Quality of service “Smart queue” and traffic prioritization for NB-IoT

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Introduction and problem description

Introduction

NB-IoT characteristics

- An LPWAN radio technology
- Based on LTE
- Licensed spectrum
- Supports wide range of M2M applications
- The priority is uninterrupted data transmission and low power consumption.

The benefits of implementing IoT based on LTE architecture

1. The guaranteed QoS when using the license spectrum
2. The flexibility of managing the QoS
3. Adaptive allocation of network resources
4. High scalability with IPv6 addressing support
5. The support of the network architecture for the implementation of new services and device-to-device interaction
6. The ability to serve the growing number of devices with high transmission rates

Introduction

Prioritization

- In 4G/5G networks a “smart queue” should be used.
- Priority depends on the type of service.
- Ex. low jitter for video conferencing, guaranteed bandwidth for multimedia.

- Within the QoS requirements, all types of services are divided into nine classes.

Types of resource allocation

The end-to-end channels organized for traffic transmission are divided into two groups in accordance with the type of resource allocated:

- With guaranteed bit-rate
  - Real-time services
- With an unguaranteed non-guaranteed bit-rate transmission rate
  - Highly susceptible to packet loss due to network congestion
  - Does not block any specific transmission resources in the LTE network

Ensuring QoS in LTE

- The main method for ensuring QoS is the use of communication channels with high bandwidth.
  - Expensive
- The essence of other methods is to give priority to the provision of network traffic resources due to protocols that do not require high quality of service

Problem

NB-IoT’s limitations

Low bandwidth:

- Problems with effective QoS management
- No guarantees on the data transmission speed and total E2E delay

- NB-IoT technology does not differentiate between individual streams from IoT devices, taking into account their QoS requirements.

Problem

NB-IoT’s limitations

Results:

- Suboptimal load balancing
- No guarantees on the E2E delay

- Deterioration of the QoS for real-time traffic, because the GBR bearer is not created for NB-IoT RAT type.

- Limited use of NB-IoT for Industrial Internet and Tactile Internet

What is done in LTE?

- A certain memory buffer is dedicated to serve as a queue.
- To eliminate failures, additional buffer is reserved to serve as an extension to the queue.

  - This will reduce the queues or waiting time for a service.

- The random access channel can usually become a major bottleneck.
- To improve QoS parameters, an effective RACH procedure is required.
  - With regard to the interaction between the static properties of the physical radio channels and the dynamic properties of the queue developing in each IoT device.

Requirements and considerations

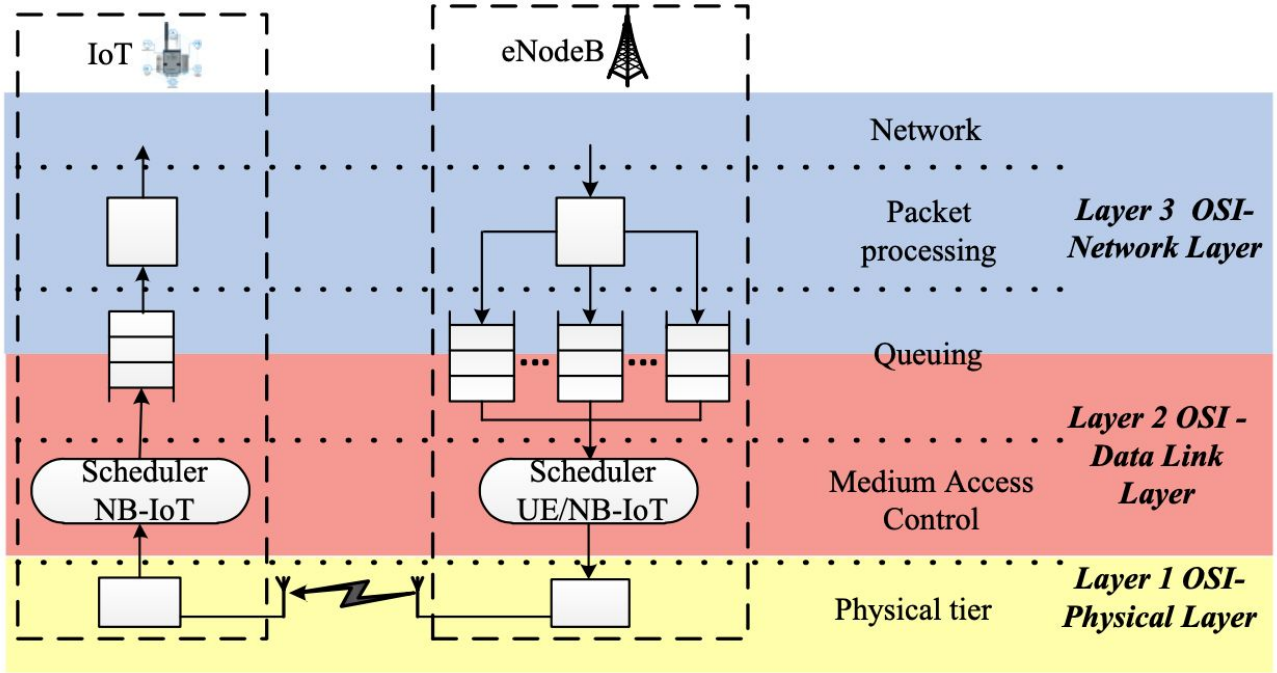
1. Speed allocation
2. Distance
3. Mobility

NB-IoT controller

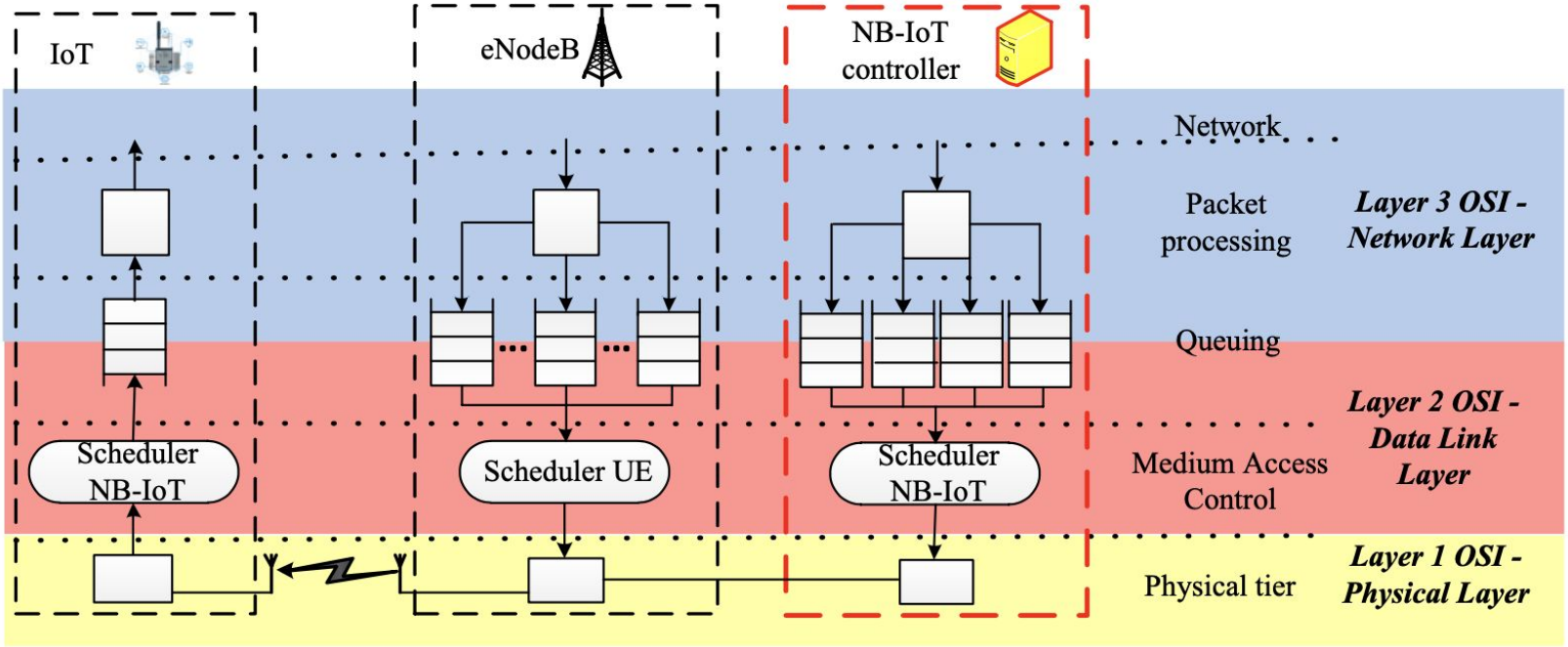
The interworking architecture

- The ability to meet the specified requirements for the QoS in LTE depends on how the BS is planning the transmission of various packets using the resources of the wireless channel.
- The scheduler at the BS is responsible for planning radio resources.
- Despite the fact that the capacity of 4G/5G networks is sufficient to meet the needs of most devices, the signal load generated by them exceeds the capabilities of the BS.
- Solution: Utilization of the classical architecture of LTE-based 4G/5G BS interworking with the NB-IoT device.
- To minimize the changes in the LTE network and the corresponding equipment costs, it is suggested that an NB-IoT controller be introduced into the architecture.

The classical NB-IoT architecture of base-station interworking with IoT device



The proposed NB-IoT architecture of base-station interworking with IoT device



The controller

- The controller is responsible for downlink and uplink channel planning for IoT devices and allows network operators to leave existing BSs eNodeB unchanged.
- The controller is a separate server machine on which the IoT scheduler is installed.
- It is possible to install this controller near the LTE BS or deployed in the cloud.
- To enable IoT services, network designers need to separately allocate a narrowband spectrum of 200 KHz.
- If it is necessary to provide high speeds, it is proposed to transmit data in the spectrum of LTE.
- The proposed solution: Priority classes.
- ToS parameters: the type of the transmission channel, rate, error rate, and delay.

NB-IoT service classes

Criterations

- Allowable delays
- The average number of service failures

NB-IoT service classes

Type	Service class	Allowed delay (ms)	Allowed service denial (R%)
Guaranteed transmission delay for real time traffic	L1	10	0.01
Guaranteed transmission delay for non-real time traffic	L2	20	0.1
Non-guaranteed transmission delay for non-real time traffic	L3	1000	5
-	L4	undefined	undefined

The procedure

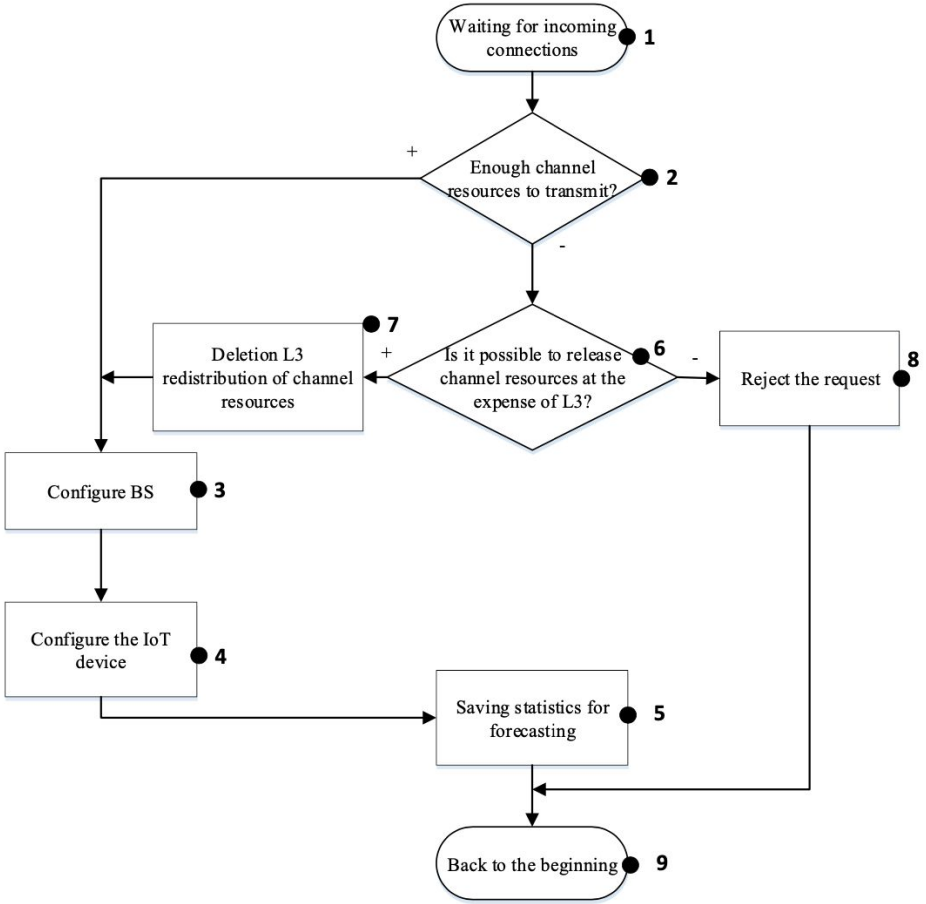
- When a low priority reaches its maximum delay in the smart queue, the counter that monitors the waiting time of the priority message will decide to immediately allocate resources to it for transmission.
- The message becomes the highest priority, but physically it does not change dynamically in marking by a QCI identifier.
- The proposed structure reduces the overload from the base station when planning radio resources. It also provides the required QoS for IoT services, taking into account their priorities.

Smart queue management algorithms

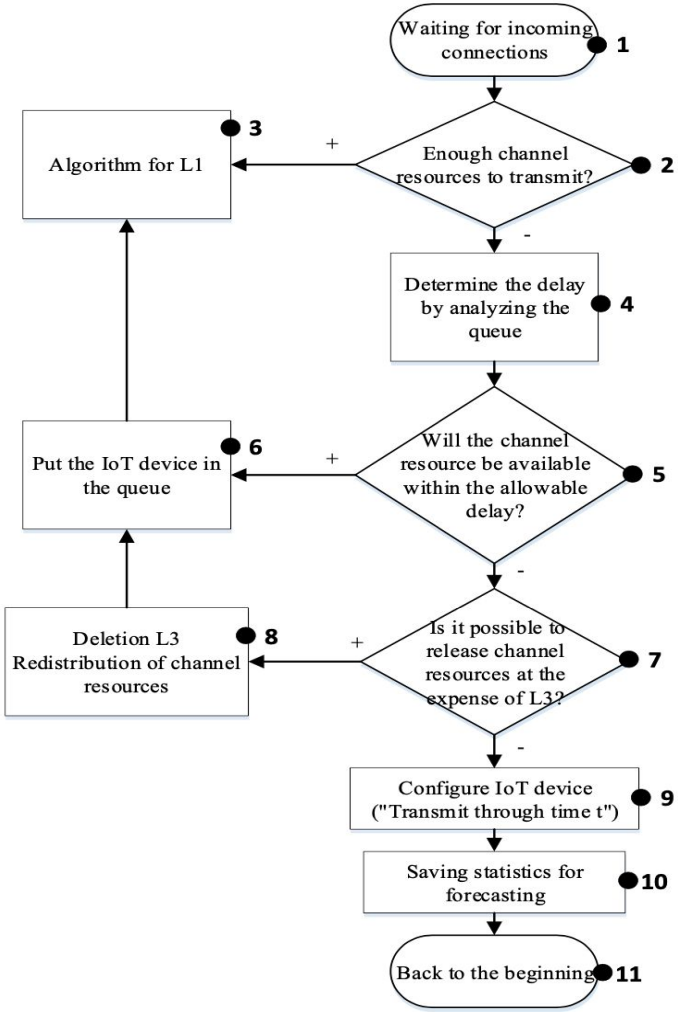
The smart queue

- It is important to agree on QoS parameters that must be ensured at both ends of the transmission.
- To enable priority, certain memory buffers should be formed on the proposed IoT controller to serve as a queue.
- As the packets are sent, the locations of sent packets in the queue are released for the incoming packets.
- To avoid service denial, an additional buffer is installed. The additional buffer serves as an extension to the queue, and at the same time, decreases queuing delays for high priority packets.

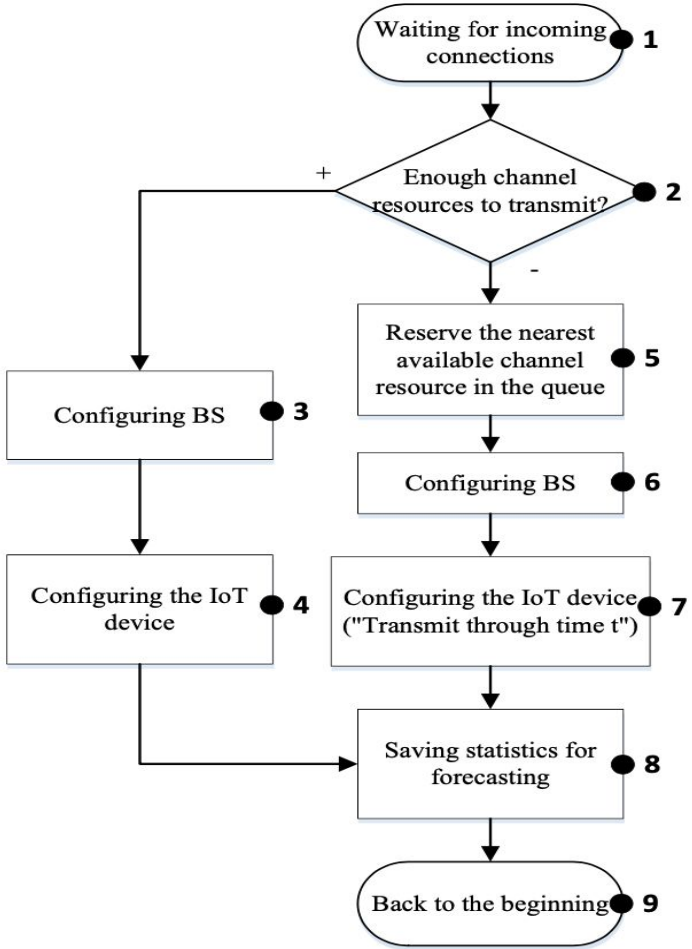
IoT class L1


Waiting for incoming connections
1
Enough channel resources to transmit?
2
+
-
Is it possible to release channel resources at the expense of L3?
6
+
-
Deletion L3 redistribution of channel resources
7
Reject the request
8
Configure BS
3
Configure the IoT device
4
Saving statistics for forecasting
5
Back to the beginning
9

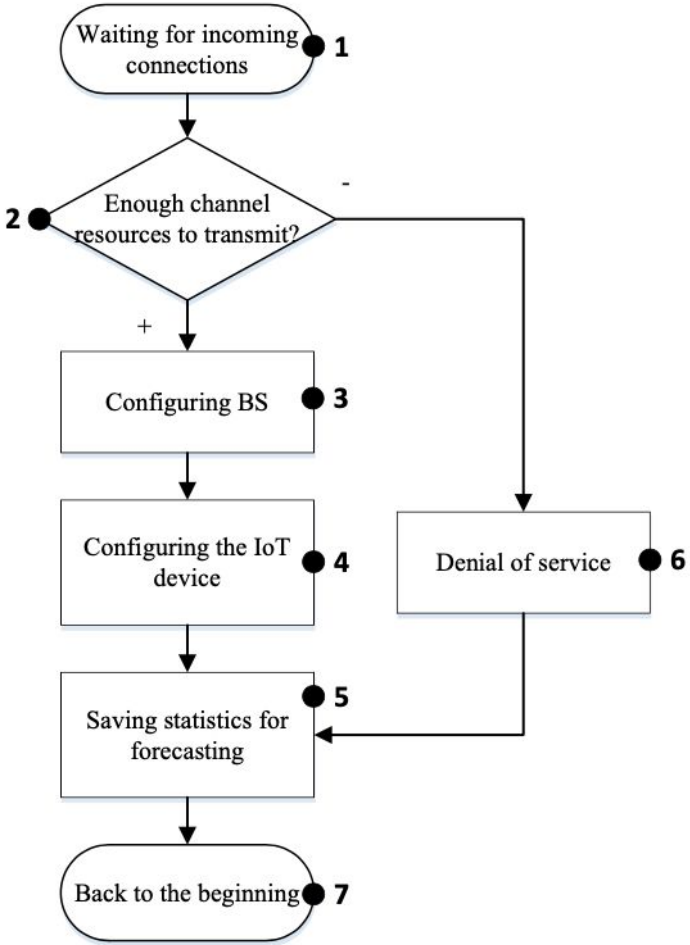
IoT class L2


Waiting for incoming connections
1
Enough channel resources to transmit?
2
+
Algorithm for L1
3
-
Determine the delay by analyzing the queue
4
Will the channel resource be available within the allowable delay?
5
+
Put the IoT device in the queue
6
-
Is it possible to release channel resources at the expense of L3?
7
+
Deletion L3 Redistribution of channel resources
8
-
Configure IoT device ("Transmit through time t")
9
Saving statistics for forecasting
10
Back to the beginning
11

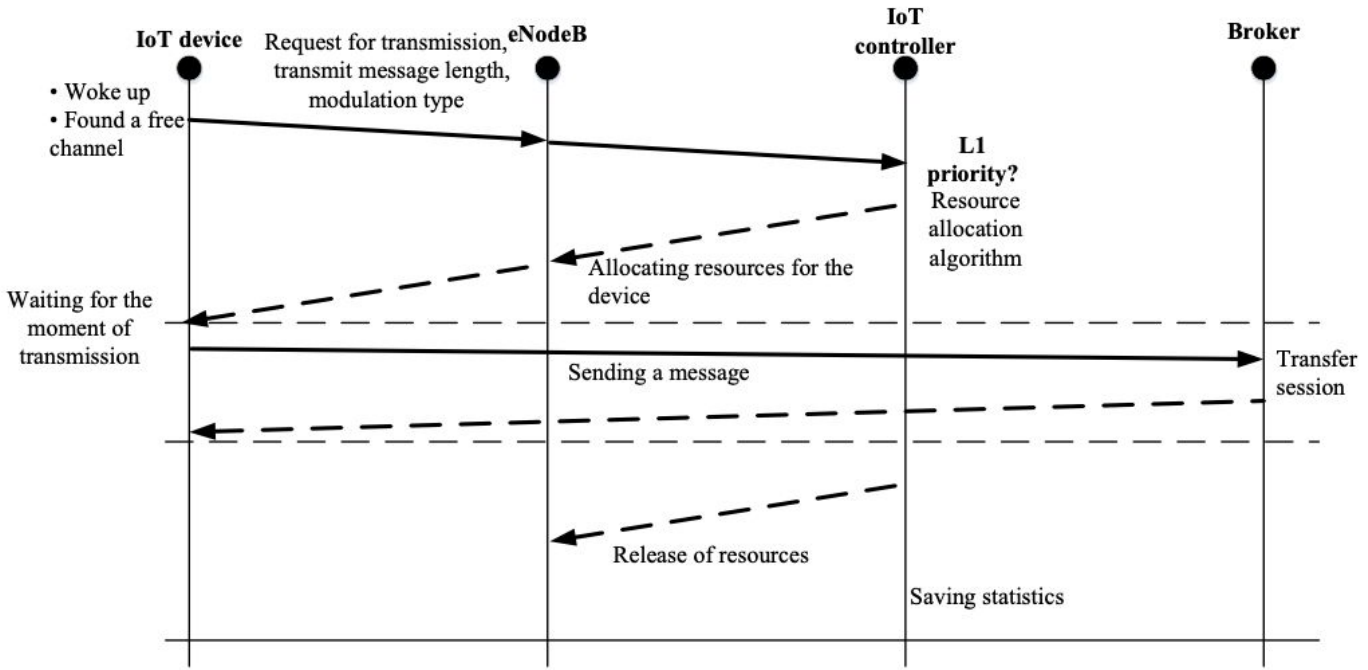
IoT class L3


Waiting for incoming connections
1
Enough channel resources to transmit?
2
+
-
Configuring BS
3
Configuring the IoT device
4
Reserve the nearest available channel resource in the queue
5
Configuring BS
6
Configuring the IoT device ("Transmit through time t")
7
Saving statistics for forecasting
8
Back to the beginning
9

IoT class L4


Waiting for incoming connections
1
Enough channel resources to transmit?
2
-
+
Configuring BS
3
Configuring the IoT device
4
Denial of service
6
Saving statistics for forecasting
5
Back to the beginning
7

The interaction between LTE/IoT network elements while transmitting the L1 message

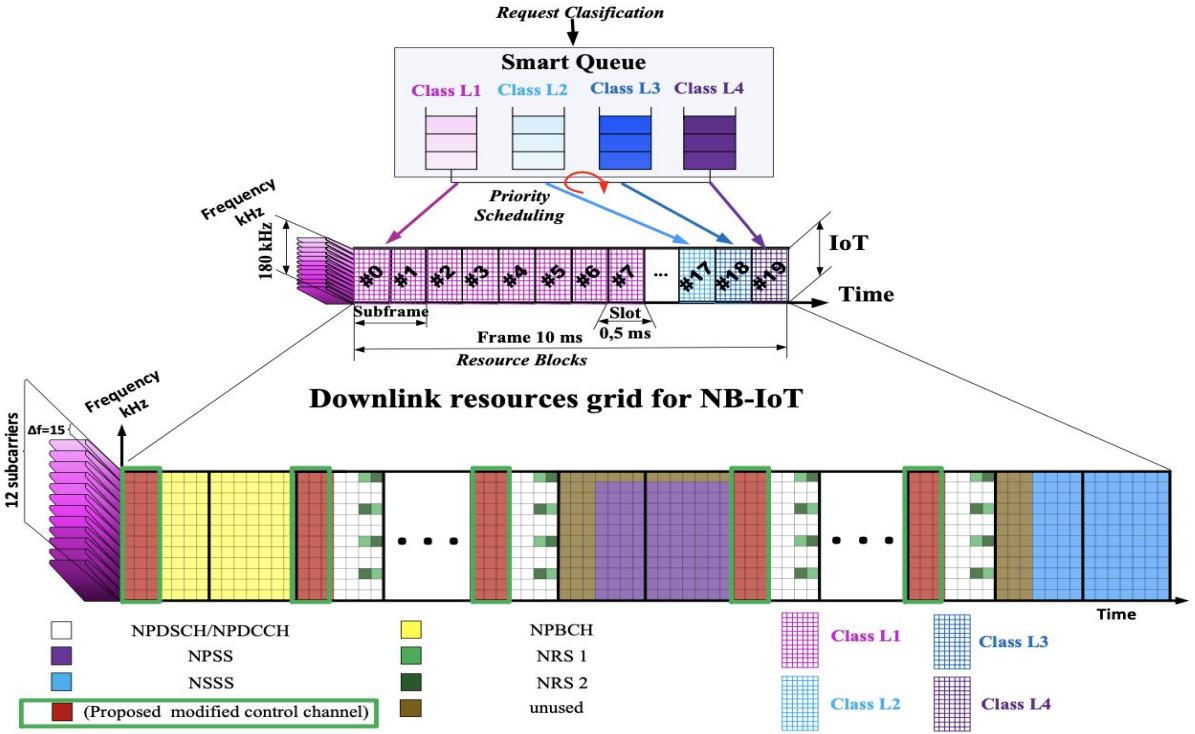


Service resource distribution

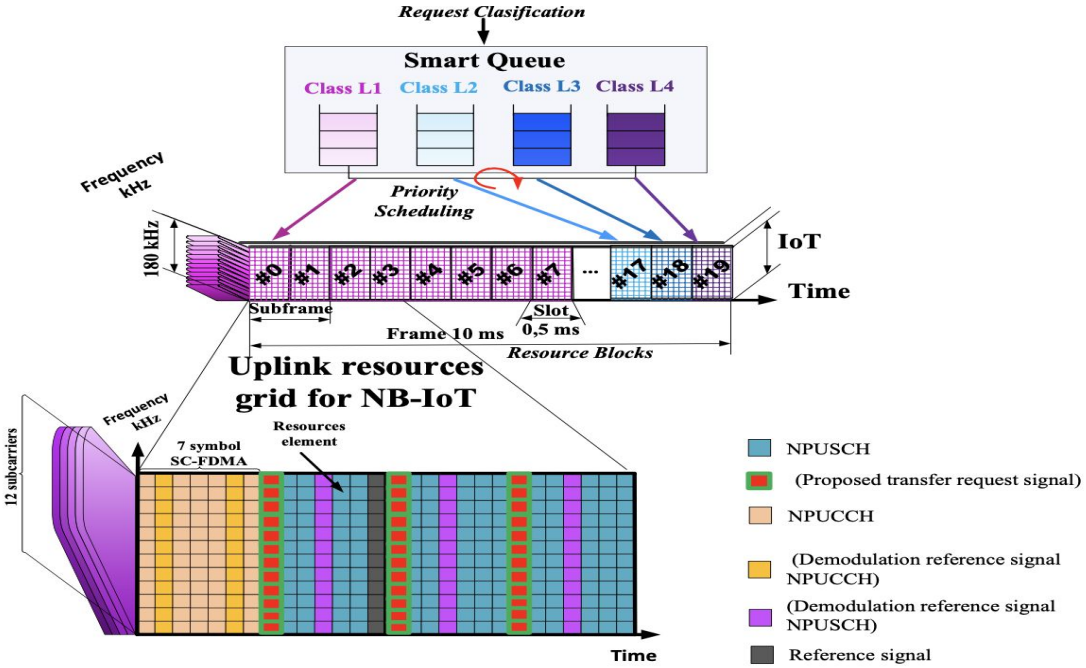
Service resource distribution

- The most effective result is achieved by tackling the problem of frequency and time allocation in the downlink and uplink channels.
- The smallest unit of the time-frequency resource of the LTE frame is the resource block.

Resource grid of LTE/IoT for downlink



Resource grid of LTE/IoT for uplink



Downlink modifications

- A modification for the control channels that consist of LTE PDCCH, LTE Cell Specific Reference Signal channels and intelligent queue consistency control channels on an IoT controller communicating with an end IoT device is provided.
- The control channel also transmits information about resources' usage to the controller.
- These control channels are proposed for the flexibility of managing the QoS at the link layer, which transmits signaling information about the resource block for a specific IoT sensor message with its priority and unique device identifier.
- These channels make it possible to allocate a single resource block to transmit a small message from an IoT sensor and provide it with a minimum delay of 0.5 ms within the frame.

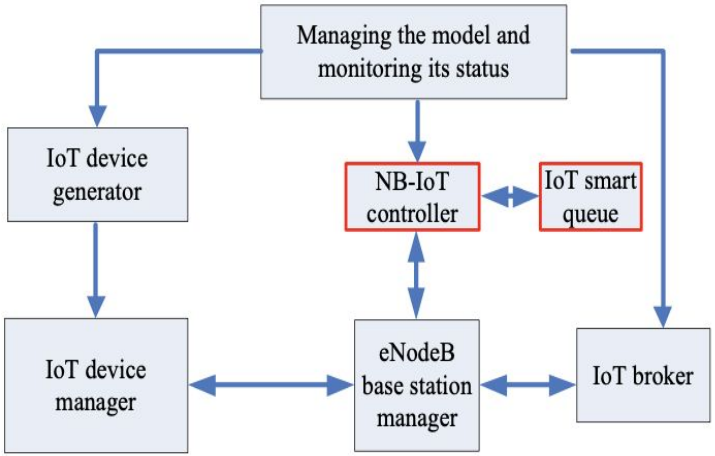
Uplink modifications

- NB-IoT devices can transmit the HARQ feedback over NPUSCH or over NPUCCH.
- Options for defining the physical structures of the NPUCCH and NPUSCH and user multiplexing on the uplink (UL) are provided.
- The use of a new transfer request signal for communication with the IoT controller is also proposed.

Results and discussion

The simulation

- Phase I. Focuses on E2E QoS when processing the incoming flow using the Proportional Fair Scheduling method.
- Phase II. Focuses on E2E QoS when processing the incoming flow the proposed traffic prioritization method.



Simulation results

Load	Gain	Phase 1, L1 exceeds	Phase 1, L2 exceeds	Phase 2, L1 exceeds	Phase 2, L1 exceeds	Phase1, Loss	Phase2, Loss
12%	1.17	yes	no	no	no	no	L4
18%	1.45	yes	yes	0.1%	no	yes	L3
50%	1.85	yes	yes	no	0.5%	L1 = 25% L2 = 12%	L3 & L4
75%	2.08	yes	yes	NP	NP	L1 = 55% L2 = 65%	L1 = 1% L2 = 1%
1	2.12	yes	yes	yes	yes	L1 = 64% L2 = 73%	L1 = 4% L2 = 4% L3 = 26% L4 = 26%

Revision

- Compared to all previous generations, LTE networks achieve lower delays in data transmission due to fewer intermediate elements.
- Modifications were made to the LTE architecture by transferring part of the functions from eNodeB to the NB-IoT controller.
- Modifications were made to the structure of NB-IoT frame where a logical data channel is allocated to reduce the delay and communication of the NB-IoT controller.
- A prioritization method aka an algorithm for managing a “smart queue” based on the IoT traffic prioritization procedures was proposed to provide E2E QoS in the integrated LTE/NB-IoT network.

My points

- Modifications needed in UEs?
- Increase in processing power and resources?
- Exact costs on the controller?

Reference:

Beshley, Mykola, et al. "End-to-End QoS “smart queue” management algorithms and traffic prioritization mechanisms for narrow-band internet of things services in 4G/5G networks." Sensors 20.8 (2020): 2324.

THANK YOU!

Any Questions?