Integrating the Internet of Things Into 5G and Beyond Networks

Roberto Verdone

Radio Networks, DEI, Alma Mater Studiorum Università di Bologna
iDESIO, CSO & Co-Founder

SENSE, ACT, COMMUNICATE

iDESiO

SENSE, ACT, COMMUNICATE

Environmental Intelligence

TIM

TIM #WCAP
ACCELERATOR

Acknowledgements

- **Telecom Italia**
  - Antonio Manzalini, Fabio Luigi Bellifemine, Roberto De Bonis
- **Radio Networks, Univ. of Bologna**
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- **Newcom / EuWIn partners**
  - Sergio Palazzo, Giacomo Morabito, and others
- **iDESIO srl**
  - Co-Founders
- **Colleagues involved in submitted projects**
  - David Gesbert, Jaime Jose Garcia Reinoso, and others
- **Other Colleagues**
  - Stavros Toumpis

Introduction

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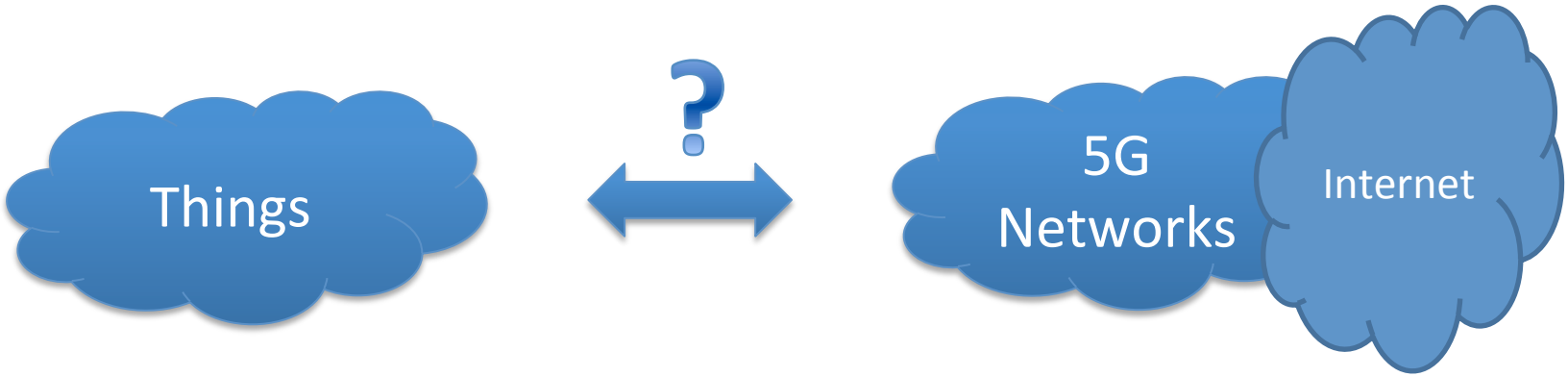
- **50 billion *Things* connected by 2020 *(Cisco)***
- **7 trillion *Devices* connected by 2020 *(5G PPP)***
- **5G claimed to be the main enabler for the IoT**



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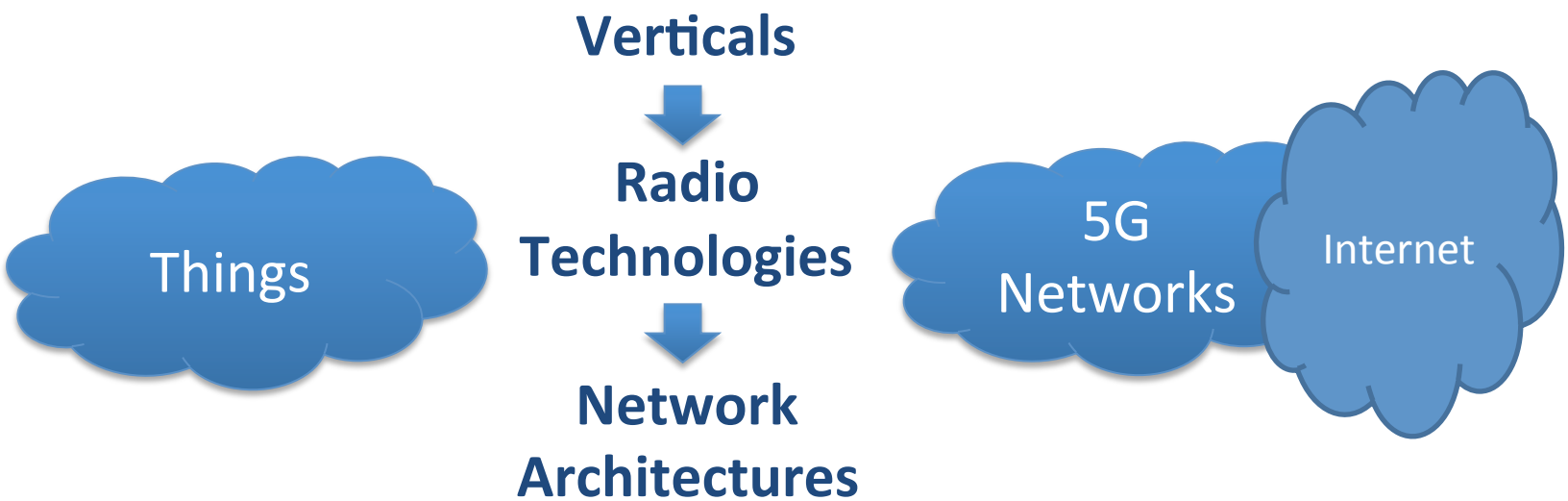

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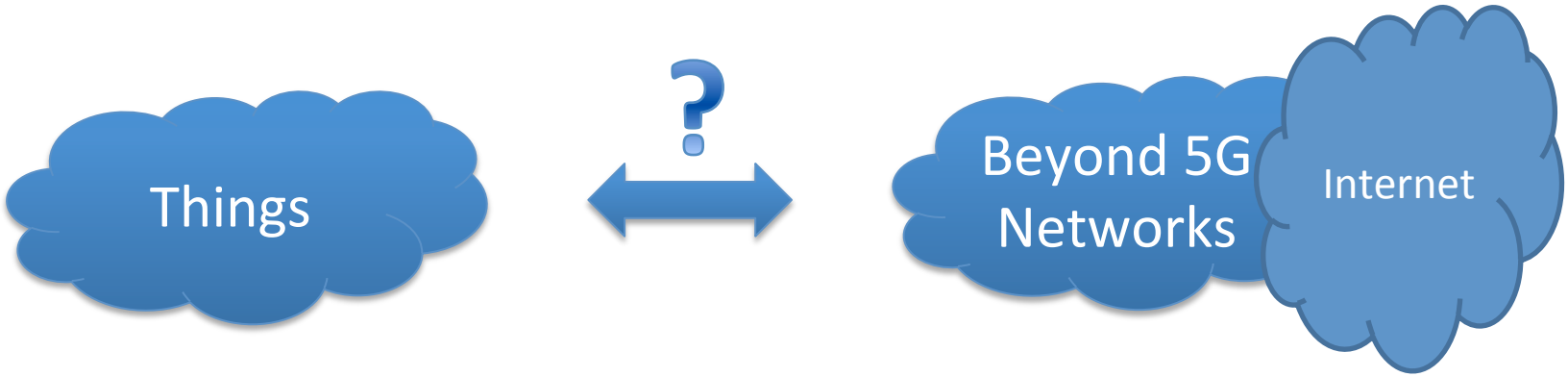

Outline

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- **Introduction**

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- Introduction
  - Internet of Things and 5G

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    - IoT Application Areas (Verticals)

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Core

Break

Internet of Things and 5G

Internet of Things and 5G

Extracted from HIRP Journal, June 2015

New Requirements
A Software Defined Network
A New Air Interface

Internet of Things and 5G

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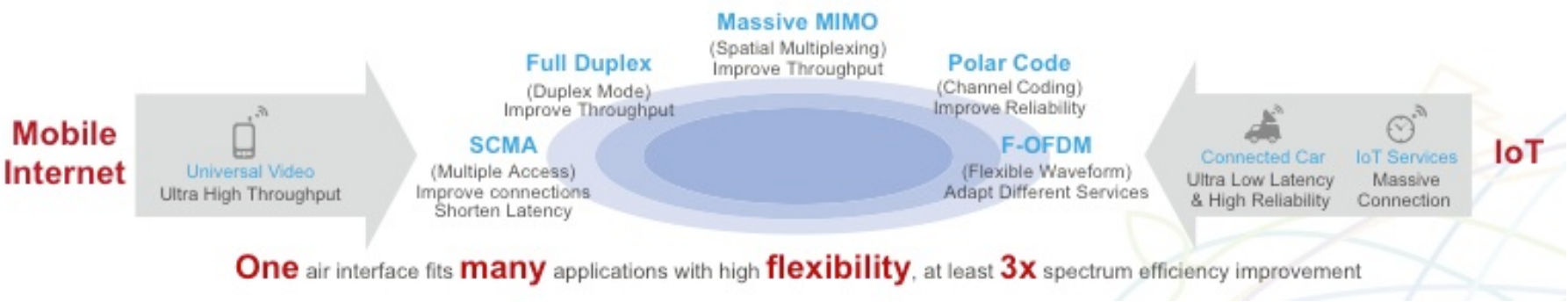
New Requirements

A Software Defined Network

A New Air Interface

Internet of Things and 5G

Ultra Capacity	**x 1000**
Ultra High Rate	**x 100**
Ultra Low Latency	**÷ 10**
Massive Connectivity	**x 100 (x 1000 ?)**
Ultra Low Energy Consumption	**÷ 1000**



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Internet of Things and 5G

Ultra Capacity	x 1000	
Ultra High Rate	x 100	
Ultra Low Latency	÷ 10	(< 1 ms)
Massive Connectivity	x 100 (x 1000 ?)	
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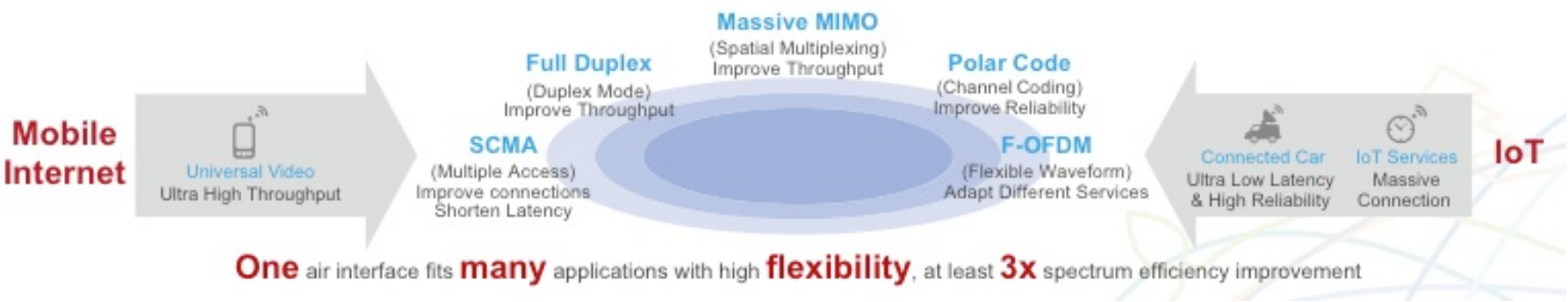

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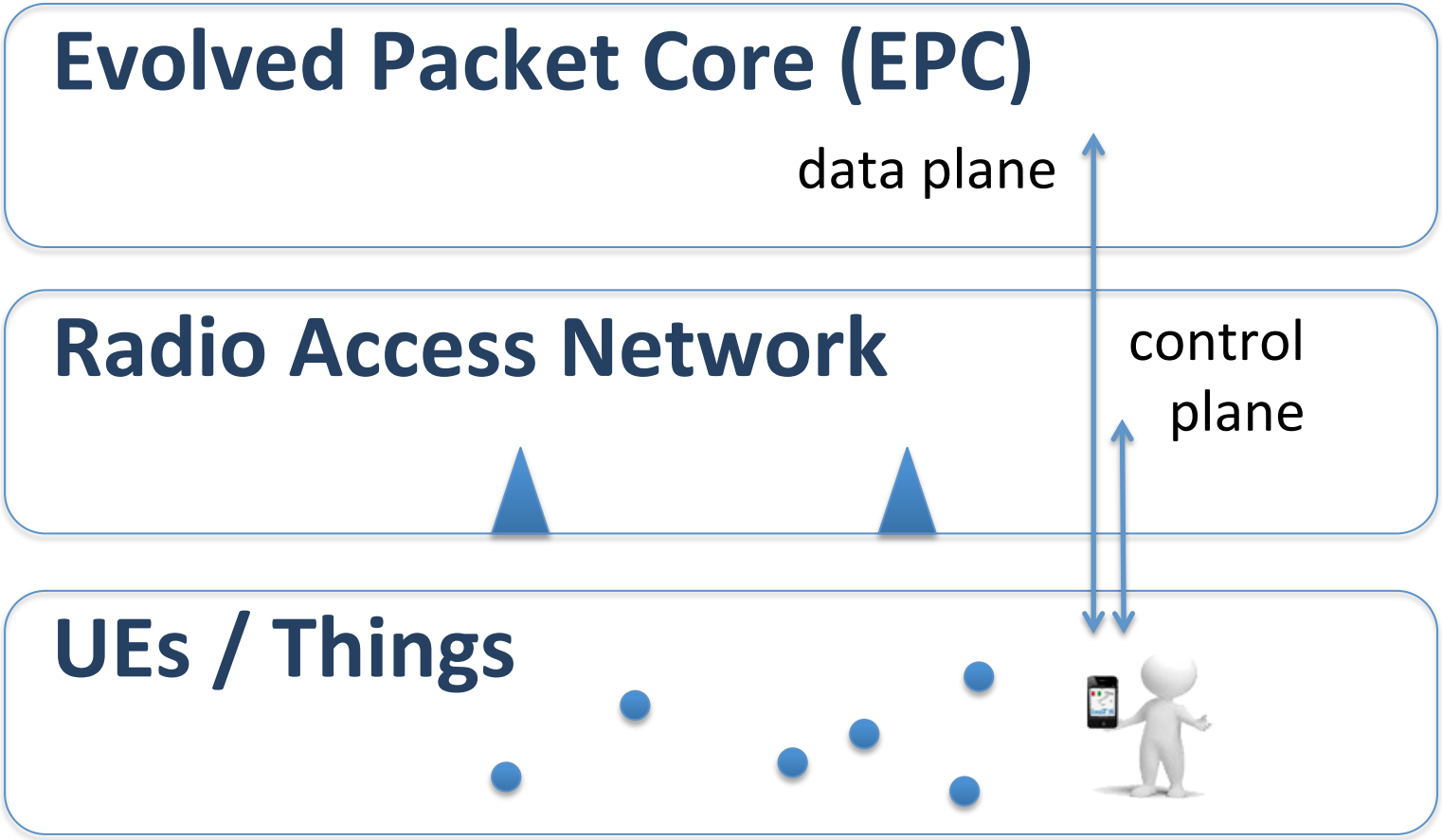

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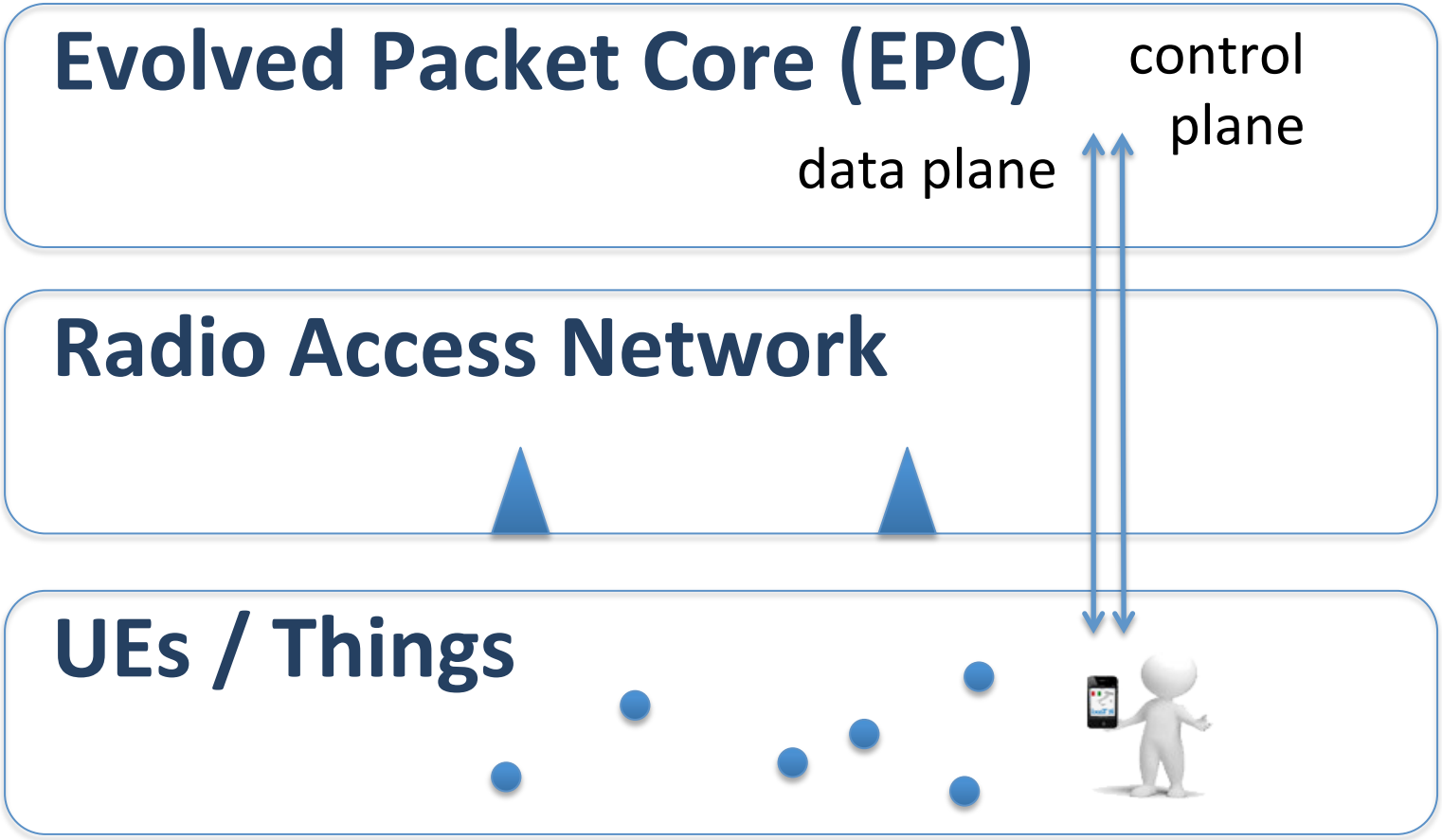

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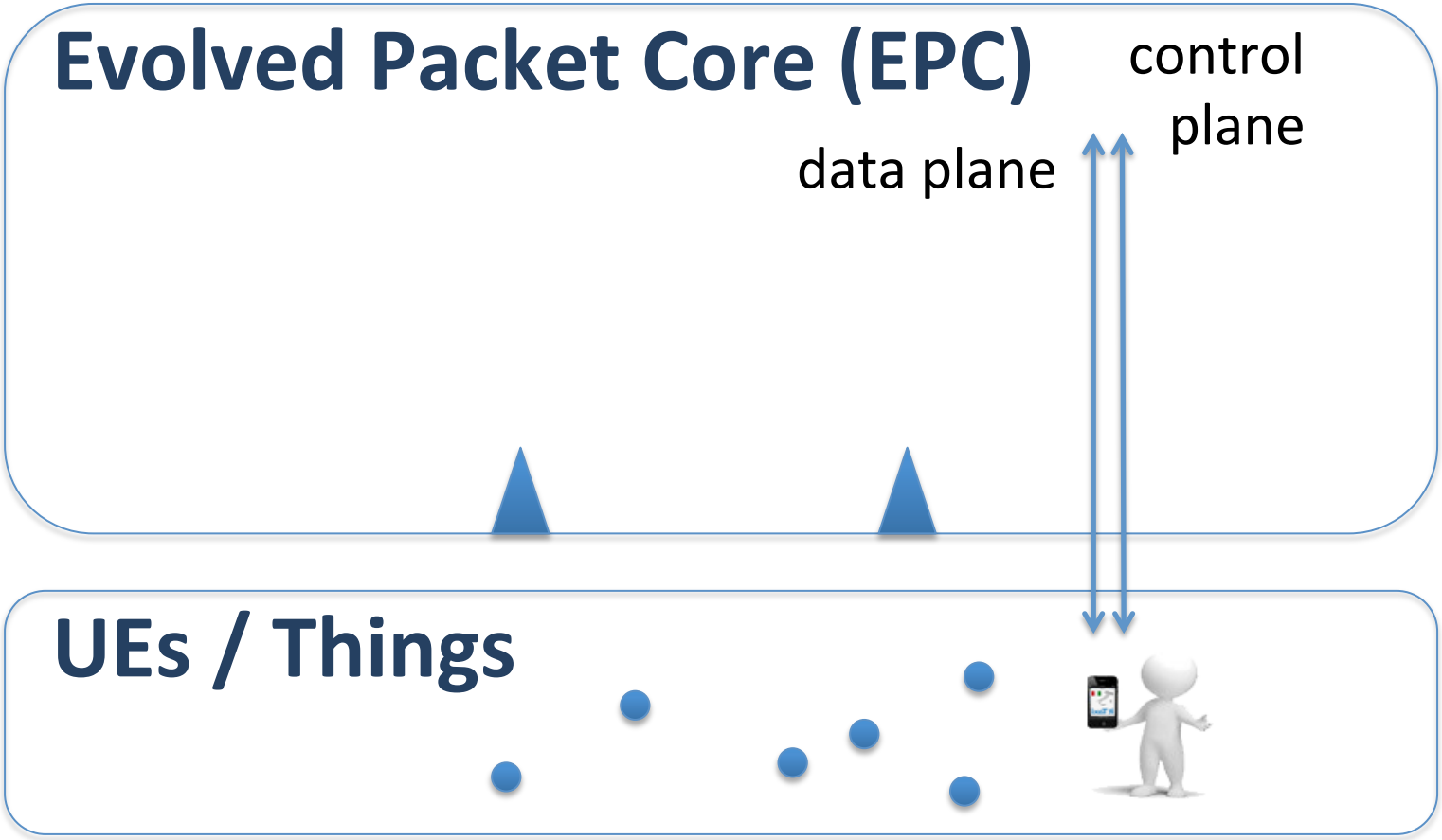
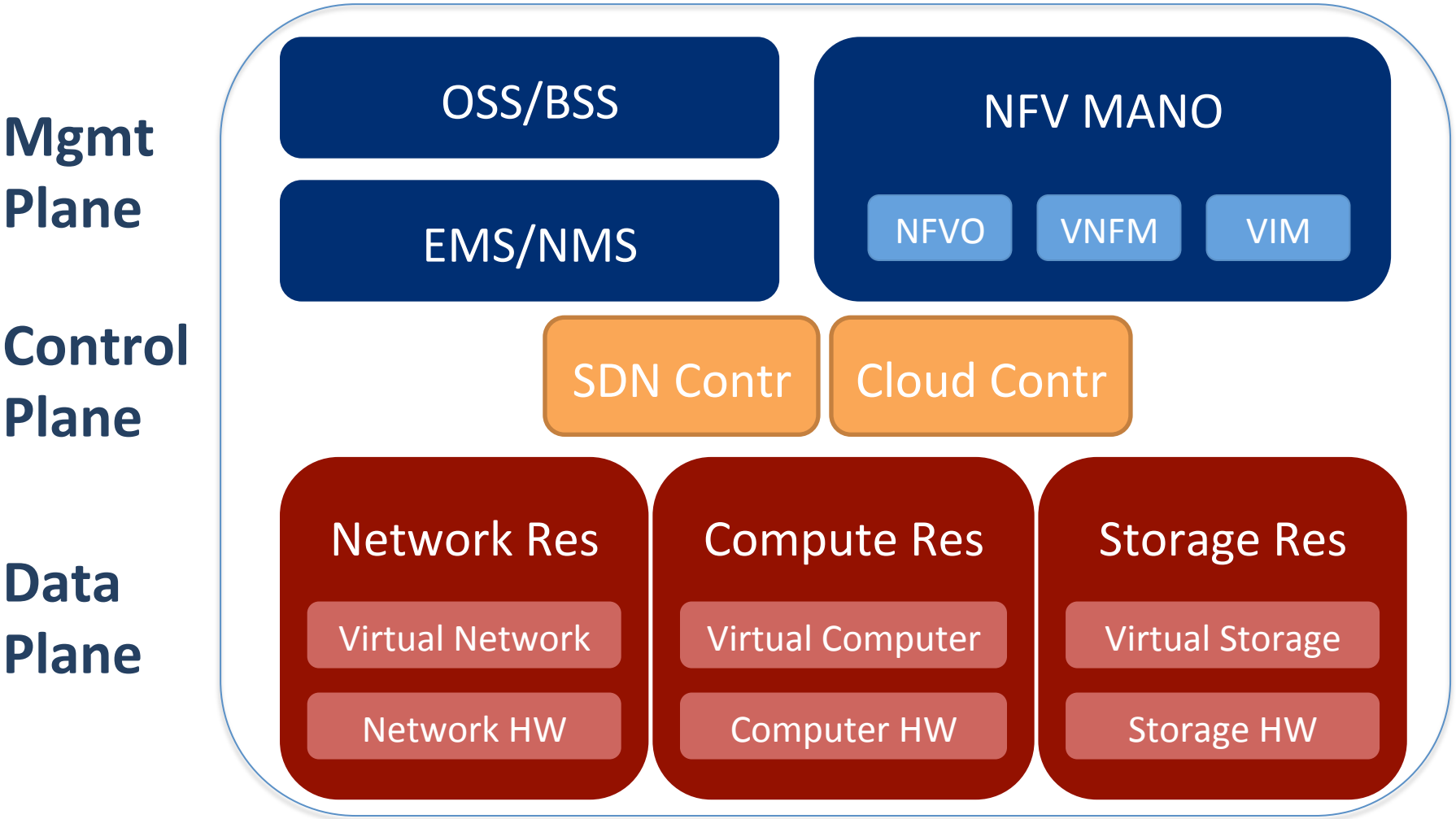


Internet of Things and 5G

EPC



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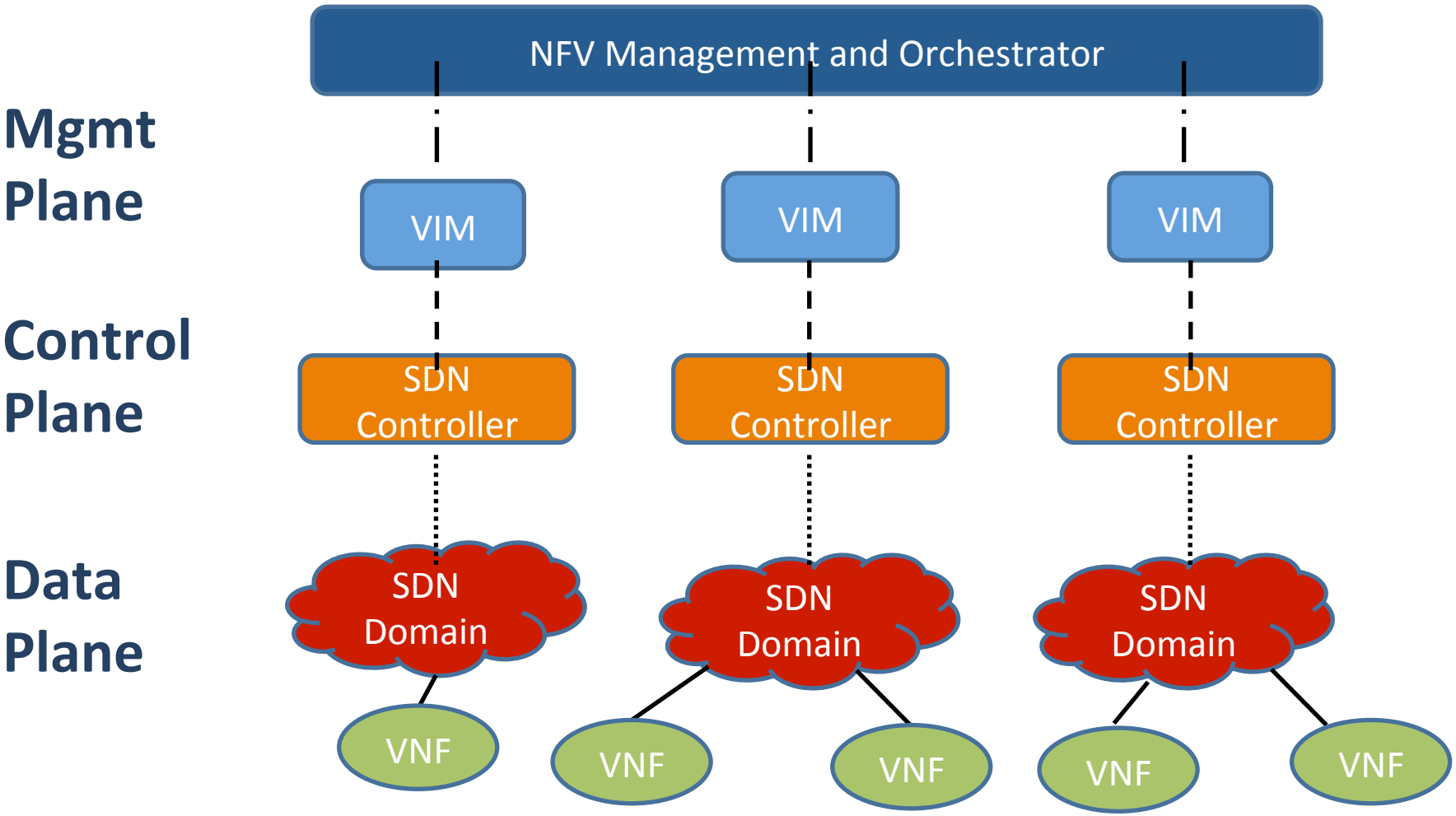

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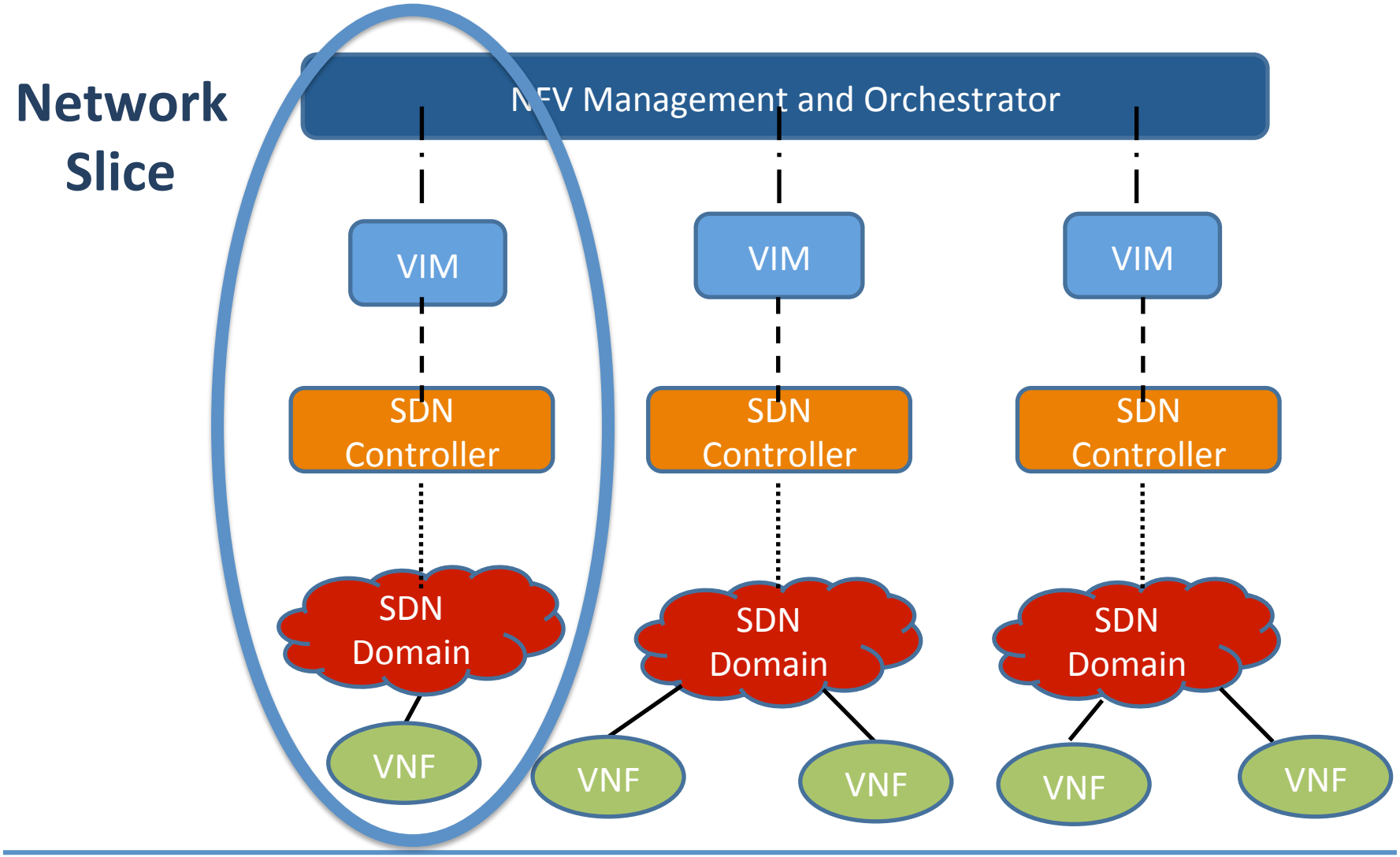

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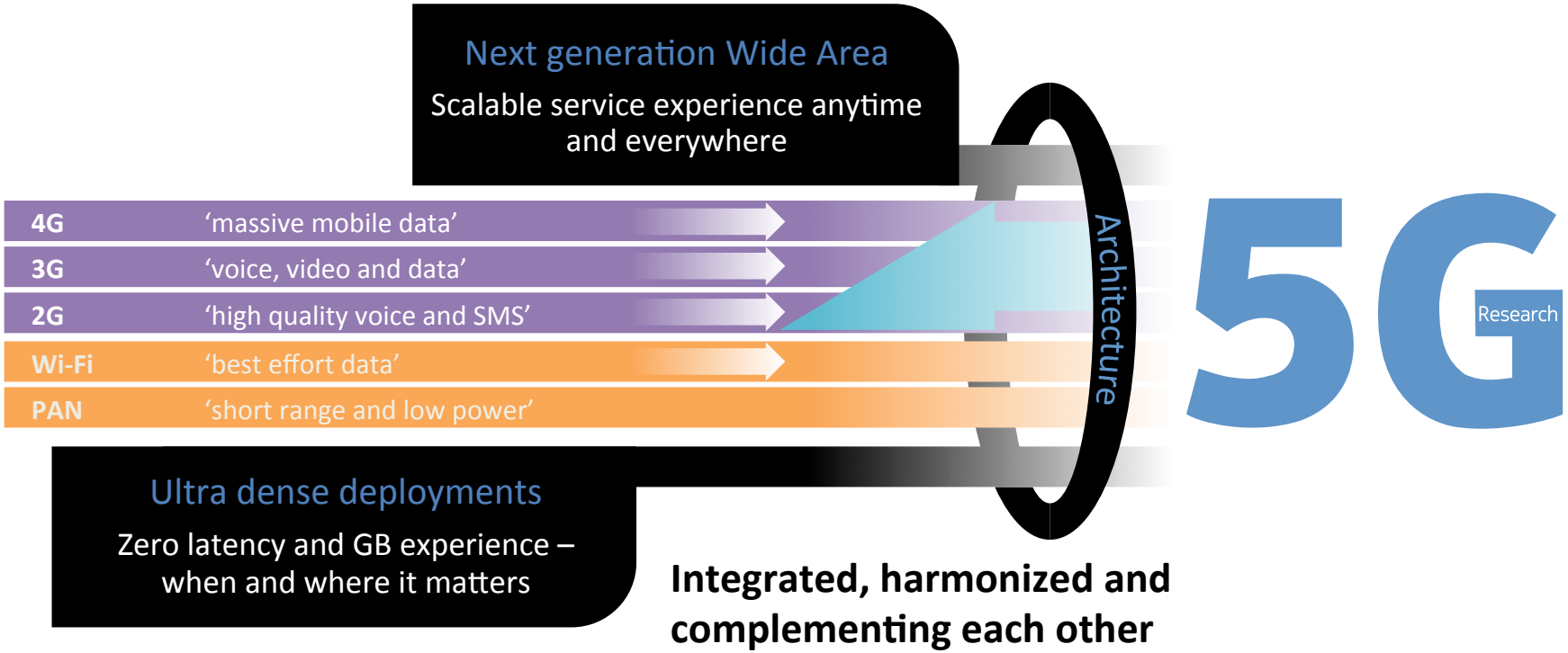
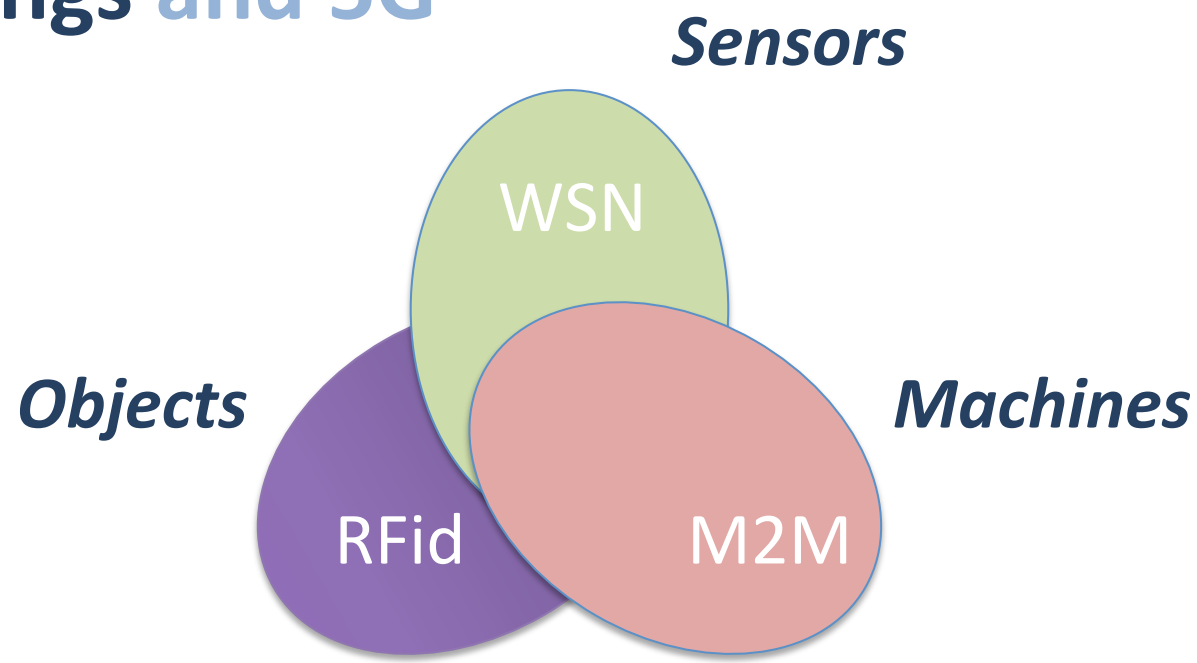


New Requirements

A Software Defined Network

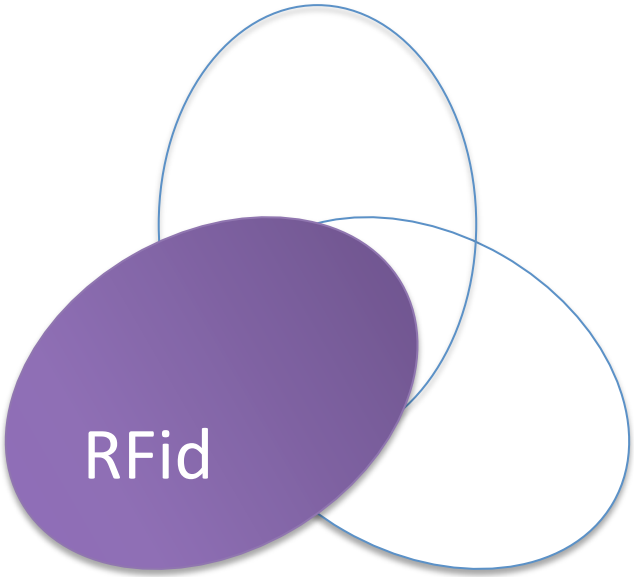
A New Air Interface → **A network of networks**

Internet of Things and 5G



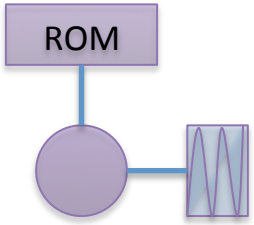
Internet of Things and 5G

Objects



objects equipped with RFid Tags:

- **Identification**
- **Passive**
- **No computing capabilities**



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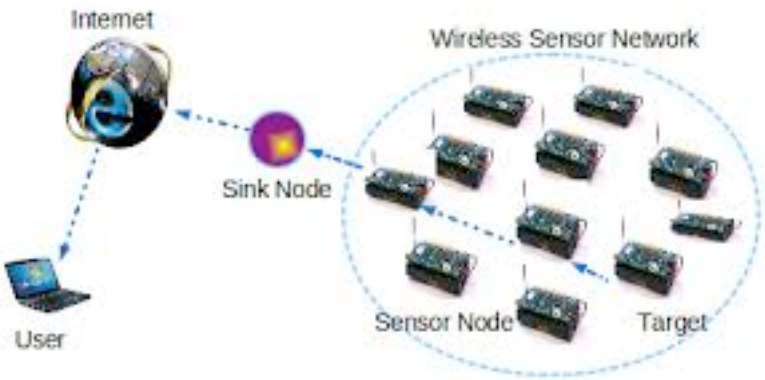
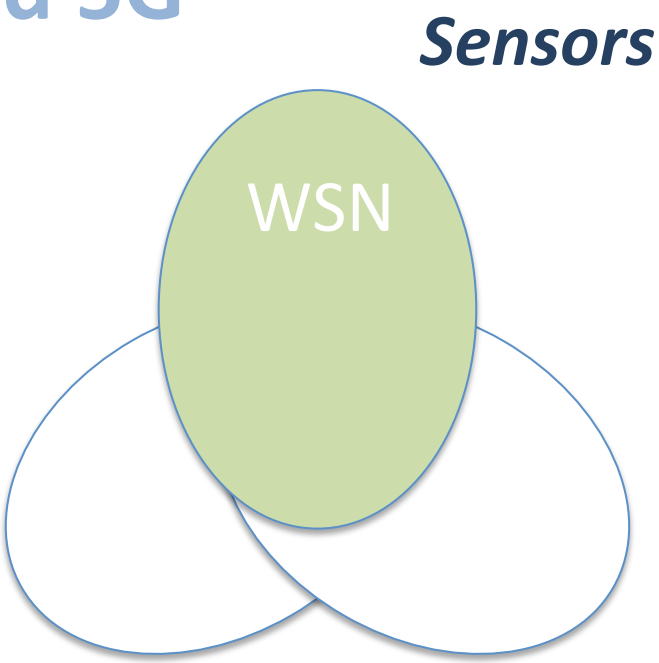
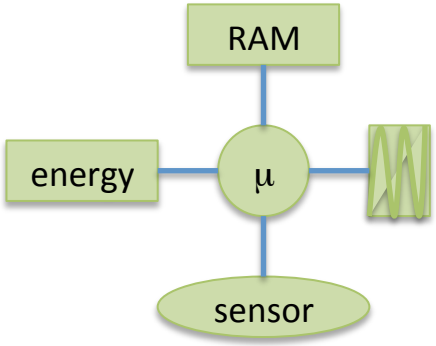




(embedded) devices equipped with sensors:

- **Sensing**
- **Battery or energy grid**
- **Some computing capabilities**



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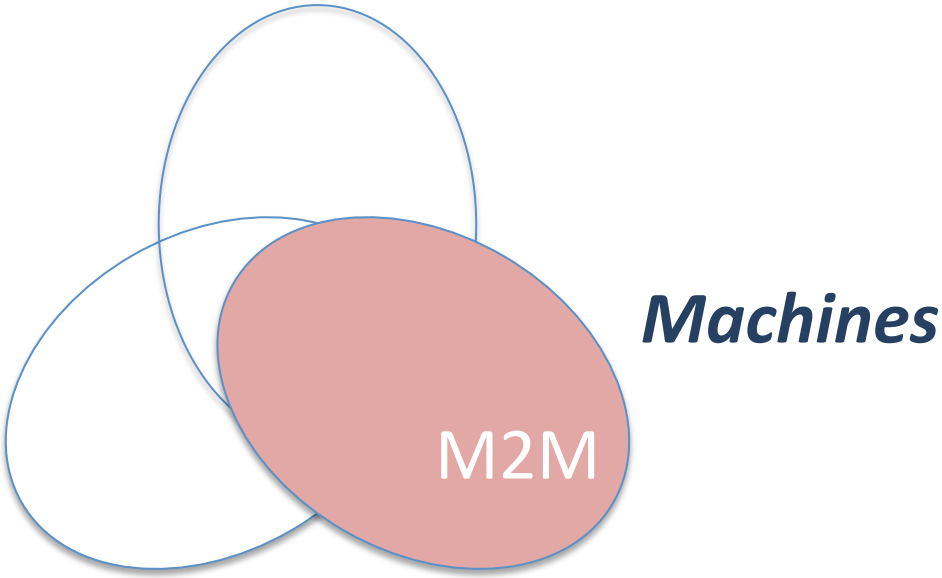
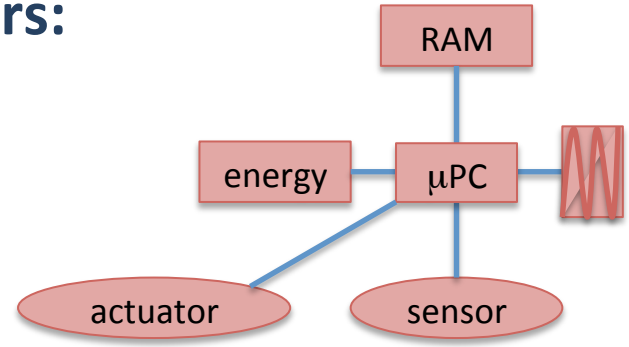


machines equipped with sensors / actuators:

- **Sensing & Actuation**
- **Industrial Control**
- **High computing capabilities**



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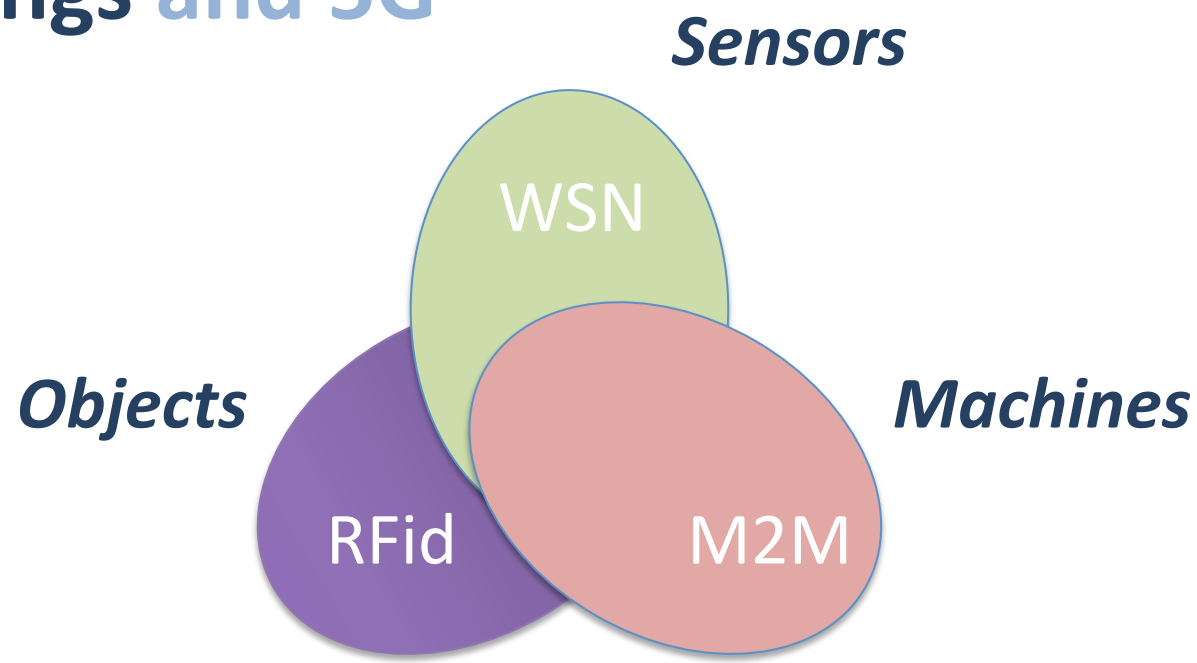
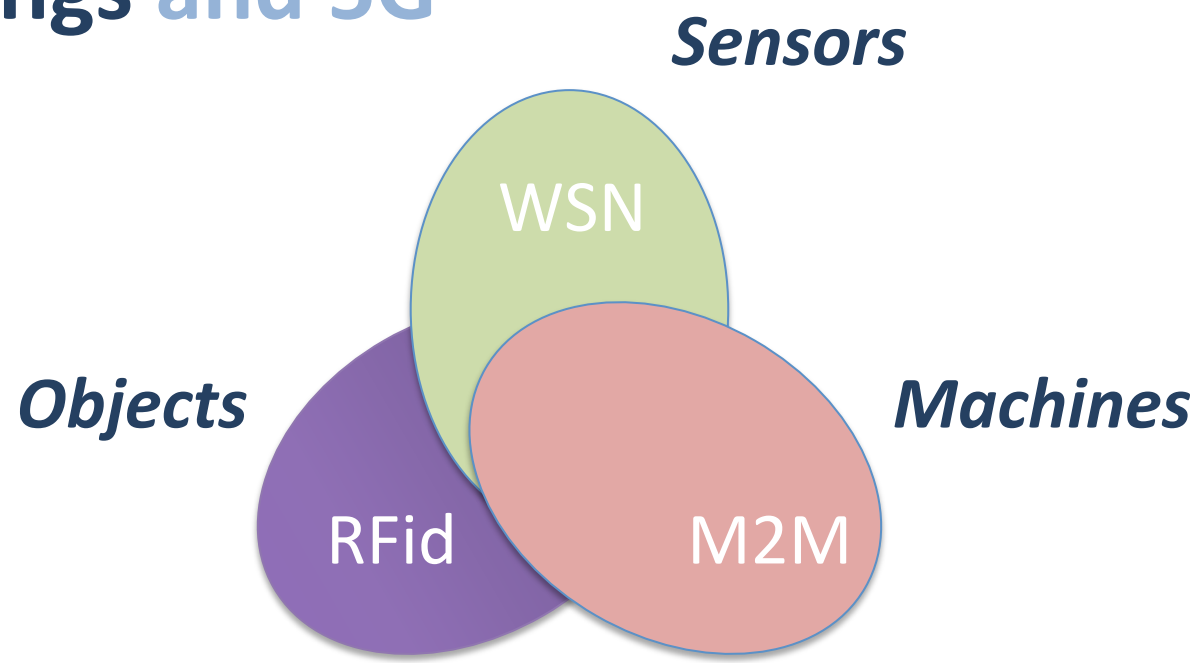


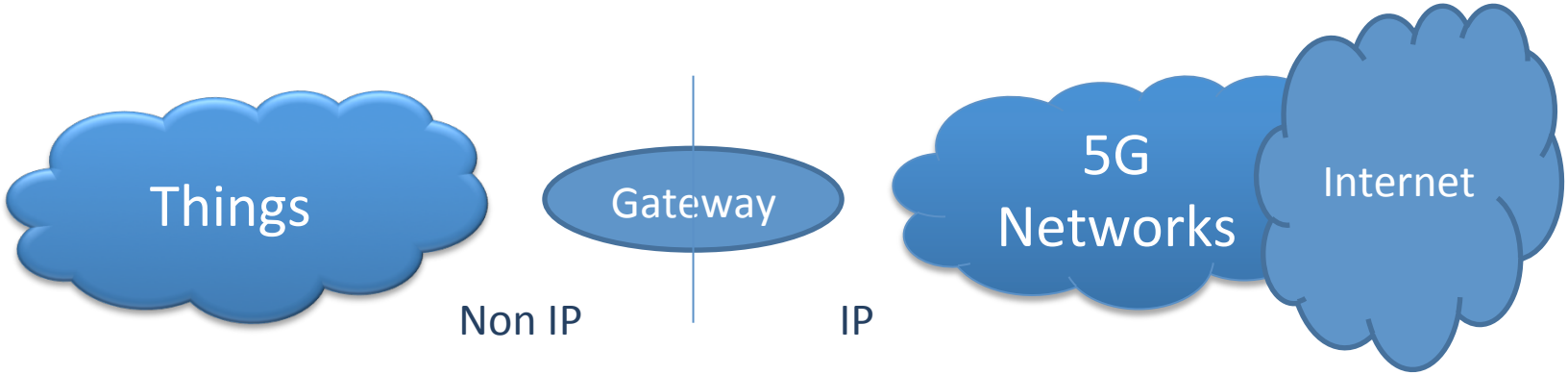
The IoT intends to connect to the Internet, wirelessly,

***unmanned* devices**

of very different nature, complexity and capabilities.

Internet of Things and 5G





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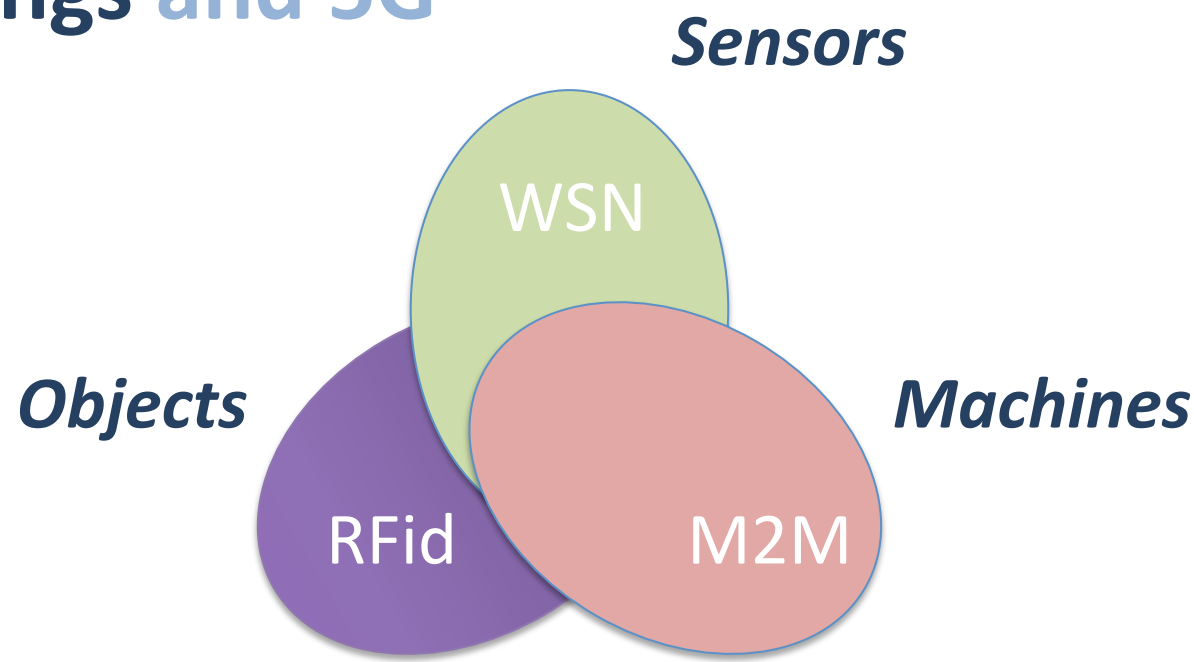

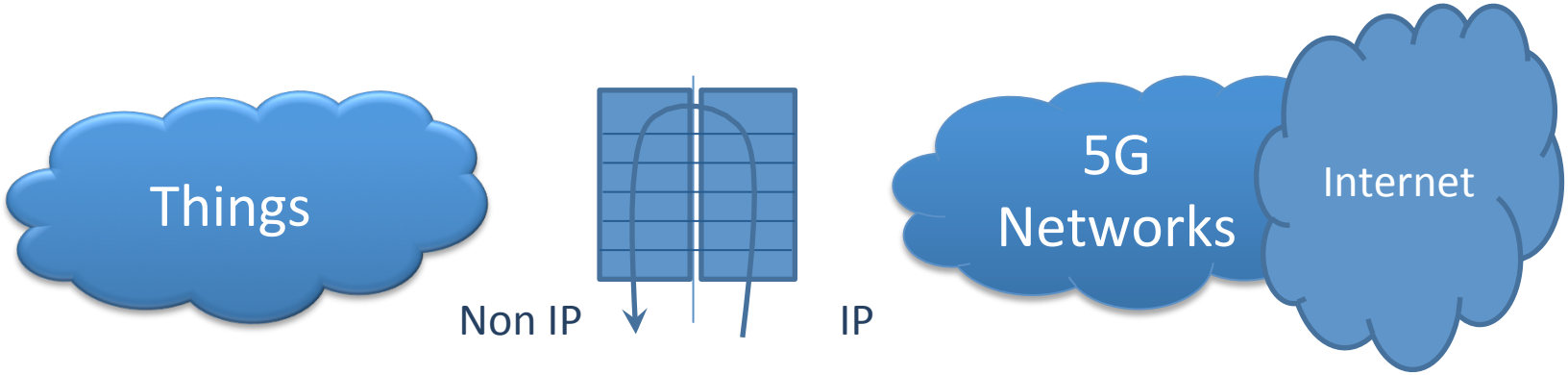

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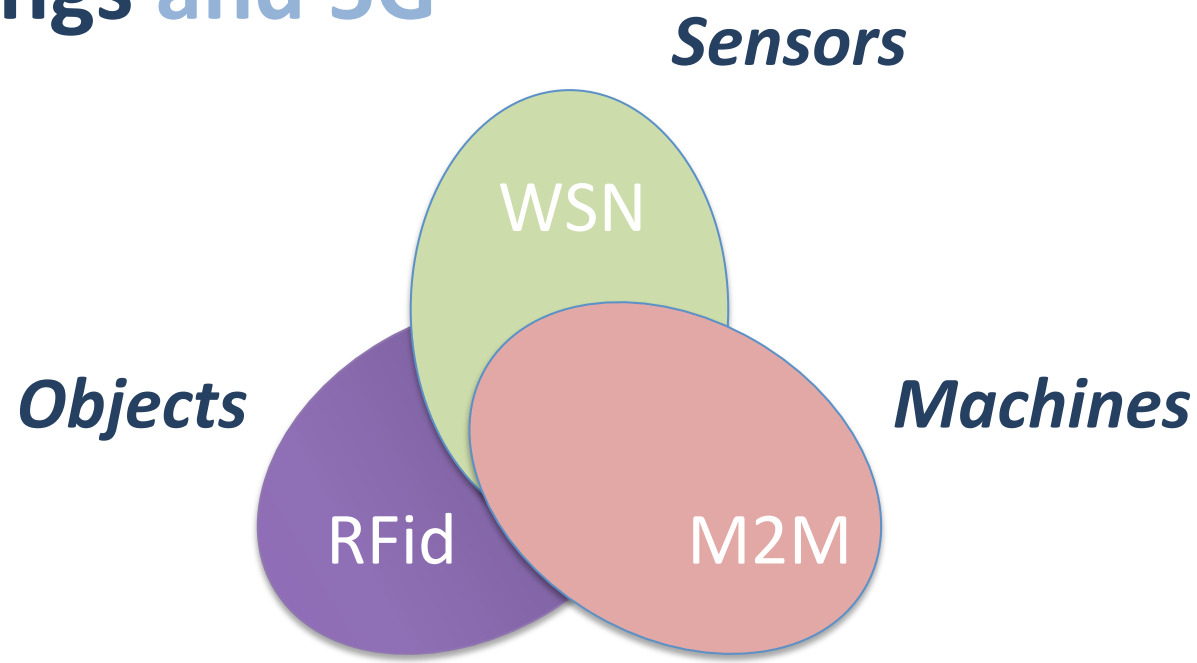

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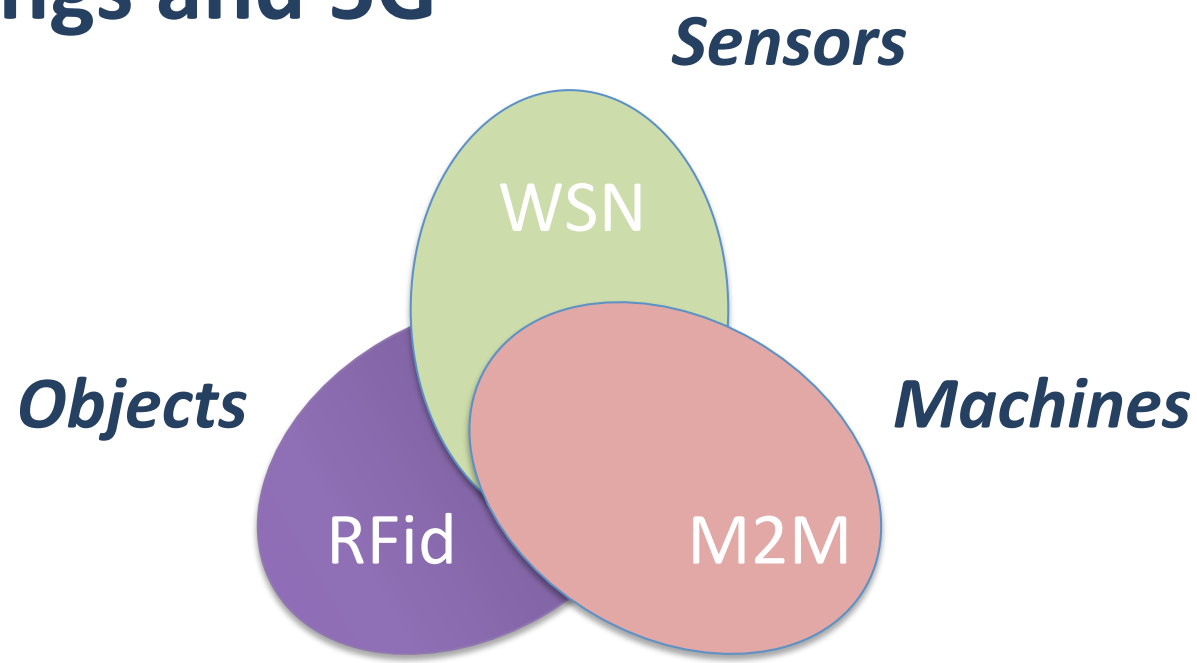
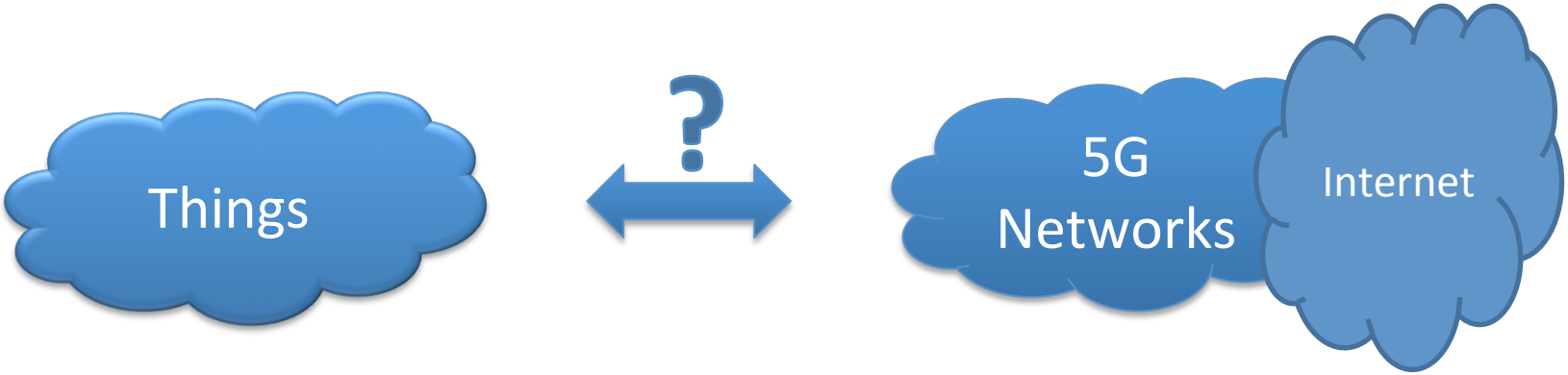
Internet of Things and 5G





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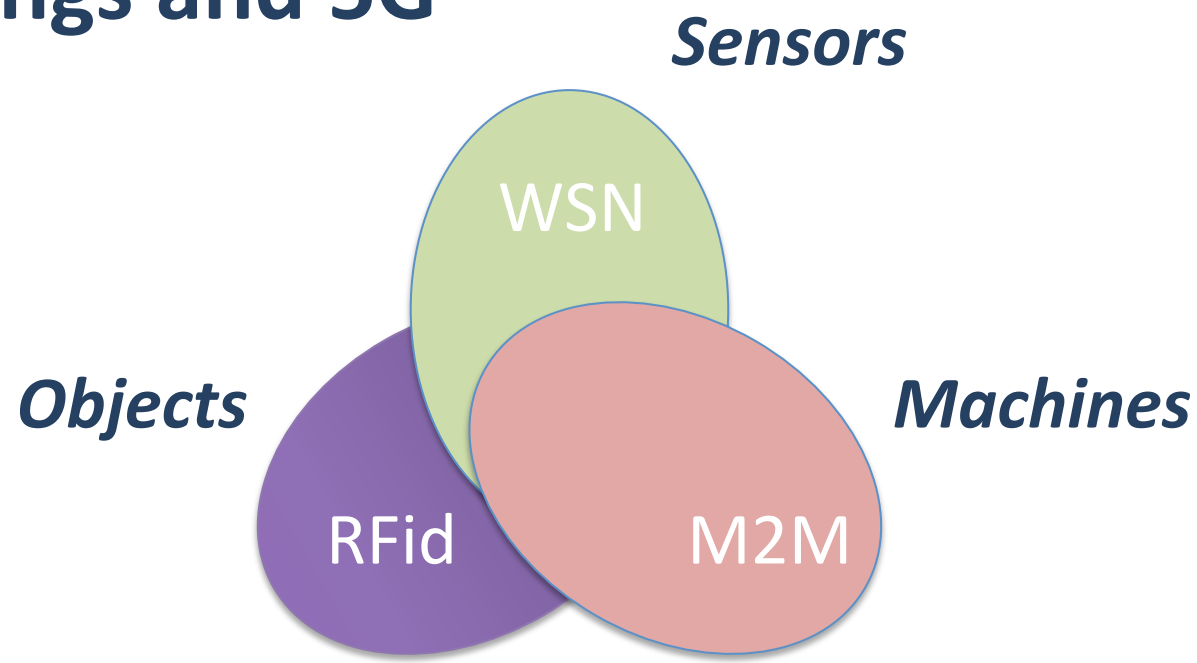

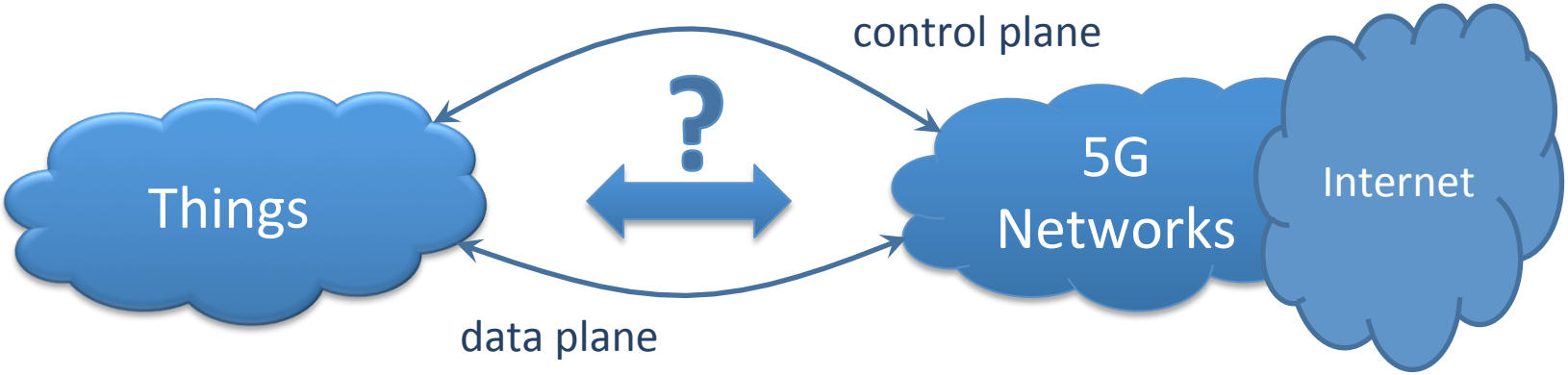

Internet of Things and 5G Takeaways

One Size Does Not Fit All

The IoT is more than just Connected Things

IoT Application Areas (Verticals)

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Application Areas of the early ages:

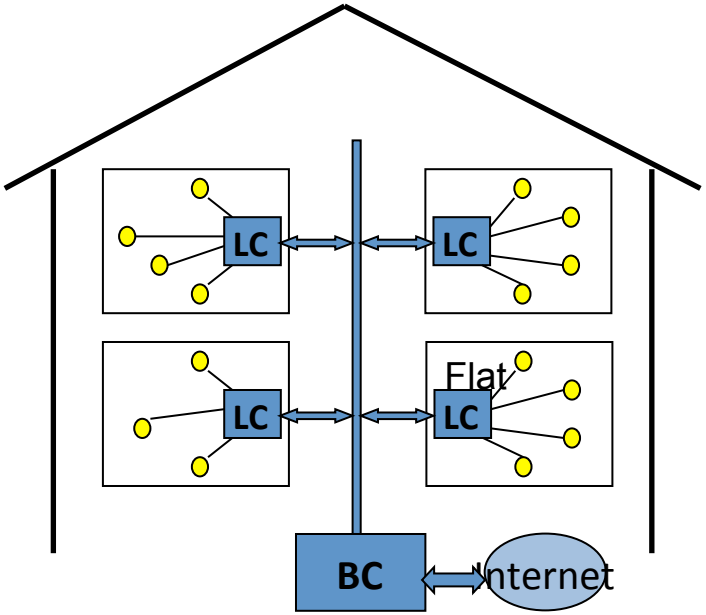
- Smart Buildings
- Smart Cities

IoT Application Areas (Verticals)

Application Areas of the early ages:

- Smart Buildings
- Smart Cities

Energy
Gas
Water
Surveillance
Maintenance
…



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Public Lighting
Energy
Wastes
Traffic
Surveillance
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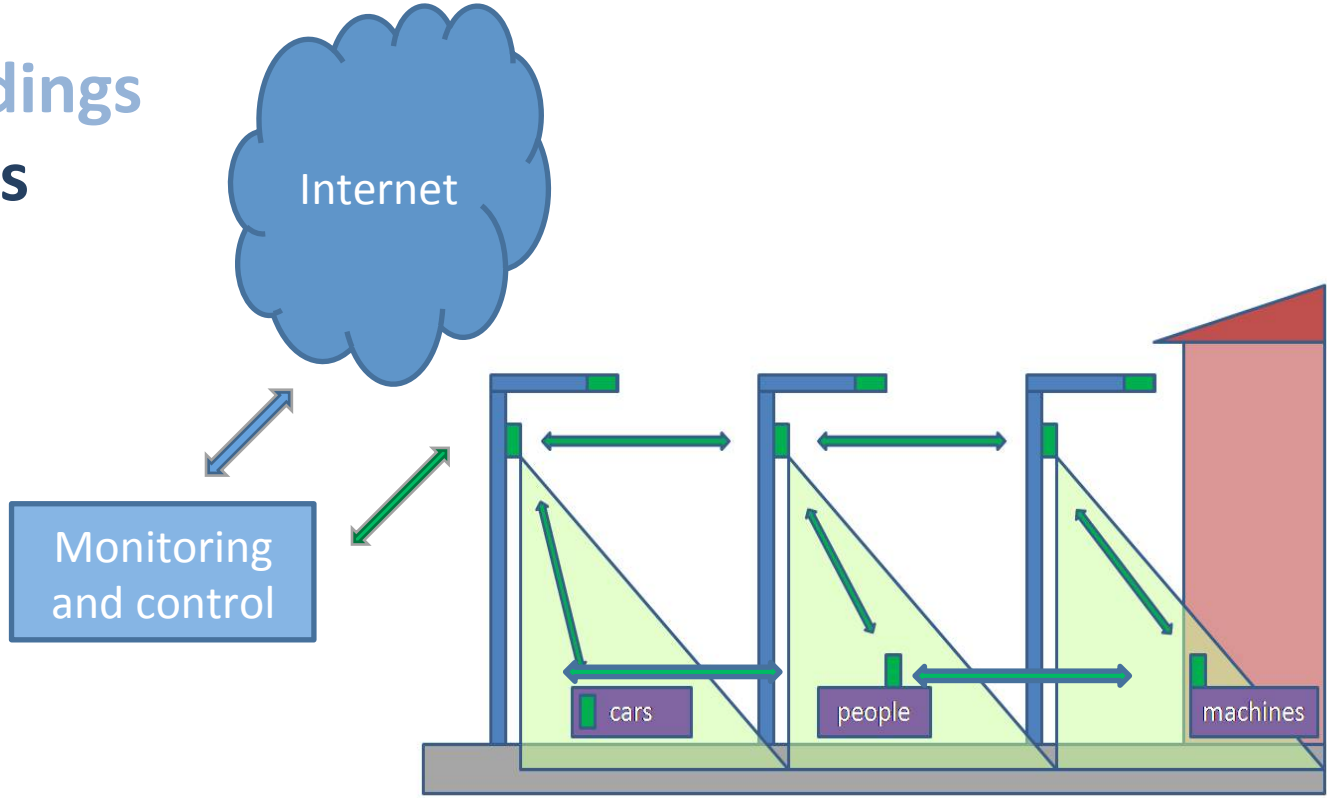

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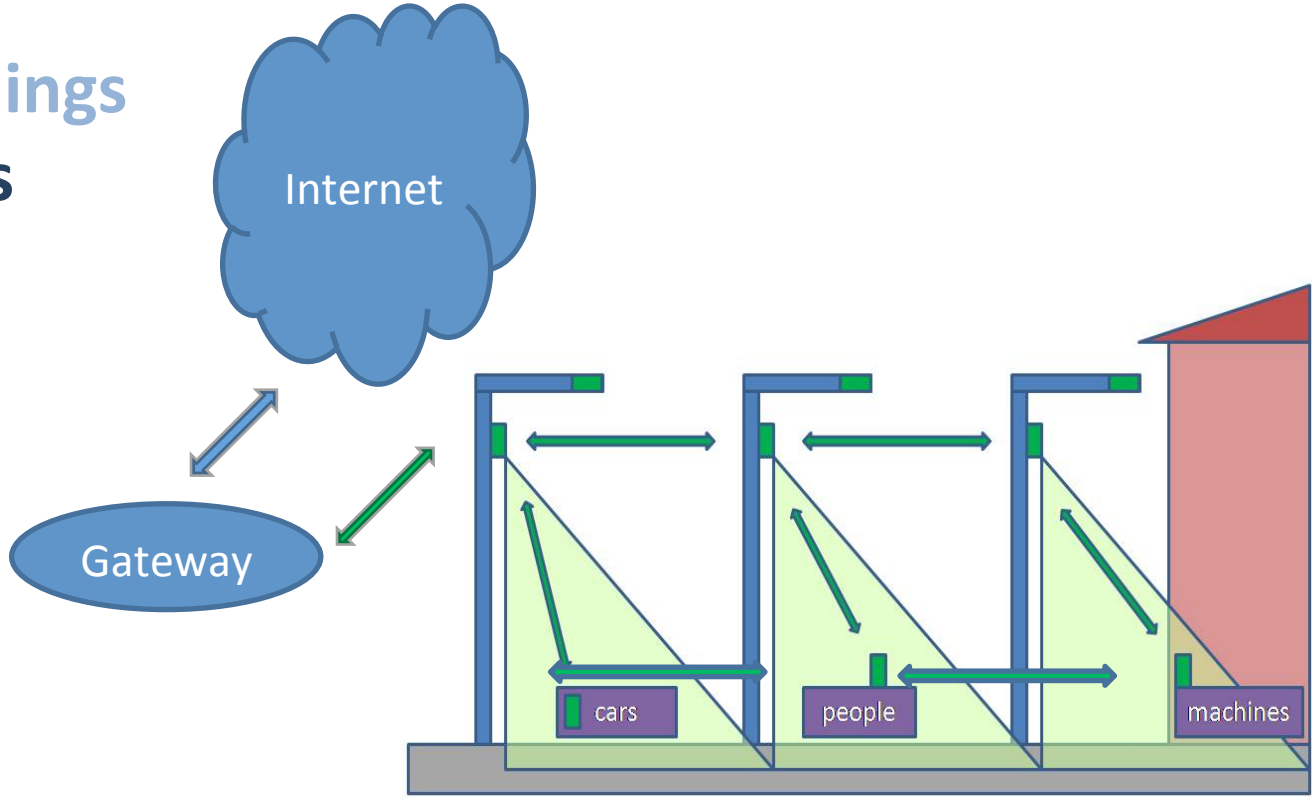

IoT Application Areas (Verticals)

Many actors are currently looking into the crystal ball analysing and categorising IoT verticals and their business potentials:

- **5G PPP IA**
- **GSMA**
- **IoT fora/projects**
- **… (startups…)**

IoT Application Areas (Verticals)

Macro Group	Main Parameters					Use Case		GSMA Group
	Latency	*Energy*	*Data Stream*	*Multicast*	*Channel*	*Category*	*Name*	
Group 0	<10 ms	-	-	-	-	Automotive	Cooperative Driving	n.a.
						Industrial	Machine Control	Type 3
Group P	>10 ms	Unlimited	-	-	-	Smart Cities	Smart Lighting	Type 4
						Automotive	Infotainment	n.a.
						Healthcare	Robotics	n.a.
						Smart Cities	Smart Grid	Type 3
						Other	Vending Machines	Type 4
Group B+	>10ms	Limited	Up + Down	-	-	Precision Agricolture	Stationary Monitorin	Type 3
						Consumer	White Goods	Type 3
						Industrial	Asset Tracking	Type 2
						Precision Agricolture	Animal Tracking	Type 2
						Industrial	Tank Safety Monitoring	Type 2
						Consumer	Wearable	Type 1
						Consumer	VIP/Pet/Object Tracking	Type 1
						Smart Cities	Smart Parking	Type 3
						Smart Buildings	Home Automation	Type 3
Group BHMID	10ms - 10s	Limited	Up	Absent	Dynamic	Healthcare	Remote Patient Monitoring	Type 1
						Smart Buildings	Smoke Detector	Type 2
Group BHMIS	10ms - 10s	Limited	Up	Absent	Static	Environmental	Event Monitoring (fires)	Type 2
Group BDTD	>10s	Limited	Up	Absent	Dynamic	Consumer	Smart Bicycle	Type 1
						Smart Cities	Waste Management	n.a.
Group BDTS	>10s	Limited	Up	Absent	Static	Smart Buildings	Gas&Water Metering	Type 3
						Smart buildings	Microgeneration	Type 2
						Environmental	Static Monitoring	Type 2

IoT Application Areas (Verticals)

Zero Latency

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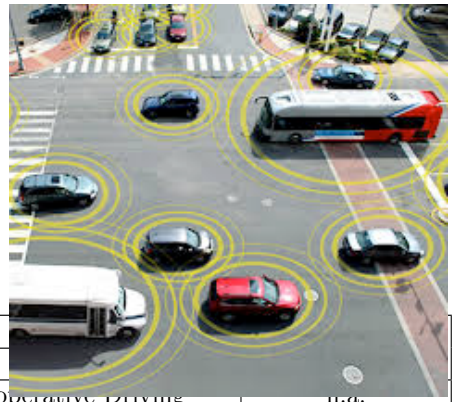

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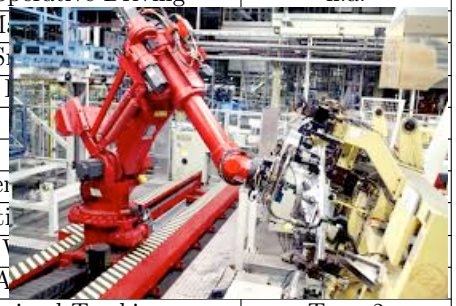

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Group BDTS	>10s	Limited	Up	Absent	Static	Smart Buildings	Gas&Water Metering	Type 3
						Smart buildings	Microgeneration	Type 2
						Environmental	Static Monitoring	Type 2

IoT Application Areas (Verticals)

Delay Constrained

Macro Group	Main Parameters					Use Case		GSMA Group
	Latency	*Energy*	*Data Stream*	*Multicast*	*Channel*	*Category*	*Name*	
Group 0	<10 ms	-	-	-	-	Automotive	Cooperative Driving	n.a.
						Industrial	Machine Control	Type 3
Group P	>10 ms	Unlimited	-	-	-	Smart Cities	Smart Lighting	Type 4
						Automotive	Infotainment	n.a.
						Healthcare	Robotics	n.a.
						Smart Cities	Smart Grid	Type 3
						Other	Vending Machines	Type 4
Group B+	>10ms	Limited	Up + Down	-	-	Precision Agricolture	Stationary Monitorin	Type 3
						Consumer	White Goods	Type 3
						Industrial	Asset Tracking	Type 2
						Precision Agricolture	Animal Tracking	Type 2
						Industrial	Tank Safety Monitoring	Type 2
						Consumer	Wearable	Type 1
						Consumer	VIP/Pet/Object Tracking	Type 1
						Smart Cities	Smart Parking	Type 3
						Smart Buildings	Home Automation	Type 3
Group BHMID	10ms - 10s	Limited	Up	Absent	Dynamic	Healthcare	Remote Patient Monitoring	Type 1
						Smart Buildings	Smoke Detector	Type 2
Group BHMIS	10ms - 10s	Limited	Up	Absent	Static	Environmental	Event Monitoring (fires)	Type 2
Group BDTD	>10s	Limited	Up	Absent	Dynamic	Consumer	Smart Bicycle	Type 1
						Smart Cities	Waste Management	n.a.
Group BDTS	>10s	Limited	Up	Absent	Static	Smart Buildings	Gas&Water Metering	Type 3
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IoT Application Areas (Verticals)

Delay Constrained

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Group P	>10 ms	Unlimited	-	-	-	Smart Cities	Smart Li	
						Automotive	Infotain	
						Healthcare	Robo	
						Smart Cities	Smart	
						Other	Vending M	
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						Consumer	White C	
						Industrial	Asset Tr	
						Precision Agricolture	Animal Tracking	Type 2
						Industrial	Tank Safety Monitori	
						Consumer	Wearable	
						Consumer	VIP/Pet/Object Tracl	
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						Smart Buildings	Home Automation	
Group BHMID	10ms - 10s	Limited	Up	Absent	Dynamic	Healthcare	Remote Patient Monito	
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Group BDTD	>10s	Limited	Up	Absent	Dynamic	Consumer	Smart Bicycle	
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Group BDTS	>10s	Limited	Up	Absent	Static	Smart Buildings	Gas&Water Meterin	
						Smart buildings	Microgeneration	
						Environmental	Static Monitoring	

IoT Application Areas (Verticals)

Delay Tolerant

Macro Group	Main Parameters					Use Case		GSMA Group
	Latency	*Energy*	*Data Stream*	*Multicast*	*Channel*	*Category*	*Name*	
Group 0	<10 ms	-	-	-	-	Automotive	Cooperative Driving	n.a.
						Industrial	Machine Control	Type 3
Group P	>10 ms	Unlimited	-	-	-	Smart Cities	Smart Lighting	Type 4
						Automotive	Infotainment	n.a.
						Healthcare	Robotics	n.a.
						Smart Cities	Smart Grid	Type 3
						Other	Vending Machines	Type 4
Group B+	>10ms	Limited	Up + Down	-	-	Precision Agricolture	Stationary Monitorin	Type 3
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						Industrial	Tank Safety Monitoring	Type 2
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Group BDTD	>10s	Limited	Up	Absent	Dynamic	Consumer	Smart Bicycle	Type 1
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Group BDTS	>10s	Limited	Up	Absent	Static	Smart Buildings	Gas&Water Metering	Type 3
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IoT Application Areas (Verticals)

Delay Tolerant

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	Latency	*Energy*	*Data Stream*	*Multicast*	*Channel*	*Category*	*Name*	
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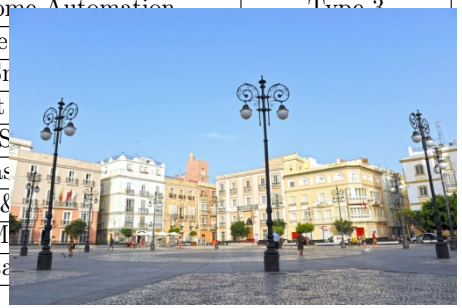
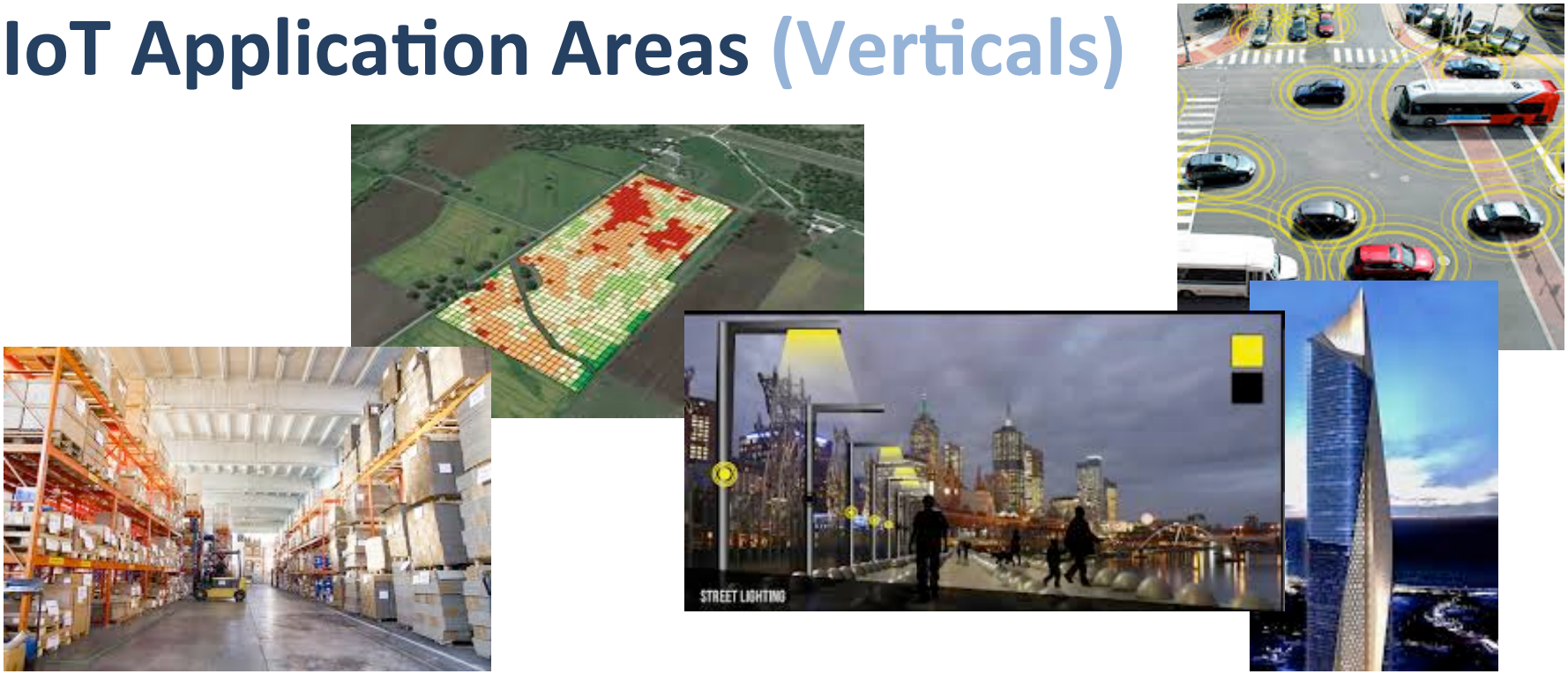
						Healthcare		
						Smart Cities		
						Other	Ve	
Group B+	>10ms	Limited	Up + Down	-	-	Precision Agricolture	Stati	
						Consumer		
						Industrial	A	
						Precision Agricolture	A	
						Industrial	Tank	
						Consumer		
						Consumer	VIP	
						Smart Cities	S	
						Smart Buildings	Ho	
Group BHMID	10ms - 10s	Limited	Up	Absent	Dynamic	Healthcare	Remote	
						Smart Buildings	S	
Group BHMIS	10ms - 10s	Limited	Up	Absent	Static	Environmental	Event	
Group BDTD	>10s	Limited	Up	Absent	Dynamic	Consumer	S	
						Smart Cities	Was	
Group BDTS	>10s	Limited	Up	Absent	Static	Smart Buildings	Gas&	
						Smart buildings	M	
						Environmental	Sta	



IoT Application Areas (Verticals)

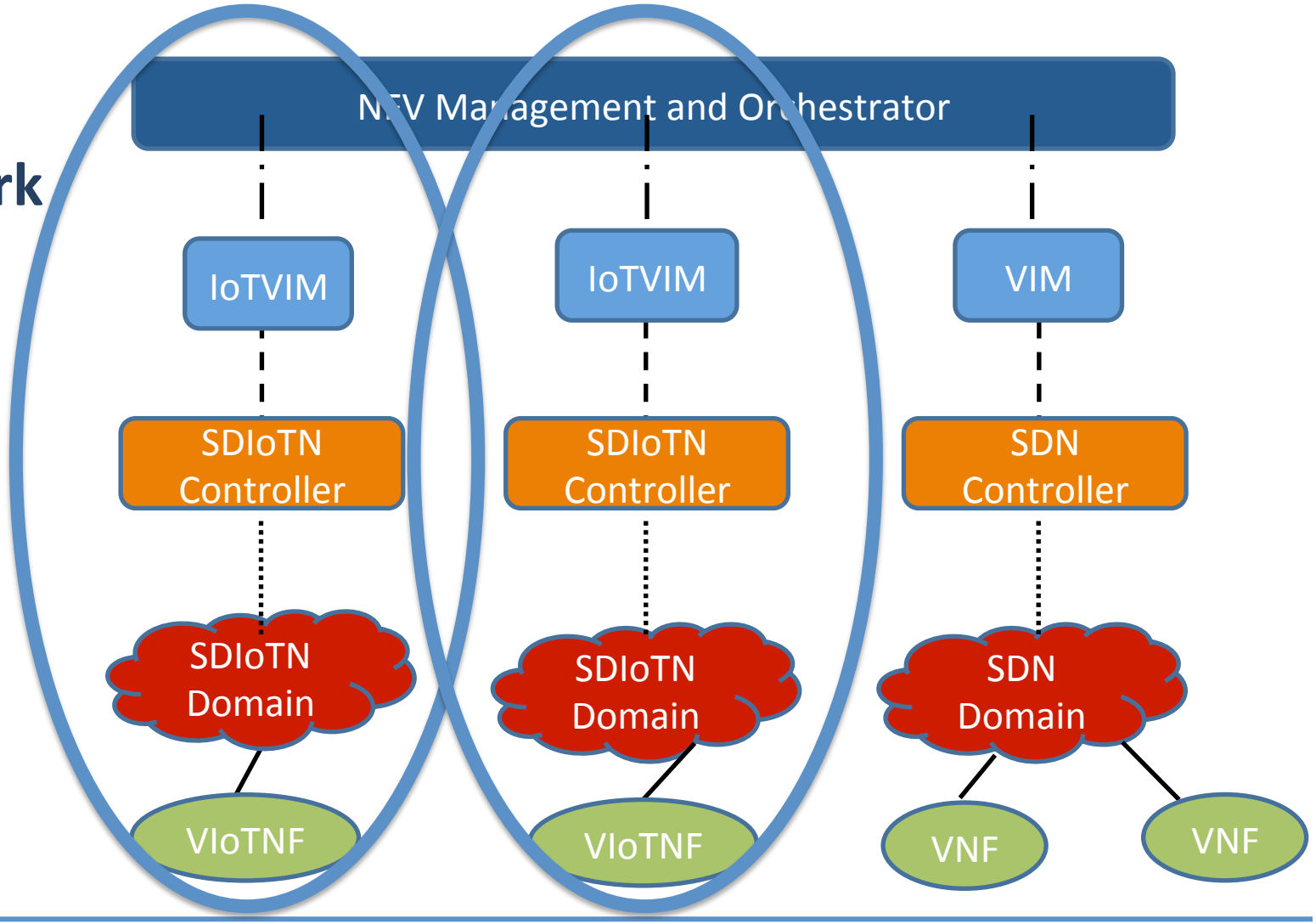


IoT applications might even be categorised wrt *node mobility*

- ***Static* Things**
- ***Nomadic* Things**
- ***Mobile* Things**

IoT Application Areas (Verticals)

IoT Network Slices



IoT Application Areas (Verticals) Takeaways

Most IoT applications will require *non-zero latency*

Most Things will be *static* or *nomadic*

Some IoT applications deserve a vertical approach, not all!

Radio Technologies

Radio Technologies

Traditional options:

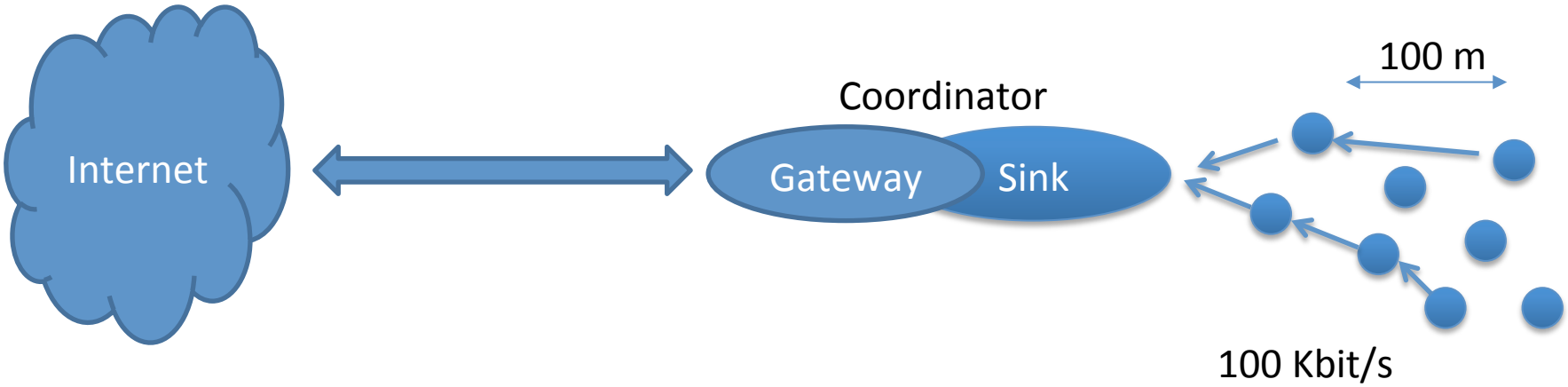
- 802.15.4 w Zigbee
- 802.15.4 w 6lowPAN / 6TiSCH
- WiFi
- GPRS
- 3G / 4G
- … many others (WMBUS, BT-LE, etc)

Radio Technologies

Most successful ones:

- 802.15.4 w Zigbee
- 802.15.4 w 6lowPAN / 6TiSCH

Short Range Low Rate Low Power



Radio Technologies

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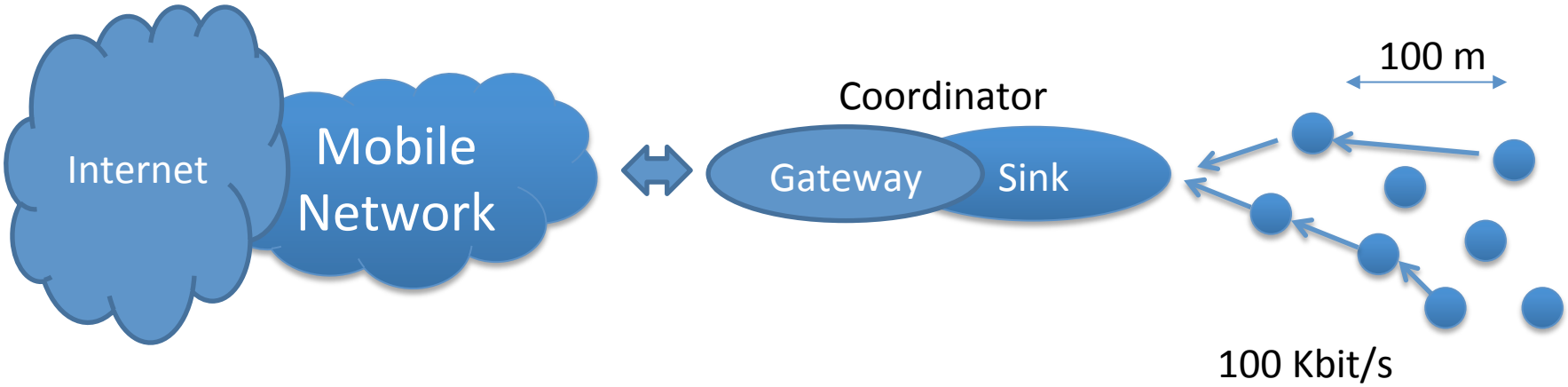
Short Range Low Rate Low Power

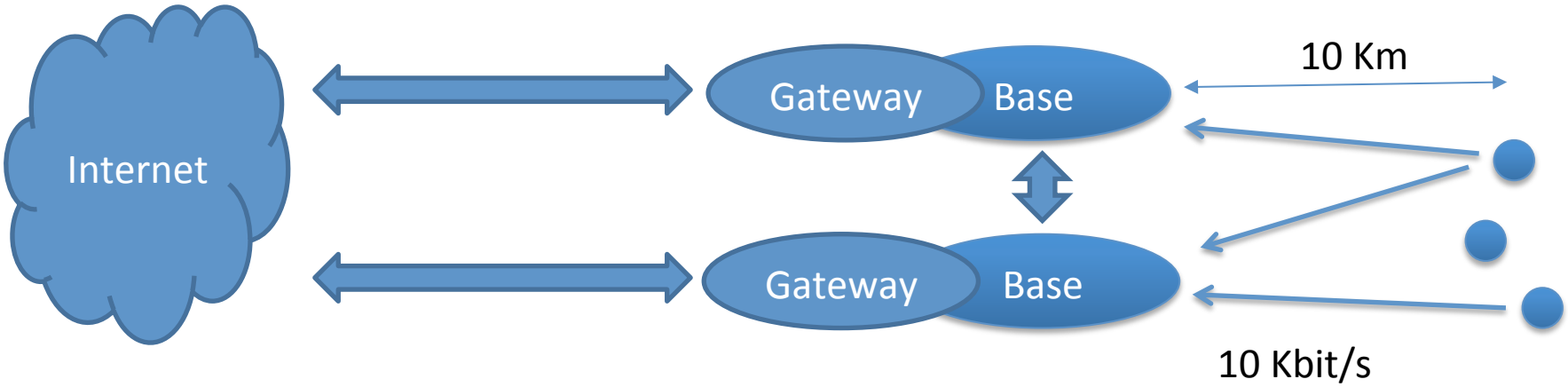


Radio Technologies

Emerging options:

- LoRA
- SIGFOX
- …

Low Power Wide Area Network



Radio Technologies

Emerging options:

- LoRA
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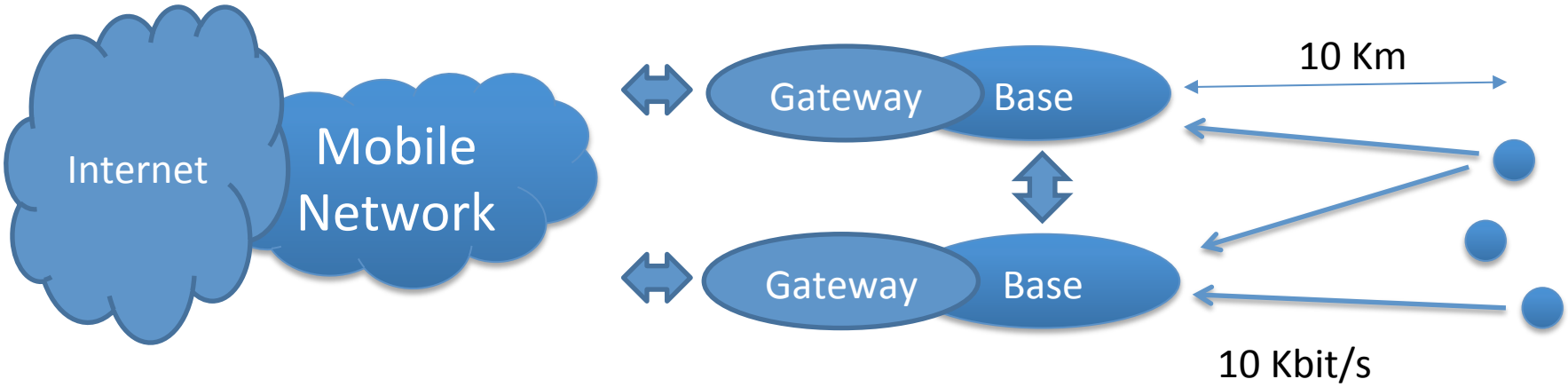
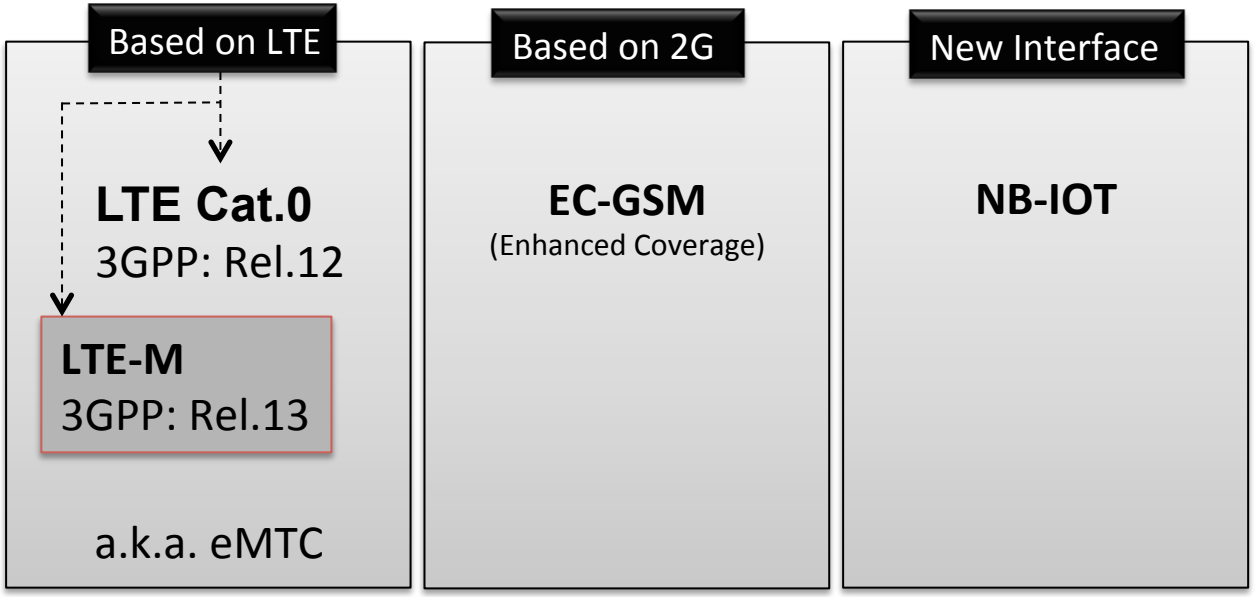
Low Power Wide Area Network



Radio Technologies

New options:

Low Power Wide Area Network

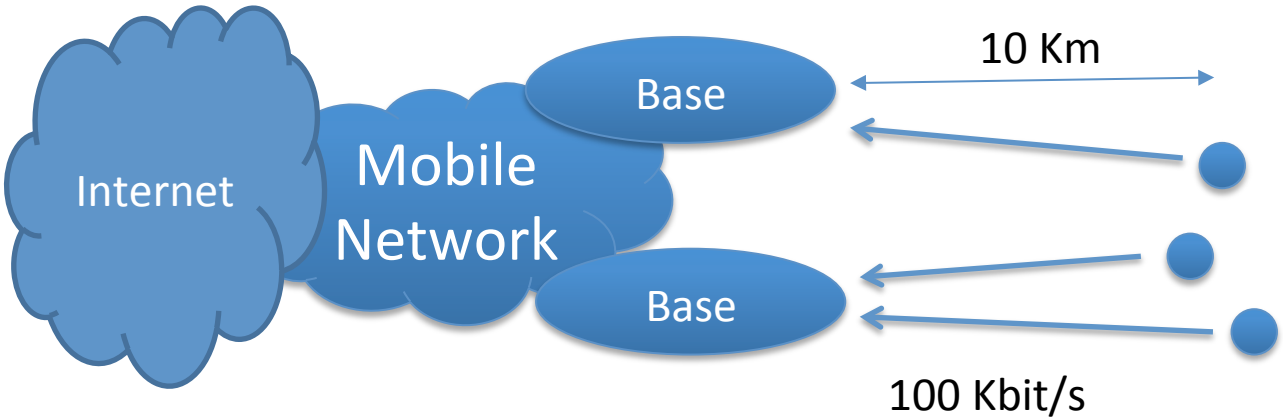


Radio Technologies

New options:

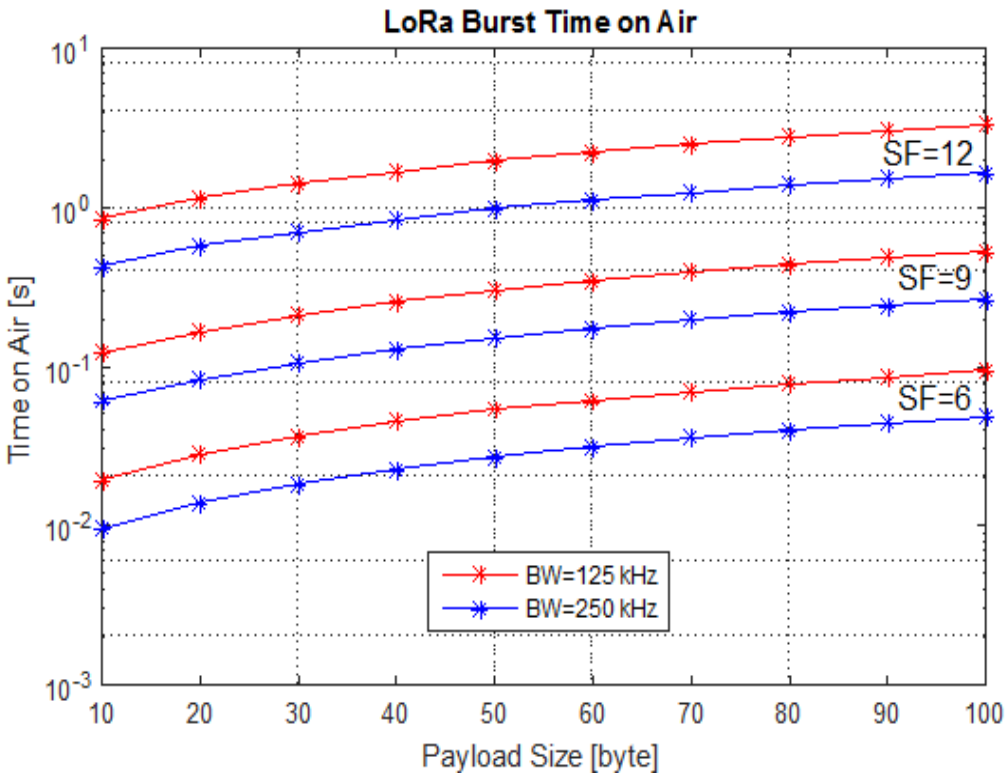
Low Power Wide Area Network

NB-IOT



Radio Technologies / LoRa

➢ Data Block Duration vs Receiver Sensitivity



Receiver Sensitivity [dBm] (SX1272)			
SF	BW [kHz] 125	BW [kHz] 250	BW [kHz] 500
6	-121	-118	-111
7	-124	-122	-116
8	-127	-125	-119
9	-130	-128	-122
10	-133	-130	-125
11	-135	-132	-128
12	-137	-135	-129

Radio Technologies / LoRa

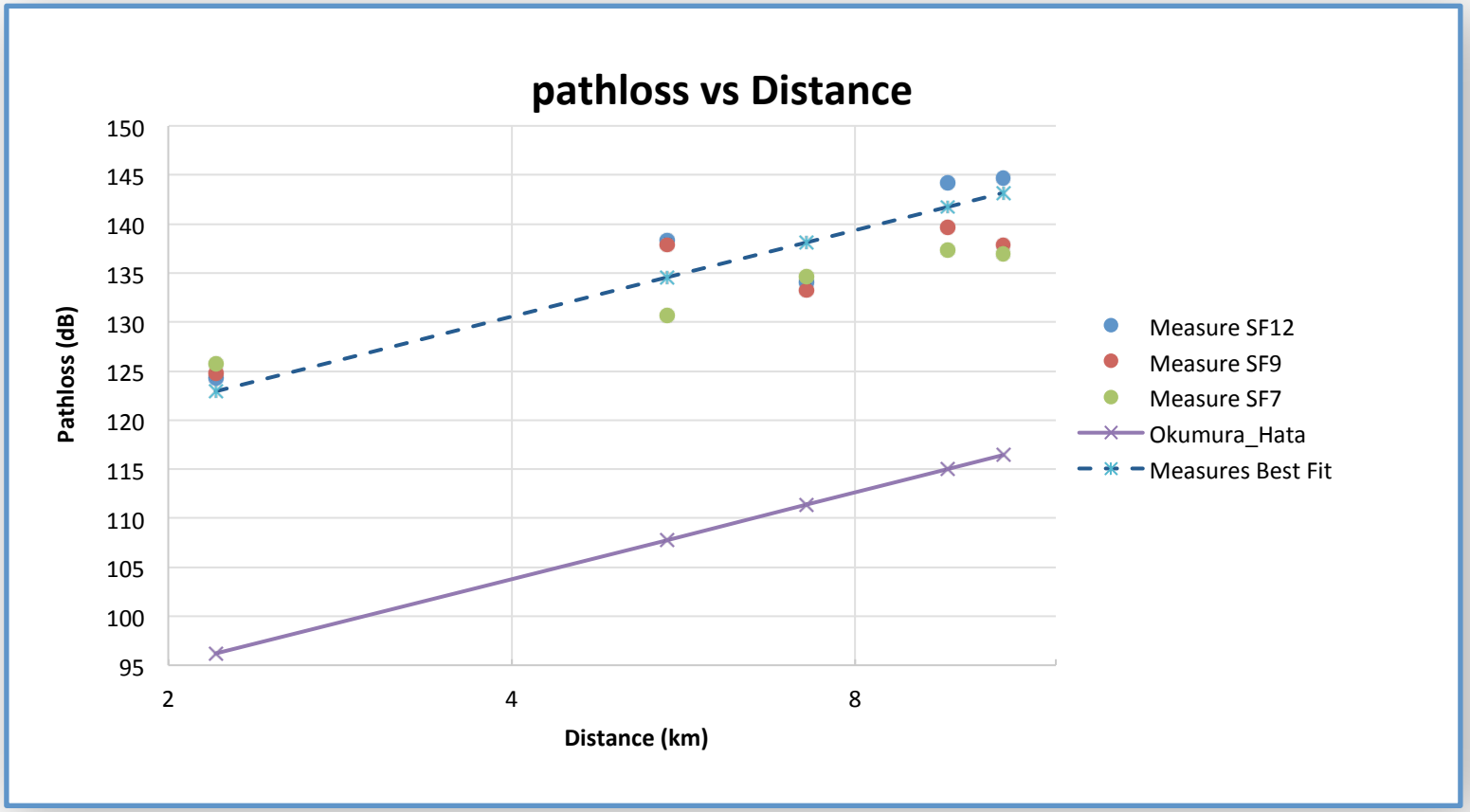
➢ Path Loss vs Distance

Impossibile visualizzare l'immagine. La memoria del computer potrebbe essere insufficiente per aprire l'immagine oppure l'immagine potrebbe essere danneggiata. Riavviare il computer e aprire di nuovo il file. Se viene visualizzata di nuovo la x rossa, potrebbe essere necessario eliminare l'immagine e inserirla di nuovo.

11 km

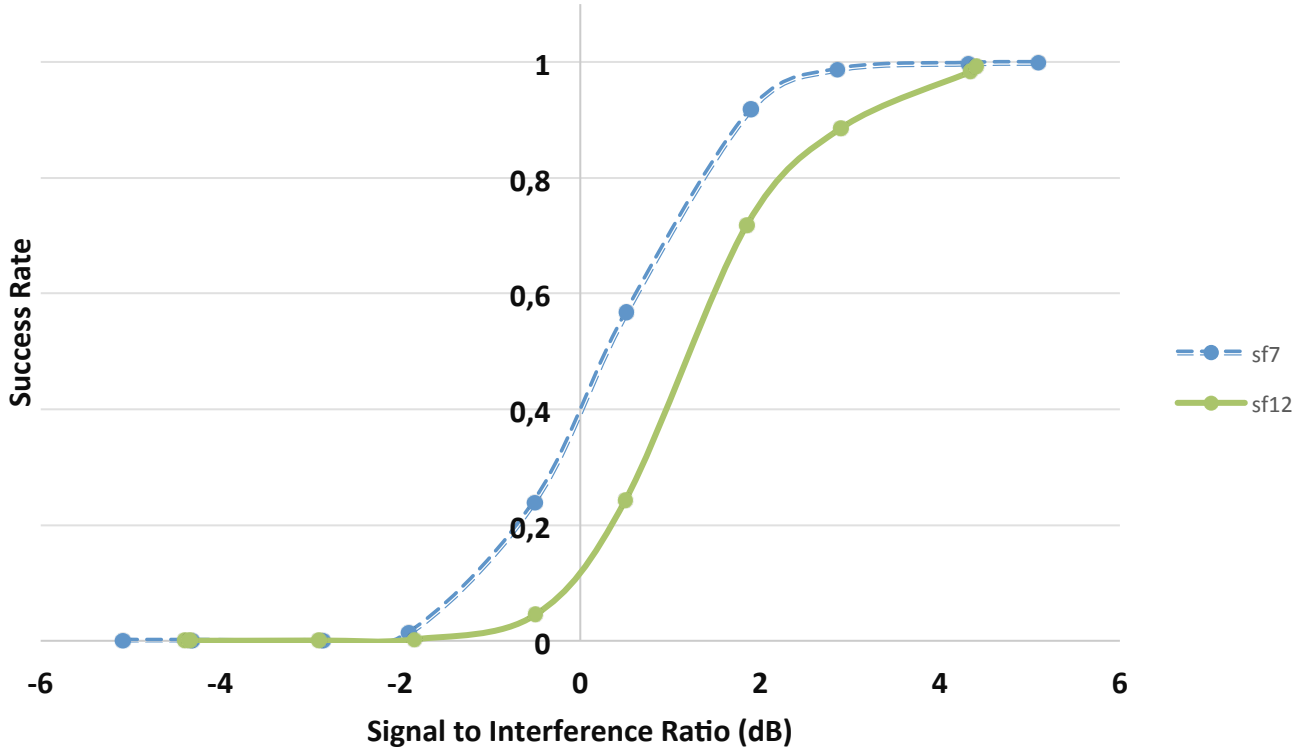
Radio Technologies / LoRa

➢ Path Loss vs Distance



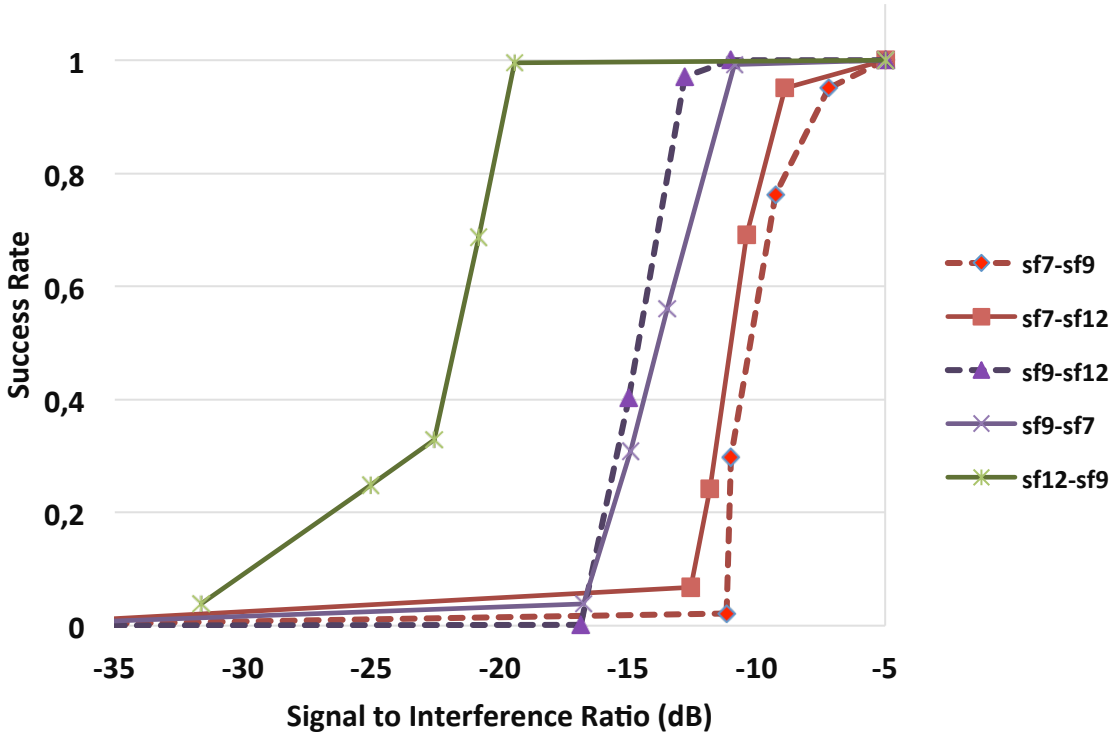
Radio Technologies / LoRa

➢ Inter-code interference (same SF)



Radio Technologies / LoRa

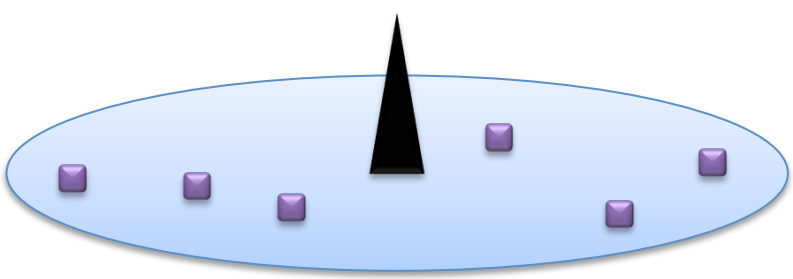
- Inter-code interference (different SF, synchronous)

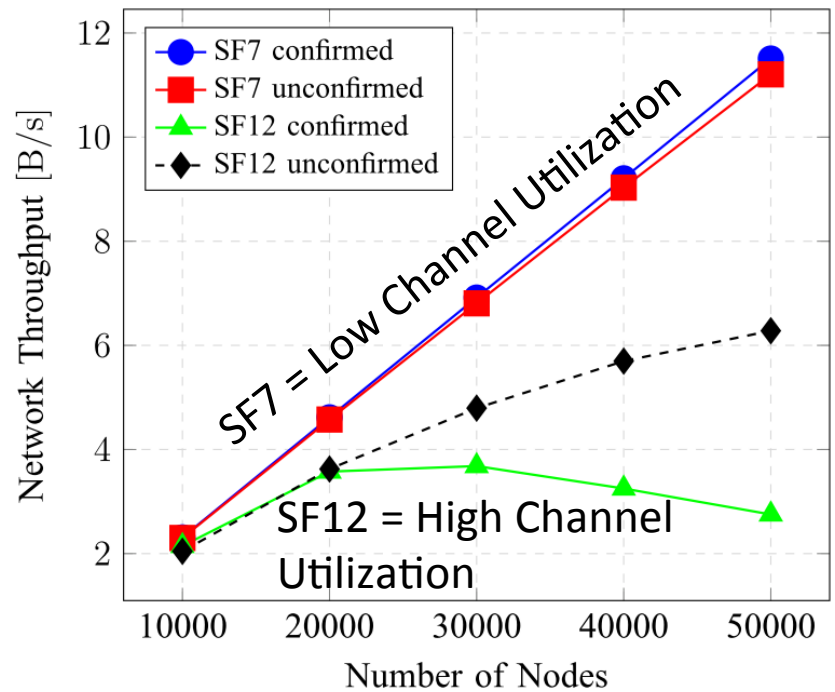


Radio Technologies / LoRa

➢ Performance

3 x 125 kHz channels (sub band 868MHz G1)
Traffic:,
Rural Scenario
Deployment area: side
Number of Devices: from 10k to 50k

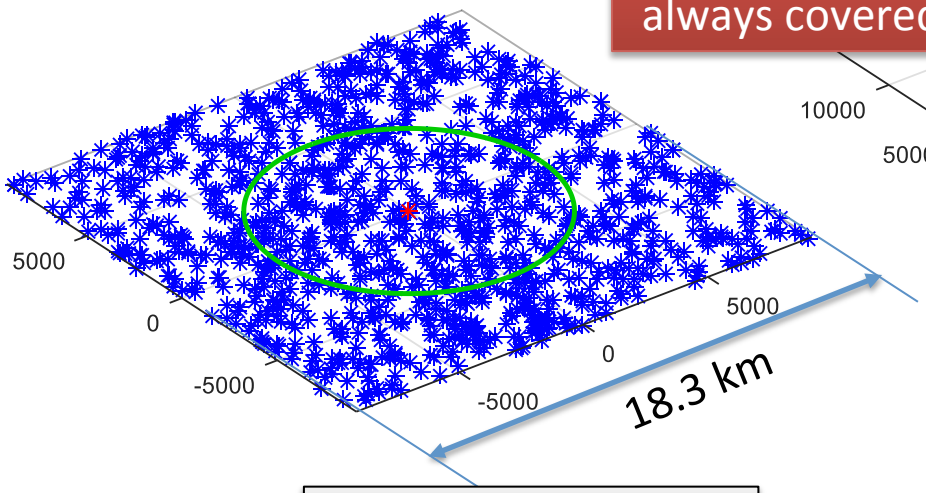




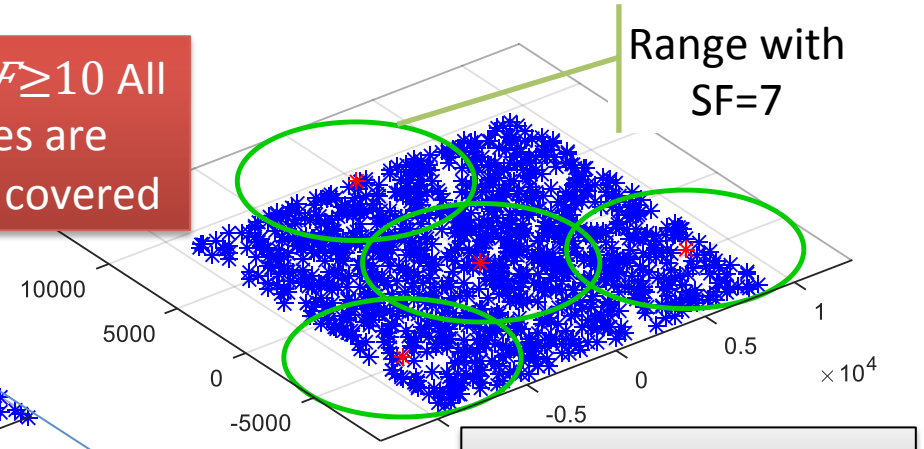
Radio Technologies / LoRa

➢ Performance

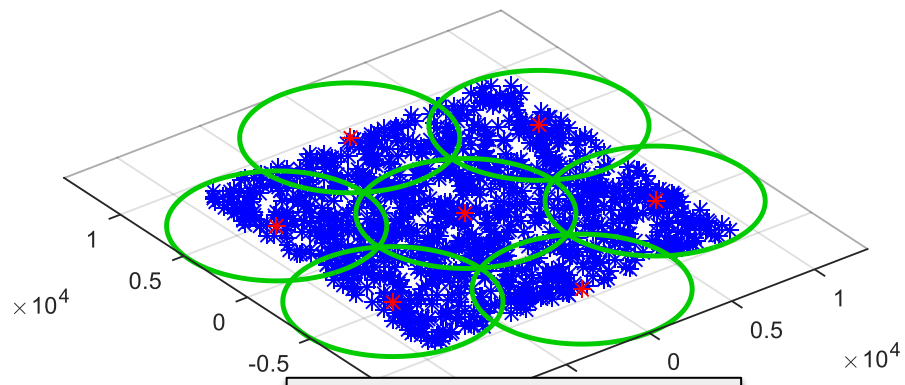
With $SF \geq 10$ All nodes are always covered



Gateway Number = 1



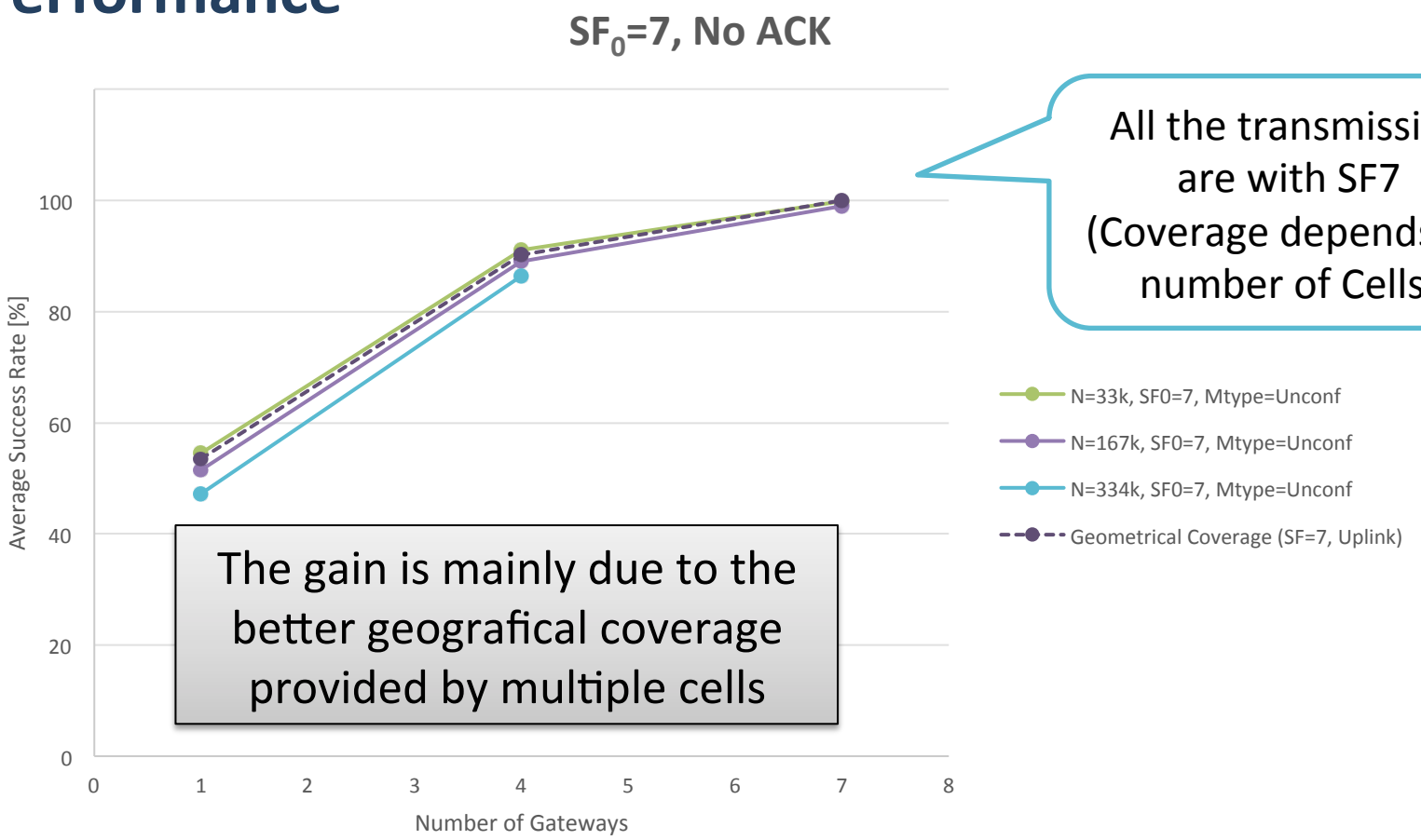
Gateway Number = 4



Gateway Number = 7

Radio Technologies / LoRa

➢ Performance

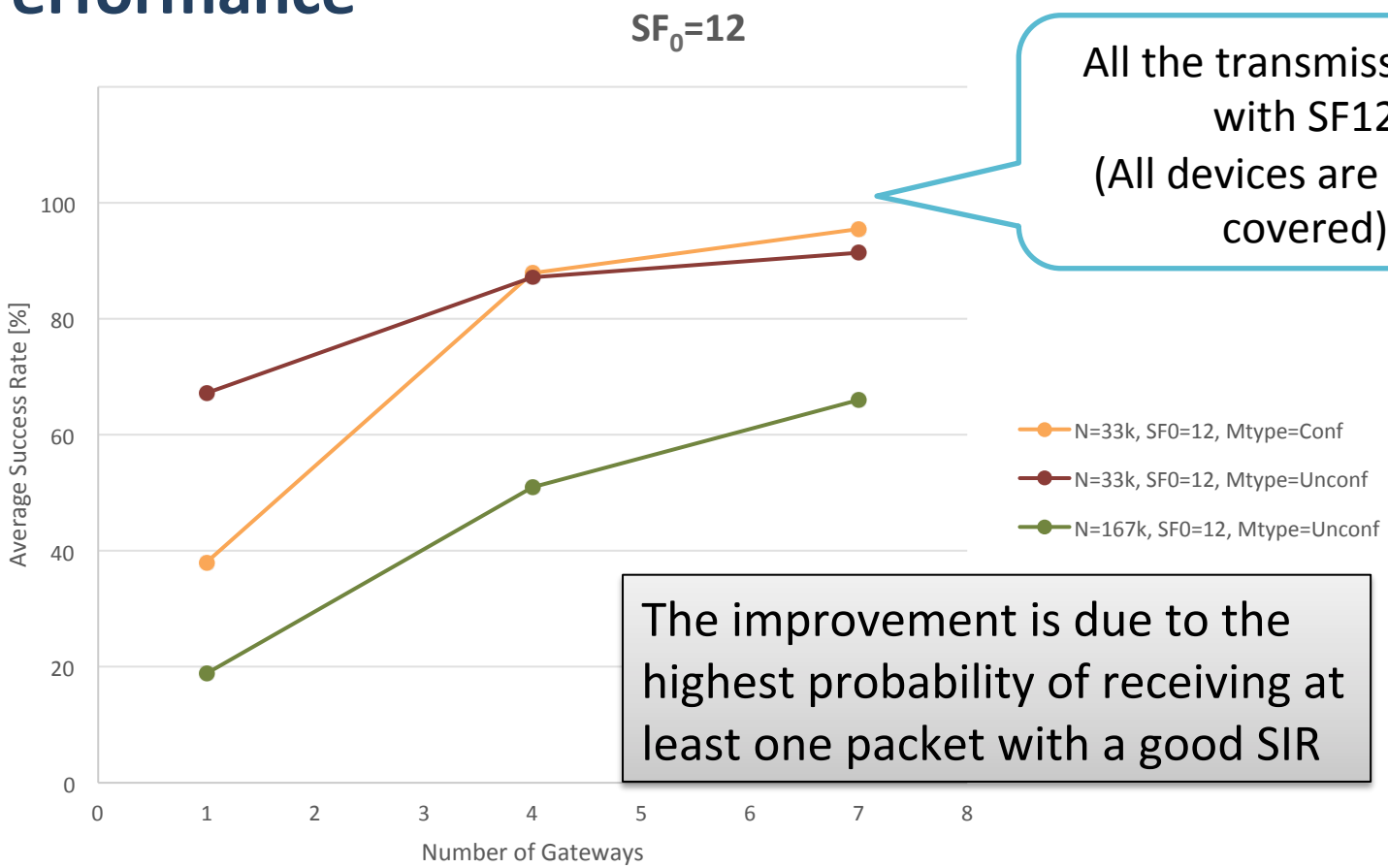


All the transmission are with SF7 (Coverage depends on number of Cells)

The gain is mainly due to the better geografical coverage provided by multiple cells

Radio Technologies / LoRa

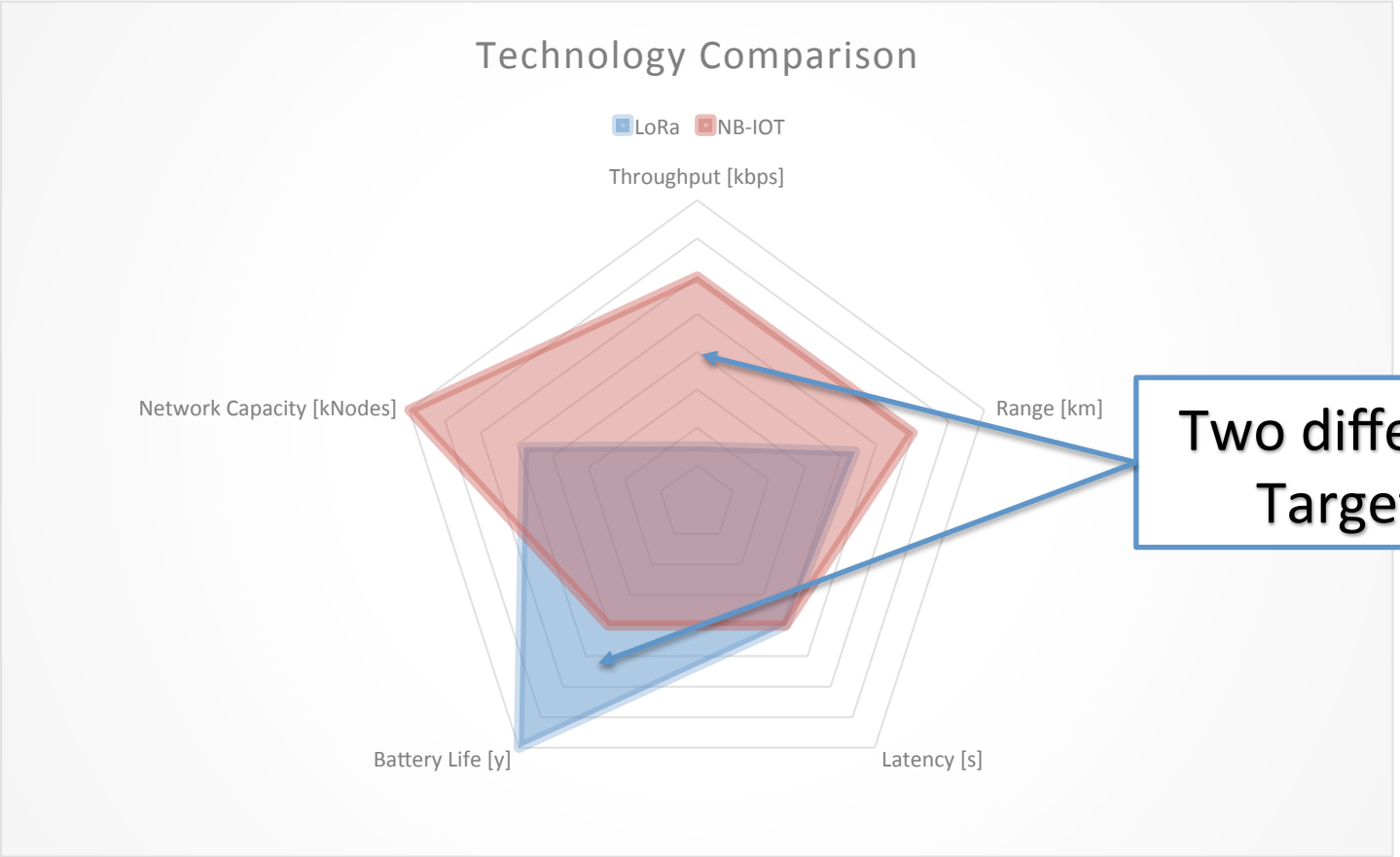
➢ Performance



All the transmission are with SF12
(All devices are always covered)

The improvement is due to the highest probability of receiving at least one packet with a good SIR

Radio Technologies / NB-IOT

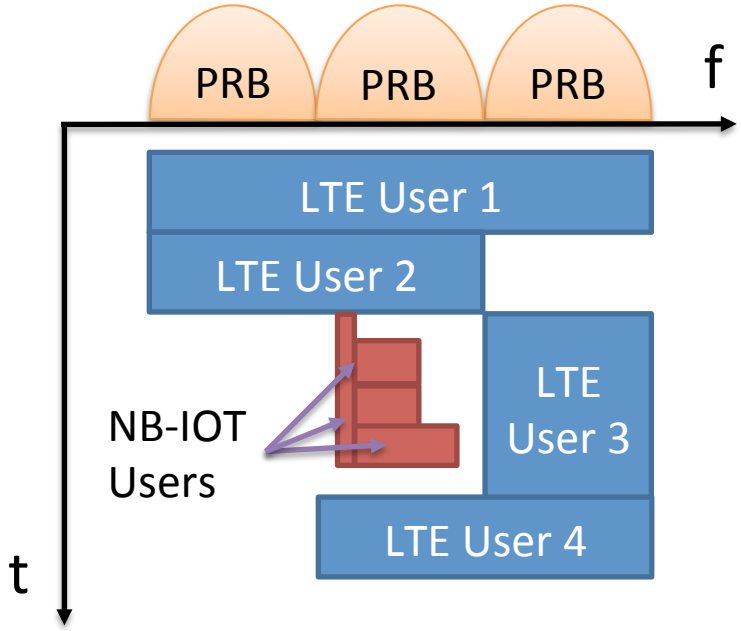


Two different Targets

Radio Technologies / NB-IOT

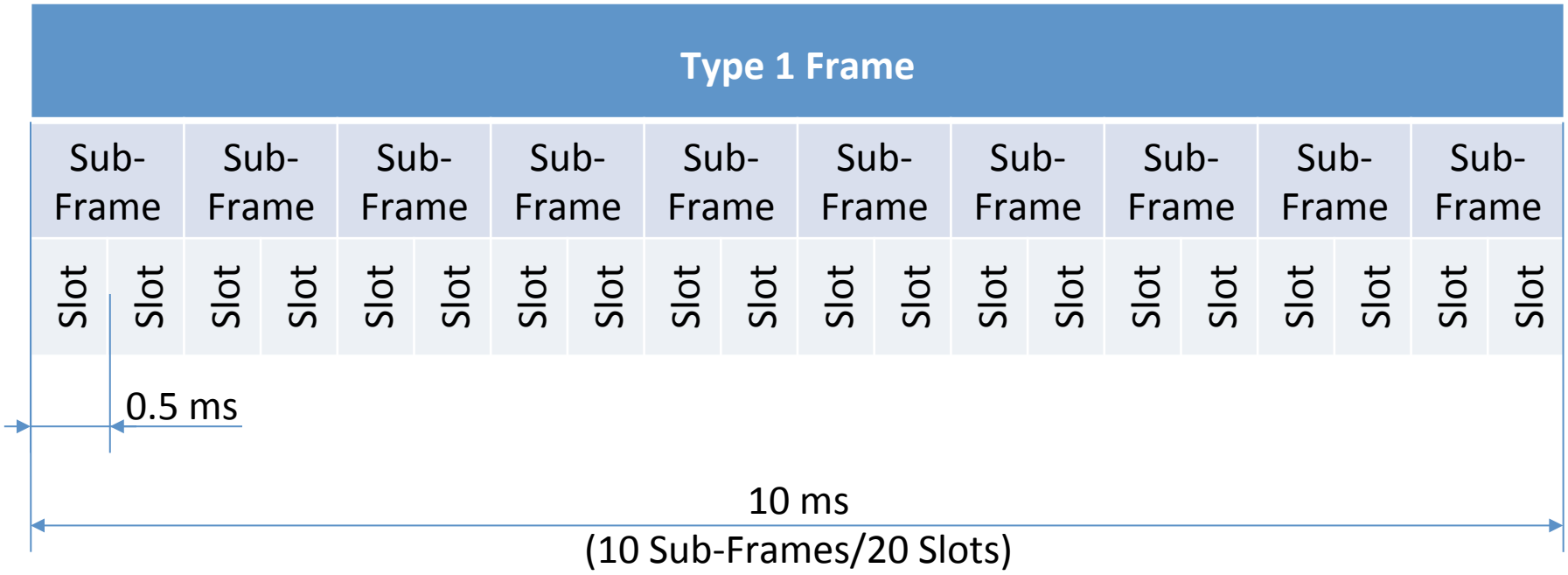
- Radio Resources

  - out of band
  - guard bands
  - in band



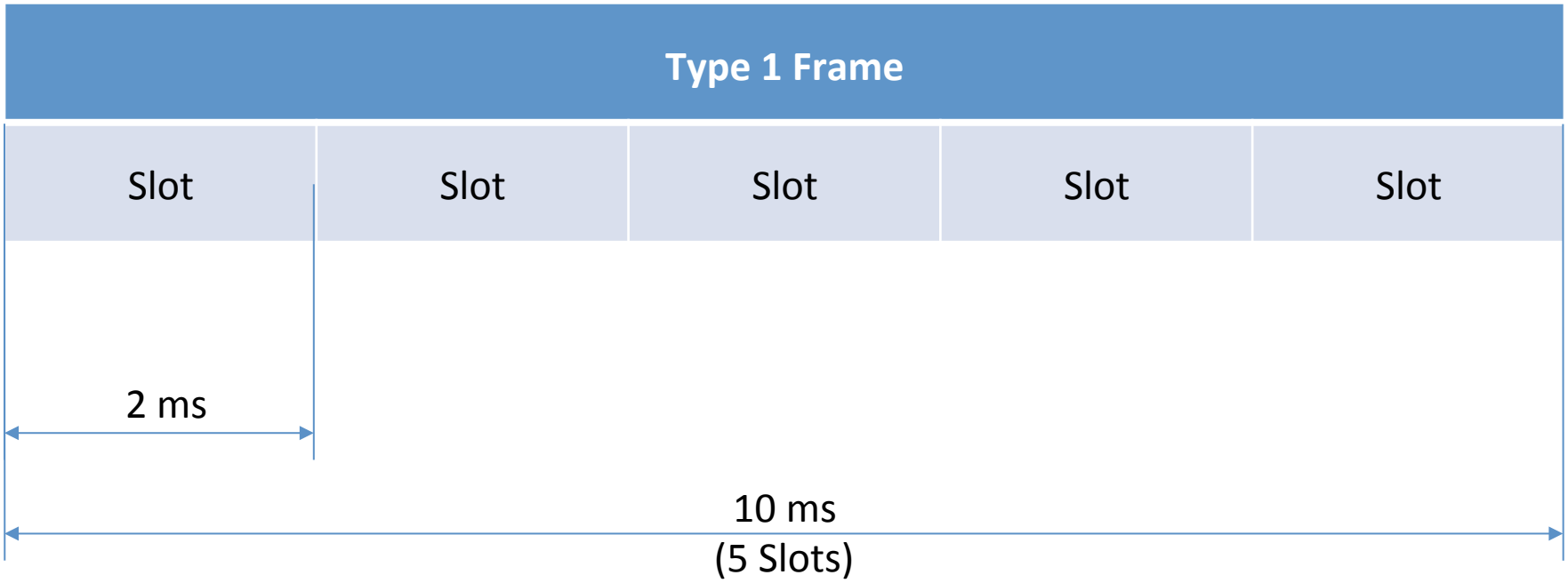
Radio Technologies / NB-IOT

➢ Radio Frame Structure (15 kHz) Type 1



Radio Technologies / NB-IOT

- **Radio Frame Structure (3,75 kHz) Type 1**



Radio Technologies / NB-IOT

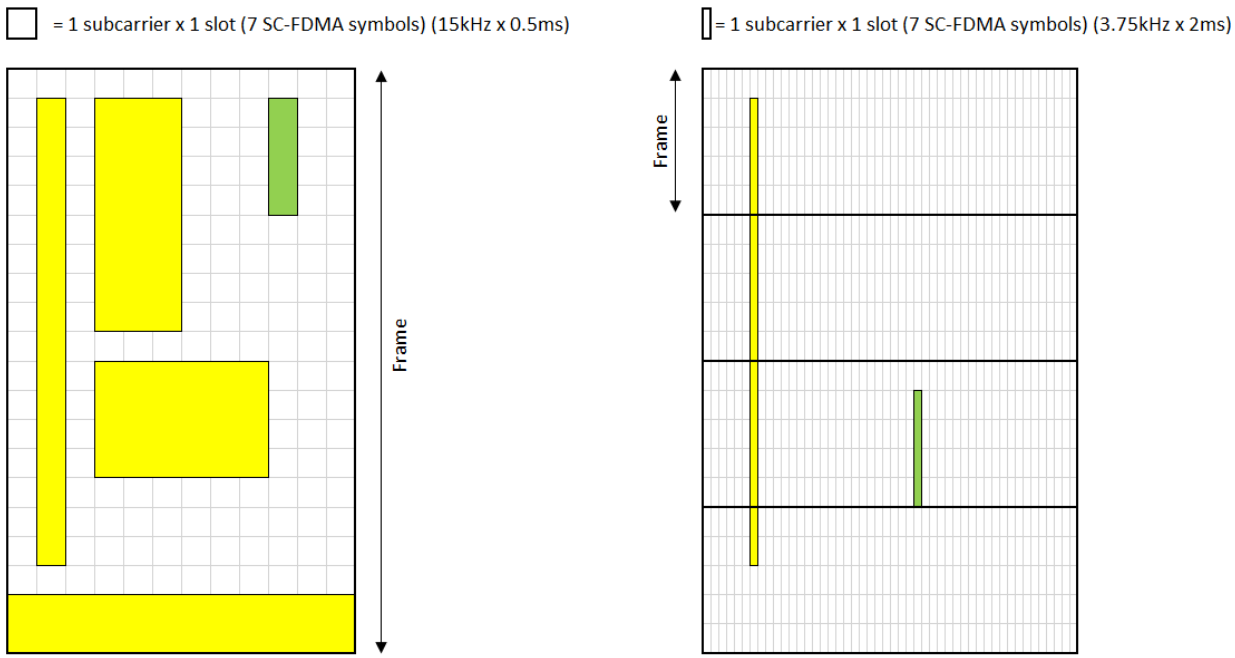
➢ Radio Resources

NPUSCH format		Subcarriers per LTE band	Symbols per slot	Subcarriers per Resource Unit	Slots per Resource Unit	Resource Elements	Band Occupation	Time on Air
1 (Data)	3.75 kHz	48	7	1	16	112	3.75 kHz	32 ms
	15 kHz	12		1	16	112	15 kHz	8 ms
				3	8	168	45 kHz	4 ms
				6	4	168	90 kHz	2 ms
				12	2	168	180 kHz	1 ms
2 (Control)	3.75 kHz	48		1	4	28	3.75 kHz	8 ms
	15 kHz	12		1	4	28	15 kHz	2 ms

3.75 kHz: only single tone RUs, 2 ms Slot Duration

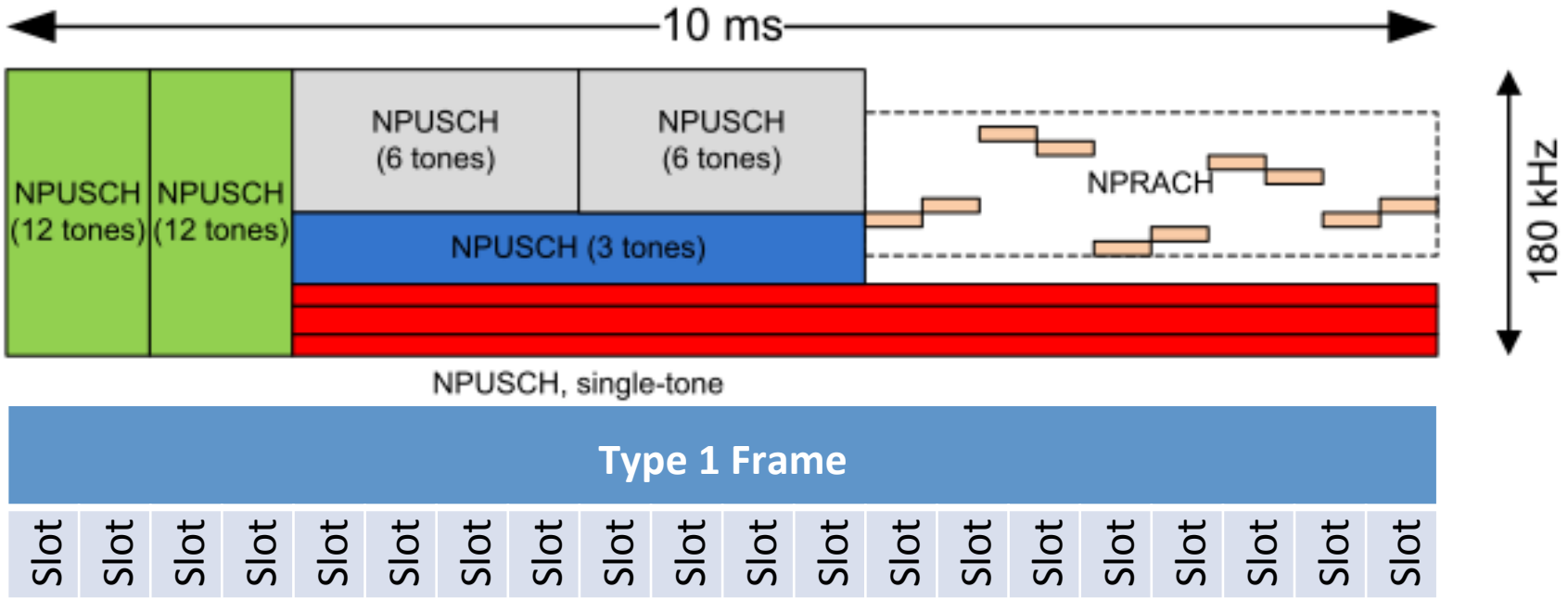
Radio Technologies / NB-IOT

➢ Radio Resources



Radio Technologies / NB-IOT

➢ Radio Resources: Assignment



Radio Technologies / NB-IOT

➢ Expected Performance

See Report TR 45.820

- **Node Number**
  - < 50k nodes per LTE band
- **Throughput**
  - Uplink: 250 kbps – 20 bps (128 repetitions)
  - Downlink: 250 kbps – 35 bps (512 repetitions)
- **Coverage**
  - MCL: 170 dB (max repetitions) (LTE + 30 dB)
- **Battery Life**
  - 10 year (200 B per day)

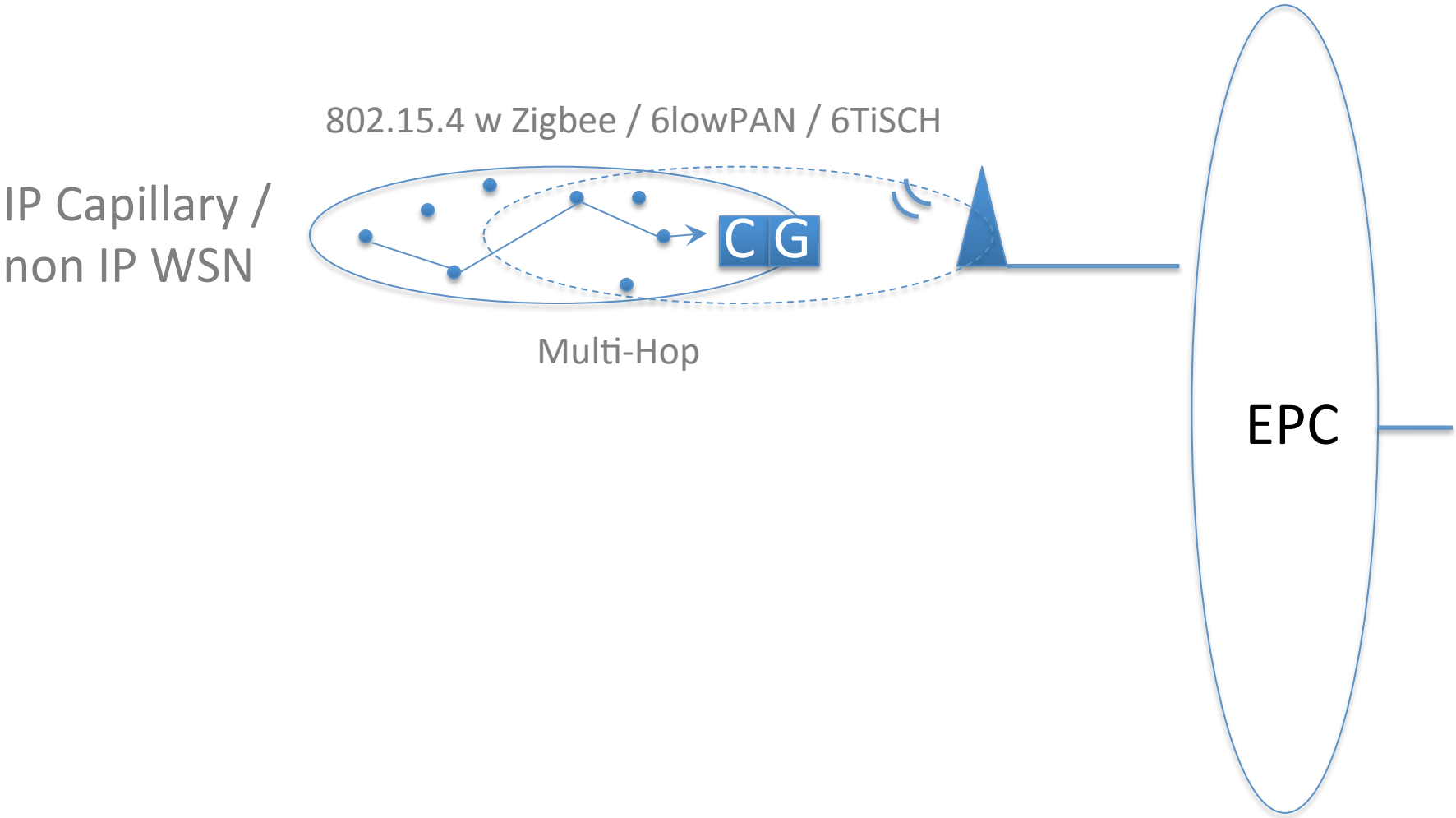
Radio Technologies Takeaways

About 20 options

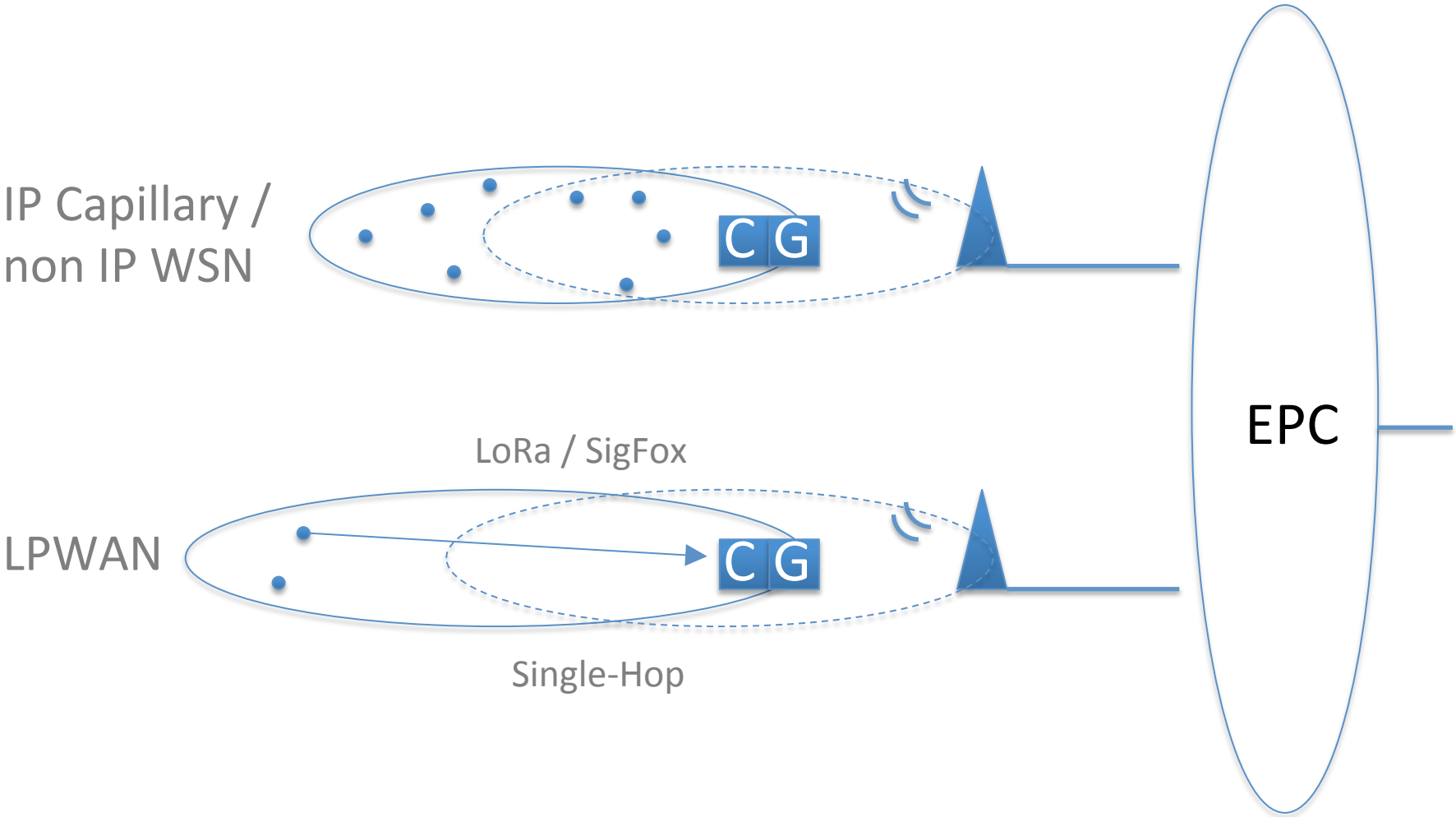
Break!

Network Architectures

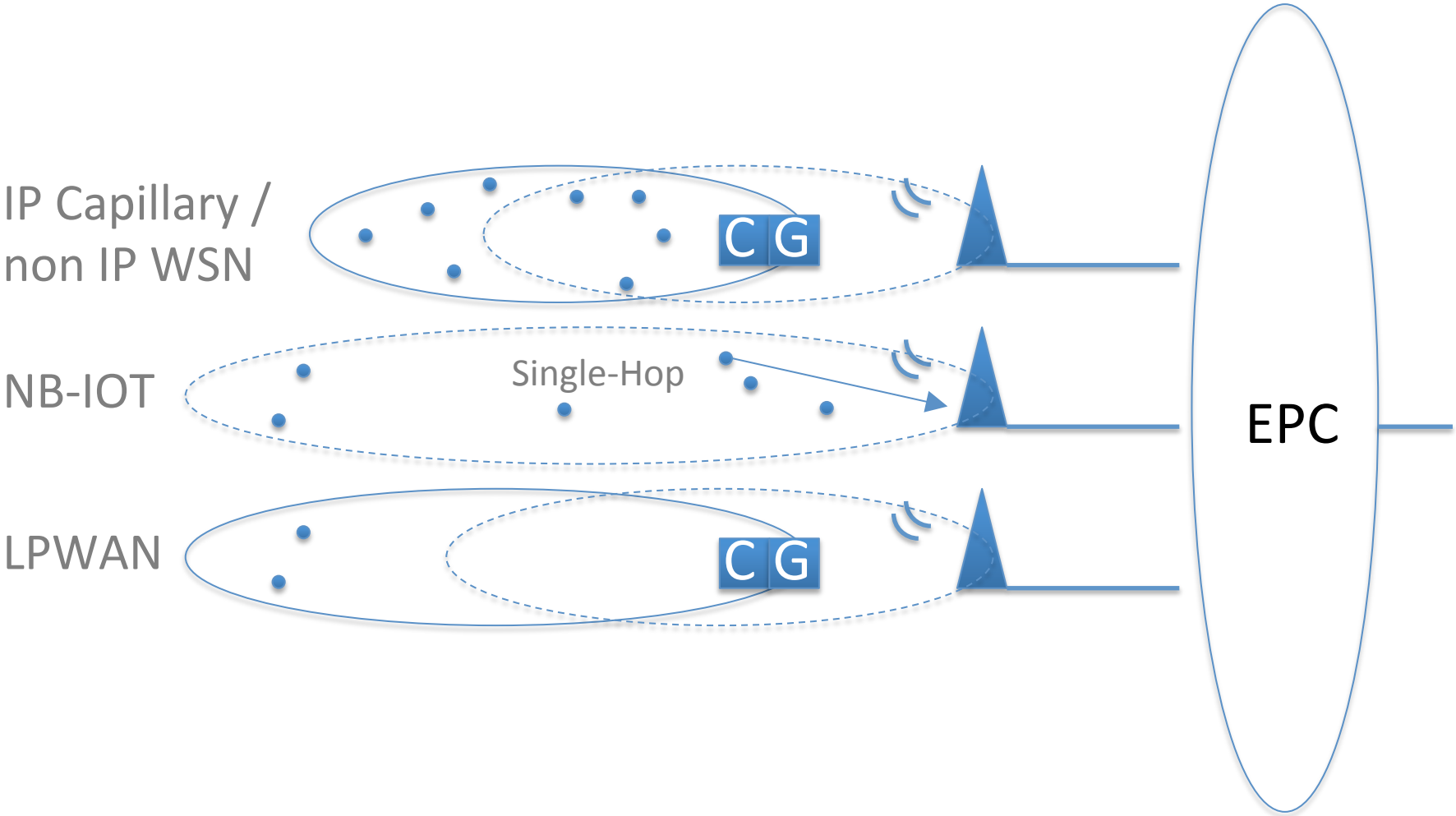
Network Architectures / Traditional



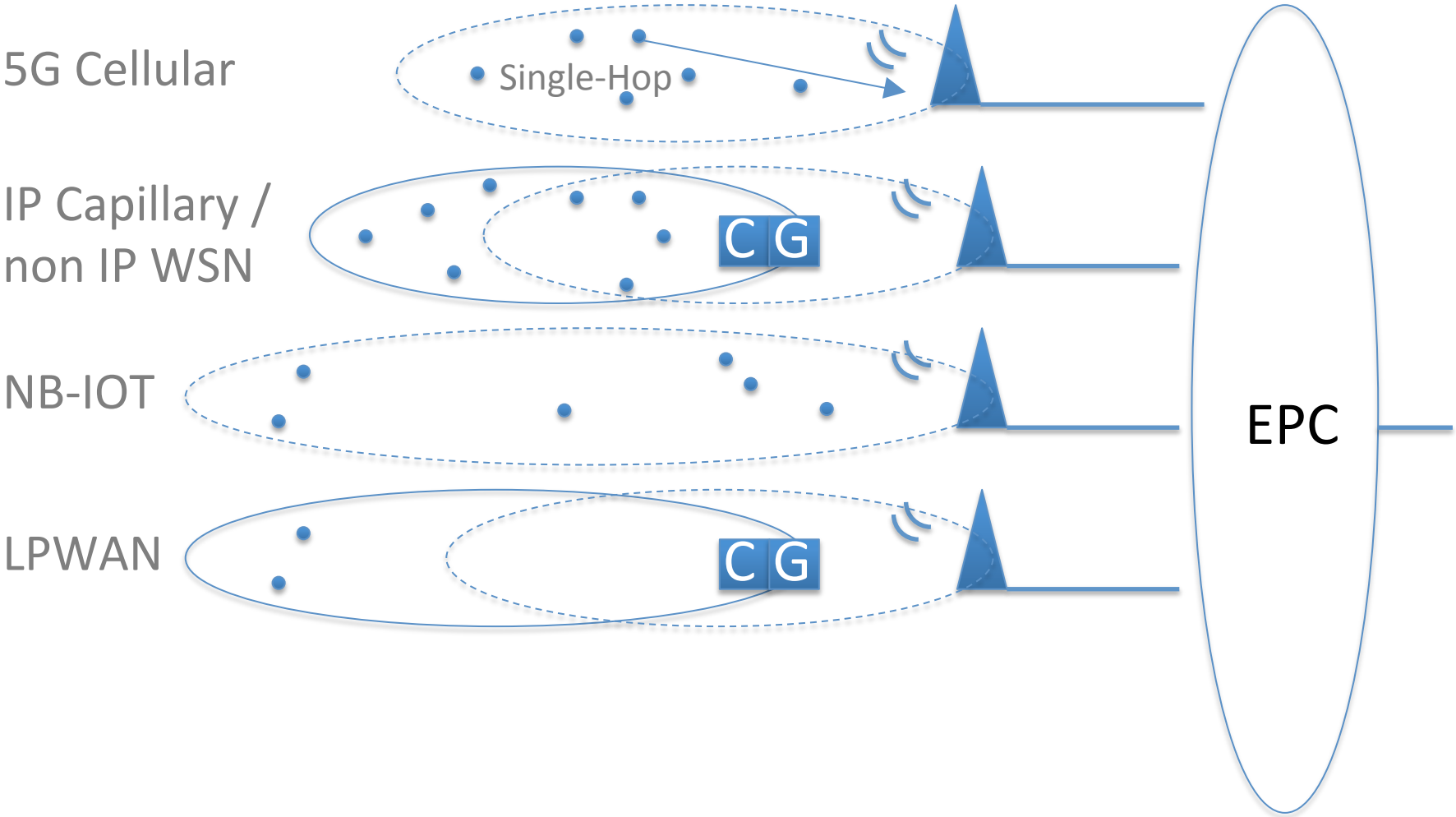
Network Architectures / Emerging



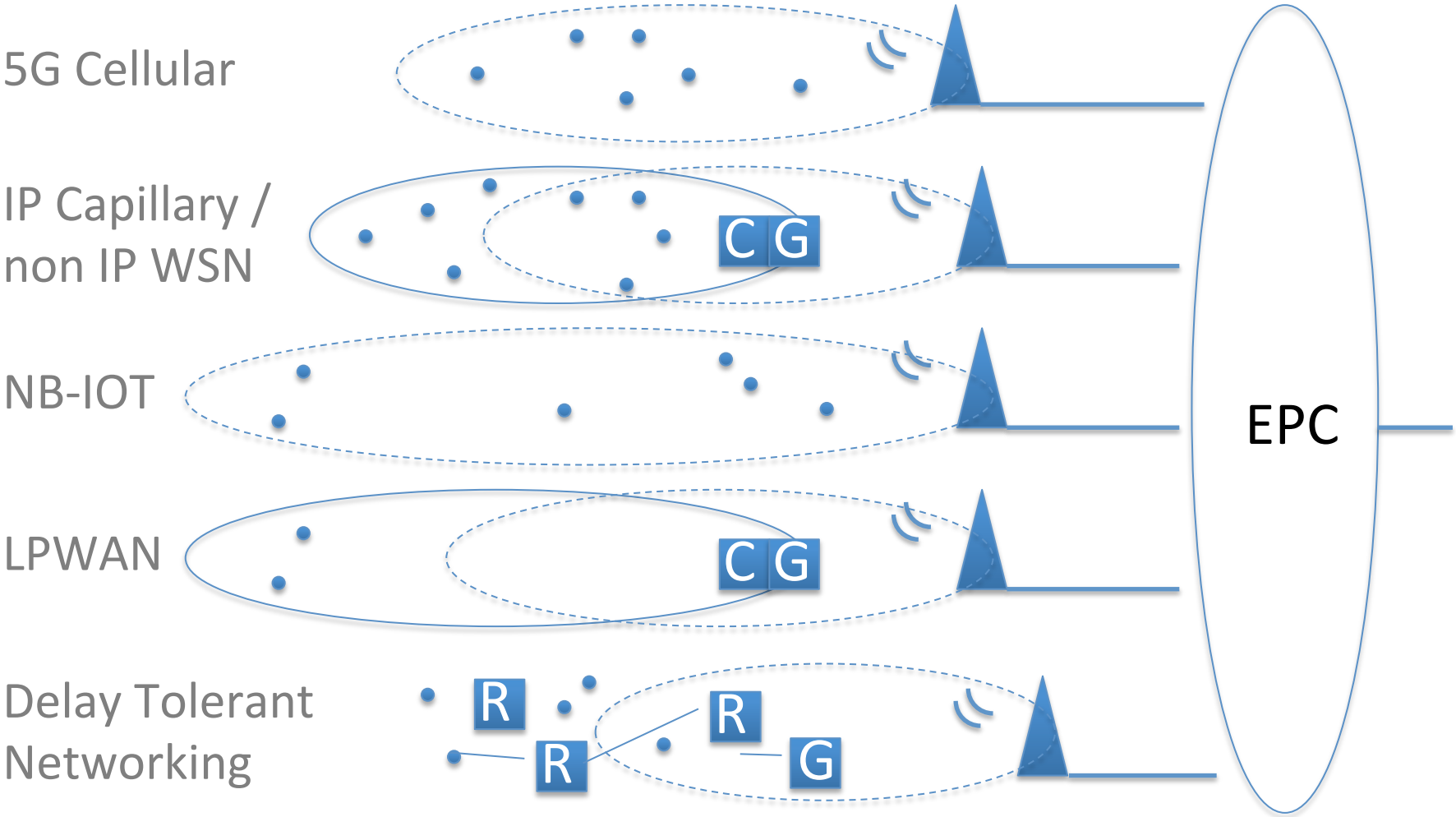
Network Architectures / Next Step



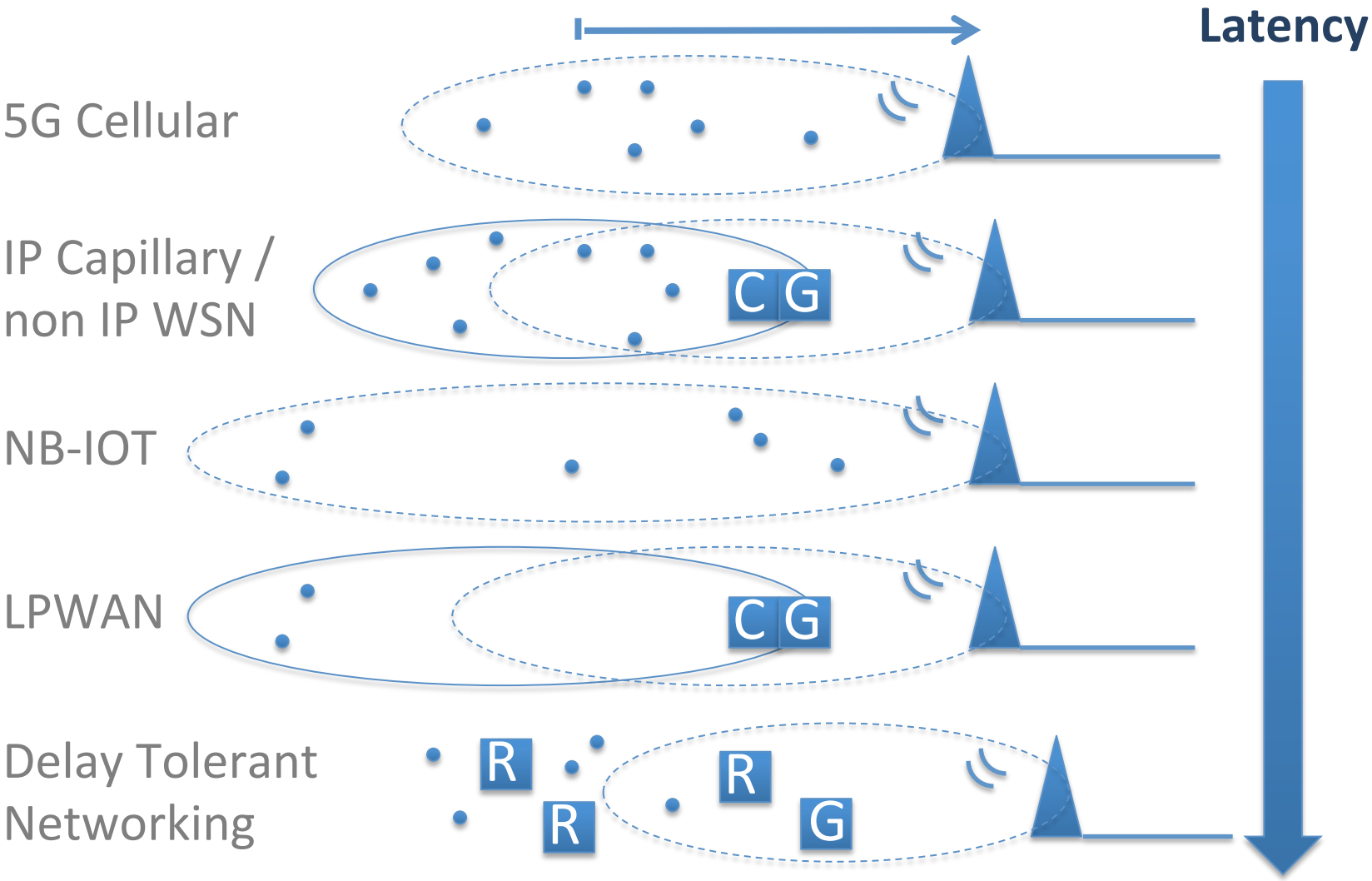
Network Architectures / 5G



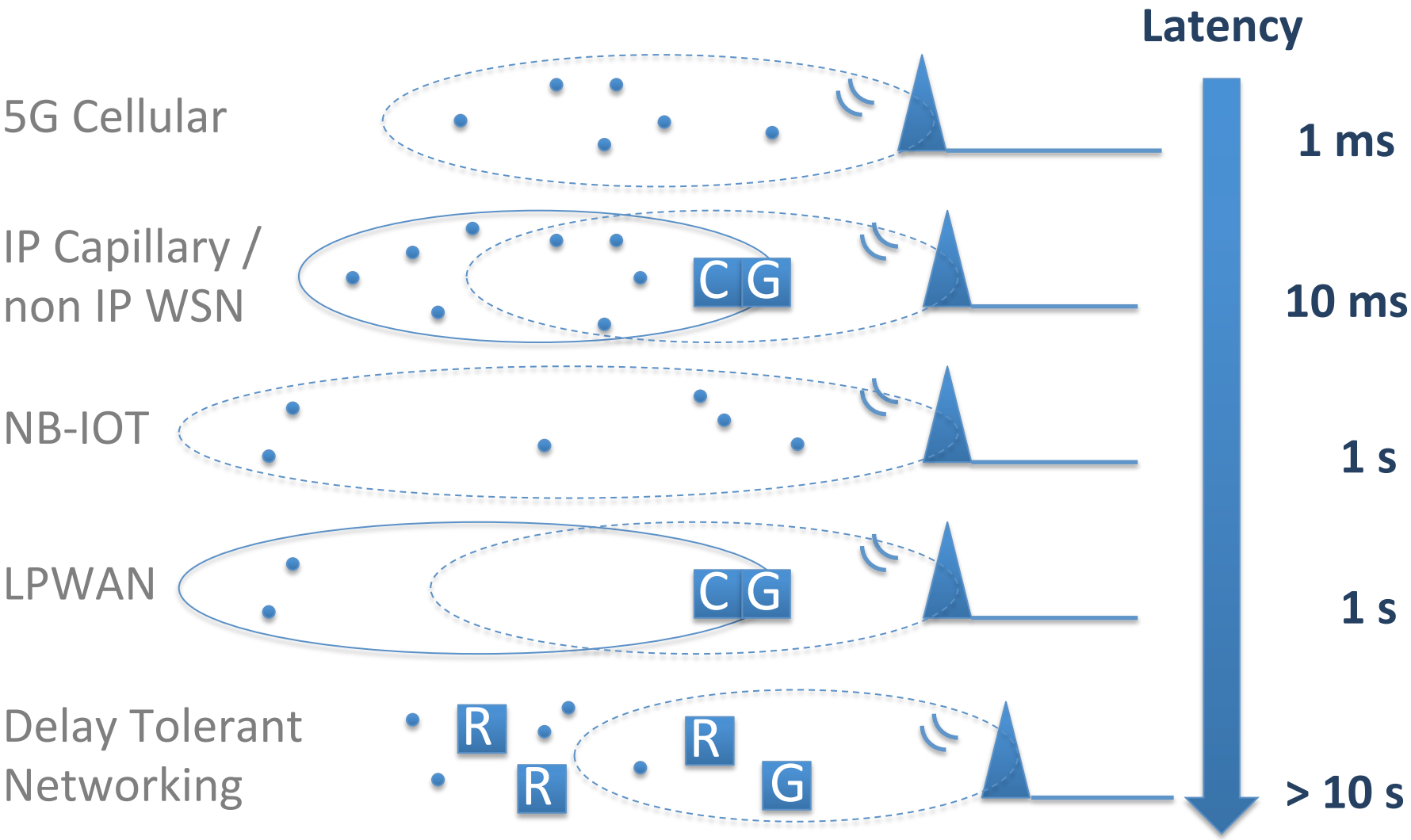
Network Architectures / DTN



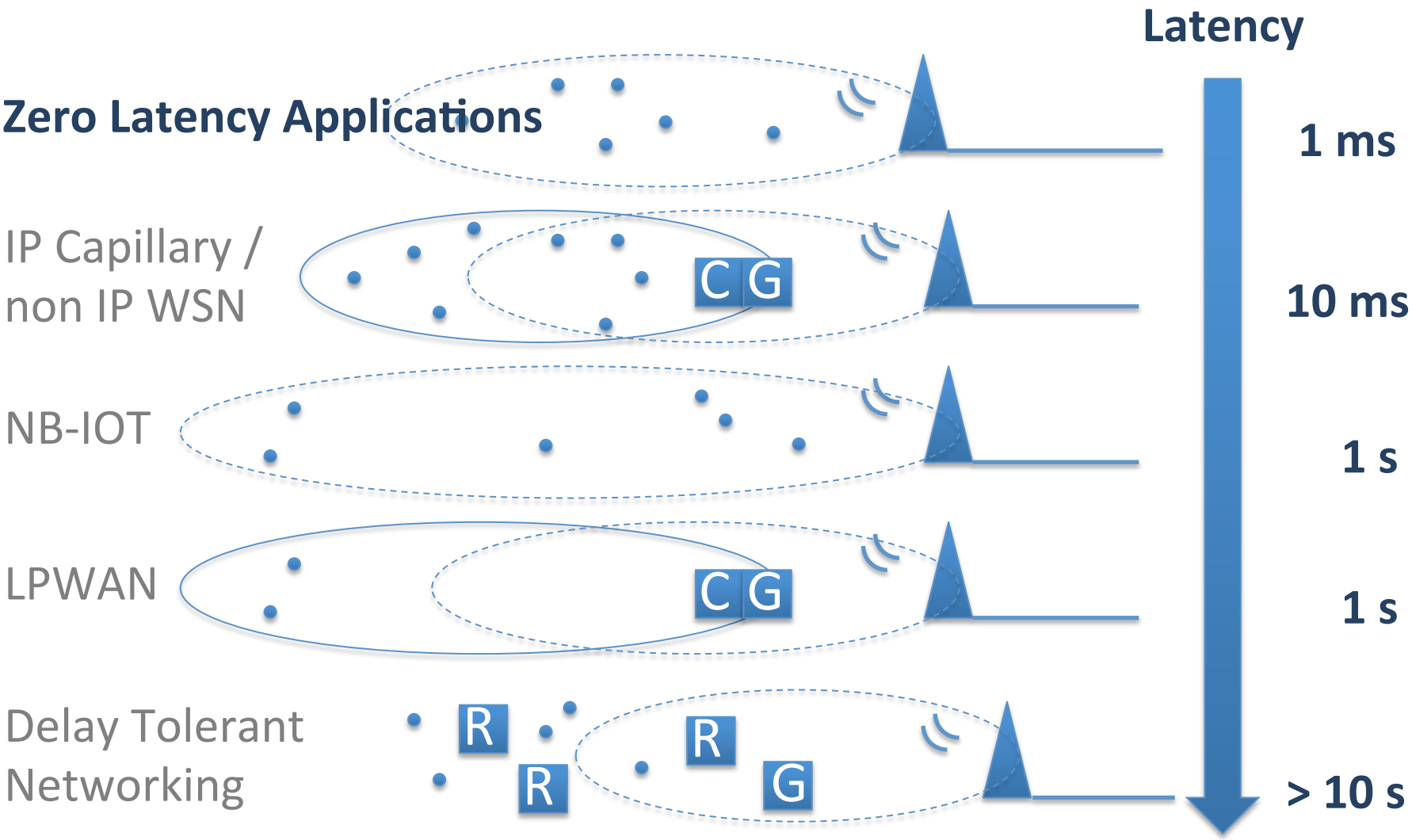
Network Architectures



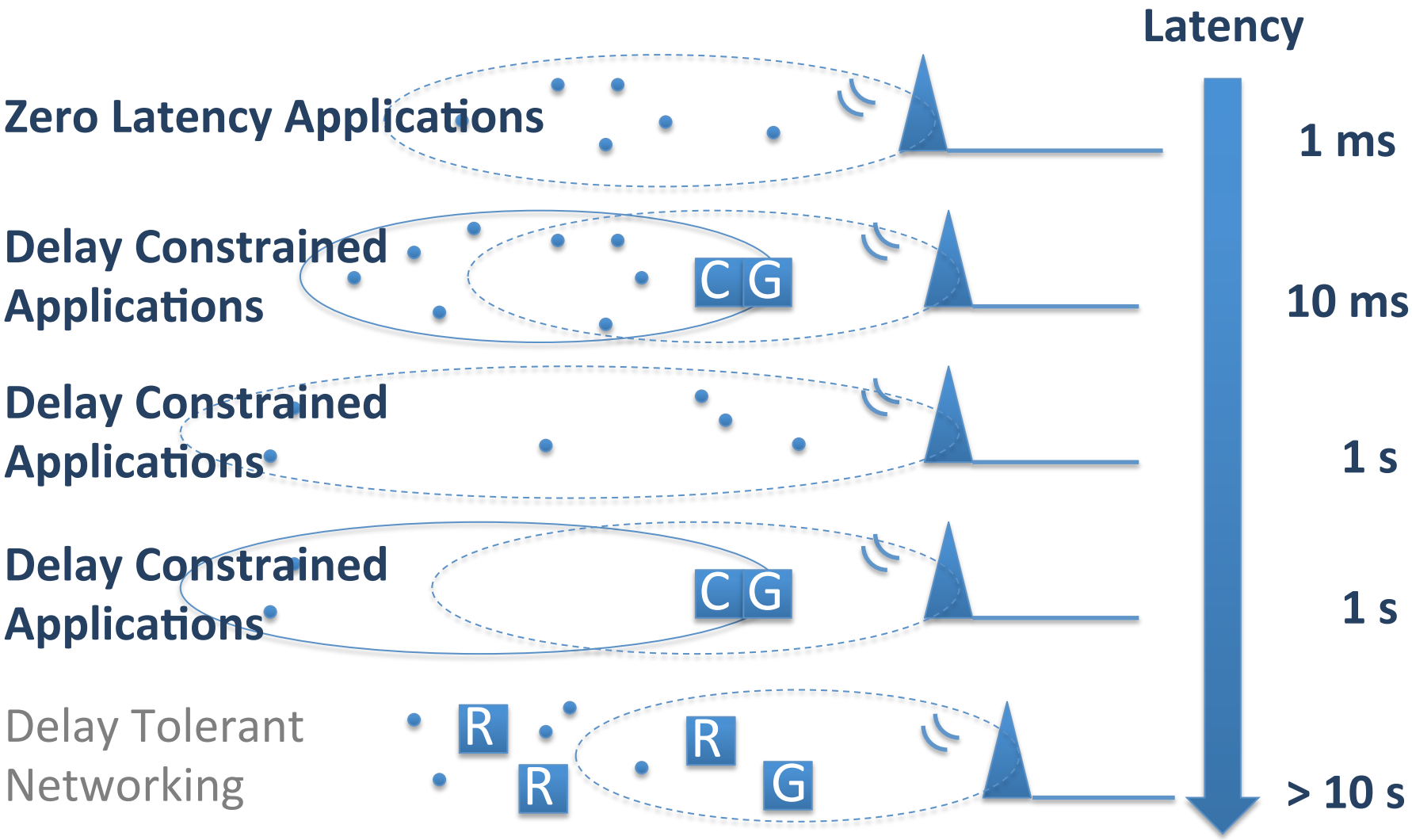
Network Architectures



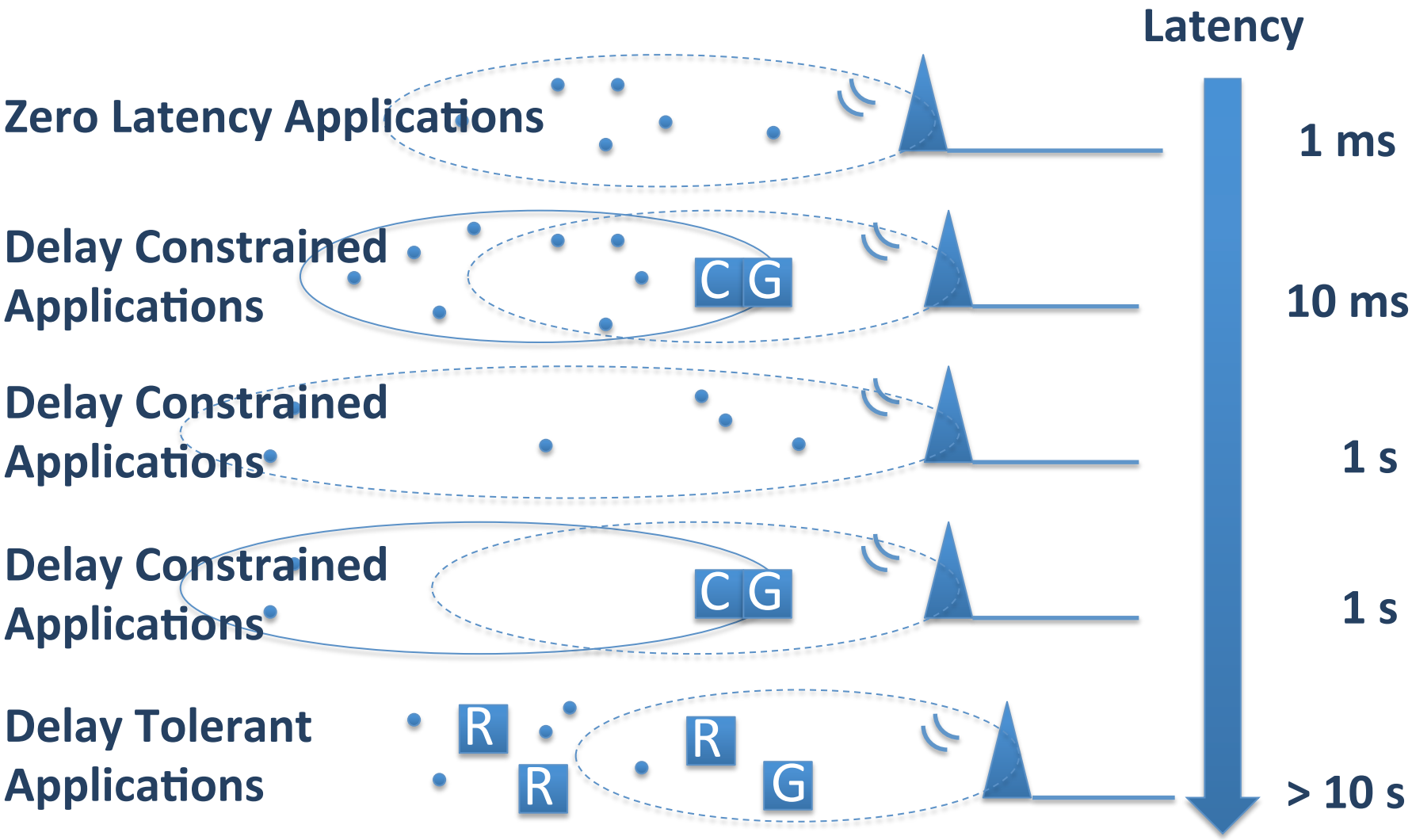
Network Architectures



Network Architectures



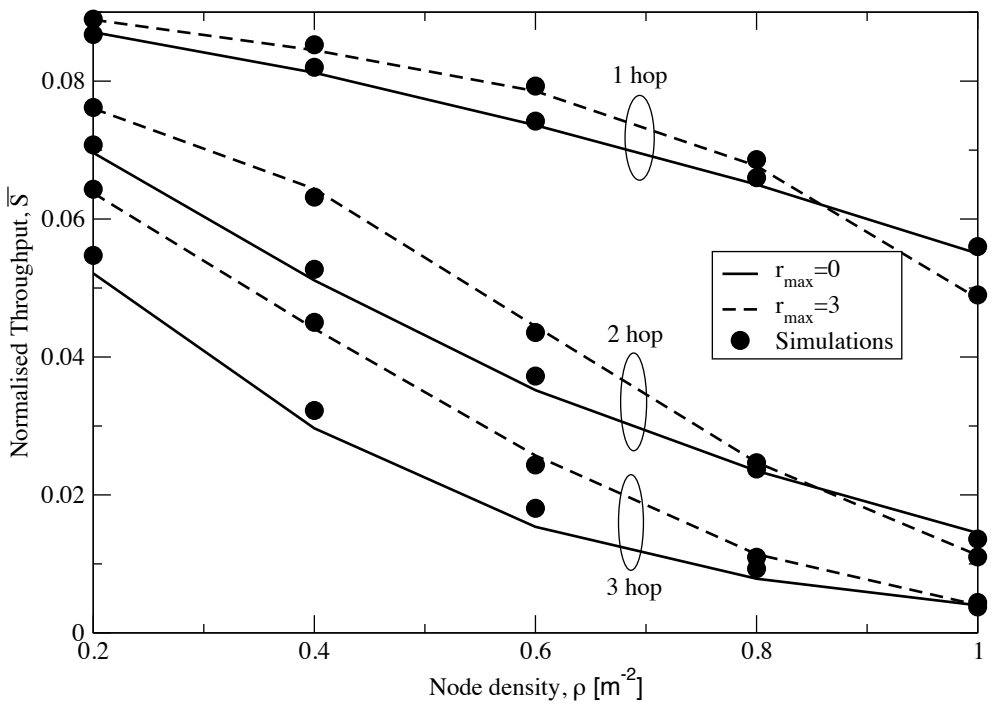
Network Architectures



Network Architectures / Multi-Hop

End-to-End Throughput of Ad Hoc Multi-Hop Networks Through Path Level Markov Chains

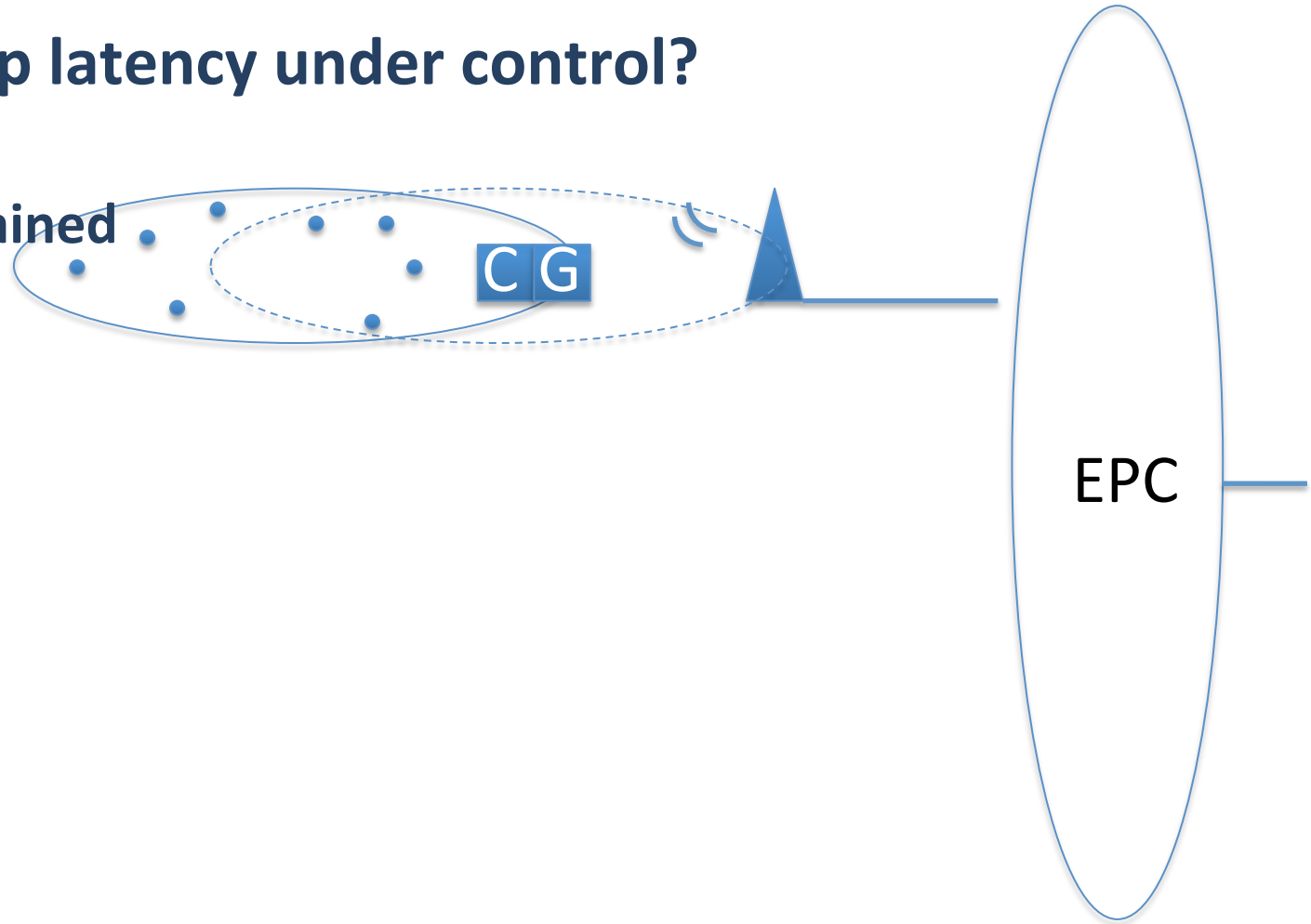
Chiara Buratti, Roberto Verdone



Network Architectures / Multi-Hop

How to keep latency under control?

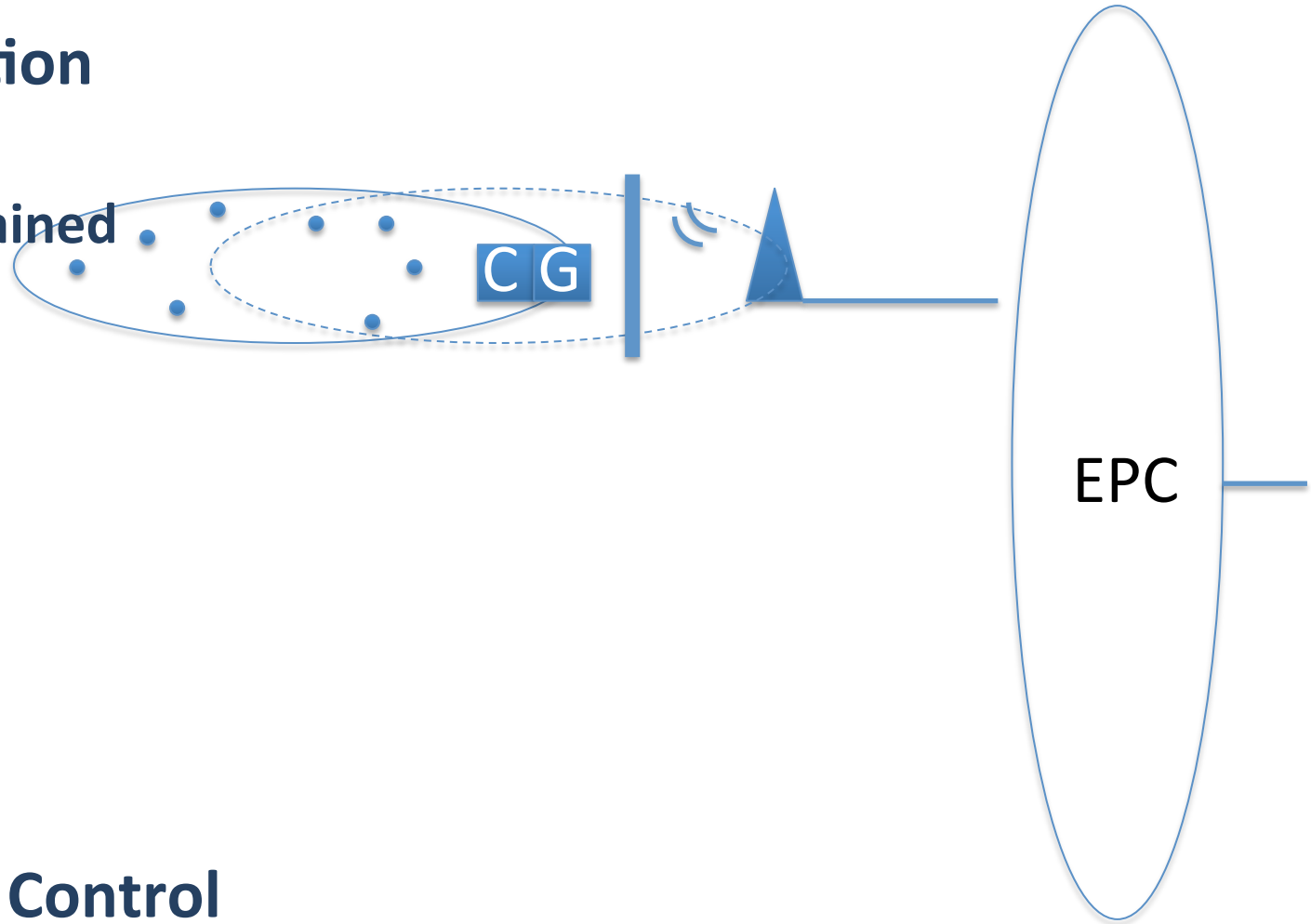
Delay Constrained Applications



Network Architectures / Multi-Hop

Full separation

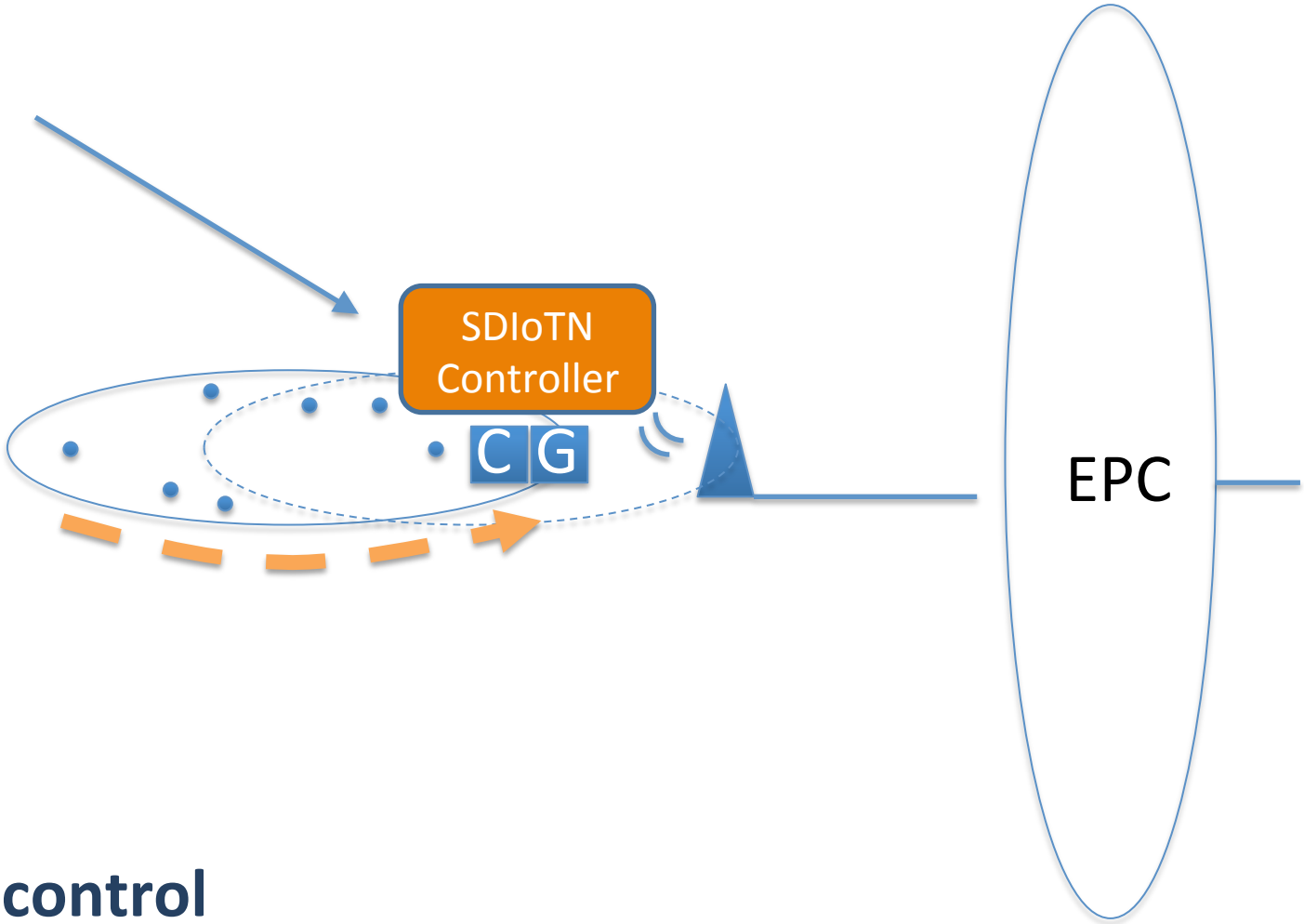
Delay Constrained Applications



Distributed Control

Network Architectures / SDWN

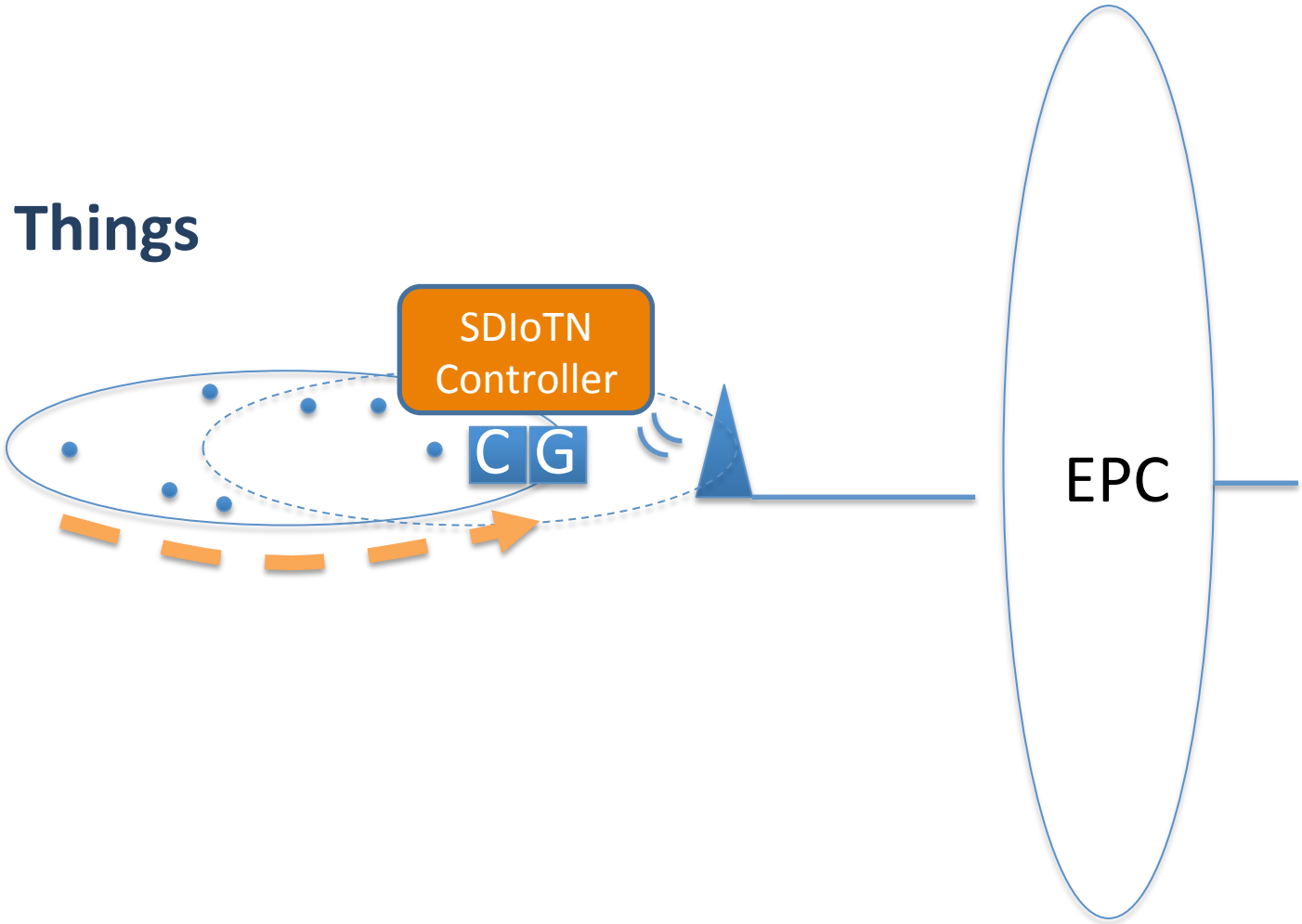
Controller



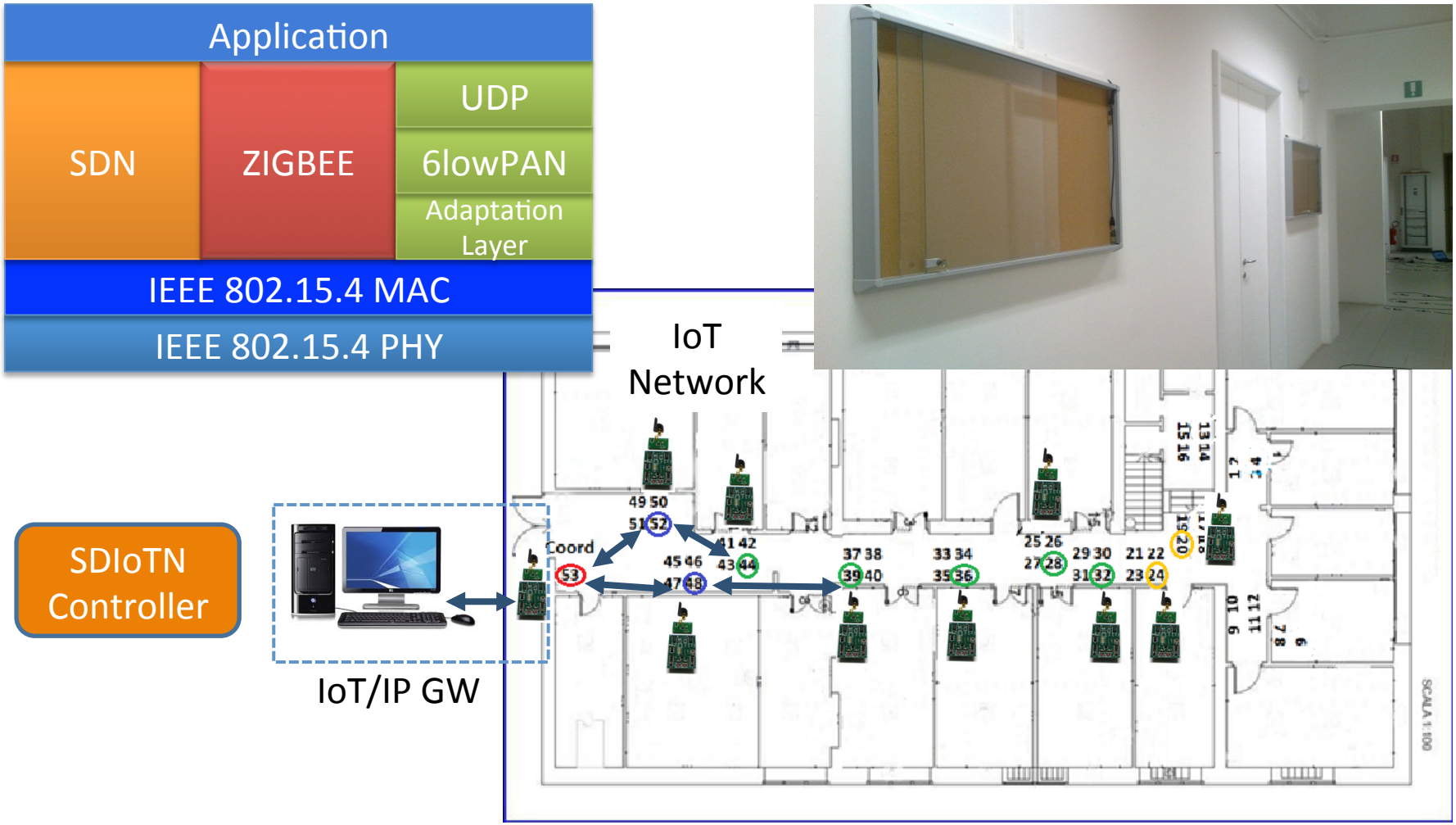
Centralised control

Network Architectures / SDWN

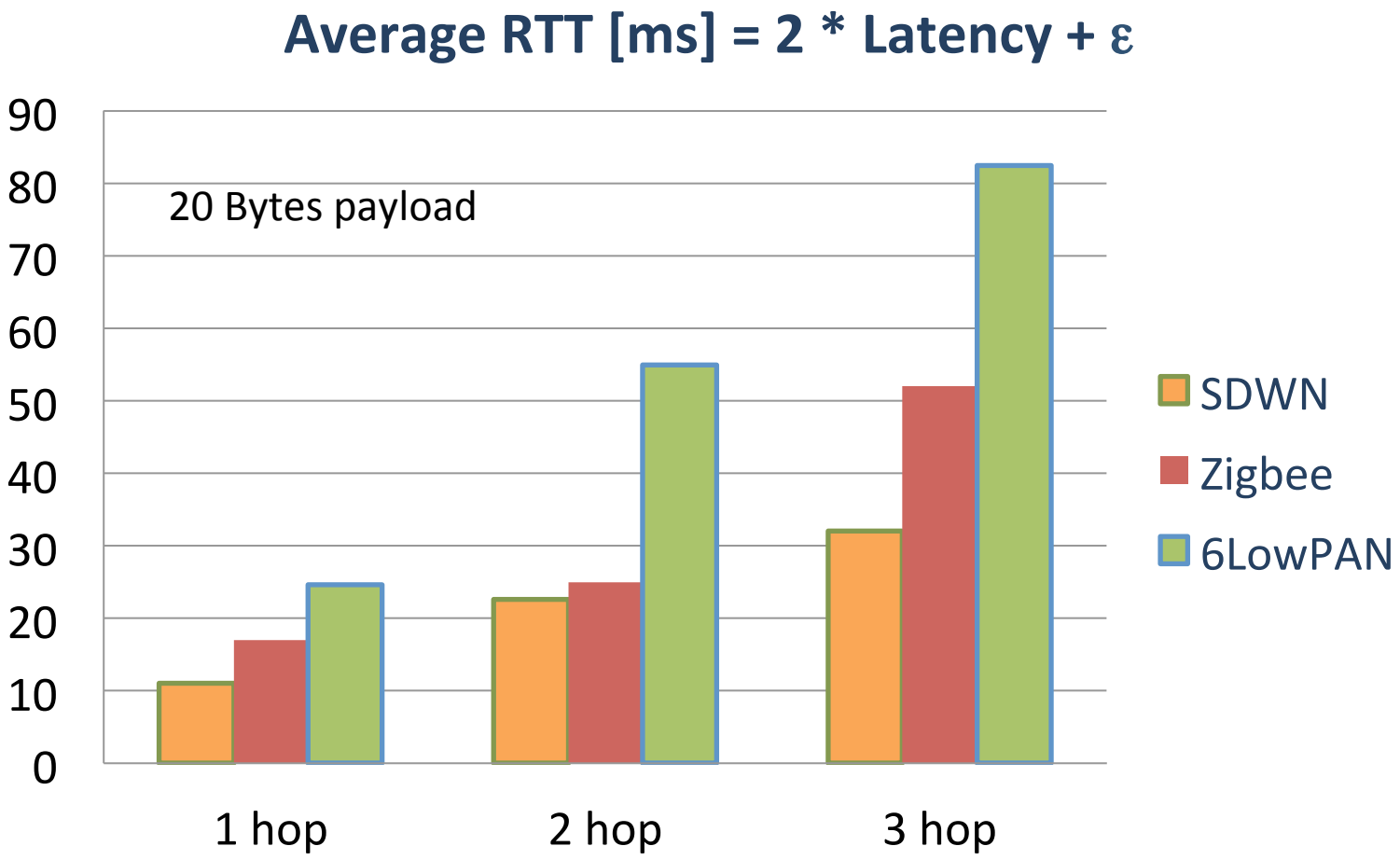
Static Things



Network Architectures / SDWN



Network Architectures / SDWN

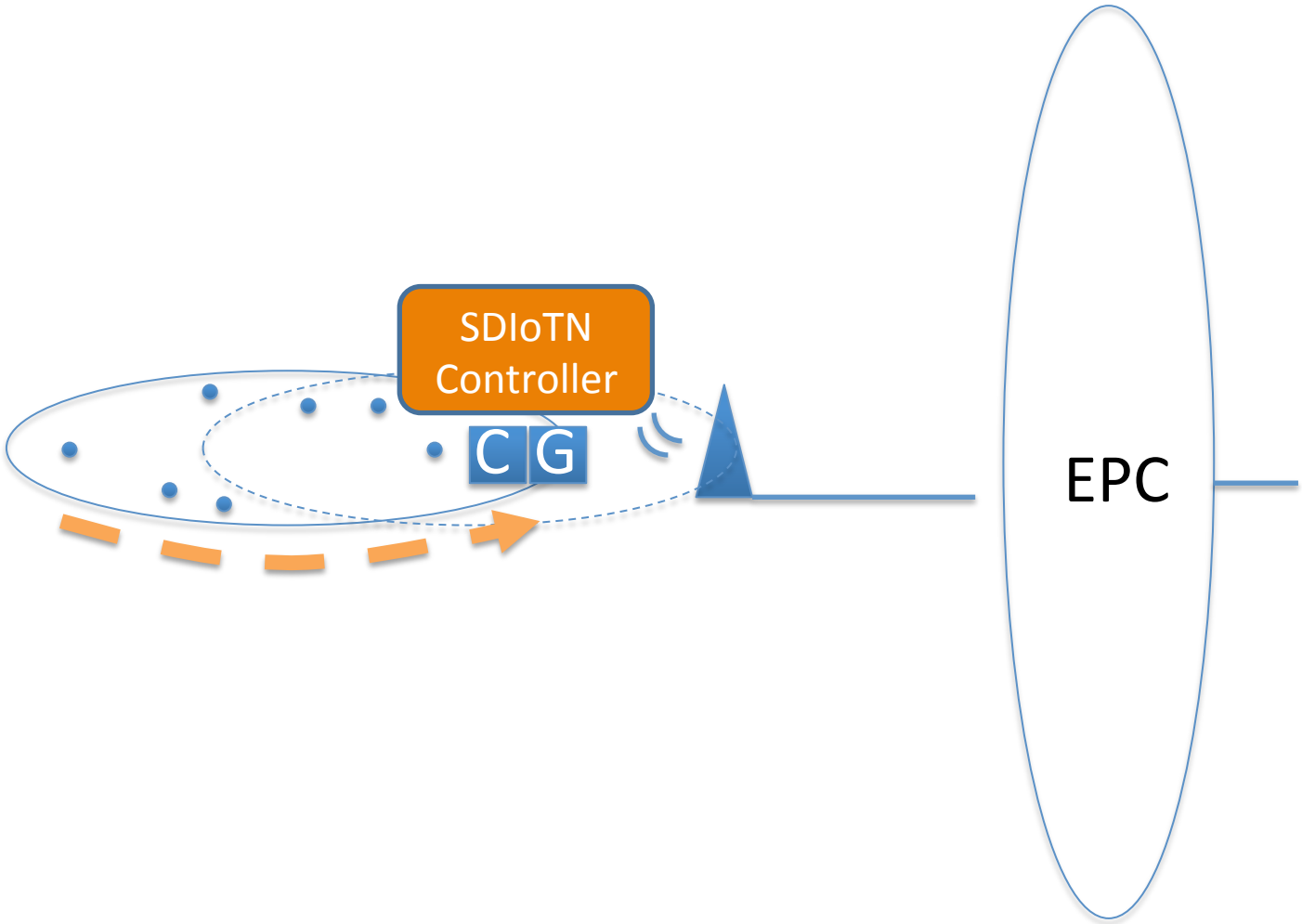


Network Architectures / SDWN

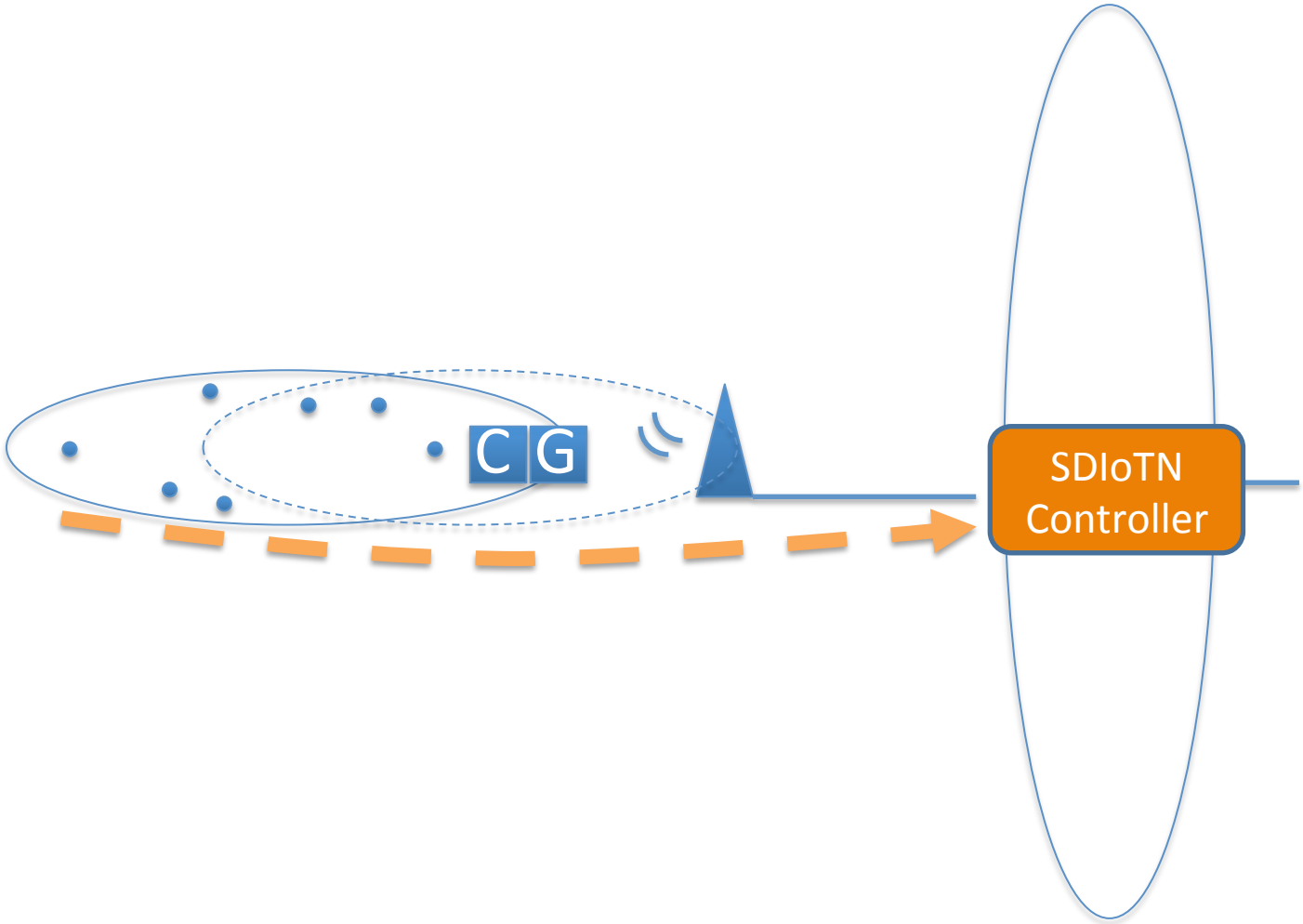
Overhead

	One Hop	Two Hops
SDWN	2.5	5.5
Zigbee	6.5	11.5
6LowPAN	10.5	16.5

Network Architectures / SDWN

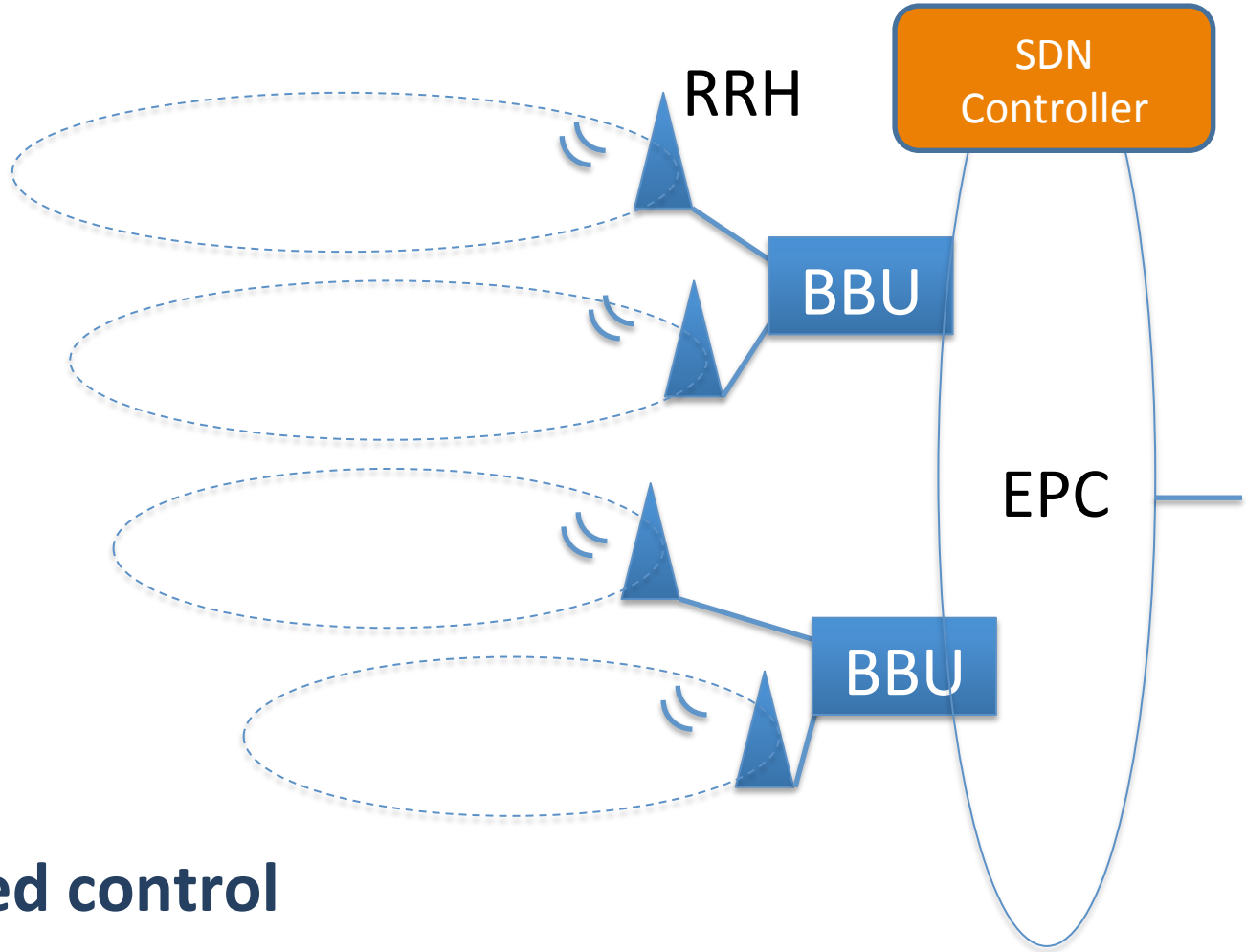


Network Architectures / SDWN → SDN



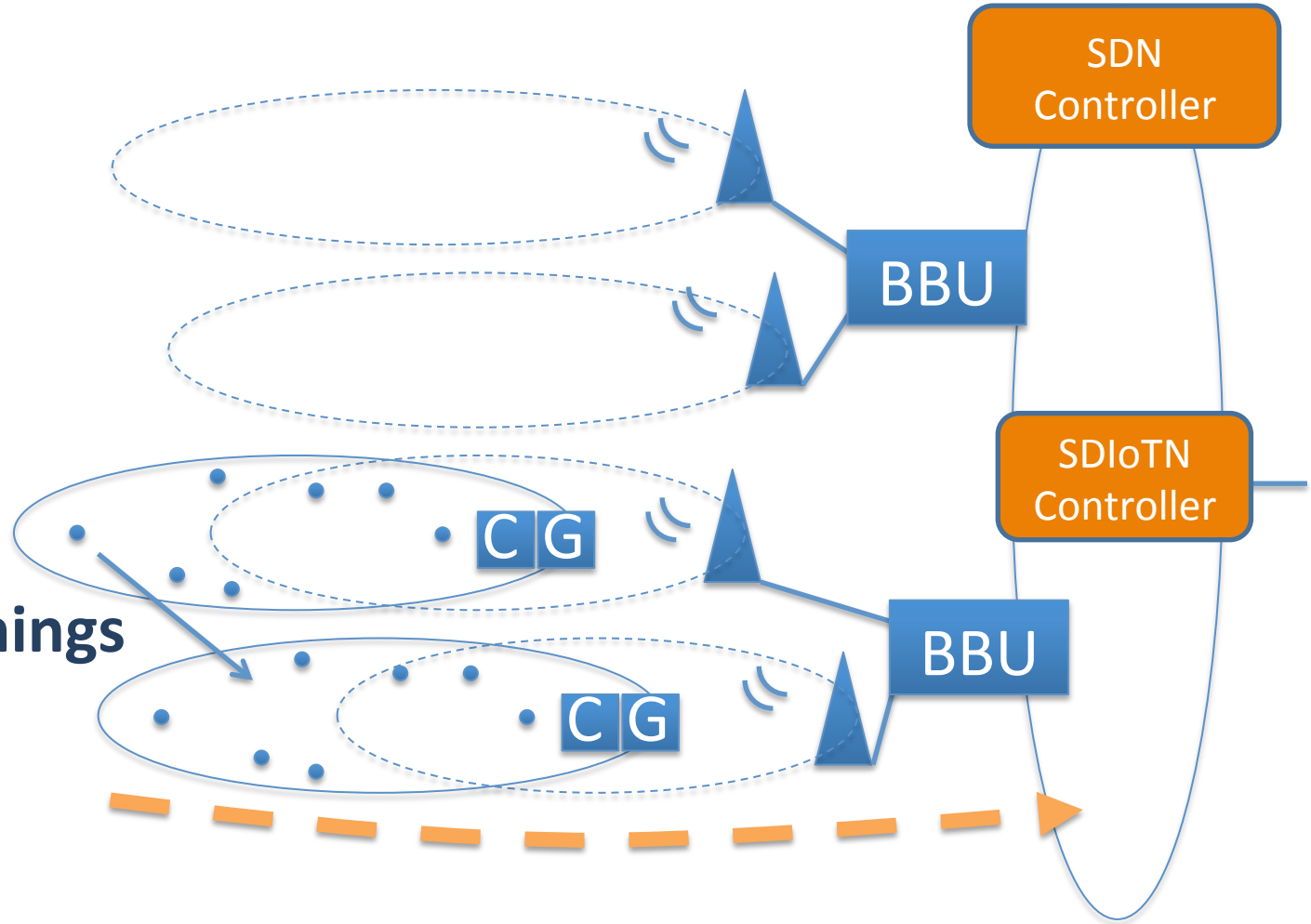
Network Architectures / SDN

Cloud RAN



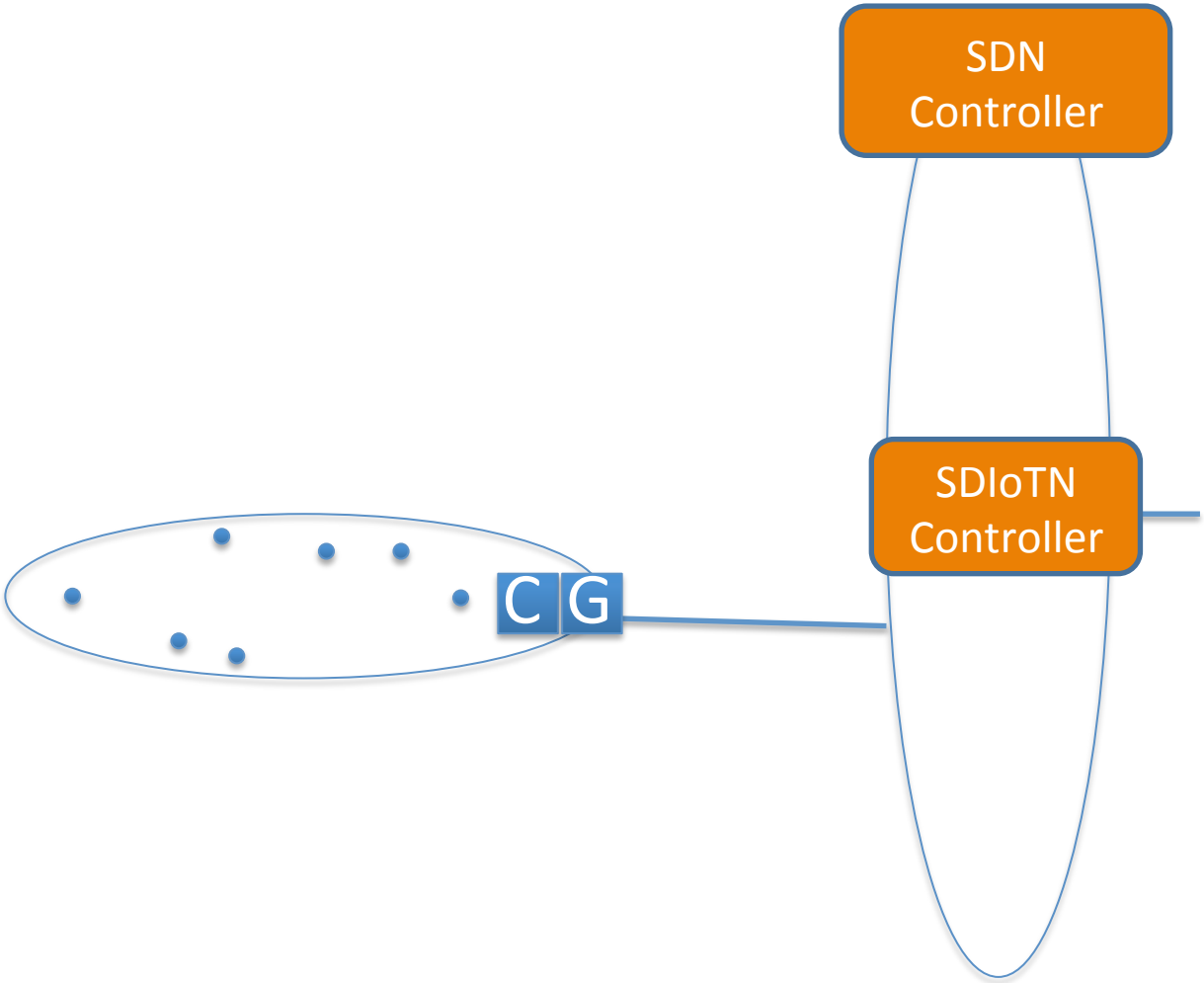
SDN: Centralised control

Network Architectures / SDN

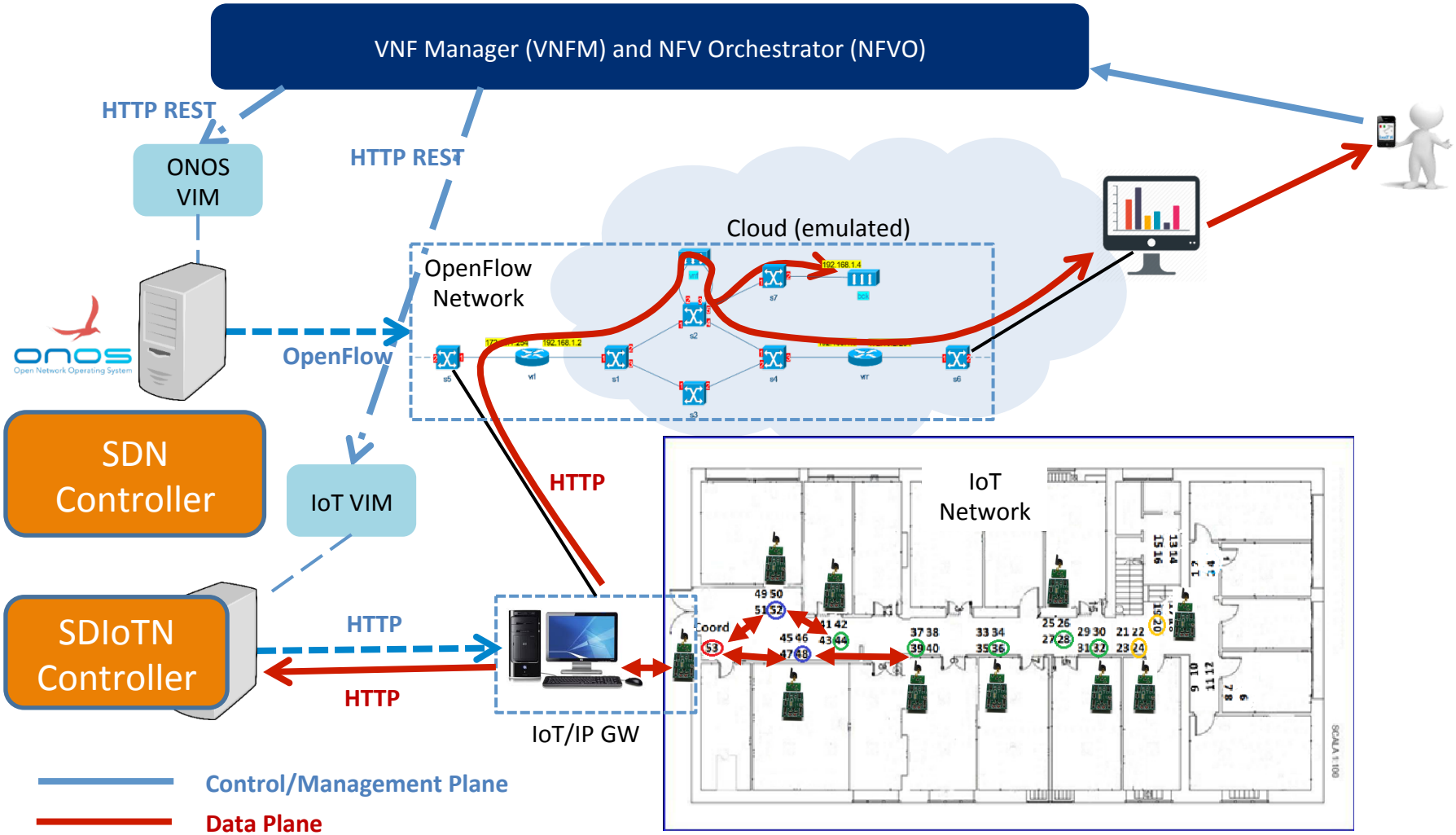


Nomadic Things

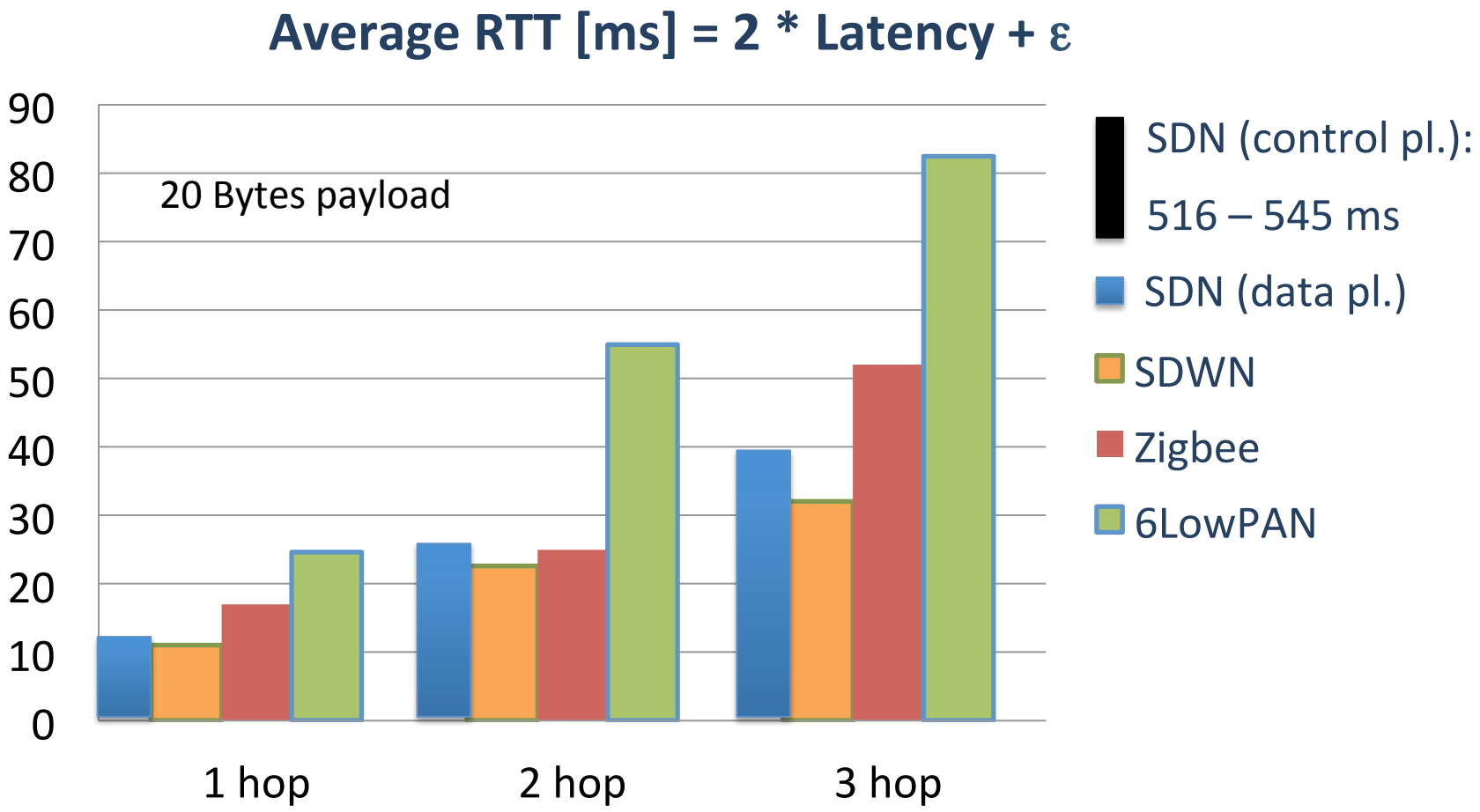
Network Architectures / SDN



Network Architectures / SDN



Network Architectures / SDN



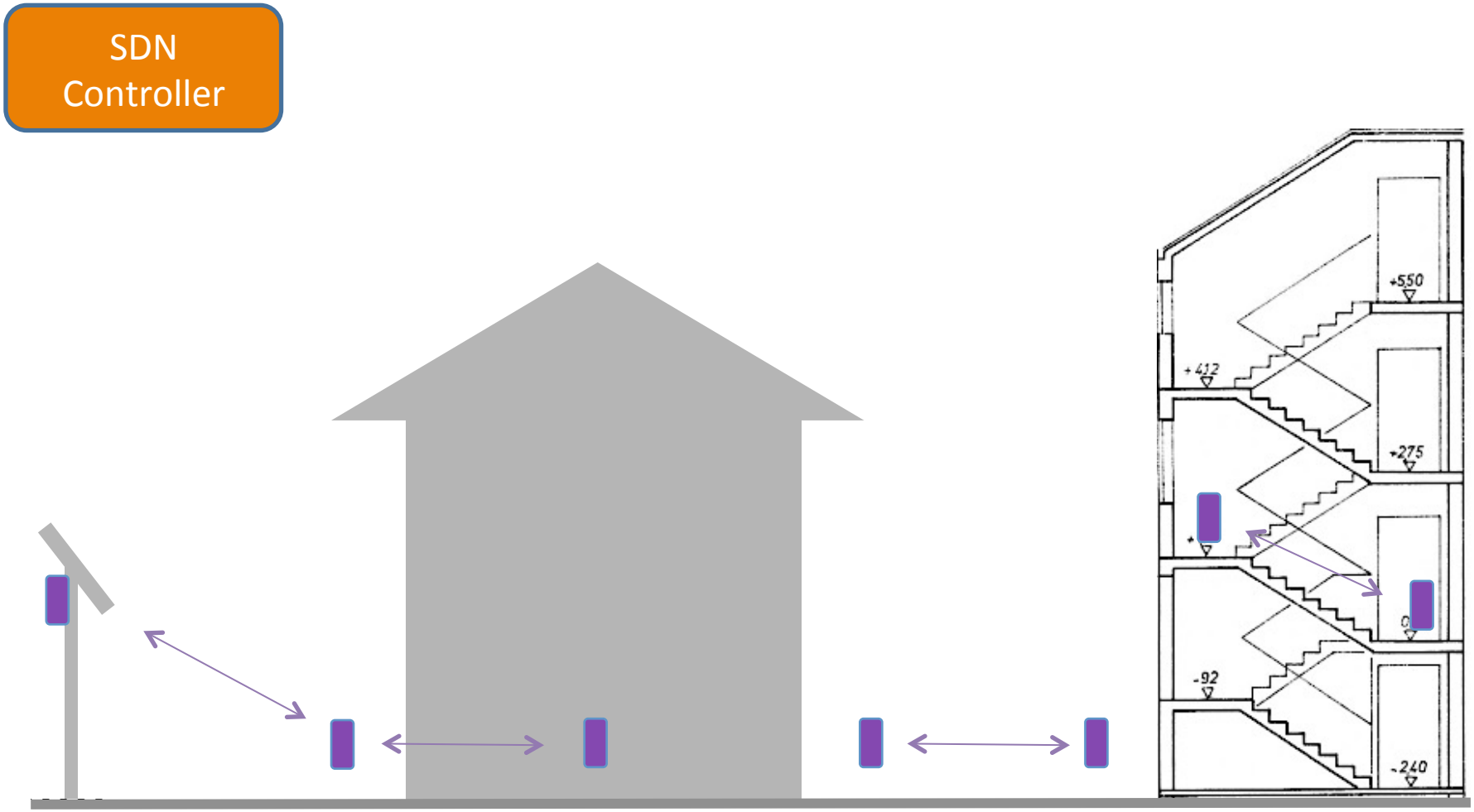
Network Architectures Takeaways

SDN can efficiently reduce latency for Delay Constrained Applications with Static or Nomadic Things

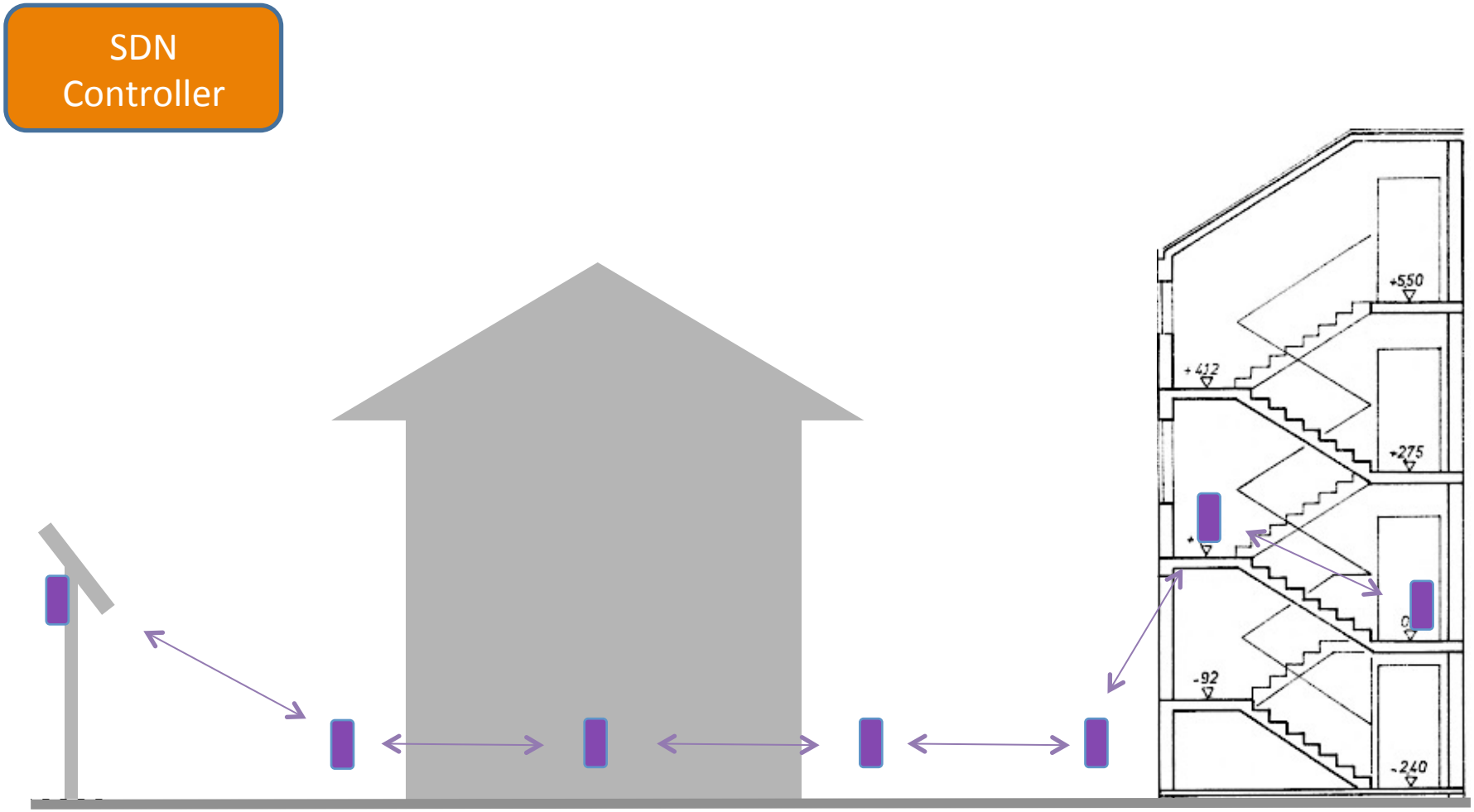
DTN can be applied for Delay Tolerant Applications

Future Scenarios for B5G

Future Scenarios / D2D

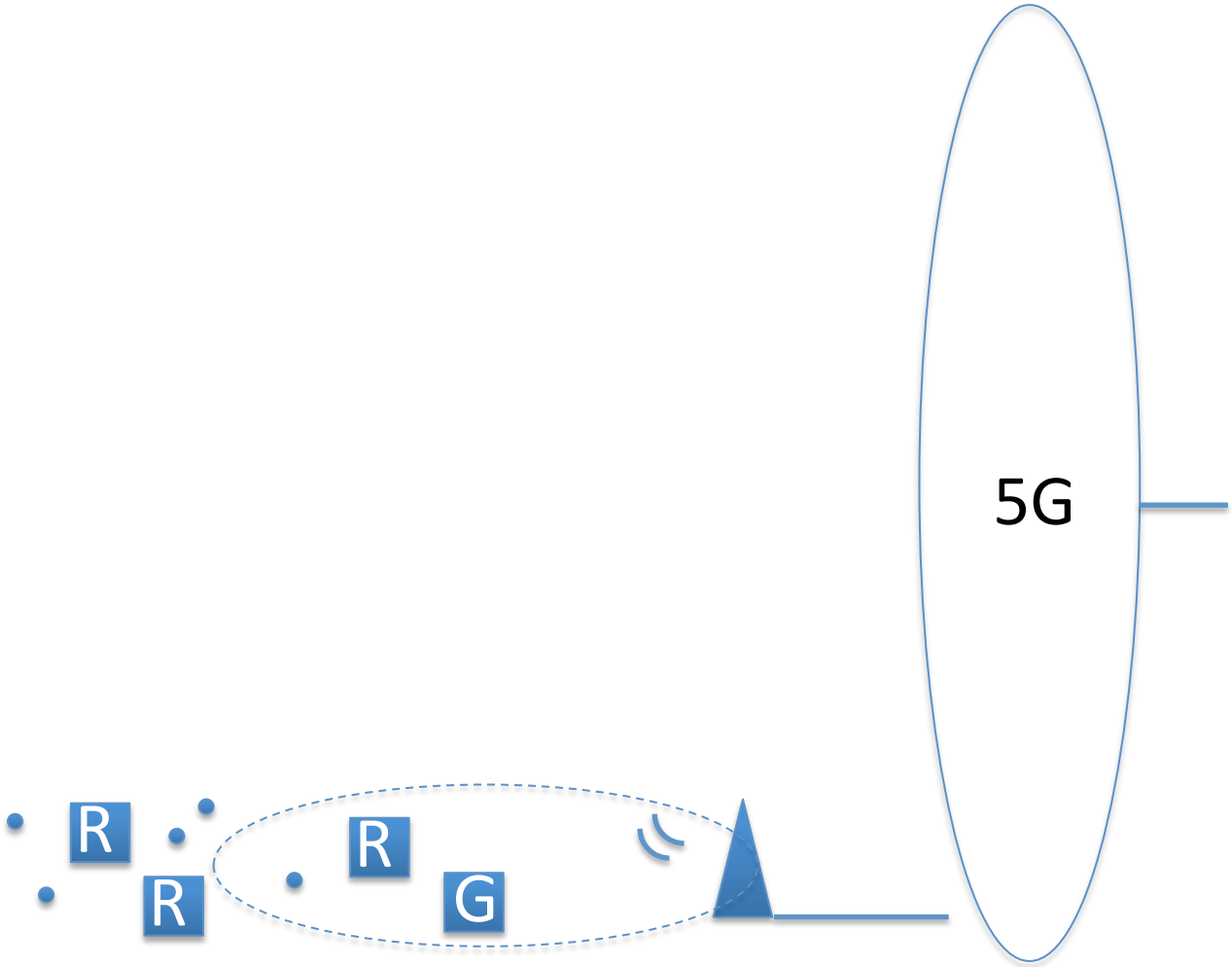


Future Scenarios / Multi-Hop D2D



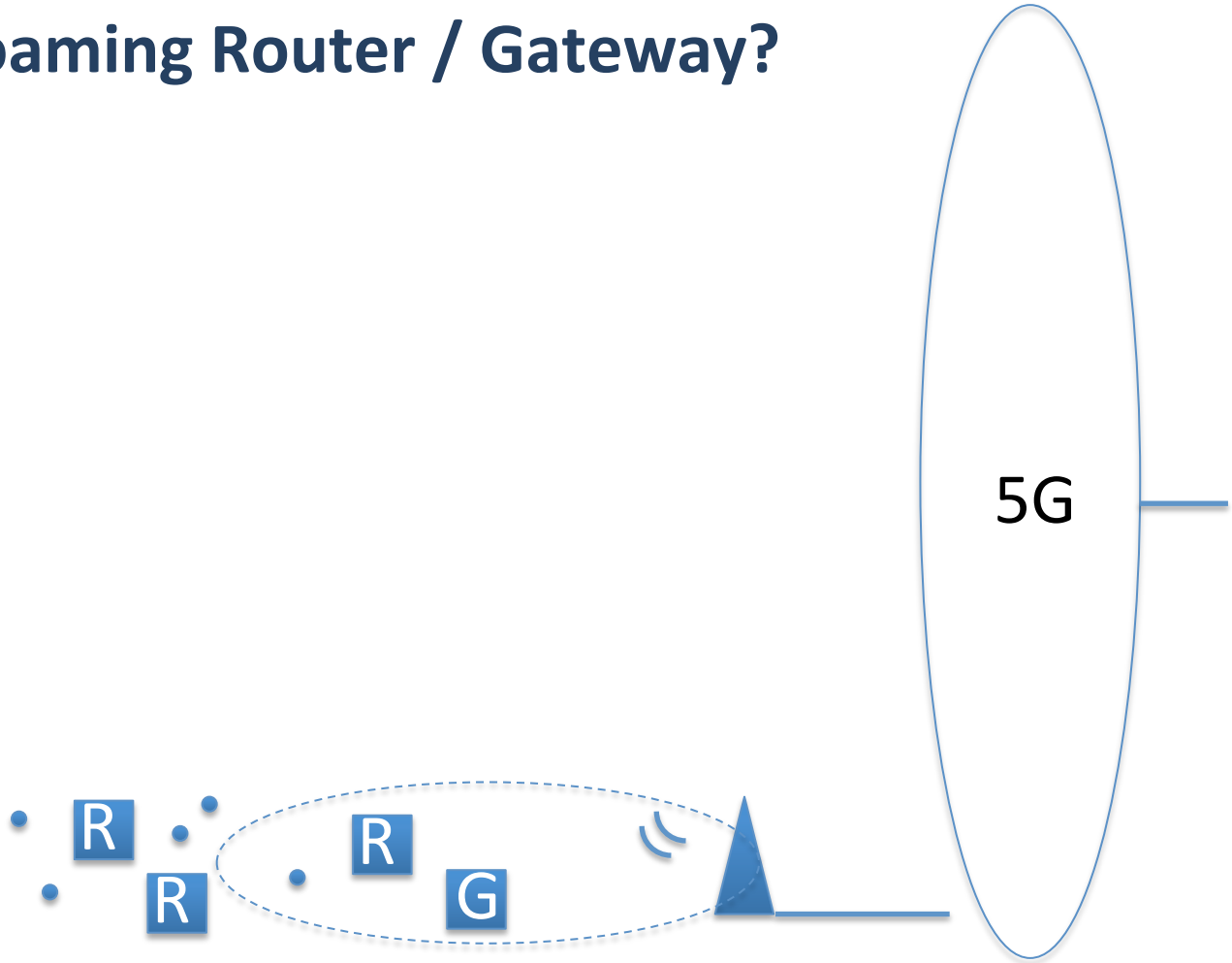
Future Scenarios / DTN

Delay Tolerant Networking



Future Scenarios / DTN

What Kind of Roaming Router / Gateway?

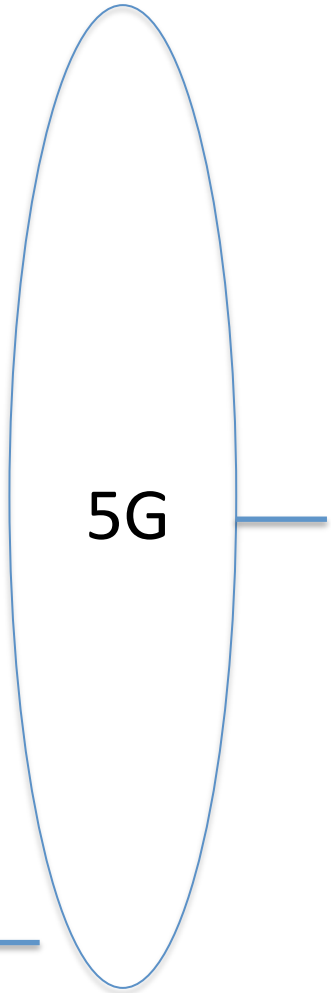


Delay Tolerant Applications

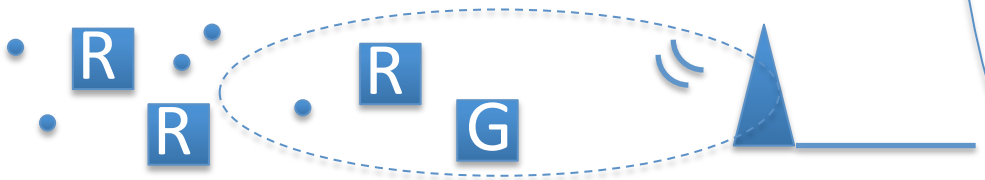
Future Scenarios / DTN

What Kind of Roaming Router / Gateway?

In the city centre of Bologna 60% of buildings can be connected to any other within 4 hours exploiting *pedestrian* and *bus* mobility and their WiFi.



Delay Tolerant Applications



Future Scenarios / DTN

The solution might be in the sky

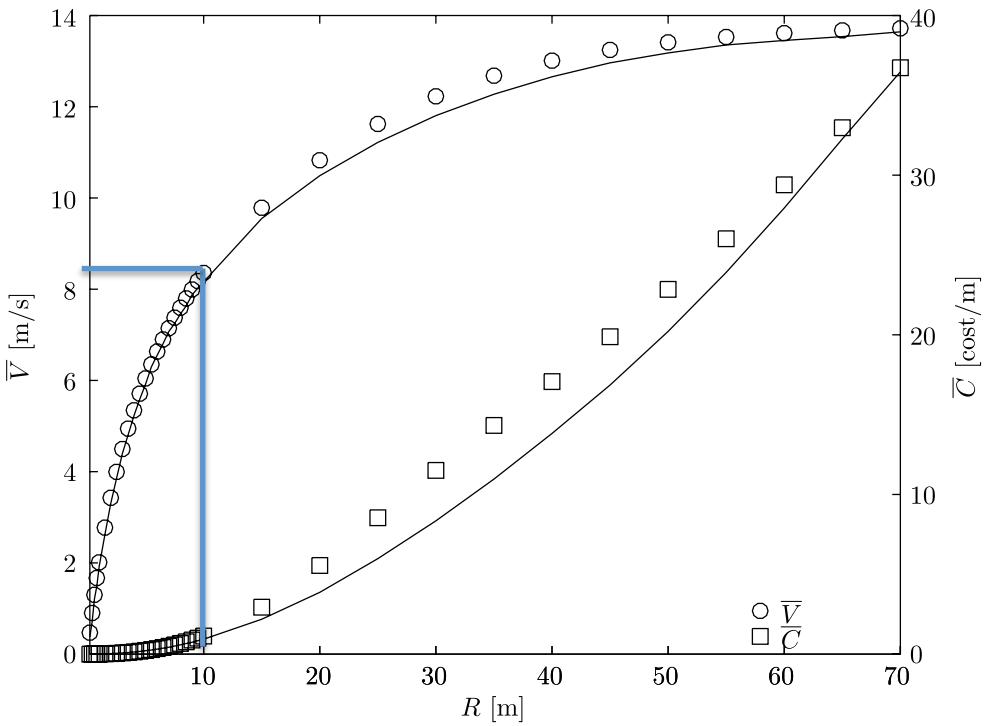
In the city centre of Bologna
there are 1000 pigeons per sqKm

Future Scenarios / DTN

Cost/Speed Analysis of Mobile Wireless DTNs under Random Waypoint Mobility

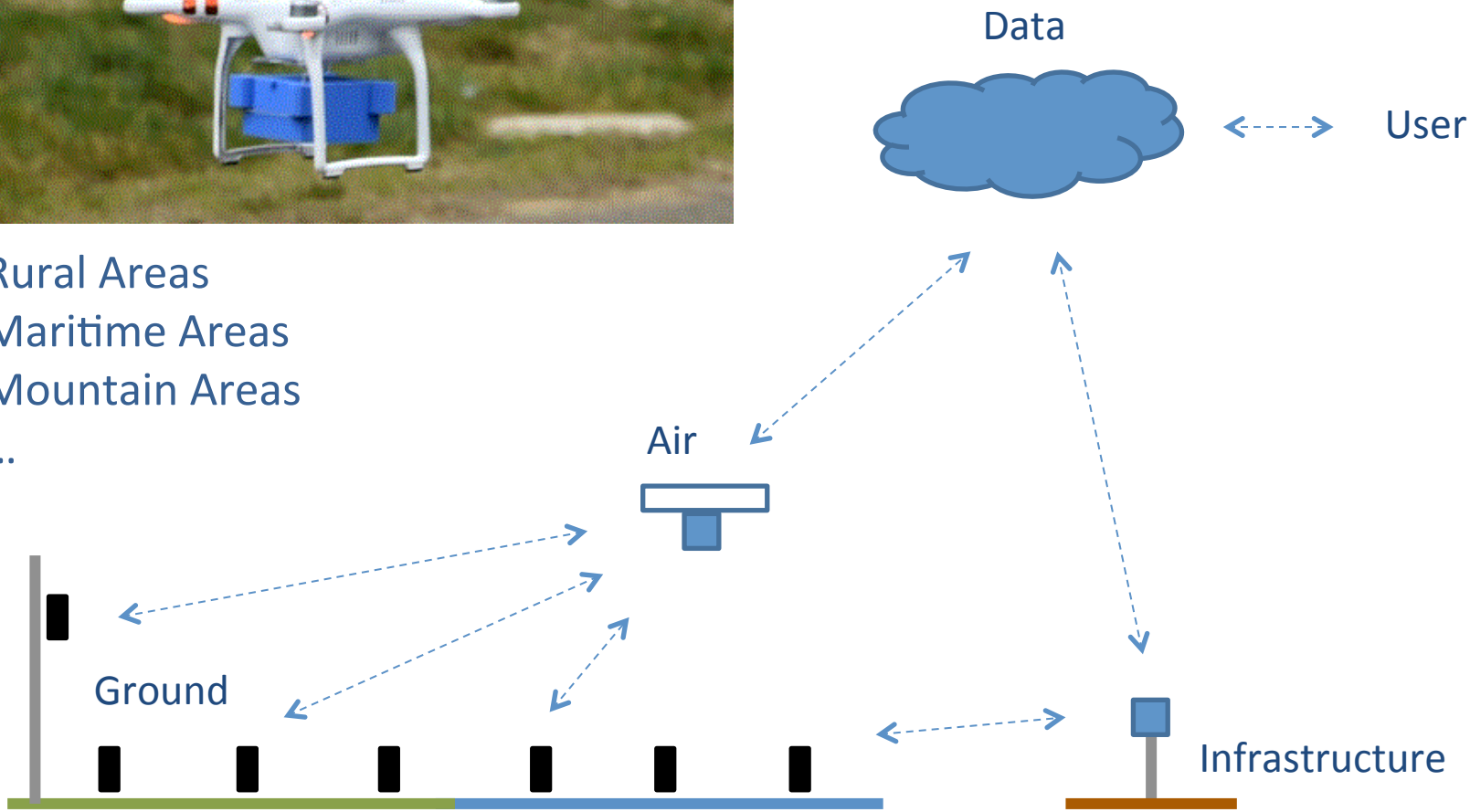
Riccardo Cavallari*, Roberto Verdone*, and Stavros Toumpis†

$v_0 = 13.9$ m/s, $\lambda = 0.001$ m^{-2}, $r_0 = 0.1$ s^{-1}



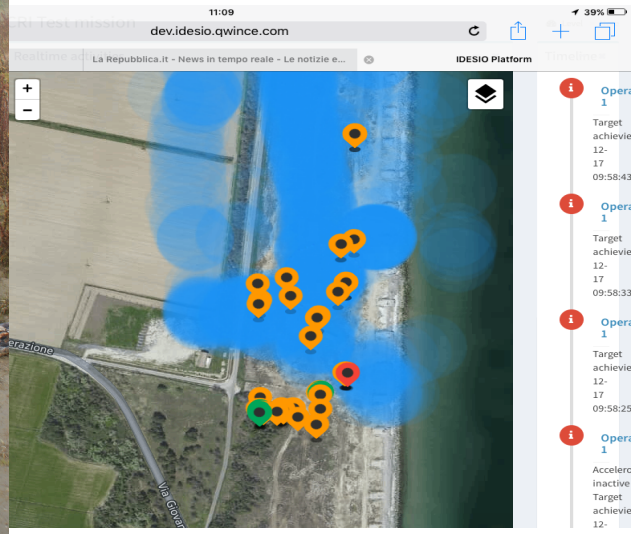
Future Scenarios / DTN

Rural Areas
Maritime Areas
Mountain Areas
...



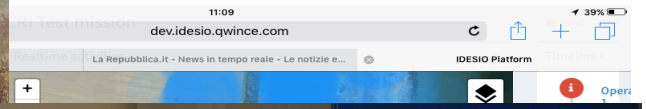
Future Scenarios / DTN

Croce Rossa Italiana
Comitato di Bologna



Future Scenarios / DTN

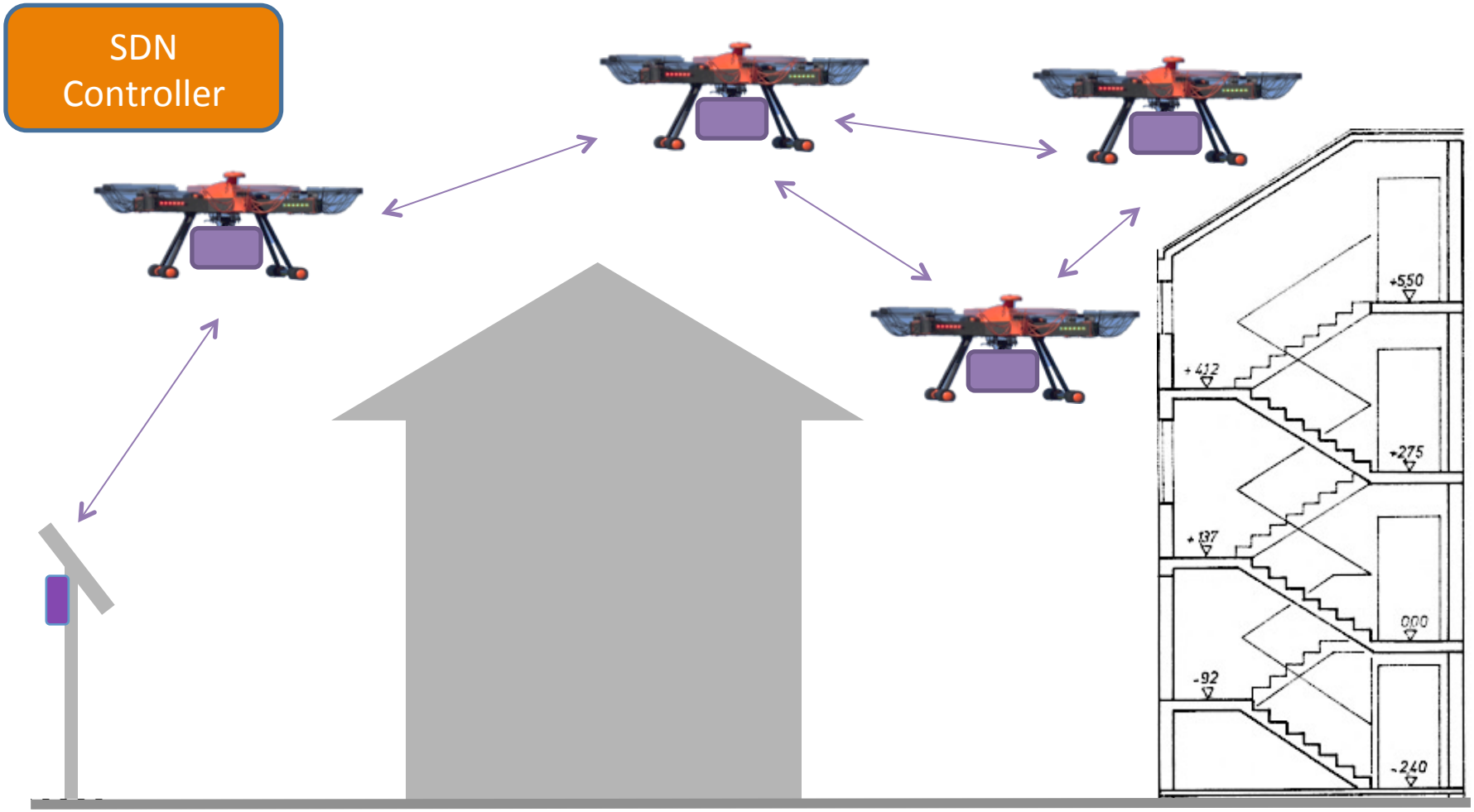
Croce Rossa Italiana
Comitato di Bologna



Future Scenarios / DTN

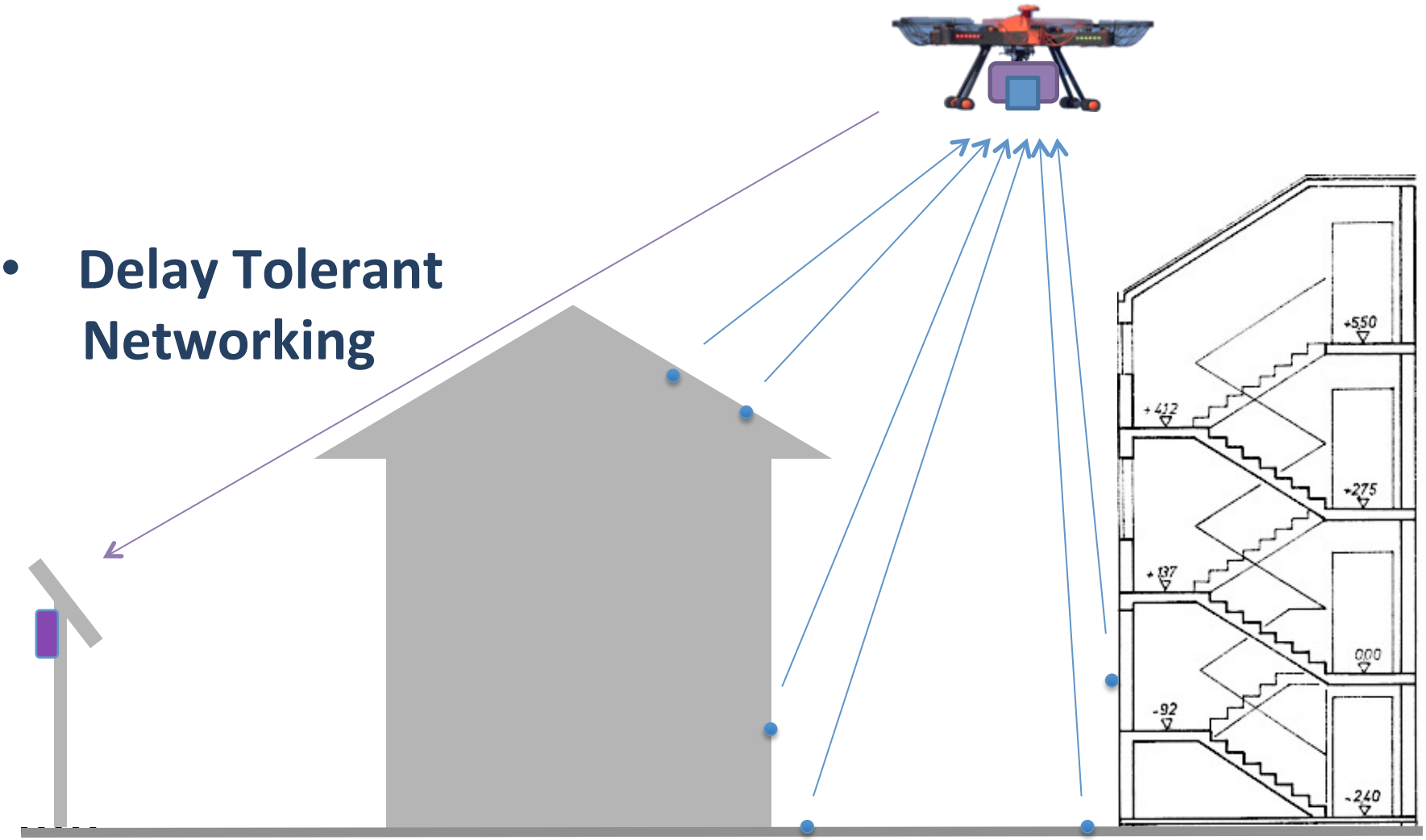
Future Scenarios / DTN

Future Scenarios / UAV-Aided Networks



Future Scenarios / UAV-Aided Networks

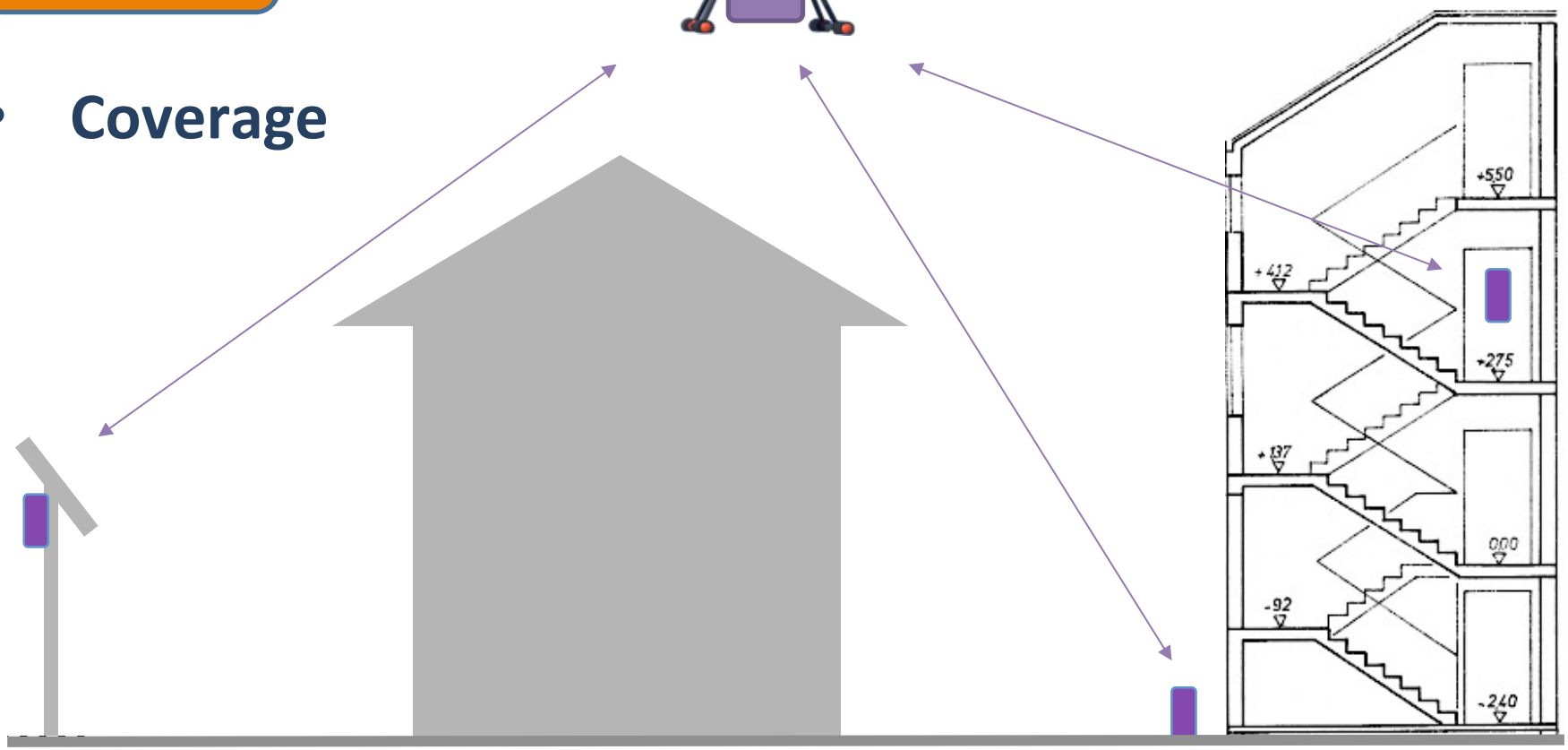
- **Delay Tolerant Networking**



Future Scenarios / UAV-Aided Networks

SDN Controller

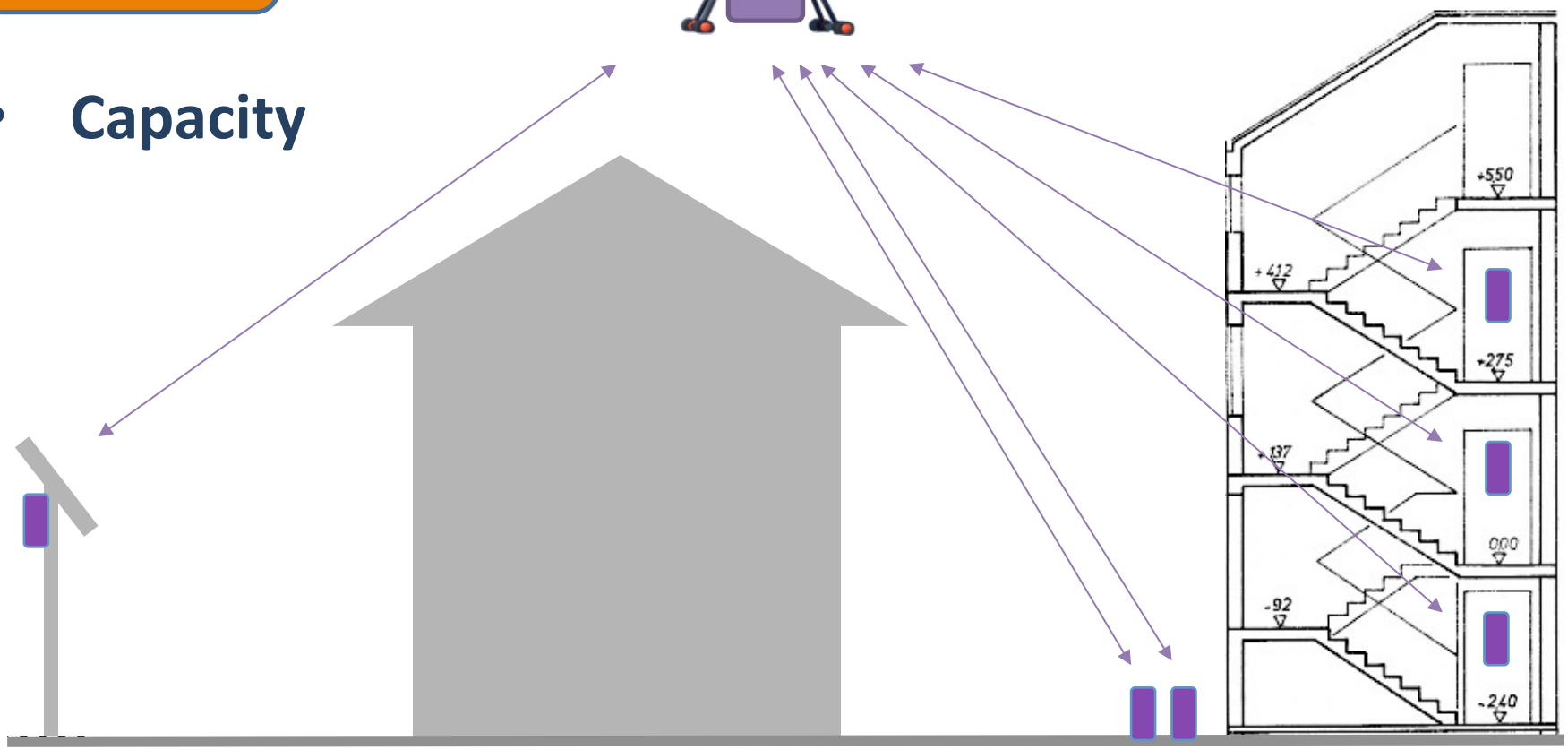
- **Coverage**



Future Scenarios / UAV-Aided Networks

SDN Controller

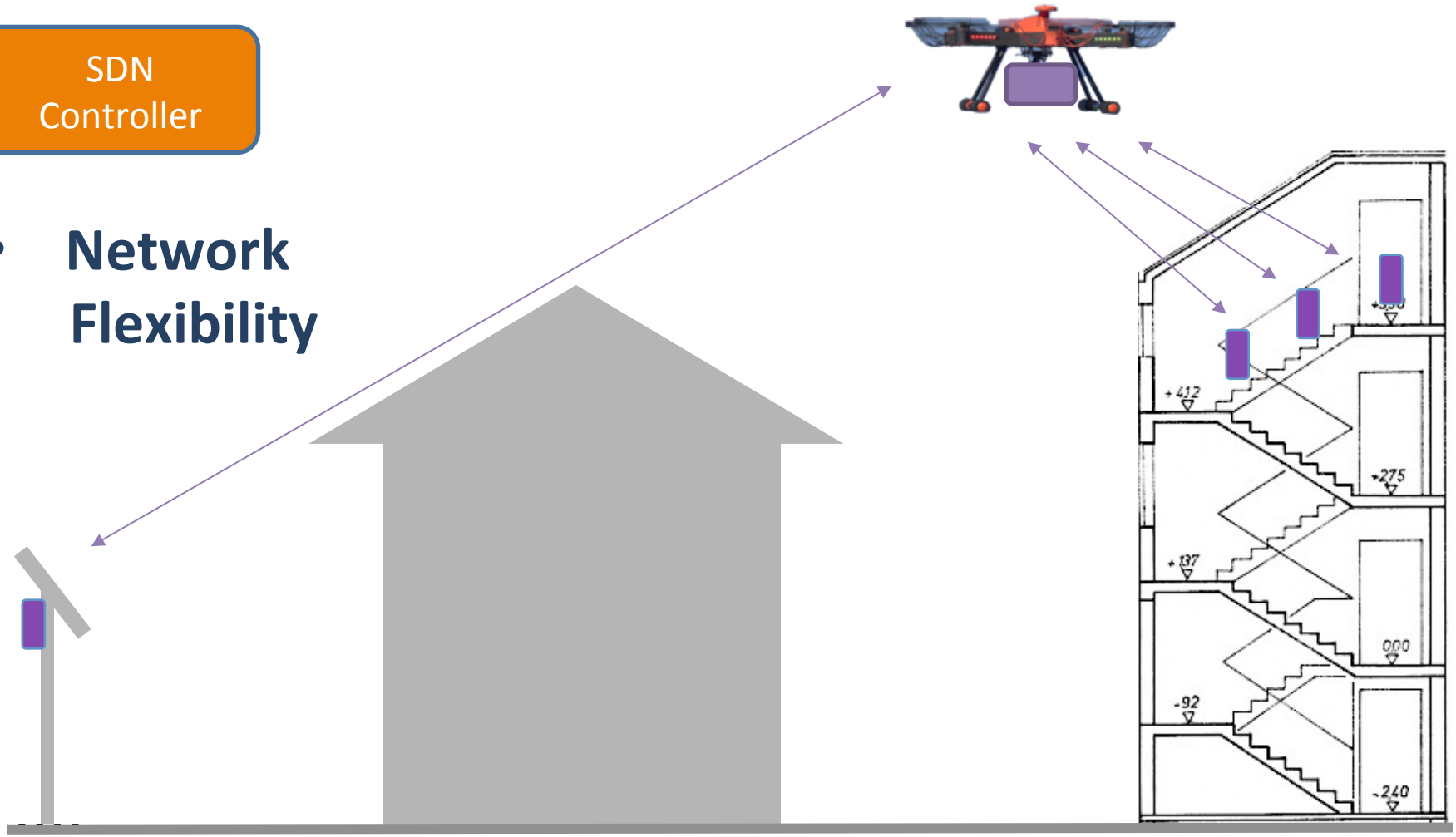
- **Capacity**



Future Scenarios / UAV-Aided Networks

SDN Controller

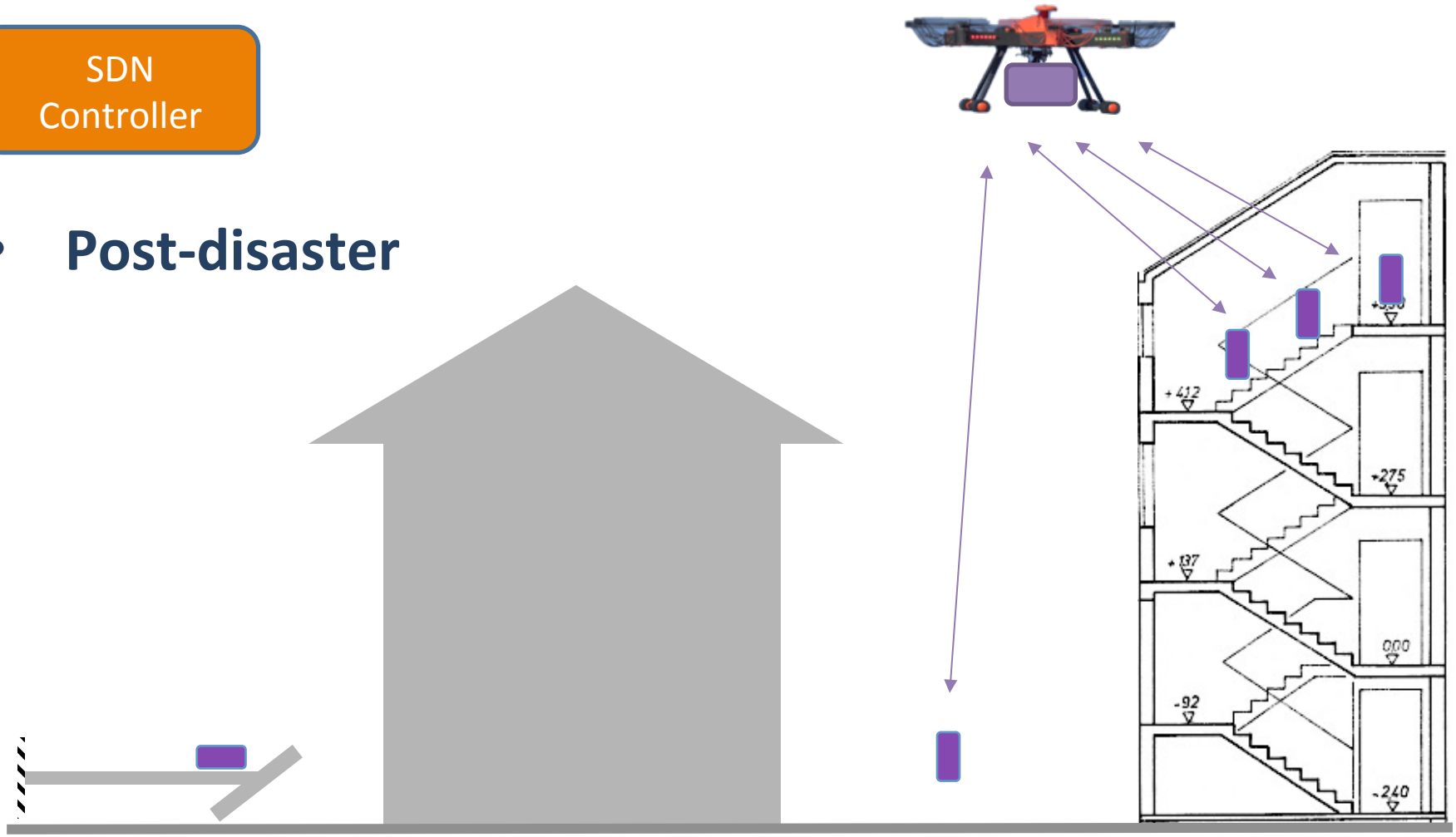
- **Network Flexibility**



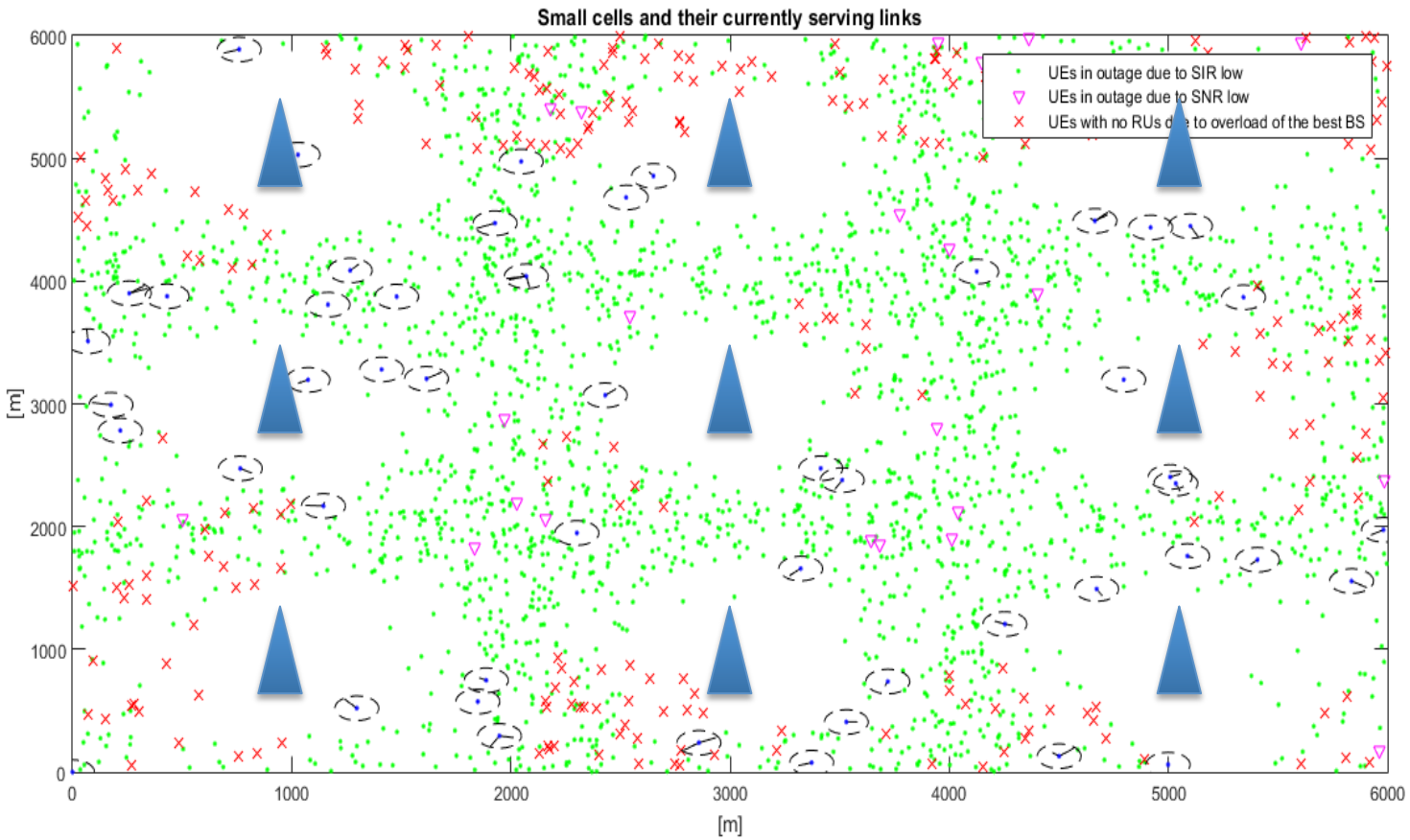
Future Scenarios / UAV-Aided Networks

SDN Controller

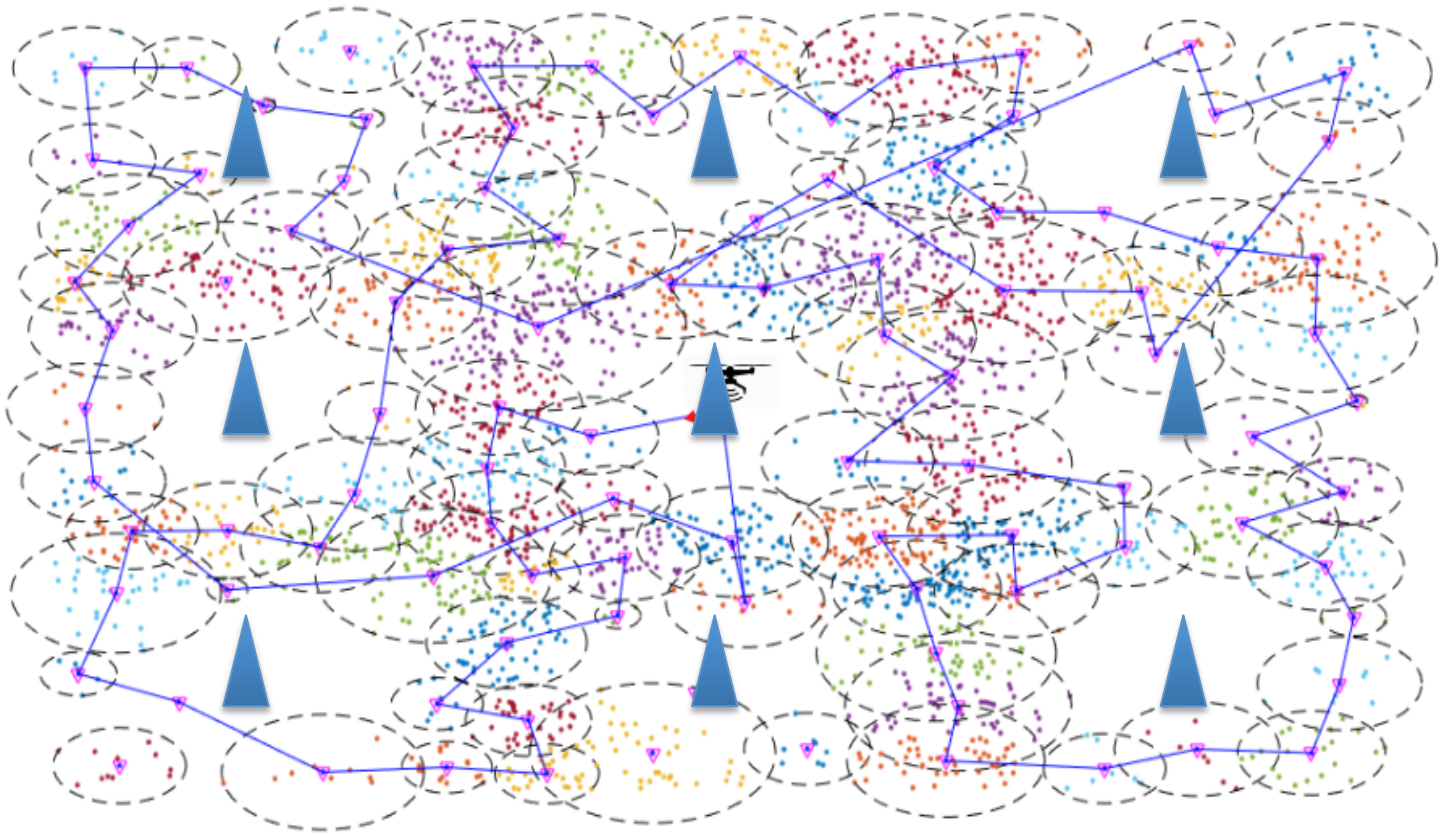
- **Post-disaster**



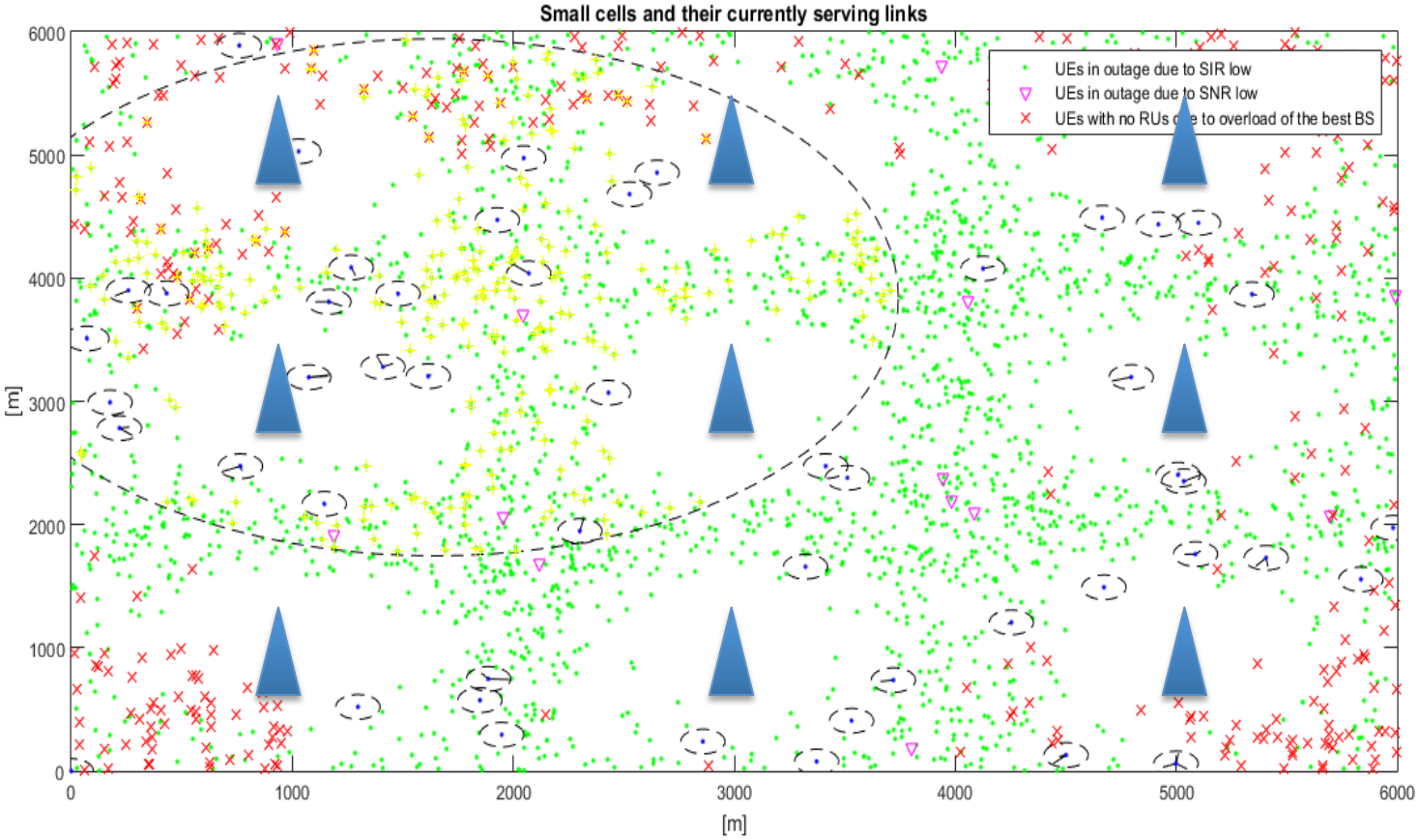
Future Scenarios / UAV-Aided Networks



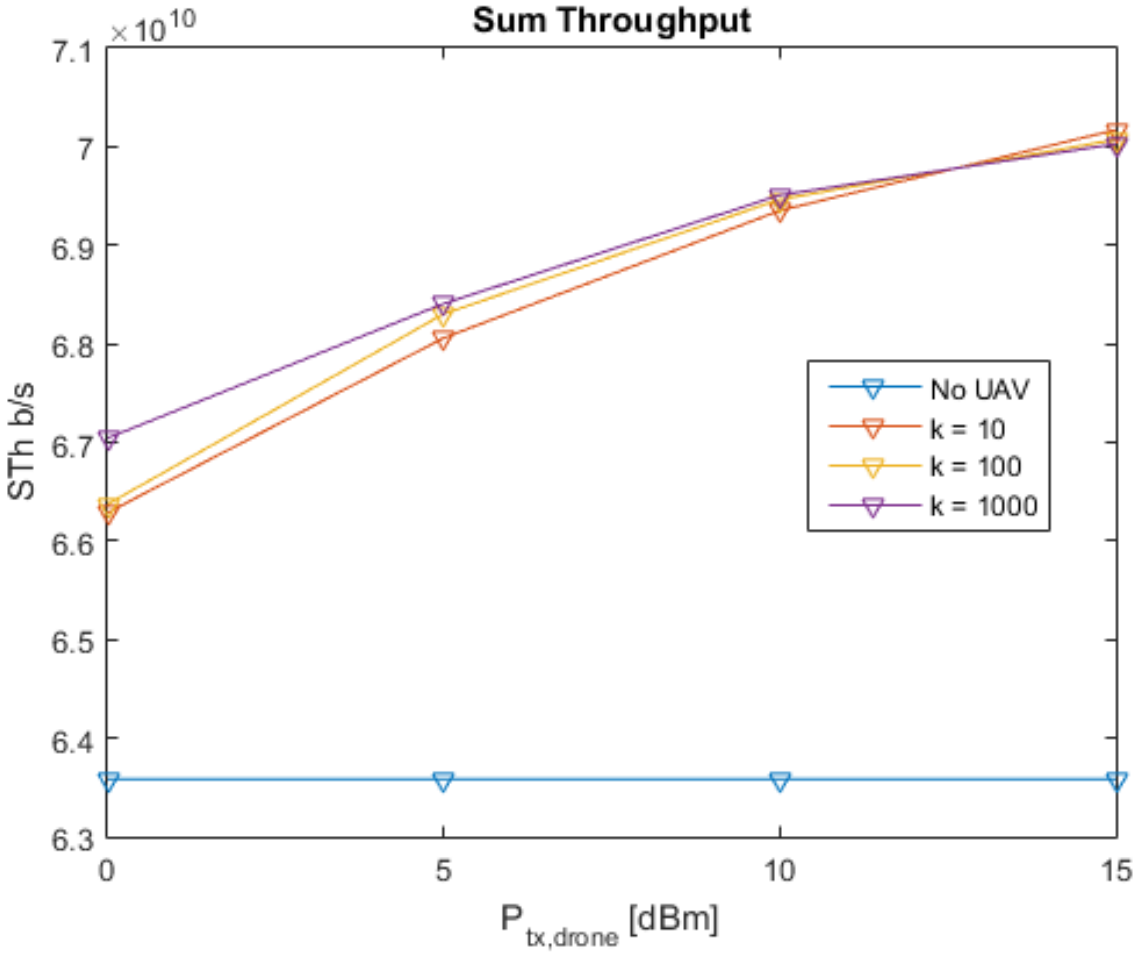
Future Scenarios / UAV-Aided Networks



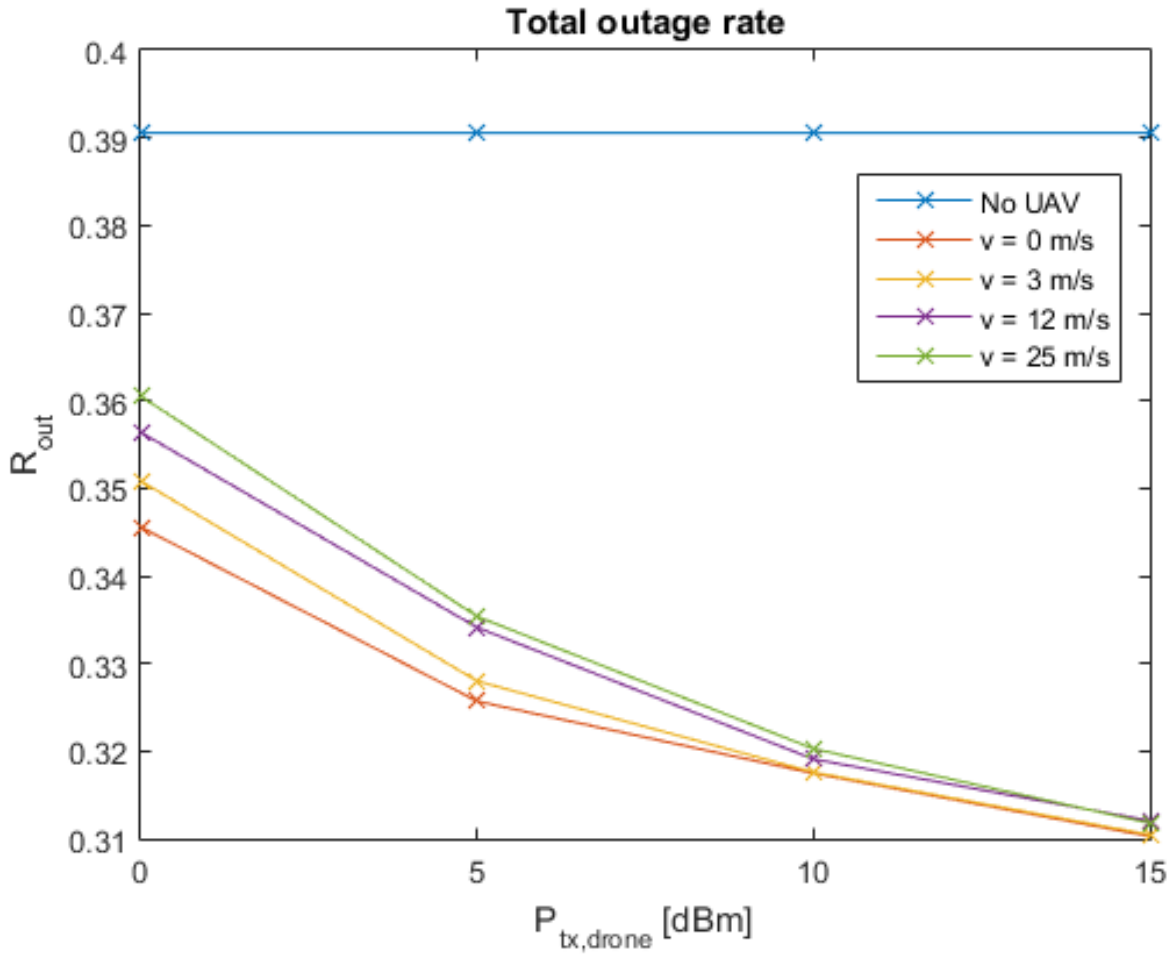
Future Scenarios / UAV-Aided Networks



Future Scenarios / UAV-Aided Networks

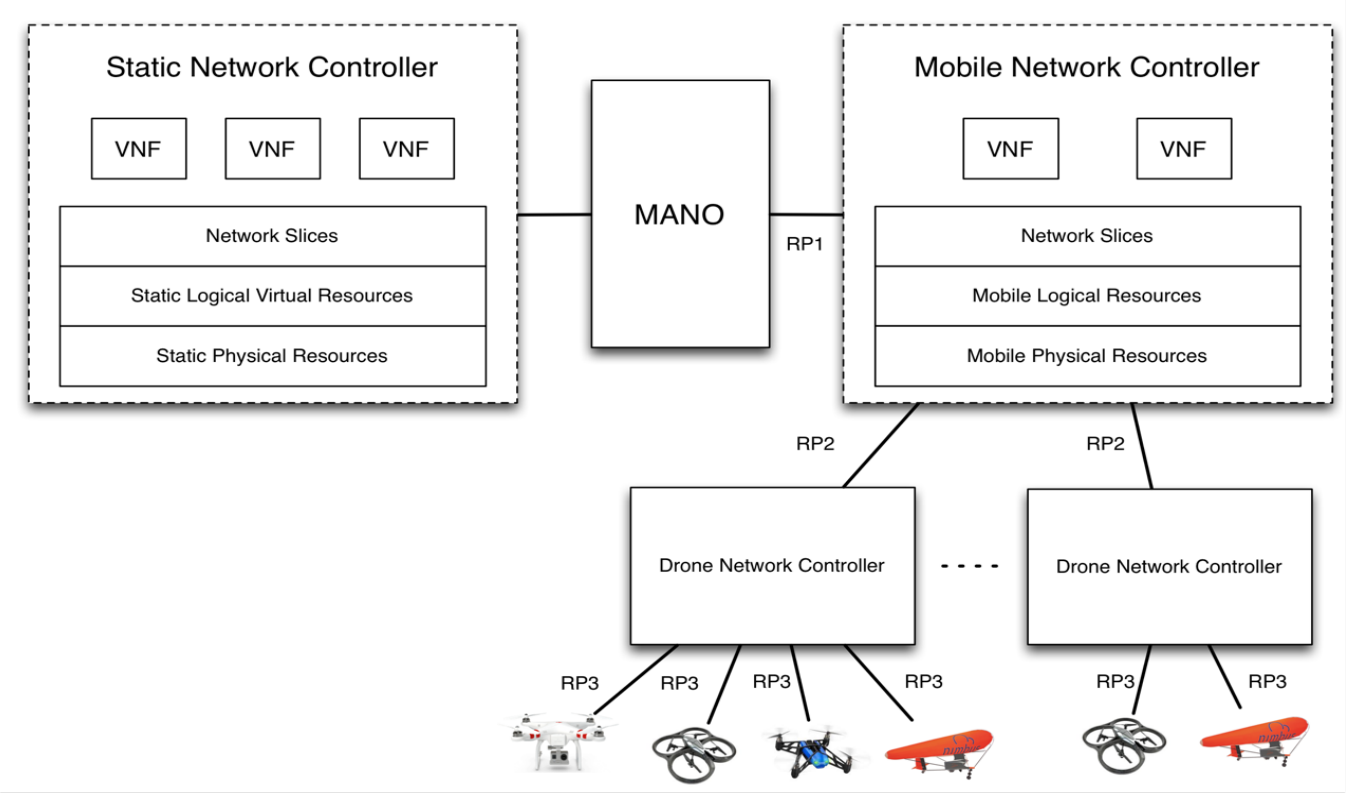


Future Scenarios / UAV-Aided Networks



Future Scenarios / UAV-Aided Networks

MSNet



Main Takeaways

Main Takeaways / 1

From the POV of Network Architectures there are three main IoT Application Categories:

a) Industrial and Automotive IoT with "zero latency" constraints

b) Delay Constrained IoT

c) Delay Tolerant IoT

Main Takeaways / 1a

a) Industrial and Automotive IoT.

The solution is in 5G networks

We just need to *wait*

Two verticals for 5G networks

Two network slices?

Main Takeaways / 1b

b) Delay Constrained IoT

The solution is already out there …

We just need good *business models* and use the right technology option

Implementation of SDN solutions will allow better control

Main Takeaways / 1c

c) Delay Tolerant IoT

The solution might be in the sky…

Main Takeaways / 1c

c) Delay Tolerant IoT

The solution might be in the sky…

Integrating the Internet of Things Into 5G and Beyond Networks

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rv@idesio.com

Thank you