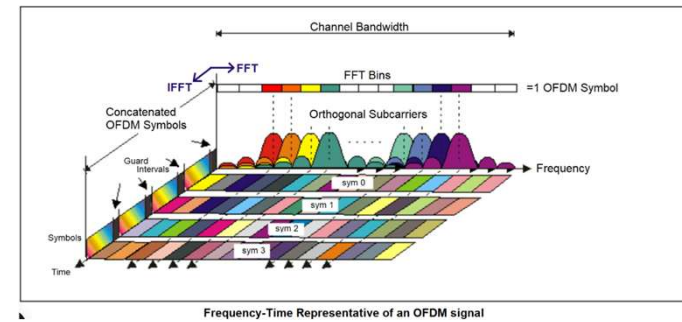
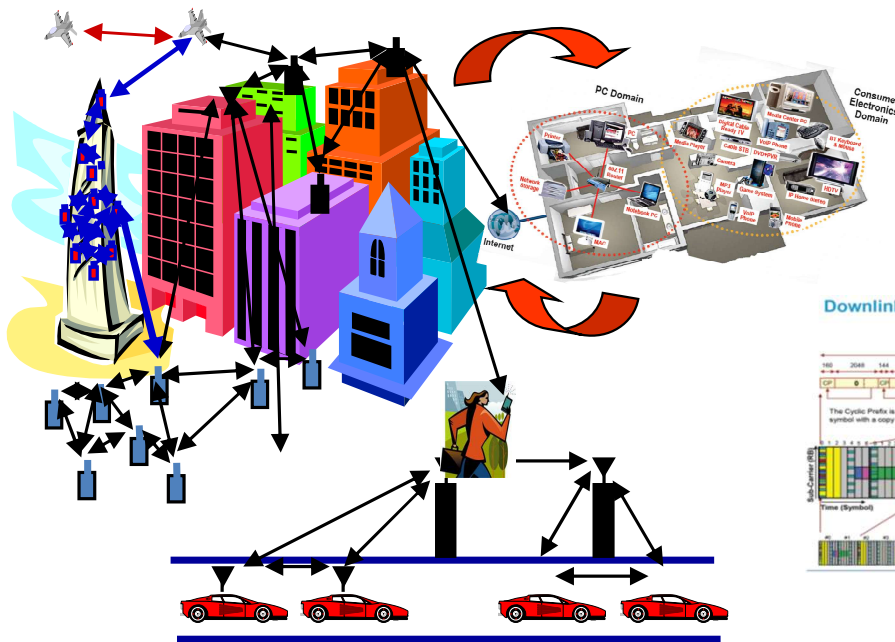
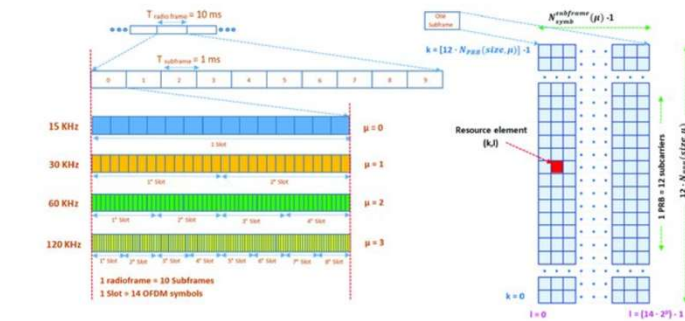
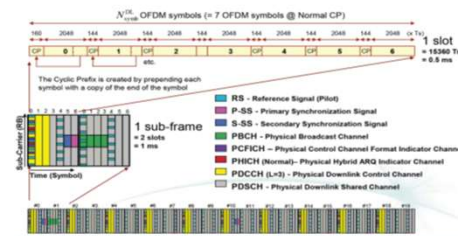


IEE2650: Cellular Communication Technologies

Muhammad Mahtab Alam, Professor



Downlink Frame Structure Type 1



5G and Internet of Things

TABLE OF CONTENT

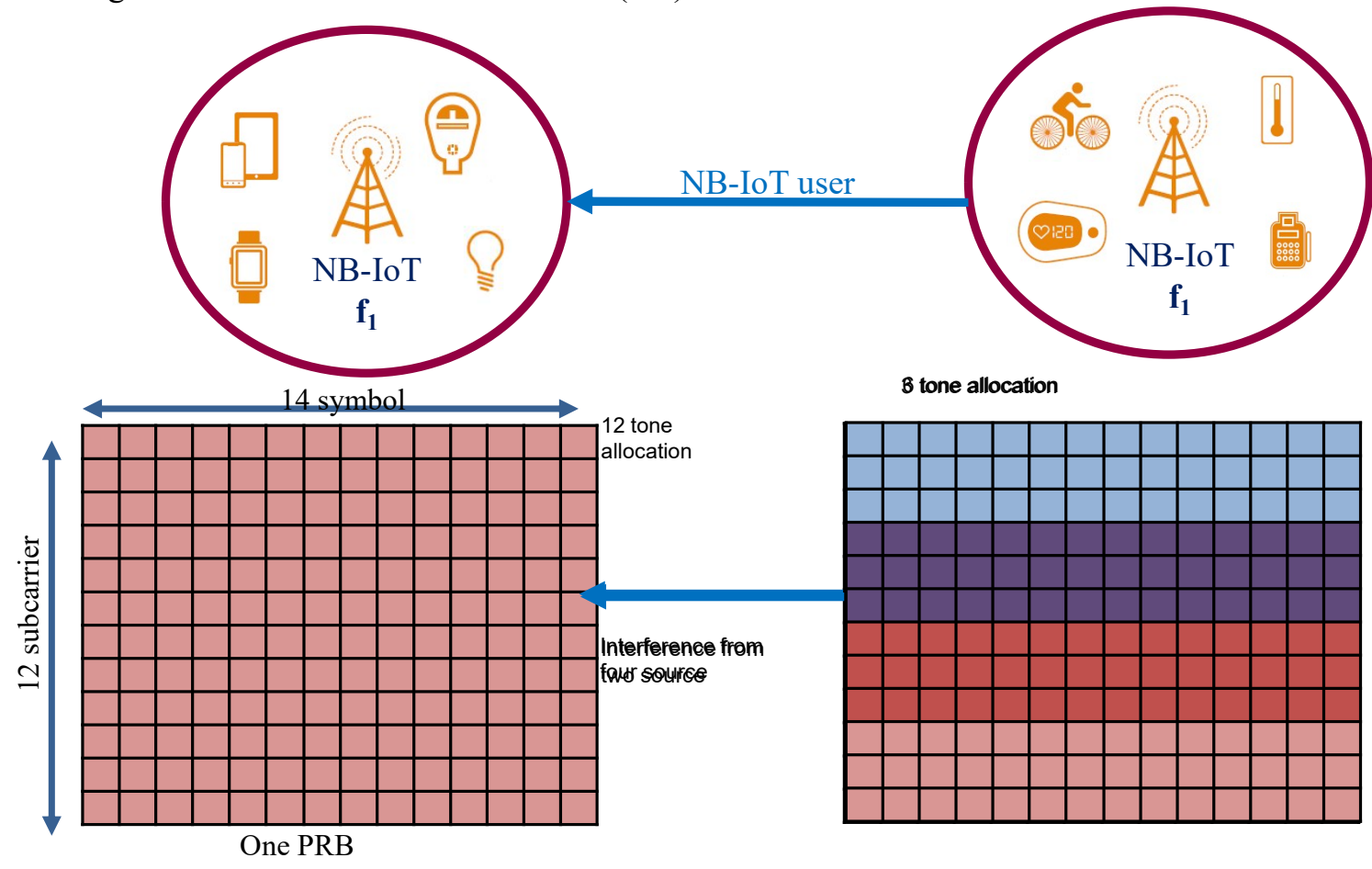
- ❑ Open Challenges for NB-IoT
 - ✓ Interference management
 - ✓ Control channel overhead
 - ✓ Joint Downlink and uplink optimization
 - ✓ Repetition optimization
 - ✓ Asymmetric traffic accommodation
 - ✓ Security and privacy management
 - ✓ Mobile Positioning

- ❑ Solutions
 - ✓ Sum-rate maximization using cooperative and noncooperative approach
 - ✓ A Radio Resource Management Framework Assisted by Interference Prediction and Flexible Duplexing for NB-IoT Networks

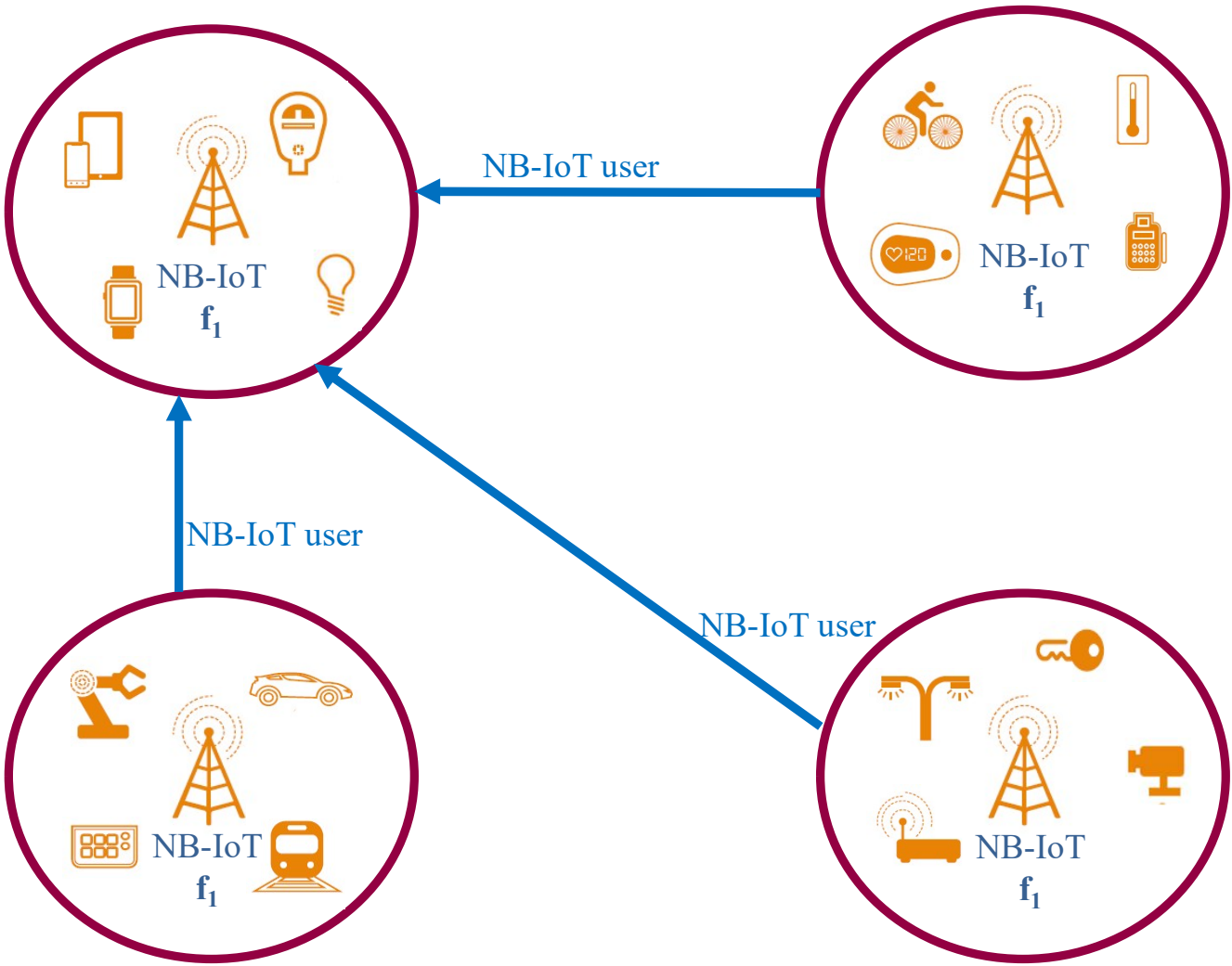
- ❑ NB-IoT Use-case and Testbed

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).



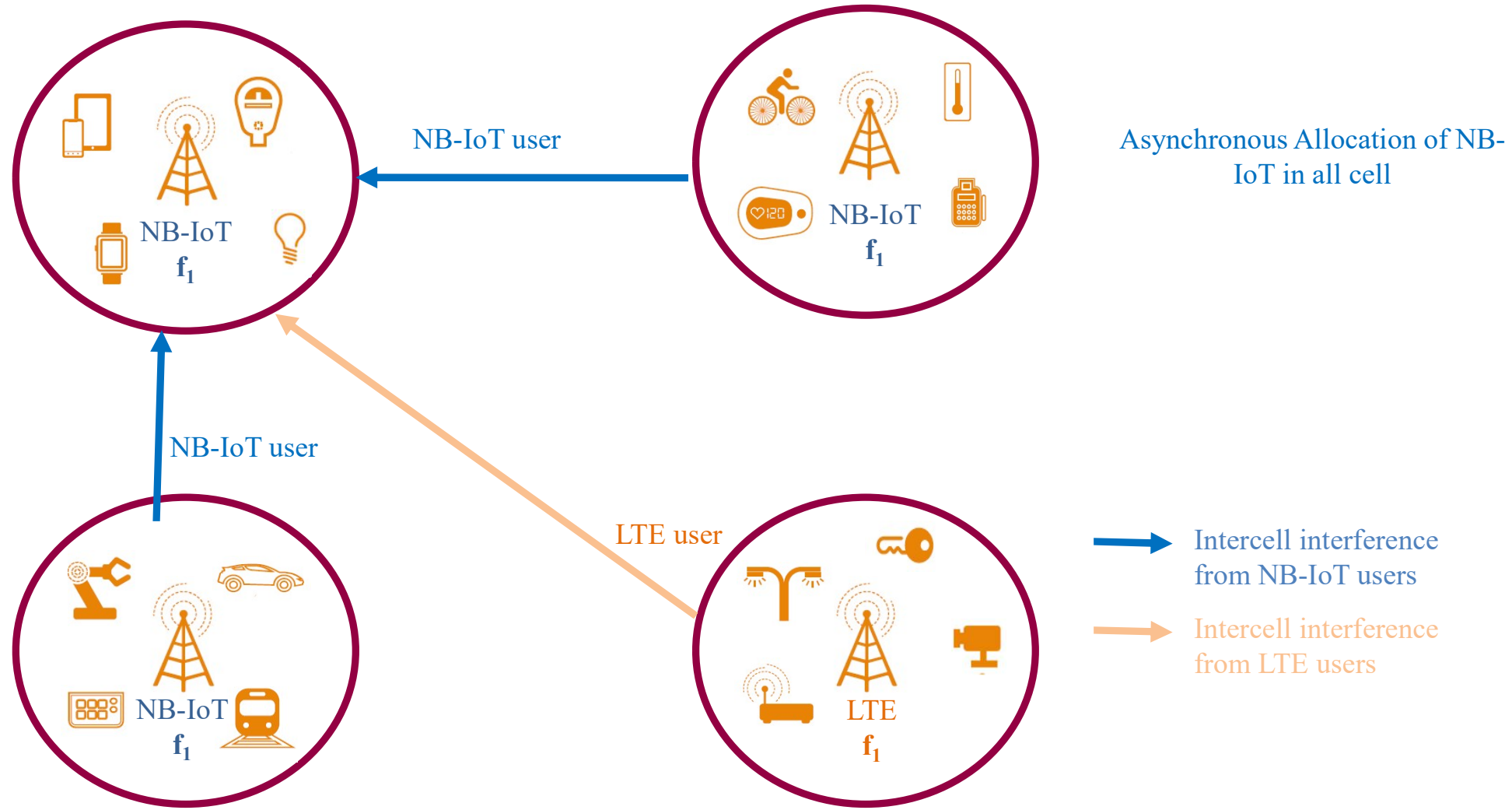
NB-IOT DEPLOYMENT STRATEGIES



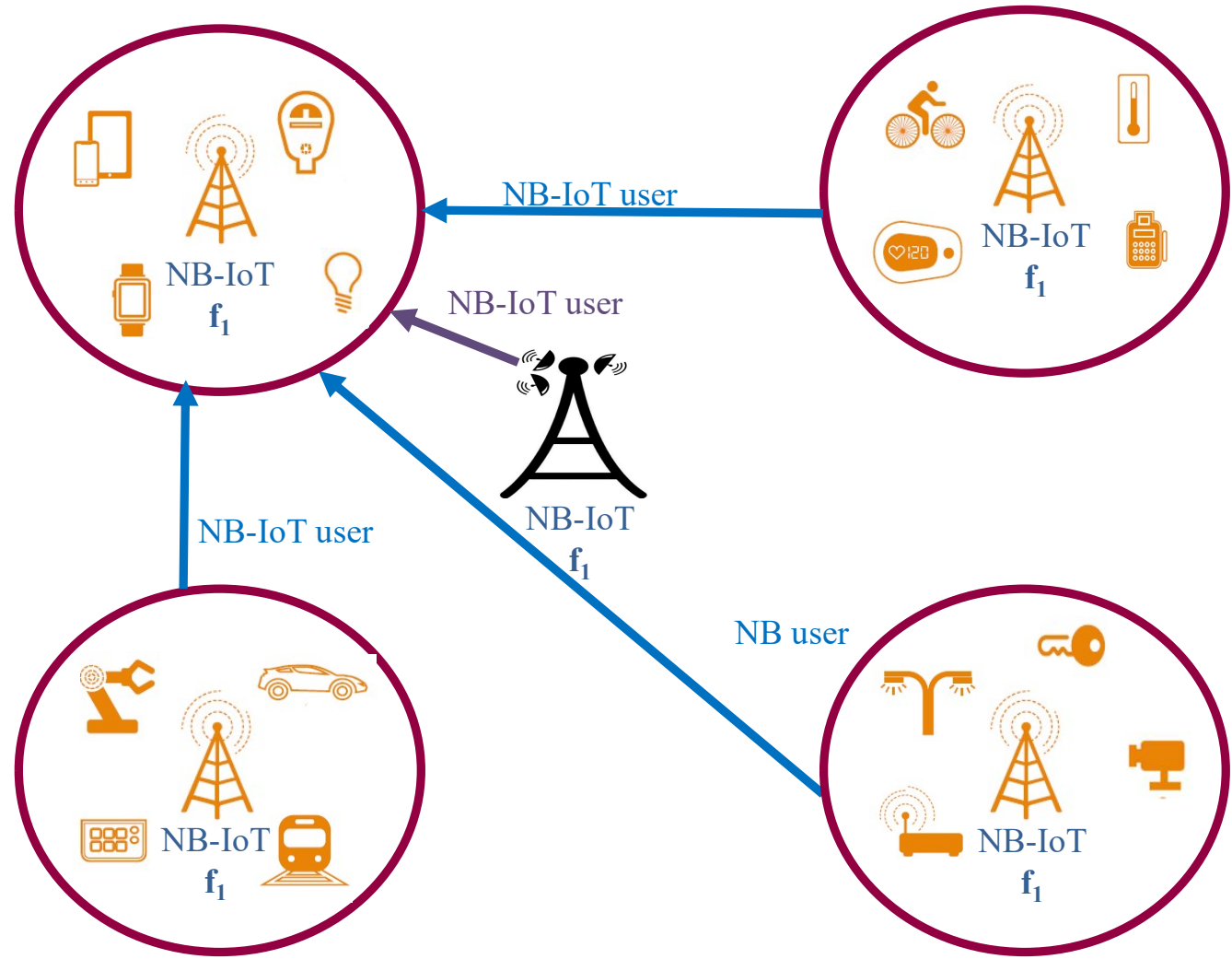
Synchronous Allocation of NB-IoT in all cell

→ Intercell interference from NB-IoT users

NB-IOT DEPLOYMENT STRATEGIES



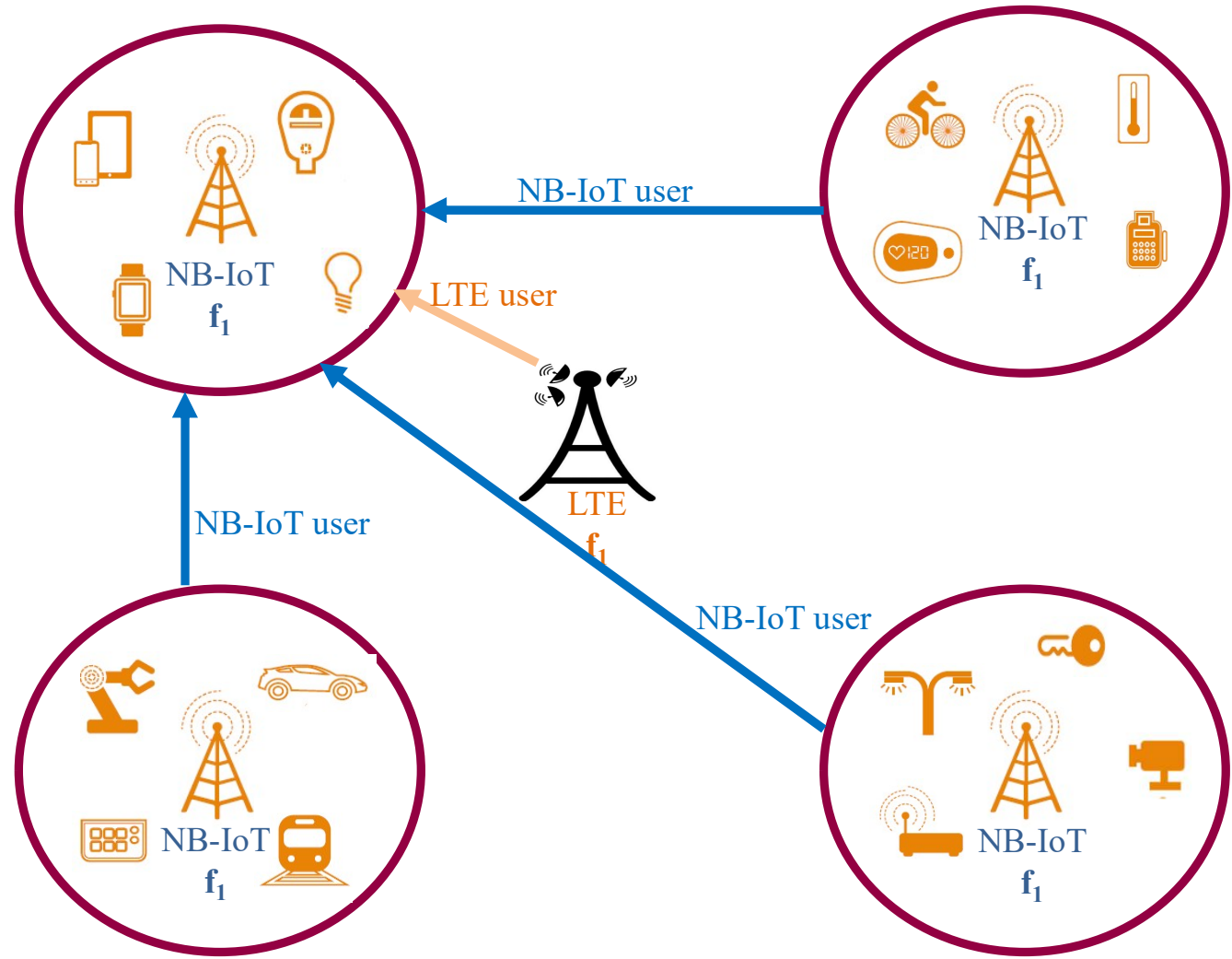
NB-IOT DEPLOYMENT STRATEGIES



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 LTE users

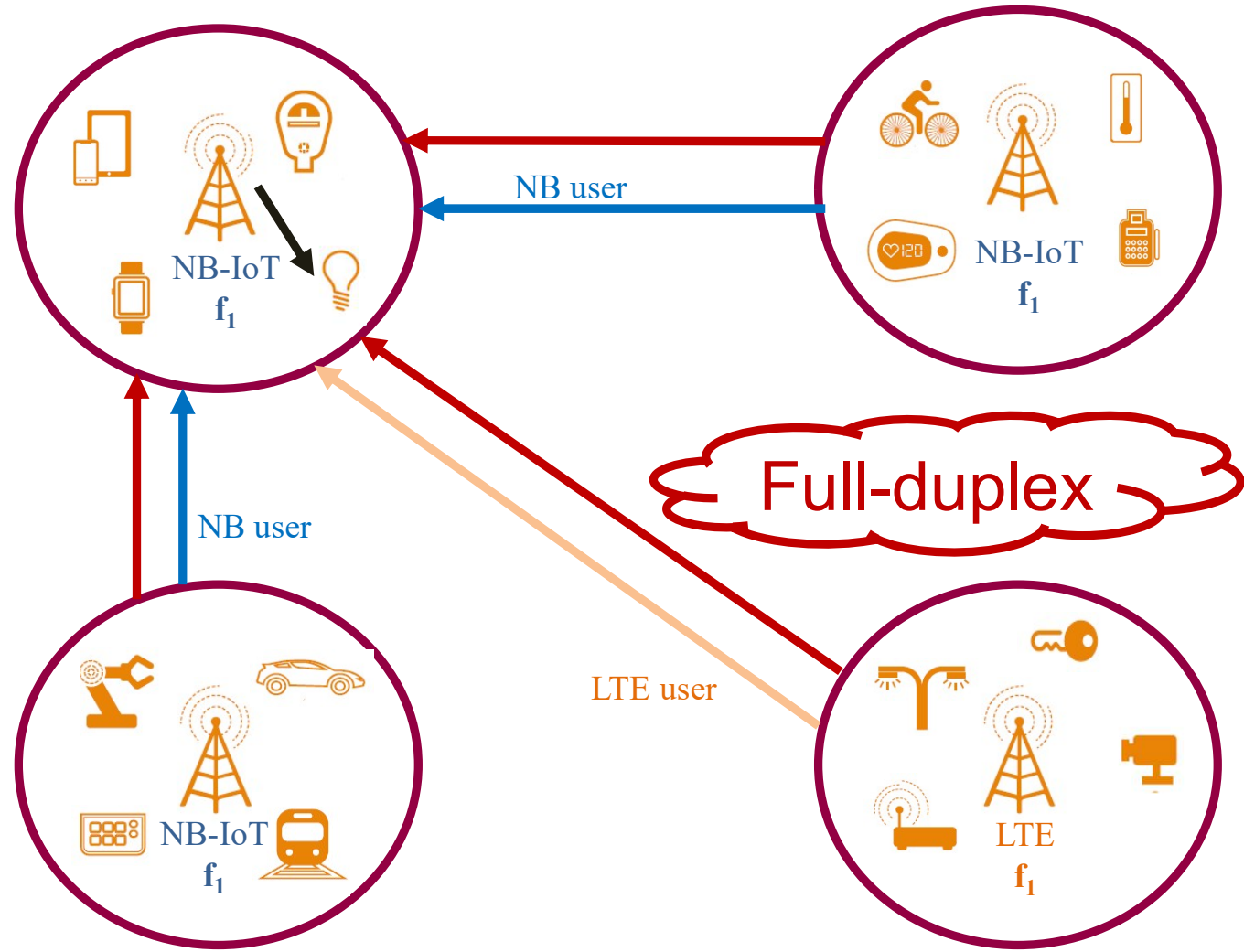
FULL/HALF/SIMPLEX DUPLUX SYSTEM

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

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).

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.

NB-IOT DEPLOYMENT STRATEGIES

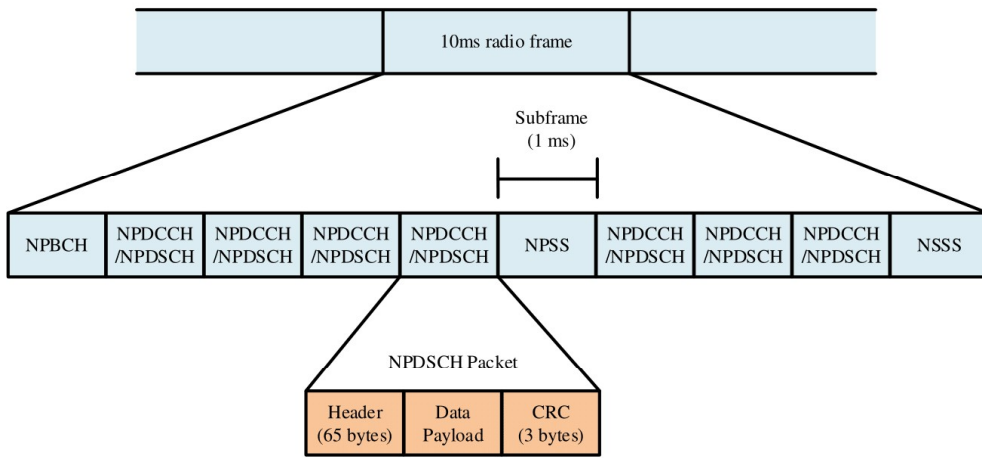


Asynchronous Allocation of NB-IoT in all cell

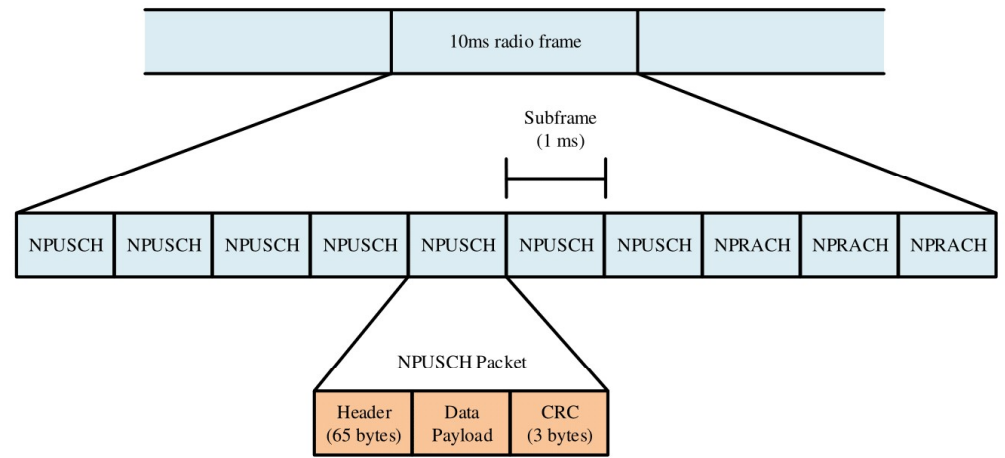
- Intercell interference from NB-IoT users
- Intercell interference from macrocell LTE users
- Intracell interference due to FD user in same cell
- Intercell interference due to FD user in neighbouring cell

CONTROL CHANNEL

- NPBCH on 0th subframe of every frame. NPSS on 5th and NSS on 9th 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.

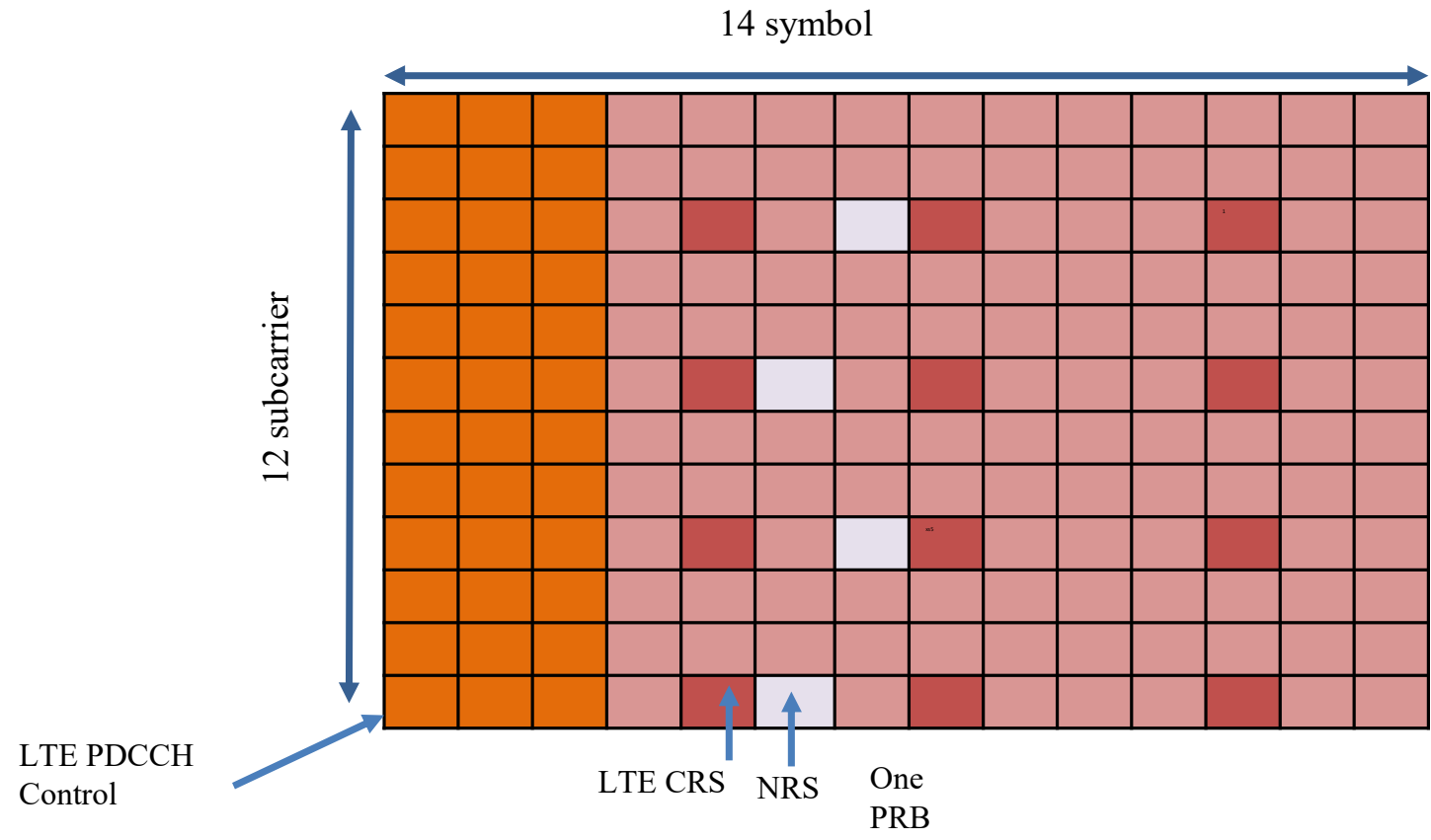


(a) Downlink Frame Structure



(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: Narrowband Reference Signal

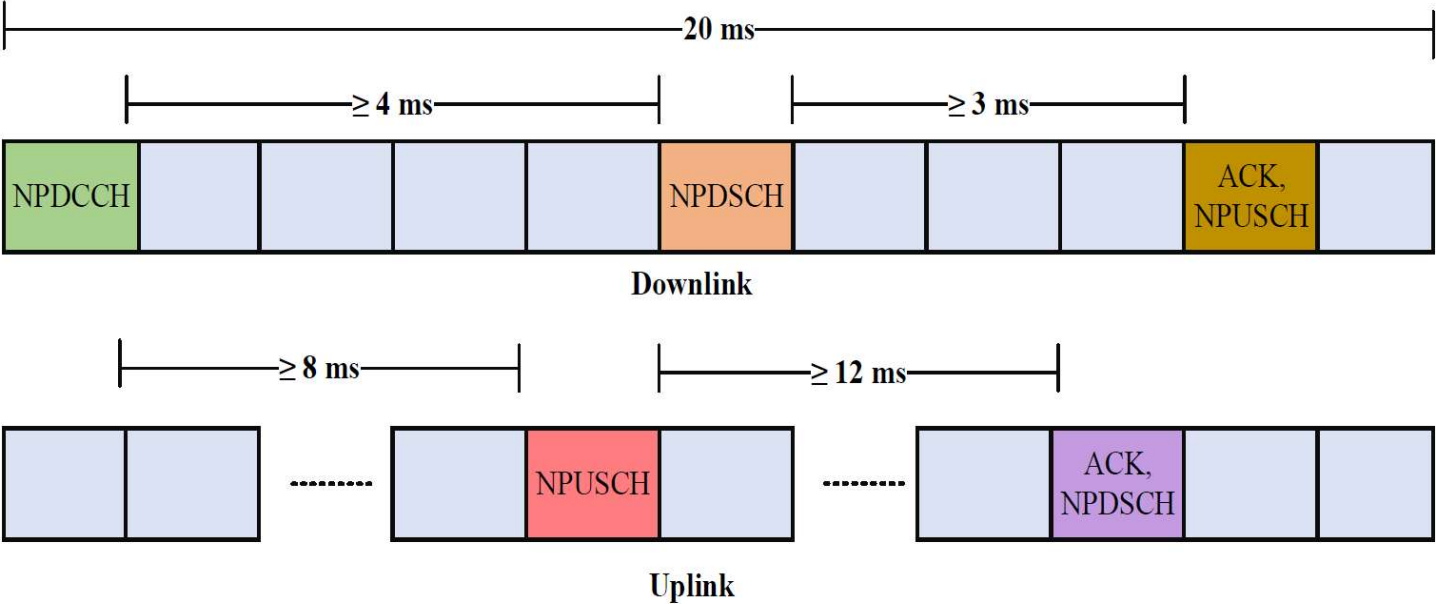
REPETITION

- ❑ Although retransmissions help recover a packet, they add significant redundancy and overhead, thereby reducing spectrum efficiency, battery lifetime and increases maintenance cost of user devices.
- ❑ Each retransmission requires both physical (PHY) and medium access control (MAC) headers, which consume up to 65 bytes or 29 bytes (i.e., compressed).
- ❑ In fact, each retransmission nearly doubles the packet delivery time.
- ❑ 2-dimensional link adaptation considering both modulation and coding scheme (MCS) and retransmission selection for NB-IoT
- ❑ The maximum number of retransmissions allowed in downlink and uplink are 2048 and 128, respectively.

Clearly, improving the packet reception rate with retransmissions is not an optimal choice

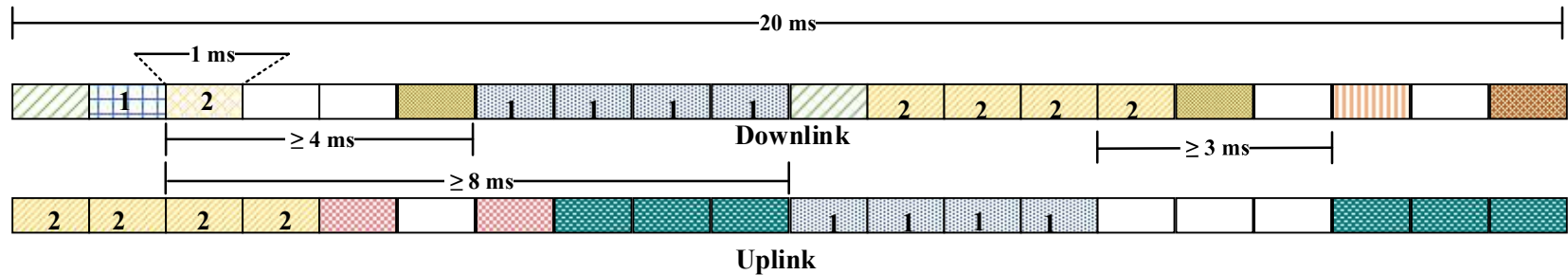
JOINT OPTIMIZATION OF DOWNLINK AND UPLINK

- ❑ 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

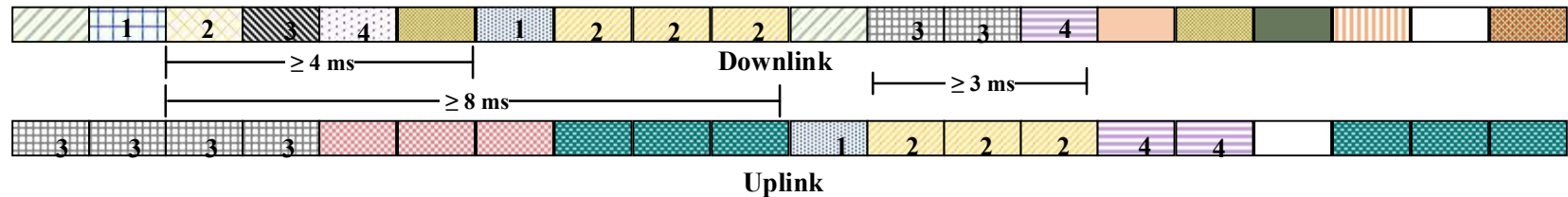


Recommended Scheduling delays by 3GPP

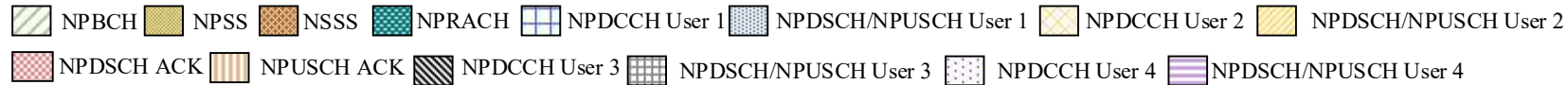
ASYMMETRIC TRAFFIC



(a) Fixed payload size



(b) Varied payload size



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

HOW TO SOLVE ABOVE MENTIONED CHALLENGES

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

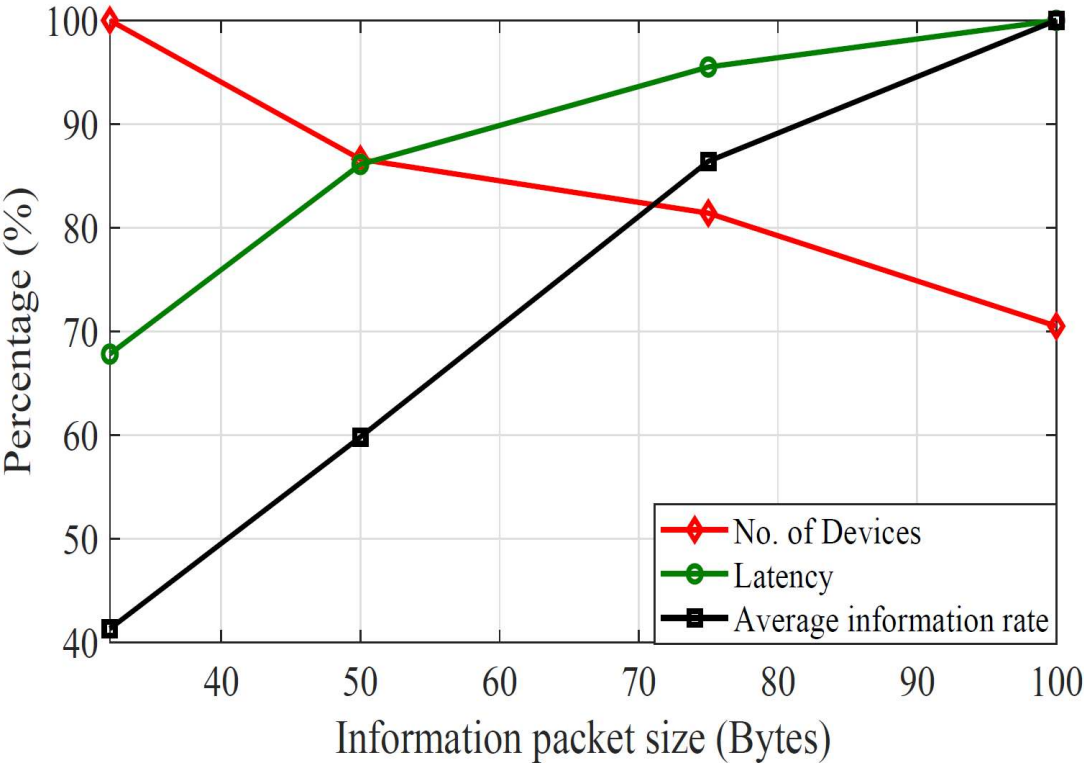
Parameters	Standalone		In-band	
	144	164	144	164
MCL (dB)	144	164	144	164
Target SNR (dB)	15.4	-4.6	7.4	-12.6
BLER NPDSCH	8.07 %	9.58 %	9.54 %	7.43 %
BLER NPDCCH	1 %	0.5 %	0.52 %	0.6 %
Repetition NPDSCH	1	32	1	128
Required subframe	6	6	8	8
Duration NPDSCH (ms)	6	250	8	1362
Repetition NPDCCH	1	128	1	256
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	
	144	164	144	164
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

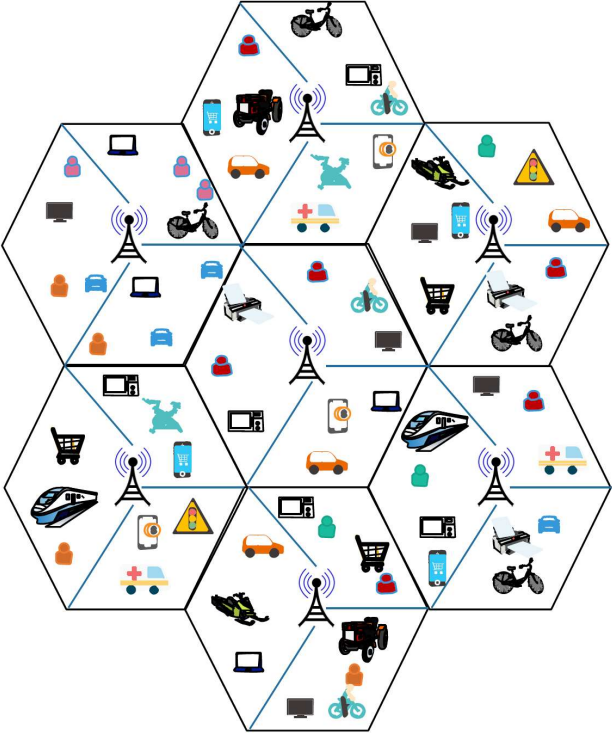
NB-IoT uplink effective data rate in different deployment scenarios with a TBS = 1000 bits, modulation = QPSK and Code rate = 1/3

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

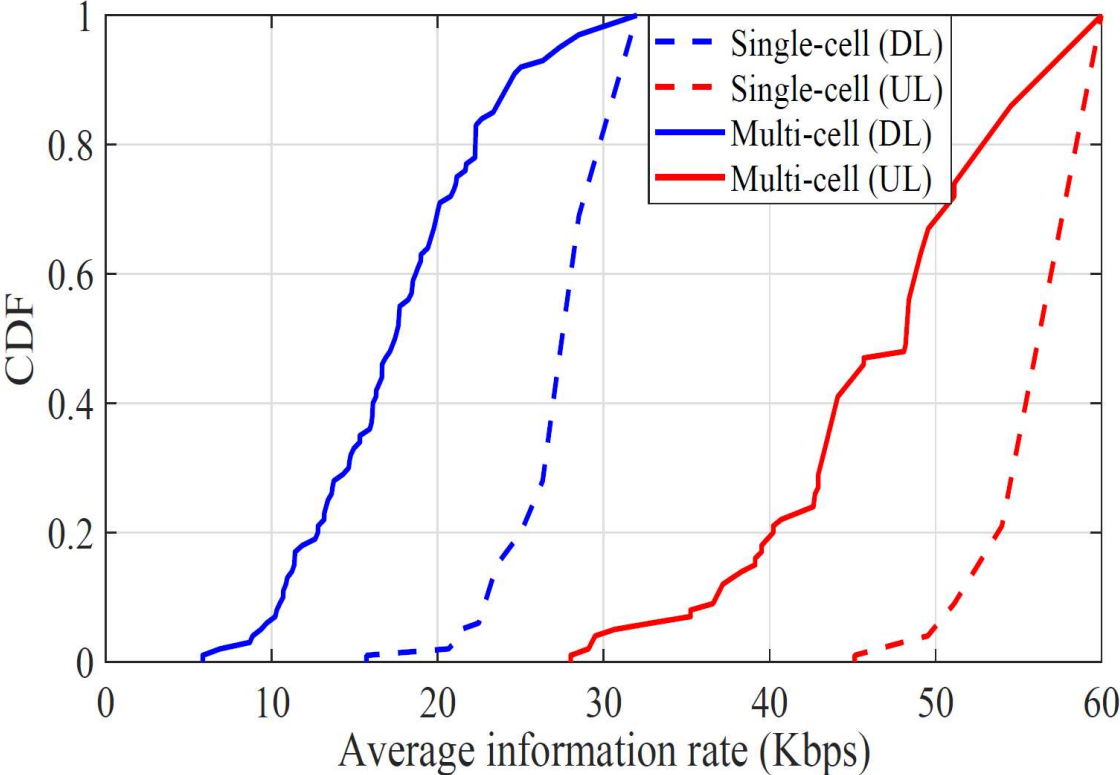


Multi-cell scenario under study

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

PROBLEM FORMULATION

Sum-rate maximization problem with the constraints can be formulated as:

$$\max_{x_{m,s,t}, P_{m,s,t}} \sum_{m \in \mathcal{M}} \sum_{b \in \mathcal{B}_t} \sum_{t \in \mathcal{T}} x_{m,s,t} R_{m,s,t} \quad \forall m \in \mathcal{M}, s \in \mathcal{S}, t \in \mathcal{T}$$

subject to

$$x_{m,b,t} \in \{0, 1\}$$

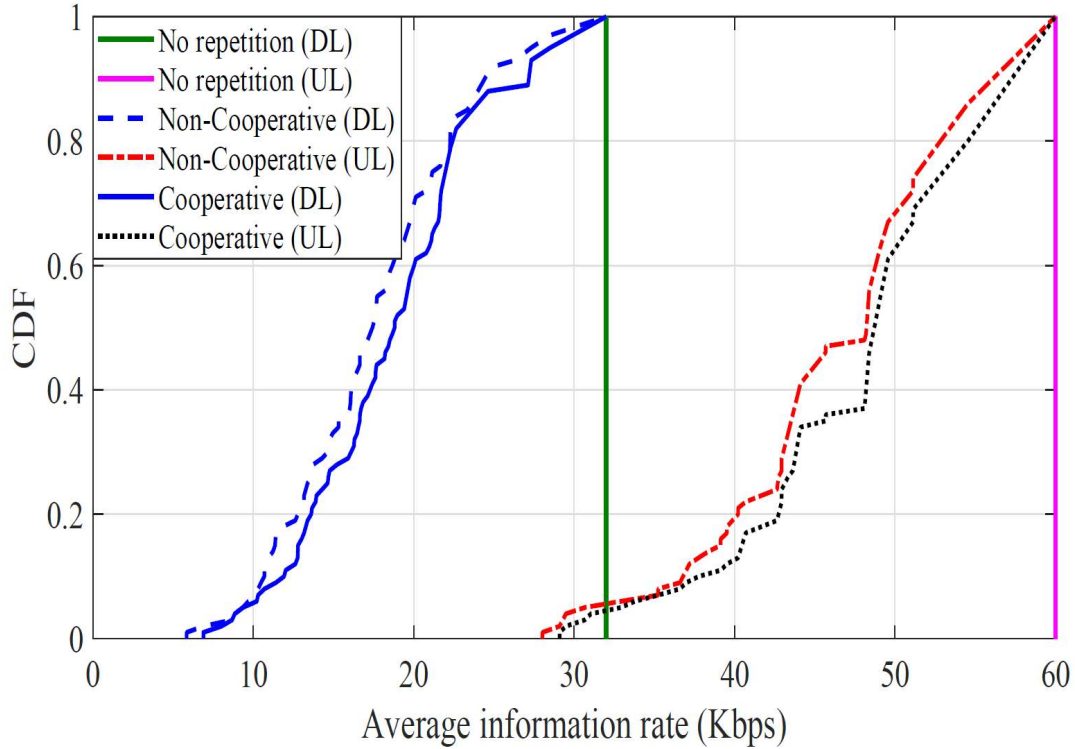
$$\Phi_{m,b,t}^{sum} \leq \Phi_{m,b,t}^{max}$$

$$\sum_{t \in \mathcal{T}} R_{m,b,t} \geq R_{m,b,t}^{min}$$

$$\sum_{t \in \mathcal{T}} P_{m,b,t} \leq P_{max},$$

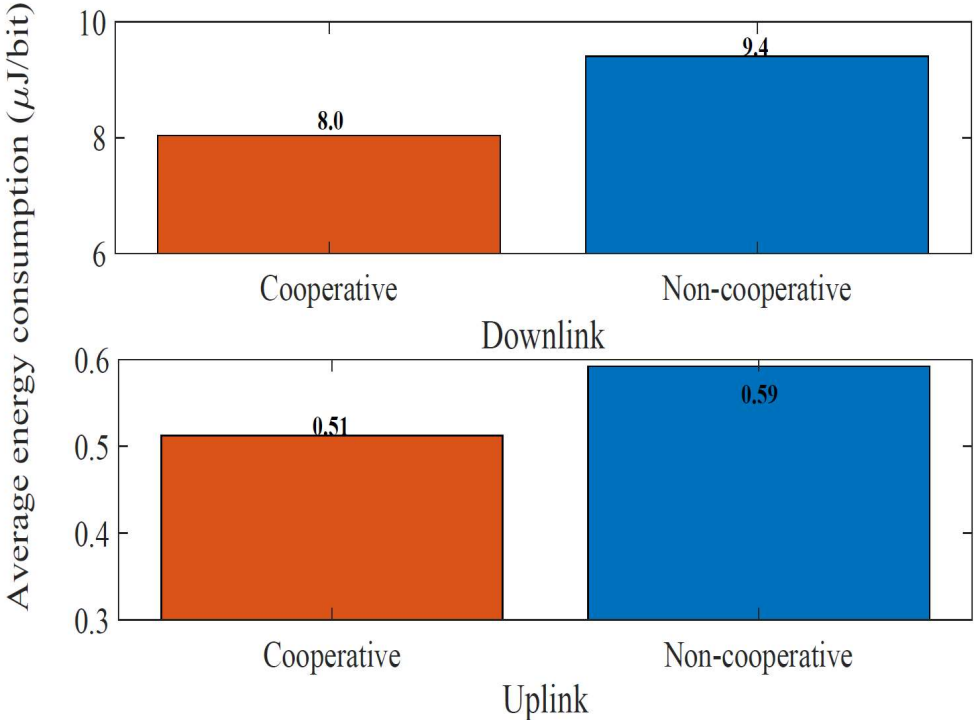
$$P_{m,b,t} \geq 0$$

PROPOSED SUM-RATE MAXIMIZATION SOLUTION



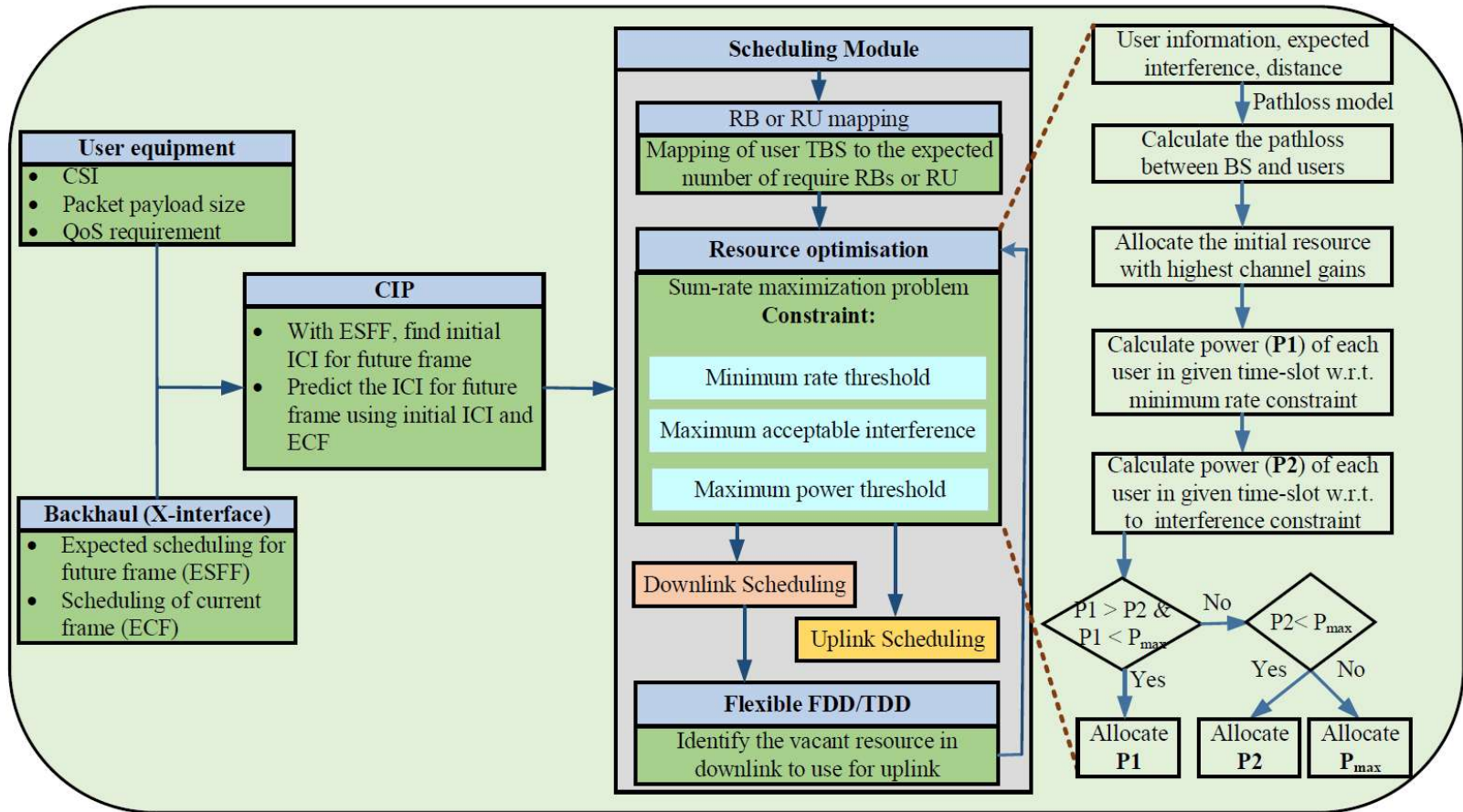
Cooperative scheme provides up to 12% rate improvement compared to non-cooperative

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, Time of Flight + AoA Method (ToA/ToF)

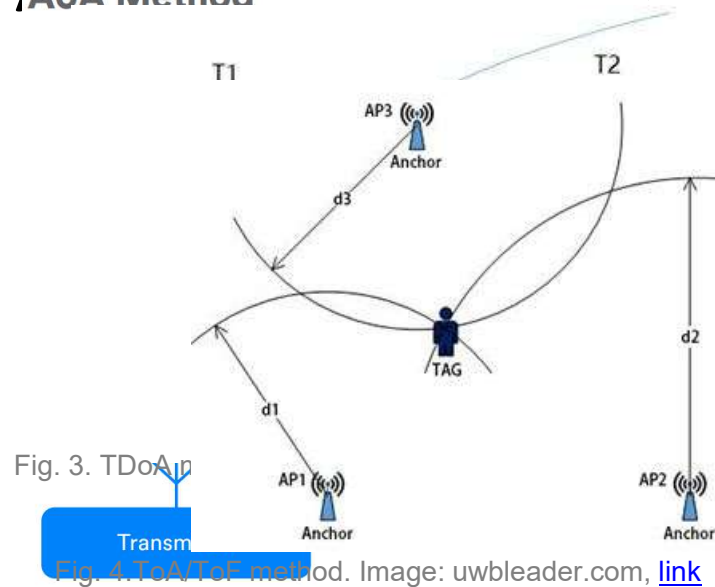


Fig. 2. Angle of Arrival method. Image: MICROCONTROLLER TIPS, [link](#)

MOBILE POSITIONING IN 5G

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

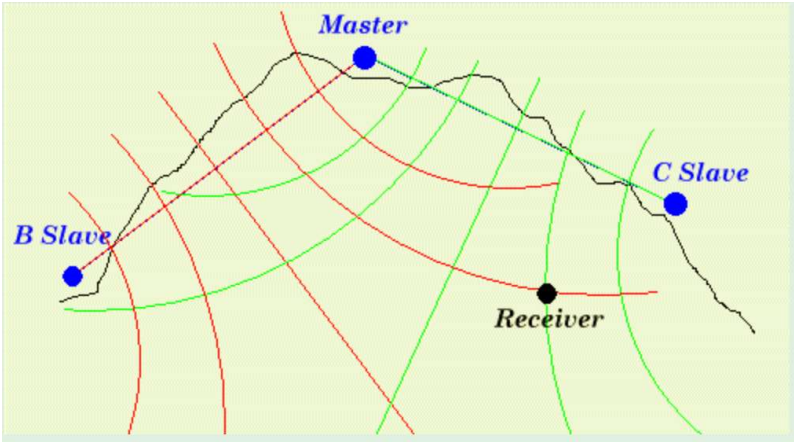
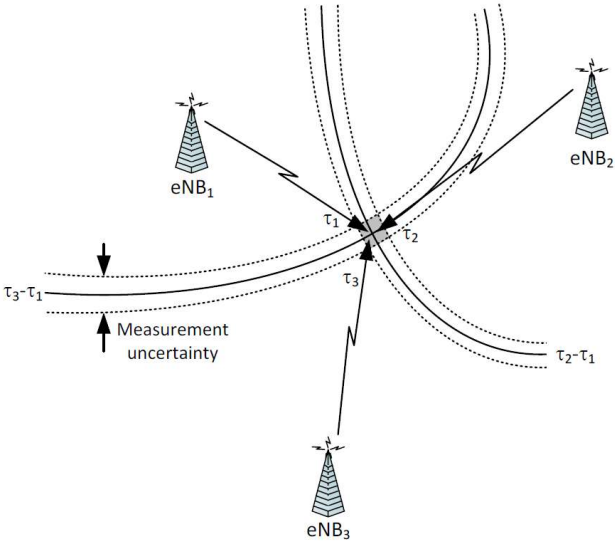
CELL ID AND ENHANCED CELL ID

- 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).



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).