Narrowband Internet of Things

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INTRODUCTION

- What is NB-IoT?
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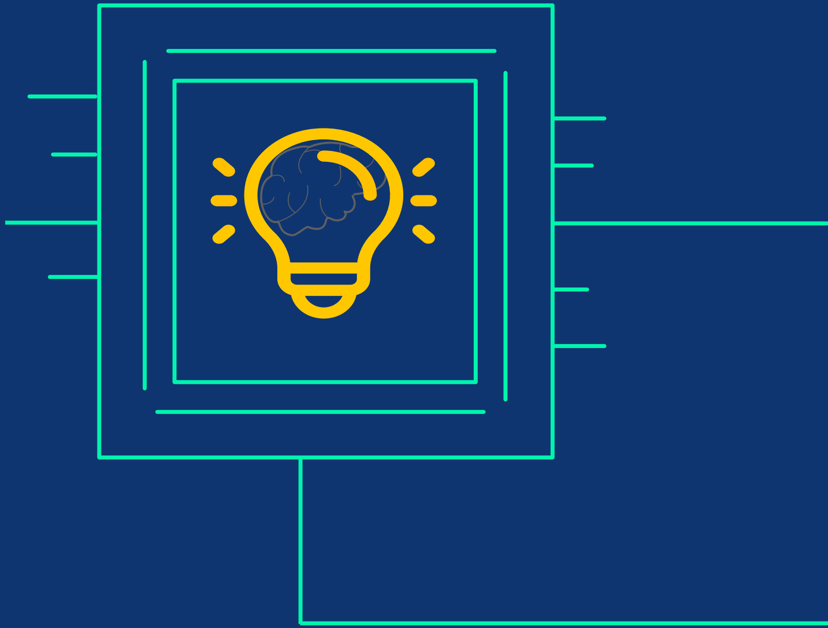


WHAT IS NB-IOT?

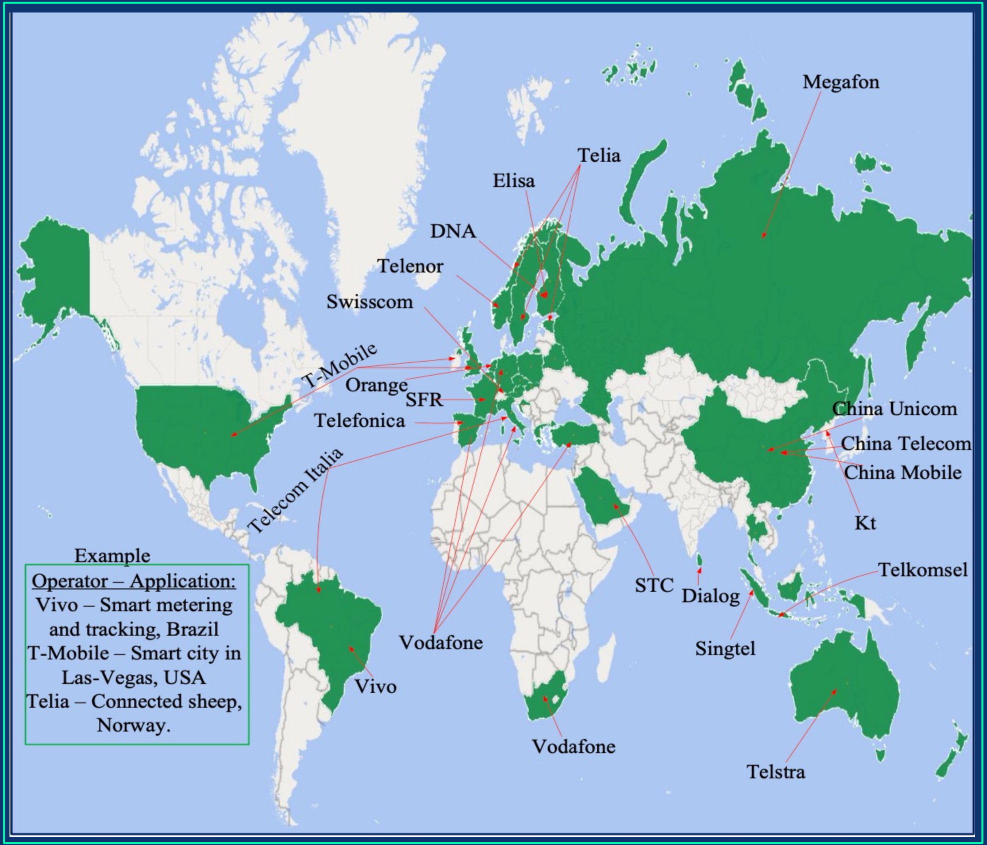
- A cellular radio access technology based on Long-Term Evolution (LTE)
- Introduced by Third-Generation Partnership Project (3GPP) for licensed Low-Power Wide-Area Networks (LPWAN)
- Supports massive machine-type communication (mMTC)
- Enables low-power, low-cost, low-data-rate communication
- Allows for connectivity of devices in challenging positions

WHAT IS NB-IOT?

- The term Narrowband refers to NB-IoT's bandwidth of maximum 200 kHz.
- It can coexist either in the Global System for Mobile Communications (GSM) spectrum or by occupying one of the legacy LTE Physical Resource Blocks (PRBs) as in-band or as guard-band.
- NB-IoT delivers better performance in terms of the supported number of devices, and coverage enhancements for latency-insensitive applications with maximum coupling loss (MCL) of about 20 dB higher than LTE.

REAL-LIFE DEPLOYMEANTS

Practical feasibility on diverse use cases are provided by features such as flexible deployment and the possibility of over-the-air firmware upgrades.



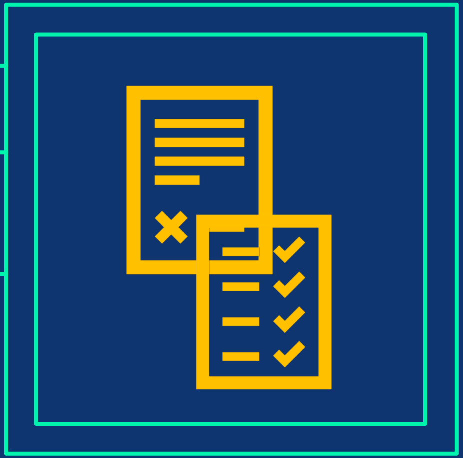
REAL-LIFE DEPLOYMEANTS

USE CASES

- Connected sheep in Norway
- Smart metering and tracking in Brazil
- Smart city in Las Vegas

VENDORS

- Skyworks
- Media tek
- Intel
- Nuel (Huawei)



STANDARD AND RELEASES

- NB-IoT standardization history
- Different releases prospects and enhancements

NB-IOT STANDARDIZATION HISTORY

MAY 2014

Huawei and Vodafone

AUGUST 2014

Qualcomm

MAY 2015

3GPP merged the two proposals

JULY 2015

Ericsson

SEPTEMBER 2015

3GPP included all proposals as a work item for Release 13

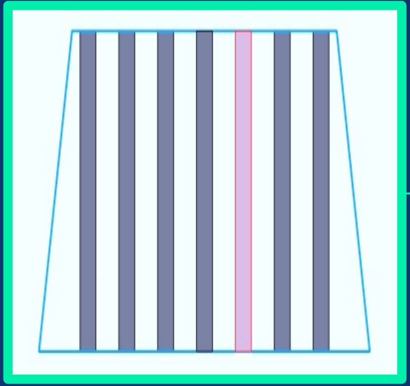
NB-M2M → NB-OFDMA → NB-CIoT → NB-LTE → Release 13

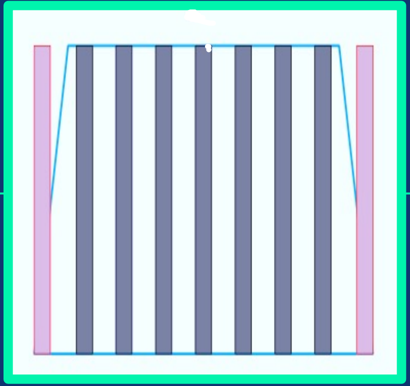
RELEASE 13

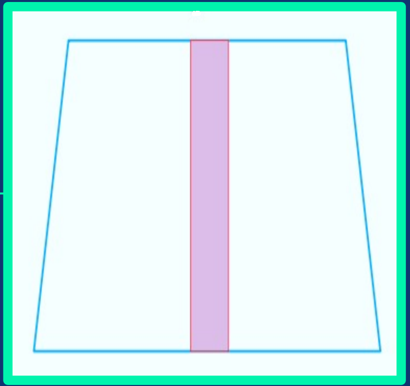
In order to enable cellular massive IoT deployment with low power, low complexity and hence low cost, 3GPP introduced the following features:

- Mode of operation
- Multi-Tone transmission support
- Complexity and cost reduction methods
- Power reduction methods
- Physical channels and signals
- Coverage enhancement methods

MODES OF OPERATION







Inband
allocation (180 kHz)
one LTE PRB within a carrier
bigger than 1.4 MHz

Guardband
allocation (180 kHz)
LTE spectrum

Standalone
allocation (200 kHz)
GSM spectrum
”Refarming”

MULTI-TONE TRANSMISSION SUPPORT

- The allocation of Resource Units to multiple User Equipment to reach the massive device deployment objective (contrary to LTE uplink)
- Tones (frequency domain) with different durations are allocated to UEs
- Uplink (SC-FDMA) spacing options:
  - 15 kHz (The standard subcarrier spacing)
  - 3.75 kHz (Higher robustness)
- Downlink (OFDM) spacing:
  - 15 kHz

MULTI-TONE TRANSMISSION SUPPORT

- 15 kHz spacing

Single-tone	Multi-tone	
Duration (ms)	Number of tones	Duration (ms)
8	3	4
	6	2
	12	1

MULTI-TONE TRANSMISSION SUPPORT

- 3.75 kHz spacing
  - only single-tone allocation to different users
  - 48 subcarriers
  - 32 ms duration

COMPLEXITY AND COST REDUCTION METHODS

01 Relaxed base-band processing

02 Low memory storage

03 Reduced RF components

04 Reduced frequency and time synchronizations

05 Use of restricted BPSK and QPSK

06 Only one antenna support for both UL and DL

POWER REDUCTION METHODS

- NB-IoT devices are intended to have a 10 years battery life.
- The devices can be synchronized to wake up by either RTC, triggering from sensors, or both.

PSM

Completely sleep while remaining registered online but cannot be reached by the base station signaling, can be in PSM mode up to about 413 days

eDRx

Inactive mode for a few minutes to a few hours only, allows more accessibility compared to PSM

POWER REDUCTION METHODS

- In idle state the UE periodically monitors paging channel to check for incoming data.

- In eDRx mode, this periodicity (DRx cycle) has been extended (from a maximum value of 2.56s in LTE to a maximum value of about 175 minutes).

- In PSM mode the UE is registered but not reachable, meaning that paging is not monitored and further energy saving with respect to the idle state can be resulted.

UPLINK PHYSICAL CHANNELS AND SIGNALS

NPRACH	Used by UEs to perform initial access to the network, to request transmission resources, and to reconnect to the base station after a link failure
NPUSCH	Used to carry the uplink data packets transmissions
DMRS	Used for uplink channel estimation accuracy

DOWNLINK PHYSICAL CHANNELS AND SIGNALS

NPSS	Used by the UE for its initial frequency and timing synchronization with the base station and to get partial information regarding the cell identity
NSSS	Used to accomplish full DL synchronization by obtaining the physical narrow-band cell ID
NPDSCH	Used to carry the downlink data packets transmissions, supports a maximum block size of 680 bits

DOWNLINK PHYSICAL CHANNELS AND SIGNALS

NPBCH	Used by the UE to acquire MIB and is used to broadcast information about cell and network configurations
NPDCCH	Used by the UE to receive SIB, transfers all the control signals from the eNodeB to the UE via DCI
NRS	Used for cell search and initial system acquisition and as a reference point for the DL power

MORE ON NPDCCH

- The NPDCCH carries the Downlink Control Information (DCI) for both data reception and transmission with related number of repetitions.
- The periodicity of NPDCCH occasions varies depending on the use case.
- NB-IoT has three DCI formats:
    - N0: Used for UL grant
    - N1: Used for DL scheduling
    - N2: Used for paging

MIB-NB CONTENT

- Operation mode (stand-alone, in-band, guard-band)
- In case of in-band and guard-band, the frequency raster offset (2.5, 7.5 kHz)
- Four MSBs of the SFN (System Frame Number)
- Two LSBs of the H-SFN
- SI value tag, which is essentially a version number of the SI.
- Access barring (AB) information

SIB1 CONTENT

- Hyperframe information
- Network information such as PLMN, tracking area and cell identities
- Access barring status, thresholds for evaluating cell suitability
- Valid subframe bitmap
- Scheduling information regarding other System Information Blocks

COVERAGE ENHANCEMENT METHODS

- The exploitation of repetitions to reach devices in challenging positions
- An additional coverage of 20 dB as compared to the legacy LTE system (164 dB of MCL)
- Up to 128 retransmissions in uplink
- Up to 2048 retransmissions in downlink

COVERAGE ENHANCEMENT METHODS

- Each replica can be decoded separately or multiple replicas can be combined to further increase the reception probability.
- Suitable for use cases that are latency insensitive as it can tolerate up to 10 seconds transmission delay.

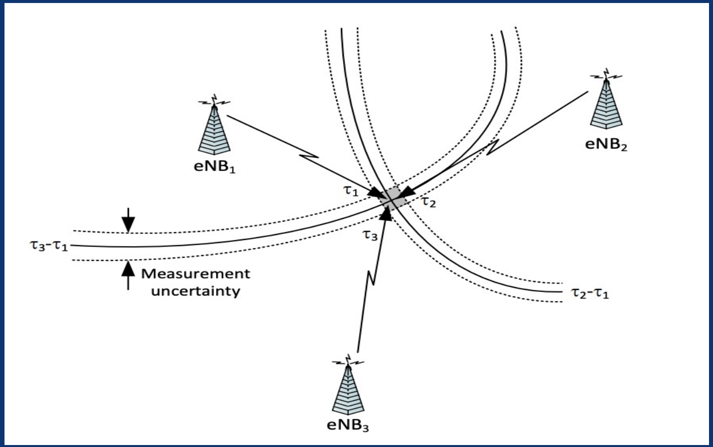
RELEASE 14

After the implementation of Release 13 features, studies erupted along with field trials that revealed the need for further enhancements to improve the quality of service as well as user experience. 3GPP introduced the following features in release 14:

- Improved Positioning Technique
- Multicast services
- New Power Class for Narrowband-IoT User Equipment
- New Transport-Block-Size Support
- Multicarrier Operation
- User Equipment Mobility Enhancement

IMPROVED POSITIONING TECHNIQUE

Observed time difference of arrival (OTDOA): The UE measures the times of arrival (ToAs) of positioning reference signals (PRSs) received from different transmitters with respect to a reference node's PRS transmission to form the reference signal time difference (RSTD) measurements.



IMPROVED POSITIONING TECHNIQUE

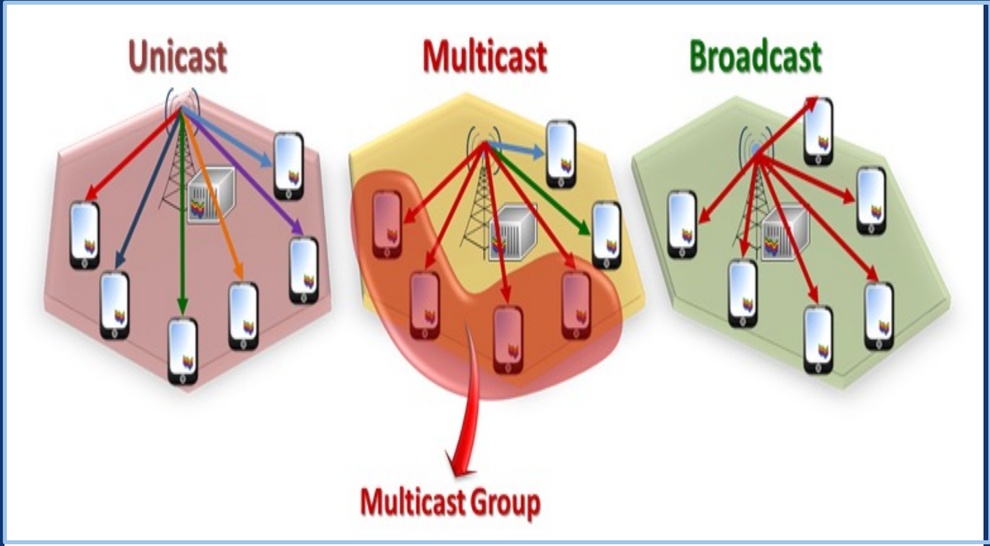
OTDOA is used to enhance UE position measurement of cell identity (CID) the measurement requirements include:

- The base station receive and transmit time difference
- Reference signal received power
- Reference signal received quality

MULTICAST SERVICES

Multimedia Broadcast Multicast Services (MBMS) is introduced to:

- optimize resources
- reduce transmission latency



SINGLE-CELL POINT-TO-MULTIPOINT

In release 14 MBMS is supported through single-cell point-to-multipoint (SC-PTM).

- A mix of unicast transmissions and the eMBMS framework
- Efficient and dynamic for optimal radio resource usage
- Allows broadcast or multicast services to a specific group based on real-time traffic load and user requirement
- Uses NPDSCH by mapping Single-cell MBMS Control Channel and Single-Cell MBMS Traffic Channel that carry control and data traffic to the physical layer scheduled by using the downlink control information.

SC-PTM PROCEDURE

1. The available services for SC-PTM are broadcasted.
2. The devices subscribe to services in order to receive the content.
3. Upon subscription, the device receives a group Radio Network Temporary Identifier (G-RNTI).
4. Control information (session start and stop, resource allocation, etc.) is carried in the NPDSCH periodically.
5. A generic multicast radio bearer is established and UE receive the multicast content in a similar way as for unicast transmission using their G-RNTI.

SC-PTM VS. UNICAST IN A USECASE

Firmware update delivery usecase:

- The effective gains of SC-PTM with respect to unicast mode are strictly related to the location of UEs.
  - The bigger the cell size or ISD, the greater the propagation loss and repetitions requirement thus, the more significant the delivery time decrease in SC-PTM with respect to unicast.
- The delivery time is affected by the number of UEs for the unicast case, whereas the SC-PTM's performance does not vary with the number of UEs.

NEW POWER CLASS FOR USER EQUIPMENT

The newly introduced power class allows the serving base station to acquire the device power class during the establishment of the connection.

The maximum allowed device's output power is reduced to 14 dBm → Coverage relaxation of 9 dB → Reduction of the drained current → Facilitation of the use of small coin-cell batteries (for limited size devices) → Compensation of the reduced power by increasing the transmission time

NEW TRANSPORT-BLOCK-SIZE SUPPORT

- 3GPP Release 14 introduces a new NB-IoT device category which supports the improved data rates by enhancing the Transport Block Size (TBS) to 2536 bits
- Improved data rates can be reached because of the ability to support a second Hybrid Automatic Repeat Request (HARQ) process, useful for enhancing the reliability of the link.
- Implementation of this optional second HARQ process results in throughput gain as it reduces the overhead caused by NPDCCH scheduling gaps.

MULTICARRIER OPERATION

- To enable the massive NB-IoT deployment, in Release 14, NB-IoT can monitor paging and perform random access on non-anchor carriers.
- one or more non-anchor carriers are added to the anchor carrier to carry out the synchronization and mobility measurements by using the NRS.
- Therefore, paging occasions and hence paging load will be spread over the anchor and non-anchor carriers and all carriers can then monitor paging.

USER EQUIPMENT MOBILITY ENHANCEMENT

- For the use cases that involve mobility, the temporary loss of radio increases transmission errors.
- The possibility of Radio Resource Control (RRC) re-establishment for the UE that supports data transfer via the control plane is provided.
- The UE will try to re-establish the connection on that cell and resume the data transfer and hide the temporary loss of the radio interface to the upper layers.

RELEASE 15

The following improvements were introduced in Release 15 to satisfy the fast adoption of massive deployment with further improved quality of service:

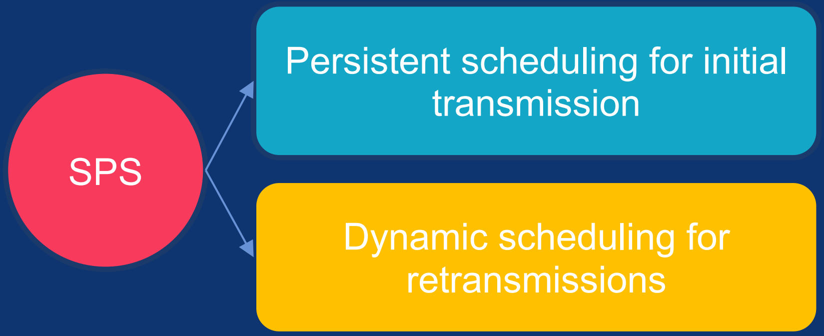
- Latency reduction
- Semi-Persistent Scheduling
- Small Cell Support
- Enhanced User Equipment Measurements
- Time Division Duplex (TDD) Support

LATENCY REDUCTION

- The physical layer Scheduling Request (SR): a special message to request the network to send the access grant so that the UE can transmit data.
- NB-IoT uses a wake-up signal to wake up the main receiver when the UE is required to decode the physical downlink control channel in paging occasions (idle mode only).
- Significant power consumption reduction is achieved even when a common wake-up signal is used for a group of UEs.
- Quick RRC release and early data transmission during random access channel (RACH) procedure are supported to reduce the UE transmission latency and hence power consumption.

SEMI-PERSISTENT SCHEDULING

- Better support of voice messages
- Data reception at a regular configured periodicity



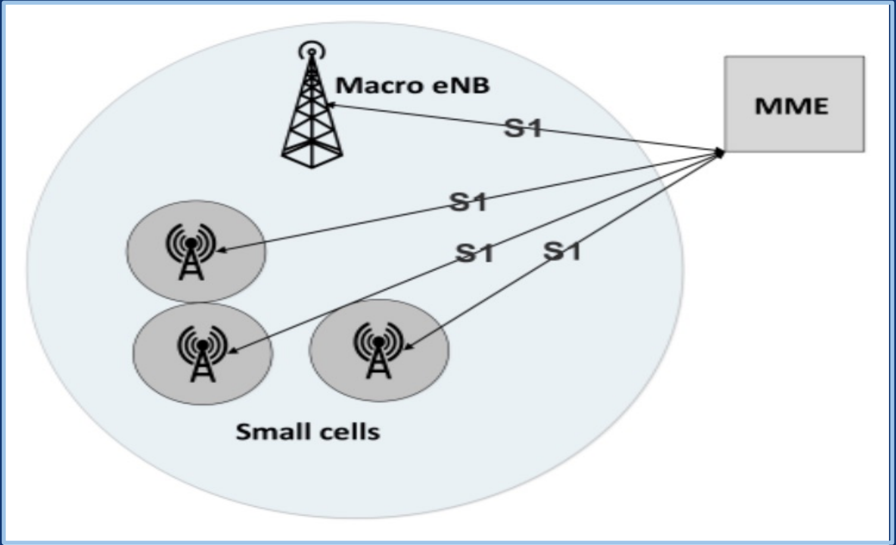
SEMI-PERSISTENT SCHEDULING

- The base station assigns specific resource units to be used for voice messages with specific interval to save control plane overhead and optimize the radio resource usage.

- The base station preconfigures the UE with the Radio Network Temporary Identifier which is used to differentiate one NB-IoT UE from another, or one radio channel from another.

SMALL CELL SUPPORT

- NB-IoT UE is not allowed to transmit more power than the configured maximum power in order to avoid interference.
- However small cell support improved capacity and coverage (up to 100km)
- This could be achieved with a software upgrade only.

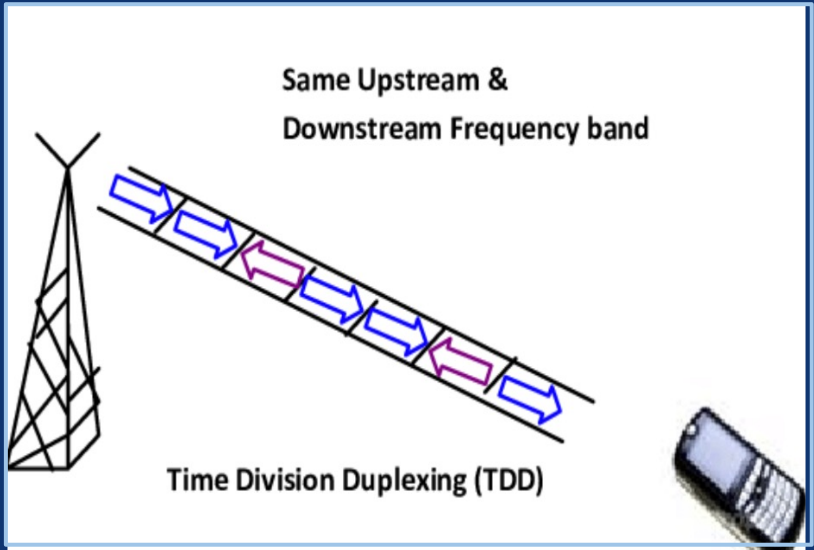


ENHANCED USER EQUIPMENT MEASUREMENTS

- Only NSSS additionally to NRS is defined for radio resource management measurement enhancement.
- NRS is determined by the resource elements that carry NSSS in the NSSS occasions that the UE measures.
- The cell search and initial cell acquisition are improved.

TIME DIVISION DUPLEX SUPPORT

- A new TDD frame structure is introduced.
- Only a normal cyclic prefix is supported for transmission.
- Some of the system information can be transmitted on non-anchor carriers.
- The UE will have reduced system information acquisition and search time, hence reduced UE differentiation and access control.



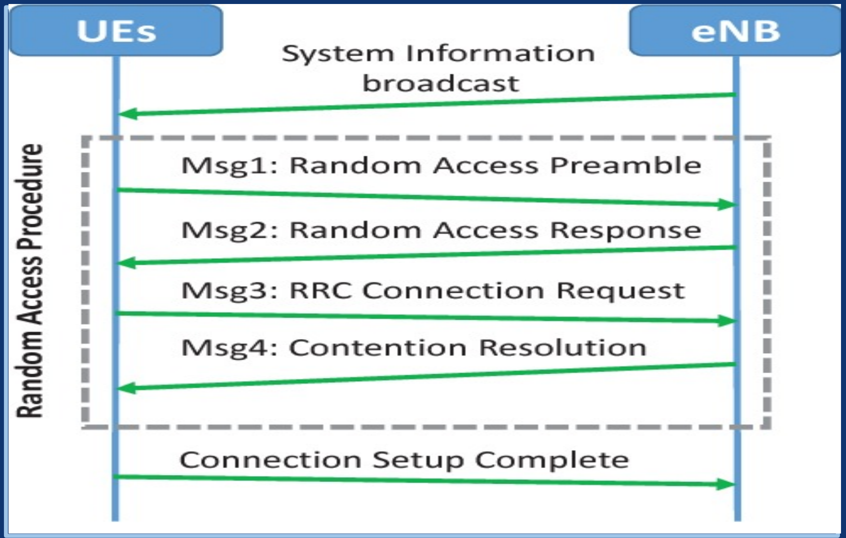
RELEASE 16

3GPP and many industrial players are involved in ongoing discussions for Release 16 enhancements. The features include:

- Grant-free access
- Simultaneous multi-user transmission
- Enhanced group message mechanism
- Inter-RAT idle-mode mobility
- Network management tool enhancement to improve UE differentiation

GRANT-FREE ACCESS

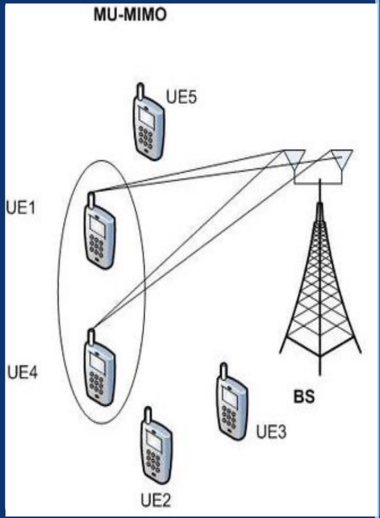
- Most of the power consumption takes place during the UE active time.
- The UE will transmit during RRC-Idle mode through Msg3 without access grant.
- A UE in RRC connected mode can transmit without grant or with the simplified control-less grant.

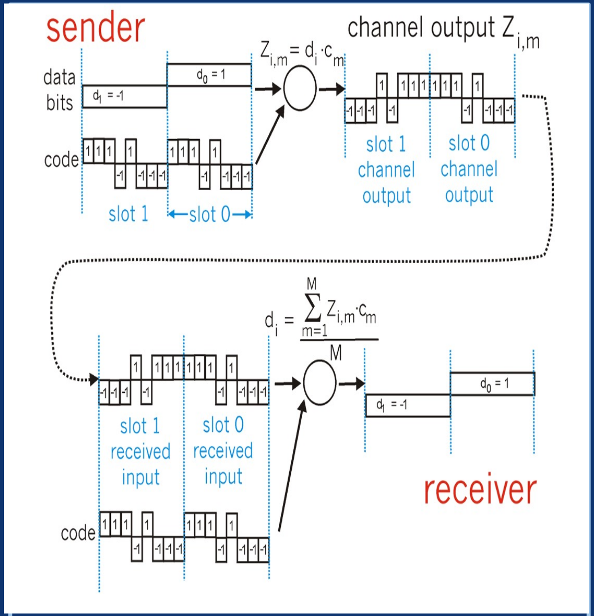


SIMULTANEOUS MULTI-USER TRANSMISSION

Using a shared resource in time and frequency domains without increasing the number of antennae:

- Code division multiplexing
- multi-user multiple inputs multiple outputs





SIMULTANEOUS MULTI-USER TRANSMISSION

- More dynamic access can be achieved through enhanced base station receiver for detection of multiple users that are using the same resource unit as cluster and hence be able to schedule them effectively.

- UE uses the static or semi-static configuration of more resources for the unexpected application traffic handling.

- The introduction of transmission without grant will cause a collision of data packets so dynamic handling of multiplexing is necessary.

ENHANCED GROUP MESSAGE MECHANISM

- MBMS proposed in release 14 is only efficient for large size downlink command message transmission and requires many UEs to be deployed.

- An application layer common message can be very small but sent to many UEs.

- In release 16 there are more enhancements to support downlink command between user groups and group RNTIs.

INTER-RAT IDLE-MODE MOBILITY

For applications that involve mobility, the the UE may need to be accessible when moved to the area served by other BS.

The UE support for inter-RAT mobility in idle mode is introduced with optional handover support in connected mode through procedure simplification.

Handover helps to reduce system information reading time.

UE DIFFERENTIATION IMPROVEMENT

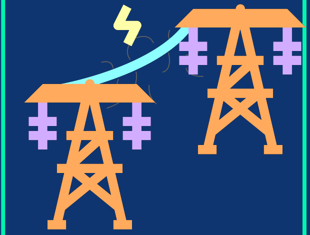
- NB-IoT UE is expected to be able to perform differentiation according to maximal tolerable delay per service to optimize the radio resource usage.

- The UE can be differentiated according to traffic model (periodic communication indicator, periodic time, scheduled communication time, traffic profile) and battery indication.

- Differentiation is done by tuning parameters of the physical channels and network procedures.

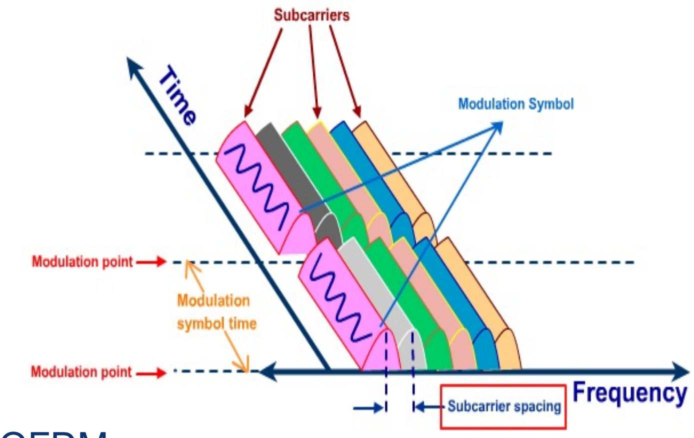
PHYSICAL LAYER

NB-IoT physical layer numerologies and challenges



PHYSICAL LAYER

- Same numerologies as legacy LTE for the sake of co-existance
- OFDM signal waveform for downlink (high spectral efficiency)
- SC-FDMA signal waveform for uplink (helps reduce power consumption)
- Subcarrier (or tone) as the resource scheduling unit (scalability)

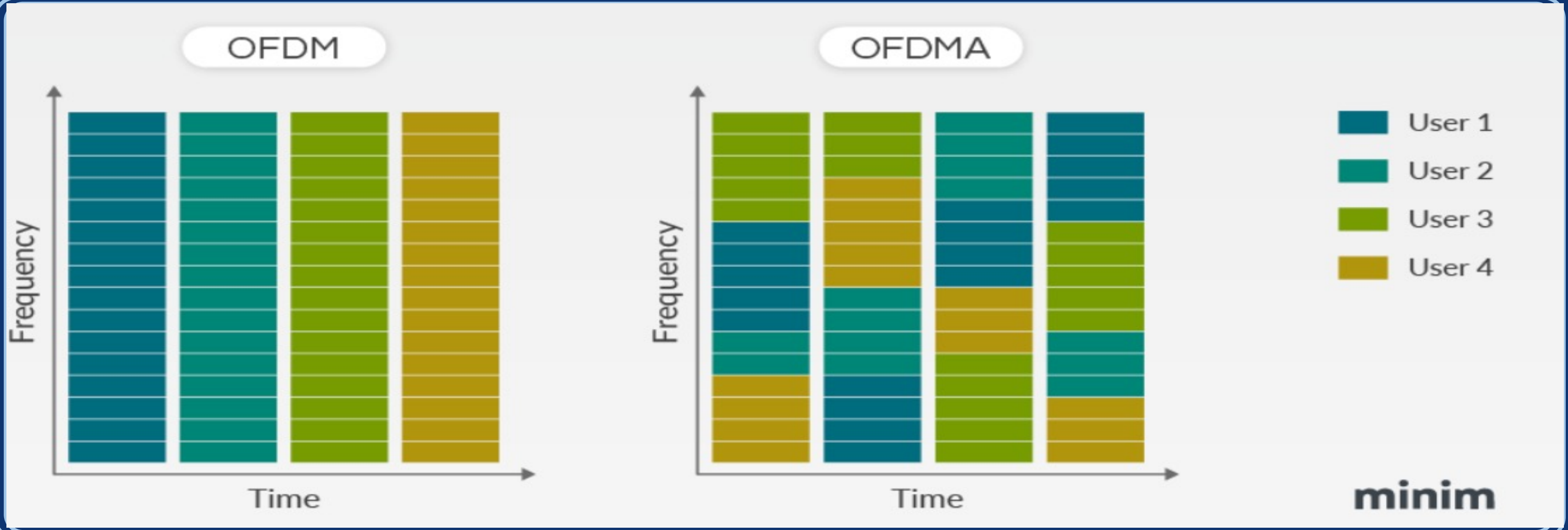


OFDM

OFDMA

- OFDMA is a multiple access scheme based on orthogonal frequency division multiplexing (OFDM) technique. In fact OFDMA is the multi-user version of OFDM.
- Its main principle is to split the data stream to be transmitted onto a high number of narrowband orthogonal subcarriers using an inverse fast Fourier transform operation.
- Since these subcarriers are mutually orthogonal, overlapping between them is allowed, yielding a highly spectral efficient system.
- Drawback: Inefficient power consumption

OFDM VS. OFDMA



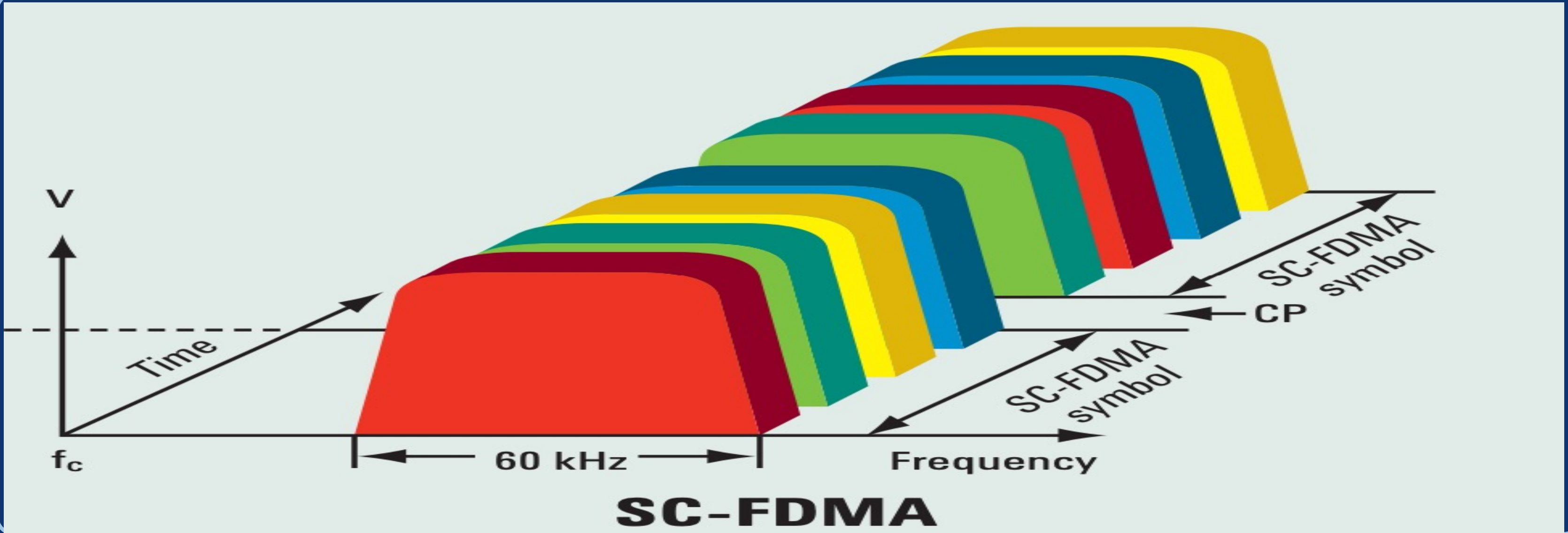
SC-FDMA

- SC-FDMA is a multiple access scheme based on the single carrier frequency division multiplexing (SC-FDM) modulation technique. Its main principle is the same as for OFDM.

- The difference is that a discrete Fourier transform is performed prior to the IFFT operation, which spreads the data symbols over all the subcarriers carrying information and produces a virtual single-carrier structure.

- As a consequence, SC-FDM presents a lower power consumption making it attractive for uplink transmissions.

SC-FDMA

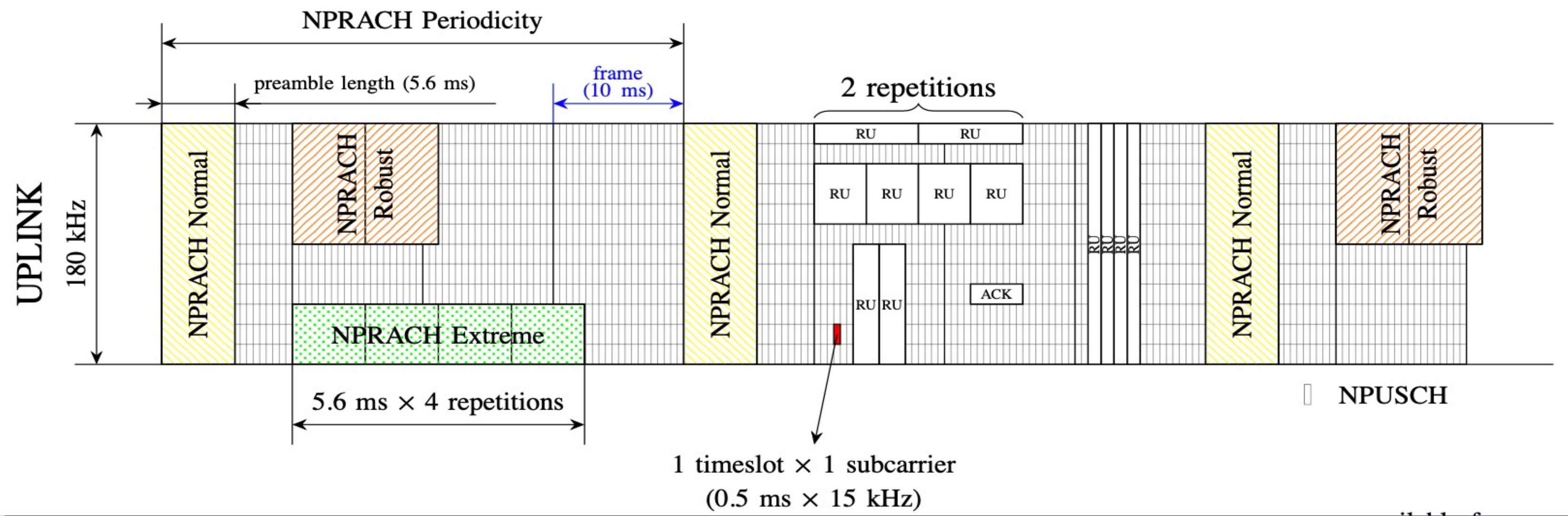

V
Time
f_c
60 kHz
Frequency
SC-FDMA symbol
CP
SC-FDMA symbol
SC-FDMA

PHYSICAL LAYER

- In both DL and UL the channel is divided into 12 subcarriers of 15kHz each.
- The time domain is divided into time slots, each lasting 0.5ms and consisting of 7 OFDM/SC-FDMA symbols.

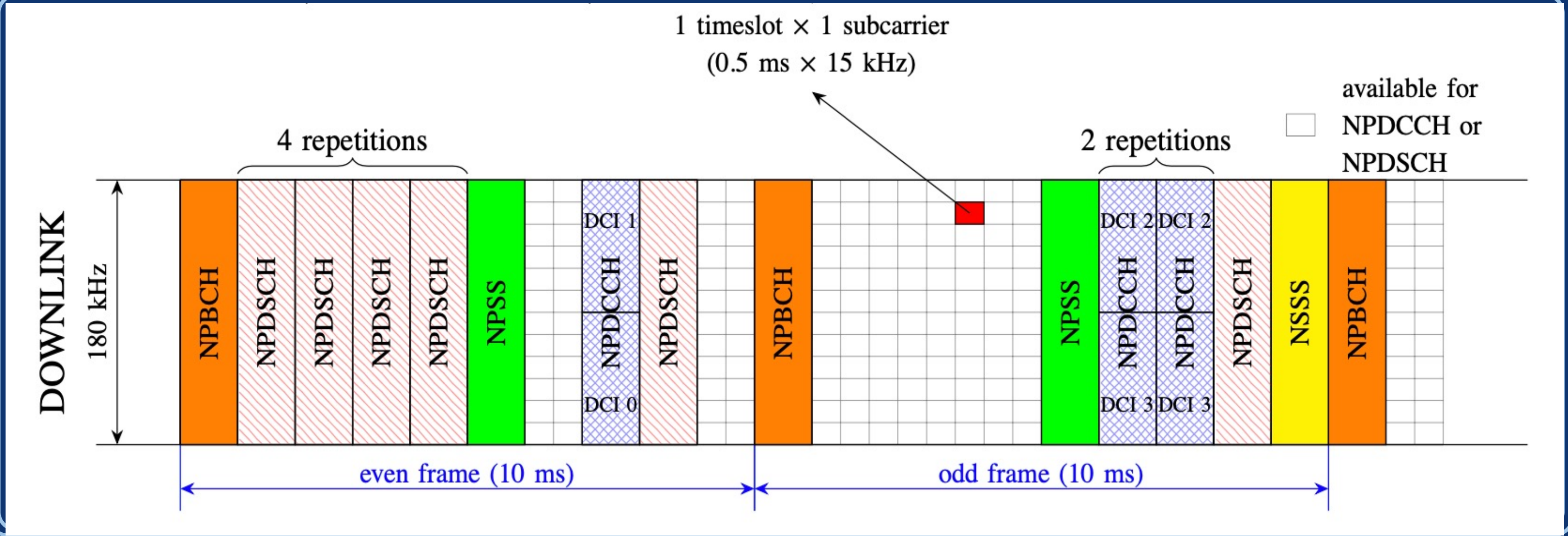
The smallest time-frequency resource, namely Resource Element (RE) is composed of one subcarrier and one symbol.

UPLINK



NPRACH Periodicity
preamble length (5.6 ms)
frame (10 ms)
2 repetitions
UPLINK
180 kHz
NPRACH Normal
NPRACH Robust
NPRACH Extreme
RU
ACK
5.6 ms × 4 repetitions
1 timeslot × 1 subcarrier
(0.5 ms × 15 kHz)
NPUSCH

DOWNLINK



1 timeslot × 1 subcarrier
(0.5 ms × 15 kHz)
available for
NPDCCH or
NPDSCH
4 repetitions
2 repetitions
DOWNLINK
180 kHz
NPBCH
NPDSCH
NPDSCH
NPDSCH
NPDSCH
NPSS
DCI 1
NPDCCH
DCI 0
NPDSCH
NPBCH
NPSS
DCI 2
DCI 2
NPDCCH
NPDCCH
DCI 3
DCI 3
NPDSCH
NSSS
NPBCH
even frame (10 ms)
odd frame (10 ms)

FRAME STRUCTURE

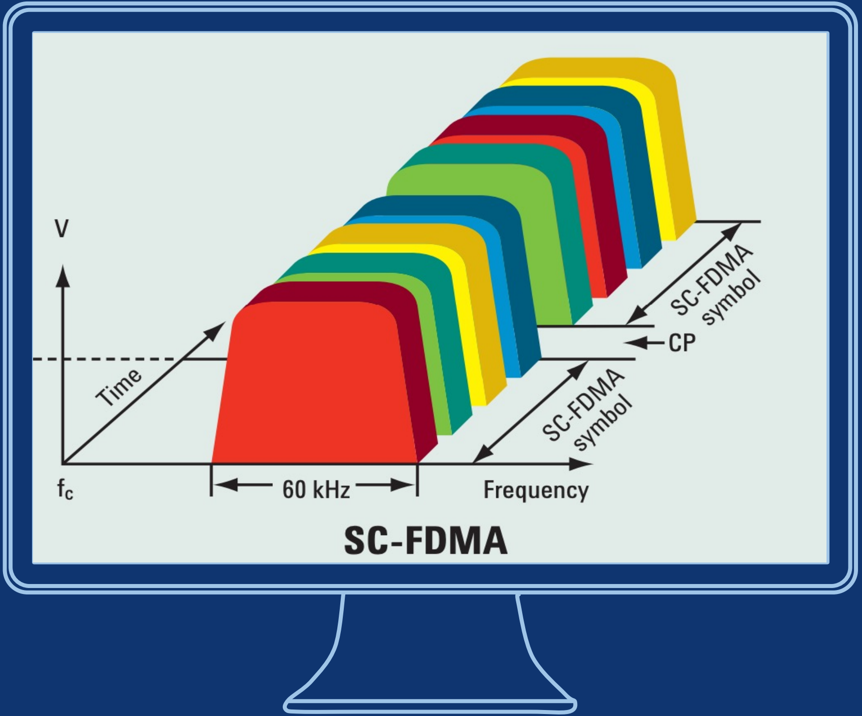
- Subframe: Two time slots form a subframe (1ms).
- Frame: Ten subframes form a frame (10ms).
- Frames are identified by a "system frame number", reset every 1024 frames. This structure is then repeated 1024 times, forming the hyper frame lasting about 3 hours.
- In DL, apart from the subframes allocated to NPBCH and NPSS/NSSS, the rest of DL subframes are dynamically allocated to either NPDCCH or NPDSCH.
    - The possible locations of the NPDCCH are called search spaces.

THE SECOND NUMEROLOGY

- 48 subcarriers of 3.75 kHz each
- Used for the preamble transmission of random access procedure and optionally for UL transmission.
- The time slot in this numerology lasts 2ms and one frame is composed of 5 time slots (10ms).
- This second numerology further improves the coverage.

PHYSICAL LAYER

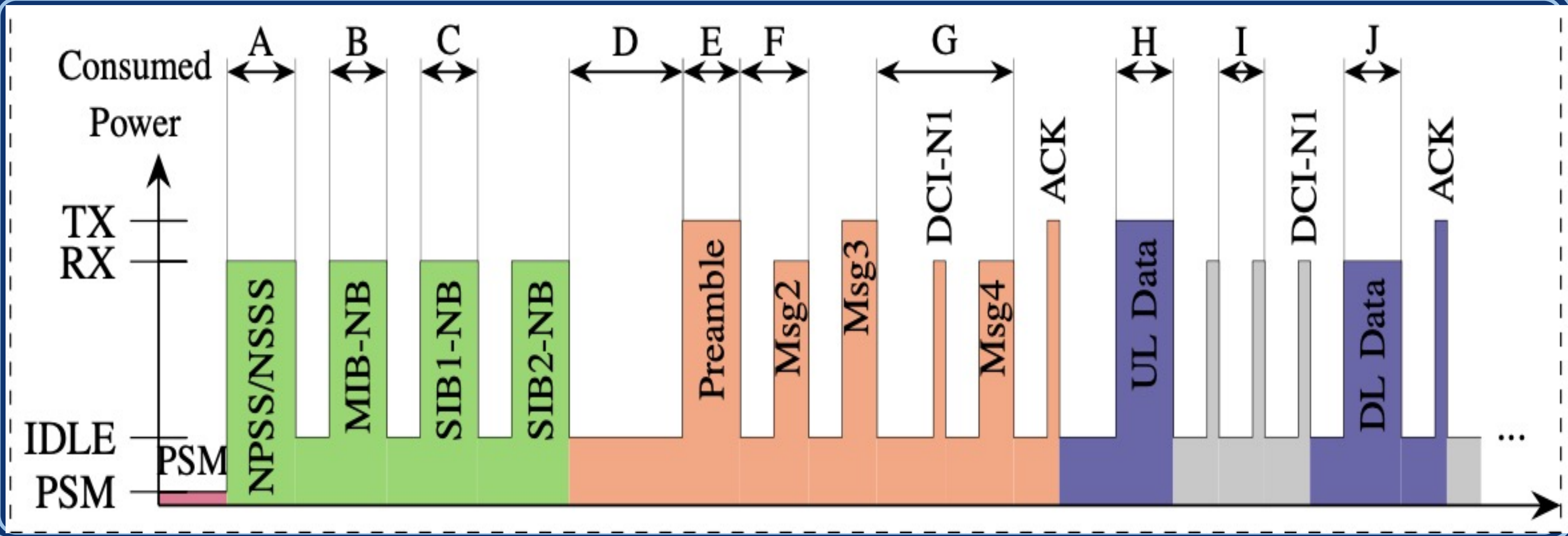
- The base station uses DCI to specify the scheduling information.
- The UE learns the deployment mode and CID through its initial acquisition.
- Then the UE can map NPDCCH and NPDSCH symbols to available resource elements.



PHYSICAL LAYER

- NPDCCH, NPDSCH, and NRS cannot be mapped to the already occupied resource elements for LTE
- When NB-IoT UE receives NPDCCH which carries DCI, it decodes it and uses the device's scheduling feature (k0) to know the delay over which it will start to receive NPDSCH.
- The scheduling information is used to identify the allocated resources over NPDSCH and NPUSCH.
- If repetitions are indicated, identical copies of the data are transmitted in consecutive subframes using one subframe inter-leaving.

A DETAILED INSIGHT OF THE PROCEDURE



RESOURCE UNIT

- To perform a UL transmission, the eNodeB allocates a certain amount of resources to the UE.

The minimum amount of resource is called a Resource Unit (RU), where the possible RU configurations depend on UE capabilities and the configured numerology and the transmission option (single-tone or multi-tone) and affect the latency.

RESOURCE UNIT

- Worst case:
  - 3.75 kHz spacing
  - single-tone
  - ➢ RU is 32ms long with either BPSK or QPSK

- Best case:
  - 15 kHz spacing
  - multi-tone capabilities
  - ➢ RU is composed of 12 subcarriers and 2 time slots with QPSK

PHYSICAL LAYER FEATURES AND CHALLENGES

CELL ACQUISITION AND SYNCHRONIZATION

RANDOM ACCESS PROCEDURE

CO-CHANNEL INTERFERENCE

CHANNEL ESTIMATION AND ERROR CORRECTION

CELL ACQUISITION AND SYNCHRONIZATION

- To camp on a cell, NB-IoT UE goes through frequency and timing synchronization to obtain the center carrier frequency, the allocated slot and frame timing used for the cell acquisition.

- If MIB and SIB are properly decoded, cell ID, a subframe number, scheduling information, and system bandwidth can be detected successfully.

- The low complexity of devices may lead to poor synchronization and cell acquisition due to carrier frequency offsets and poor channel estimation capacity.

An ex of works done	Time and frequency synchronization for cell search improvement using NPSS and NSSS frequency diversity reception

RANDOM ACCESS PROCEDURE

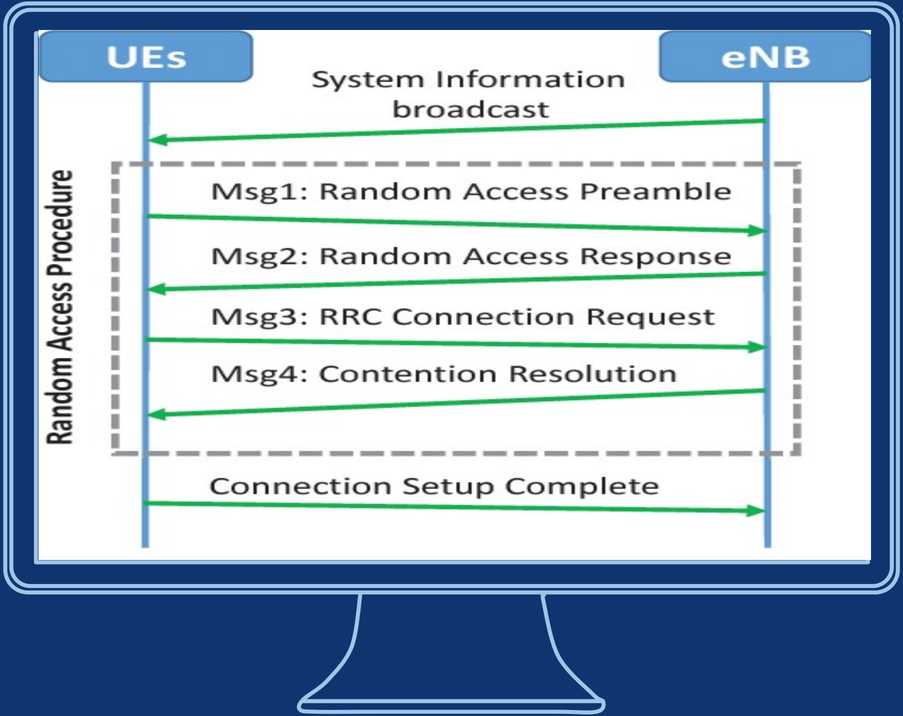
- Random access is intended for initial UE uplink synchronization.
- the UE acquires its unique UE ID used for communication with the base station.
- RA is also used to regain the lost UE access due to the long inactivity which has led to the loss of synchronization.

An ex of works done	Minimization of random access collision by Random Access with differentiated barring algorithm

RANDOM ACCESS MESSAGES

- The RA can be triggered as either a response to a paging message or for UL data transmission.
- The RA includes four messages:

   1. Preamble (msg 1)
   2. Random access response (msg 2)
   3. Radio Resource Control (RRC) connection request (msg 3)
   4. Connection resolution



RANDOM ACCESS PROCEDURE

1. The preamble is transmitted on the first available NPRACH opportunity.
   - A preamble is composed of four symbol groups, each transmitted on a different subcarrier.
   - If multiple UEs choose the same initial subcarrier the preamble sequence will collide.
   - eNodeB wouldn't be aware of the collision in this stage.

RANDOM ACCESS PROCEDURE

2. The UE starts a random access response window during which it expects the RAR message (msg 2) through NPDCCH.
    - Msg 2 indicates the preambles identified by the eNodeB.
    - For each preamble listed in the RAR, the eNodeB provides a grant for the transmission of msg 3.
    - The UEs that did not receive the msg 2 within the window will perform a new random access attempt.

RANDOM ACCESS PROCEDURE

3. The UE transmits the msg 3 (transmitted using HARQ) on NPUSCH according to the UL grant received in msg 2.
    - Msg 3 carries information like UE identity and the buffer size report.
4. The UE starts a contention resolution timer during which it expects the msg 4 (transmitted using HARQ) through NPDSCH.
    - Msg 4 carries the UL grant for data transmission.
    - Msg 4 is also used to resolve the collisions.

CHANNEL ESTIMATION AND ERROR CORRECTION

- NB-IoT performance depends on the quality of the channel estimation.
- The poor quality of channel estimates is highly influenced by the low complexity of the UEs that can lead to misdetection of signals, frequency offset and phase noise.

An ex of works done	NB-IoT error correction by using cryptographic redundancy and error correcting code in a new iterative algorithm for transmission scheme

CO-CHANNEL INTERFERENCE

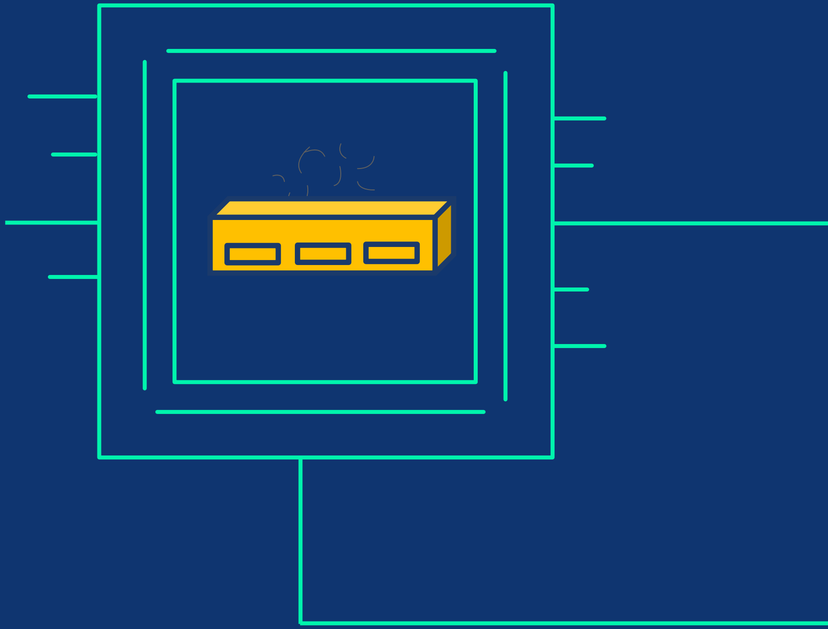
- A narrow-band signal allows the receiver to filter out more noise thus improving the SINR.
- However, for NB-IoT is being deployed in the existing LTE spectrum, co-channel interference may occur between NB-IoT and LTE UEs.
- The reasons include sampling rate mismatch, inter-PRB interference due to power leaking between NB-IoT and LTE PRBs and … .

An ex of works done	Intersymbol Interference mitigation by the phase-shifted channel frequency responses (CFR) to conquer the sampling mismatch between NB-IoT and base station with a new channel equalization algorithm

MEDIA ACCESS CONTROL LAYER

NB-IoT mac layer

numerologies and challenges



MAC LAYER

- Some of the tasks executed by the MAC layer:

HARQ

Multiplexing

Random access

Timing advance

Priority management

MAC LAYER FEATURES AND CHALLENGES

RADIO RESOURCE ALLOCATION

LINK ADAPTATION

COVERAGE AND CAPACITY

POWER AND ENERGY MANAGEMENT

RADIO RESOURCE ALLOCATION

- Resource allocation is the key feature to ensure the expected massive connections in a cell.

- Tone allocations, PRBs, repetition number options, power configurations, subframes, or time slots, etc. must be optimized to maximize performance with minimum possible resources.

An ex of works done	Mitigation of the impact of interference for partial deployment of NB-IoT by resource blanking

LINK ADAPTATION

- NB-IoT link adaptation involves adaptive modulation and coding schemes as well as adaptive power allocation.
- The modulation schemes are limited to QPSK to enable low complexity and hence reduce the overall power consumption.
- To extend the coverage and increase the link reliability, a repetition number of up to 128 times is introduced.

An ex of works done	Coverage enhancement by characterizing SNR, repetition number and supported bandwidth Link adaptation with an algorithm using the mathematical expression of Shannon theorem

COVERAGE AND CAPACITY

- INB-IoT's narrow bandwidth and support for repetition are the key features to enable the enhanced coverage especially for applications in hard-to-reach areas

An ex of works done	Capacity and spectral efficiency improvement using two less complex scheduling schemes: The preconfigured access scheme and the joint spatial and code domain scheme.

POWER AND ENERGY MANAGEMENT

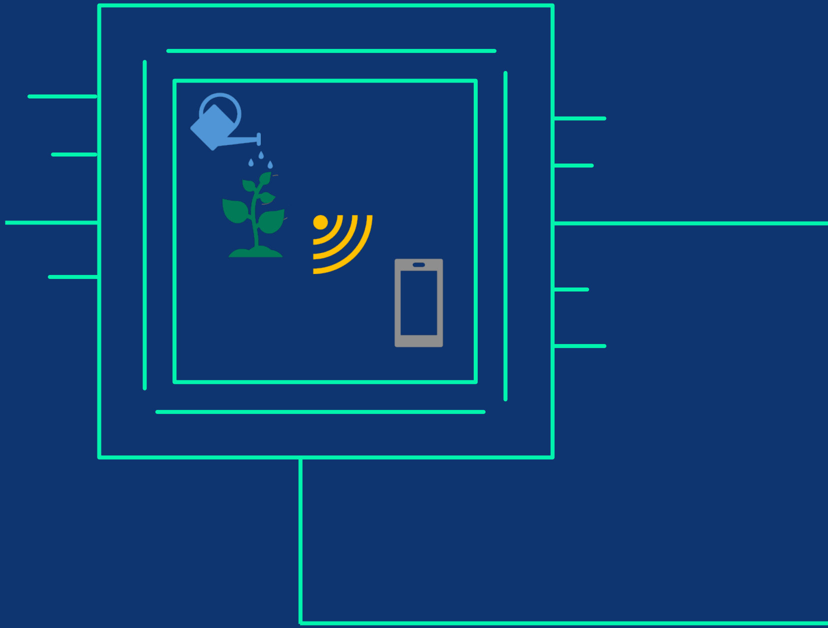
- The NB-IoT reduced complexity is intended to reduce the power consumption in different modes.
- PSM and eDRX are the implemented features dedicated to foster the long-lasting battery life.

An ex of works done	Reduction of power consumption by predicting the uplink packet occurrence through a deep packet inspection and then using an algorithm that predicts the processing delay and pre-assigns radio resource.

UPPER LAYERS

Upper layers' challenges

and enhancements



UPPER LAYERS

- NB-IoT implements new small data transmission procedures based on CIoT Evolved Packet System on both Control Plane and User Plane.

- The procedures are optimized to efficiently support the small data transfer (burst) as follows:
    - Mandatory Control Plane CIoT EPS
    - Optional User Plane CIoT EPS

EPS CONTROL PLANE AND DATA PLANE OPTIMIZATIONS

CP CIoT

encapsulates the data packets in Non-Access Stratum by using control plane signaling messages. The UE skips some steps required for each data transfer. It best fits short data transfer.

UP CIoT

requires the RRC connected mode to get the scheduled radio resources and Access Stratum (AS) between the UE and the network. This mode uses the introduced connection to Suspend and Resume procedures. Suitable for both small and large transactions.

SUSPEND AND RESUME PROCEDURES

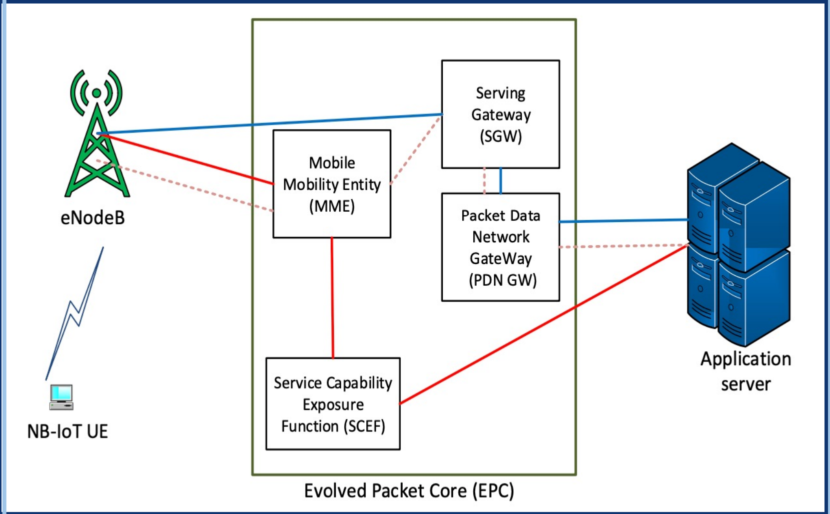
- Connection suspend procedure helps to retain the network context so that the UE can resume the connection when traffic is available.

- Retaining the context helps the UE and the network to skip the AS and RRC reconfiguration in each data transfer.

MORE UPPER LAYER FEATURES

- For NB-IoT Service Request procedure is optional. However, a UE with UP optimization support needs to support SR.

- If the UE wants to transmit in idle state, it will send the preamble and the base station and UE will establish RRC connection and UE will be allocated with the radio resources for data transfer.



IN THIS PRESENTATION WE DISCUSSED

- A brief introduction to Narrow-band Internet of Things
- Different features of NB-IoT releases
- NB-IoT's physical layer challenges and tasks
- NB-IoT's MAC layer challenges and tasks
- NB-IoT's upper layers challenges and improvements

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Thank you

for your attention

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