

Tutorial Proposal

Title of the Tutorial

LPWAN for the Internet of Things: Framework, Optimization, and Challenges of LoRaWAN and NB-IoT

Abstract of the Tutorial

Low-Power Wide Area Networks (LPWAN) have recently gained considerable attention in the Internet of Things (IoT). The key objective of these wireless technologies is to connect low-power devices over very large areas, with low data rates. LPWANs are promising for various emerging IoT applications, complementing the traditional cellular and short-range technologies.

In this tutorial, we present the recent advances in LPWAN technologies with focus on LoRaWAN and NB-IoT. We analyse the link level and system level design aspects. We further focus on link budget analysis and radio network dimensioning for both LoRaWAN and NB-IoT. Precisely, we present best practices in the network design and deployment of these technologies. Acquiring such best practices is of paramount importance for the engineering and optimization of LPWANs. We also provide a comparative scientific analysis of the performance of LoRaWAN and NB-IoT in terms of coverage and capacity.

Finally, we cover the research directions and scientific challenges in these technologies. Particularly, we present research directions for radio resource management in both LoRaWAN and NB-IoT.

Objectives and Motivation

Our tutorial sheds light on the recent advances in LPWAN technologies for IoT. We answer the following crucial questions related to the design, performance evaluation, and challenges of LPWAN: How do LPWAN complement traditional cellular and short-range wireless technologies? What are the fundamental mechanisms that enable to meet the LPWAN requirements? What are the major design choices made in the LoRaWAN and NB-IoT specifications? How do we evaluate the performance of a LoRaWAN and NB-IoT deployment in terms of coverage and capacity? What are the recent research directions for radio resource management in LoRaWAN and NB-IoT?

Our approach fills the gap in the state-of-the-art by introducing a set of generic building blocks that enable to meet the LPWAN requirements. We provide an overview on the two major technologies in LPWAN, namely LoRaWAN and NB-IoT, covering the radio interface, and the physical and protocol architectures. Participants will acquire deep understanding of the major design principles of both technologies and how they integrate the generic building blocks of LPWAN. Our approach is supported by novel results on path loss models and original use cases with numerical computations comparing the performance of LoRaWAN and NB-IoT in terms of coverage and capacity. We also provide a comprehensive scientific overview on the state-of-the-art and the promising research perspectives for radio resource management in LPWANs. This overview is of paramount importance for researchers to get a classification of the approaches, tools, and latest research results related to LoRaWAN and NB-IoT.

Timeliness and Intended Audience

Low-Power Wide Area Networks (LPWAN) represent a novel wireless communication paradigm, which will complement traditional cellular and short-range wireless technologies in addressing diverse requirements of IoT applications. LPWANs are attracting a lot of attention primarily because of their ability to offer large coverage and long battery life operating devices. Machina Research (2016) expects 11 percent of IoT connections in 2025 to use LPWAN technologies. This tutorial is of strong interest to the WPMC community working in the fields of communications technology. First,

engineers and professionals will benefit from an overview on the two major technologies in LPWAN, namely LoRaWAN and NB-IoT. They will acquire deep understanding of the major design choices of both technologies, and best practices in link budget analysis for capacity and coverage planning. Second, academic and industry researchers will benefit from a scientific overview on the state-of-the-art, and the promising research perspectives for radio resource management in LPWANs. Finally, graduate students will benefit from a technology overview on the radio interface, and the physical and protocol architectures for LoRaWAN and NB-IoT. This tutorial is accessible to a broad audience in the WPMC community as it only requires familiarity with communication and networking concepts.

Previous lecture and Tutorial experience of the Tutorial speaker(s)

The authors chose to make the tutorial sources available under Creative Common license CC BY-NC-SA 4.0 on the public repository <https://github.com/samerlahoud/tutorial-lpwan-iot>. The different versions are the result of a continuous effort to keep the tutorial material up to date. The tutorial was given in multiple scientific events:

- IEEE 5G World Forum, 5GWF 2019, Dresden, Germany, October 2019, <https://ieee-wf-5g.org/tutorial-cellular-internet-of-things-framework-optimization-and-challenges-of-nb-iot/>
- 25th International Conference on Telecommunications, ICT 2018, Saint-Malo, France, June 2018, <http://ict-2018.org/tutorials/>, 30 attendees
- International Symposium on Performance Evaluation of Computer and Telecommunication Systems, Bordeaux, France, July 2018, <http://atc.udg.edu/SPECTS2018/>
- Seminar of the Faculty of Engineering at Saint-Joseph University of Beirut, June 2018, <https://bit.ly/2NJmvGb>, 30 attendees
- Labex DigiCosme Seminar on Future Access Networks: Cloud-RAN and Optimization problems, Paris Saclay, June 2017, <http://bit.ly/2B2ak1f>, 20 attendees
- Course on Internet of Things Technologies, ESIB, Saint-Joseph University of Beirut, <http://bit.ly/2BcXU7I>, a total of 42 students from 2016 to 2018
- The speakers are participating in the deployment of the first academic LPWAN network in Lebanon. The network supports monitoring of micro-climate conditions in vineyards. The experimental platform implements an end-to-end LoRaWAN solution (http://wiki.lahoud.fr/doku.php?id=exploring_lorawan). Currently, the speakers are leading scientific and experimental studies for measuring, assessing, and modelling the coverage, capacity, and quality of service of the LoRaWAN deployment. The tutorial will also be an occasion to present the latest results of these scientific studies published in the IEEE Internet of Things Journal

Outline of the Tutorial and the topics the speakers will cover

Services and applications that foster low power wide area networks; Samer Lahoud

Architecture and characteristics of low power wide area networks; Samer Lahoud

LoRaWAN design rationale - how LoRaWAN meets LPWAN requirements, in terms of device complexity and cost, coverage, power consumption, capacity, and network topology and deployment?; Melhem El Helou

NB-IoT design rationale - how NB-IoT leverages and adapts 3GPP LTE infrastructure and mechanisms to meet LPWAN requirements?; Melhem El Helou

LoRaWAN specification: radio interface, physical architecture, protocol architecture; Samer Lahoud

NB-IoT standard: radio interface, physical architecture, protocol architecture; Melhem El Helou

Radio models and link budget analysis for LoRaWAN; Melhem El Helou

Radio models and link budget analysis for NB-IoT; Melhem El Helou

ALOHA based model for LoRaWAN dimensioning; Samer Lahoud
Bandwidth based dimensioning for NB-IoT; Samer Lahoud
Performance comparison of LoRaWAN and NB-IoT; Melhem El Helou
Research directions for radio resource management in LoRaWAN and NB-IoT; Samer Lahoud

The tutorial speakers

Samer Lahoud, ESIB, Saint Joseph University of Beirut, Lebanon, samer.lahoud@usj.edu.lb
Melhem El Helou, ESIB, Saint Joseph University of Beirut, Lebanon, melhem.helou@usj.edu.lb

Samer Lahoud is an Associate Professor at the Saint-Joseph University of Beirut where he lectures computer networking courses at the Faculty of engineering (ESIB). His research activities focus on routing and resource allocation algorithms for wired and wireless communication networks. He has co-authored more than 80 papers published in international journals and conference proceedings. Mr. Lahoud received the Ph.D. degree in communication networks from Telecom Bretagne, Rennes, in 2006. After his Ph.D. degree, he spent one year at Alcatel-Lucent Bell Labs Europe. From 2007 to 2016, he was with the University of Rennes 1 and with IRISA Rennes as an Associate Professor.

Melhem El Helou received the engineer's degree and master's degree in telecommunications and networking engineering from the Ecole Supérieure d'Ingénieurs de Beyrouth (ESIB), Faculty of Engineering at the Saint Joseph University of Beirut, Beirut, Lebanon, in 2009 and 2010, respectively and the Ph.D. degree in computer and telecommunications engineering from IRISA Research Institute, University of Rennes 1, Rennes, France and Saint Joseph University of Beirut, in 2014. He joined ESIB in September 2013 where he is currently an Assistant Professor (*fr*: Maître de conférences). His research interests include wireless networks, radio and energy resource management, Internet of Things, and quality of service.

Selected Publications

R. El Chall, **S Lahoud**, and **M El Helou**, LoRaWAN Network: Radio Propagation Models and Performance Evaluation in Various Environments in Lebanon, accepted for publication in IEEE Internet of Things Journal.

M. Yassin, **S. Lahoud**, K. Khawam, M. Ibrahim, D. Mezher, and B. Cousin, Centralized versus decentralized multi-cell resource and power allocation for multiuser OFDMA networks, In Computer Communications, volume 107, 2017.

S. Lahoud, K. Khawam, S. Martin, G. Feng, Z. Liang, and J. Nasreddine, Energy Efficient Joint Scheduling and Power Control in Multi-Cell Wireless Networks, In IEEE Journal on Selected Areas in Communications (JSAC), volume 34, 2016.

M. El Helou, **S. Lahoud**, M. Ibrahim, K. Khawam, B. Cousin, and D. Mezher, A Hybrid Approach for Radio Access Technology Selection in Heterogeneous Wireless Networks, In Wireless Personal Communications, volume 86, 2016.

K. Khawam, **S. Lahoud**, M. Ibrahim, M. Yassin, S. Martin, **M. El Helou**, and Farah Moety, Radio access technology selection in heterogeneous networks, In Physical Communication, Special Issue on Radio Access Network Architectures and Resource Management for 5G, volume 18, Part 2, 2016.

M. El Helou, M. Ibrahim, **S. Lahoud**, K. Khawam, D. Mezher, and B. Cousin, A Network-Assisted Approach for RAT Selection in Heterogeneous Cellular Networks, In IEEE Journal on Selected Areas in Communications - Special Issue on Recent Advances in Heterogeneous Cellular Networks (JSAC), volume 33, 2015.