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5G NB-IoT: Design, Considerations, Solutions and Challenges

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Abstract

The Internet of Things (IoT) is transforming the telecommunication landscape these days, and it has infiltrated every part of our life with applications in smart health, home automation, smart logistics, smart industries, and smart cities. Mobile IoT, such as narrowband-IoT (NB-IoT) and long-term evolution (LTE) for machines (LTE-M), are important advancements in this rapidly evolving field of IoT technology. Narrowband Internet of Things (NB-IoT) is a low-power wide-area (LPWA) technology built on long-term evolution (LTE) characteristics and standardized by the 3rd-Generation Partnership Project (3GPP).With the arrival of the 5G era, this article demonstrates how NB-IoT is an important aspect of 5G, despite the fact that it is not yet fully deployed from the LPWA standpoint. This article goes on to say that NB-IoT will continue to serve LPWA 5G use cases, and that it will coexist with other 5G components that address different use cases.

Keywords: NB-IoT; 5G

1. Introduction

NB-IoT (Narrowband Internet of Things) technology has emerged as a leading solution in the context of LPWAN since its establishment by the 3GPP (3rdGeneration Partnership Project) in Release 13 (Rel-13) (Low Power Wide Area Networks) [1]. LPWAN is a prominent network technology for IoT applications suitable for long-range communications and machine-to-machine (M2M) cellular networks [2]. By exploiting existing cellular architecture in a cost-effective manner, NB-IoT, in conjunction with other technologies, provides IoT services for massive machine type communications (mMTC) in 5G, including use cases for smart cities and industrial automation [3].The first version of 5G NR (New Radio), the term coined for the global 5G standard new radio connectivity technology, covers eMBB (enhanced mobile broadband) and URLLC (ultra-reliable, low-latency communication) application cases

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NB-IoT is a 3GPP specification designed to coexist with other 3GPP 5G technologies in order to meet the long-term 5G LPWA standards[4]. To complete the 5G system's NB-IoT support, the 3GPP is also looking at ways for the 5G core network to support the NB-IoT radio access network. This will enable operators to transition smoothly to 5G NR frequency bands while maintaining NB-IoT deployments. Generally speaking, 5G has three main applications:

- LPWA / Mobile IoT(NB-IoT and LTE-M) / Massive IoT :The 3GPP-standardised Low Power Wide Area (LPWA) technologies employing licensed spectrum bands such as NB-IoT and LTE-M are referred to as Mobile IoT. This term implies enhanced network coverage, extended device operational lifetime, and high connection density referred as mMTC (Massive MTC).
- Critical Communications:Industrial IoT and mission-critical applications that require high performance, ultra-reliability, and low latency. It's also known as URLLC (Ultra Reliable Low Latency Communications).
- Enhanced Mobile Broadband:When it comes to accessing multimedia information for communication purposes, consumers will have a better experience.
  5G dynamically allocates resources in order to support divers use cases.

1.1. Objectives and Scope of this Review

In recent years, IoT technologies have received a lot of attention. A lot of work has gone into gathering data and creating a comprehensive understanding of these technologies, their protocols, architectures, application domains, and future problems. In this review we briefly demonstrate how NB-IoT is an important aspect of 5G. For the sake of brevity a detailed technical aspects of 5G and NB-IoT is out of the scope.

2. 5G Overview

To enable NB-IoT and a wide range of IoT applications, 5G networks use intelligent radio access technology (RAT) architectures that are dynamic by nature, coherent, and versatile across various advanced technologies [6]. As per 3GPP releases 16 and 17, 5G-IoT services may connect practically anything in our environment with high-performance, low-complexity connectivity [7].

The availability of more cheap devices, as well as the first commercial 5G mobile cellular networks, are generating demand and market interest among both consumers and businesses. 5G cellular networks that are currently being deployed are an evolution of existing 4G networks, which will continue to serve a wide range of applications. 5G will most likely be around for a long time [8]. While 4G will continue to be used in IoT sectors, 5G offers a number of advantages that 4G does not, including the ability to serve a large number of IoT devices with varying speed, bandwidth and quality of service requirements [9]. As 5G increases network capacity, cloud computing, artificial intelligence and edge computing will help process the volumes of data created by the IoT. Additional 5G innovations, such as network slicing, non-public networks, and 5G core, will eventually aid in the realization of the goal of a worldwide IoT network that can handle a large number of connected devices [10].

Based on transmission distance, 5G-based IoT wireless technologies may be divided into two categories: short-range (Wi-Fi, Bluetooth,...) and long-range (LPWA: Sigfox, LoRa,..). In terms of frequency spectrum licensing, LP-WAN is divided into two groups: unlicensed spectrum and licensed spectrum. The unlicensed spectrum has limited access to the channel because they shared spectrum with other technologies,thus the transmission period has a limited duty cycle to avoid interference with coexisting technologies.Licensed spectrum, on the other hand, is based on cellular networks(2G/3G/4G/5G) and does not suffer from duty cycle or unpredictable interference [11] [12].

3GPP has decided that the LPWA use cases would continue to be addressed by evolving NB-IoT as part of the 5G specifications, thus supporting the idea that NB-IoT supports the 5G LPWA needs. As a result, NB-IoT is now considered part of the 5G family. As more 5G components supporting 5G use cases other than LPWA are specified and rolled out in the future, it is expected that NB-IoT will coexist with these other 5G components. To boost support for IoT devices used by consumers and businesses, the standards group 3GPP has introduced a number of modifications to 5G network architecture and NR specifications such as: Ultra-Reliable Low Latency Communications (URLLC) and Non-public Networks [13].

2.0.1. *Ultra-Reliable Low Latency Communications(URLLC)*

The 5G NR includes ultra-reliable low-latency communication (URLLC) for new applications that demand reliability and latency, such as augmented/virtual reality, industrial automation, and driverless vehicles.The physical design of 5G in release 15 provides a foundation for URLLC with features such as Flexible sub-carrier spacing, a sub-slot-based transmission scheme, a new channel quality indicator, new modulation and coding scheme tables, and configured-grant transmission with automated repetitions.In Release 16 a number of new features has been added such as the capability to monitor the downlink physical layer channel and the control channel for uplink physical layer[14].Release 17 aims to improve URLLC performance by adding feedback, intra-user-equipment multiplexing and prioritization of traffic with varying priorities, time synchronization support, and new quality of service related characteristics [15]. URLLC is crucial for Social IoT netwotk as well as smart city and smart home applications . Smart cities may, for example, employ URLLC IoT devices to better control traffic, alleviate congestion, and notify drivers of impending accidents, all of which would benefit road users [10].Thus, 5G technology, which is supported by worldwide standards, will provide the reliability and low latency required for vital IoT.

2.0.2. *Non-Public Networks*

Although 3GPP Rel-15 was designed primarily for public usage, the idea of 5G networks being implemented for private use has recently piqued the industry's interest.As a result, their research was recently included in the 3GPP Rel-16 for the second phase of 5G networks [16].This has resulted in a new classification, according to which networks can be divided into two categories based on their intended use: Public Land Mobile Networks (PLMNs) and NonPublic Networks (NPNs).PLMN provides network services for public usage within a certain region, with nationwide coverage normally. A PLMN is run by a Mobile Network Operator (MNO), which also serves as the PLMN's operator. A 5G non-public network (NPN), also known as a private network, on the other hand, is designed for the exclusive use of a single private organization, usually Campus networks in universities, hospitals, and military posts, as well as marine ports, manufacturing plants, and transportation centers, are all possible use cases [17]. The deployment of an NPN in the industry 4.0 ecosystem enables a business to use an end-to-end, in-premise 5G network, allowing private traffic to be limited within the defined premises without the need to reach the public network.This is advantageous for a variety of reasons, including:

- High Quality of service requirements
- Extremely stringent security requirements, which are met by the use of strong security credentials and particular authorisation processes.
- Isolation from the general public. This allows the NPN to be protected from security threats or PLMN failures (such as service outages).
- The Enterprise or organization can manage authentication and authorization of NPN devices, as well as maintain track of their subscription data for accounting and auditing purposes, thanks to its network-independent functioning.

Traditional public networks may be unable to meet the severe requirements demanded by these applications.Thus, the need for NPN network.

3. NB-IoT As part of 5G

The growth of 3GPP standards connected to IoT has increased in recent years as a result of demand from cellular users who need a standard solution that goes one step further to deliver a real cellular and consistent solution for LPWA (Low Power Wide Area) networks. The billions of potential additional subscribers generated by IoT use cases are driving this pressure. Other prior 3GPP technologies such as GSM or Machine Type Communication (MTC) launched in Release 8, as well as newer ones such as eMTC or EC-GSM and unlicensed LPWA such as Lora or Sigfox, can only address a limited number of use cases [3].Thus, the 3GPP established NB-IoT to handle a huge number of use cases with ultra-low cost, extended coverage, and delay tolerance, which are referred to as massive Machine Type communication use cases in 5G language. Previous publications[11][18] [12] have examined the principles of NB-IoT technology,its comparison with other LPWA technologies as well as its background. This current research focuses on

NB-IoT technology in the context of 5G.

NB-IoT was created with the 4G LTE standard in mind. However, the 3GPP, which is responsible for both 5G and NB-IoT standards, has included NB-IoT in the 5G standard. In addition, 3GPP plans to support NB-IoT for LPWA use cases that necessitate low cost, low power, high capacity, and low energy consumption. Furthermore, much as NB-IoT can coexist with LTE technologies, it can also coexist with upcoming 5G technologies such as 5G New Radio (NR). As a result, NB-IoT is now considered part of the 5G family.

The 5G New Radio (NR) standard was created to accommodate a wide range of deployment methods, spectrum usage, and device capabilities.

Additionally, operators can utilise the sub-6 GHz wireless spectrum now used by 4G LTE, NB-IoT, and LTE-M for 5G NR thanks to Dynamic Spectrum Sharing (DSS), a new capability introduced by 5G NR.[8]

3.0.1. NB-IoT Integration with 5G Architectural Design

The use of wireless software-defined networking and the network function virtualization (NFV) paradigm through the relationship between the 5G radio access network (RAN) and the 5G architectural infrastructure allowed NB-IoT to be incorporated into the ongoing 3GPP 5G architectural design. The introduction of WSDN and NFV enabled the NB-IoT model to provide cost-effective service support for communication between NB-IoT devices and applications [4] [19] [20]. The two technologies allow for network slicing, which allows for tailored QoS and unique functionality for various vertical markets.The GSMA has published a document outlining network slicing, demonstrating how it may be used by business clients to fulfill their unique requirements in a similar way to a private network [10].

The 5G New Radio (NR) standard was created to accommodate a wide range of deployment methods, spectrum usage, and device capabilities. Allowing NB-IoT broadcasts to be inserted straight into a 5G NR frequency band has been one of the deployment scenarios endorsed by 3GPP since the beginning of 5G NR work [21].Although NR channel bandwidth flexibility is similar to that of LTE and NB-IoT, coexistence with NB-IoT can improve resource efficiency and reduce mutual interference between the two networks. Specific design limits that must be overcome, including as interference, scheduling, and resource utilization, can be used to determine subcarrier orthogonality between NR and NB-IoT. The resource utilization between the NR and NB-IoT can be increased by using aligned resource blocks (RBs).

Macro-cell and small-cell infrastructures of heterogeneous networks make up 5G networks and currently deployed LTE networks. Interference occurs when small cells are overlayed over macro-cells, affecting small-cell edge users and NB-IoT UEs' ability to acquire appropriate QoS in the NB-IoT network. Four kinds of possible support for NB-IoT coexistence with legacy LTE and continuing 5G have been proposed to improve NB-IoT performance in a small-cell network, based on spectral efficiency, coverage, and capacity over heterogeneous infrastructures (macrocell and small cells):

- Synchronous distribution of NB-IoT in all small cells: All synchronized small cells appear to be in a mode to use the same PRB in this circumstance. Despite the maximum broadcast power capacity, all NB-IoT UEs should use the same transmit power to avoid co-channel interference among several UEs sharing the same radio resources.
- Asynchronous distribution of NB-IoT in all small cells: For NB-IoT UEs, this scenario necessitates a particular frequency design as well as a specified power arrangement. All small-cells with NB-IoT enabled are designed using distinct PRBs. This approach minimizes interference between NB-IoT UEs from different small cells, but it may generate co-channel interference between NB-IoT and 5G NR/LTE UEs that use the same radio resources. Several methods for reducing co-channel interference that have been proposed need to be improved further.
- Synchronous distribution of NB-IoT in small cells and macro-cells: On the same PRBs, the technique enables NB-IoT in both small and macro-cells with varied transmit powers. The macro-cell UEs should be designed to transmit at a higher power than the small-cell UEs. The remaining PRBs are set up to support 5G NR/LTE. If the UEs scheduled are on the same resource unit, co-channel interference may occur on small-cell edge UEs. The impact of co-channel interference may be amplified for UEs in mobile mode, which may necessitate the usage of handover to smooth the UE's transfer from one serving cell to the next. While considering the low complexity yet wide coverage range of NB-IoT, it is critical to use existing geographical planning, frequency reuse, frequency hopping, and power regulation.

- Asynchronous distribution of NB-IoT in small cells and macro-cells: To ensure enhanced spectral efficiency, performance, and extensive NB-IoT distribution with other technologies, the approach assesses numerous aspects such as use case specifications, environmental limits, equipment state, and so on. Separate PRBs for NB-IoT among small cells and macro-cells are used in this method, with various PRBs for small cells and macro-cells. To avoid interference from a neighboring cell of NB-IoT users with similar resource units, the technique necessitates effective PRBs planning. NR/LTE users with similar resource elements are also prone to clash with small cell or macro-cell UEs. To avoid interference, different transmitting power control configurations are used.

In general, because NB-IoT is part of the 5G RAN technology, unlike LTE, the design and implementation of an effective channel interference mitigation scheme will be dependent on the use cases, deployment scenario, and size of the cooperative set, while maintaining an intelligent level of flexibility for resource planning.

4. Use Cases and Applications for 5G NB-IoT

When it comes to IoT applications, one of the most well-known is the SIoT, which is a derivative of the IoT whose goal is to employ social networking principles within the IoT to allow devices to develop social interactions on their own. Self-driving vehicles, random pedestrians browsing their phones can actually be controlled through this innovation as shown in Fig. 1 below.

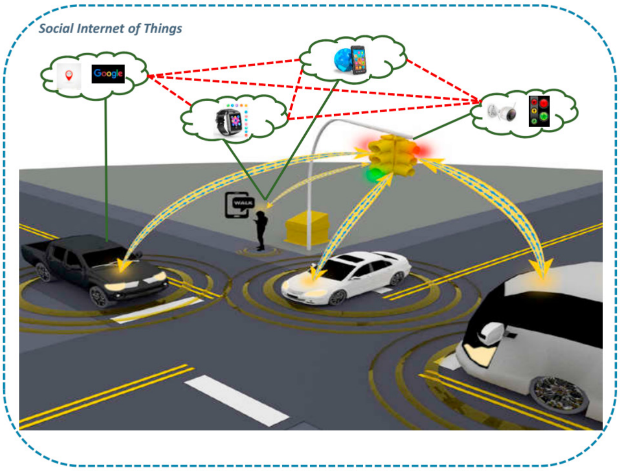

Fig. 1: The SIoT Architecture.

As illustrated in Fig. 1 above, it is now possible for you, a random person who may have nothing to do with self-driving cars, to have a ride in one of those fully autonomous vehicles. The motivation of the SIoT in the IoT era is that a social-oriented approach is expected to support the discovery, selection and composition of services and information provided by distributed objects and networks [22]. According to the SIoT, a set of forms of socialization among objects exist and establish co-location object relationship and co-work object relationship, like humans do when they share personal (e.g., cohabitation) or public (e.g., work) experiences [23].

Another type of relationship is defined for objects owned by the same user (i.e., mobile phones, game consoles, etc.) which is called ownership object relationship [24]. The ownership object relationship is established when IoT devices come into contact for reasons purely related to relations among their owners (e.g., devices/sensors belonging to friends) and it is named social object relationship [25]. Then, the resultant social network can then be shaped as required to guarantee the network navigability, so that the discovery of information is performed efficiently, as illustrated in Fig. 1. Moreover, by leveraging the degree of interaction among friends, it is possible to achieve a high level of trustworthiness, in order to clear the uncertainty of the services received.

NB-IoT enables the realization and aspirations of a wide range of use cases and applications without the need for human interaction. These use cases and applications can be divided into three categories which are: Industrial IoT, Consumer IoT and Enterprise IoT.

4.1. Industrial IoT

The Industrial Internet of Things (IIoT) is aimed at complicated industrial processes and systems with unique network requirements. Through remote monitoring and control capabilities, it focuses on improving operational efficiency, safety, and sustainability.Typical applications are: Smart factories,Agricultural monitoring and Industrial assets.

4.2. Consumer IoT

By automating and simplifying day-to-day tasks, Consumer IoT aims to improve the quality of life and well-being of individual users.Typical applications are: smart homes, environmental surveillance and smart offices.

4.3. Enterprise IoT

The Enterprise Internet of Things is the next technological innovation that allows physical 'things' with embedded computing devices (small computers) to participate in business operations, eliminating human labor and enhancing overall corporate efficiency.Typical applications are : smart city and all public utilities such as energy plant and management.

5. Open Challenges

This section identifies some challenges that should be addressed in future research:

5.1. Channel Interference

Interference is an inherent limitation of the NB-IoT network operating frequency reuse of the new 5G NR and 4G LTE wireless systems in the context of 5G NB-IoT, even though the concept of frequency reuse improves maximum spectrum utilization while also limiting spectral efficiency, network, and user performance. Thus, minimizing co-channel interference is clearly required for coexistence of NB-IoT and 5G systems.Unlike the LTE interference mitigation scheme, because NB-IoT is part of the 5G RAN technology, the design and implementation of an effective channel interference mitigation scheme will be dependent on the use cases, deployment scenario, and size of the cooperative set, while maintaining an intelligent level of flexibility for resource planning [4].

5.2. Network Congestion

The fundamental benefit of 5G is that it has more capacity, allowing new networks to drastically expand coverage beyond cellphones to include general internet service for traditionally fixed connectivity to the home, office, factory, and other places of business. Similar transitions, on the other hand, have repeatedly demonstrated that congestion and QoE issues would remain the same or worsen.

The "If you build it, they will come" model has been proven time and over again by mobile technology. If you build a new roadway or add lanes, for example, more people will drive, boosting demand and causing more traffic. In telecom, the same concept applies: as bandwidth becomes more widely available, demand rises. In order to secure and better utilize their 5G capabilities for delivering IoT services, mobile and wireless networks must include many mechanisms that will remotely manage such devices and apps and allow for intelligent scheduling.

5.3. Energy-efficient Operation

Another feature of the IoT industry is that, in some cases, devices and applications can be installed and actively used for many years while running on batteries or needing very little power. To ensure a longer gadget lifetime, the communication module must consume relatively minimal energy in this situation.
eDRX and PSM, the two energy-saving strategies employed in the NB-IoT network to increase device battery life, are inefficient when a large number of devices communicate at low data rates frequently.Thus, a new scheme for energy efficiency should be proposed.

5.4. Delay Tolerant

Low-latency support is an important method for NR and NB-IoT systems to coexist. The NB-IoT network has a delay of 10s, while NR has a delay of 1ms to improve the signal-to-interference-plus-noise ratio distribution across users. There have been a number of ways proposed to reduce the time requests of NB-IoT transmitting devices in LTE networks and to reduce transmission delay. However, considering the basics of mini-slot (as the smallest slot) that may be planned to reduce latency in 5G NR, the idea of NB-IoT deployment in NR carrier requires a different strategy.

5.5. Security and Privacy

The embedding of NB-IoT into 5G NR networks ensures that security and privacy are guaranteed. Because of its low complexity in comparison to the 3GPP standard, the NB-IoT operation lacks a realistic access-authentication method in 5G networks.To enable mutual authentication with the network, NB-IoT uses traditional access-authentication methods, which can result in a lot of signaling overhead. However, this makes protecting NB-IoT devices extremely difficult. Thus, an approach for NB-IoT authentication access is required.

6. Conclusion

The purpose of this article was to show that NB-IoT will continue to serve LPWA 5G use cases and coexist with other 5G use case components. The overviews of 5G and NB-IoT were presented with the understanding that the technical aspects of both technologies were outside the scope of this study. It then goes on to discuss some 5G use cases and applications in NB-IoT, as well as open problems for future research. As a result, we encourage more research into NB-IoT as part of 5G cellular technology and future technologies like 6G.

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References

[1] Caso, Giuseppe and Kousias, Konstantinos and Alay, and Brunstrom, Anna and Neri, Marco, "NB-IoT Random Access: Data-driven Analysis and ML-based Enhancements",*IEEE Internet of Things Journal*, 2021.

[2] Hassan, Mona Bakri and Alsharif, Sameer and Alhumyani, Hesham and Ali, Elmustafa Sayed and Mokhtar, Rania A and Saeed, Rashid A, "An Enhanced Cooperative Communication Scheme for Physical Uplink Shared Channel in NB-IoT" *Wireless Personal Communications*, pp. 1 - 20, 2021.

[3] Z. Almudena and Rivas Tocado, Francisco Javier and Rodriguez., "Evolution and Testing of NB-IoT Solutions," *Applied Sciences*, vol. 10, no. 21, pp. 7903, 2020.

[4] S.A.Gbadamosi,G.P.Hancke and A M. Abu-Mahfouz., "Building Upon NB-IoT Networks: A Roadmap Towards 5G New Radio Networks" *IEEE Access*, vol. 8, pp. 188641–188672, 2020.

[5] S. Li, L. D. Xu, and S. Zhao., "5G Internet of Things: A survey," *Journal of Industrial Information Integration*, vol. 10, , pp.1–9, 2018.

[6] Qualcomm., "3GPP charts for the next Chapter of 5G standards," *https://www.qualcomm.com/news/onq/2019/12/13/3gpp-charts-nextchapter-5g-standards*, March 2020.

[7] S.N Hiroki Harada, K.Aoyagi and H.Takahashi "5G Evolution Directions and Standardization Trends," *Special articles on 3Gpp release 16 Standardization Activities*,vol 22, No 3 Jan 2021.

[8] GSMA,"The 5G Guide", GSMA Intelligence, 2019

[9] Mohsen Attaran, "The impact of 5G on the evolution of intelligent automation and industry digitization" *Journal of Ambient Intelligence and Humanized Computing*, Feb 2021.

[10] GSMA,"The 5G Era Opportunities and Benefits for Enterprises and Consumers", GSMA Intelligence, 2019

[11] K.F Muteba, K. Djouani, and T.O Olwal, "A comparative Survey Study on LPWA IoT Technologies: Design, considerations, challenges and solutions,"*Procedia Computer Science* vol.155, pp. 636 - 641, 2019.

[12] K.F Muteba, k. Djouani, and T.O Olwal, "Opportunistic Resource Allocation for Narrowband Internet of Things: A Literature Review," *2020 International Conference on Electrical, Communication, and Computer Engineering (ICECCE)*, Istanbul, Turkey, 2020, pp. 1-6.

[13] GSMA,"Mobile IoT in the 5G future", GSMA Intelligence, April 2018

[14] T.K. LE, U. Salim, and F. Kaltenberger, "An Overview of Physical Layer Design for Ultra-Reliable Low-Latency Communications in 3GPP Releases 15, 16, and 17," *IEEE Access*,vol 9, 2021,

[15] F.H.Sepehr, M.Sajadieh, S.Panteleev,T.Islam, I.Karls, D.Chatterjee, and J. Ansar "5G URLLC: Evolution of High-Performance Wireless Networking for Industrial Automation" *IEEE*, 2021,

[16] J.O.Lucena, J.F. Chavarria, L. M. Contreras, A. Pastor "The use of 5G Non-Public Networks to support Industry 4.0 scenarios" *IEEE Conference on Standards for Communications and Networking (CSCN)*, 2019,

[17] 5GACIA "5G Non-Public Networks for Industrial Scenarios" *5G Alliance for Connected Industries and Automation*, 2019,

[18] K.F Muteba, K.Djouani, and T.O Olwal, "Challenges and Solutions of Spectrum Allocation in NB-IoT Technology,"*SATNAC*,Ballito, KwaZulu-Natal, South Africa. Sept, 2019.

[19] K.Kim, D.Kim, and S.Shoi "GPP SA2 Architecture and Functions for 5G Mobile Communication System,"*Elsevier*,Amsterdam, Netherland, 2017.

[20] P. Marsch, Ö. Bulakci, O. Queseth, and M. Boldi, "5G System Design,Architectural and Functional Considerations and Long Term Research,"*Wiley*, UK. Sept, 2018.

[21] 3GPP , "clauses 4.2 and 4.3 in "NR - Physical channels and modulation","*3GPP TS 38.2*, 2018.

[22] L. Atzori, A. Iera, and G. Morabito, "SIoT: Giving a Social Structure to the Internet of Things," *IEEE Communications Letters*, vol. 15, no. 11, pp. 1193 - 1195, November 2011.

[23] L. Atzori, A. Iena, G. Morabito, and M. Nitti, "The Social Internet of Things (SIoT) - When Social Networks Meet the Internet of Things: Concept, Architecture and Network Characterization," *Computer Networks*, vol. 56, no. 16, pp. 3594 - 3608, November 2012.

[24] W. Abdelghani, C. A. Zayani, I. Amous, and F. Sedes, "Trust Management in Social Internet of Things: A Survey," *in the 15th IFIP Conference on e-Business, e-Services and e-Society (I3E2016)*, Swansea, UK, 13 - 15 September 2016.

[25] R. Girau, S. Martis, and L. Atzori, "Neighbor discovery algorithms for friendship establishment in the social Internet of Things," *IEEE 3rd World Forum on Internet of Things (WF-IoT)*, pp. 1 - 6, 2016.