IEE IEE2620: System Aspects in Communications

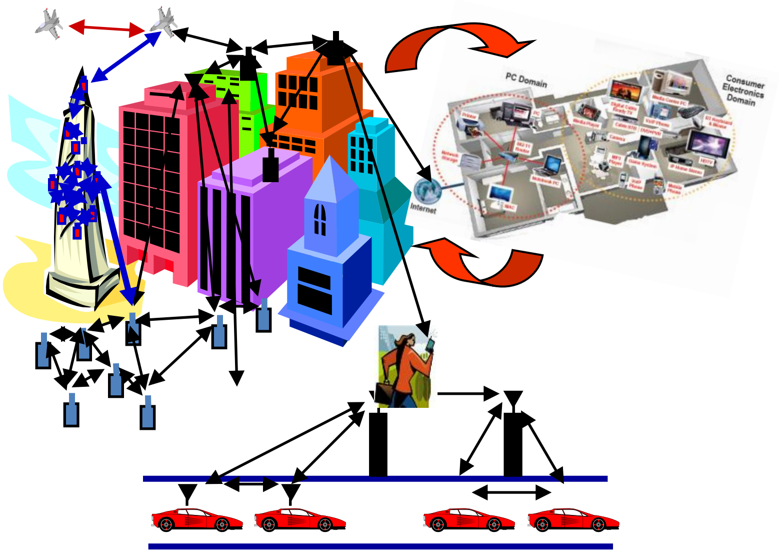
Osama Elgarhy, Osama.elgarhy@taltech.ee

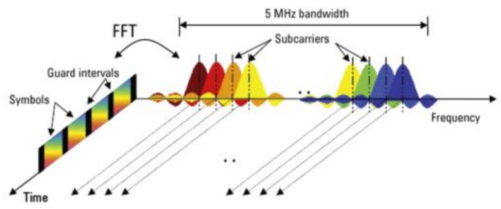
Tunniplaan | Tunniplaani kalendrivaade | 2023/2024 kevad

Muhammad Mahtab Alam (1-16. õppenädal)

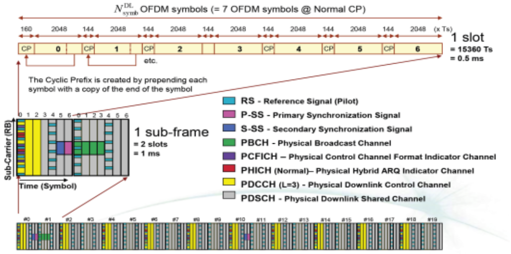
Muu · Paaris · Paaritu · 1 - 16 | Kopeeri URL | Ekspordi iCalendar fail | Nädal | Semester

Aeg	Õppeaine	Keel	Kohustuslik / Valik / Vaba	Tüüp	Õppejõud	Ruum	Õppenädalad	Rühmad	Ainekava	Kommentaar
Esmaspäev										
12:00 - 13:30	IEE2620 - Süsteemiaspektid sides	Eesti keel	valik	loeng	Muhammad Mahtab Alam (täisprofessor tenuuris)	Distantsõpe SOC-218	1-16	IAVM21	Vaata	





Downlink Frame Structure Type 1



5G and Internet of Things

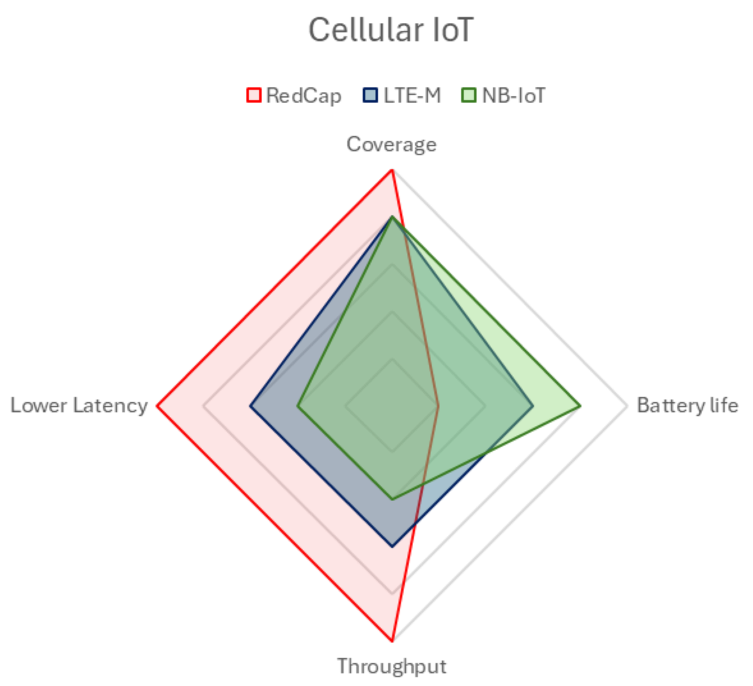
TABLE OF CONTENT

The global NB-IoT market was valued at $11.54 billion in 2024 and is projected to grow to $16.13 billion in 2025, with a long-term forecast of reaching $1.69 trillion by 2037

China accounts for nearly 90% of global NB-IoT connections

NB-IoT often cover use cases that require large numbers of low cost, low power and low maintenance connected devices, such as smart metering, smart parking and smart agriculture.

Imposes constraints on the energy efficiency and the coverage.



GSMA "Mobile IoT in a 5G Future NB-IoT and LTE-M in the context of 5G", October 2024

•Bandwidth: 180 kHz (1 resource block),

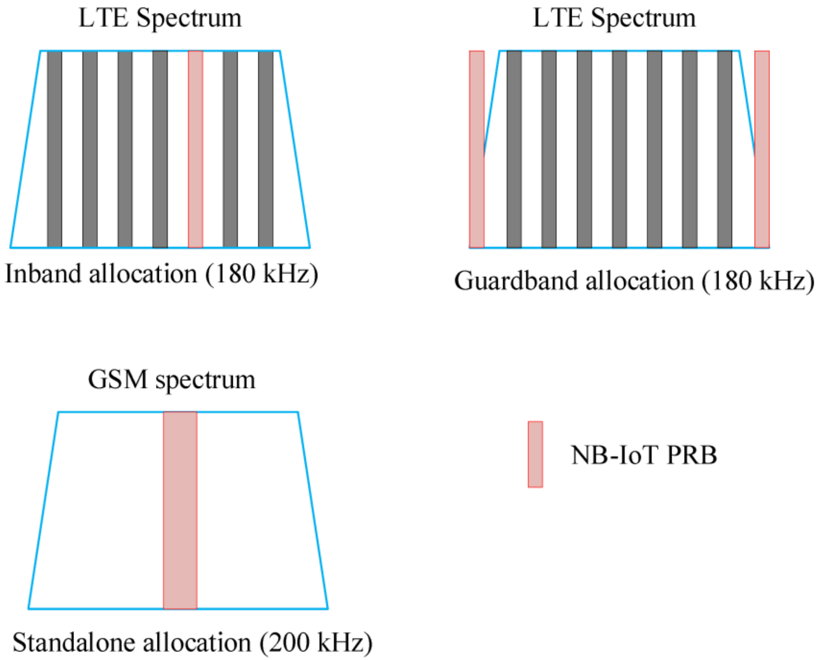
•Frequency Bands: Operates in sub-1 GHz licensed spectrum (e.g., 700–900 MHz).

•Uplink Power: Power classes: (23 dBm ; 20 dBm); 14 dBm.

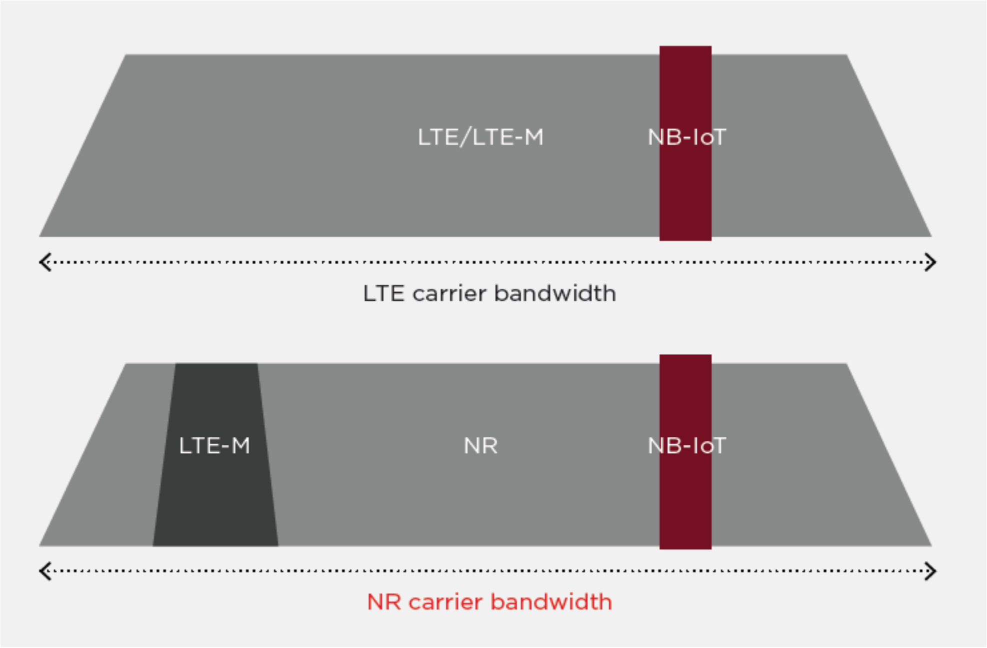
•Power Saving: Supports PSM (Power Saving Mode) and eDRX (Extended Discontinuous Reception).

•Duplexing: Half-duplex .

•Coverage: 164 dB MCL (Maximum Coupling Loss), enabling deep indoor/underground connectivity. Through repetitions



Mwakwata, Collins Burton, et al. "Narrowband Internet of Things (NB-IoT): From physical (PHY) and media access control (MAC) layers perspectives." Sensors 19.11 (2019): 2613.



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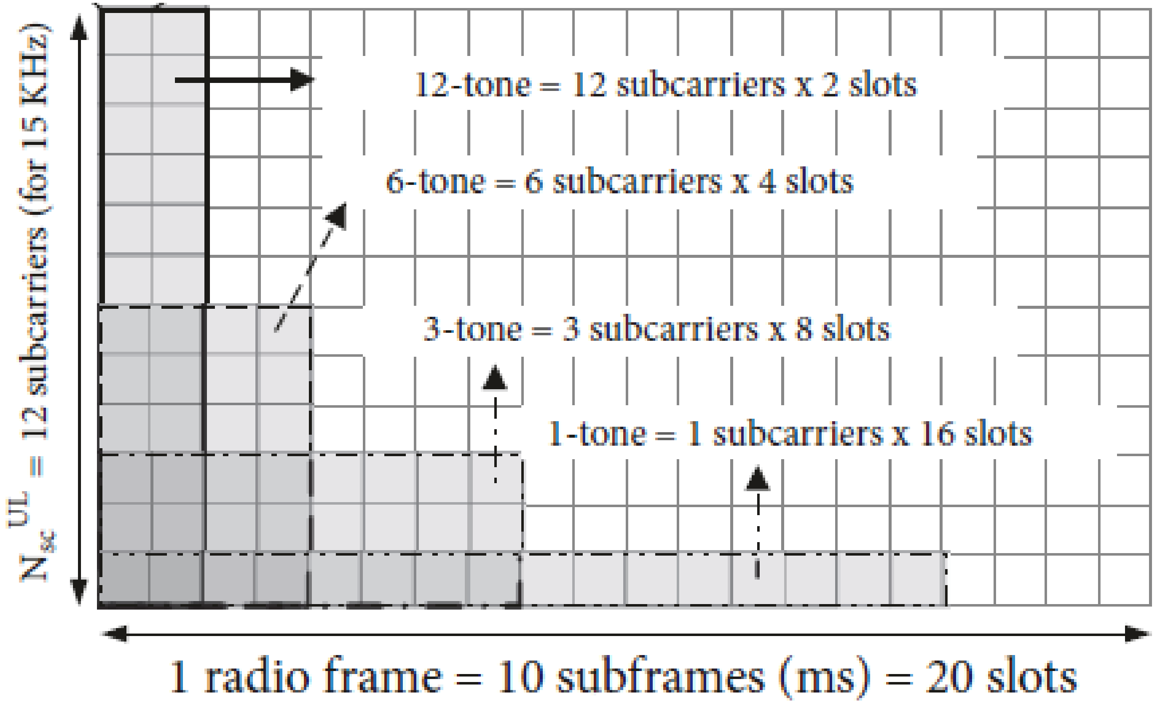
FULL/HALF/SIMPLEX DUPLUX SYSTEM

Full-duplex communication is a communication system that allows for two-way communication between two or more parties, where each party can send and receive information simultaneously. In other words, full-duplex communication enables multiple parties to communicate in real-time, with the ability to send and receive data at the same time. **Examples of full-duplex communication are speaking on a mobile phone call, video conferencing and online gaming.**

Half-duplex communication is a communication system that allows for two-way communication between two or more parties, but only one party can transmit data at a time. Half-duplex communication enables both parties to send and receive information, but not at the same time. A good example of half-duplex communication is a **walkie-talkie**. In some cases a VOX PTT can be used (Voice-operated PTT).

Simplex communication is a one-way communication system where information is transmitted from one device to another, but the receiving device cannot send information back to the transmitting device. In other words, simplex communication is a unidirectional form of communication, where the communication is one-way only. **Examples of Simplex:** Television, Radio Broadcasts & Monitors are great examples of a simplex transmission; Aircraft VHF AM and marine radios



RUC	SCs	Time
RUC1	1	8ms
RUC2	3	4ms
RUC3	6	2ms
RUC4	12	1ms

REPETITIONS AND MCL

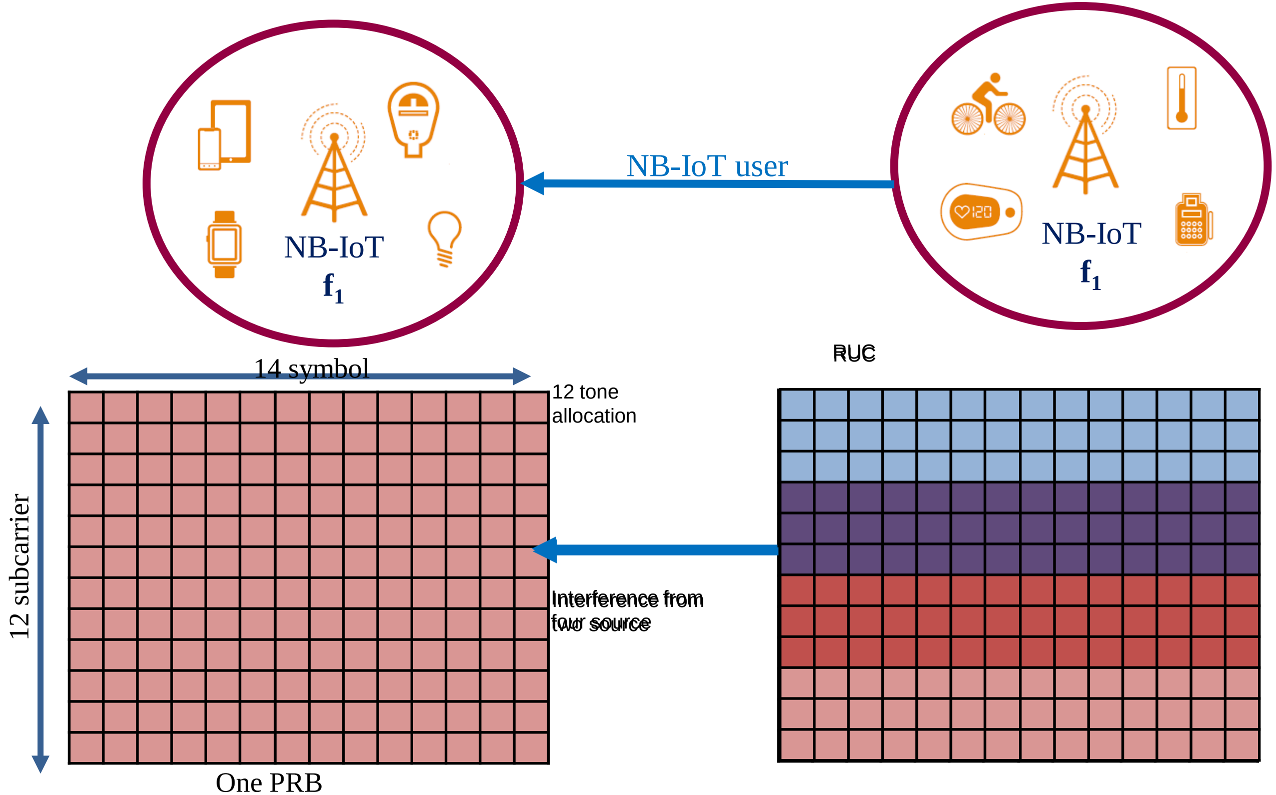
Coverage: 164 dB MCL up to 2048

MCL INPUT	VALUE
Transmitter	
(0) Max Tx power (dBm) (1) Power in Channel Bandwidth (dBm)	PA power of UE or eNB Calculated
Receiver	
(2) Thermal noise density (dBm/Hz)	Constant -174 dBm/Hz
(3) Receiver noise figure (dB)	Depends on LNA
(5) Occupied channel bandwidth (Hz)	Bandwidth of signal
(6) Effective noise power = (2) + (3) + 10 log((5)) (dBm)	Calculated
(7) Required SNR (dB)	Value comes from link simulation
(8) Receiver sensitivity = (6) + (7) (dBm)	Calculated
(9) MCL = (1) - (8) (dB)	Calculated

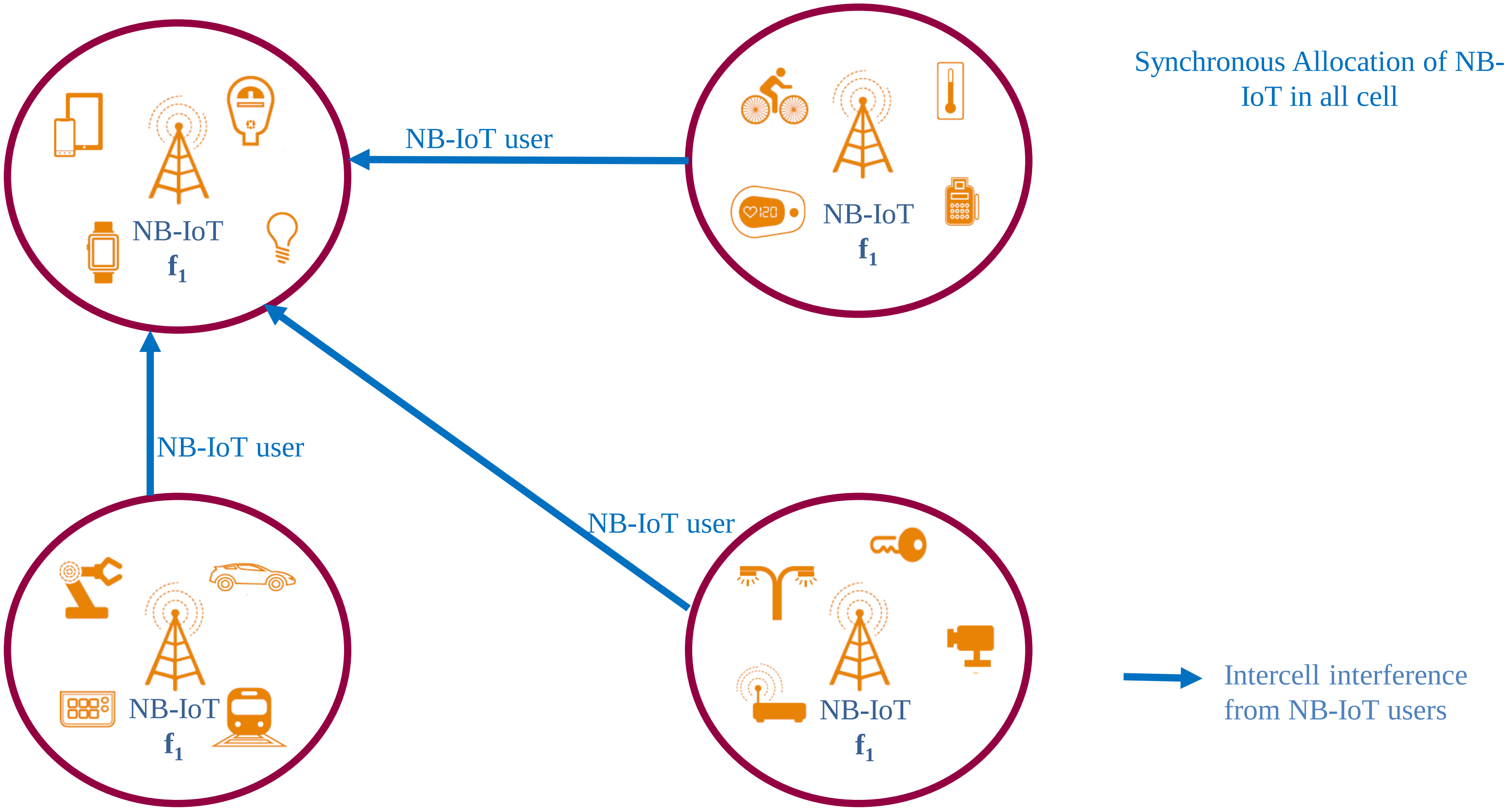
White paper"Coverage Analysis of LTE-M Category-M1", Version 1.0, January 2017

MASSIVE INTERFERENCE

- With extensive possibilities of deployment, massive interference on NB-IoT is expected due to use of LTE frequency band
- The allocation of uplink resources with sub-carrier granularity, however, leads to many scenarios where the uplink transmission wholly or partially overlaps in the frequency and time domains with the transmission in the neighbouring cell, resulting in severe inter-cell interference (ICI).



NB-IOT DEPLOYMENT STRATEGIES



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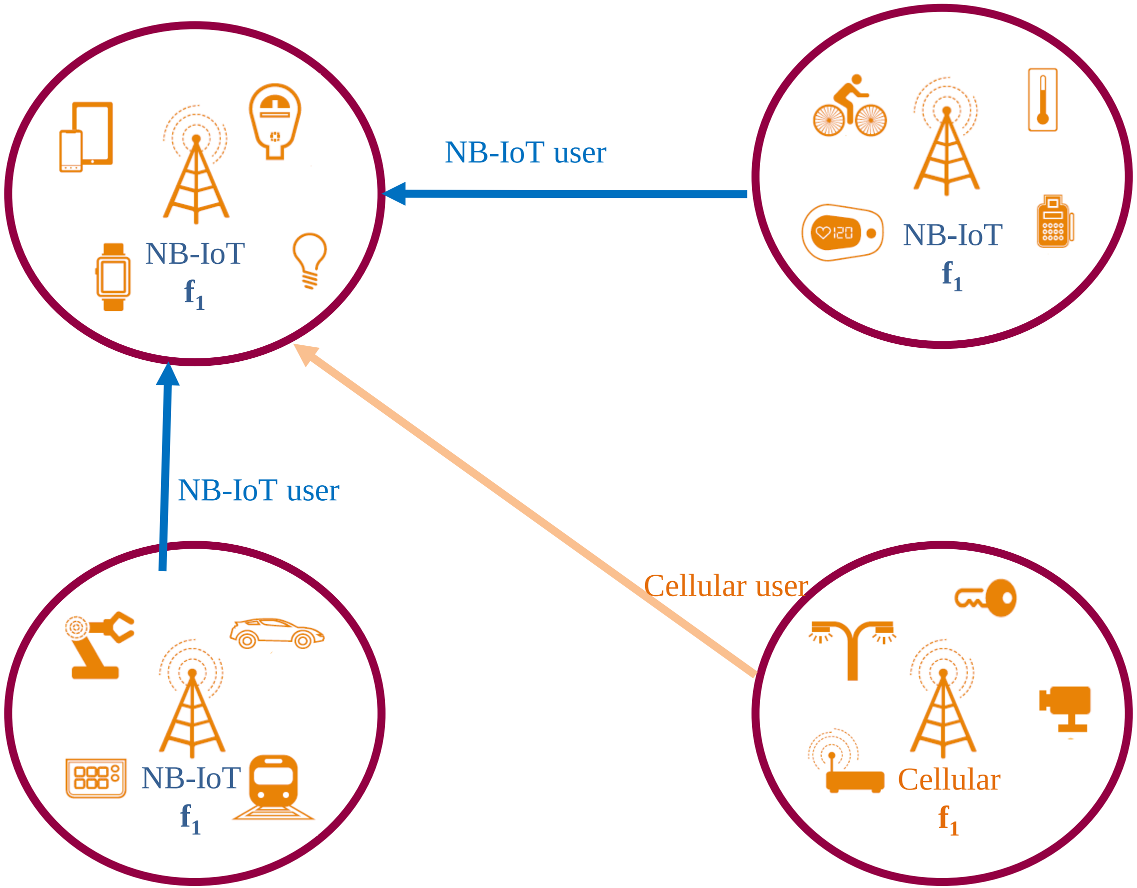

Asynchronous Allocation of NB-IoT in all cell

Intercell interference from NB-IoT users

Intercell interference from Cellular users

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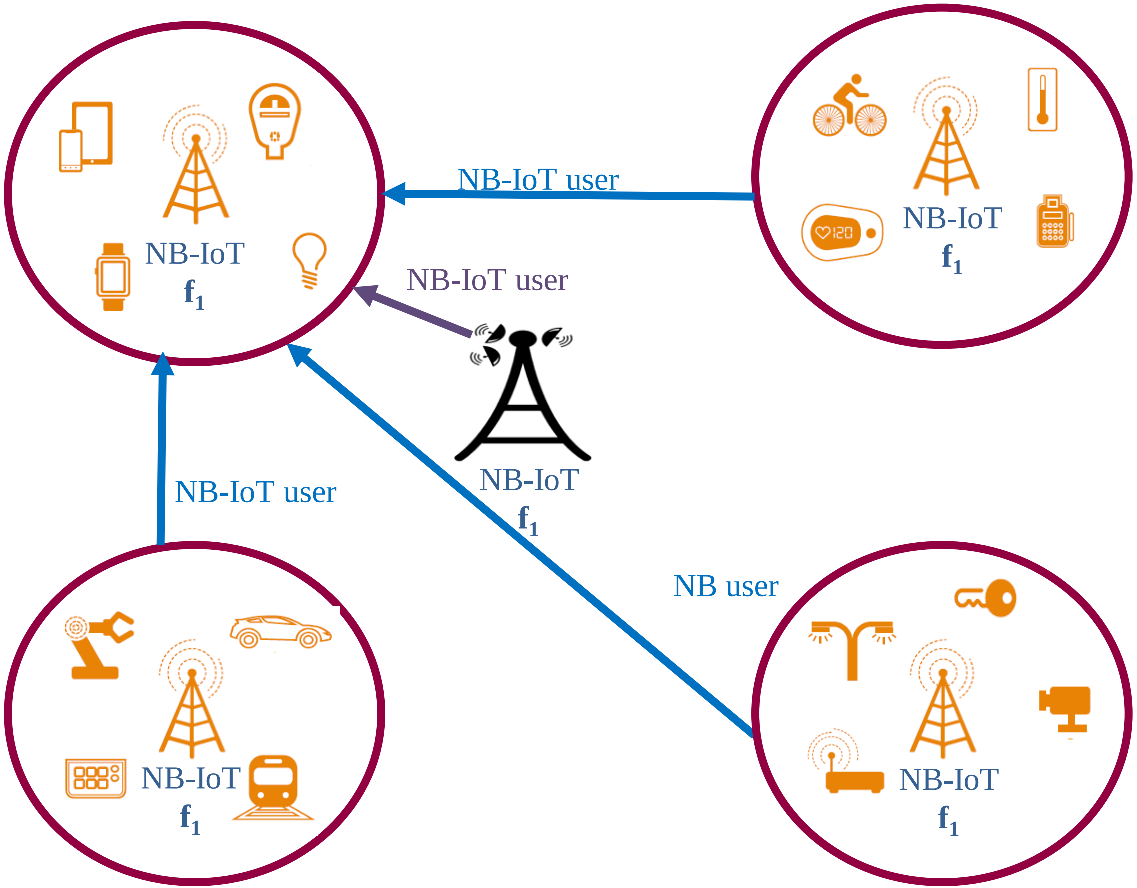
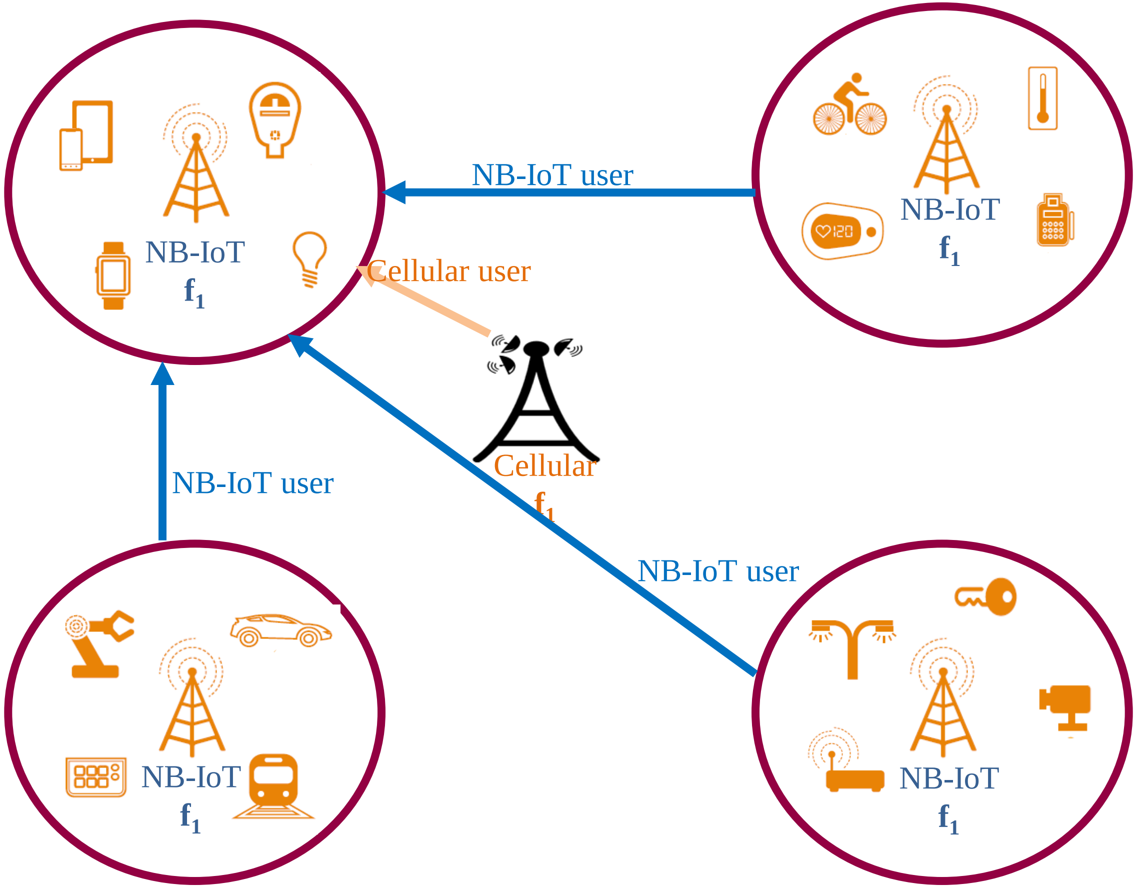


Synchronous Allocation of NB-IoT in small cell and macro-cell

Intercell interference from NB-IoT users

Intercell interference from microcell NB-IoT users

NB-IOT DEPLOYMENT STRATEGIES



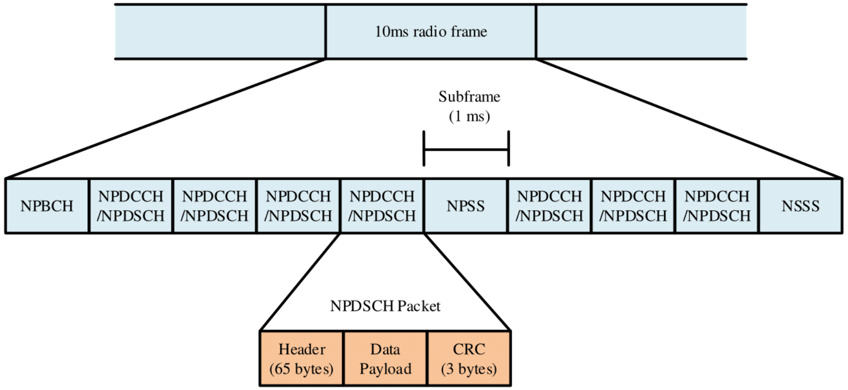
Asynchronous Allocation of NB-IoT in small cell and macro-cell

Intercell interference from NB-IoT users

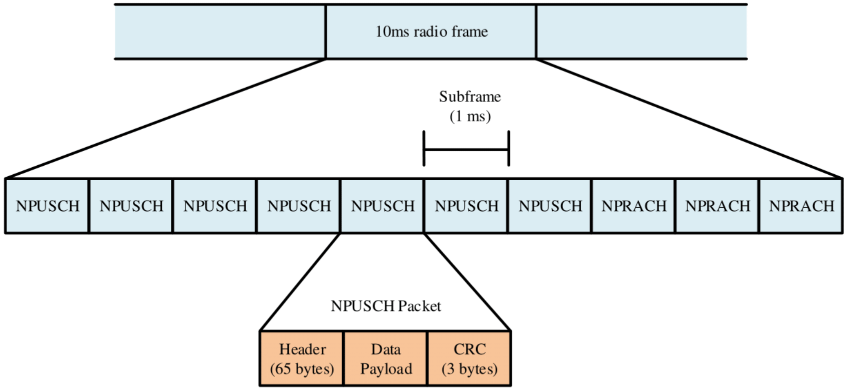
Intercell interference from microcell Cellular users

CONTROL CHANNEL

- NPBCH on 0^{th} subframe of every frame. NPSS on 5^{th} and NSS on 9^{th} with periodicity of 20 ms.
- NPDCCH carries control information such as paging, UL/DL assignment, random access channel (RACH) response, type of modulation being used for transmission, power control, and so on. The size of the control information is fixed at 23 bits, and is encoded over one subframe. Coverage extension is achieved through the use of repetition coding, with support for a maximum of 2048 repetitions.

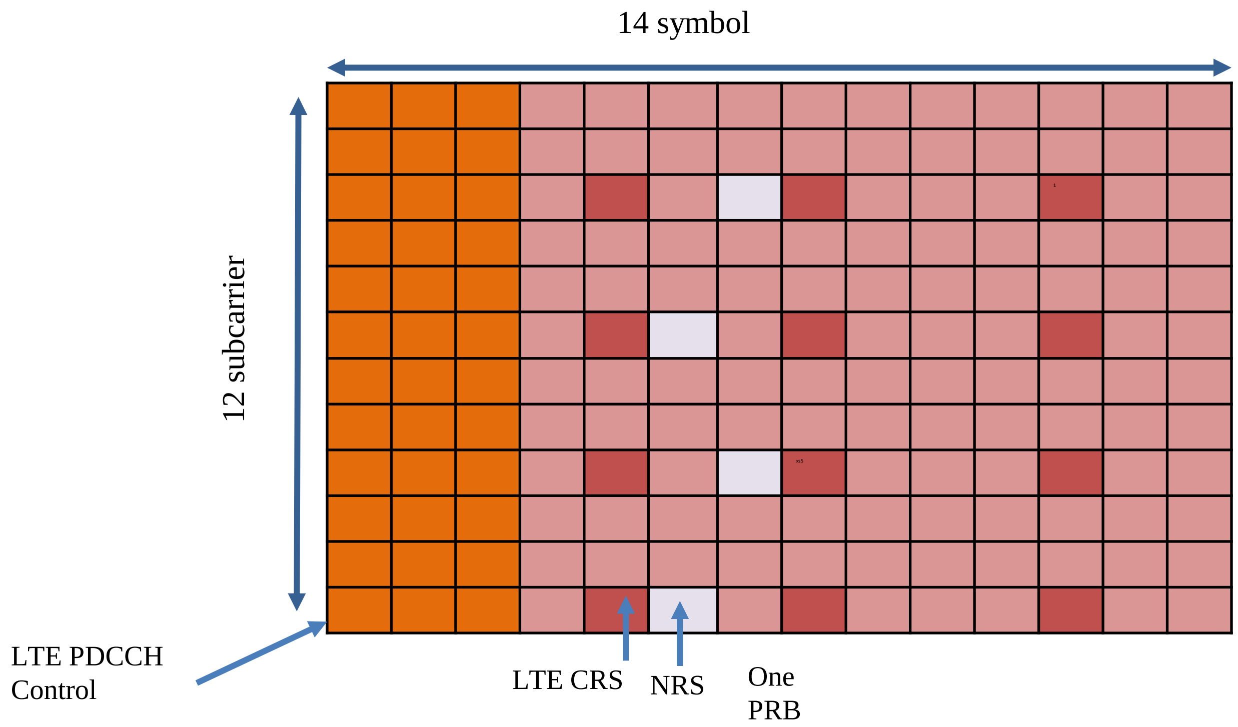


(a) Downlink Frame Structure



(b) Uplink Frame Structure

CONTROL CHANNEL OVERHEAD



NB-IoT physical channels of the in-band mode share REs with LTE in the DL
CRS: Cell-Specific Reference Signal
NRS: Narriowband Reference Signal

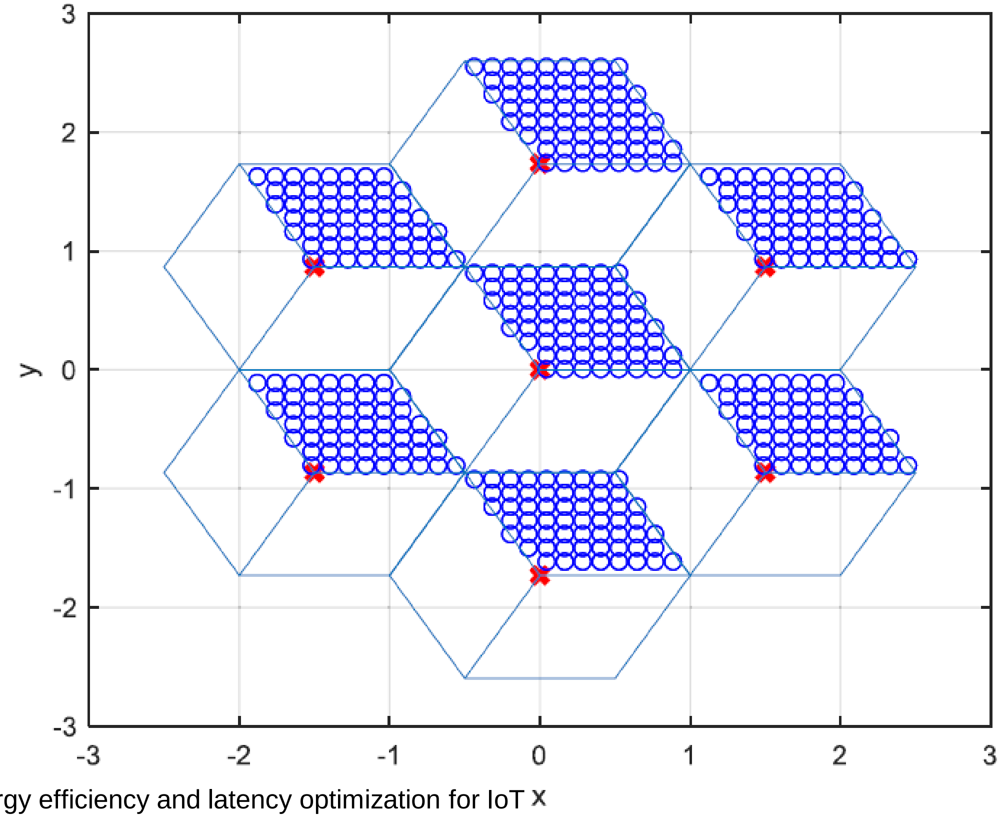
RESOURCE ALLOCATION FOR NB-IOT

- The NB-IoT requirements in terms of energy efficiency, achievable rates, latency, and extended coverage, make the resource allocation, in a limited bandwidth, even a more challenging problem.

- The introduction of the new resource unit configurations, increases the flexibility of allocation, but increases the complexity of the optimization as well.

Elgarhy, Osama, et al. "Rate-latency optimization for NB-IoT with adaptive resource unit configuration in uplink transmission." IEEE Systems Journal 15.1 (2020): 265-276.

EE FOR NB-IOT (RESEARCH WORK)



Elgarhy, Osama, et al. "Energy efficiency and latency optimization for IoT URLLC and mMTC use cases." IEEE Access 12 (2024): 23132-23148.

$$SINR_i = \frac{G_{ii}P_i}{\sum_{j \neq i} G_{ji}P_j + n_i}.$$

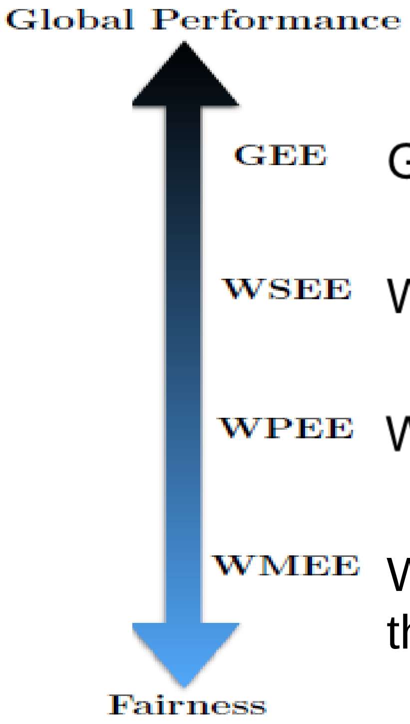
$$Rate \ = BW \ log_2(1 + SINR)$$

$$Energy \ Efficiency = \frac{Rate}{Power} \ [Bit/Joule]$$

$$\frac{\sum Rate}{\sum P_T + P_c}$$

Power = Transmit power (P_T) + circuit power (P_C)

Elgarhy, Osama, et al. "Energy efficiency and latency optimization for IoT URLLC and mMTC use cases." IEEE Access 12 (2024): 23132-23148.



Global energy efficiency (GEE): $\frac{\sum R}{\sum P_T + P_C}$

Weighted sum energy efficiency (WSEE): $\sum w \frac{R}{P_T + P_C}$

Weighted product energy efficiency (WPEE): $\prod \left(\frac{R}{P_T + P_C} \right)^w$

Weighted minimum energy efficiency (WMEE): goal is to maximize the minimum energy efficiency.

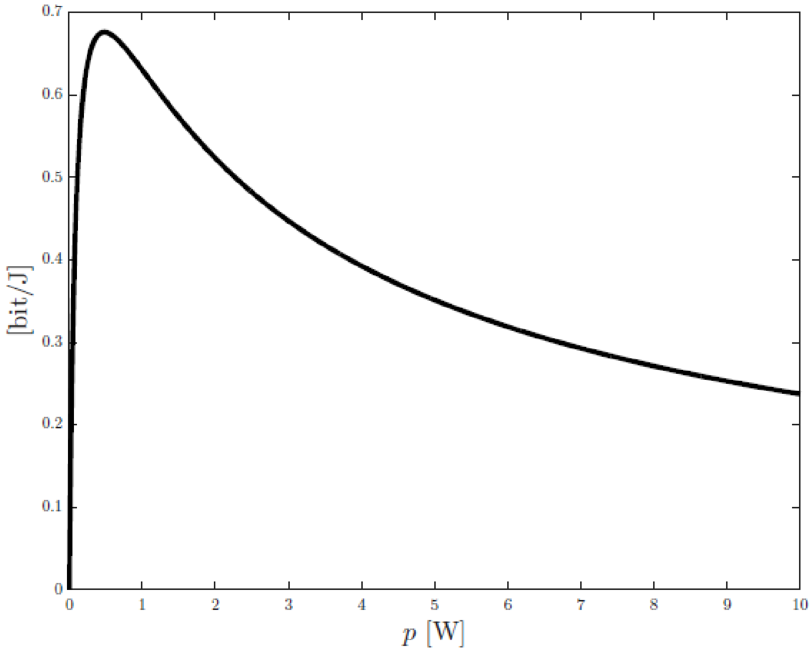
Zappone, Alessio, and Eduard Jorswieck. "Energy efficiency in wireless networks via fractional programming theory." Foundations and Trends® in Communications and Information Theory 11.3-4 (2015): 185-396.

	Case	Relation
EE - P_T	no interference - no P_C	EE decreases as P_T increases
	no interference - P_C	EE has a unique maximum
	interference	non-convex
SE - P_T	no interference	SE increases as P_T increases
	fixed interference	SE of the target user increases as its P_T increases
	interference	non-convex
EE - SE	no interference - no P_C	EE decreases as SE increases
	no interference - P_C	EE has a unique maximum
	interference	non-convex

In a Multi cell scenario, i.e., interference, the rate is non-convex

Neglecting the circuit power, changes the EE behavior

Elgarhy, Osama, et al. "Energy efficiency and latency optimization for IoT URLLC and mMTC use cases." IEEE Access 12 (2024): 23132-23148.



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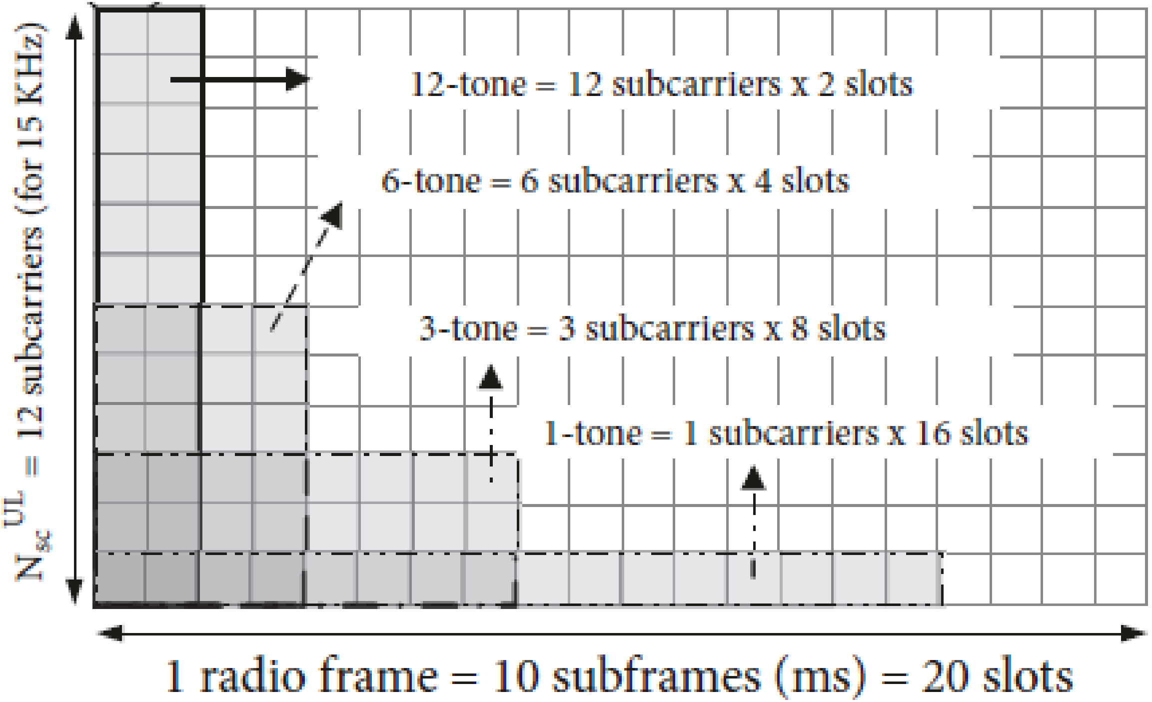
$$Rate \ = BW \ log_2(1 + SINR)$$

$$\frac{\sum Rate}{\sum P_T + P_c}$$



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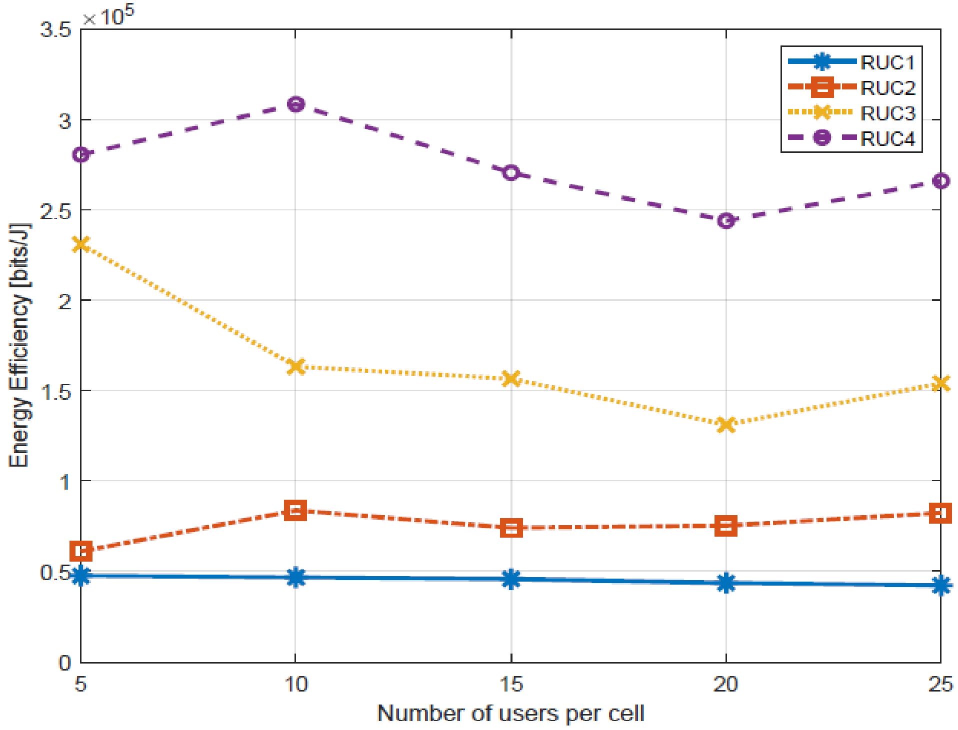

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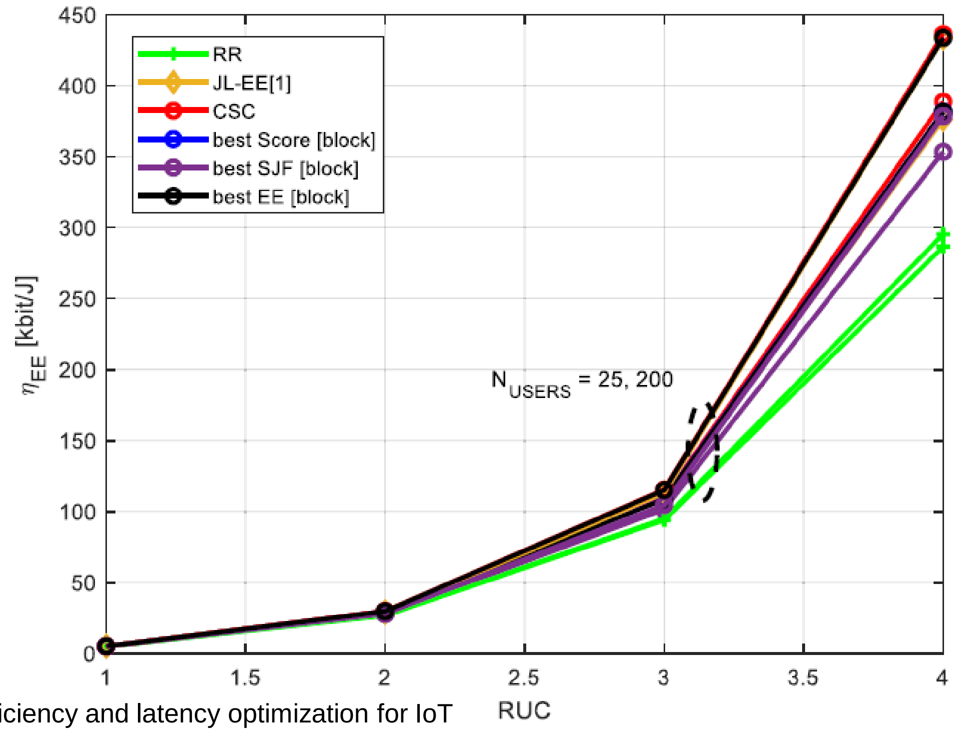
$$f_{OPT}(x_{c,t,s}^{(u)}) = w_1 \cdot f_E(x_{c,t,s}^{(u)}) - w_2 \cdot f_L(x_{c,t,s}^{(u)})$$

Constraints:

- Non-overlapping devices in the same cell, i.e. no intracell interference
- Allocation and shape of the RUs, which force the scheduler to choose one of the pre-defined RUCs or none
- Forcing a given number of repetitions, from a minimum to a maximum according to the specifications
- Minimum rate and maximum power

- Rate (sum-rate) in presence of interference: non-convex
- OFDMA allocation constraints makes the problem NP-hard
- binary scheduling variables complicates further the problem

Elgarhy, Osama, et al. "Energy efficiency and latency optimization for IoT URLLC and mMTC use cases." IEEE Access 12 (2024): 23132-23148.



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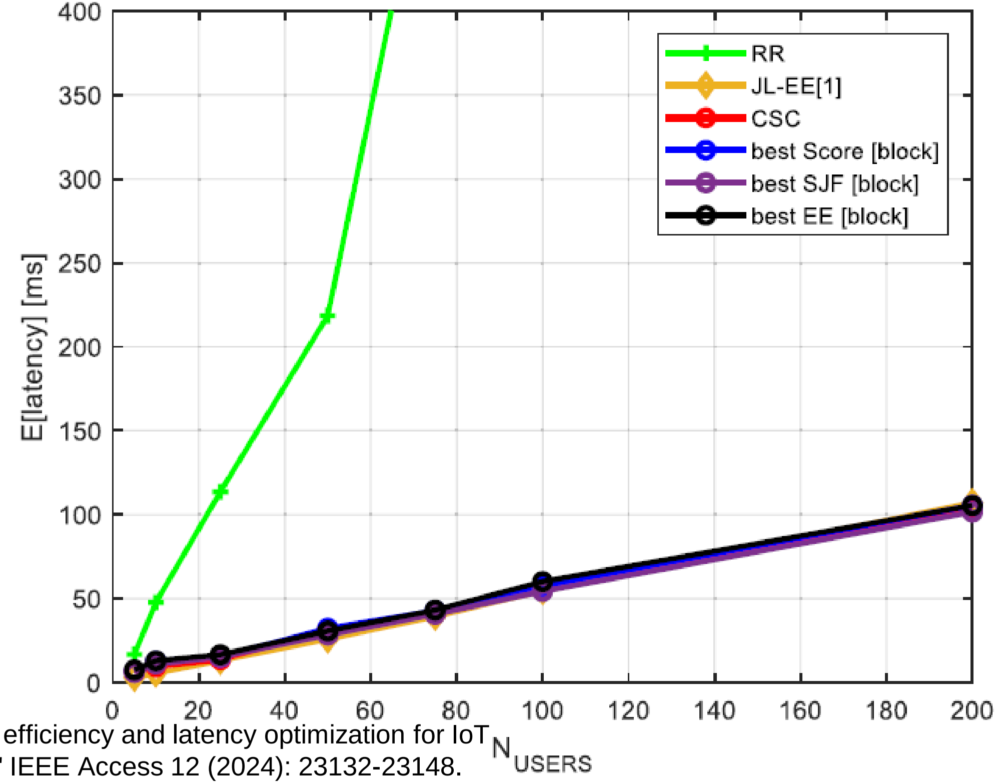

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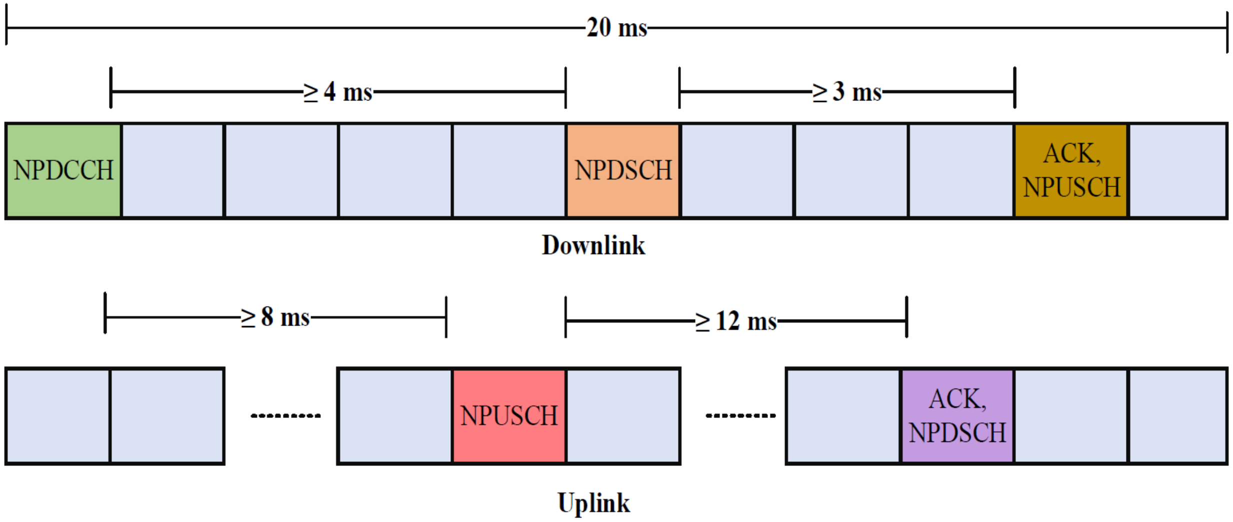
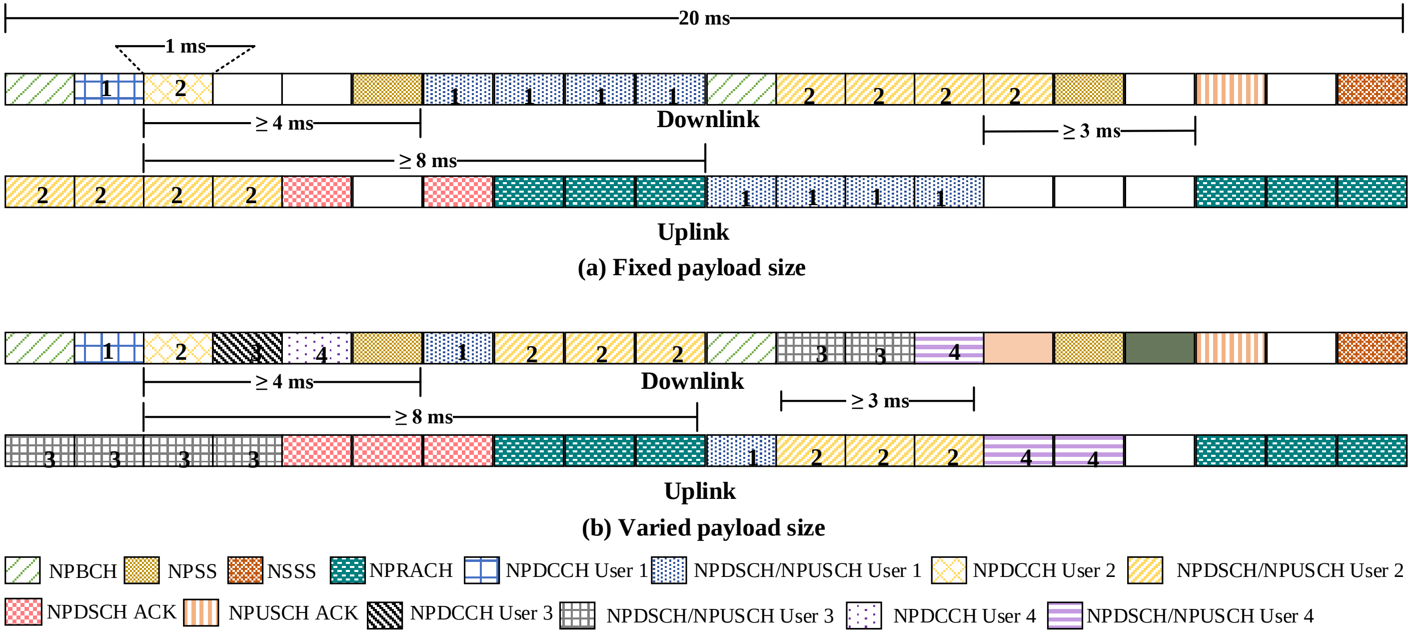
JOINT OPTIMIZATION OF DOWNLINK AND UPLINK

- Requires joint downlink and uplink scheduling
- Even with the best selection of scheduling delay, there is still a significant resource wastage due to signalling overhead



Recommended Scheduling delays by 3GPP

ASYMMETRIC TRAFFIC



Example of downlink and uplink scheduling in NB-IoT with no retransmission in two different scenarios: (a) Fixed payload size (b) Varied payload size.

IMPACT OF CONTROL CHANNEL ON PERFORMANCE OF NB-IOT

- Investigate how the performance of NB-IoT is impacted by the repetition factor, time offset, control channel overhead, radio environment, interference and so on?
- An analytical model for the theoretical upper bound on the achievable data rate of NB-IoT network including the effects of repetition factor and control channels overhead along with the trade-off between data rate, latency and number of supported devices are presented.
- Rates are significantly lower than the theoretical peak data rate of 226.7 kbps and 250 kbps in downlink and uplink, respectively

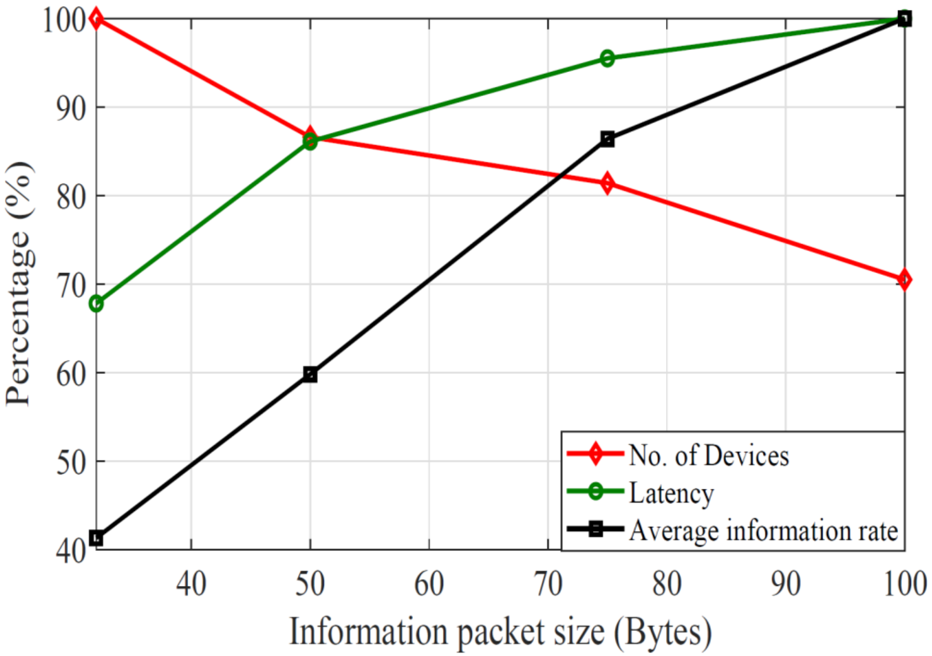
Parameters	Standalone		In-band	
MCL (dB)	144	164	144	164
Target SNR (dB)	15.4	-4.6	7.4	-12.6
BLER NPDSCH	8.07 %	9.58 %	9.54 %	7.43 %
BLER NPDCCH	1 %	0.5 %	0.52 %	0.6 %
Repetition NPDSCH	1	32	1	128
Required subframe	6	6	8	8
Duration NPDSCH (ms)	6	250	8	1362
Repetition NPDCCH	1	128	1	256
Duration NPDCCH (ms)	1	165	1	341
Duration Total (ms)	7	415	9	1703
Effective Data Rate (Kbps)	**89.2**	**1.48**	**68.4**	**0.369**

NB-IoT downlink effective data rate in different deployment scenarios with a TBS = 680 bits, modulation = QPSK and Code rate = 1/3

Parameters	15 kHz		3.75 kHz	
Maximum Coupling Loss (dB)	144	164	144	164
Tones	12	12	12	12
Target SNR (dB)	15.4	-4.6	7.4	-12.6
Repetitions NPUSCH	1	64	1	16
Required subframe	7	7	3	3
Duration NPUSCH (ms)	7	448	12	192
Duration Total (ms)	10	637	17	273
Effective Data Rate (Kbps)	**92**	**1.42**	**53.2**	**3.4**

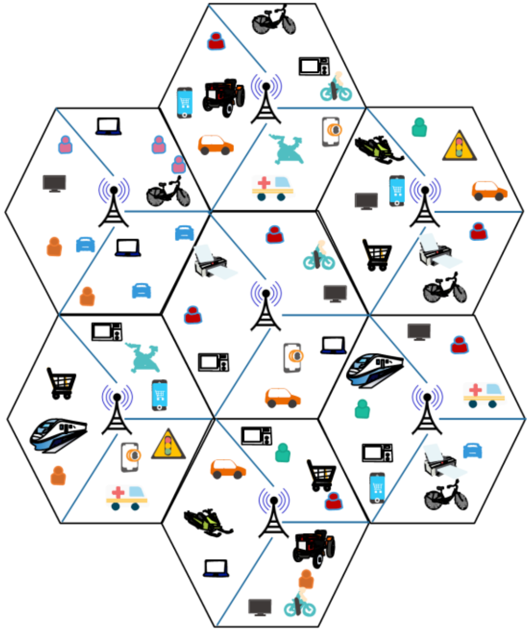
NB-IoT uplink effective data rate in different deployment scenarios with a TBS = 1000 bits, modulation = QPSK and Code rate = 1/3

IMPACT OF PACKET SIZE ON PERFORMANCE OF NB-IOT



Percentage increase or decrease in number of supported devices, latency and information rate with varying packet sizes

IMPACT OF INTERFERENCE ON PERFORMANCE OF NB-IOT

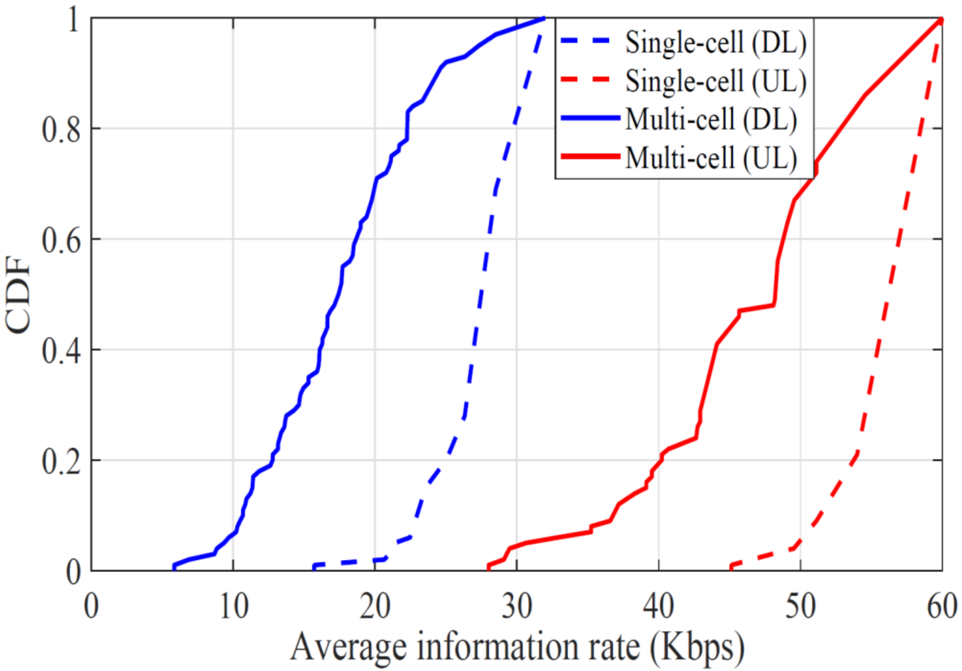


Multi-cell scenario under study

Simulation parameters

Parameters	Assumptions
Cell layout	Hexagonal grid, 3 sectors per site
Frequency band	900 MHz
Inter-site Distance	500 m
User distribution	Users dropped uniformly in entire cell
BS transmit power	32 dBm (3 dB boosting applied)
UE Tx power	23 dBm
Pathloss Model (BS-UE)	L= I + 37.6 $\log_{10}(R)$, I=120.9 for the 900 MHz band where R in kilometers
Pathloss Model (UE-UE)	38.45 + 20 $\log_{10}(d)$; $d \leq 50$, 55.78 + 40 $\log_{10}(d)$; $d \geq 50$, where d in meters
Shadowing standard deviation	8 dB
SC distance	110 m
SC between cell-sites	0.5
SC between cell sectors	1.0
BS antenna gain	18 dBi
UE antenna gain	-4 dBi
BS cable loss	3 dB
Building penetration loss	40 dB
Noise figure at BS	5 dB
Noise figure at UE	3 dB
Noise power spectral density	-174 dBm/Hz

IMPACT OF INTERFERENCE ON PERFORMANCE OF NB-IOT



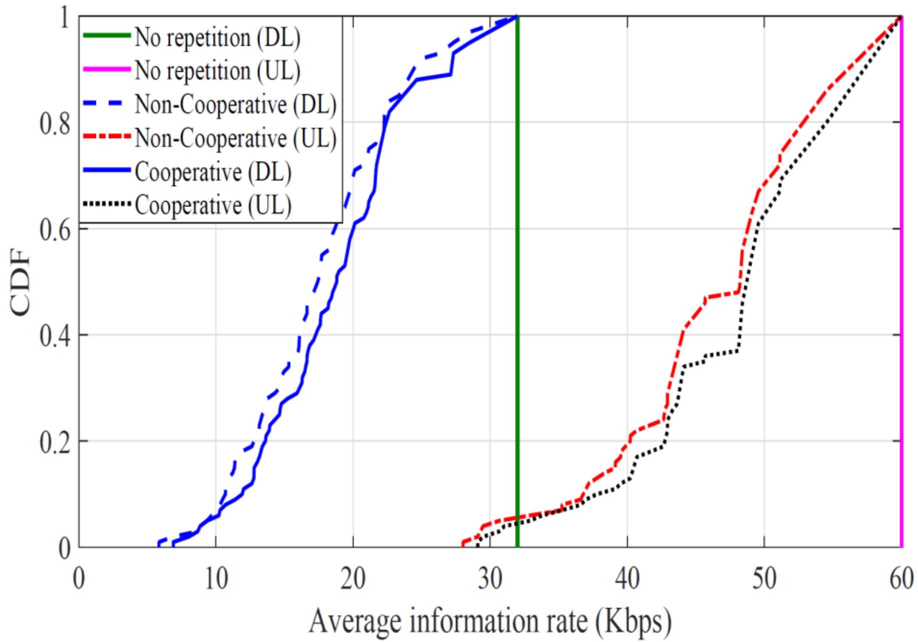
Performance degradation of 35% in downlink and 23% in uplink in a multi-cell scenario due to ICI

PROPOSED SUM-RATE MAXIMIZATION SOLUTION

- Due to the **limited spectrum resource** (i.e. 180 kHz) availability for NB-IoT systems, one of the concerns is how to efficiently allocate resources to **massive IoT device** in the presence of **massive interference**?
- An efficient radio resource allocation for NB-IoT based on heuristic approach with both cooperative and non-cooperative approach is proposed.
- Aim is to mitigate interference and maximize sum-rate of whole system

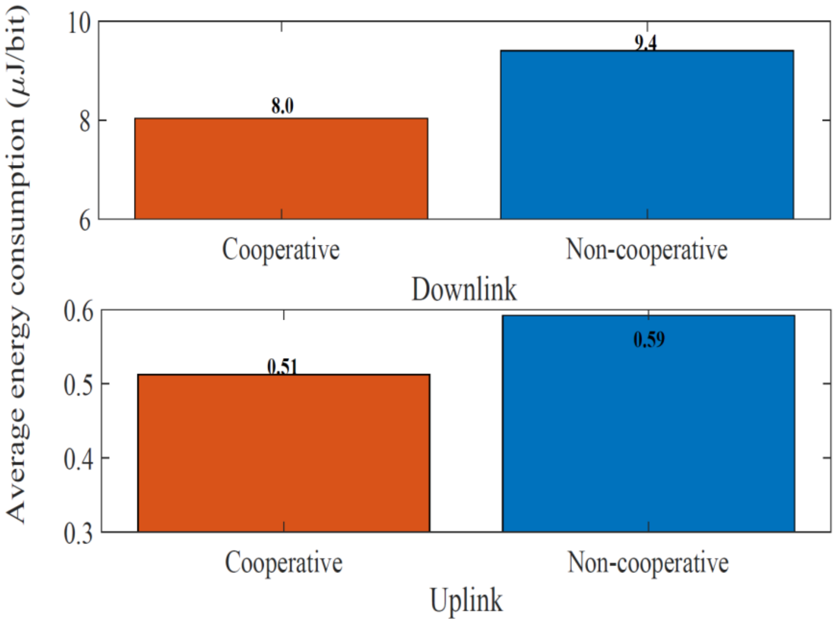
Source: H. Malik, H. Pervaiz, M. Mahtab Alam, Y. Le Moullec, A. Kuusik and M. Ali Imran, "Radio Resource Management Scheme in NB-IoT Systems," in *IEEE Access*, vol. 6, pp. 15051-15064, 2018.

PROPOSED SUM-RATE MAXIMIZATION SOLUTION



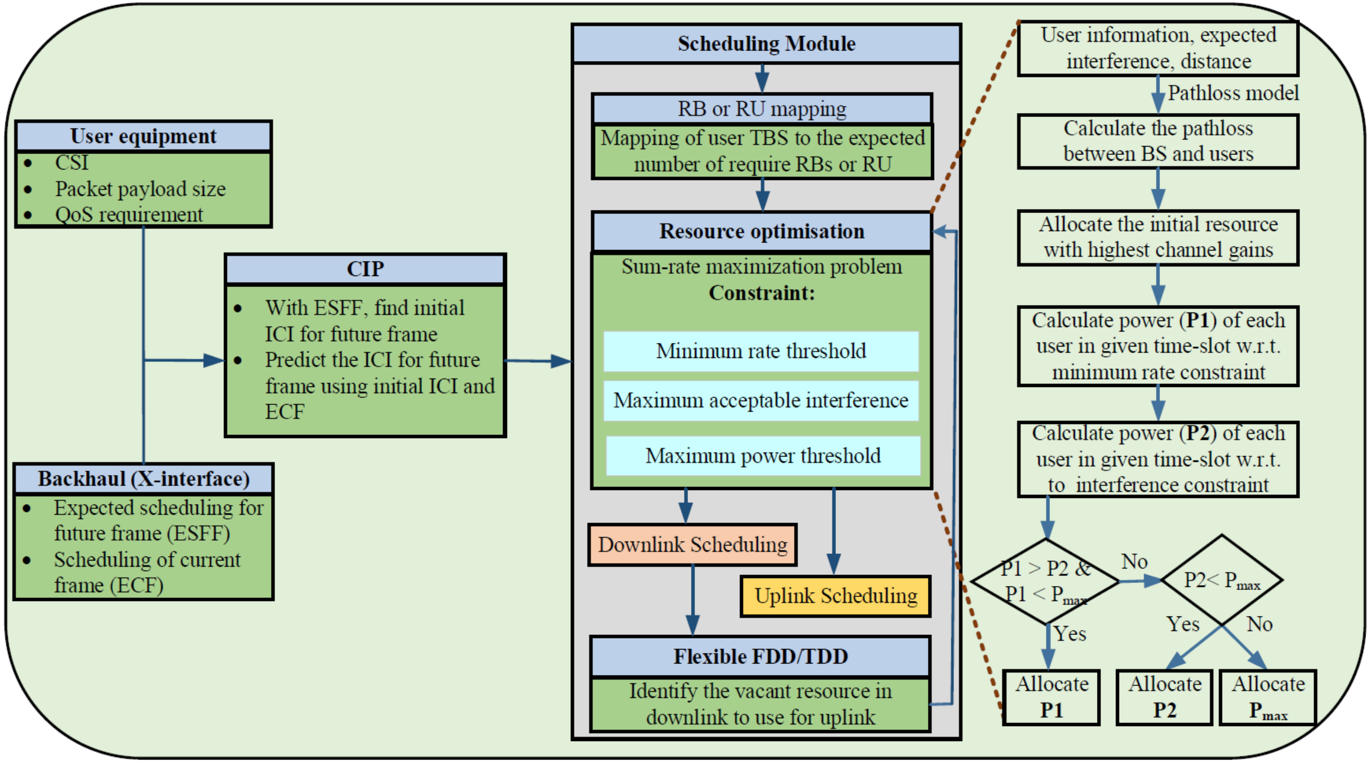
Cooperative scheme provides up to 12% rate improvement compared to non-cooperative

PROPOSED SUM-RATE MAXIMIZATION SOLUTION



Cooperative scheme provides up to 17% reduction in energy consumption is achieve in downlink and 15% in uplink as compared to the non-cooperative case

A RADIO RESOURCE MANAGEMENT FRAMEWORK



MOBILE POSITIONING

Positioning Methods

- Angle of Arrival (AoA)
- Time Difference of Arrival (TDoA)
- Time of Arrival/Time of Flight (ToA/ToF)

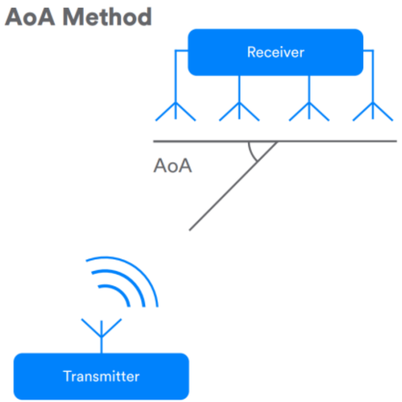


Fig. 2. Angle of Arrival method. Image: MICROCONTROLLER TIPS, link

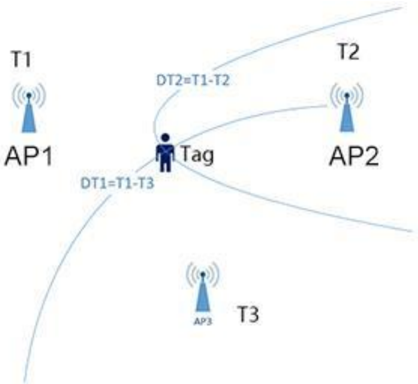


Fig. 3. TDoA method. Image: uwbleader.com, link

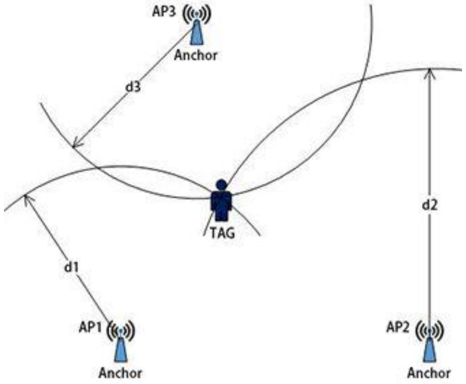


Fig. 4.ToA/ToF method. Image: uwbleader.com, link

Observed Time Difference of Arrival (OTDOA)

On DownLink (DL) a new reference signal known as the positioning reference signal (PRS) is introduced in Release 16 for the UE to perform downlink reference signal time difference (DL RSTD) measurements for each base station's PRSs.

Uplink Time Difference of Arrival (UL-TDOA)

On UpLink (UL) the Release-16 sounding reference signal (SRS) is enhanced to allow each base station to measure the uplink relative time of arrival (UL-RTOA) and report the measurements.

Angle of Arrival (AoA) and Departure (AoD) measurements with NR

gNB measures the angle-of-arrival based on the beam the UE is located in.

UE measures the downlink reference signal receive power (DL RSRP) per beam from gNB. Measurement result is used to determine the AoD based on UE beam location for each gNB.

POSITIONING ALGORITHM

- On top of the communications and reliability requirements of a wireless link, many IoT applications will require or benefit from knowing the location of certain devices.
- Such location information will be needed seamlessly, both indoors and outdoors, and without the battery-draining Global Navigation Satellite Systems (GNSS) chipsets.
- Positioning system with an IoT network is not a trivial task.
- Low per unit cost of their IoT devices, resulting in devices with very limited hardware components, such as CPU, memory and battery.
- Biggest challenge for enabling a positioning system lies on the proper management of the devices' radio.
- Proper radio management becomes evident as there are devices with known coordinates which will broadcast specific payloads on a regular basis and other devices whose locations are to be determined, which will need to scan the spectrum frequently.
- Too frequent broadcasting will lead to spectrum congestion and increased packet collision
- Frequent scanning leads to high battery consumption

Balance the power consumption against the performance of the system

POSITIONING ALGORITHM

- ❑ Two commonly used positioning algorithms

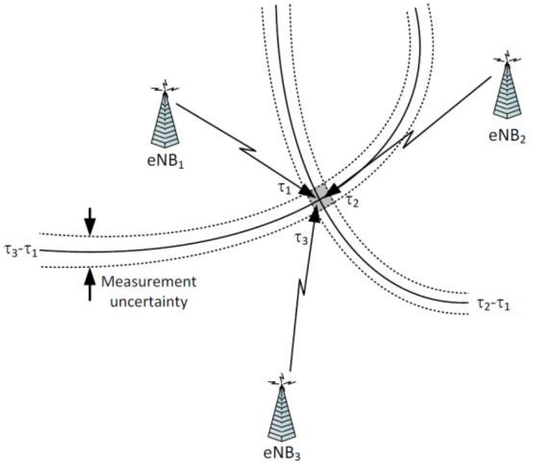
- ✓ Cell ID and Enhanced Cell ID
- ✓ Observed Time Difference of Arrival (OTDOA) Positioning

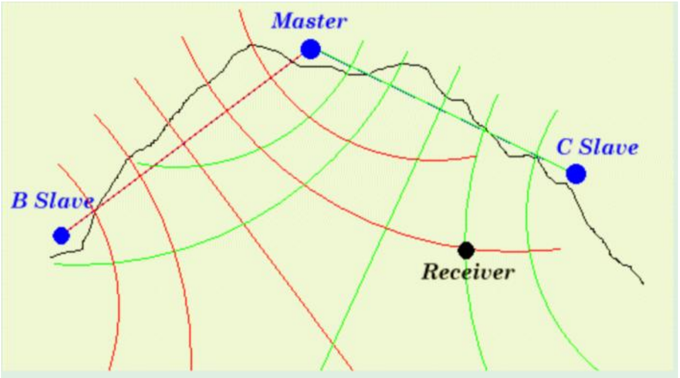
CELL ID AND ENHANCED CELL ID

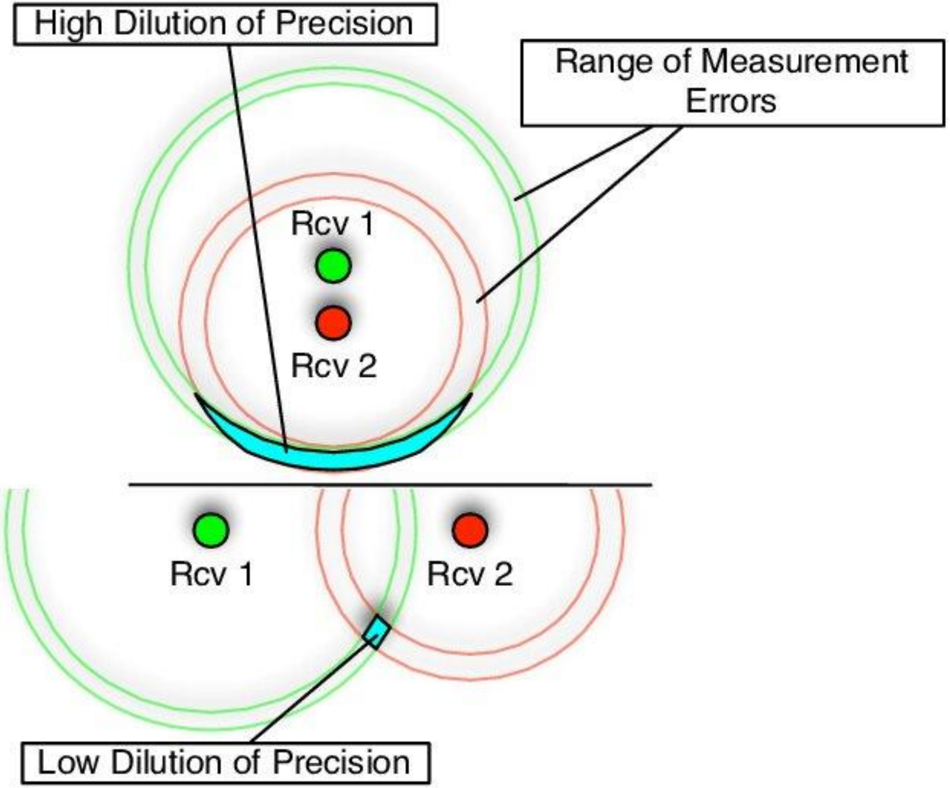
- ❑ Cell ID (CID) positioning is a network based technique
- ❑ Very low accuracy
- ✓ position of the UE is estimated to be the position of the base station it is camped on
- ❑ Enhanced Cell ID
- ✓ In ECID, the Round Trip Time (RTT) between the base station and the UE is used to estimate the distance to the UE. In addition, the network can use the Angle of Arrival (AoA) of signals from the UE to provide directional information.

OTDOA POSITIONING

- Downlink positioning Algorithm
- Based on hyperbolic multilateral algorithm
- Determine time of arrival (ToA) of downlink signals from multiple eNBs (includes 1 serving eNB and 2 or more neighbour eNBs).





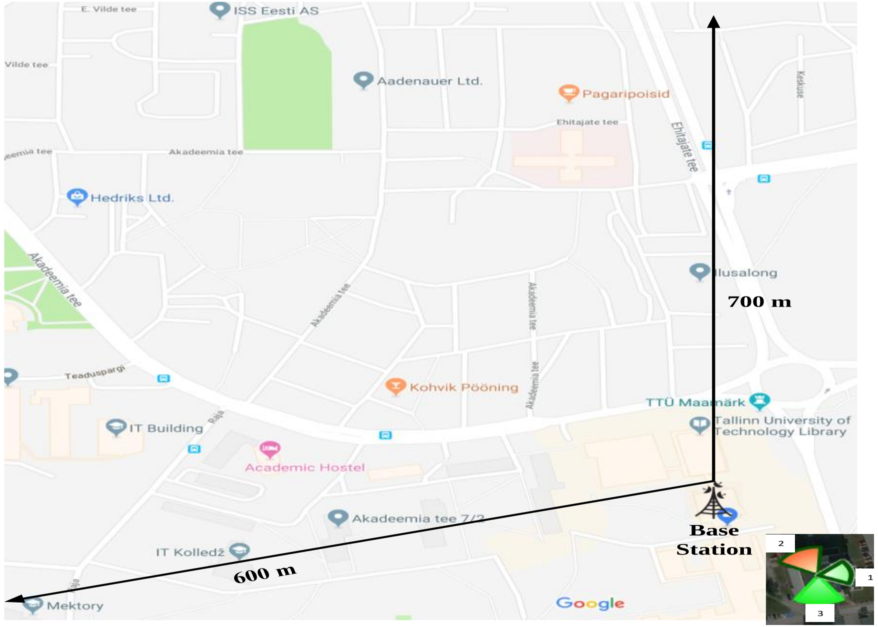

High Dilution of Precision
Range of Measurement Errors
Rcv 1
Rcv 2
Rcv 1
Rcv 2
Low Dilution of Precision

ISSUES WITH POSITIONING ALGORITHMS

- Receive timing uncertainty (which affects the RTT calculation)
- Multipath reflections
- Measure neighbouring cell RS accurately enough for positioning.
- Determine time of arrival (ToA) of downlink signals from multiple eNBs (includes 1 serving eNB and 2 or more neighbour eNBs).

NB-IOT NETWORK TRIAL: INDOOR, OUTDOOR AND UNDERGROUND COVERAGE CAMPAIGN

- Fully understand the potential of NB-IoT in different use-case scenarios
- Help the operators to plan cell deployments and to estimate Capex costs
- First empirical measurement campaign in open literature to study the coverage of this technology in collaboration with **Telia Eesti**.

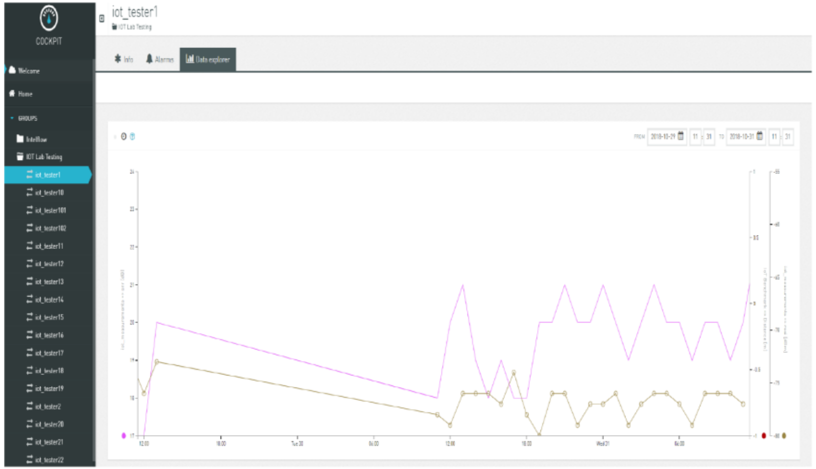


H. Malik *et al*., "NB-IoT Network Field Trial: Indoor, Outdoor and Underground Coverage Campaign," *2019 15th International Wireless Communications & Mobile Computing Conference (IWCMC)*, Tangier, Morocco, 2019, pp. 537-542, doi: 10.1109/IWCMC.2019.8766568.

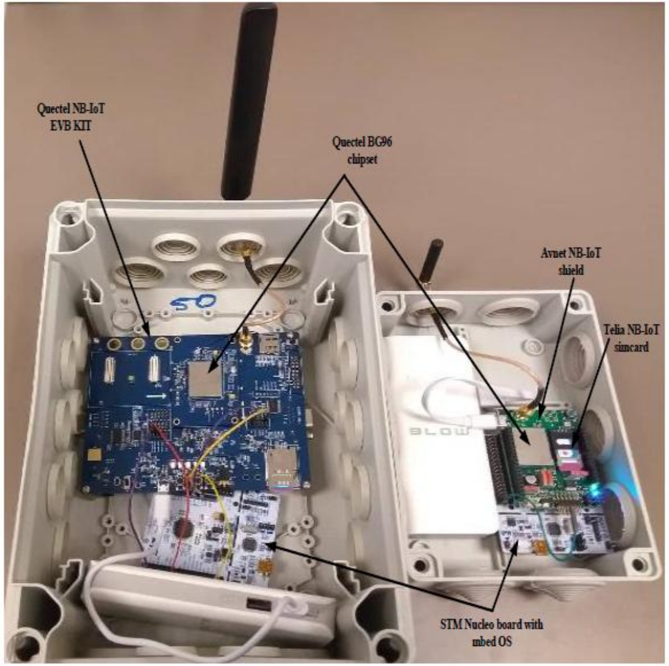
The antenna is mounted on one of Taltech University building at a height of 20 m from sea-level

NB-IOT NETWORK TRIAL: INDOOR, OUTDOOR AND UNDERGROUND COVERAGE CAMPAIGN

- ❑ Quectel boards firmware degradation
- ❑ Timing Issue
- ❑ Cumulocity integration
- ❑ RF antenna component
- ❑ Getting permission from the building owners

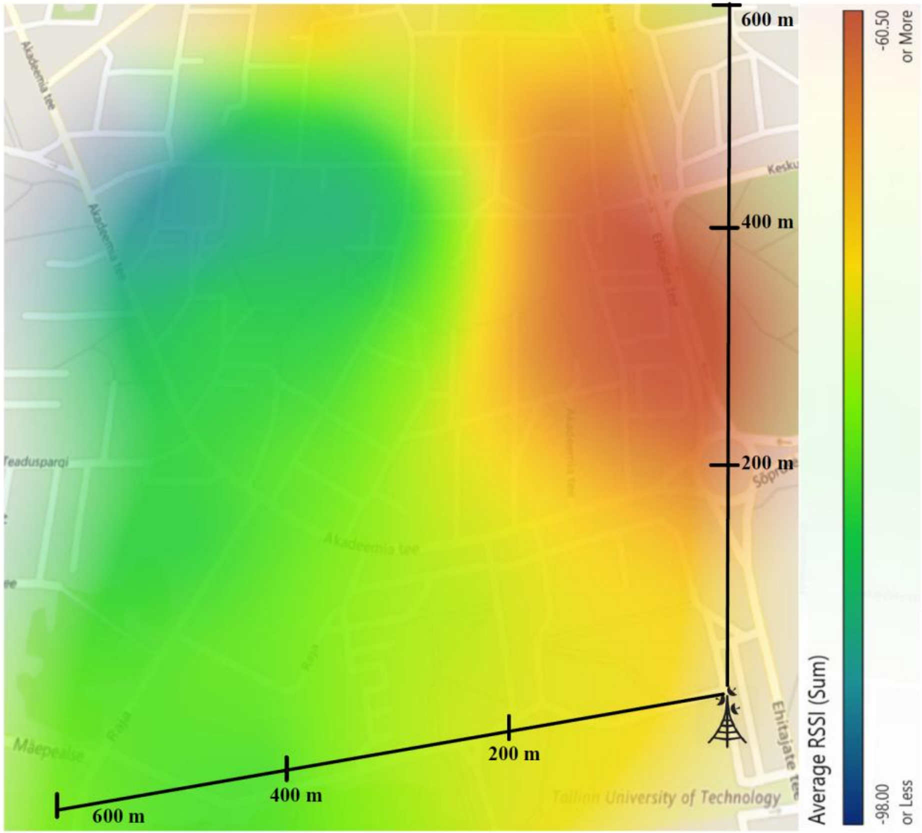


Cumulocity cloud platform



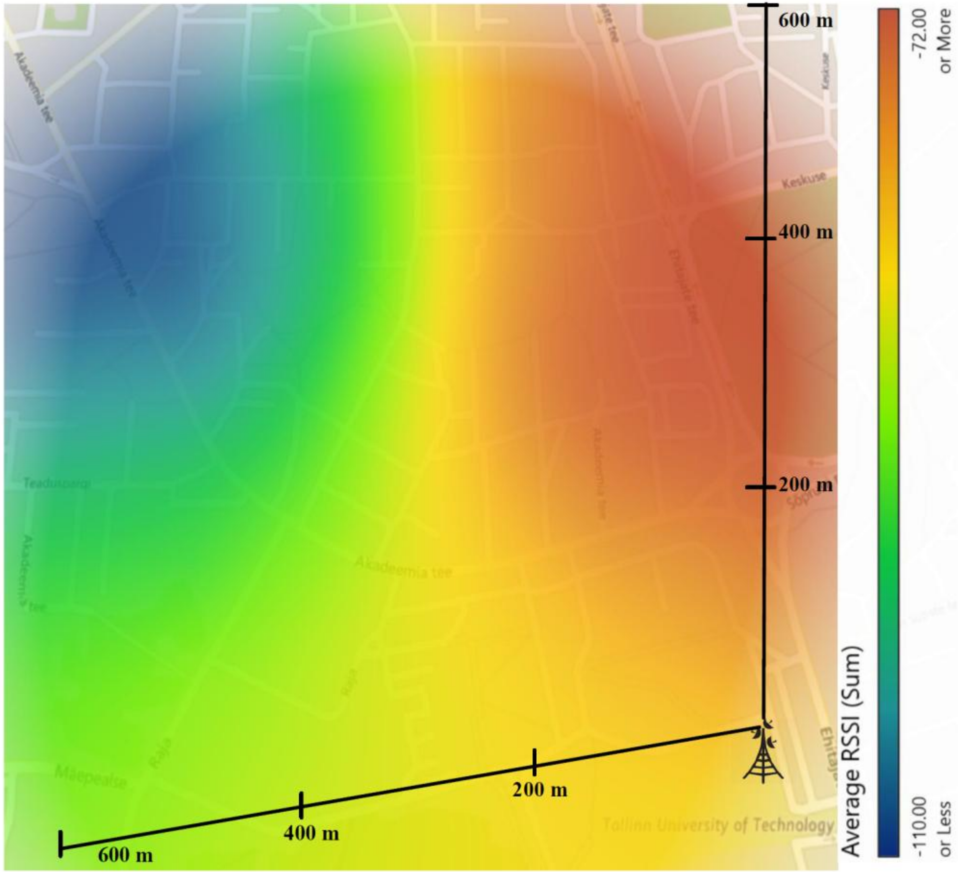
NB-IoT user node

NB-IOT NETWORK TRIAL: INDOOR, OUTDOOR AND UNDERGROUND COVERAGE CAMPAIGN



Coverage of NB-IoT in outdoor in terms of RSSI

NB-IOT NETWORK TRIAL: INDOOR, OUTDOOR AND UNDERGROUND COVERAGE CAMPAIGN

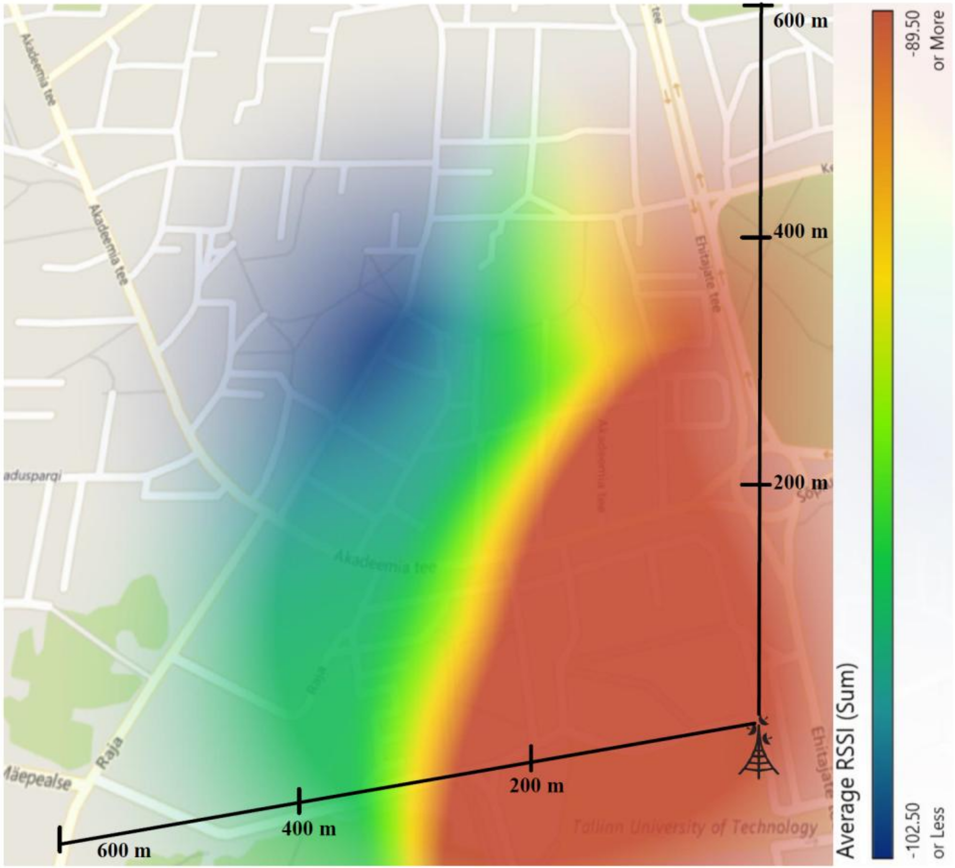


Coverage of NB-IoT in indoor in terms of RSSI

NB-IOT NETWORK TRIAL: INDOOR, OUTDOOR AND UNDERGROUND COVERAGE CAMPAIGN

- NB-IoT extends the coverage as compared to LTE and is able to meet the IoT application requirements in outdoor and indoor scenarios.

- So far, the coverage for underground scenarios are not as wide.



Coverage of NB-IoT in underground in terms of RSSI