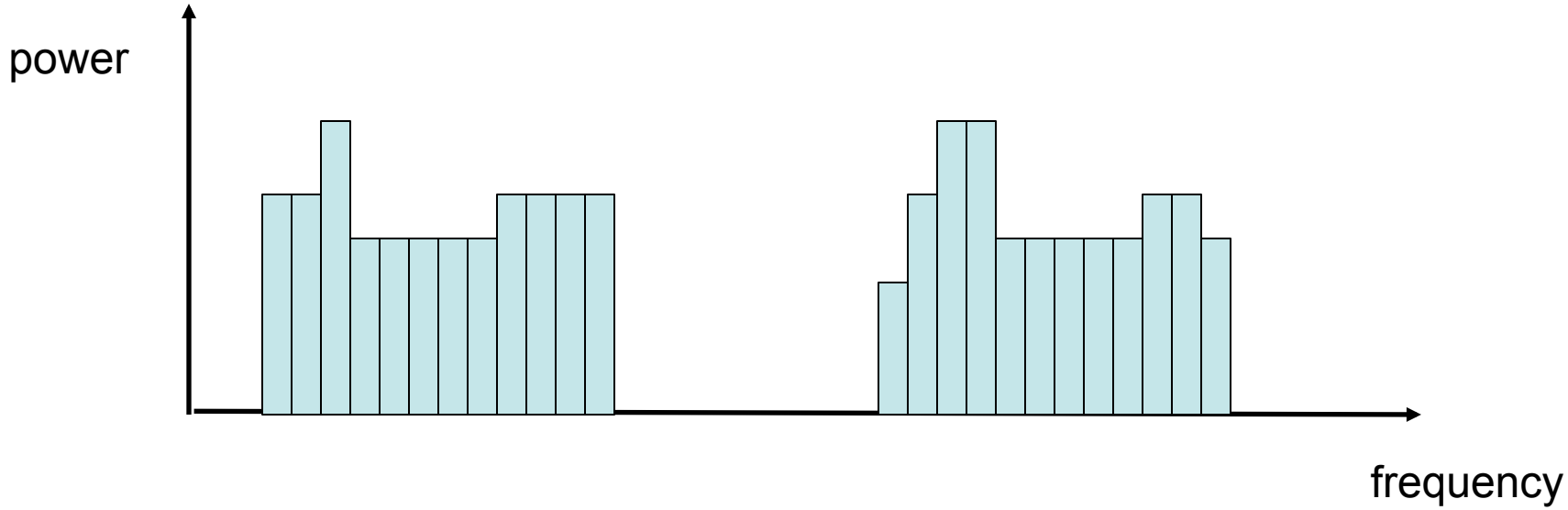
4G: OFTDMA

Sub-carrier spacing:
15 KHz

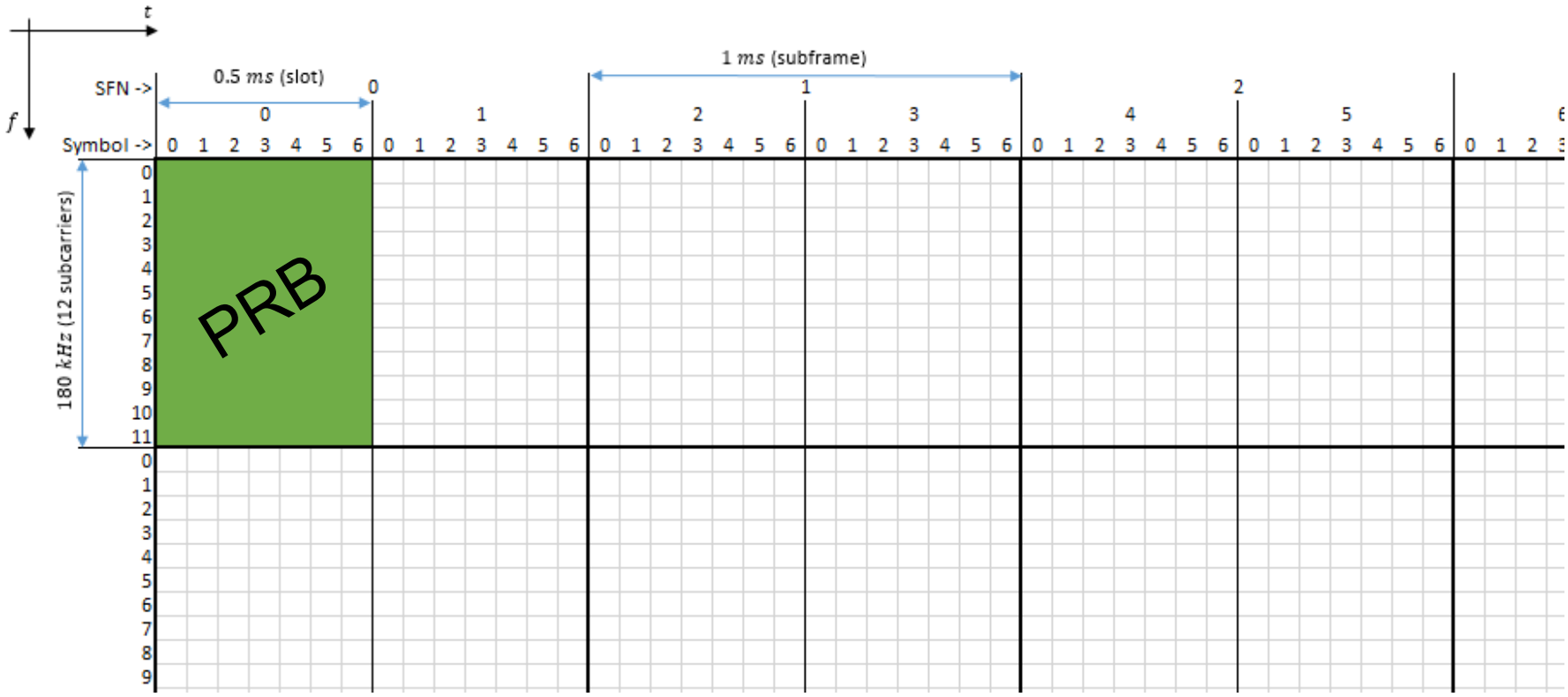


4G: OFTDMA

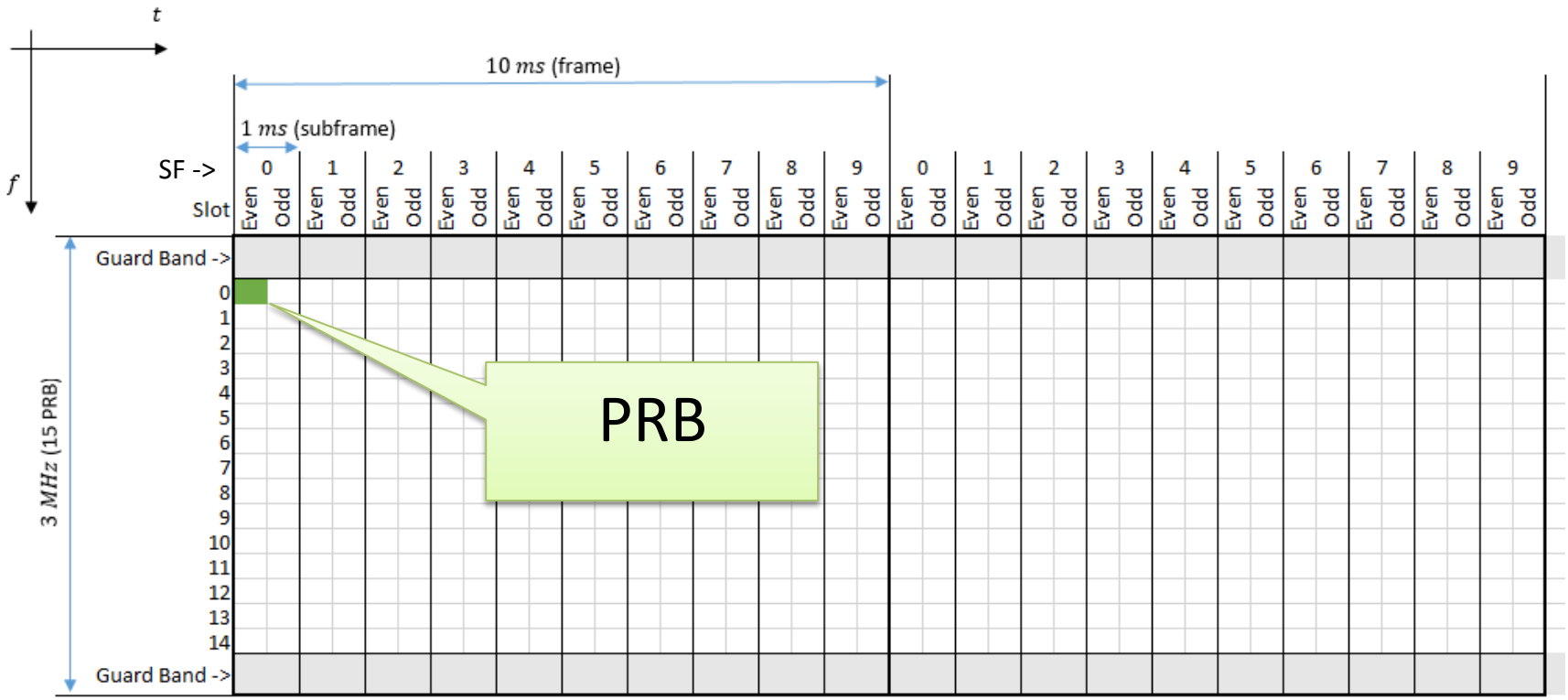
Sub-carrier spacing:
15 KHz



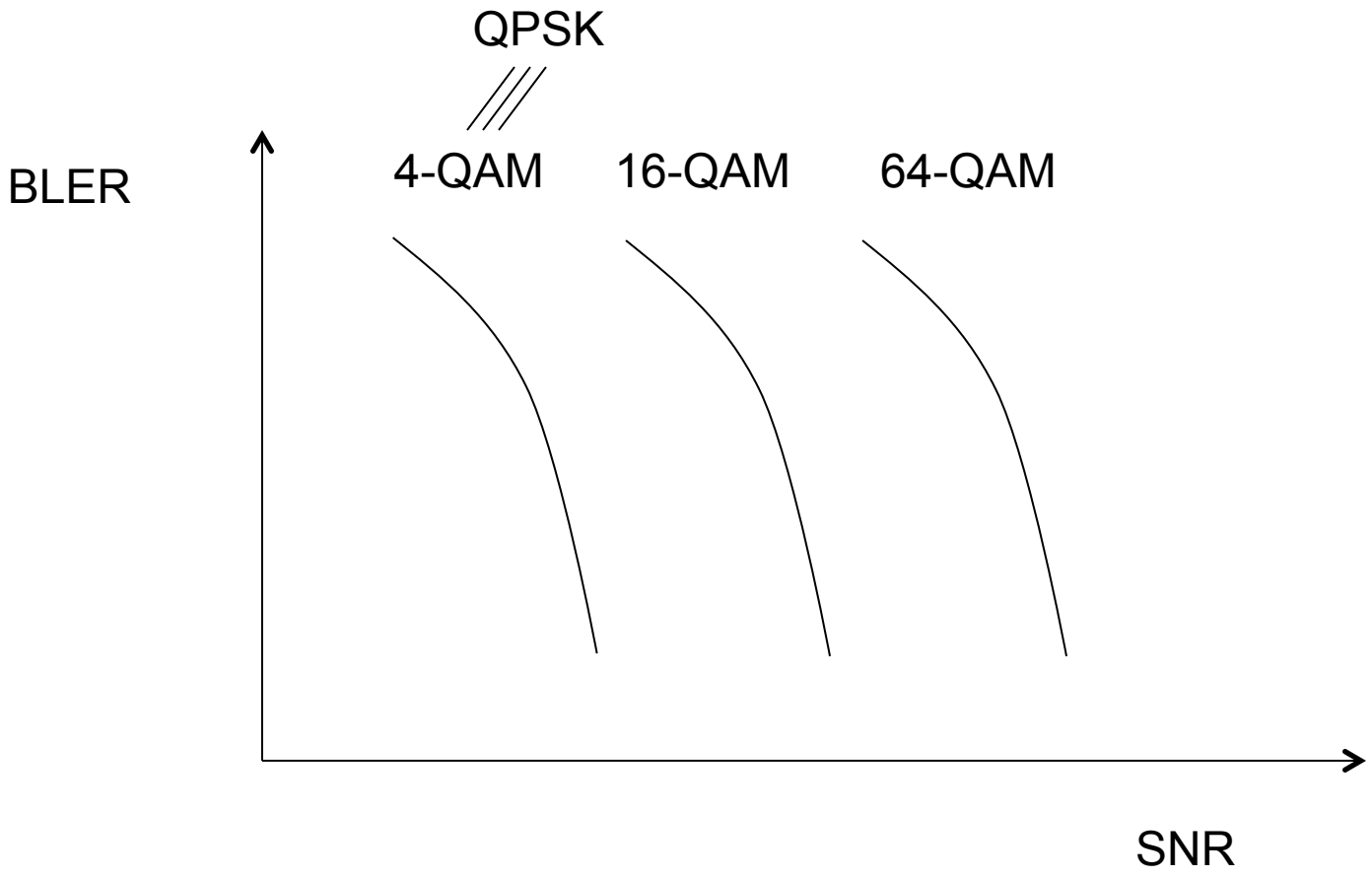
4G: Physical Resource Block (PRB)



4G: Physical Resource Block (PRB)



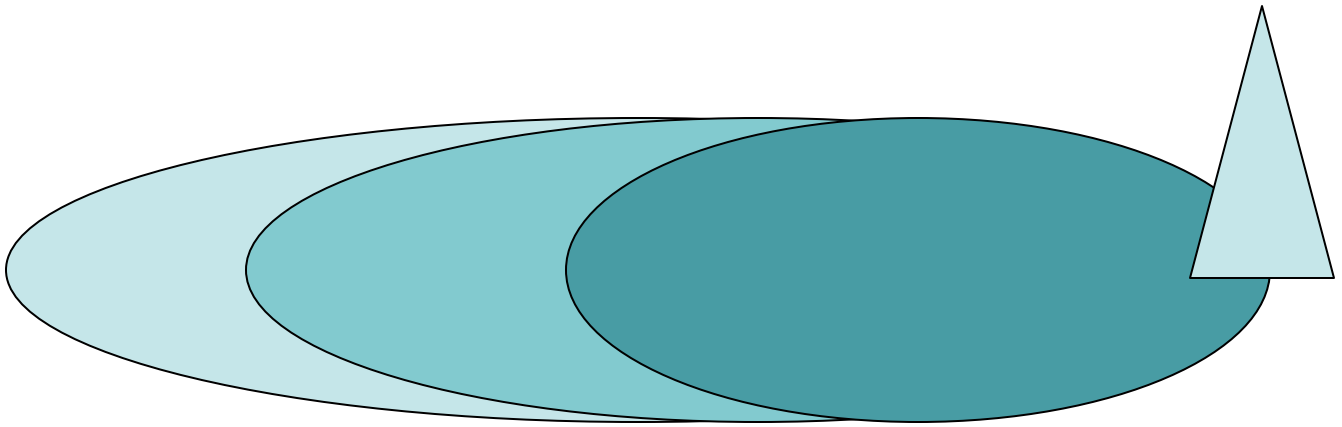
4G: Modulations



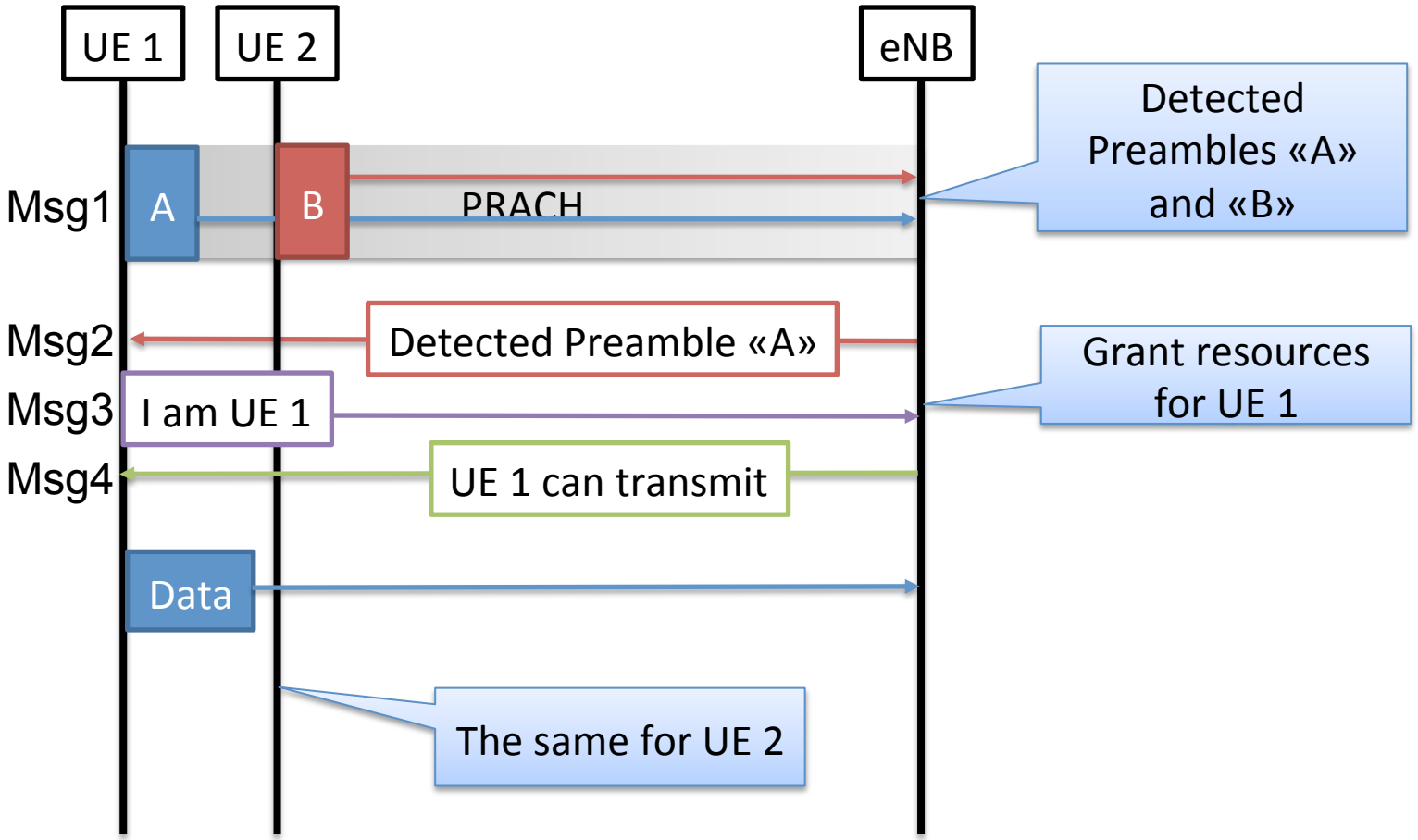
4G: Modulations

	Before Rel.12			*Rel.12 and beyond*		
CQI	Modulation	Code rate	Bits per RE	Modulation	Code rate	Bits per RE
0	Out of range					
1	QPSK	0.0762	0.1524	QPSK	0.0762	0.1524
2	QPSK	0.1172	0.2344	QPSK	0.1885	0.377
3	QPSK	0.1885	0.377	QPSK	0.4385	0.877
4	QPSK	0.3008	0.6016	16QAM	0.3691	1.4764
5	QPSK	0.4385	0.877	16QAM	0.4785	1.914
6	QPSK	0.5879	1.1758	16QAM	0.6016	2.4064
7	16QAM	0.3691	1.4764	64QAM	0.4551	2.7306
8	16QAM	0.4785	1.914	64QAM	0.5537	3.3222
9	16QAM	0.6016	2.4064	64QAM	0.6504	3.9024
10	64QAM	0.4551	2.7306	64QAM	0.7539	4.5234
11	64QAM	0.5537	3.3222	64QAM	0.8525	5.115
12	64QAM	0.6504	3.9024	256QAM	0.6943	5.5544
13	64QAM	0.7539	4.5234	256QAM	0.7783	6.2264
14	64QAM	0.8525	5.115	256QAM	0.8634	6.9072
15	64QAM	0.9258	5.5548	256QAM	0.9258	7.4064

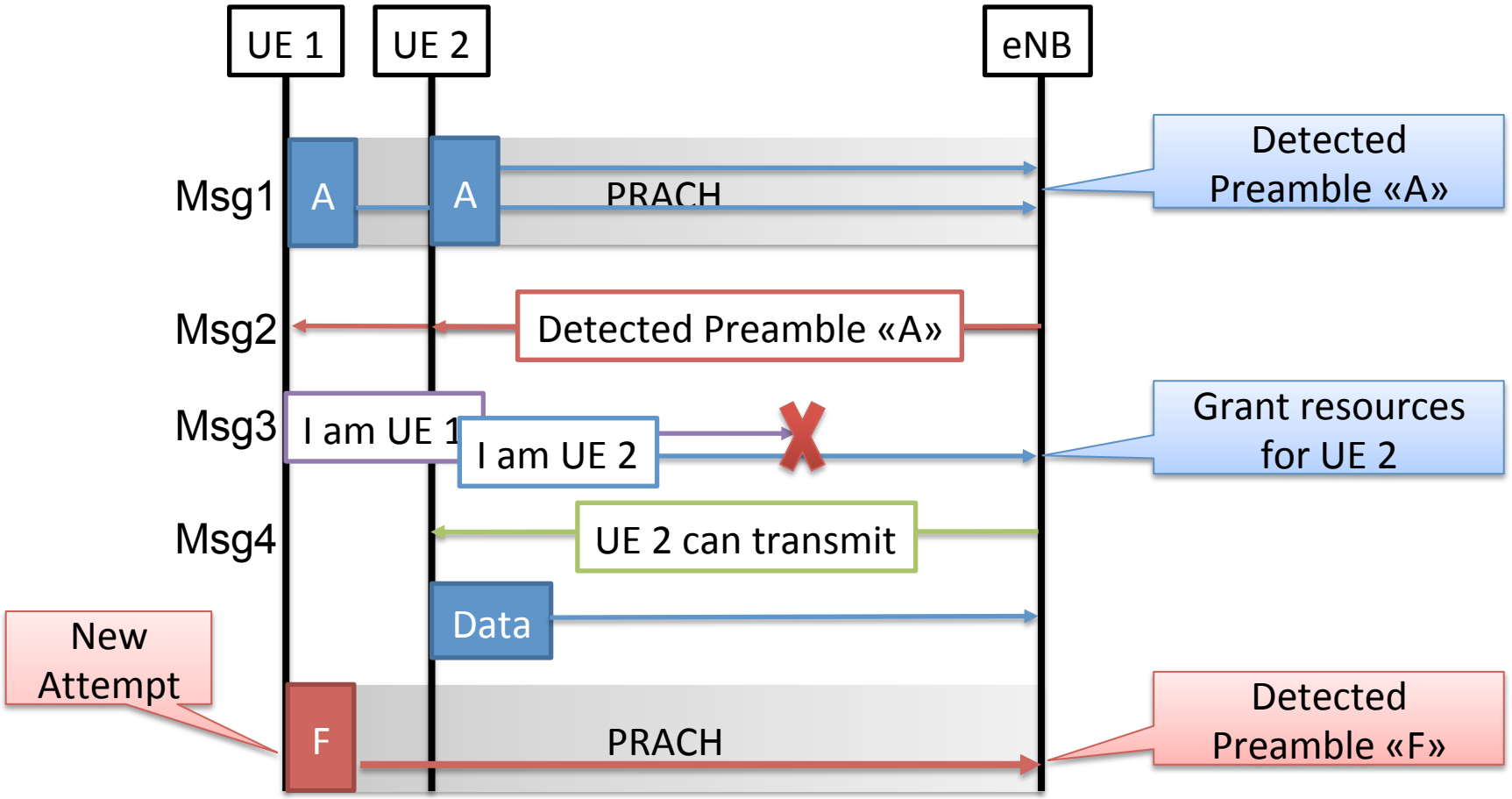
4G: Modulations



Random Access Procedure



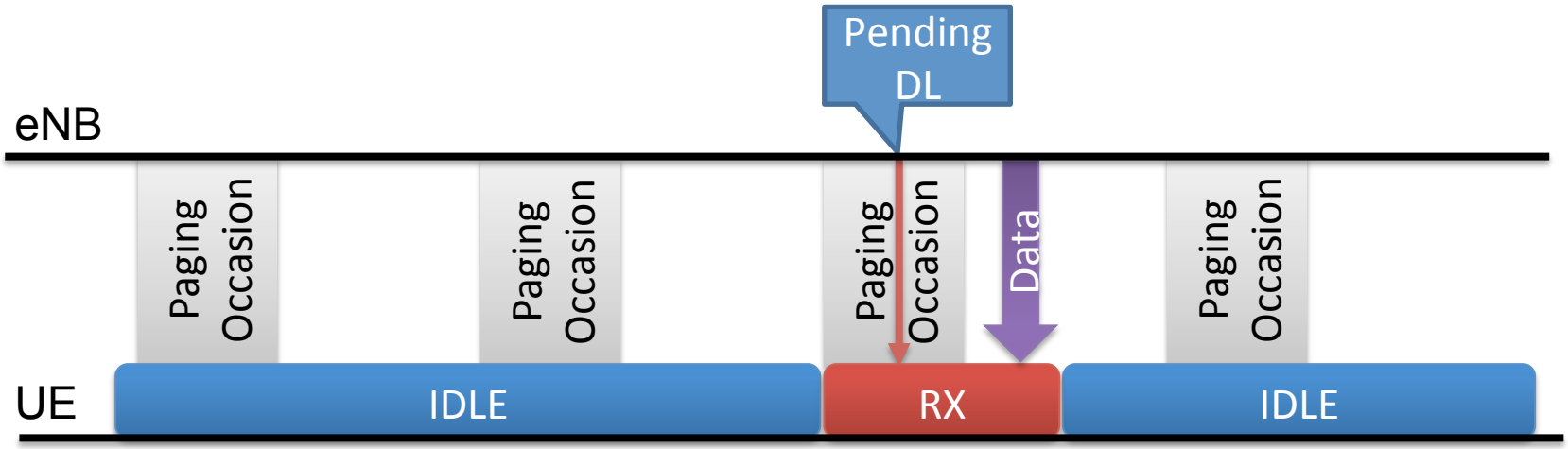
Random Access Procedure



Paging

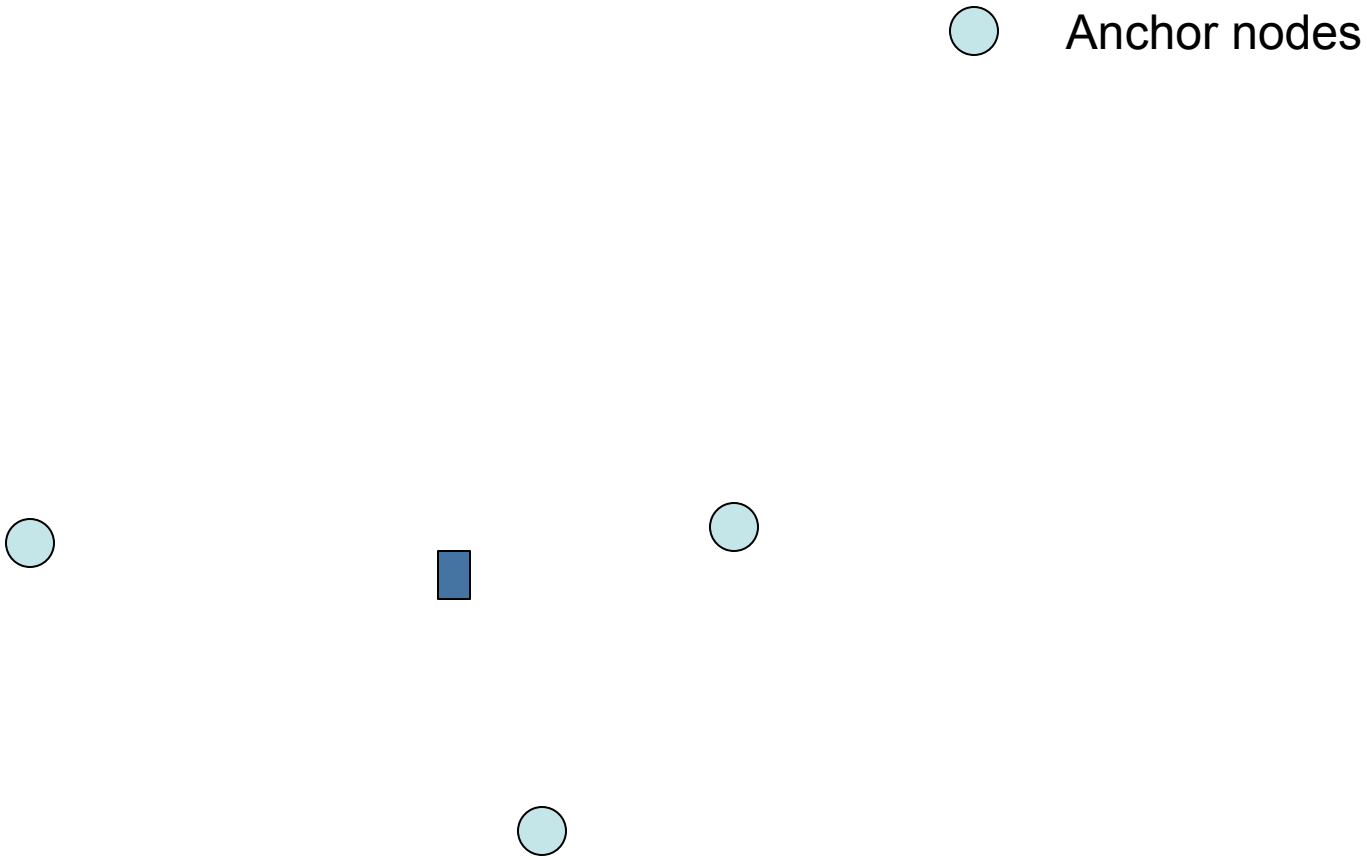
Monitor sporadically
Lower Energy Consumption
Higher Latency

Monitor often
Higher Energy Consumption
Lower Latency

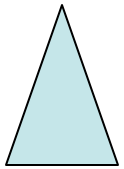


Localisation and Tracking

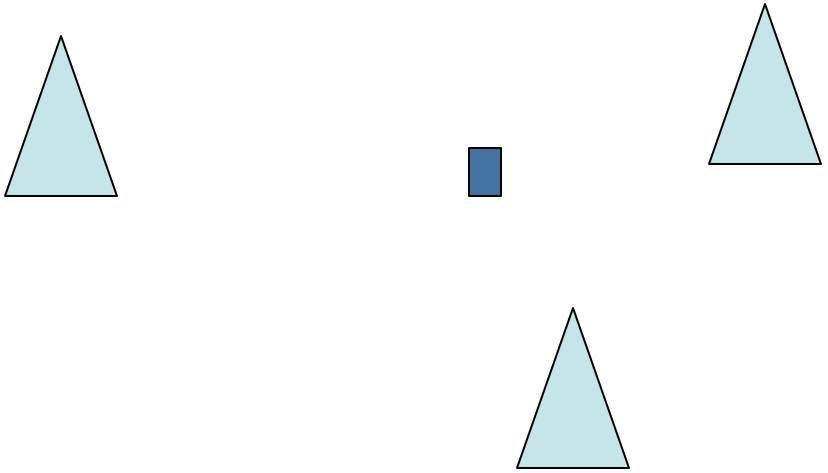
Triangulation



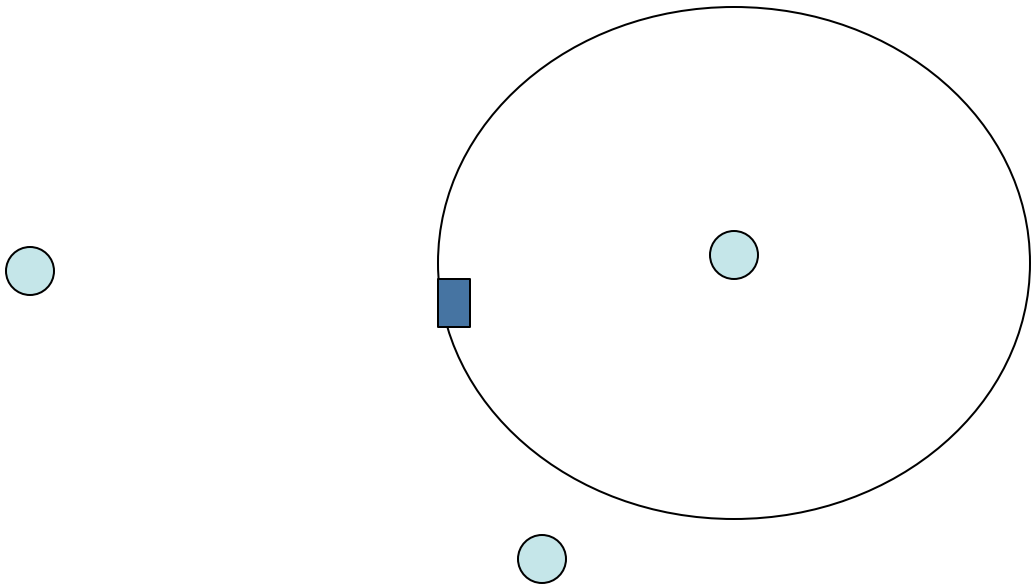
Triangulation



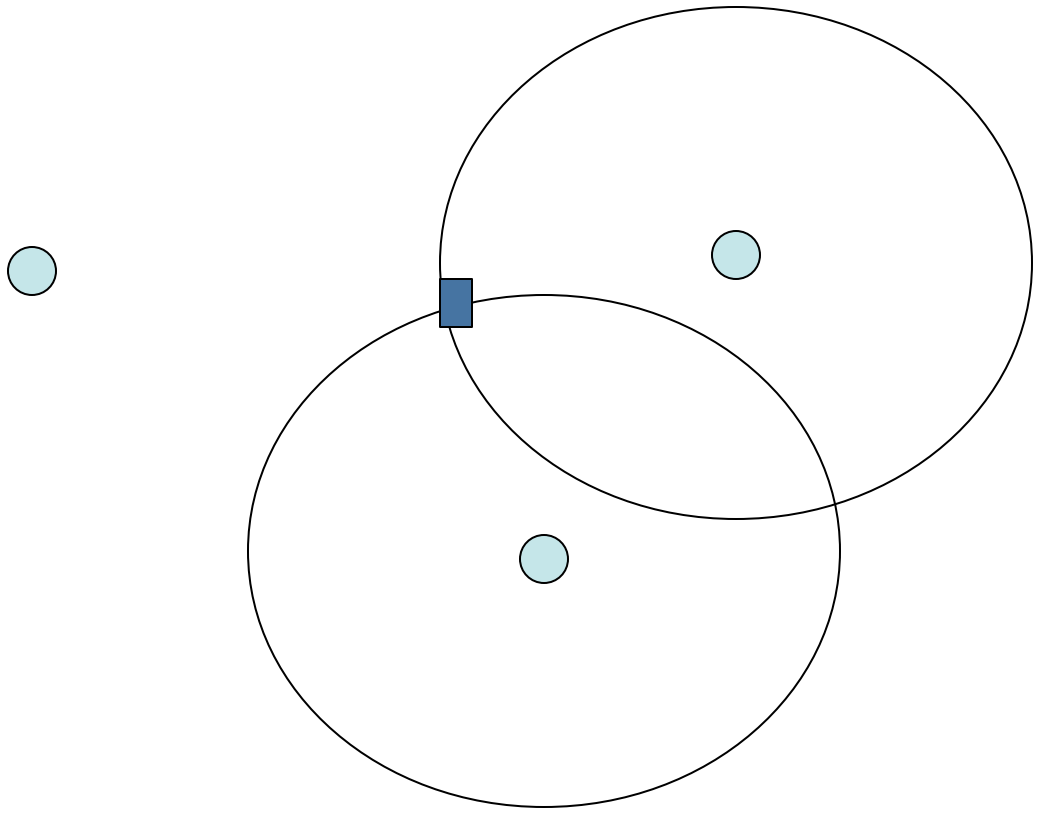
Base stations



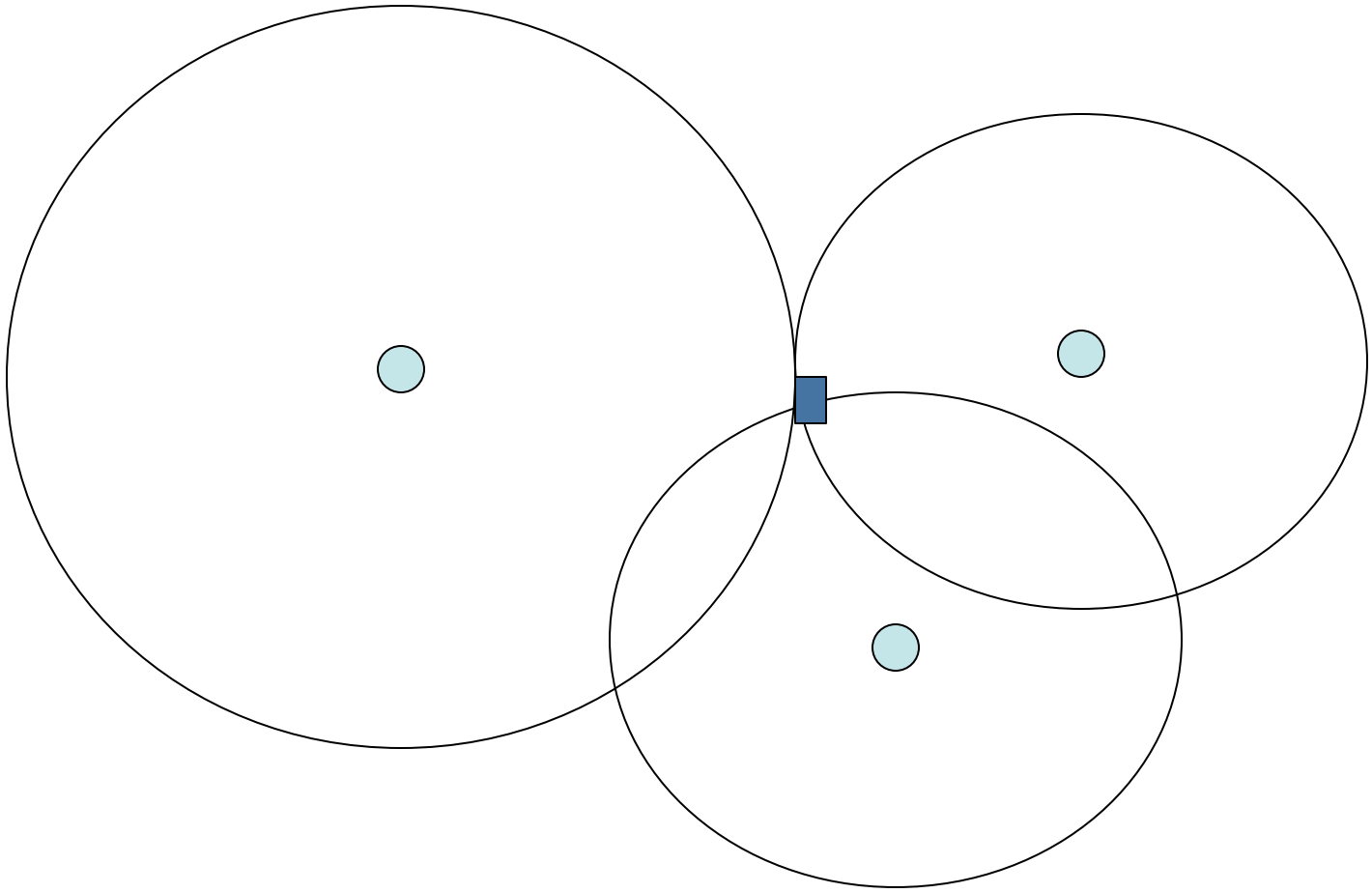
Triangulation



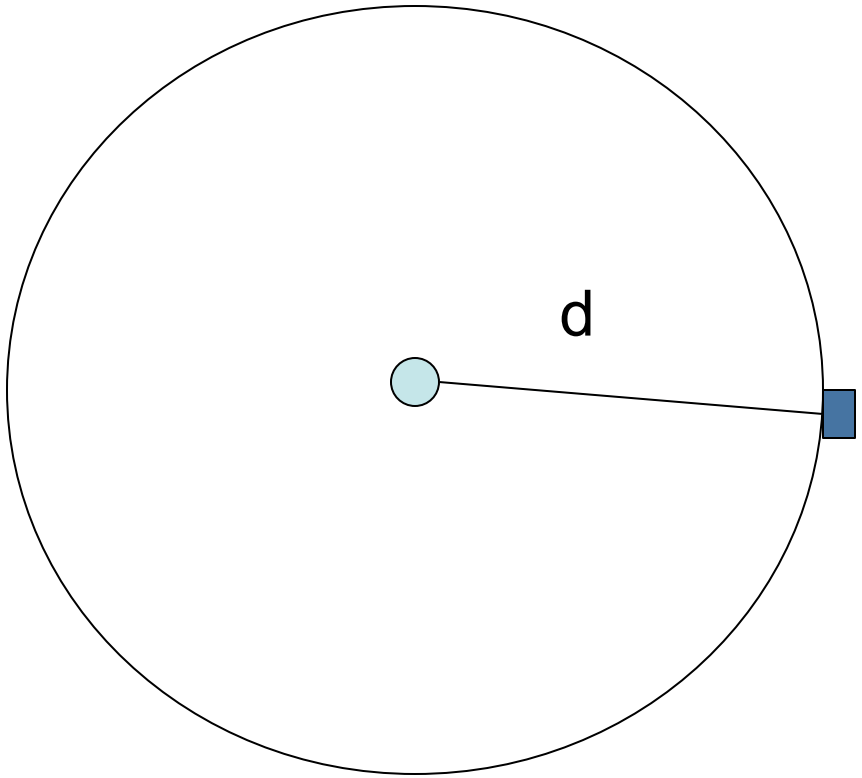
Triangulation



Triangulation



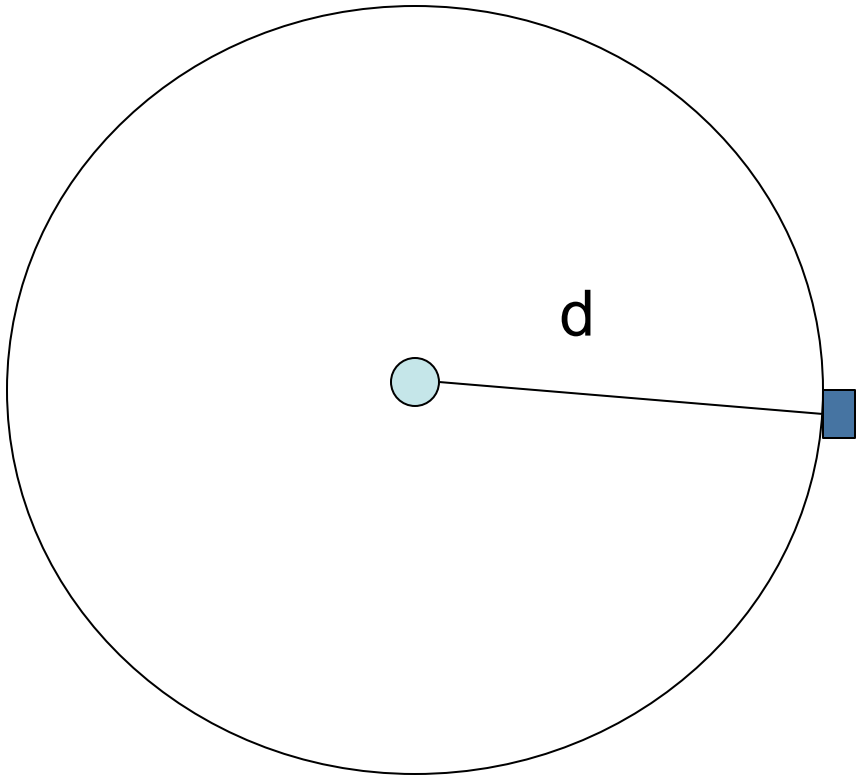
Triangulation



???

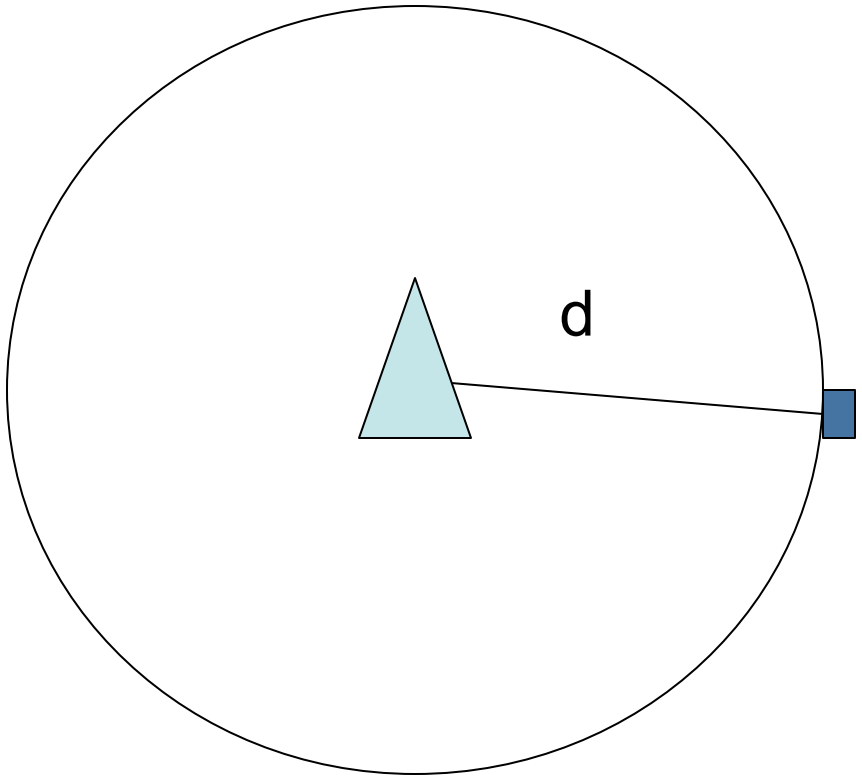
Triangulation

RSSI Based



$$Pr = k\, d^{-\beta}$$

Triangulation

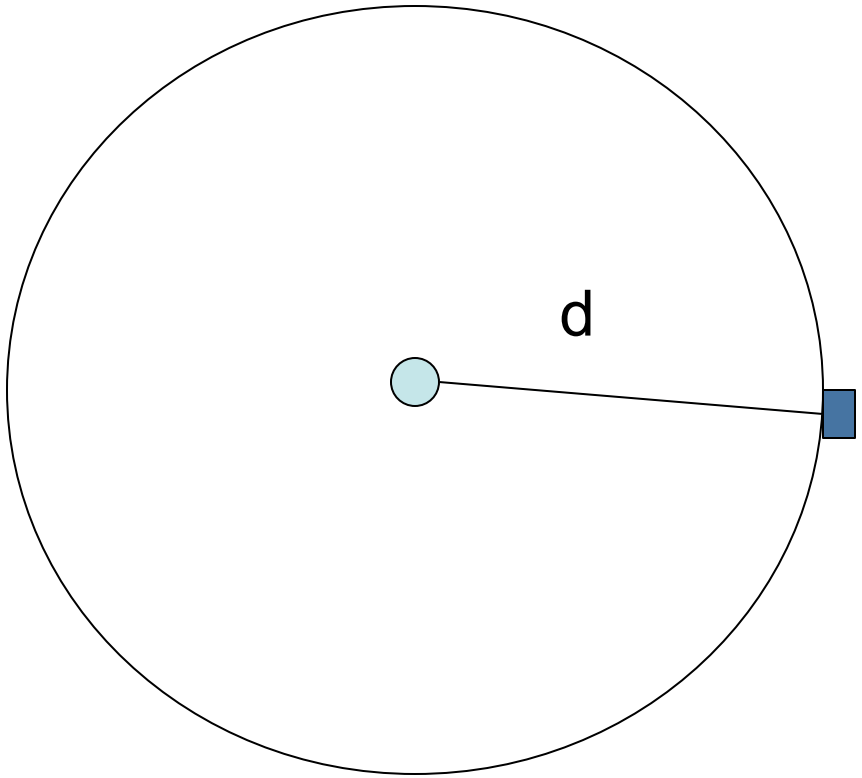


RSSI Based

Fading, shadowing …

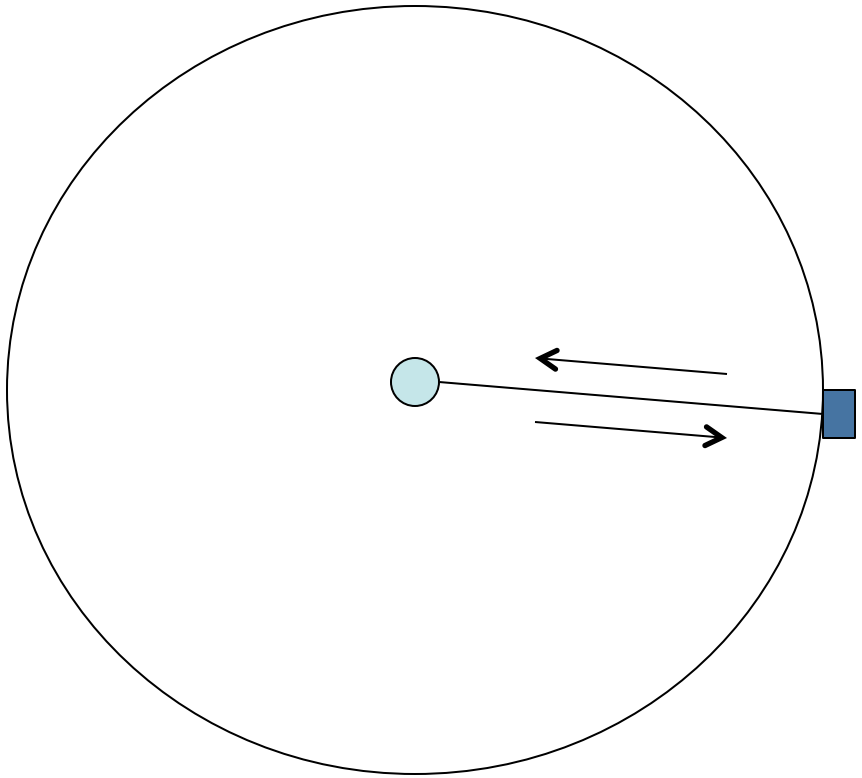
$$Pr = k\, d^{-\beta}$$

Triangulation

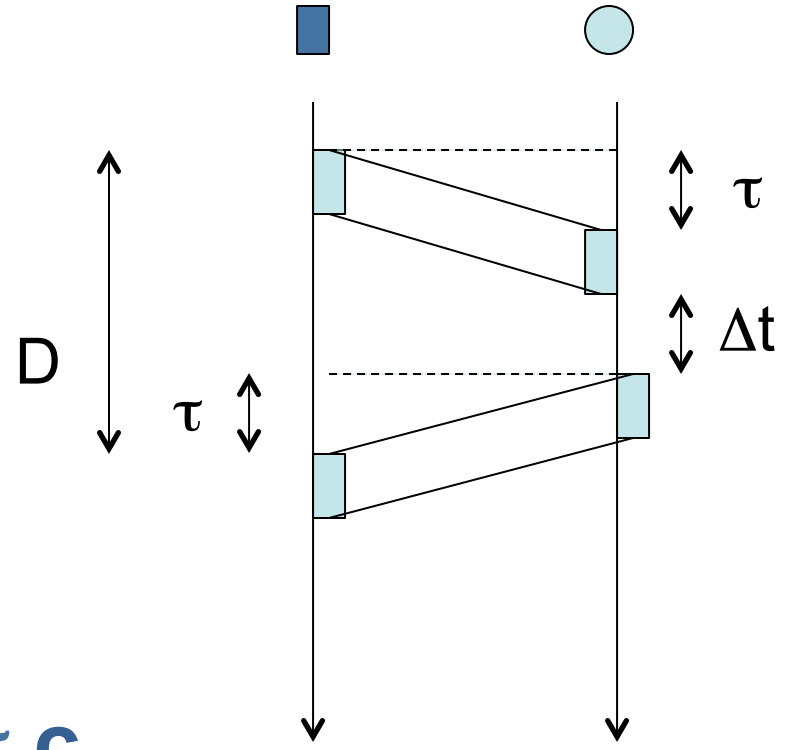


1. **Two way**
2. **One way**

Triangulation

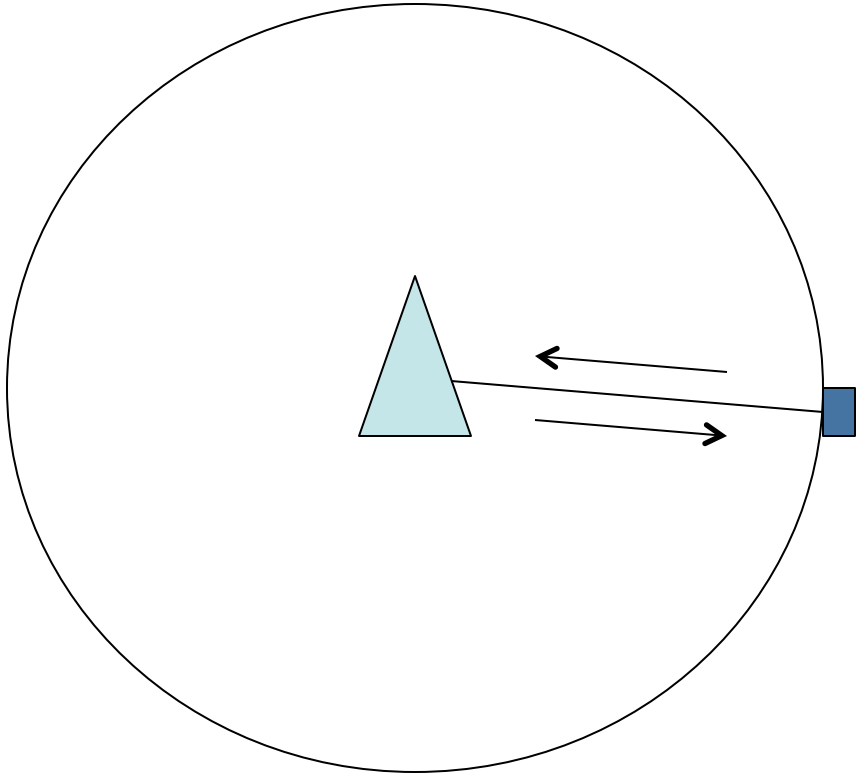


1. Two way

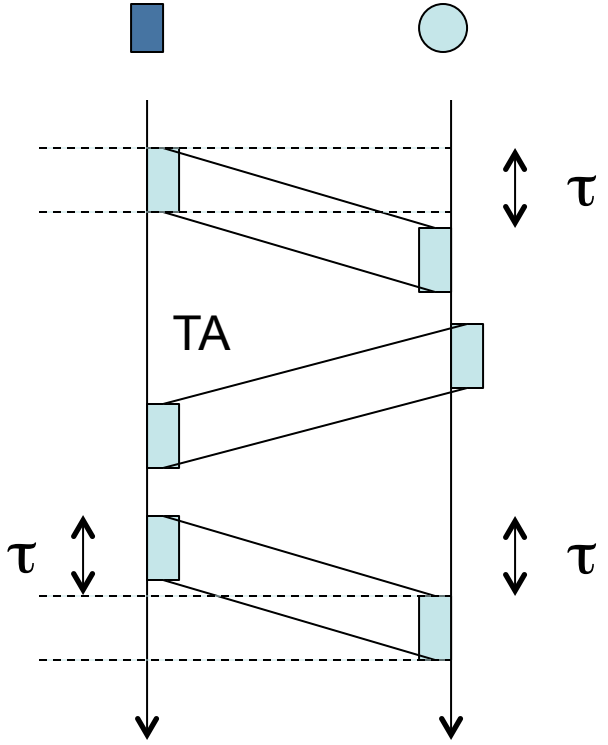


$$d = \tau\, c$$

Triangulation

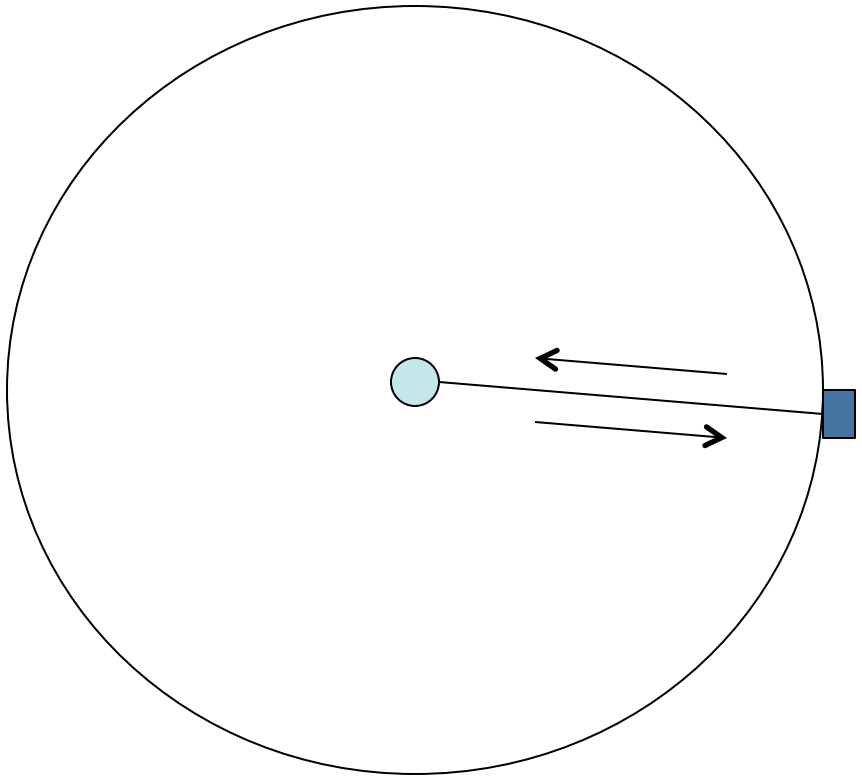


Timing Advance

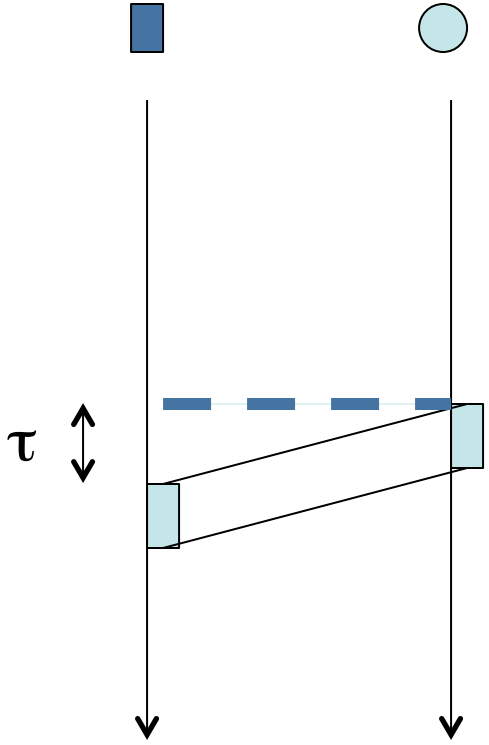


Connected mode

Triangulation

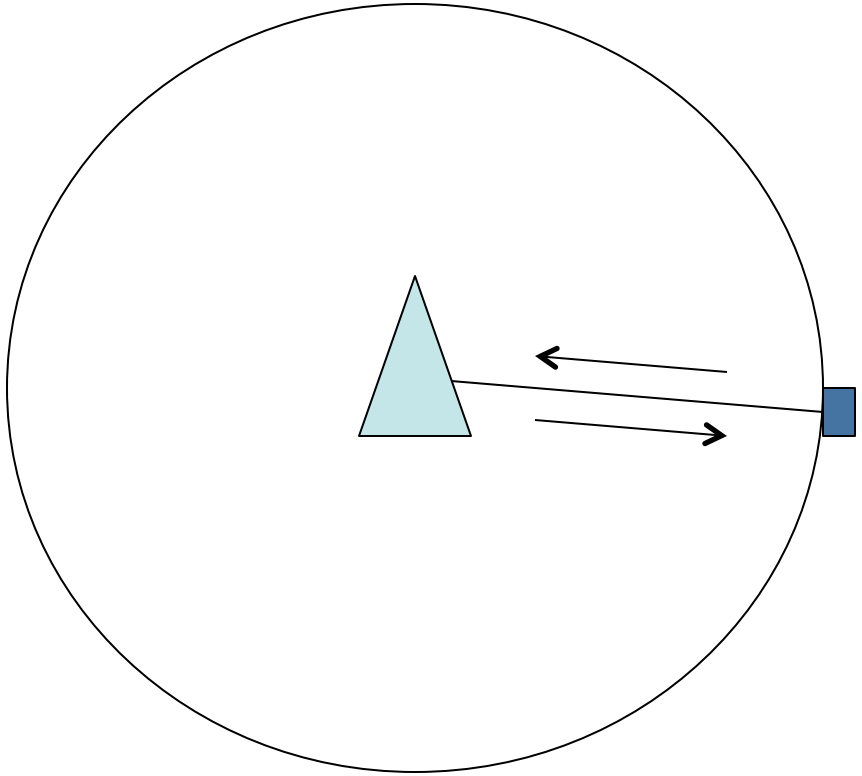


2. One way

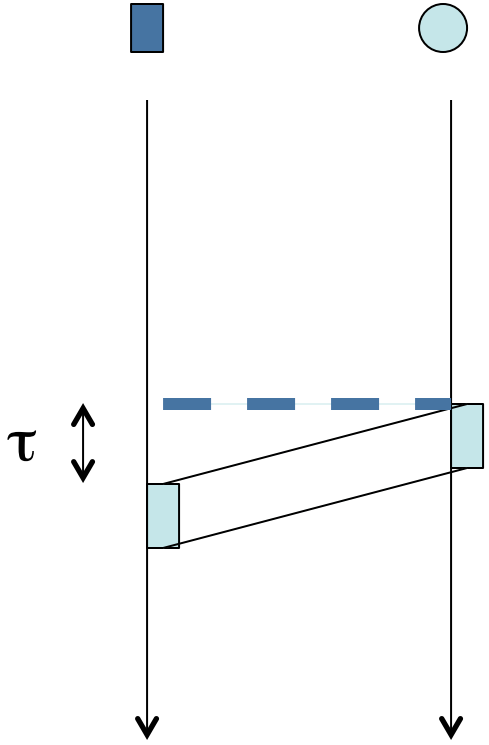


$$d = \tau c$$

Triangulation

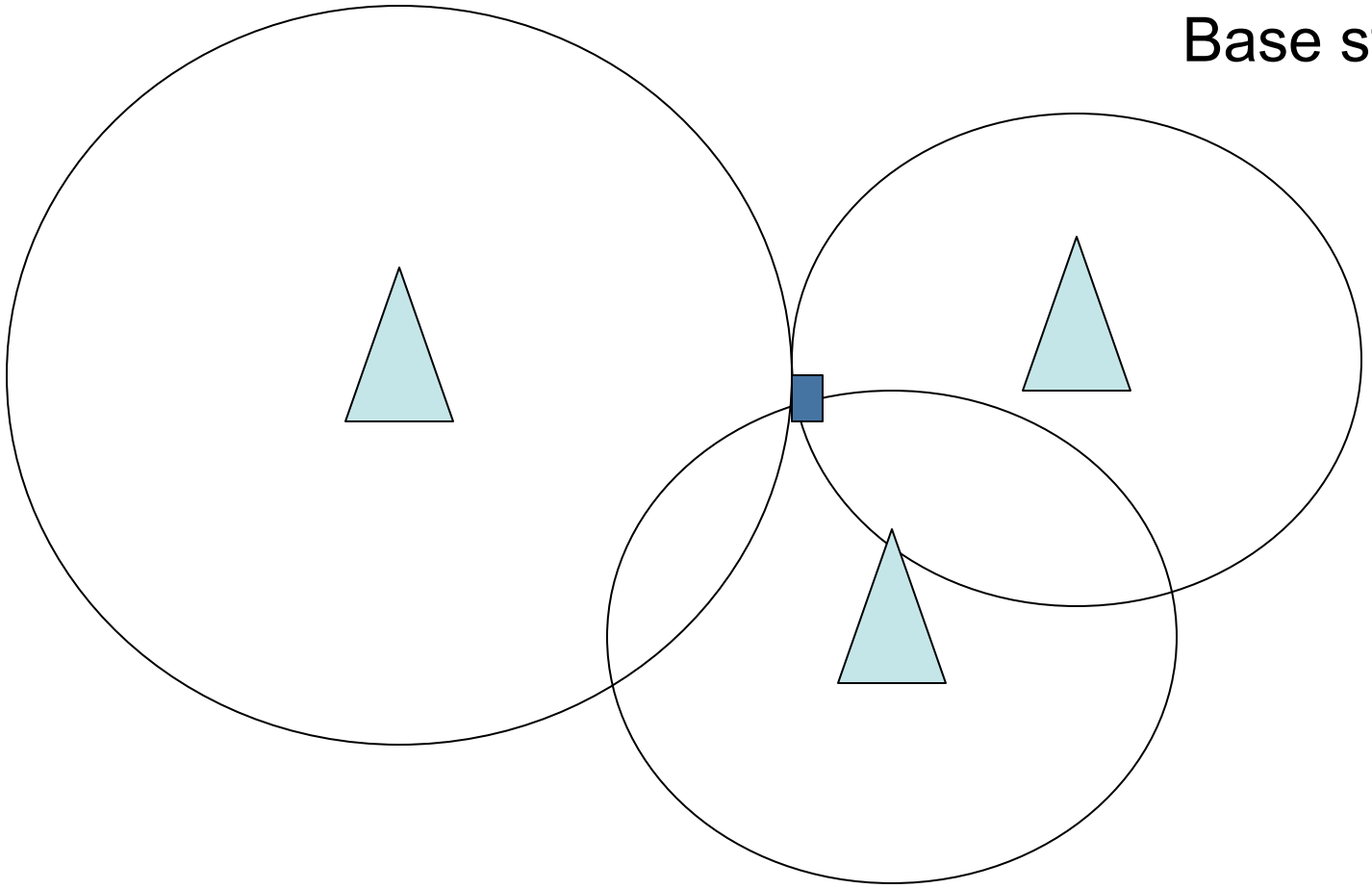


2. One way



Network synchronisation

Triangulation in 4G

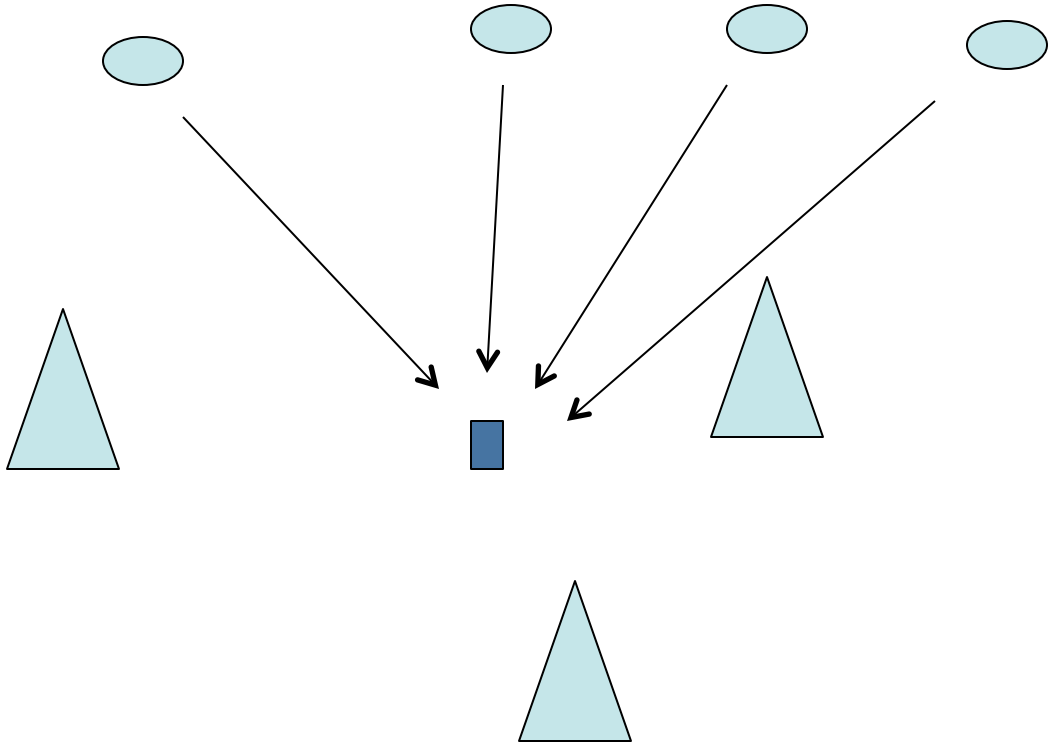


Idle and Connected Modes: RSSI

Accuracy = 150 m

Triangulation in 4G

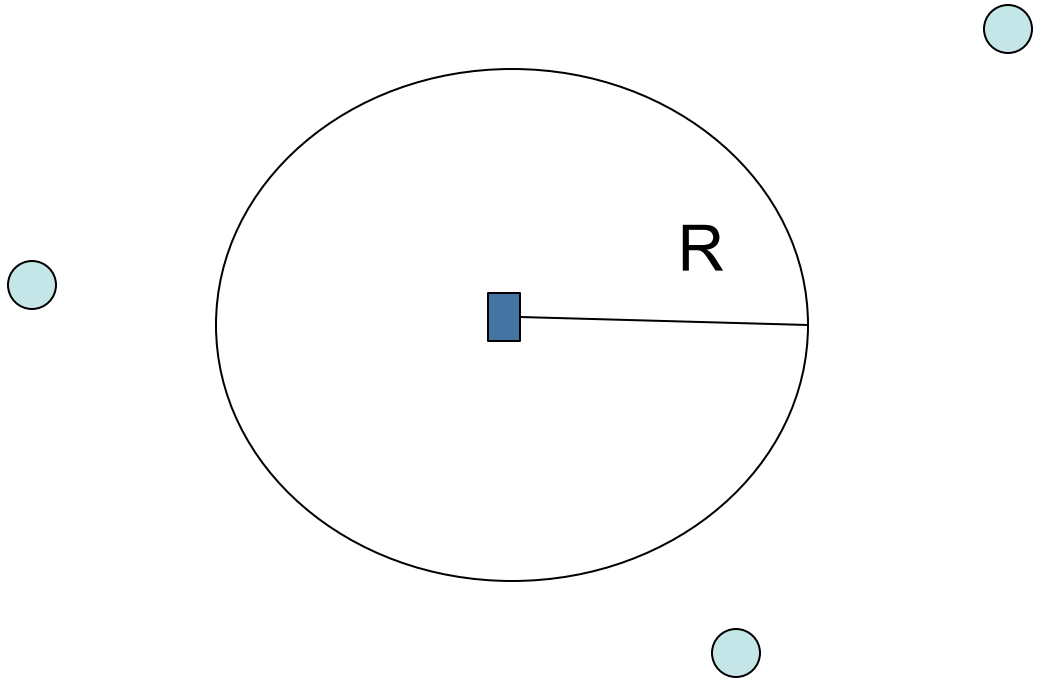
Satellites



Connected Mode: MDT, based on GPS

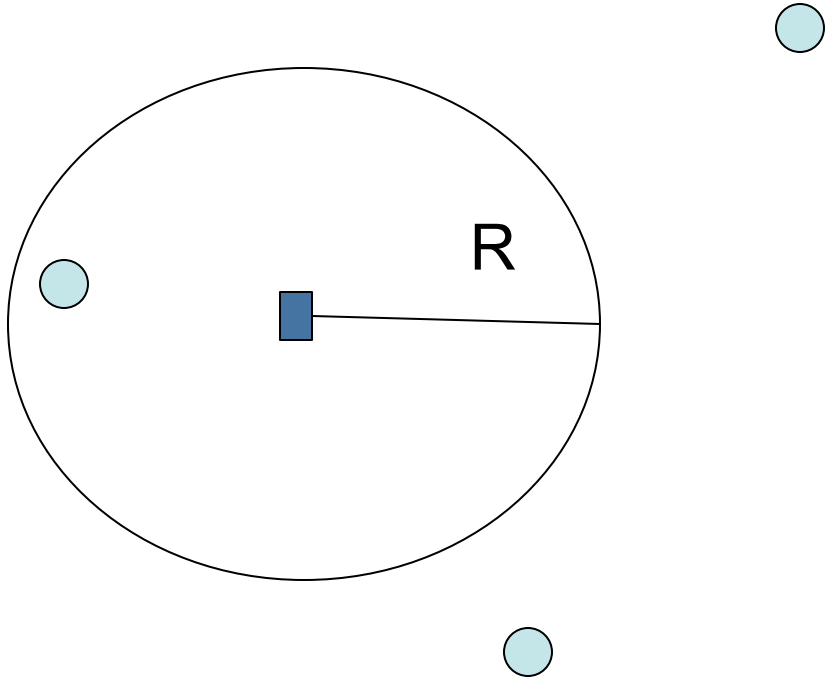
Accuracy = 10 m

Inter-node contacts



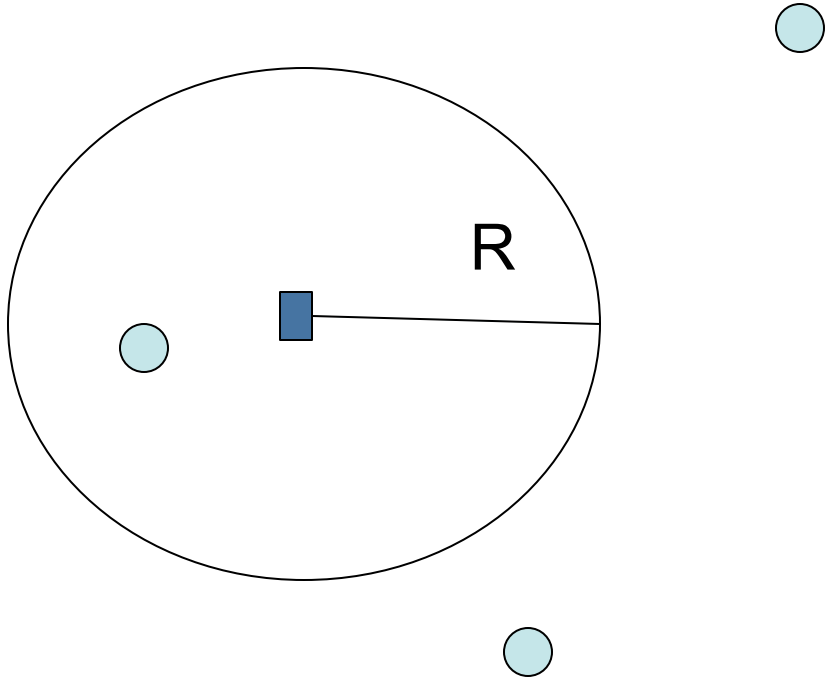
$$Pr = k\, d^{-2}$$

Inter-node contacts



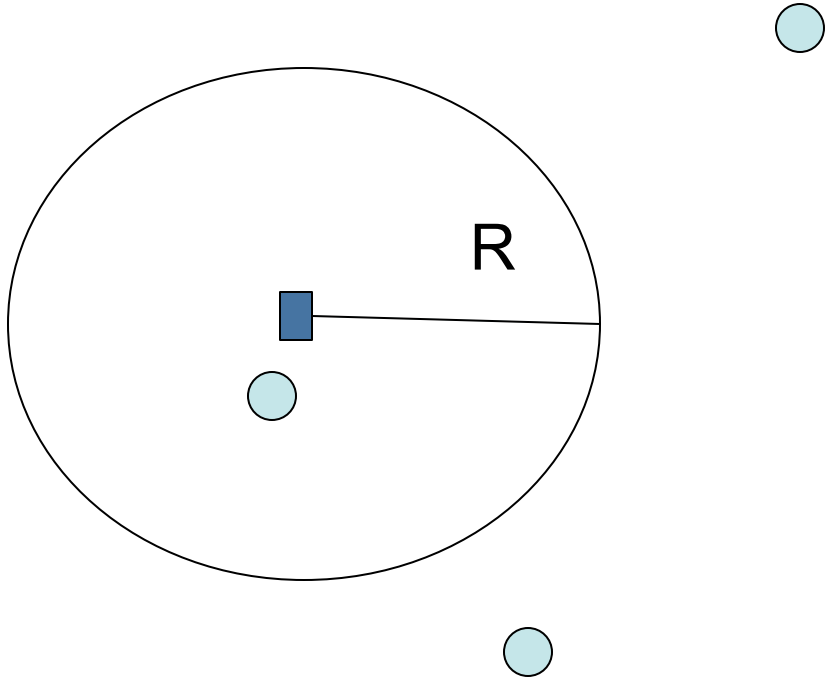
$$Pr = k\, d^{-2}$$

Inter-node contacts



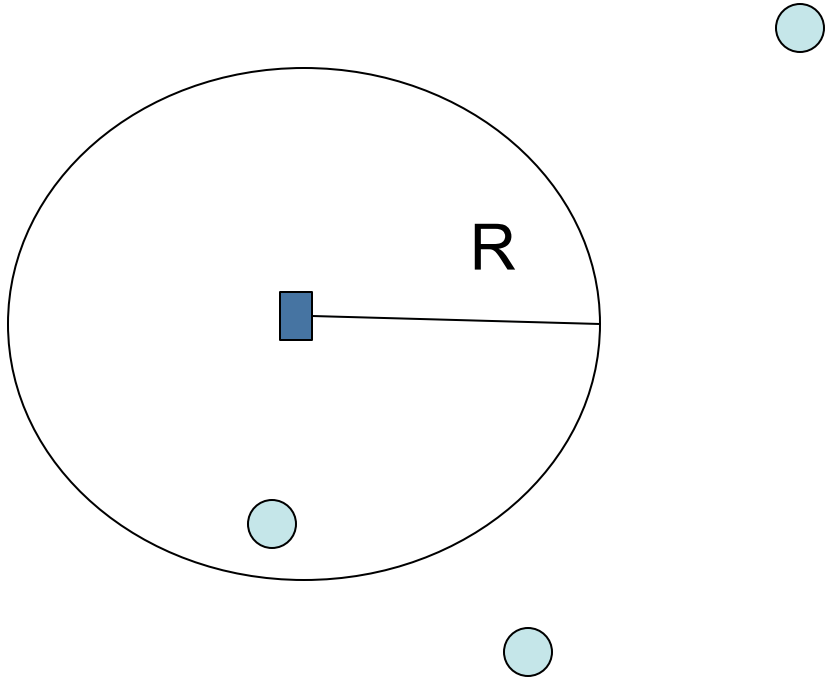
$$Pr = k\, d^{-2}$$

Inter-node contacts



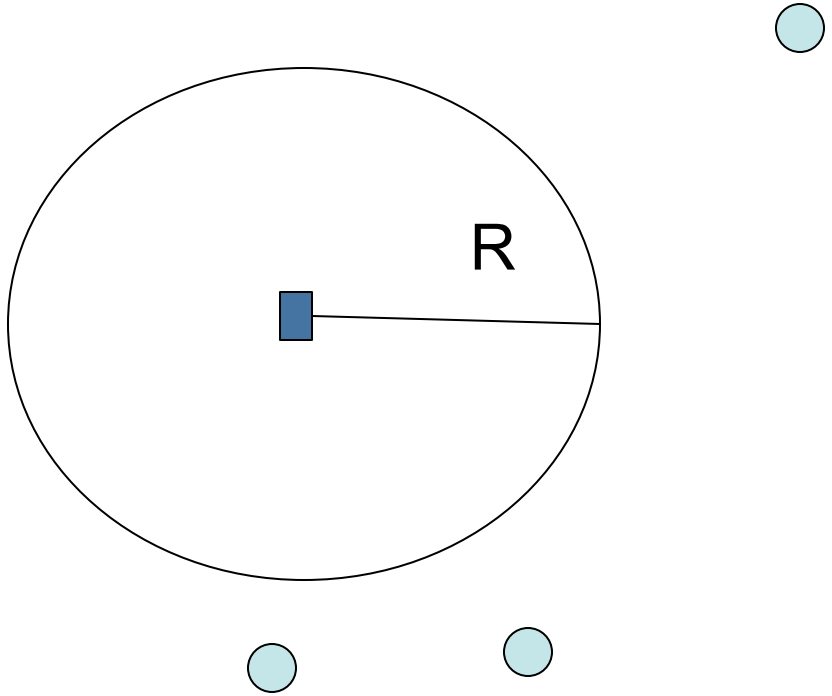
$$Pr = k\, d^{-2}$$

Inter-node contacts



$$Pr = k\, d^{-2}$$

Inter-node contacts and Immuni



Idle and Connected Mode: based on Bluetooh Accuracy = 1 m