Performance of NB-IoT

The technology that aims to reach the 5G-IoT requirements

Wednesday, December 1st, 2021

Romain Barbau

IRIT AIRBUS

Agenda

01 **NB-IoT Context : 5G & IoT**

02 NB-IoT Inside the Communication Procedure

03 Our Model

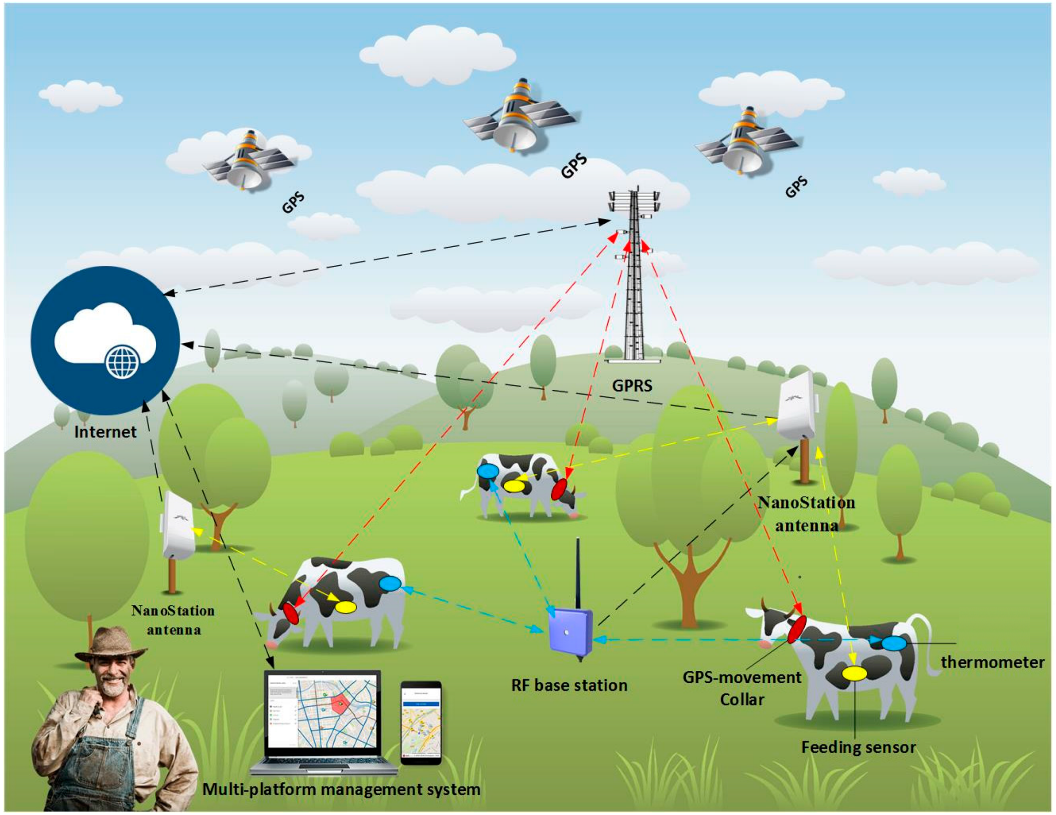
04 Performance Evaluation

Introduction to IoT

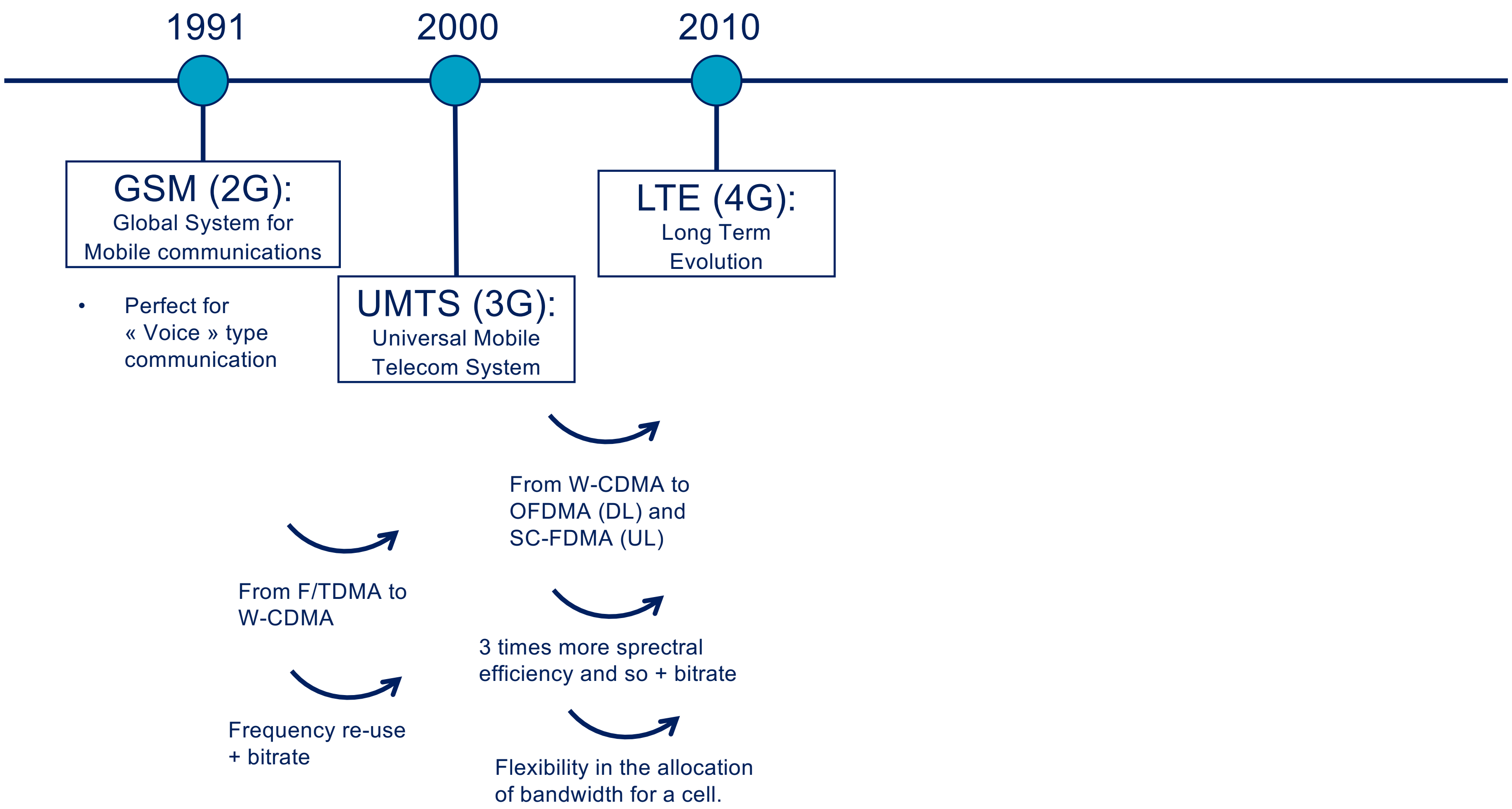
Internet of Things
IoT

Introduction to IoT

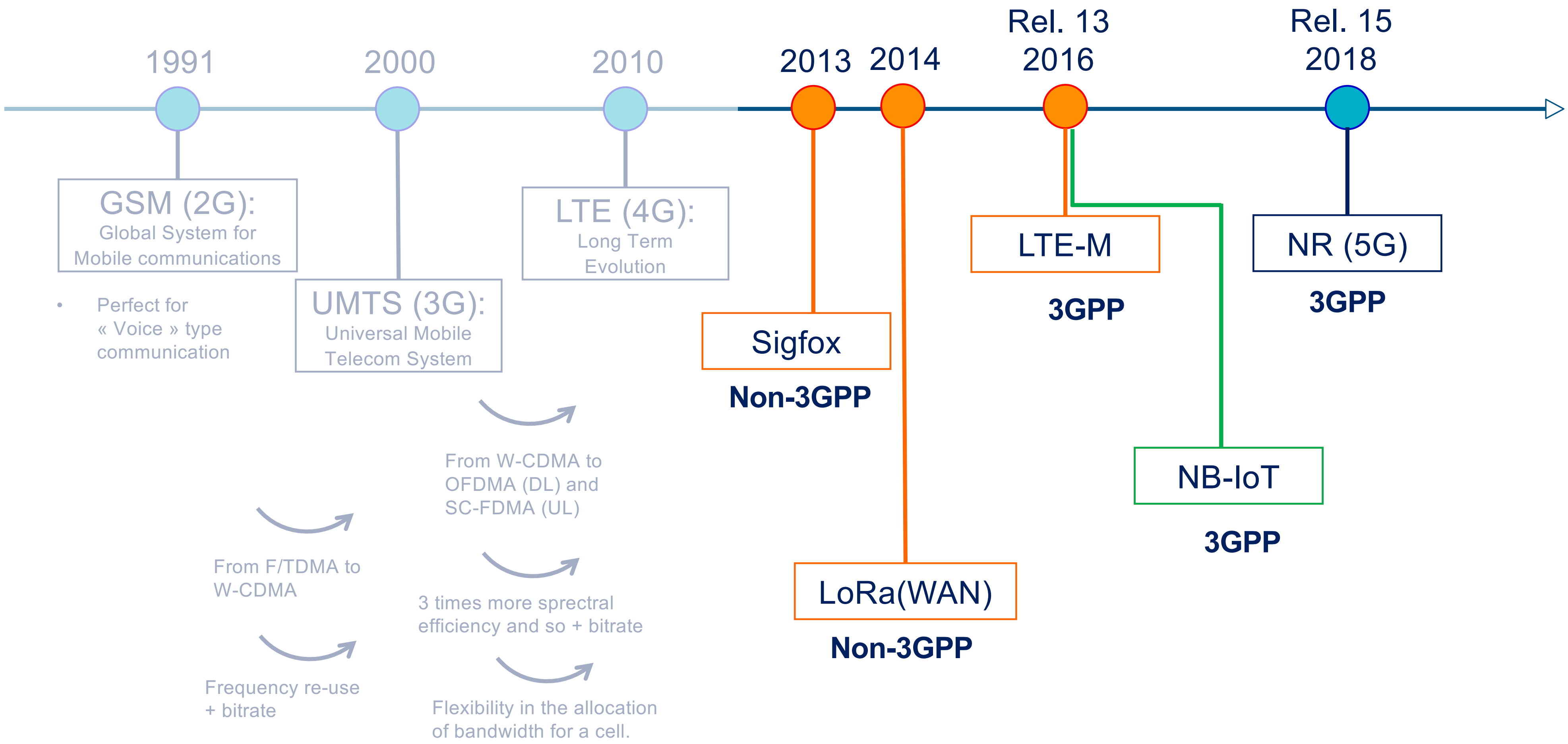
An emblematic use case:
The Connected Cow



Evolution of Cellular Technologies



Evolution of Cellular Technologies



NB-IoT Objectives

IoT Key Metrics

- Low Data rate
- Low Battery → 10 years on 4AA batteries
- Latency non-sensitive
- High concentration of devices → 1 million devices per km^2
- Wide Coverage → +20dB coverage compared to LTE, +14dB compared to GSM

Playing on both metrics (Low Data rate, Latency non-sensitive)

(5) TR 45.820
(6) IMT-2020

5G and IoT

How does 3GPP foresee the IoT in the future 5G ecosystem?

5G and IoT

Critical IoT

Bounded latencies
Ultra-reliable data delivery
Ultra-low latency

Broadband IoT

High data rates
Large data volumes
Low latency (best effort)

Massive IoT

Low-cost devices
Small data volumes
Extreme coverage

https://www.ericsson.com/

Agenda

01 NB-IoT Context : 5G & IoT

02 **NB-IoT Inside the Communication Procedure**

03 Our Model

04 Performance Evaluation

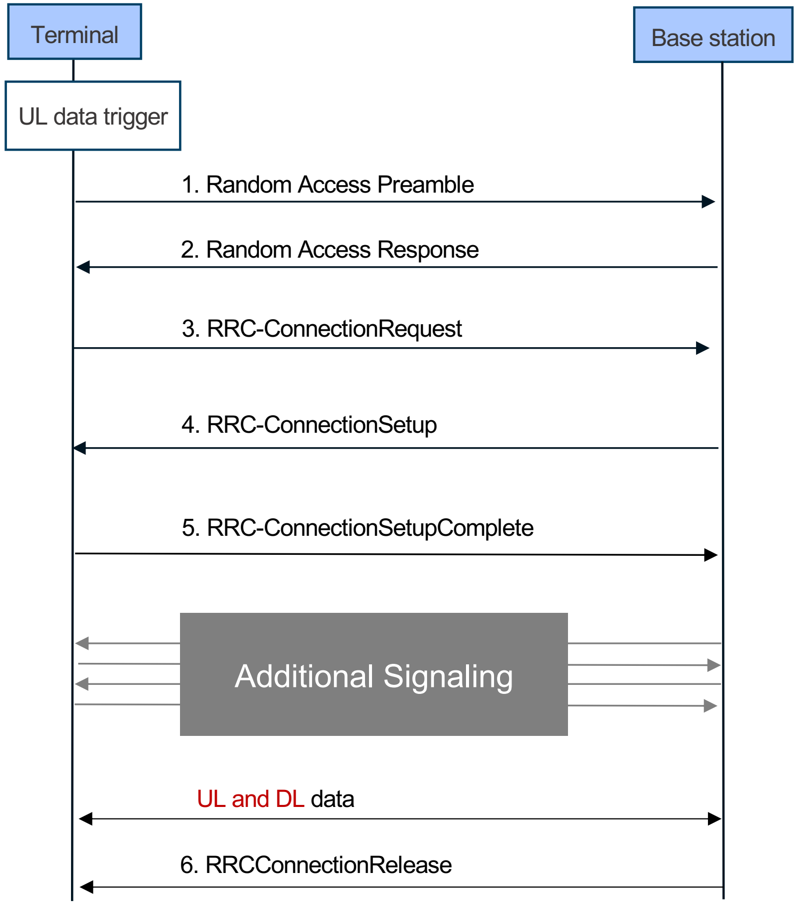
PHY Layer

→ Same as LTE
But with a narrower transmission bandwidth = more power per symbol (increase the coverage)

MAC Layer and Communication Procedure

LTE Classic Procedure

Communication Procedure with connection



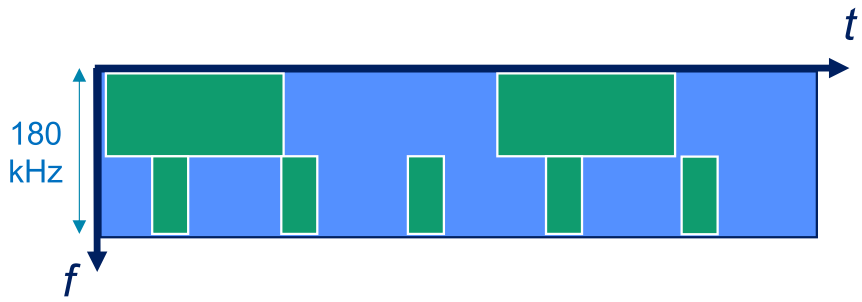
MAC Layer

Downlink Carrier

Channels

- **NPBCH** : Broadcasts info for system access.
- **NPCCH** : Control. UL and DL scheduling info.
- **NPSCH** : Shared. Dedicated and common Data.
- **NPSS/NSSS** : time and frequency synchronization.

Uplink Carrier



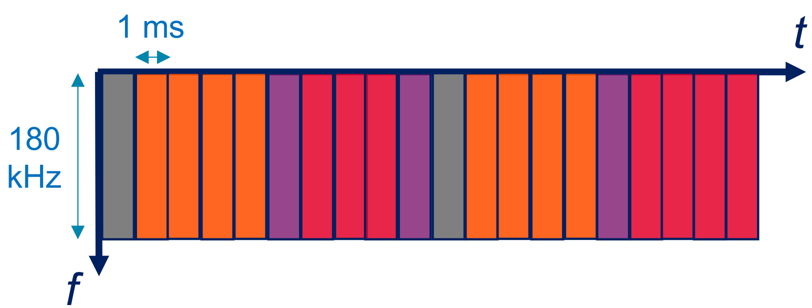
Channels

- **NPRACH** : Random access.
- **NPUSCH** : Uplink dedicated data.

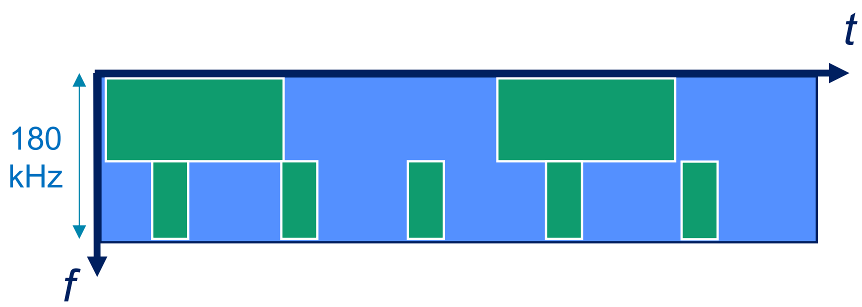
NB-IoT Insides

Communication Procedure

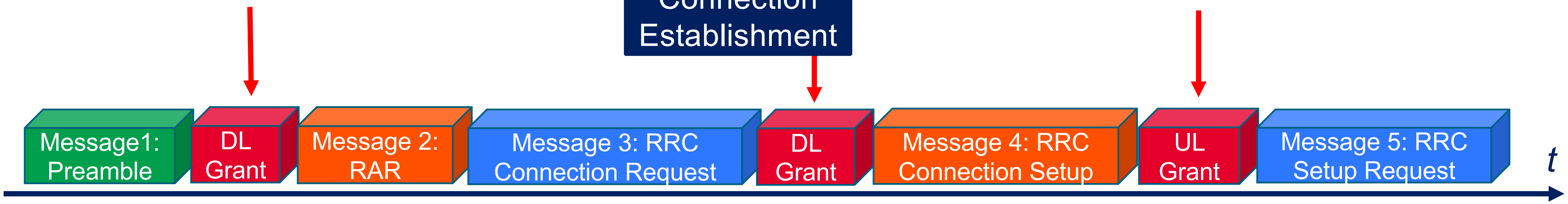
Downlink Carrier



Uplink Carrier



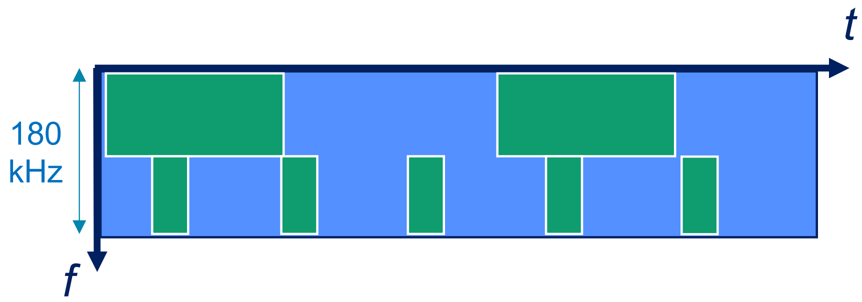
Connection Establishment



Communication Procedure

Downlink Carrier

Uplink Carrier

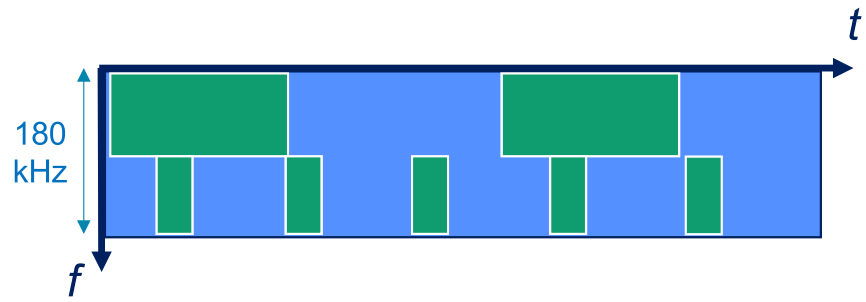


Data Report

Communication Procedure

Downlink Carrier

Uplink Carrier



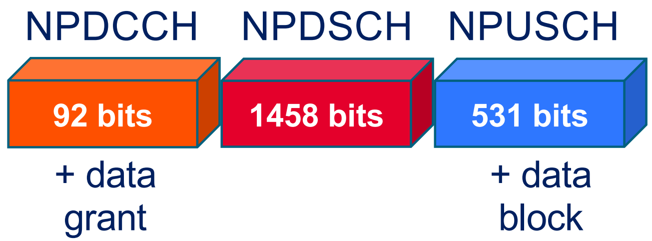
End of Connection

Communication Procedure

Message Exchanges during Connection Establishment, Data Report and Connection Termination

	Channel	Message	Payload Size (bits) Uplink	Payload Size (bits) Downlink
Connection establishment	↑ NPRACH	Message 1: Preamble	-	-
	↓ NPDCCH	Downlink Grant	-	23
	↓ NPDSCH	Message 2: Random Access Response	-	56
	↑ NPUSCH	Message 3: RRC Connection Request	59	-
	↓ NPDCCH	Downlink Grant	-	23
	↓ NPDSCH	Message 4: RRC Connection Setup	-	304
	↓ NPDCCH	Uplink Grant	-	23
	↑ NPUSCH	Message 5: RRC Setup Complete	128	-
		Additional Signalling	≈344	≈1032
Conn-ected	↓ NPDCCH	Uplink Grant (+ piggybacked ACK)	-	23
	↑ NPUSCH	Data (+ buffer status)	Variable	-
Releasing	↓ NPDCCH	Downlink Grant	-	23
	↓ NPDSCH	RRC Connection Release	-	66

Connection Overhead



1 million devices per km² ?

Agenda

01 NB-IoT Context : 5G & IoT

02 NB-IoT Inside the Communication Procedure

03 **Our Model**

04 Performance Evaluation

Modelling the use of time/frequency resources

How to compute the capacity in terms of terminal per km^2 ?

→ 3GPP methodology:

- Traffic definition (payload size, communication interval)
- Coverage definition (SINR distribution and cell area)
- Set a number N of device in the cell
- Implement an algorithm to compute the reliability *r*
- If *r* > 0.99 : increase N
- else: decrease N
- Loop until r matches 0.99
- Compute capacity

*3

Modelling the use of time/frequency resources

Contention Phase

Periodicity and number of sub-carriers per RAO are defined by CE level.
Each UE select a preamble index at random. Collisions can occur, leading to retries and failures.

↓ Poisson arrivals on slots

Congestion Phase

Each UE demand is composed of resource blocks assigned to the different contention-free queues.
If the sojourn time exceeds impatience on one of the blocks, the demand is dropped.

↓ Waiting queues

Outputs:

- Collision and Congestion probabilities → reliability

*3

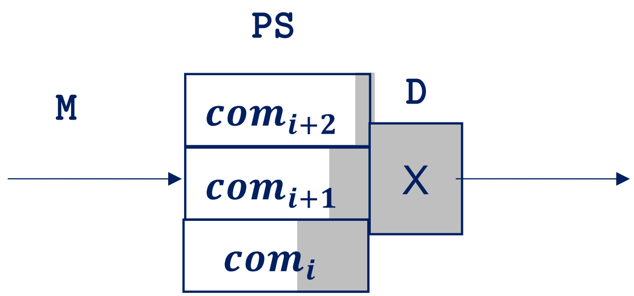
Allocation Modelling

Found in litterature [2] – M/M/1-FIFO with impatience

- Exponential arrivals - M
- Exponential services - M
- FIFO

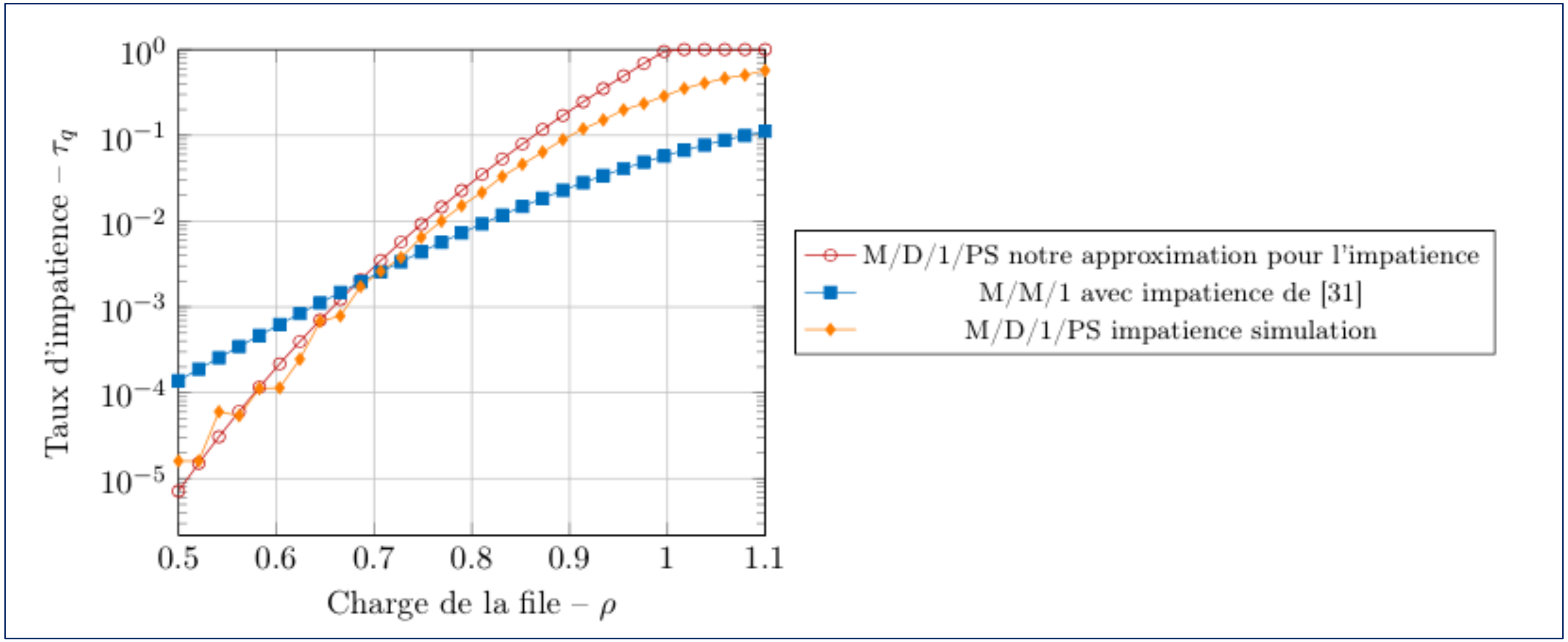
What we proposed – M/D/1-PS with impatience

- Exponential arrivals - M
- Deterministic services - D
- Processor Sharing - PS



Idea: we use an approximation for the impatience probability

Impatience Rates



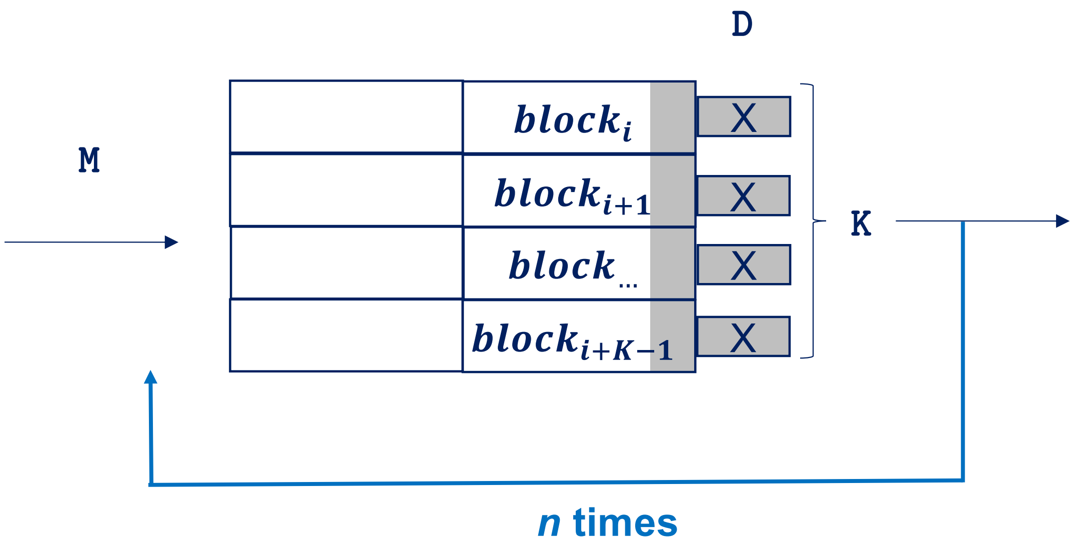
Allocation Modelling

Ideas:

- **several servers**
- **each communication can be segmented in *n* blocks**

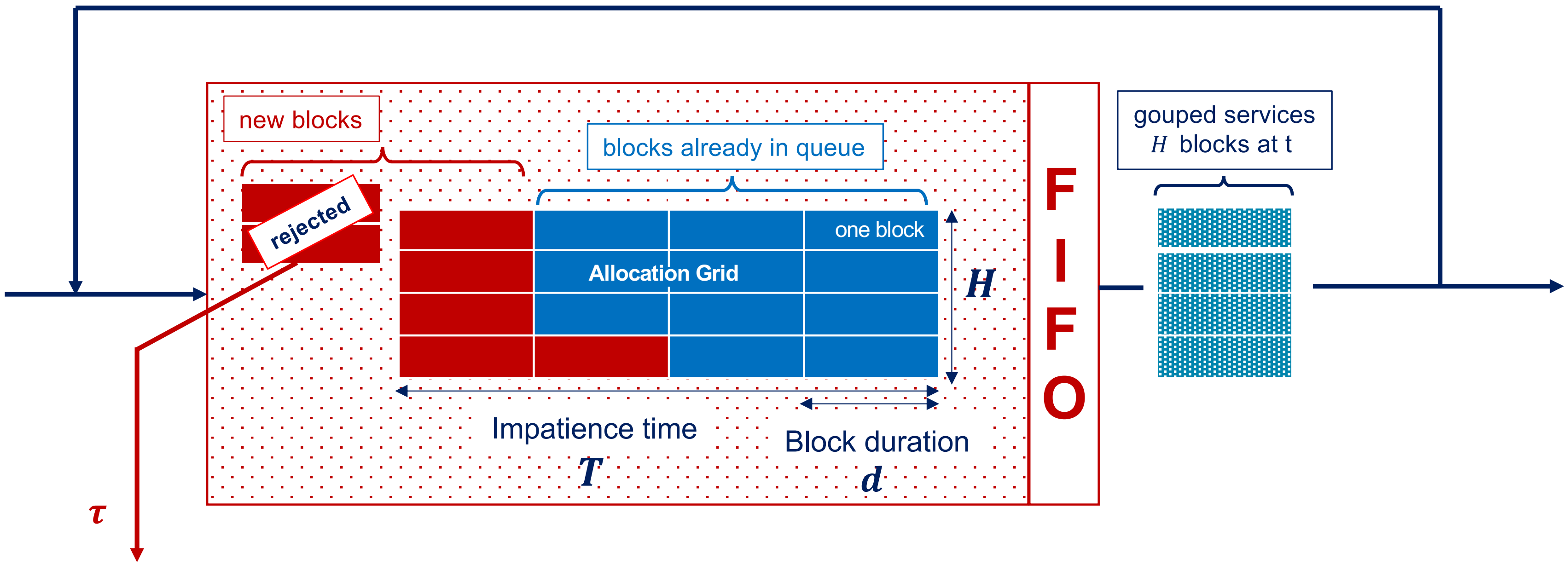
What we did next – M/D/H/K

- Exponential arrivals - M
- Deterministic services - D
- Several subcarriers/servers - H
- A queue with a limited size - K



Impatience in M/D/H/K

We know the duration of a block so we know when the new blocks will be served and can compute the impatience rate τ



Allocation Modelling

Benefits of using M/D/H/K:

- Avoid modelling the possibility of zero useful traffic
- Compute the impatience probability
- Precision – knowing how many blocks have been served

Agenda

01 NB-IoT Context : IoT & 5G

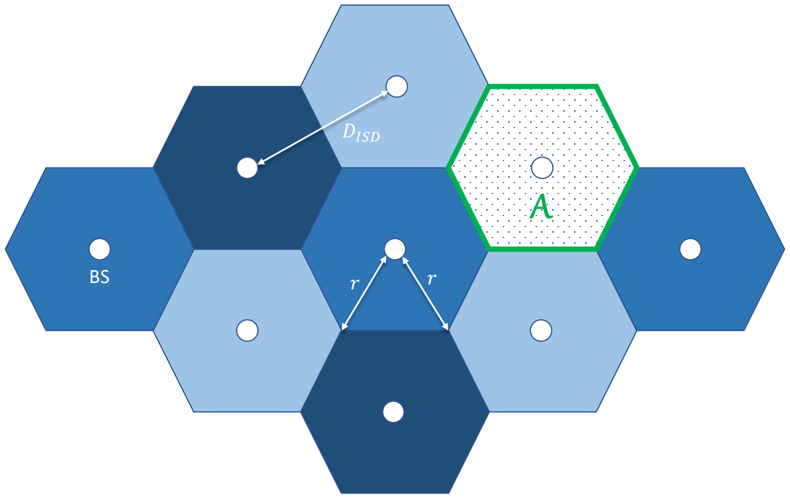
02 NB-IoT Insides : PHY & MAC layers

03 C-IoT optimizations

04 **Performance Evaluation**

Traffic and Cell definition

Parameter	Value
Payload UL/DL	32 bytes / 0 bytes
Communication Interval	2 hours
Cell Radius - r	500 meters



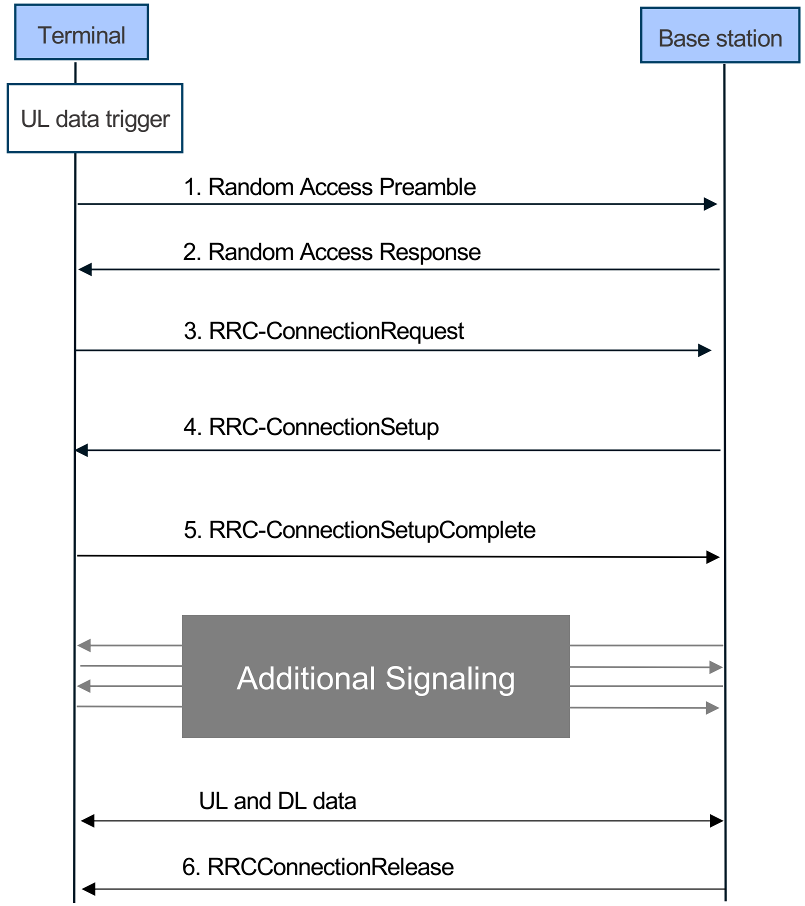
Performance according our model

Parameter	Value
Communication per second r=0.99	22.05
Capacity per carrier	182 900 devices/km^2
Nb of carrier needed to reach 5G-IoT requirements	6
Total bandwidth needed	2 160 kHz

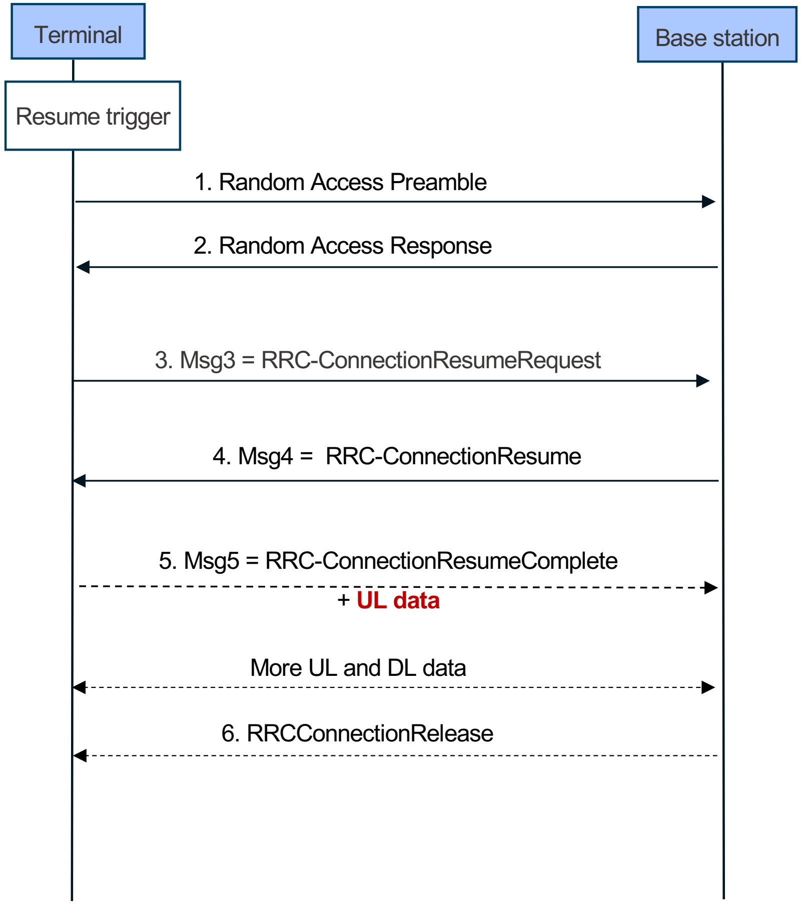
User Plane Optimization

Sequence Diagram

Classic - LTE



User Plane Optimization



Performance according our model

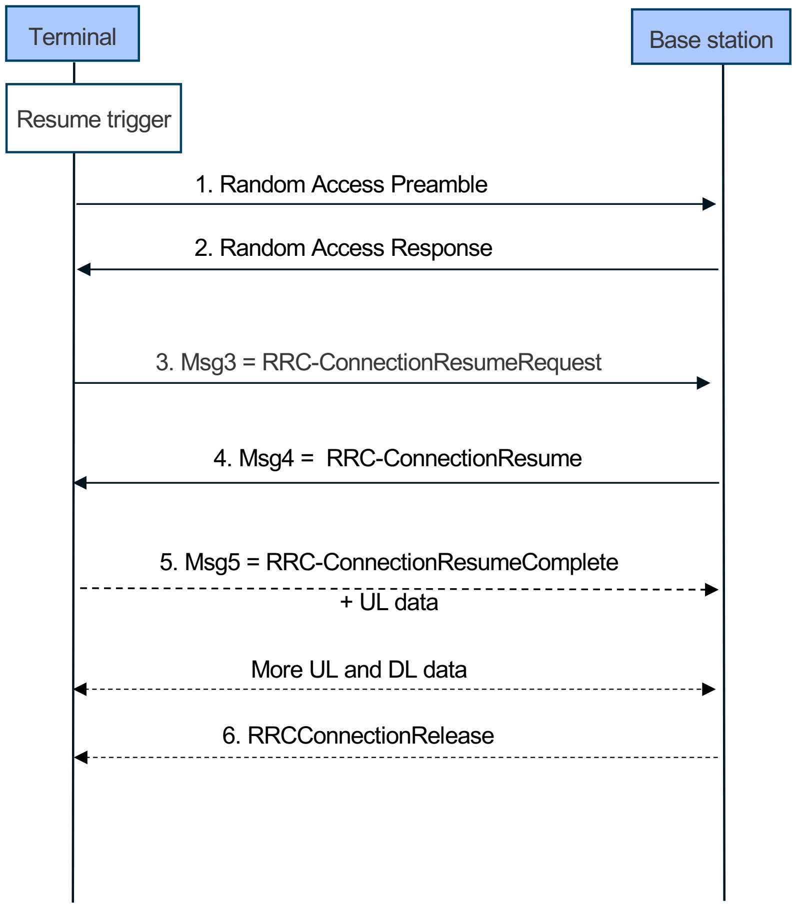
Parameter	Value
Communication per second r=0.99	61.95
Capacity per carrier	515 000 devices/km^2
Nb of carrier needed to reach 5G-IoT requirements	2
Total bandwidth needed	720 kHz

Early Data Transmission

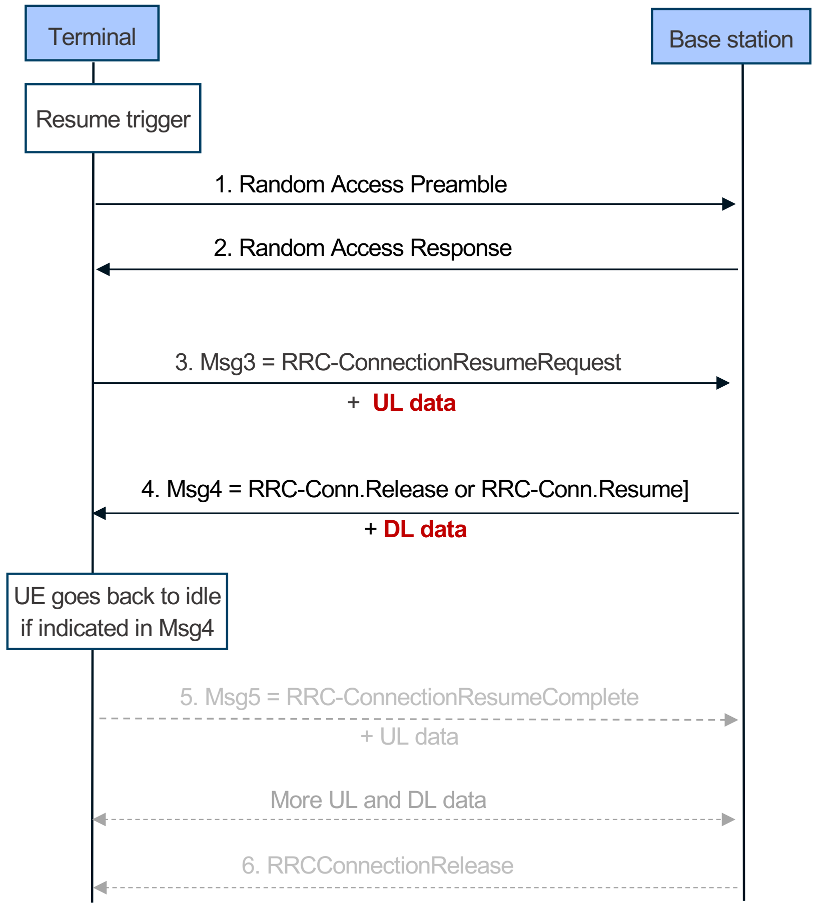
Or the ultimate way to reduce connection overhead

Sequence Diagram

User Plane Optimization



Early Data Transmission



Performance according our model

Parameter	Value
Communication per second r=0.99	139.5
Capacity per carrier	1 159 800 devices/km^2
Nb of carrier needed to reach 5G-IoT requirements	**1**
Total bandwidth needed	360 kHz

5G and IoT

Critical IoT

Bounded latencies
Ultra-reliable data delivery
Ultra-low latency

Broadband IoT

High data rates
Large data volumes
Low latency (best effort)

Massive IoT

Low-cost devices
Small data volumes
Extreme coverage

https://www.ericsson.com/

Overview of our other research activities

Or the teasing of the thesis defence

I. Deep study on the limitation of NB-IoT capacity

Thank you

Romain Barbau: romain.barbau@airbus.com