Dto. de Ingeniería Eléctrica y de Computadoras
Universidad Nacional del Sur

DIEC

Cellular Internet of Things (IoT) Technologies

Objetives:

We introduce concepts of the Internet of things based on cellular communication networks. In particular, we consider Narrowband IoT (NB-IoT), as an example case derived from the general 3GPP LTE standard. We pay attention to how LTE energy efficiency and congestion control techniques fit NB-IoT. In addition, special emphasis is placed on the management of uplink and downlink signals (multiple access, synchronization).

The course includes demonstrative laboratories where students will learn to characterize parameters of the physical layer with the aim to determine the Quality of Service (QoS). These laboratories include velocity and bandwidth test, coverage level, latency and power consumption.

Synthetic Program

Introduction – motivation

IoT applications and challenges
IoT proprietary and/or licensed solutions

OFDM

OFDM system - Discrete model – Spectral efficiency – Characteristics
OFDM Sensitivity to synchronization errors.
Downlink time and CFO synchronization

3GPP LTE Characteristics

Network architecture
LTE layer functions
Physical channel characteristics
Congestion control and power efficiency

NB-IoT basics

Physical Layer numerology - Design principles
DL and UL Physical Channels and Signals

NB-IoT layers

NB-IoT layer functions: PDCP, RLC, and MAC
Congestion control: ACB and EAB
Power efficiency: PSM, I-DRX, C-DX

NB-IoT Idle and Connected Mode Procedures

Idle Mode
Connected Mode

NB-IoT DL synchronization methods

System model - Cell search
Timing and frequency acquisition

NB-IoT UL synchronization

NPRACH preamble design
NPRACH estimation methods 1 and 2

NB-IoT in ISM bands

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Detailed Program

1- Introduction – motivation

- IoT applications and challenges: Types of IoT applications. Why IoT? 5G triangle. General characteristics.
- IoT proprietary and/or licensed solutions: Low power wide area networks (LPWAN). LoRa, Sigfox, LTE-M, NB-IoT. Characteristics and performances.

2- OFDM

- OFDM system: Discrete model. Spectral efficiency. Characteristics. Multiple access schemes (OFDMA, SC-FDMA).
- OFDM Sensitivity to synchronization errors: Time, frequency and sampling clock synchronization characteristics. Error analysis.
- Downlink time and CFO synchronization: synchronization tasks: timing and carrier frequency offset estimation and correction. Coarse and fine synchronization.

3- 3GPP LTE Characteristics

- Network architecture: Evolved packet core (EPC). Evolved UMTS Terrestrial Radio Access Network (E-UTRAN). Evolved node B (eNodeB).
- 3GPP LTE Channel characteristics: Delay spread. Doppler spread. Channel characteristics. Basic LTE OFDM signal parameters. OFDMA resource block structure.
- LTE layer functions: Packet data convergence protocol (PDCP). Radio link control (RLC) Medium access control (MAC). Physical layer (PHY). Logical, transport and physical channels.
- Physical channel characteristics: Uplink and downlink physical channel structure. Aspects of general physical channel procedures: UL or DL transmission, synchronization, random access, etc.
- Congestion control and power efficiency: Basic access control techniques. Congestion control: contention free or contention based. Access class barring (ACB). Enhanced access barring (EAB). Discontinuous reception (DRX). Power saving mode (PSM).

4- NB-IoT basics

- Physical Layer numerology: To which point it is possible simplify LTE? NB-IoT similarities and differences with LTE. Deployment scenarios. NB-IoT physical layer design principles.
- DL and UL physical channels and signals: synchronization signals, broadcast channel, DL control channel, DL shared channel, UL random access channel, UL shared channel. Link budget. NB-IoT – LTE comparison.

5- NB-IoT layers

- NB-IoT layer functions: LTE and NB-IoT logical, transport and physical channels. NB-IoT protocol stack. Radio resource control (RRC). Control and data plane IoT optimization. PDCP functional diagram. RLC modes. MAC RACH procedure.
- Congestion control: Access class barring (ACB). Enhanced access barring (EAB) in NB-IoT.
- Power efficiency: Power saving mode (PSM). Connected mode (C-DRX) and idle mode (I-DRX) discontinuous reception.

6- NB-IoT Idle and Connected Mode Procedures

- Idle mode procedures: cell selection, system information acquisition, paging and enhanced DRX, PSM, random access control.
- Connected mode procedures: DL control channel (NPDCCH) search spaces, DL and UL scheduling, power control. Multicarrier operation.

7- NB-IoT DL synchronization methods

- Cell search and initial synchronization: system and signal models. Timing and frequency acquisition. Cell search.
- Some illustrative examples: cell ID and frame detection. Coarse timing and fractional CFO estimation. Fine timing estimation.

8- NB-IoT UL synchronization

- Random access (NPRACH) preamble design: symbol group, hopping pattern.
- NPRACH estimation: heuristic (frequency domain) method. Suboptimal (detection based) method: detection and threshold setting, use in AWGN and Rayleigh channels. Coverage analysis: UL time of arrival and CFO estimation.
- Some illustrative examples: performance comparison.

9- NB-IoT in ISM bands

- Regulations: US ISM bands. CEE short range devices.
- Alternatives for NB-IoT: Temporal diversity (primary signal densification, primary signal enhancement). Spatial diversity (artificial fast fading).

Bibliography

Books

- M.O. Pun, M. Morelli and C.C-J. Kuo, "Multicarrier techniques for wireless communications: A signal processing perspective", Imperial College Press, 2007.

- O. Liberg, M. Sundberg, Y.-P. E. Wang, J. Bergman, J. Sachs, "Cellular Internet of Things Technologies, Standards, and Performance", Academic Press 2018.

- H. Fattah, "5G LTE Narrowband Internet of Things (NB-IoT)", CRC Press 2019.

Articles

- M. Morelli, C.-C. Jay Kuo and M.-O. Pun, "Synchronization Techniques for Orthogonal Frequency Division Multiple Access (OFDMA): A Tutorial Review", Proceedings of the IEEE, Vol. 95, No. 7, July 2007.

- A. Ali and and W. Hamouda, "On the Cell Search and Initial Synchronization for NB-IoT LTE Systems", IEEE Communications Letters, Vol. 21, No. 8, Aug. 2017.

- J-K. Hwang, C-F. Li and C. Ma, "Efficient Detection and Synchronization of Superimposed NB-IoT NPRACH Preambles", IEEE Internet of Things Journal, Vol. 6, No. 1, Feb. 2019.

- X. Lin, A. Adhikaryand Y.-P.E. Wang, "Random Access Preamble Design and Detection for 3GPP Narrowband.

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Cellular Internet of Things (IoT) Technologies
Schedule 2021

Class 1 Introduction – motivation
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Class 3 3GPP LTE Characteristics
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Class 6 NB-IoT Idle and Connected Mode Procedures
Idle Mode
Connected Mode

Class 7 NB-IoT DL synchronization methods
System model - Cell search
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Class 8 NB-IoT UL synchronization
NPRACH preamble design
NPRACH estimation methods 1 and 2

Class 9 NB-IoT in ISM bands
Characteristics - Alternatives for NB-IoT

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Laboratories

There will be at least 4 demonstrative (self-contained) laboratories that address the use of a specific NB-IoT transceiver in terms of performance (coverture, consumption, latency, and rate).

After the first classes a laboratory guide and a specific schedule for the contents of the laboratories will be provided.

Schedule

Laboratory 1: Speed test

Measurement of the speed performance of the NB-IoT link.
Client and server configuration. Uplink – downlink analysis.

Laboratory 2: Latency test

Determination of the transmission delay of the NB-IoT link.
Uplink performance.

Laboratory 3: Range test

Getting RSRP and RSRQ downlink parameters.
Effects of increasing the coverage.

Laboratory 4: Energy consumption test

Analysis of NB-IoT modem power consumption.
Uplink – downlink analysis.

Evaluation

The evaluation will be oriented to the study (through simulation in Matlab or Simulink) of different aspects of NB-IoT. The thematic alternatives contemplate aspects of synchronism, detection - estimation and handling of interferences.

The study will require a final report and respect a delivery date.

The final grade will have the following components:
- Study work: 65%
- Laboratories: 25%
- Classroom participation: 10%