IEEE Future Networks Webinar
5G Networks for Rural and Remote Areas Applications

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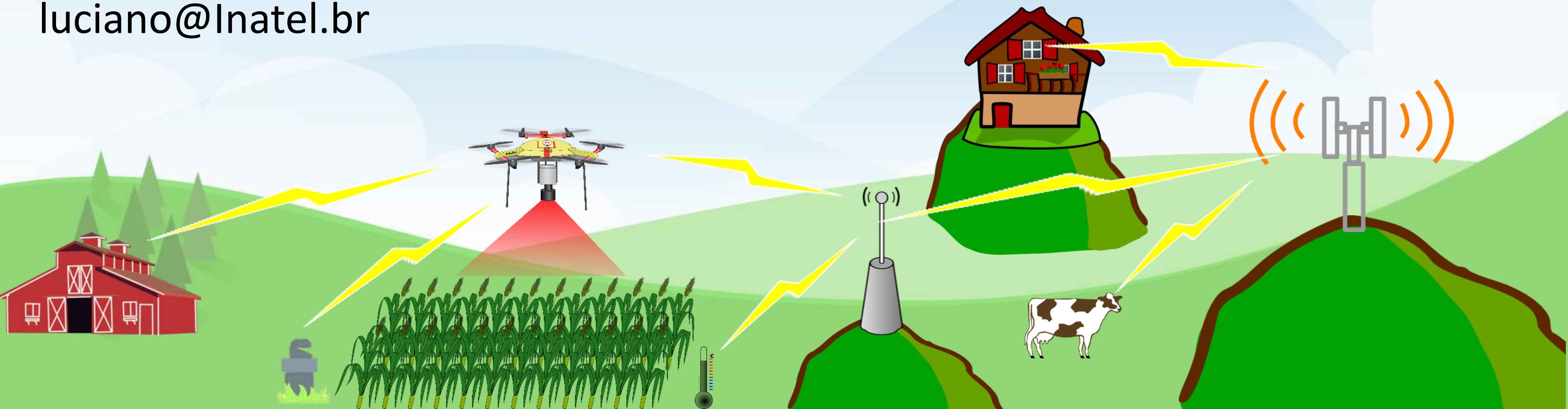

Outline

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- **Brief History**
- **5G Scenarios**
- **What is missing for a universal Internet access?**
- **5G-RANGE: Enabler technologies for remote area operation**
- **5G and satellite networks**

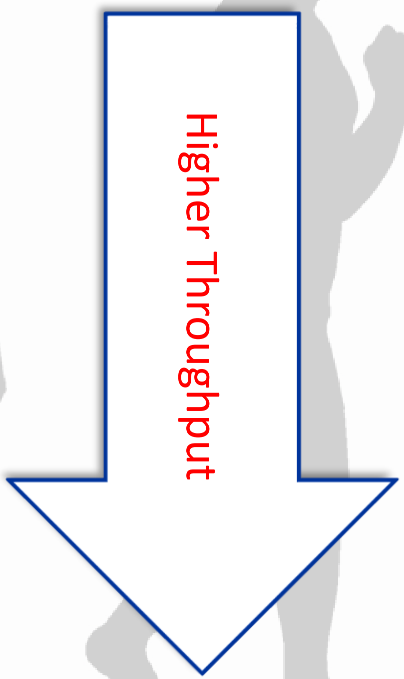
Brief History

- **1G – Freedom to call someone, and not somewhere!**

- **2G – More users, lower prices and SMS.**

- **3G – Multimedia and Internet access.**

- **4G – High data rates, music and video streaming, social media.**



Brief History

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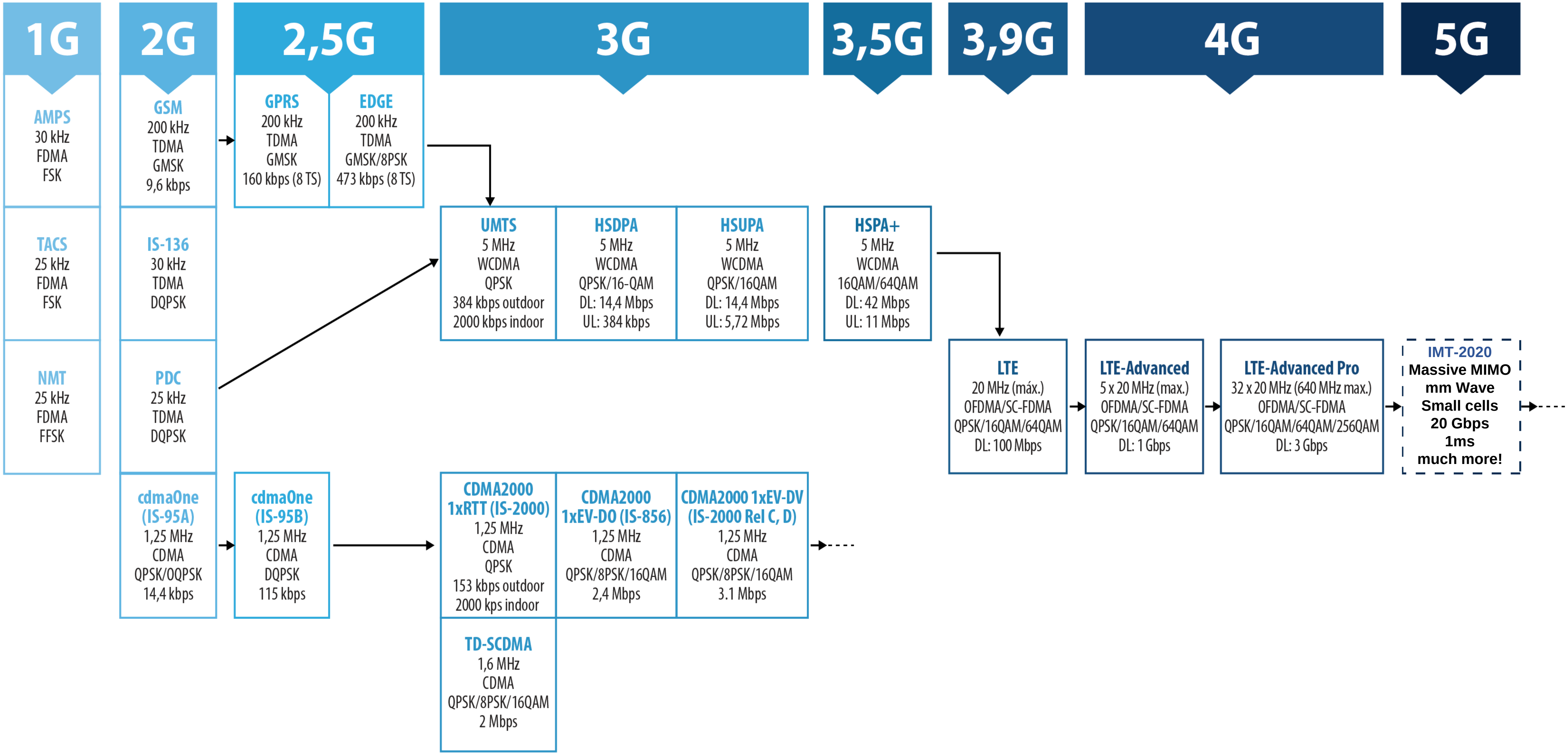

5G Scenarios

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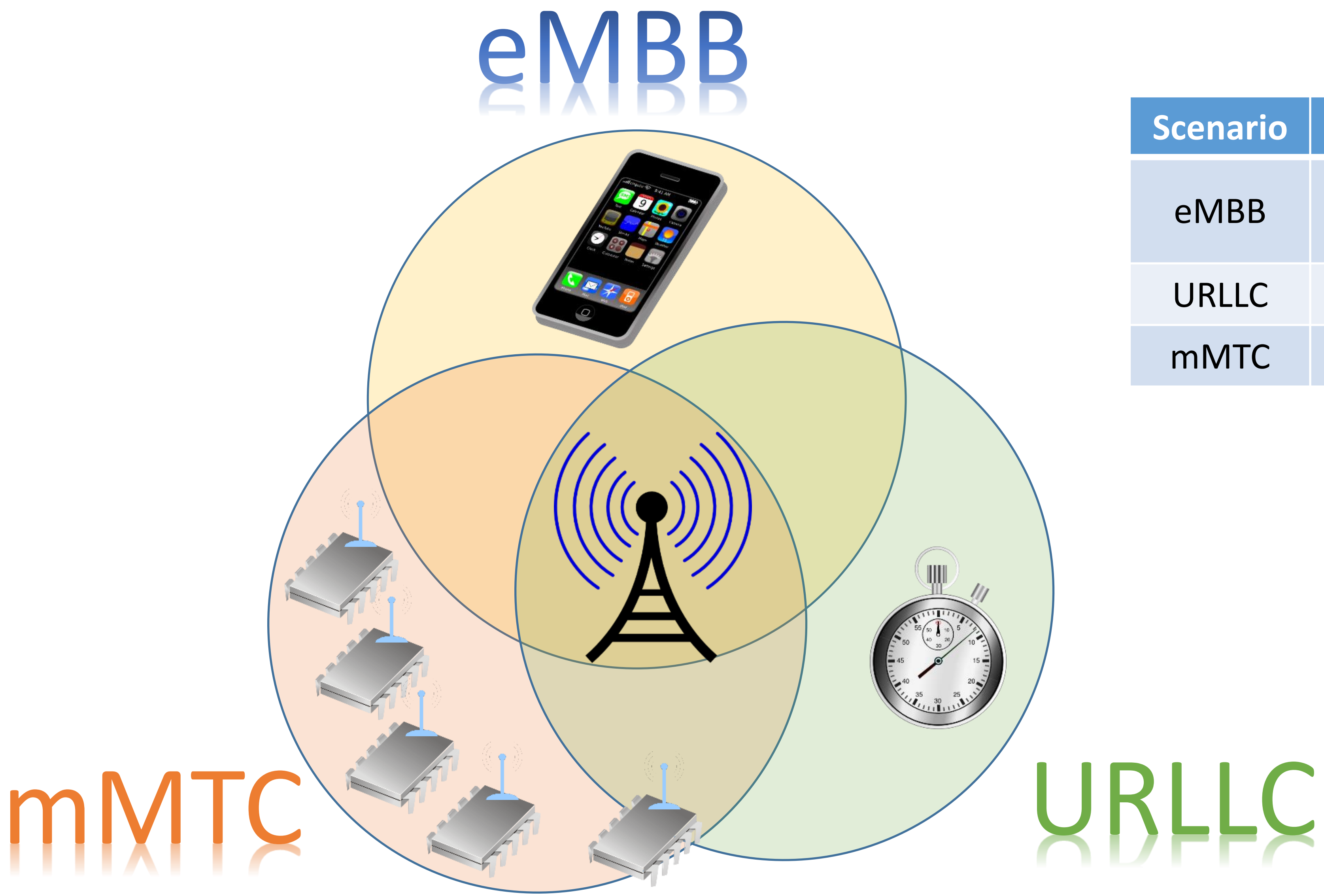

Main requirements

Scenario	Requirement	Value
eMBB	Peak data rate	UL:10 Gbps DL: 20 Gbps
URLLC	User plane latency	1ms
mMTC	# of connections	10^6devices/km^2

5G Scenarios

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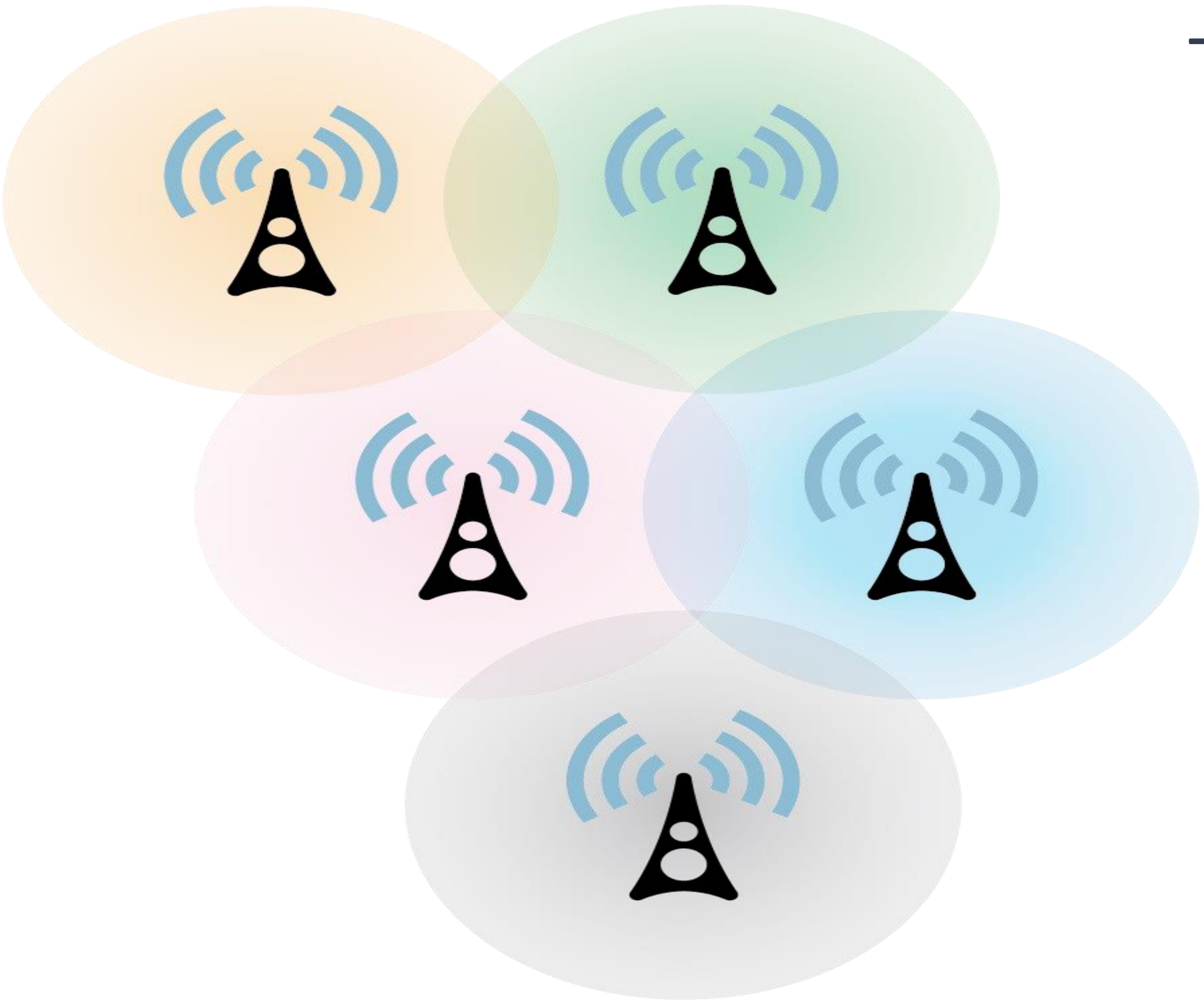


Technologies for 5G PHY

- Massive MIMO
- Millimeter wave
- Small Cells
- CoMP
- Channel Codes
- NOMA

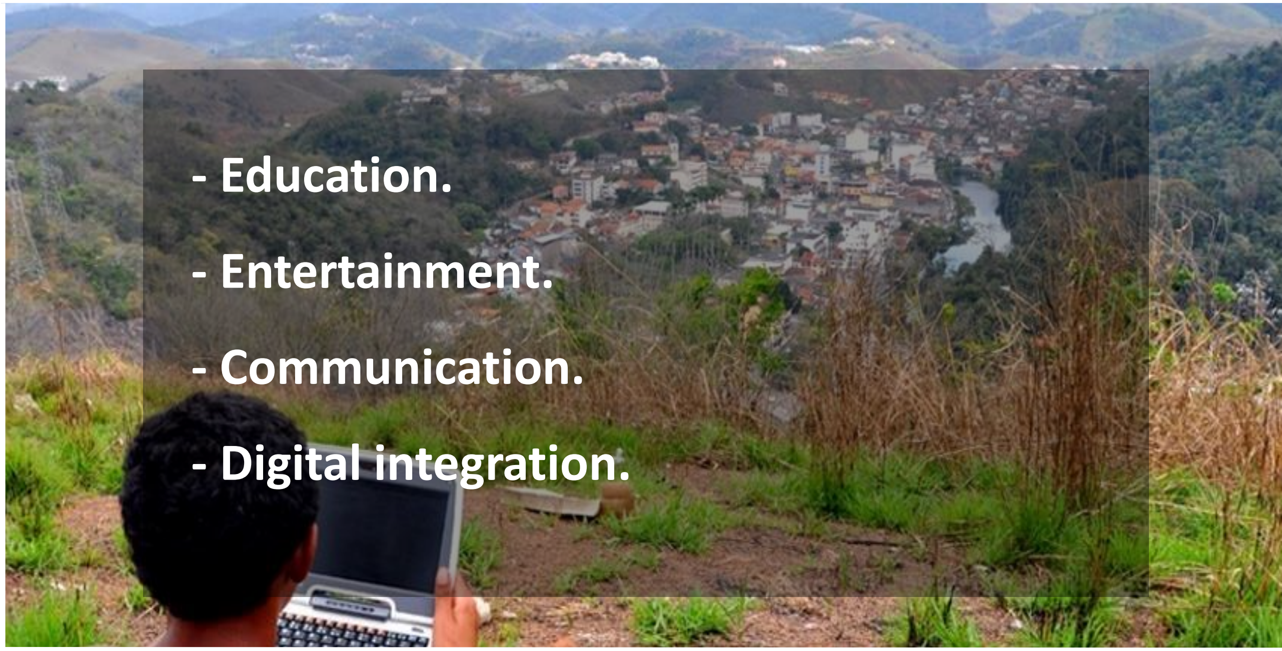
What is missing in 5G?

Motivations for a remote area network

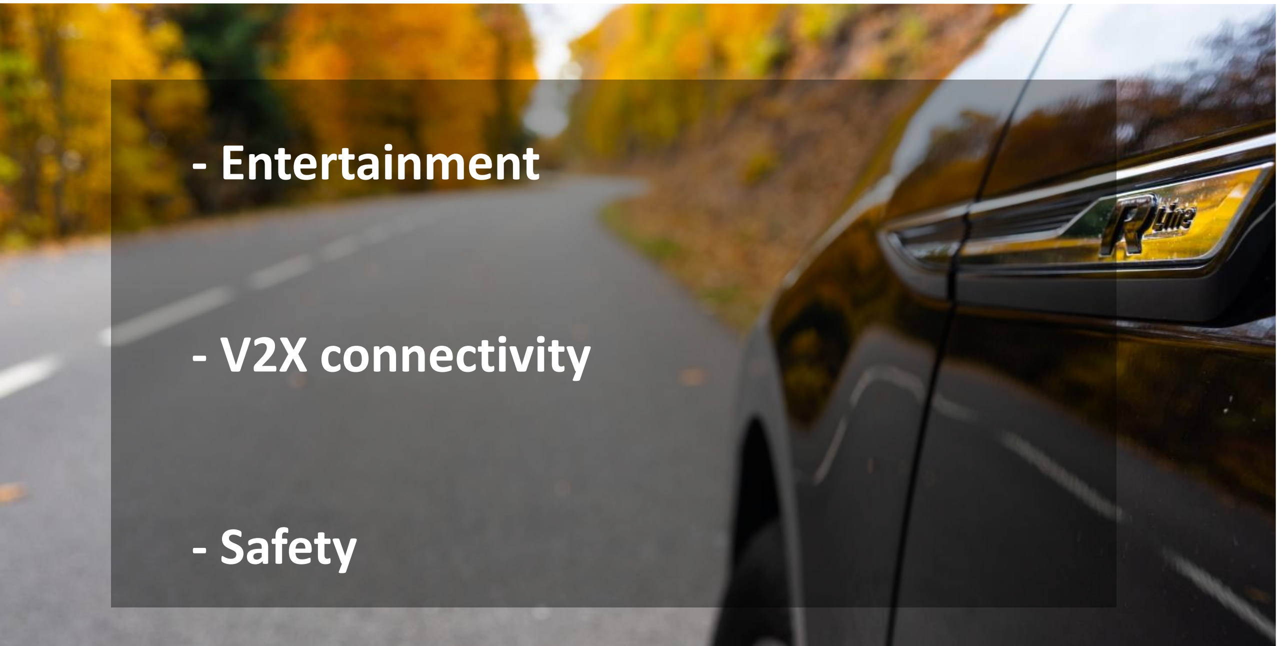
- Connectivity gap in rural areas
- New markets for operators
- Smart farms
- Road coverage
- Disaster/environment alarms

Motivations for a remote area network

- Last frontier for universal access.
- 3.9 billion people unconnected.
- High social impact



- Education.
- Entertainment.
- Communication.
- Digital integration.



- Entertainment
- V2X connectivity
- Safety

- Specialized treatment
- Monitoring on-the-go
- Home consults

Motivations for a remote area network

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- Smart farms: innovation in agrobusiness

- New market for operators.

- Several new services:

Field automation

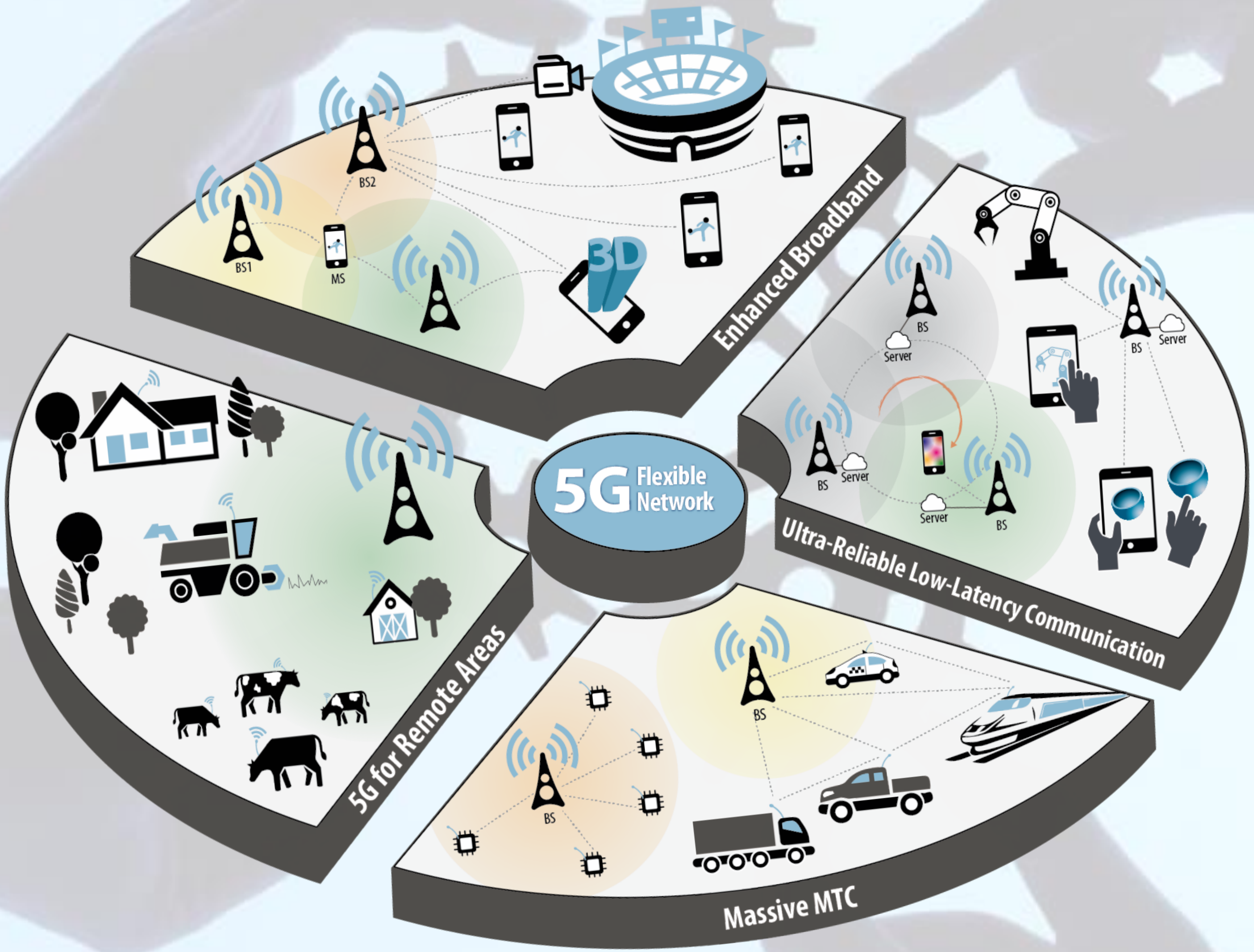
Machinery platooning

Cattle monitoring

Drones for images and fertilization

Network slicing

Seamless integration with other 5G scenarios.



RANGE

http://5g-range.eu/

5G-RANGE: Remote Area Access Network for the 5th Generation

Enabler Technologies for Remote Areas Networks

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Universidad Carlos III de Madrid

UnB

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5G-RANGE Goals

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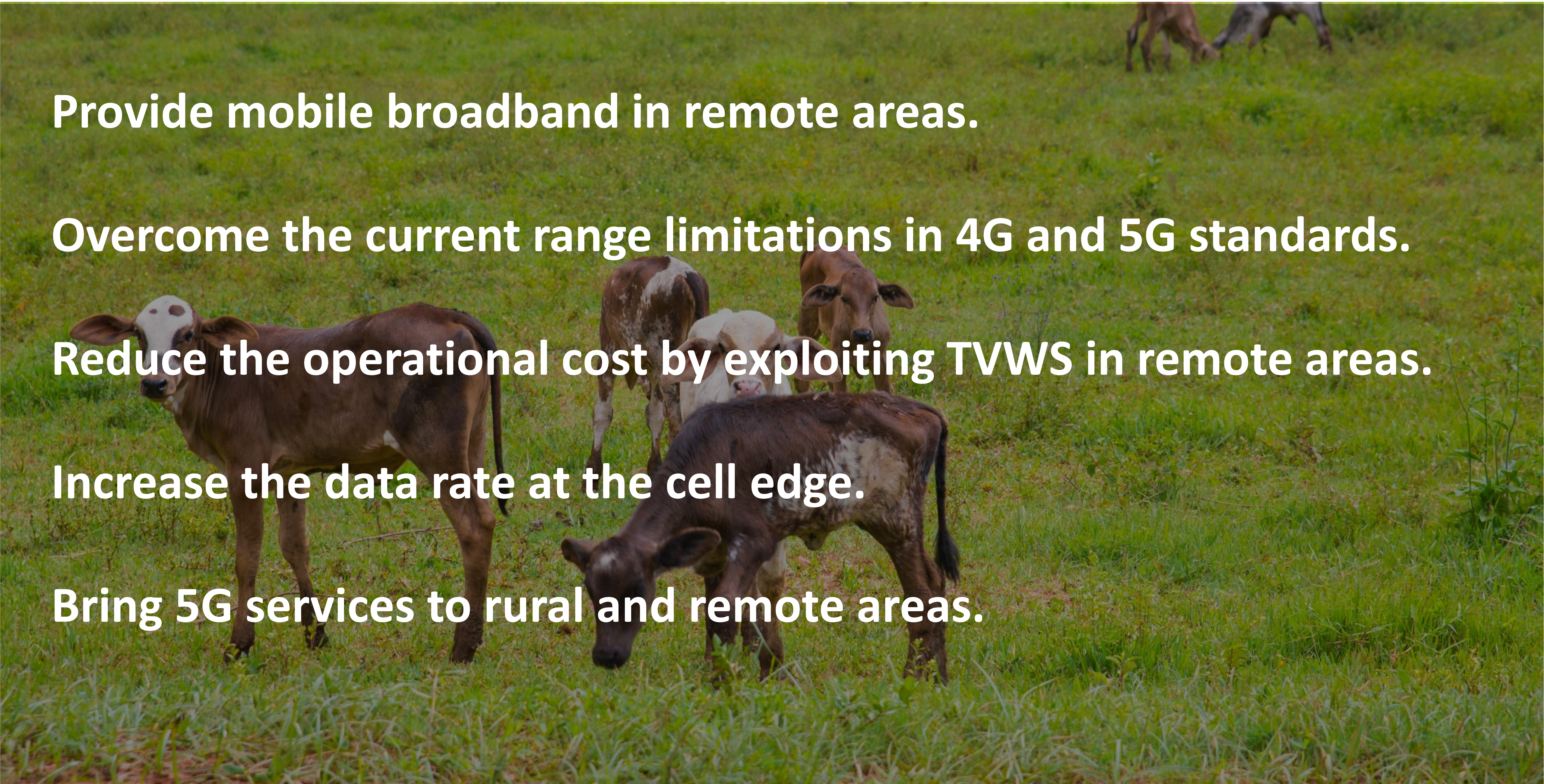

Provide mobile broadband in remote areas.

Overcome the current range limitations in 4G and 5G standards.

Reduce the operational cost by exploiting TVWS in remote areas.

Increase the data rate at the cell edge.

Bring 5G services to rural and remote areas.

5G-RANGE Structure

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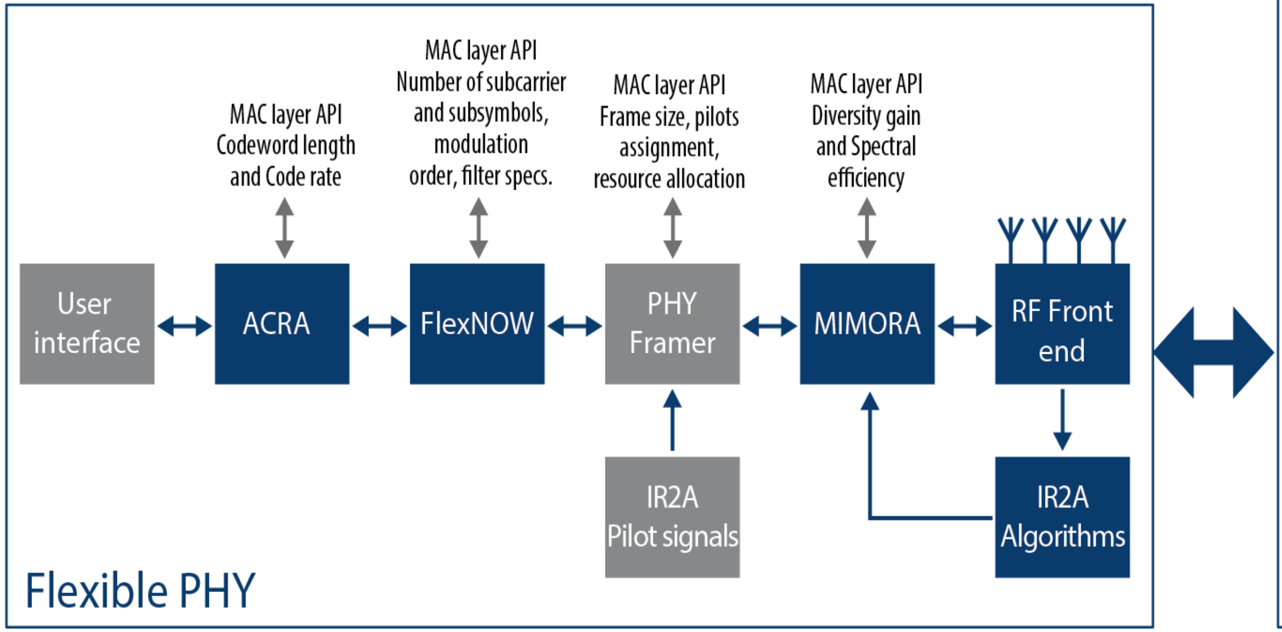
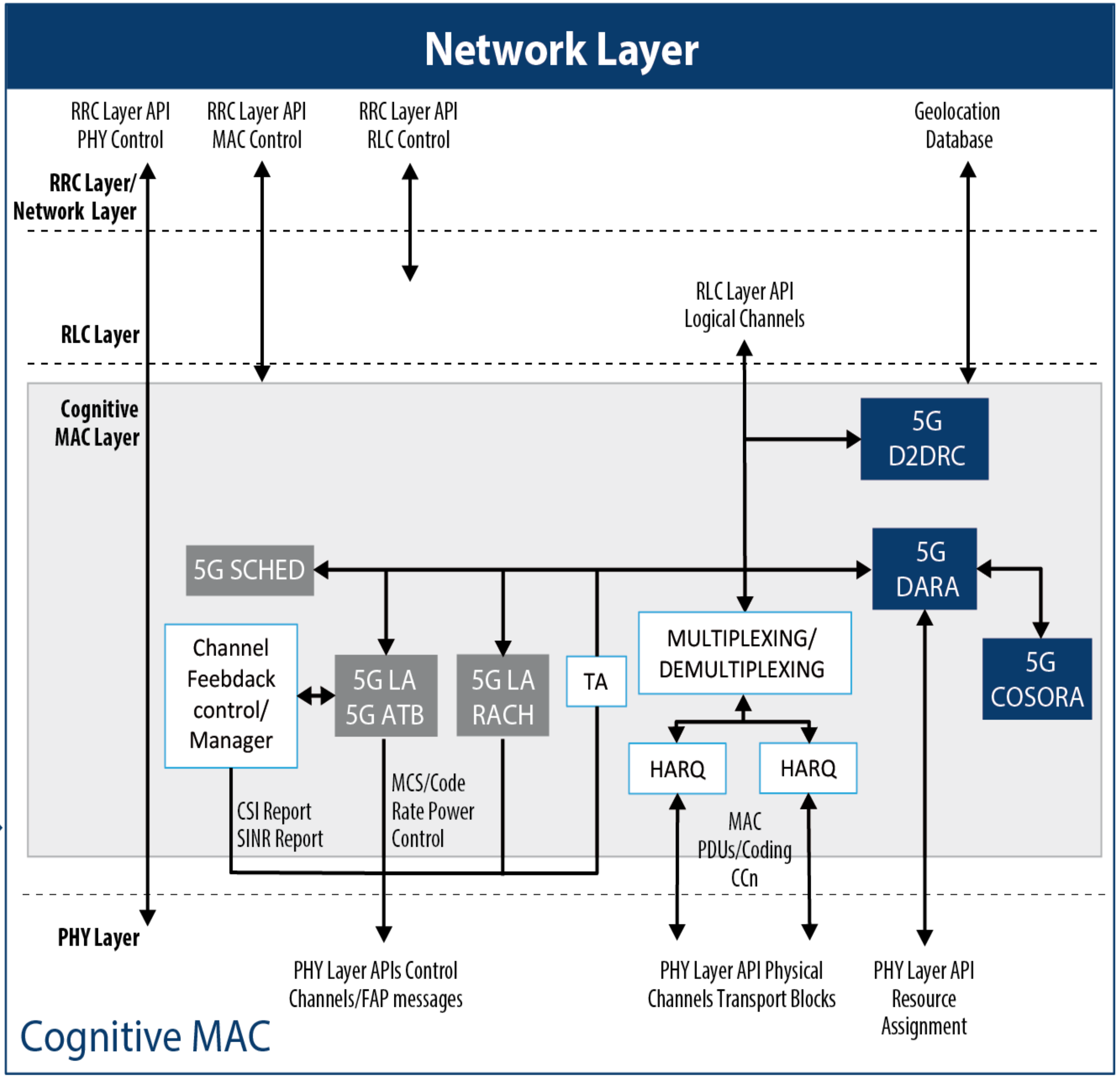
Cell radius: 50 km
Data rate: 100 Mbps
Mobility: 120 km/h
5G services: MBB & IoT





5G PHY Layer for Remote Area

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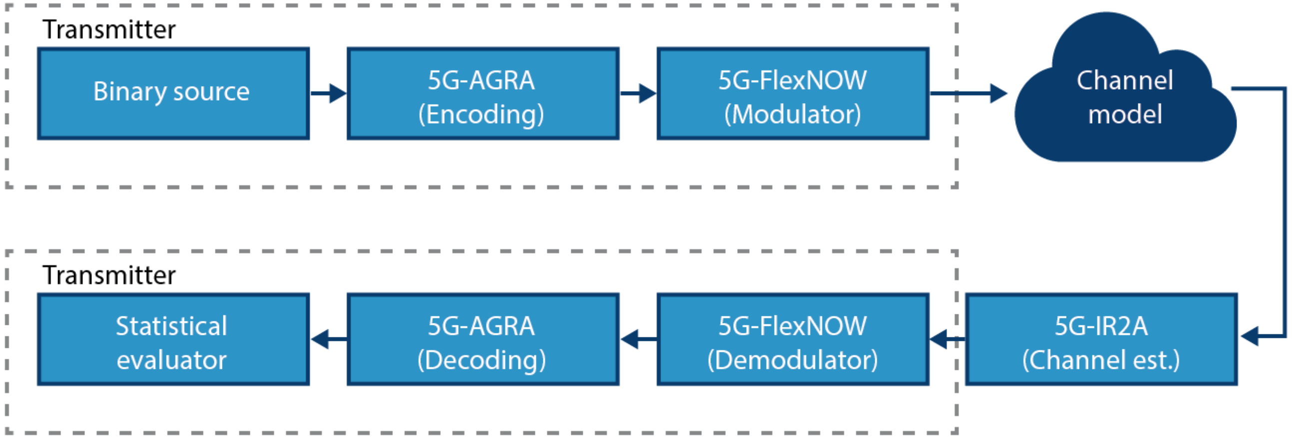
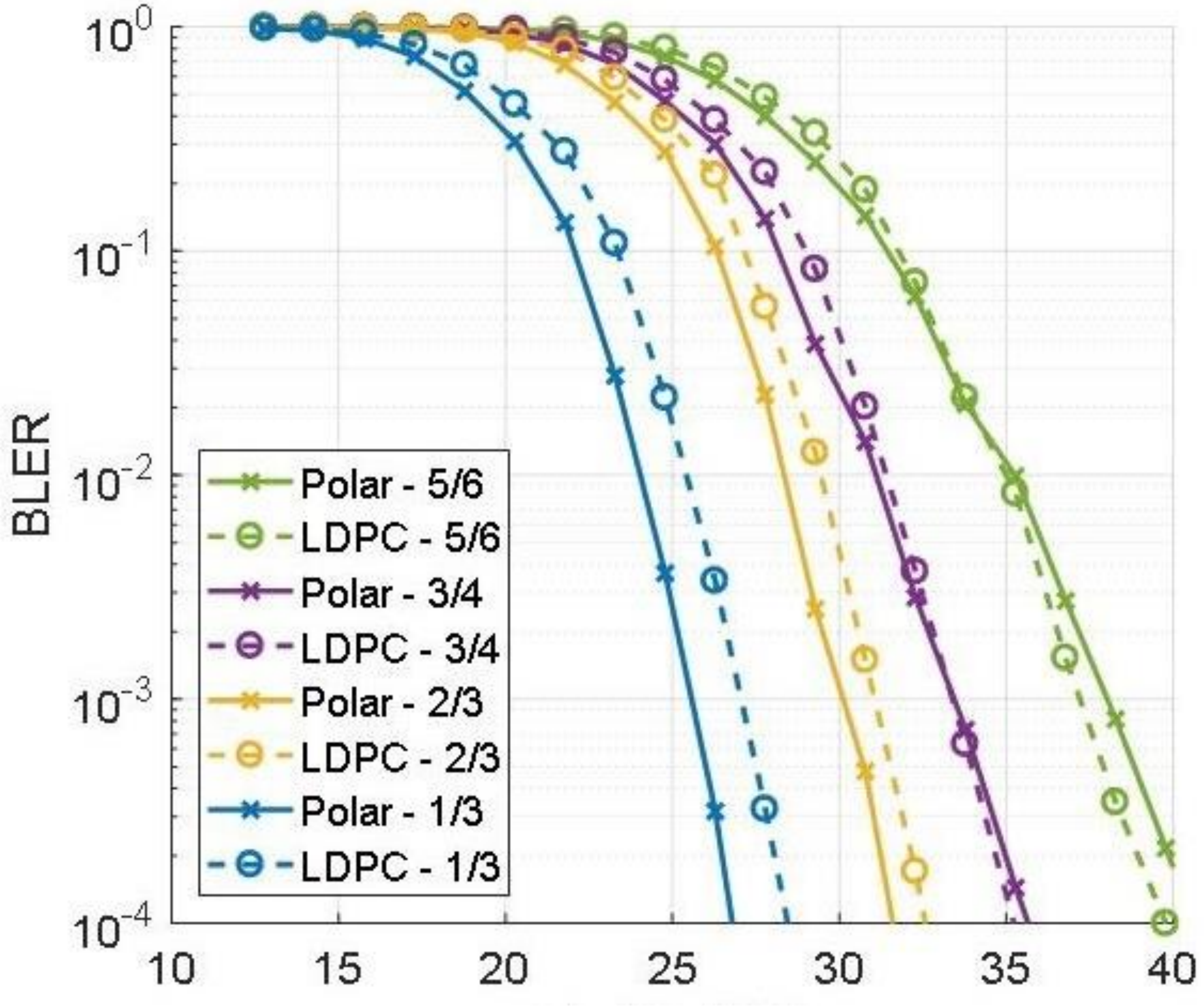
ACRA: channel coding

Channel	5G-RANGE NLOS
Modulation	GFDM + 64QAM
Number of blocks	100,000
Block size B (Polar/LDPC)	1024 / 1056
SCL list size / MSA number of iterations	8 / 20



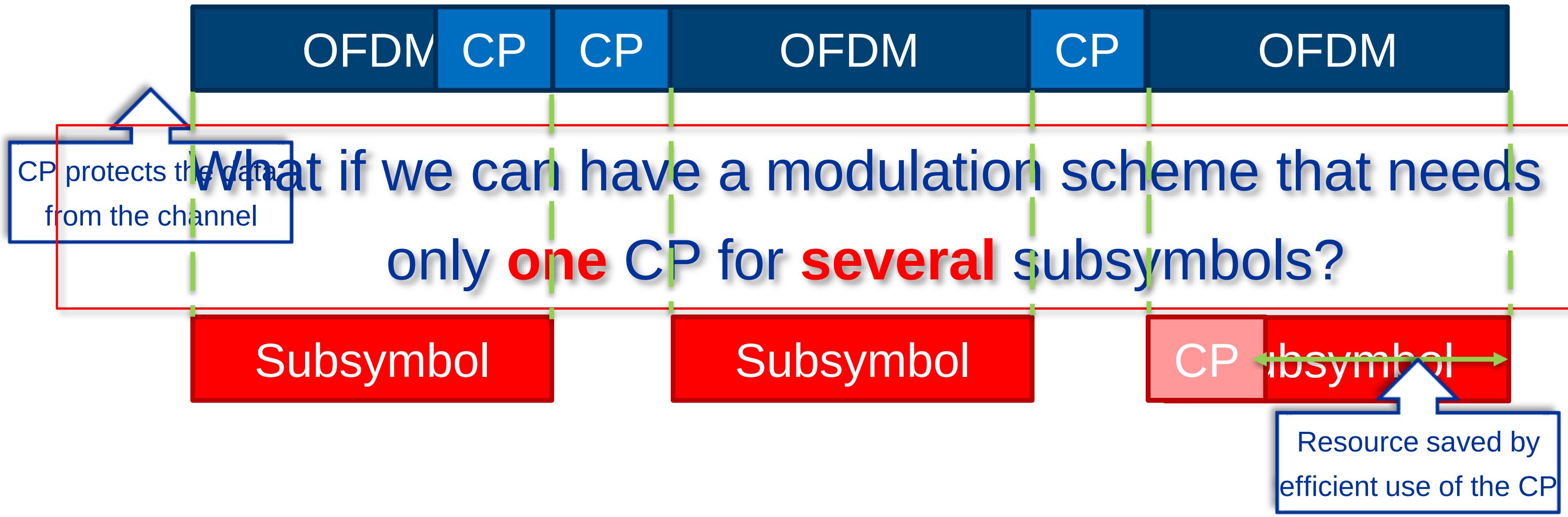


Polar code performs quite well!

5G PHY Layer for Remote Area

Energy and spectrum efficiency

CP wastes energy and throughput!



What if we can have a modulation scheme that needs only **one** CP for **several** subsymbols?

CP waste of energy and bandwidth can be significantly reduced.

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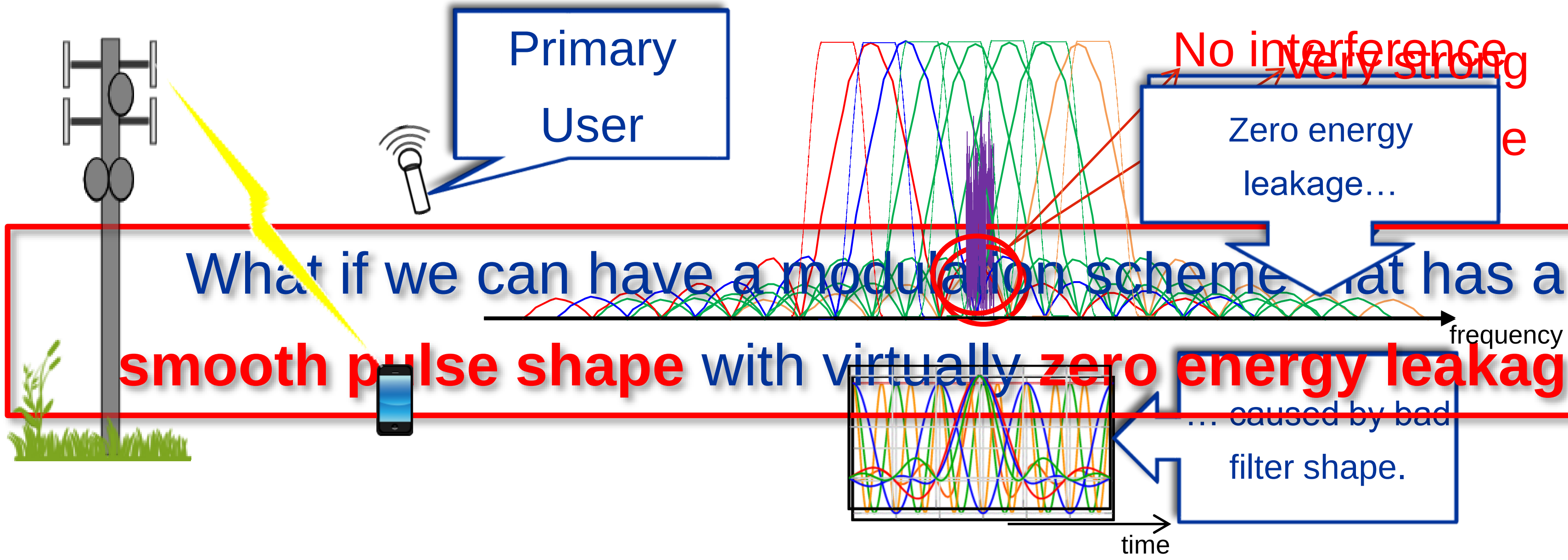
High energy leakage (Cognitive Radio)



What if we can have a modulation scheme that has a **smooth pulse shape** with virtually **zero energy leakage**?

The ability to **control the pulse-shape** allows the co-existence with other technologies.

5G PHY Layer for Remote Area

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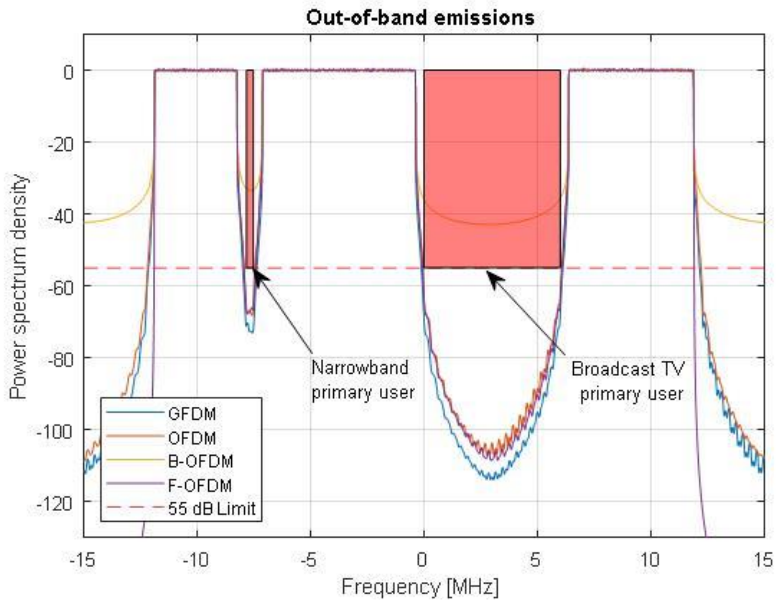
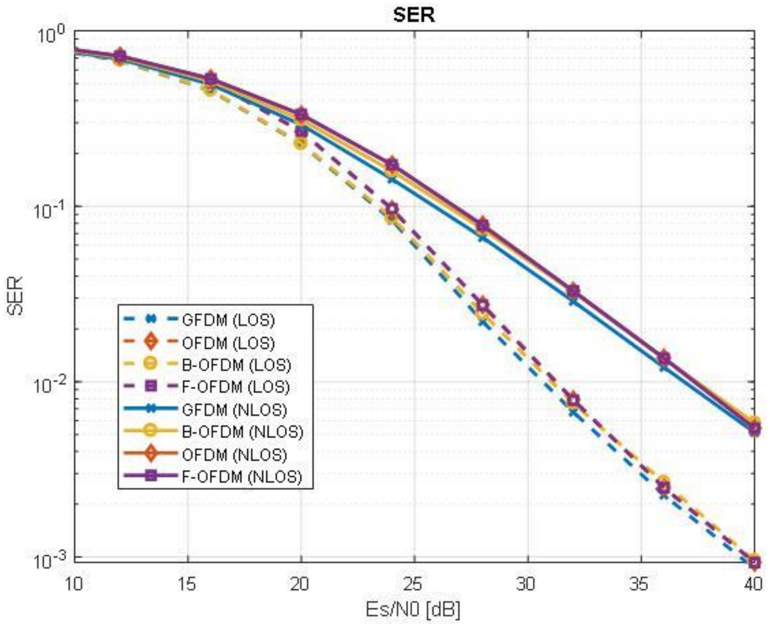
Flex-NOW: Waveform for remote areas

Key aspects: OOB emissions and spectral efficiency.

- Candidates: OFDM, GFDM, B-OFDM and F-OFDM
- Out-of-band emissions
  - F-OFDM and GFDM have the best OOBE
  - Windowing improves OOBE
  - B-OFDM is not able to fulfil OOBE requirements
- Spectral efficiency
  - GFDM and B-OFDM have higher efficiency due better usage of the cyclic extensions (92.75%)
- SER in AWGN and 5G-RANGE channel model
  - GFDM presents best performance
  - OFDM and F-OFDM performance is very similar





5G PHY Layer for Remote Area

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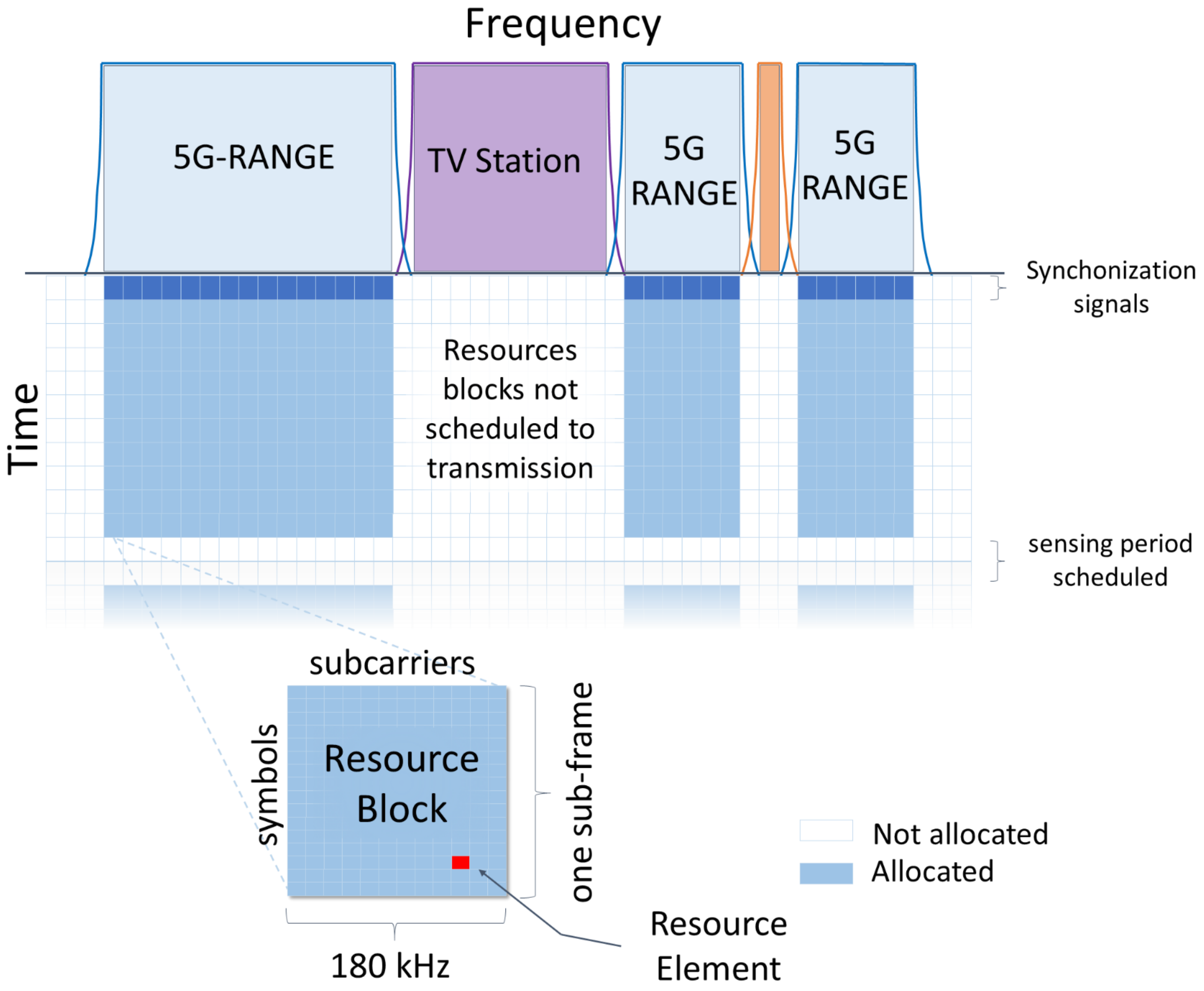
Flex-NOW: frame design

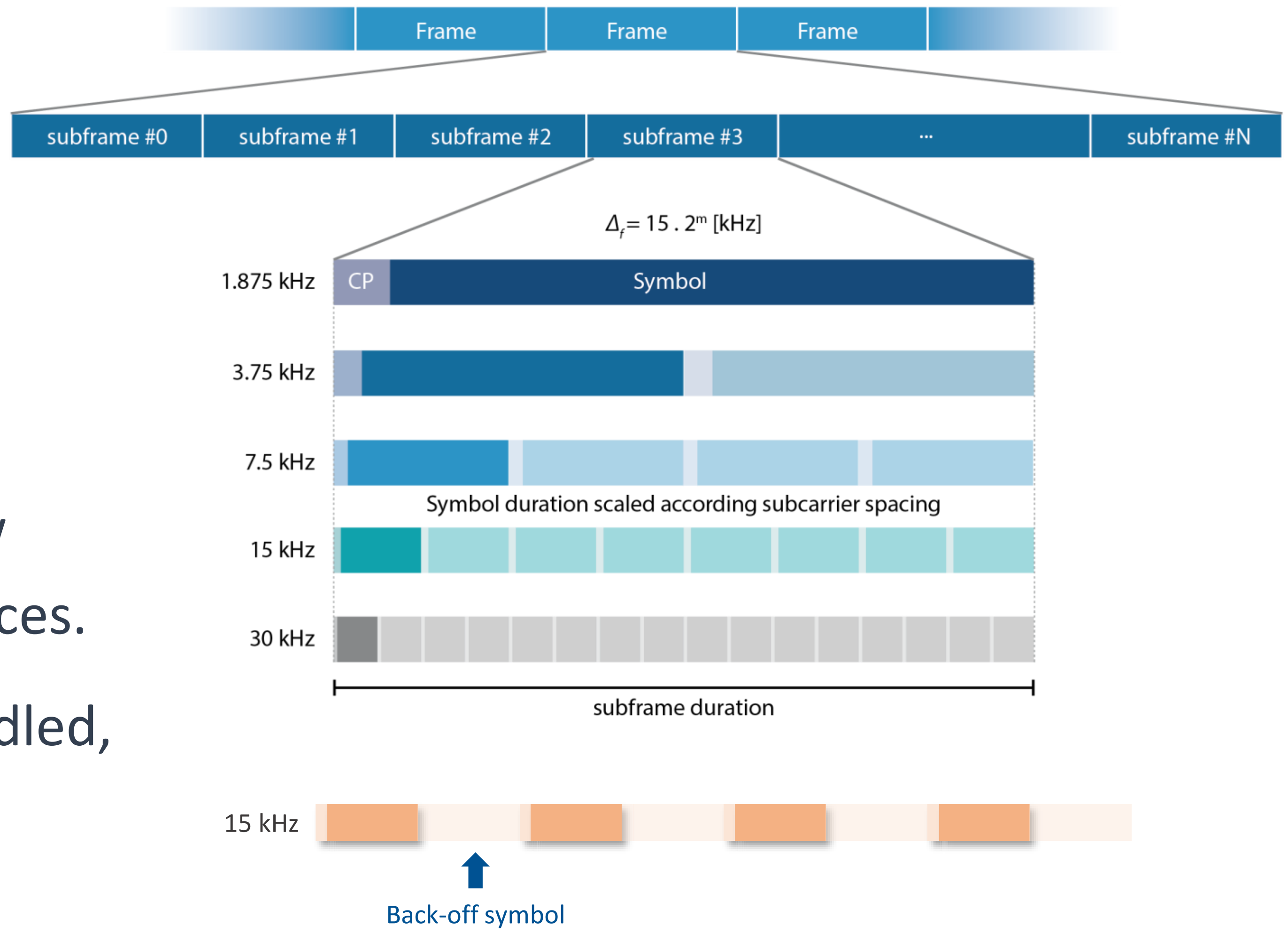
- Different numerology addresses conflicting requirements.
- Incumbent protection based on blank resources on the grid.
- Silence period for in-band spectrum sensing.
- Resource grid allows multiple numerologies.
- Dynamic selection of the numerology, on a subframe basis.



5G PHY Layer for Remote Area

Flex-NOW: frame design

- Trade-off: Doppler vs delay spread:
  - Multipath→ long symbols.
  - High mobility → short symbols.
- Scalable numerology: long range with low mobility and high mobility at short distances.
- High-speed and High mobility can be handled, but in a not bandwidth efficient way.



5G PHY Layer for Remote Area

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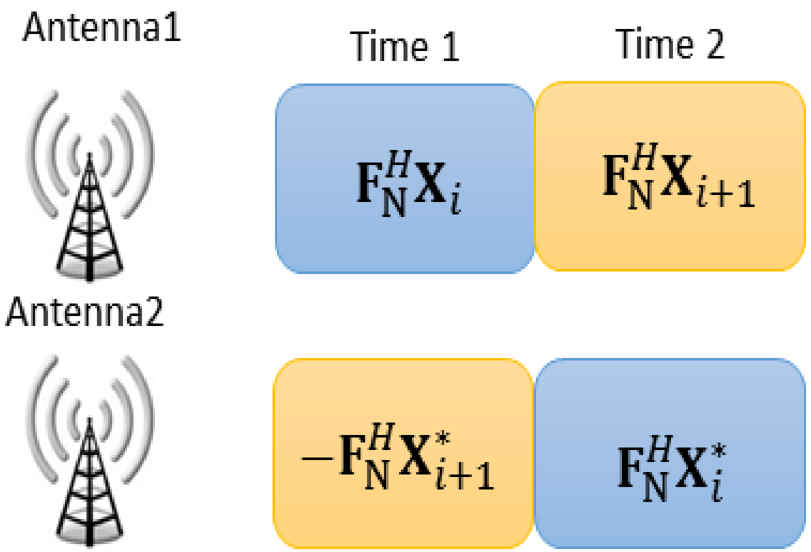
Flex-NOW: specifications

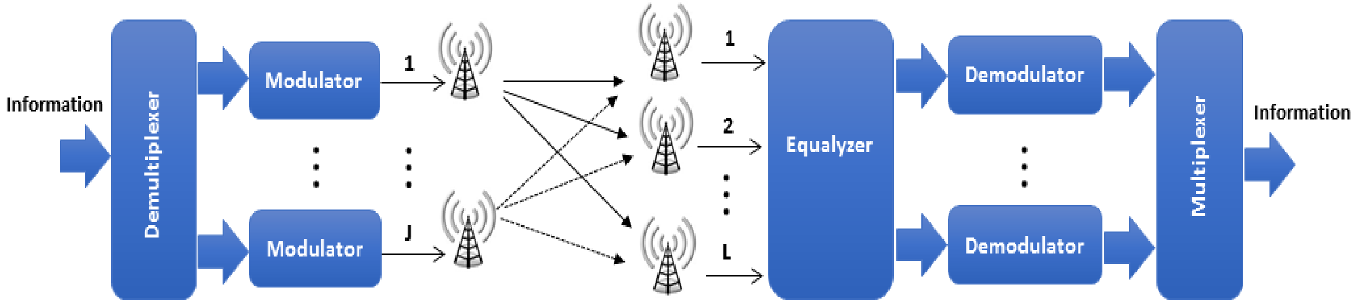
- Waveforms: GFDM and OFDM
- Scalable numerology
  - Number of numerologies: 6
  - 1.875 to 30 kHz subcarrier spacing
  - CP duration from 4.4 to 141.7 us
  - Mobile speed up to 240 km/h
- Modulation: QPSK to 256 QAM
- Bandwidth: Up to 23.76 MHz (132 RB's)

Num. ID	SCS [kHz]	CP [µs]	Symbol [µs]	Target Range (*) [km]	Target Speed [km/h]
0	1.875	141.7	2133.3	236,11	7
1	3.75	70.8	1066.7	118,06	15
2	7.5	35.4	533.3	59,03	30
3	15	17.7	266.7	29,51	60
4	30	8.9	133.7	14,76	120
5	30	4.4	66.7	7,38	240

5G PHY Layer for Remote Area

- MIMORA: MIMO for Remote Areas





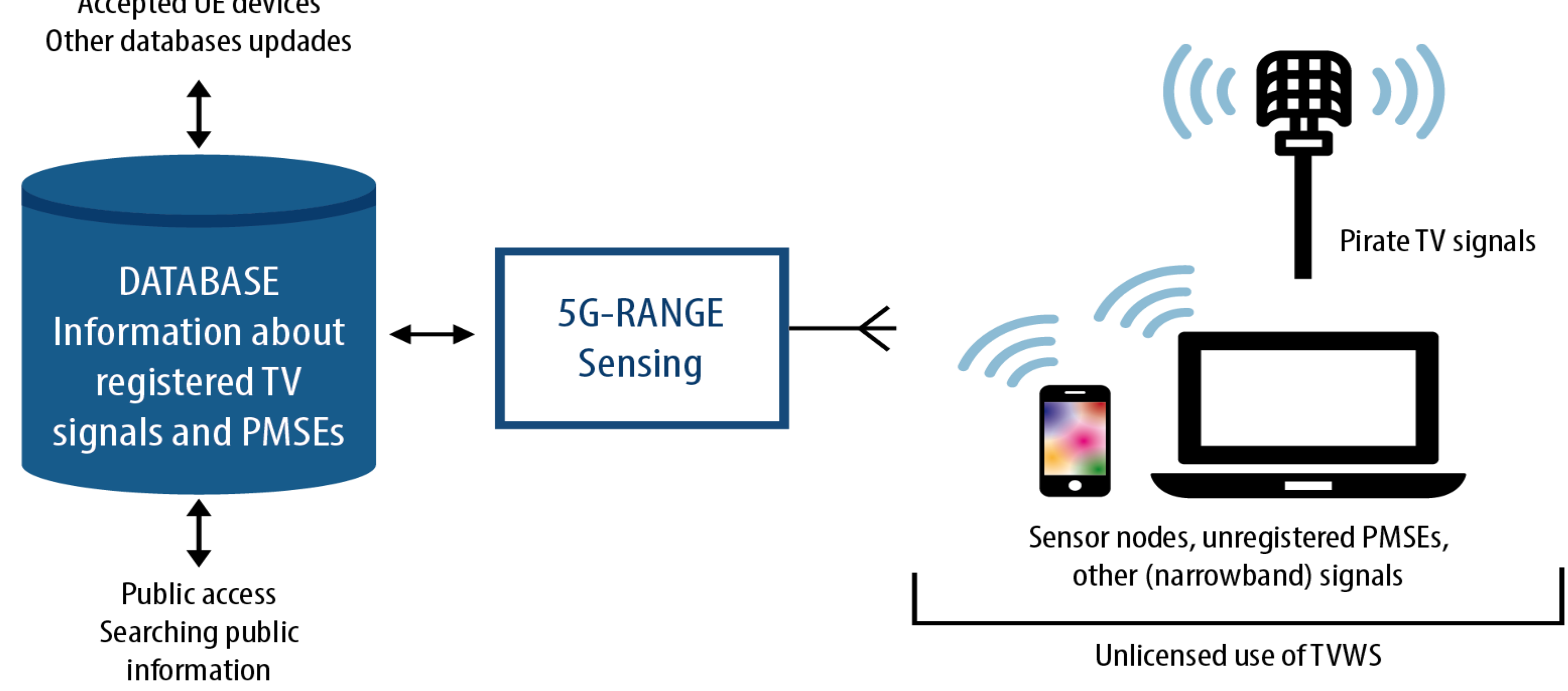
- Space time coding (STC)
  - 2 Transmitter antennas - Alamouti scheme
  - Increases robustness over fading channels
  - Users distant from the BS
- Spatial multiplexing
  - Multiple data streams between BS and UE
  - Users close to the BS
- Dual polarization
  - Necessary because of channel correlation in UHF/VHF bands (large wavelength)

Cognitive MAC Layer

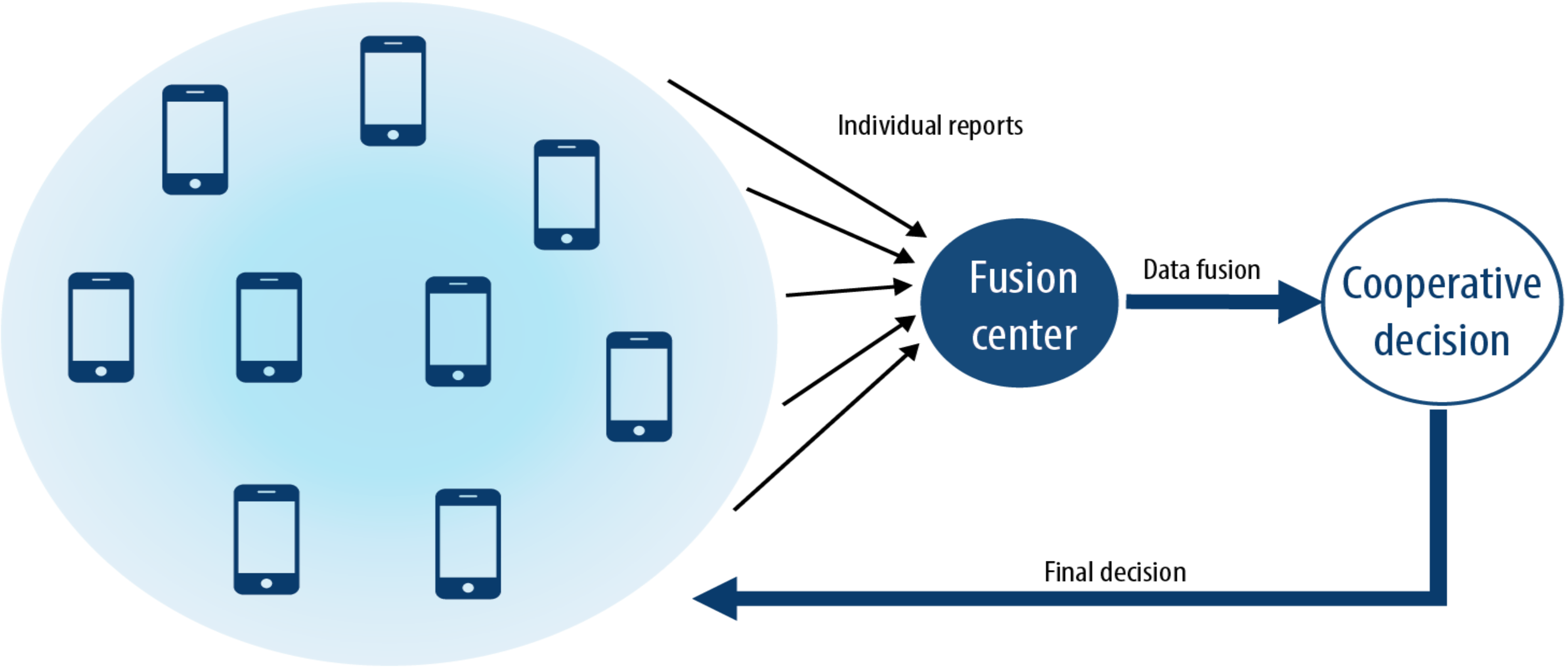
- **Add the cognitive cycle for TVWS exploitation.**
- **Combine spectrum sensing with geolocation database**
- **Protection of the incumbent**
- **Detection of unauthorized transmission (pirate TV studies)**

Cognitive MAC Layer

Geolocation Database and Spectrum Sensing must work together



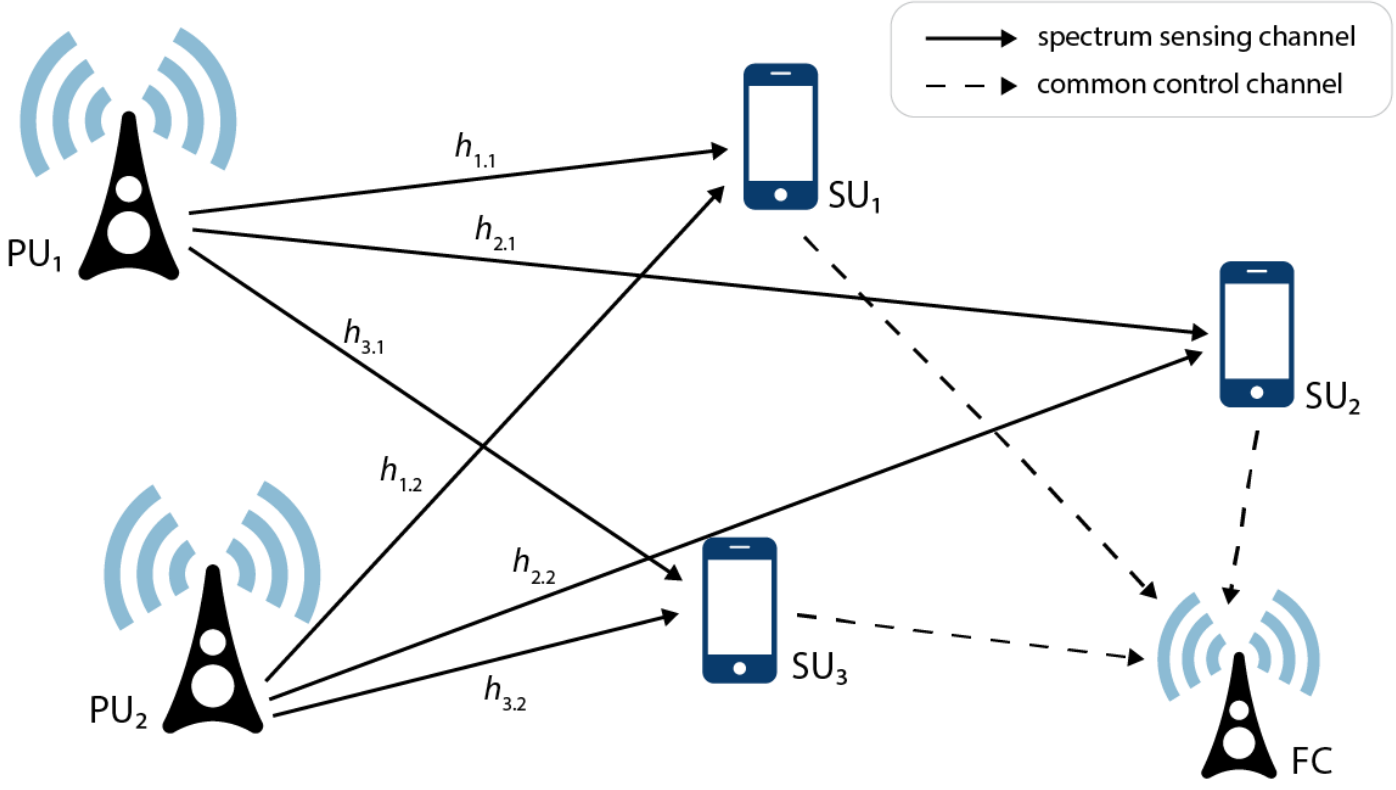
Cognitive MAC Layer

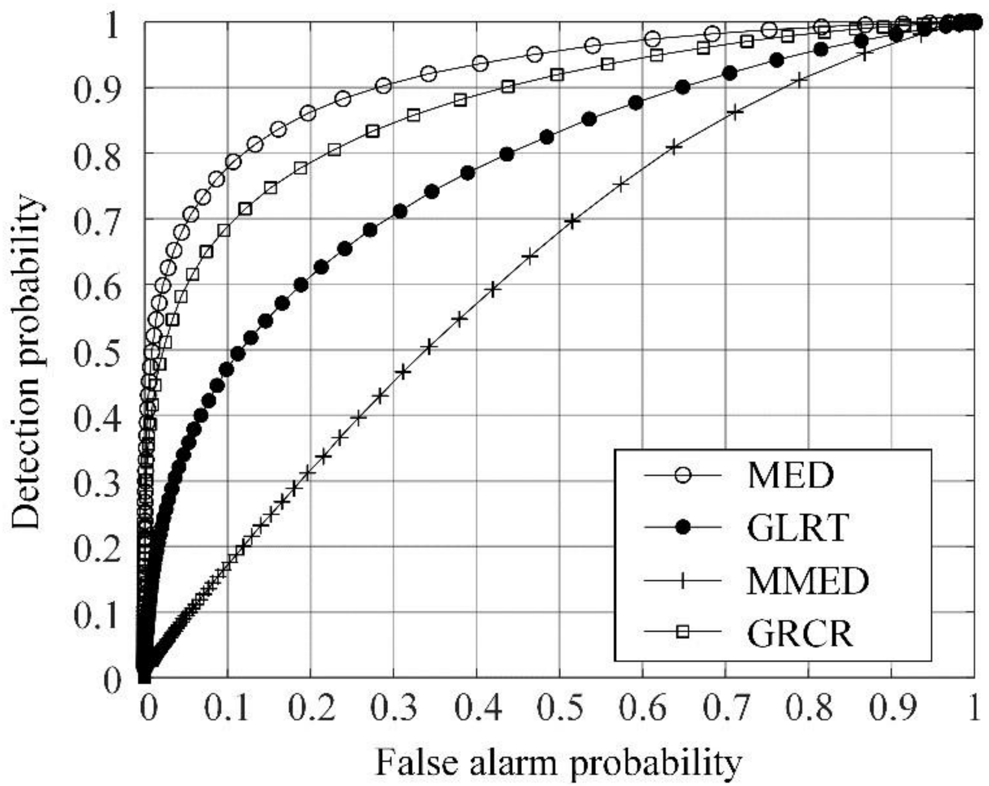


[1] J. Vartiainen, H. Karvonen, M. Matinmikko-Blue, L. Mendes, "Performance Evaluation of Windowing Based Energy Detector in Multipath and Multi-Signal Scenarios," 14th EAI International Conference on Cognitive Radio Oriented Wireless Networks (CROWNCOM), June 2019.

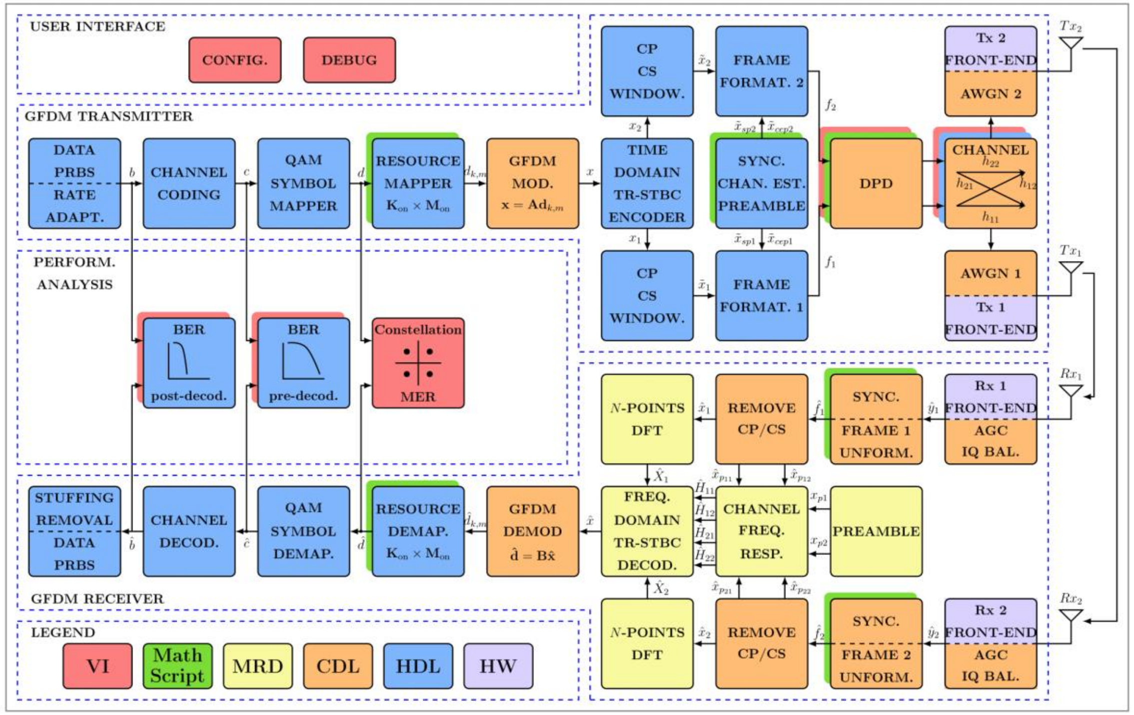
Cognitive MAC Layer

- Performance of Spectrum Sensing depends on algorithms.
- Can it be vendor-defined or should it be standardized?
- Fusion will improve the overall performance.





Proof-of-Concept



Field Tests

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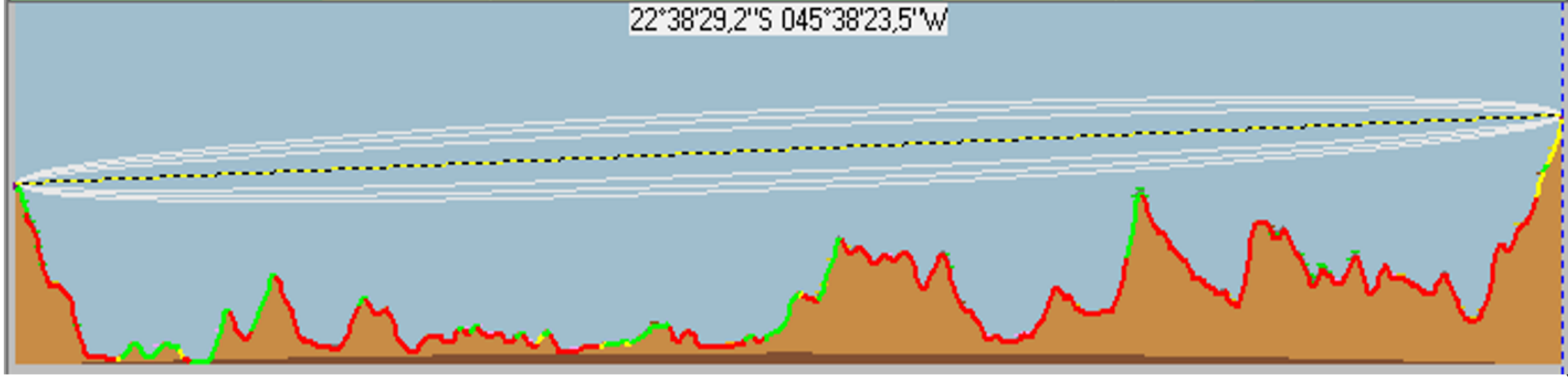
Estimated Data

Azimuth=168,05°	Elev. angle=-0,118°	Clearance at 0,13km	Worst Fresnel=2,5F1	Distance=50,60km
Free Space=123,8 dB	Obstruction=0,6 dB TR	Urban=0,0 dB	Forest=1,0 dB	Statistics=6,4 dB
PathLoss=131,9dB	E field=49,9dBµV/m	Rx level=-78,1dBm	Rx level=27,81µV	Rx Relative=1,9dB



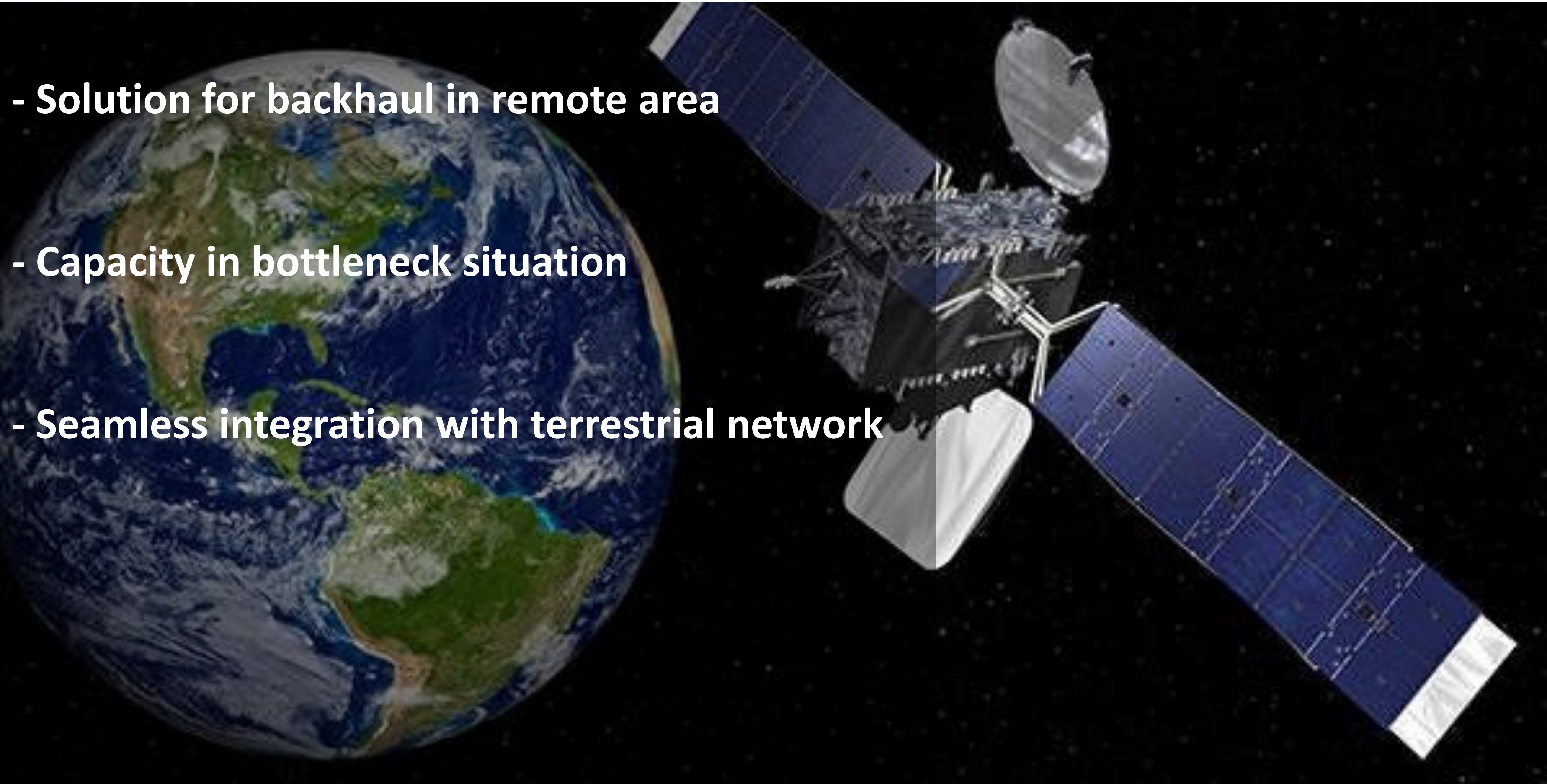
Measured Data		
Power	Ant 1	Ant 2
	-69.87 dBm	-64.9 dBm
Rate	22 Mbps	
BW	6 MHz	
Modulation	64 QAM	
Code rate	3/4	
MER	23.29 dB	
BER	≈ 0	
Distance	50.60 km	

System parameters:

- MIMO: 2+2
- TX1 power (EIRP): 50,5 dBm
- TX2 power (EIRP): 48,5 dBm
- Transmit antenna gain: 9 dBi
- Receive antenna gain: 9 dBi
- BW: 6 MHz or 12 MHz
- Frequency: 700 MHz band

BW (MHz)	Modulation	Code rate	Bit Rate (Mbps)	BER $< 10^{-6}$	SNR (dB)
6	64-QAM	3/4	22	yes	28.51
6	64-QAM	5/6	24	yes	29.98
6	256-QAM	5/6	32	yes	26.31
6	256-QAM	3/4	29	yes	29.18
12	64-QAM	5/6	48	yes	29.35
12	256-QAM	5/6	64	no	29.15
12	256-QAM	3/4	57	yes	27.33

5G and satellite networks integration



- Solution for backhaul in remote area

- Capacity in bottleneck situation

- Seamless integration with terrestrial network

5G and satellite networks integration

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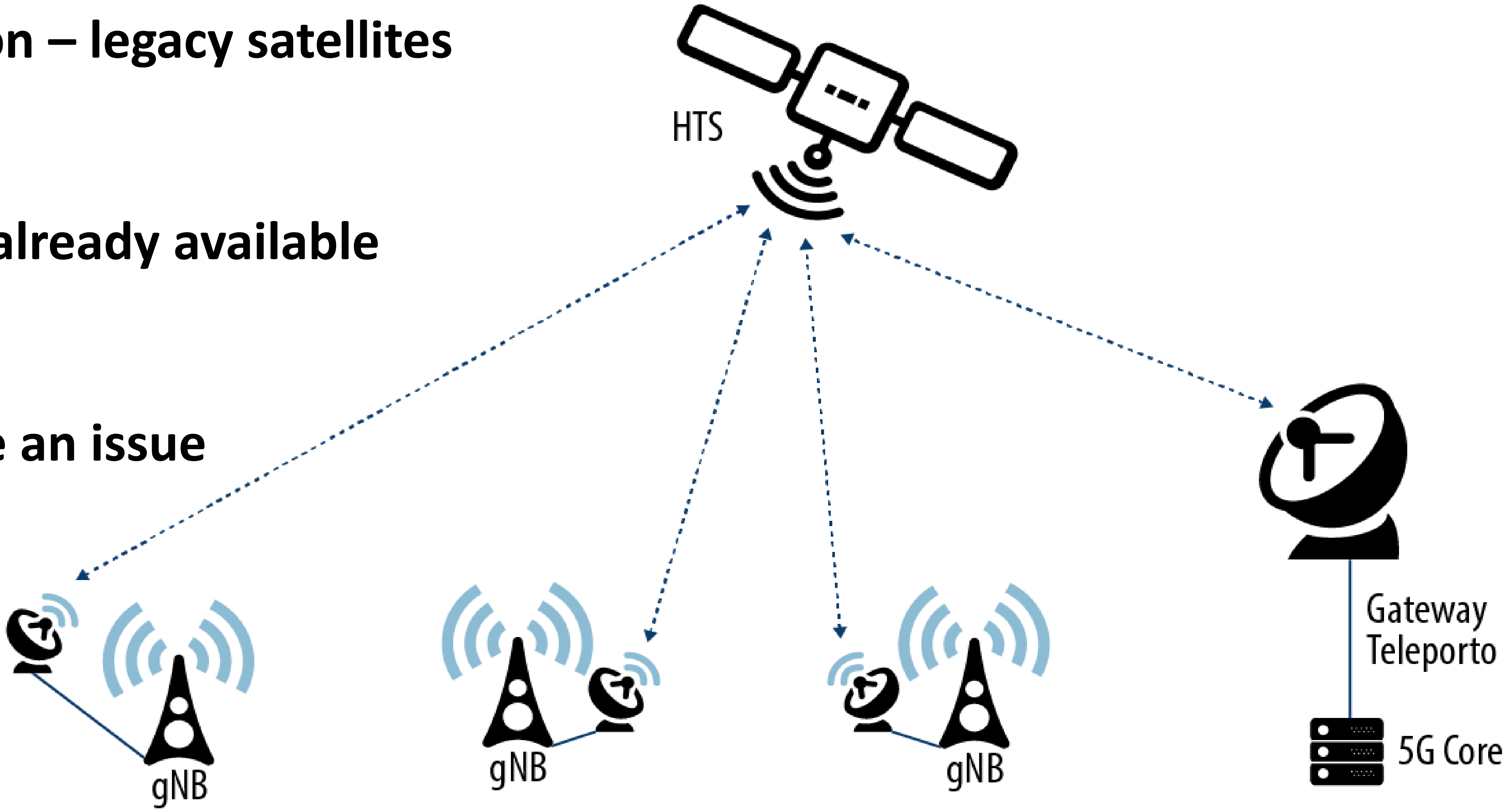
- Easy integration – legacy satellites

- High capacity already available

- Latency can be an issue



5G-Satellite Integration

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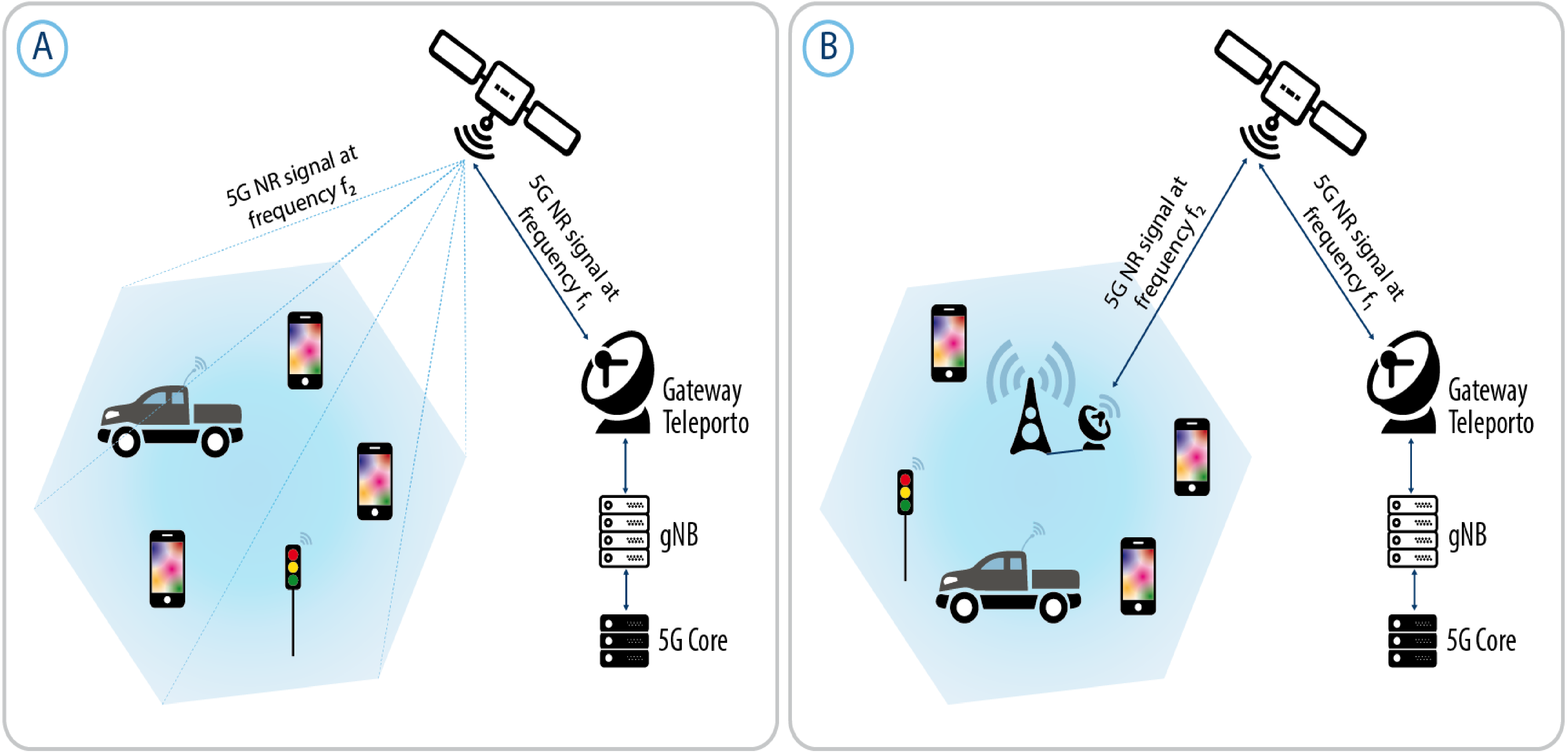
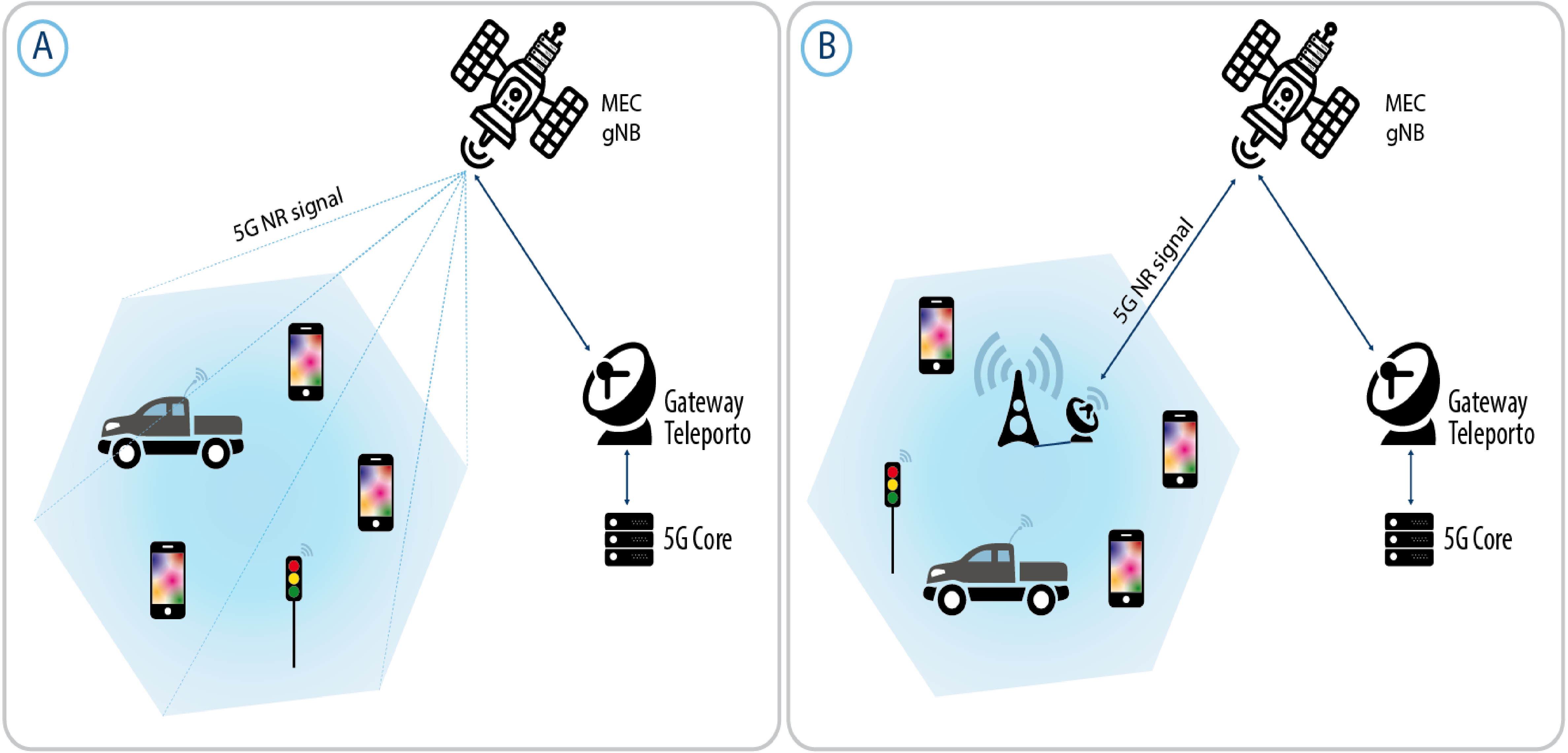
Satellites as gNB for the final users



5G-Satellite Integration

Satellites as gNB for the final users



5G-Satellite Integration

What about the latency?

Can we have low latency applications on remote areas using satellites?

5G-Satellite Integration

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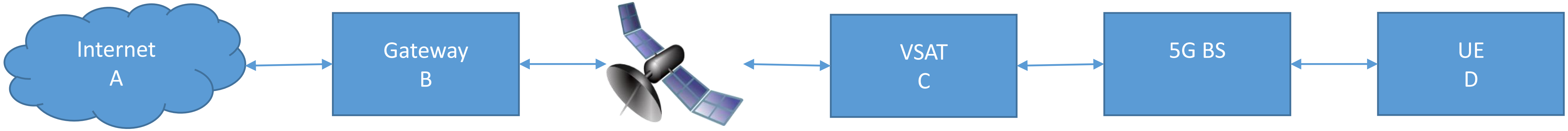
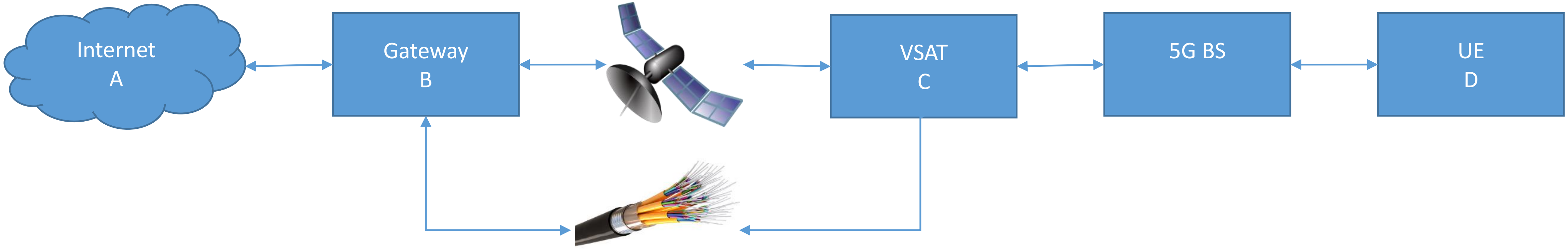
Connection	UDP Throughput	TCP Throughput	Jitter
B-C with WEB accelerator	90/34 Mbps	88/30 Mbps	0.260ms
B-C no WEB accelerator	90/34 Mbps	4.15/3.9 Mbps	0.260ms
C-D	30/30 Mbps	30/30 Mbps	0.465ms
B-D	30/28 Mbps	29/29 Mbps	0.451ms



WEB accelerator is mandatory for a good user experience.

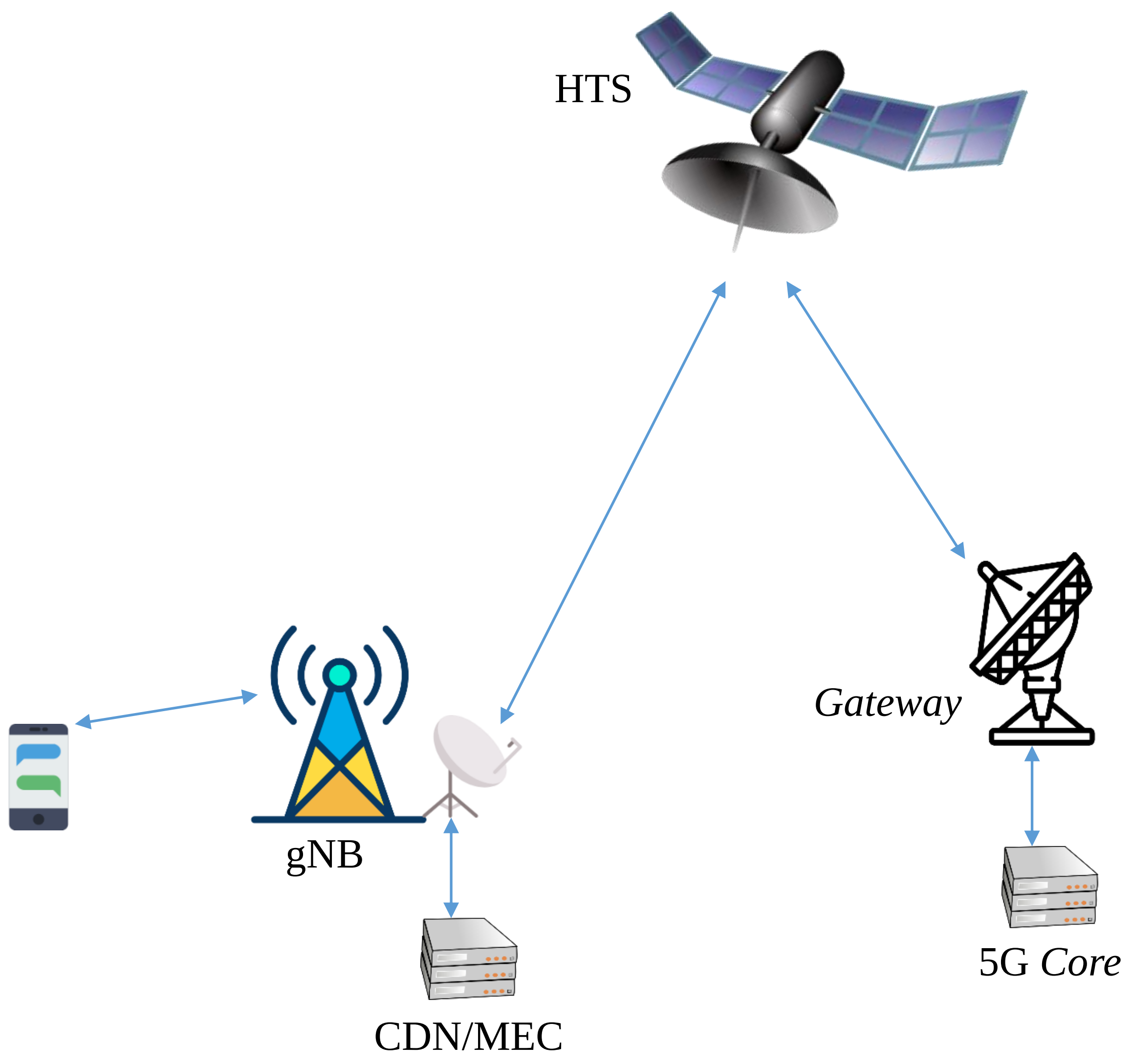
5G-Satellite Integration

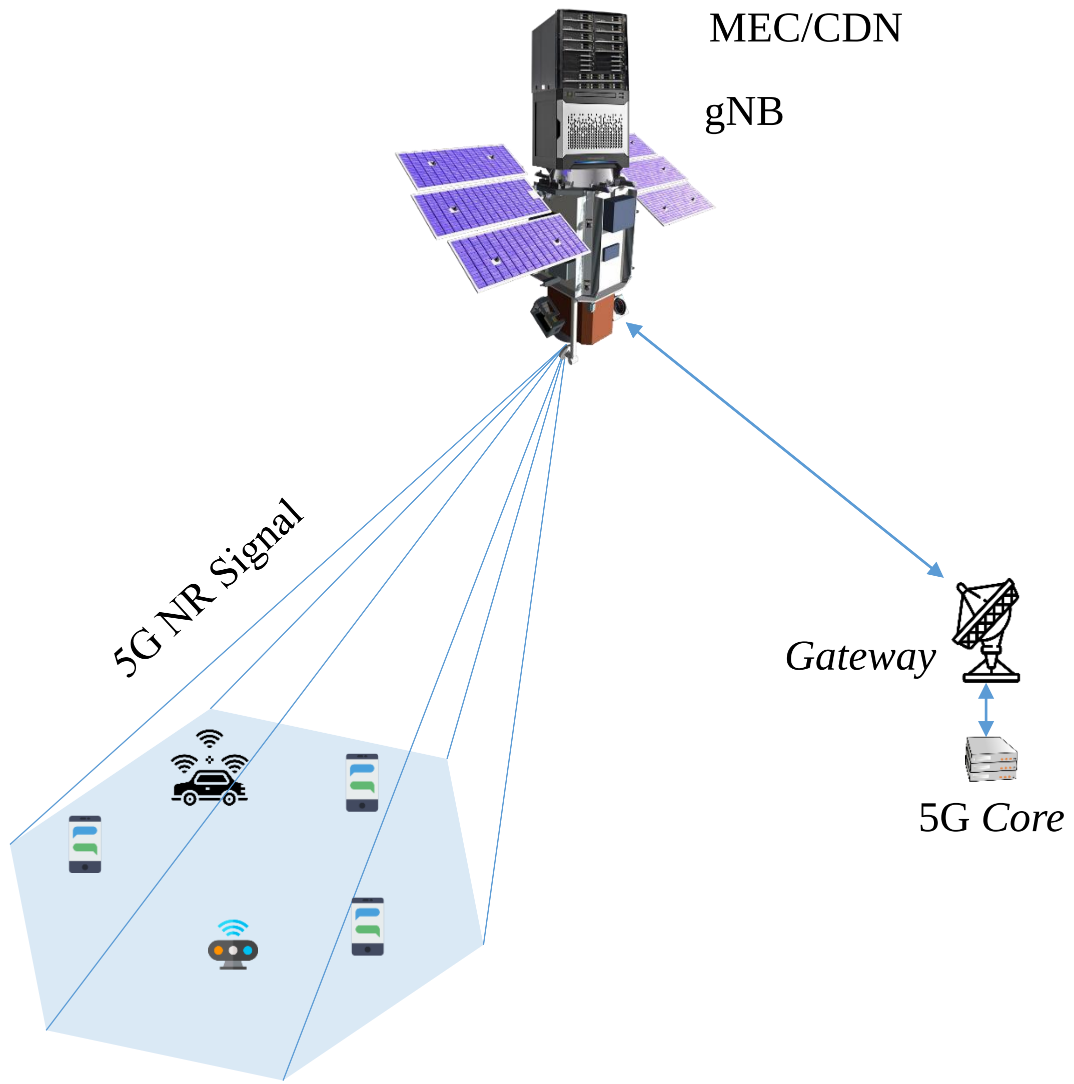
Satellite Backhaul	A-B	B-C	C-D	Total
	68.15	505.525	7.07866	580.72
Terrestrial Backhaul	A-C		C-D	Total
	66.13		7.07866	73.184



Latency is a key issue for 5G services when satellite backhaul is used

5G-Satellite Integration





Conclusions

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- 5G networks has the potential to close the connectivity gap.
- Technologies develop for 5G can be tailored for remote areas.
- Network CAPEX can be reduced by TVWS exploitation and large cells.
- Small ISP can be the bridge in a new business model.
- Satellite and 5G integration will benefit the remote area scenario.

Acknowledge and contacts

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• **Channel model**	**Carlos Silva**	**cfms@gtel.ufc.br**
• **Cognitive Radio**	**Heikki Karvonen**	**heikki.karvonen@oulu.fi**
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Thank you!

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