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A Survey on Energy Efficient Narrowband Internet of Things (NBIoT): Architecture, Application and Challenges

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ABSTRACT The advancement of technologies over years has poised Internet of Things (IoT) to scoop out untapped information and communication technology opportunities. It is anticipated that IoT will handle the gigantic network of billions of devices to deliver plenty of smart services to the users. Undoubtedly, this will make our life more resourceful but at the cost of high energy consumption and carbon footprint. Consequently, there is a high demand for green communication to reduce energy consumption, which requires optimal resource availability and controlled power levels. In contrast to this, IoT devices are constrained in terms of resources—memory, power, and computation. Low power wide area (LPWA) technology is a response to the need for efficient utilization of power resource, as it evinces characteristics such as the capability to proffer low power connectivity to a huge number of devices spread over wide geographical areas at low cost. Various LPWA technologies, such as LoRa and SigFox, exist in the market, offering a proficient solution to the users. However, in order to abstain the need of new infrastructure (like base station) that is required for proprietary technologies, a new cellular-based licensed technology, narrowband IoT (NBIoT), is introduced by 3GPP in Rel-13. This technology presents a good candidature to handle LPWA market because of its characteristics like enhanced indoor coverage, low power consumption, latency insensitivity, and massive connection support towards NBIoT. This survey presents a profound view of IoT and NBIoT, subsuming their technical features, resource allocation, and energy-efficiency techniques and applications. The challenges that hinder the NBIoT path to success are also identified and discussed. In this paper, two novel energy-efficient techniques ''zonal thermal pattern analysis'' and energy-efficient adaptive health monitoring system have been proposed towards green IoT.

INDEX TERMS Internet of Things (IoT), narrowband Internet of Things (NBIoT), low power wide area network (LPWAN), green communication, smart agriculture, smart health.

I. INTRODUCTION

5G is on the purview where IoT will seize the stage spotlight, as IoT devices would form a notable segment of the 5G network. The radical evolution of the current Internet into a network of interconnected objects harvest information from the environment and interact with the physical world. The mammoth interest of connecting sensors, actuators, meters cars, appliances, and so on with internet, results in the Internet of Things [1], [2]. According to IEA-4E (Electronic device and network annex), the number of network connected devices will be 50 billion by 2020 [3]. Thus enterprises ushers into the modern era of automation to evidently change our daily lives by providing solution related to multiple sectors of health, agriculture, retail, vehicular, industry, power grid, underwater, buildings, homes, environment, transportation, smart home [4]. By 2024 itself, it is expected that the IoT industry will generate a revenue of USD4.3 billion [5] and it's expected to grow over years. However, deployment of gigantic IoT ecosystem brings in various challenges to handle such as cost-efficient robust and flexible connectivity, interoperability of heterogeneous hardware, diverse security mechanism [6], and long battery life. However, the major deployment obstruction is due to constrained resources availability for IoT devices i.e. limited energy, limited computation, and limited processing capabilities [7]. Most importantly the flavor of IoT gets bitter, especially due to limited energy as this leads to unanticipated human intervention. Hence the burning issue of efficient utilization of energy is getting anomalous traction from academics and industry. In literature, various techniques have been proposed to tackle this critical issue such as energy harvesting, sporadic transmission, resource allocation, clustering, etc. Ju and Zhang [8] suggested the technique of predictive analysis with energy harvesting to obsolete the battery from IoT device. Na *et al.* [9] suggested a technique to charge the device wirelessly using RF. Further, a power-aware connectivity using Spanning tree algorithm is suggested by Karthikeya *et al.* [10]. Shafiee *et al.* [11] designed a circuit to manage the power of the device where a source of energy is ambient.

Another crucial challenge is to handle the diverse requirement of wide range of IoT applications. Today there are two evident classes of IoT applications: Critical IoT and Massive IoT. Critical IoT applications such as autonomous driving or remote surgery require very low latency with ultra-high reliability. Massive IoT (M-IoT) applications like smart building, logistics, tracking and fleet management, smart agriculture, etc. require low cost device with reduced complexity that consumes low power, wide coverage including uncovered areas and performance flexibility to handle multiple application with different latency and throughput requirement.

According to current statics, low data rate (<100kbps) applications i.e. M-IoT, are expected to form 60% of IoT connections in 2020 in comparison to medium and high data rate applications [12]. Hence most of the traffic will originate from cost-effective low-bit-rate services that will serve the connected world. Since massive communication between various low power IoT devices is different from H2H (Human-to-Human) in terms of delay sensitivity and traffic pattern, thus could not be supported by cellular technologies adequately. As they are designed for the different category of terminal that operates at a high data rate and consumes high power their device complexity is also high and thereby their cost, though it will aid in deployment of IoT. Apart from this, technologies such as Wi-Fi, BLE, ZigBee, etc., offer short range communications though consume less power. However, if deployed repeatedly will increase the cost. Hence not a cost effective solution for applications with wide coverage range requirements like M-IoT. Thus a technology is required that could support massive connection at reduced cost with low power consumption & provide enhanced coverage [13].

LPWAN technologies are one that could support this emerging market as it allows low power device to communicate at low data rate over wide area with radius of several kilometers. LPWA proffers abilities like Indoor penetration: as it uses Sub-1GHz band, the signal propagates more reliably with less power consumption as compared to 2.4GHz signal. Low power consumption is achieved at a cost of low data rate and latency on the higher end in seconds or minutes. This ability is achieved by using Duty cycling, by using star topology (usually), by allowing devices to directly connect to BS (thereby bifurcating the need of gateway & relays also) or by reducing burden on the device side(by using Fog or edge Computing). Further for Low cost, CAPEX (capital expenditure) & OPEX (operational expenditure) is reduced by reducing the complexity of hardware, implanting less no of BS (LPWA BS) etc. Massive connections, QoS are two abilities where still improvement is required. Standard bodies like ETSI, 3GPP, IEEE, IETF are actively working on LPWA technologies. A range of applications such as precision monitoring, Smart City, Home Automation, Industrial Asset monitoring, Logistics, Wildlife Monitoring, Smart meter, is being catered by LPWA technologies. As the LPWA market is expected to rule the market in coming years, hence competition among LPWA technologies becoming severe.

Recently to improve the foundation of IoT through cellular networks, and tussle with existing proprietary LPWA technologies (LoRa, SigFox, RPMA, etc.), 3GPP has introduced three technologies in Rel-13 namely eMTC (enhanced Machine Type Communication), NB-IoT, EC-GSM (enhanced coverage GSM). These cellular technologies will operate in licensed spectrum and will reuse the existing LTE infrastructure. Among available connecting technologies, NBIoT specifically tailored for emerging M-IoT market is one of the promising massive LPWA technology for data perception and acquisition for low data rate applications. NBIoT could handle massive connections with low power consumption and provide wide area coverage with deep indoor penetration and nomadic mobility [14]–[16]. Most outstandingly it offers reliable service by using licensed bands and avoid congestion problems. NB-IoT reduced the hardware complexity by 90% compared in comparison of LTE Cat-1. Moreover, NBIoT can coexist with existing GSM and LTE network, hence reduce deployment cost also. Beside this new RAT (Radio Access Technology) reduced the signaling required for the transmission of data in the conventional system. Altogether NB-IoT can reduce the cost and energy consumption, which are the chief limitations of cellular network technology for IoT devices.

The present communication contributes toward the Next generation Green-NBIoT and delivers a comprehensive enriched study of NBIoT. This extensive survey elaborates resource allocation and energy efficiency techniques. Along with this a detailed comparative analysis of IoT connecting technology with NBIoT is also presented. Further, two novel application specific energy efficient approaches are also proposed namely "Zonal Thermal pattern Analysis" (ZTPA) and "Energy Efficiency Adaptive Health Monitoring System" (E2AHMS). Along with this real time hardware implementation of Health application is given to support the proposed energy efficient approach. This paper would be beneficial for researchers to get an insight view of NBIoT and their respective challenges.

A. MARKET TRENDS TOWARD NBIoT

IoT market growth has accelerated across all verticals in Q1 2018. Low Power Wide Area Network (LPWAN) is seen as one of the enablers for IoT. IoT Analytics in their report quoted that LPWA connections will have a Compound Annual Growth Rate (CAGR) of 81% during 2018-2025 [17]. According to Machina in comparison of other LPWAN the share of NBIoT alone would be 48% by 2025 (Fig. 1) [18]. According to another statics, suggest by IHC the number of NBIoT connections by 2021 will be 141.7 million [19]. Thereby NBIoT module revenue worldwide might touch the figure of USD 824 million by 2020 itself. Out of all NBIoT connections 88% of NBIoT connections will be established in Asia itself [20]. Some of the key NBIoT players are Huawei (China), Intel (U.S), Ericsson (Sweden), Deutsche Telekom (Germany), Qualcomm (U.S), Vodafone (U.K). The growth of NB-IoT standard has increased pressure on proprietary technologies especially for LoRaWan and the fact of no of chips shipped in 2017: 2% of SigFox, 4 % of LTE-M, LoRaWan 58%, LTE-Cat M1 4%, NBIoT 29%, Other 7% [18], are forestalling the market drift is building toward NBIoT.

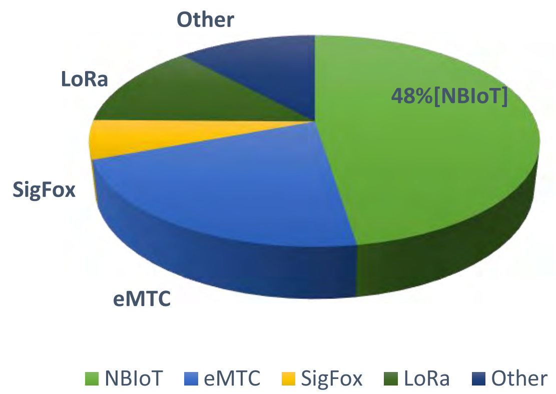

FIGURE 1. LPWA technology share by 2025, machina, 2017 [18].

B. RESEARCH MOTIVATION

As per literature survey and research availability in the area of IoT, a lot of work has been done to deliver services like smart health, smart agriculture, smart vehicle, etc. In the current scenario, IoT has become the first choice of industry, research and academia. However, there exist big gap similar to WSN i.e. energy optimization, energy efficient network which acts as a big stumbling block for IoT network. This becomes even more challenging as IoT devices have limited resource availability. This motivated us to study resource allocation techniques in detail. Furthermore, implementation of IoT on a massive scale would inflate carbon emissions in one way or the other. Hence to envision the green communication energy efficiency techniques will play an important role. Apart from this to cater the new specificities of IoT (i.e. low cost devices, wide coverage, long battery life, massive connection support) in cost effective way, NBIoT (3GPP standardized LPWA technology) presents good candidature. In this paper with an effort toward green IoT, two energy efficiency techniques using NBIoT are also proposed related to two specific area Health & Agriculture which directly or indirectly impact the human being.

C. CONTRIBUTION

This review paper contributes toward next generation green communication and in support of that two novel energy efficient techniques namely "ZTPA" & "E2AHMS". This review paper will be beneficial for researchers, who want to get a profound view of NBIoT. Whilst discussing the recent background of NBIoT, significant challenges and open issues related to the real time implementation of NBIoT are identified and discussed. In this manuscript, a detailed study related to resource allocation, and energy efficiency techniques for both IoT and NBIoT is done. Our main contributions can be summarized as follow:

The Layered Architecture of IoT is presented to specify How IoT works. In addition to this a detailed comparative analysis of NBIoT with other low power IoT communication technologies is discussed.

To provide an insight view of NB-IoT, its background research, architecture, frame structure, physical channels, connection process (cell acquisition, random access process, data transfer), modes of operation, power consumption using NBIoT, and its applications are discussed in detail.

The paucity of the resource is not a new challenge for the communication network. However, it quite challenging for IoT being so massively interconnected. Thus a detailed analysis of resource allocation techniques is discussed related to IoT and NBIoT The open issues related NBIoT implementation are then conferred

The real time implementation of IoT will inflate the CO_2 levels in environment in different ways which can be controlled by many ways one of it is efficient utilization of energy resource. Therefore a literature survey of an energy efficient techniques used for IoT are deliberated and role of deep learning in the context of power consumption is also discussed.

The open issues relate to NBIoT are then conferred. Thereafter, Green communication based energy efficient techniques are proposed for Smart Agriculture and Smart Health. In addition to this, hardware implementation is given to support the proposed energy efficient Smart Health technique.

The list of ongoing IoT projects is presented to provide the researchers and readers the knowledge of current applications being developed. In addition to this, a list of simulation tools used is also presented in the appendix section.

D. ORGANIZATION

This paper is organized as follows. Section II briefly discusses the basic layered architecture of IoT and specifies

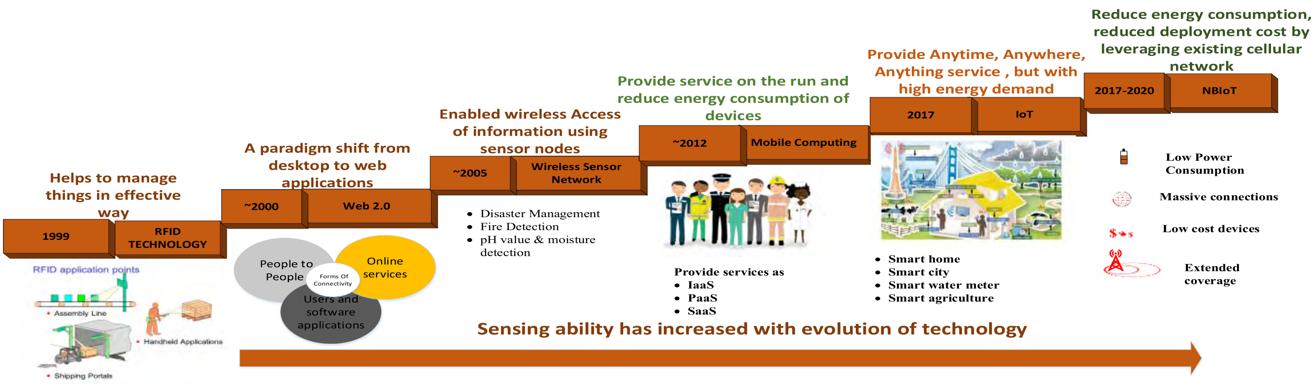

FIGURE 2. Roadmap of IoT [2].

the layer on which NBIoT operates. Hereafter comparison of NBIoT with other IoT connecting technologies is discussed in section III. Thereafter, NBIoT introduction, background research, standardization history from Rel-8 to Rel-15, subsequently architecture, frame structure, physical channels and signals used, connection process , modes of operation, power consumption using NBIoT, applications of NBIoT, are described in subsections IV-A, IV-B, IV-C, IV-D, IV-E, IV-F, IV-G, IV-H, IV-I respectively. Further section V provides a comprehensive survey of efficient resource allocation techniques used for NBIoT & IoT. Thereafter an overview of energy consumption in a sensor node during different phases is presented in section VI. Other than this, a detailed survey of energy efficiency techniques for green communication are discussed in detail in section VI-A and then the impact of usage of deep learning on power consumption is discussed in section-VI-B. Then the open issues related to NBIoT are discussed in section VII. Finally, the proposed green communication based energy efficient technique for agriculture is discussed in section VIII-A, and for health monitoring is discussed in VIII-B. In support of the proposed health technique a real time hardware implementation is described in section VIII-C subsuming system model (VIII-C-i), hardware requirement (VIII-C-ii), interface (VIII-C-iii), and performance analysis (VIII-C-iv).

II. INTERNET OF THINGS

Communication and sensing ability has evolved gradually due to advancement in technology. The evolution of IoT (Fig.2) started with RFID (radio frequency identification), which is the first technology to realize the machine to machine concept. RFID detects and ascertains the tagged entity wirelessly, by the data it transmits. Recently RFID is used in numerous IoT applications such as gestural detection [21], patient RFID tracking system [22], and smart restaurant. RFID could not sense the critical environment parameters, this stems in the requirement of sensing technologies. Hereafter, several technical fields including embedded computing, hardware miniaturization, Wireless networking aids in augmentation of real-world things capability, to sense, think, process and act, thus making things smart. Usually, these smart things have low computation capability thus clouds are used to offload the computational task which in turn reduce the energy consumption. Today the integration of. RFID, WSN, MCC (mobile cloud computing) and advancement in technology generated the umbrella term IoT. This concept is significantly revolutionizing the technical and business world, as it can offers anytime, anywhere, and anything service. The term IoT was first coined by Kevin Aston in 1999 also known as "cyber-physical systems (CPS)" [24]. In this paradigm, object/things around us are connected to the internet using Wireless technologies like Bluetooth, ZigBee, etc. Many definitions of IoT have been proposed in the literature. According to IERC, IoT is "*A dynamic global infrastructure with self-configuring capabilities based on standard and interoperable communication protocol where physical and virtual things have identities, physical attributes, virtual personalities, and use intelligent interface and seamlessly integrated into information network*" [25]. IoT network, comprised of billions of devices is highly heterogeneous. Its essence of heterogeneity can be visualized by the fact that devices from different vendors would run with diverse platforms even if they're doing the same task as a result will generate radically different ontologies. Thus for IoT to speak a common language a unified standardized IoT architecture is required to ensure interoperability and security. Many architectural layouts have been proposed for IoT but no one has converged to a standardized architecture. Some of the well-known IoT architecture such as RAMI 4.0, IIRA, IoT- ARM, P2413, Arrowhead Framework, WSO2, Microsoft Azure, Internet-of-everything reference Model, Intel IoT Platform Reference Architecture are available. Among variously available architecture this paper presents a five-layer architecture (Fig. 3): comprised of Perception Layer, network layer, Service management Layer, Application Layer, Business layer [1]. Perception Layer: This layer is composed of sensor/actuators. Here sensors are clustered according to their unique abilities such as body sensors, environmental sensors, vehicle parking sensors, home appliance sensors etc. Typically these sensors at the perception layer generate electronic signals triggered from physical event /condition aggregated at gateways using LAN/PAN technologies like Wi-Fi, Ethernet, UWB, ZigBee, BLE, Infrared, etc.

Network Layer: This layer is responsible to send the PL information to the Internet via one of the communication networks such as LAN (WIFI, Ethernet), WAN (3G, LTE, LTE-A, 5G) or satellite network.

Service Management Layer (SML): On SML services are paired based on addresses and it also processes the data received. These services are OSS (Operational Support System) which include device modeling, Performance management, Data management (periodic/Aperiodic sensed data) etc. (e.g. Nokia OSS which help in generating new revenues by handling high capacity.), BSS (Billing Support System) this provide billing report, and Security Services. Application Layer: Here application layer is classified based on the availability of network, required coverage, heterogeneity, etc. Using protocols like MQTT (Message Queue Telemetry Transport), CoAP (Constrained Application Protocol) this layer provides the requested service to the user.

Business Layer: This layer is responsible to analyze data received from the Application layer by building the business model, flowcharts, graphs, etc. thereby enable to support decision-making processes.

Thus IoT flow can be defined as first identification (to provide clear identification to each device), then sensing gather data from the physical environment), thereafter communication, then integration of service and finally extraction of knowledge.

The new IoT specificities like low power and Wide Range, Low deployment and Operational Costs, Long Battery life (10mA RX current, 100nA sleep current), Low bitrates, are different from conventional networks in many aspects and brings in many challenges. Beside this massive connectivity will further aggravate the problem. However, a solution is appearing on the horizon: is 3GPP, NB-IoT which can cater these requirements in an effective manner. As IoT has a diverse and wide range of IoT requirement, hence one solution won't fit for all. Therefore in the next section a detail comparative analysis of NBIoT and other IoT related technologies is discussed.

III. COMPARISON OF NBIoT WITH OTHER IoT CONNECTING TECHNOLOGIES

A myriad of IoT connectivity solutions is available to support a wide range of IoT application with miscellaneous requirements. Therefore to select an optimal technology for an application various factors such as *power consumption, security issues, deployment cost, communication range, data rate, throughput, latency* are required to be considered [26], [27]. A comparison of IoT connecting solutions on pre-specified factor is given in Table 1. Connecting Technologies of IoT can be coarsely classified into two categories based on their range i.e. short and long range. Wireless technologies such as BLE, ZigBee, Wi-Fi, Z-wave, WIMAX, 6LOWPAN, etc. offer short range can be used for applications like smart home, factory or supermarket. Whereas, *LPWAN technologies* such as LoRa, SigFox, NBIoT, EC-GSM-IOT, etc. offer long range. Other than the pre-specified competing technologies RPMA, Telensa, WAVIoT and Dash 7 are few other competing technologies contributing to IoT connectivity [28].

Among wireless technologies, Wi-Fi uses radio waves for communication and operates in either 2.4GHz or 5GHz band. The existing Wi-Fi standards 802.11 a/b/g/n/ac has constraints in both range and energy efficiency, thus can't be considered apposite for applications with low power consumption requisite. Thus *IEEE*has introduced two new protocols *802.11ah* and 802.11ax that can support thousands of devices with low power consumption. These two are considered to be the biggest move of IEEE towards the massive IoT market. The Wi-Fi standard *802.11ah –**HaLow*** provide a range of 1km and can easily penetrate barriers/obstacles at data rate ranging from 150kbps to 40Mbps. The 802.11ax solution will provide four time's increased capacity and data rate and improved efficiency. These new solutions have great potential to capture the M2M market. Bluetooth Low Energy (BLE) is another Wireless standard that offers much needed characteristic required for most of IoT applications i.e. consumes low power, low cost, but within a short range. BLE allows both connectionless and connection-oriented communication. It fragments the data into small packets then transmit them over the radio interface. This enables BLE to support data services with large packets. It is used in applications like wearables, for locating things, etc. Further ZigBee is a simple and low cost Wireless option that consumes low power. It is based on IEEE 802 std. and could support $\sim$ 65000 nodes/network. Its range can be extended by using repeaters in the mesh topology, but this will increase the deployment cost [29]. ZigBee 3.0 is the new solution introduces, it ensures device interoperability, it is reliable robust and above all it is green.

Z-Wave is another pioneer for short range communication, especially for home-automation industry. As it provides a reliable method to wirelessly control multiple home appliances using low-power. Z-Wave operates in the sub-gigahertz frequency range, around 900MHz. It can support up to approximately 232 nodes/ network. The Frequently Listening receiver Slave (FLiRs) enable low latency communication by employing unique beaming technology so that device can transit from sleep to fully awake modes in one second. Hence suitable for short range IoT application. Z-Wave 700 Series, could offer a range of 300 feet, hence can connect gadgets placed outside the home and far off into the yard, too [30].

Despite offering low power consumption and low cost, Wireless technologies limits in supporting long distance communication. Hence offers limited mobility and deployment possibilities for the device. Moreover, to extend the range, repeaters are required to be deployed densely, thus extortionately expensive. Whereas, LPWA technologies offer mass deployment, long range, long battery life, and require low bandwidth. Hence LPWA fills a cavity in the landscape of

TABLE 1. Comparison of IoT connecting technologies.

Technology	Wireless Technologies (Short Range) (operates in License Exempted Band)				LPWAN Technologies (Long Range)						
					Non 3GPP Unlicensed				**3GPP licensed**		
	ZigBee	Wi-Fi	BLE	Z-Wave	LoRa	SIGFOX	INGENU	Weightless- P	LTE-M	ECGSM-IoT	**NBIoT**
Range	75-100 m	70-250 meters (802.11n) (outdoor)	>100m (class 1)	~100 m	2-5 km (URBAN), 15 km (suburban)	3-10 km (URBAN), 30-50 km (RURAL)	15 Km (urban)	2km (urban)	~11kms	~15km	**10-15km**
Bandwidth	2 MHz	22 MHz	2.4GHz ISM band Each channel has 1MHz	-	< 500 kHz(channel bandwidth of 125kHz)	100 Hz	1MHz	12.5 kHz	1.08 MHz (1.4MHz carrier bandwidth)	200 kHz	**180 kHz (200kHz carrier bandwidth)**
Frequency Band	868 MHz, 915Mhz,2.4 GHz	2.4 GHz/5GHz	2.4GHz ISM band Each channel has 1MHz	908.42 MHz	868MHz and 915MHz Sub 1Ghz	915-928 MHz Sub 1Ghz band	2.4 GHz	sub GHz ISM bands	Cellular Band	2.4 GHz	**700,800,900MHz**
Data Rate	250 kbps	600Mbps (802.11n)	*1Mbps*	40kbs-100kbps	50kbps with FSK	Less than 100bps	624kbps – DL 156 kbps UL	0.625kbps to 100kbp	300/375 kbps Variable	~350bpsto70kbps	**200kbps**
Latency	~15ms	Less than 20 ms	~3ms less than 10ms	1s(wake up)	1-10 ms	High, 1-30ms	-10s		10s-15ms	10 seconds	**<10s**
Throughput	250kbps	802.11n 600Mbps	0.27 Mbps	40 kbps	~50kbps	Ultra-low ~100 bps	30Mbps		<1Mbps	10kbps	**~150kbps**
Modulation scheme	O-QPSK	QPSK	GFSK	GFSK	FSK techniques	GFSK (DL), DBPSK (UL)	Patent RPMA	GMSK, offset-QPSK	QPSK,QAM	GSM-based	**BPSK, QPSK**
Requirement	Require ZigBee kit to operate	An access point to connect	BLE station (available in smart phone)	Continuous internet connection and Z-Wave appliance module to operate	Require gateway for connectivity	SIGFOX modem and SIGFOX Network	Private Network	Require kit to and Access point to operate	Uses Existing LTE network Software upgradation	Software upgradation	**Software upgradation and a sim to operate.**
Battery lifetime	For years	-	-	Claim 10 year life of a coined size battery	>10 years	10 years if 1 message is sent <10 years if 6 message is sent	10-20+ years (target to achieve by ingenu)	3-8 years	>10years	~10years	**>10years with a battery capacity of 5Wh**
Cost	Low	Moderate	Less cost	Low cost	Low Cost	Low Cost	Low cost	Moderate	Low	Low	**Low**
Application	Smart home, Healthcare, Smart lightning, retail	Use to connect to network	Car access, smart watches, smart phones	Smart Home	Air Pollution Monitoring, Fire Detection	smart meter, pet tracking, smoke detector, agriculture	oil and gas field automation		Fleet tracking, Smart home, telematics, Wearables	Water and gas meter application, machinery control. smart grid	**street lightning, Pulse meter, Agriculture , Trach canes**
Mobility	Yes , but low	Yes	Limited mobility	Yes	Yes	Yes	No	Yes	Yes	Nomadic	**Nomadic**
Advantages	Highly Reliable and Scalable.	Easy to deploy and access	Provide more privacy Optimal for sending small chunks of data	Low cost , less vulnerable, signal remain strong up to 100 feet (claimed by Z-Wave)	Highly immune to interference Adaptive data rate ,longer battery life	High Reliability, Device Complexity is Low as , it can opt random frequency to transmit the channel	High Reliability, extreme coverage, Transmit power control to extend battery lifetime, High Capacity	Offer High Reliability, Supports high number of devices.	Provide support for multicasting Positioning, Higher data rates, Support VoLTE	Improved GSM/ EDGE security, Low complexity device, all the key mobile equipment, chipset supports EC-GSM-IoT	**Use PSM, edrx (almost upto 3 hrs), Obsolete the requirement of Gateway Better range and coverage**
Limitations	Short range communication Security is vulnerable as keys are exchanged over air.	Limited range, Vulnerable, Speed is much slower	Not very flexible, eavesdropping is possible, No accepted std. for generic gateway	Interference, Signal cant propagate over long distance due large wavelength of signals, Four hops are essential for transmission of signal to device	Supports limited size data packets Longer latency time , not acknowledges all packets	low security, No Forward Error Correction, BS could not support multiple sectors, Suffer from Interference	-No analytic study available to specify this	Scarcity of hardware and infrequent update specification	Coupling Losses occur due to indoor environment, Repetitions slowdowns the transmission		**a)No Handoff support, b)Interference immunity is low, c)Lacks in acknowledging**
Standard body	ZigBee Alliance	IEEE	IEEE	Z wave	LoRa Alliance	SIGFOX	INGENU	WEIGHTLESS SIG	3GPP	3GPP	**3GPP**

Wireless technologies. LPWAN technologies can be categorized into two categories Licensed and Unlicensed. Long Range (LoRa), SigFox, RPMA, N-Wave and Dash 7 are unlicensed, NBIoT, EC-GSM-IoT, LTE-M are licensed technologies [31], [32].

*LoRa*is developed by Semtech, to deploy its network it is required to get a NetID issued from LoRa Alliance. It uses an Adaptive Data Rate (ADR) scheme which helps in extending the battery lifetime. It is based on Chirp Spread Spectrum modulation technique, which sustains the same low power characteristics as FSK modulation yet considerably increases the communication range. LoRa-WAN being asynchronous let devices to remain in sleep mode for a long time period as desired by the application. Another advantage of LoRa is its BS provide wide coverage. However, as LoRa operates in unlicensed spectrum thus could not provide QoS and neither it could support dense network as it employs MAC based ALOHA protocol [33].

SigFox is another technology that operates in unlicensed sub 1GHz band. It operates on cloud based approach and uses ALOHA like LoRa but with a restriction on the maximum number of messages, a device could send. The prime advantage of SigFox is it doesn't spend energy on sensing medium thus saves energy. SigFox requires the user to purchase subscription. In order to provide long range communication it uses Ultra-Narrow-band modulation and transfers each message 100 Hz wide with a data rate of 100/600 bps depending on the region.

*Ingenu*is another LPWAN technology offers high throughput, high scalability, and use patented Random Phase Multiple Access scheme. RPMA helps in improving SNR by minimizing the overlapping between signals transmitted. It is slightly more complex as it uses TDMA based MAC protocol to efficiently allocate the radio resource [34].

Another LPWAN technology WEIGHTLESS-P, uses cognitive radio and TV white-spaces, such that devices utilize the bands as an opportunistic user without causing interference to the primary user. It supports two way communication thereby acknowledges all transmissions, further in order to maintain QoS and to assure reliability Automatic retransmission request (ARQ) and Forward Error Correction (FEC) is used [36].

Taking about existing cellular technology LTE could not provide solutions for M-IoT applications i.e. Low power consumption, low data rates, and wider coverage at low cost. Thus 3GPP proposed a licensed LTE-M / eMTC, in Rel-12 to cater the requirements of machine type communication which has been optimized in Rel-13. It leverages the existing LTE network and follows narrowband operation for reception and transmission and provides extended coverage. To reduce power consumption it used PSM (power saving mode) and edRx mode [37].

NBIoT (Narrow Band IoT), is another licensed technology introduced by 3GPP in Rel-13. NB-IoT in comparison to other technologies offer mMTC required features at low cost like (i) provide coverage in challenging positions like underground or basements; (ii) improved power saving mechanisms to enhance the battery life; (iii) network procedures are simplified to reduce the UE complexity. Apart from this to support small data transfer it has optimized CIoT User Plane and Control Plane

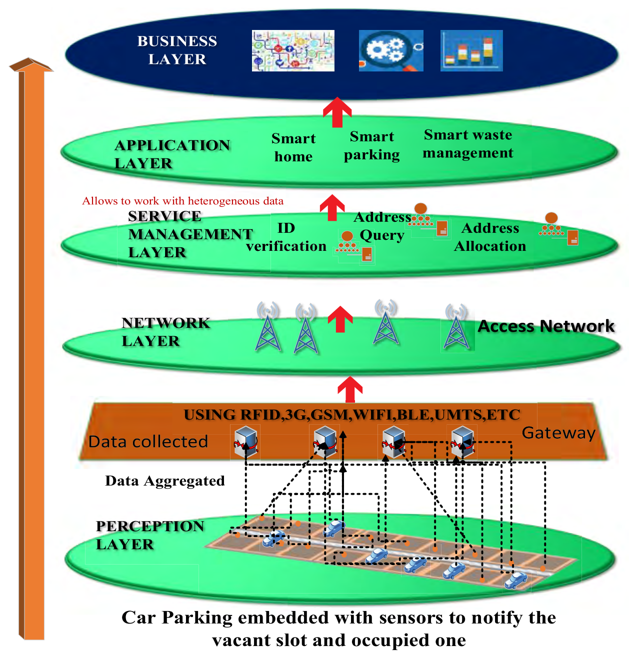

FIGURE 3. Layered architecture of IoT [23].

Another technology EC-GSM is also proposed by 3GPP which is an extension of existing GSM technology. Suitable for many applications, but it overburdens the device and network [38].

Conclusion: For M-IoT applications, individually all LPWAN technologies are prompt in one way or the other for wide range solutions but picking a clear winner is critical. LoRa, SigFox being proprietary technology has an established market and giving a tough fight to 3GPP NBIoT, EC-GSM-IoT and others also. However proprietary technologies operate in Unauthorized /Unlicensed Spectrum that suffers from Duty Cycle constraint. Thus affects the transmission time and also bears high interference as spectrum is shared between multiple technologies. Whereas, NBIoT operate in licensed spectrum and can support massive connections, operates at low data rates (but better than LoRa), offer wide coverage with deep indoor penetration, perform well in dense area, consumes less power in comparison to LoRa, & SigFox, offers very good link budgets and good scalability, provide QoS Apart from this just require a software update to LTE or existing RAN infrastructure. Thus ready to immediate role out in the market. This is essential for reducing deployment cost and time [39], [40]. Hence this ascertains that NBIoT has the ability to capture the IoT-LPWAN market specifically in comparison to other LPWAN Technologies

IV. NBIoT: NARROW BAND INTERNET OF THINGS

NB-IoT is the latest technology that is identified and standardized in a little time span, in the response of customer requirement and pressure to tussle with non-3GPP proprietary technologies. NBIoT can efficiently support the market of the M-IoT application. This an independent radio interface, tightly connected with LTE, which also shows up in its integration in the current LTE specifications [12], [13], [41], [42]. It can address the needs of mMTC (massive Machine Type Communication) by following features (Fig. 4):

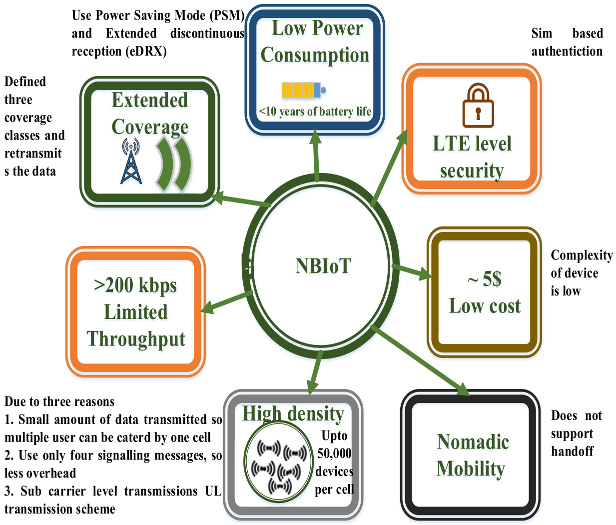

FIGURE 4. NBIoT features.

NBIoT *can support massive connections (more than 52K/channel):* as in *MTC communication model* user, transfer small data at low frequency and are insensitive to latency so multiple users can camp on one cell. Further, NBIoT supports two schemes multi-tone and single-tone transmission. This offers flexibility to schedule 12 subcarriers with sub spacing of 15 kHz or 48 subcarriers with sub spacing of 3.75 kHz with single tone scheduling. Hence eNodeB could support large no of users in parallel.

NBIoT uses a bandwidth of 180 KHz and operates in HD-FDD: In NBIoT, UL/DL bandwidth is restricted to 180 kHz. Hence less complex transceiver is used. Further, the device operates in Half Duplex mode, thus can't receive and transmit simultaneously. This further decrease device cost, as no duplexer will be required.

NBIoT design objective is to provide prolonged battery life: For long battery life, power Consumption is reduced by using eDRX (extended discontinuous reception) and PSM (power saving modes) features. In extended discontinuous reception, the UE monitors the paging channel periodically. Whereas in PSM, the device remains in receiving state.

NBIoT provides extend coverage range of 20dB as compare to GPRS (especially deep indoor penetration): To provide the wide coverage the transport block can be transmitted multiple times i.e. 128 times in UL and 2048 in DL. Hence improves Signal to noise-interference ratio (SINR) and enable proper decoding of the signal. To determine the number of repetitions for coverage extensions, three classes are defined CE level 0, CE level 1 and CE level 2. For each of these class, the number of repetitions is regulated separately. Beside this soft retransmission the network bandwidth is also reduced. Hence based on two features 20 dB coverage enhancement is achieved where ~7dB is achieved from network bandwidth reduction and ~13 dB from allowed repeated transmissions.

NBIoT offers operating mode flexibility: In order to coexist with LTE and 2G, three deployment modes are available standalone, in-band and standalone.

NBIoT doesn't support higher modulation scheme than QPSK, thus keep device complexity low and thereby cost. Moreover, to keep the PAPR (peak to average power ratio) low in UL, $\pi/2$-BPSK, $\pi/4$- QPSK is used.

NBIoT supports Low-Data-Rate applications, which obsolete the requirement for high-capacity flash memory hence reduce the chip area and thereby the cost of devices.

NBIoT operates in Licensed Band and can provide telecommunication level of security.

NBIoT achieved signaling optimization: In addition to existing RRC, NBIoT uses DONAS (data over non access stratum) and RRC (radio resource control) suspend/resume for signaling optimization. Where DONAS enable the user to transmit data without activating a user plane and support sporadic data transmissions also. The RRC suspend/resume is a user plane optimization procedure that introduced an efficient way to disable and restore the user plane.

Further, NB-IoT is designed for sporadic and small messages transmission among the device and the network. It is presumed that the device can exchange small messages via one cell, therefore obsolete the requirement of handoffs. However, if required then it needs to first go in idle state and then restart the cell selection process. Besides this, it doesn't support other EUTRA functions like Inter-RAT-mobility, handover, dual connectivity, CQI (Channel Quality Indicator) reporting.

A. BACKGROUND OF NBIoT

NBIoT is in the initial state of deployment, still, there is room for optimization. The miscellaneous work carried out in the context of NBIoT optimization is discussed in this section. Song *et al.* [43] proposed an indoor localization algorithm for NB-IoT system using Channel state information (CSI) fingerprinting. The proposed algorithm will estimate the position with less complexity by observing the similarity between two CSI values and then convert the similar value to a relative value. To improve estimation of position, triangular centroid algorithm and K nearest neighbor is used. As a result, the position error was reduced in comparison to existing techniques. Further, to enable a node, in an idle state to transmit the data. Lin *et al.* [44] proposed an efficient SDT (Smallest Data Transmission) technique to increase the number of the supportable device. In this eNB will broadcast the maximum SDT size in SIB (system information block), and also a group of SDT ids with it. Thereafter, UE will check the SDT value and determine whether to use this technique or not. If suitable then send the RA response. Successively, eNB will acknowledge by sending RA response comprised of uplink resource grant. UE on successful reception will send the PDU and starts the timer. Upon receiving the response within time, UE compares its id with group ids. As a result, authors found that more devices could be supported in comparison of conventional control plane solutions, whilst using limited uplink resources. However massive connection results in the high probability of collision thus Kim *et al*. [45] proposed an enhanced Access- Reservation-Protocol (EARP) with a partial preamble transmission mechanism. The proposed protocol although reduced the collision probability but at the cost of abdication of the detection ability. Authors found that EARP would results in effective resource utilization in reference to system load. When the load will be less then it will reduces the probability of misdetection. On the other hand, when a heavy load would be there, the collision probability gets reduced although the detection probability get deteriorates. Further Zhang *et al*. [46] done an analysis of interference caused by the NBIoT user equipment to that of LTE users. Authors considered only in-band and guard band for analysis and proposed an algorithm for removal of ISI or channel equalization. On the basis of observation, the authors stated that LTE-UE performance degrades due to the different sampling rate of NBIoT user. In addition to this, the level of interference depends upon specifically two important factors. First due to attenuation of power and second is due to guard band. A critical observation about bit error rate is made for an LTE device i.e. its BER will improve as guard-band bandwidth increases although for IoT devices BER remains unaffected. Liu *et al*. [47] taking the same issue of interference between NBIoT and LTE devices have proposed a framework based on Block Sparse Bayesian Learning (BSBL) and two algorithms for recovery of signals. Authors observed that by canceling the interfering NB-IoT signal, LTE device could operate more effectively. Further, Lin *et al.* [48] proposed a single tone design for NPRACH (narrowband physical random access channel) and this work was integrated into 3GPP Rel-13. To reduce the overhead due to cyclic prefix (CP) N-samples are repeated n times and then collectively CP corresponding to these samples is added, as a result, the length of CP got reduced. After this single carrier hopping is used where within symbols fixed hopping is used and among different symbol groups, pseudo-random hopping is applied. Further, the time of arrival (ToA) & carrier frequency offset (CFO) is jointly estimated to determine the midsection and false alarm. As a result, the authors observed that using the proposed design the probability of detection increased up to 99% and the probability of false-alarm reduced immensely below 0.1%. Further, Yang *et al*. [49] suggested using effective bandwidth (EB) to collectively handle all the components of LPWAN i.e. battery life, coverage, T_x (transmission) bandwidth, spectral efficiency. According to the suggested, concept if T_x bandwidth would be greater than EB, this would ultimately reduce the system capacity. On the other hand, if T_x would be less than EB, this would entail more Tx time. However, the journey of optimization doesn't end here. There are various open issues that are still required to be addressed to envisage NBIoT success. Some of them are discussed in section VII.

B. HISTORY OF STANDARDIZATION

Before standardization, of NBIoT. It was proposed in two formats. NBIoT-OFDMA and NBIoT-M2M in 2014. Where QUALCOMM offered NBIoT-OFDMA & Huawei and Vodafone collectively offered NBIoT-M2M. These two formats were clubbed together to form NB-CIoT (NB cellular IoT), which require a new chipset and has no backward compatibility with previous LTE Rel (8-12). Further, another format NBIoT-LTE was proposed in 2015 which is fully compatible with existing LTE specifications. Then finally in 2016, 3GPP after agreeing on two proposals gave standardized technology NBIoT. This technology has evolved over years of improvement. In this section, the roadmap of standardization (from Rel-8 to 15) is discussed to determine the improvement made (in these Rel) to support MTC. Well standardization of LTE started in 2005 when 3GPP started depth research for MTC on CN. In 2009, Rel-8 was standardization [50] and brought in the feature like peak DL data rate of 300Mbps with an ability to operate in paired and unpaired frequency band. Thus have spectral flexibility with bandwidth ranging from 1.4 to 20 MHz A new IP based network was introduced i.e. LTE, was a significant step toward the IMT-A. In addition to this, to cater the need of multiple users, multiple antenna scenario came in to picture since the first Rel of 3GPP [51]. However the basic requirement of low cost device and power issues left unattended. Thereafter Rel-9 standardized in 2010 in which LTE evolved to LTE-Advance and introduced additional features such as public warning system (PWS), location Identification service, SON (Self Organizing Network) feature to improve the network configuration, added new spectrum bands. Further in 2011 Rel-10 (also known as LTE-Advanced) was launched to extensively improve the throughput of the LTE system. For evaluation of Rel-10, it was submitted to ITU-R in 2010. In Rel-10, to enhance the bandwidth and bitrate, Carrier Aggregation was used for both TDD & FDD [52] and to reduce the interference, eICIC (enhanced Inter-Cell Interference Coordination) was added, where ABS (Almost Blank Subframes) is used to confine the data to the specific layer of the cell. Other features like eMIMO, etc. were also introduced. Further, Rel-11 [53] got frozen in 2013. An important feature CoMP (Co-ordinated Multi Point operation) was announced to facilitate the scheduling of multiple carriers. EPDCCH (Enhanced Physical Downlink Control Channel) was added to increase DLC (downlink-Capacity). Furthermore, Rel-12 [54], [55] got standardized in 2015. In this NAICS (Network Assisted Interference Cancellation and Suppression) was added to manage interference. To achieve QoE, naïve UE categories were introduced with 50% reduced cost in comparison to Rel-8, cat-1 devices.

TABLE 2. Standardization history toward NBIoT [12].

Release	Standardization Year	Category of device	Features
Rel- 8	2006-2009	Cat –(1-5)	Introduced LTE , Reduced Latency ,Variable Bandwidth, OFDM in DL(300 Mbps),SC-FDMA in UL(75Mbps) ,Multiple Antenna Applications, Efficient Broadcasting/Multicasting ,Modulation-16 , 64 Quadrature Amplitude Modulation
Rel- 9	2008-2010	-	Femto Cell introduced, Dual Layer Beamforming, Public Warning System, Efficient Multimedia broadcast and multicast Service (eMBMS), Location Pinpointing, Multi Radio Access Technology Base Station.
Rel- 10 (LTE-A)	2009-2011	Cat-(6-9)	carrier aggregation (CA),(8X8,4X4) MIMO antenna, DL/UL T_x enhancement ,Optimization of capacity and coverage, Heterogeneous Networks supported by relaying ,eICIC, Enhanced SC-FDMA
Rel-11 (LTE-A)	2010-2013	Cat-9-12	To more efficiently Support Heterogeneous network, EPDCCH introduced, uplink positioning ,Selection of enhanced Packet Data Gateway is improved based on UE location ,CoMP transmission to minimize interference , IMS, Integrated Wi-Fi
Rel-12 (LTE-A)	2011-2015	Cat-13,Cat-14,Cat-0	Signal load is reduced , Throughput is enhanced ,device to device communication, modulation scheme :256 QAM is used, Congestion Management ,Internetworking of radio, Elevated beamforming , Enhancement of mobility in HetNet, Power saving mode introduced
Rel-13 LTE-Advanced Pro	2012-2016	Cat-M1, **Cat-NB1**	To optimize the Low end market a new radio technology is introduced NBIoT ,Enhancement of D2D communication, MIMO, Indoor Coverage ,Optimized battery Consumption ,SC-PTM
Rel-14 LTE-Advanced Pro	2014-2017	Cat-NB2	Latency reduction, Massive Machine Type Communication , shorter TTI, Improved positioning accuracy, Improved peak data rates, New device Class , Non-anchor carrier operation, Multicast Authorization of coverage enhancements, Added Broadcast services like :- MPS_Mods, EnTV
Rel-15	Till not Standardize	-	Mission Critical ,Communication internetworking, enhanced isolated UTRAN, interference cancellation ,Inter band carrier aggregation ,Arial vehicle Assistance, Security Assurance

In support of machine type communication, PSM (power saving mode) was also introduced to conserve energy. Finally in Rel 13 [56], [57] to further cater the need of Machine to machine type communication, a new feature added to existing Rel-8-12: SCPTM (single cell point to multi-point), indoor-positioning, reduced latency, Dual connectivity and enhanced CA. LAA (licensed assisted access) was also introduced to allow operators to offload traffic to the femtocell, devoid of WLAN Two naïve category of devices were introduced in Rel 13 Cat-M1 (eMTC) and Cat-NB1 (NBIoT). Where the system bandwidth was confined to 1.4 MHz and coverage range was enhanced by 15 dB for Cat-M1 devices. Altogether reduced the device complexity and cost enabled operators to reach terminal devices in poor coverage range like in basements. For assurance of long battery life eDRX (extended Discontinuous Reception) feature was introduced that monitors the DL signals for only a short span of time otherwise keep the device in the sleep state. For the further evolution of LTE to support mMTC Rel-14 is also standardized with more technologies and improvement in existing features such as Additional Broadcast services, enhanced positioning, reduced latency, and massive multi antenna system. Currently, Rel-15 is under standardization process and expected to get standardize by September 2018 [56]. The expected features of Rel-15 are also enlisted in Table 2.

C. NBIoT NETWORK ARCHITECTURE

The architecture of NBIoT is shown in Fig.5, NBIoT has simplified the EPC architecture to support the small data

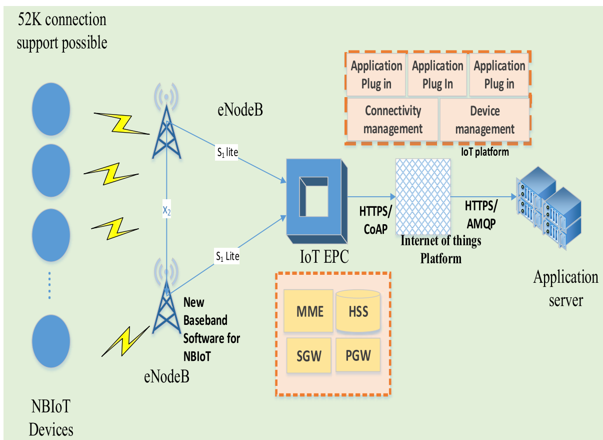

FIGURE 5. NBIoT architecture [58].

transmissions required for M-IoT applications in the form of User Plane and the Control Plane EPC optimization.

Here NB-IoT device or user equipment communicates with the eNodeB thereafter eNodeB connects with the IoT evolved packet core (EPC). This is comprised of entities: the Serving GW, the Packet Data Network GW, the Mobility management plane entity, the Home Subscriber server. After this eNodeB transfers the NAS (non-access stratum, a signaling message) to EPC using s1-lite (an optimized version of S1-Control-Plane and support efficient data handling). Basically, NAS is a protocol that transfers the non-radio signal between the user equipment and MME, which carries data for session and mobility management. Further to continue the processing EPC looks for stratum and then pass it to IoT platform. IoT platform forwards the data to application servers in supported form. This data is then processed by the Application server [58]. There are two ways in which data could be transmitted between NBIoT device and application server i.e. IP based and Non-IP based. However, Non-IP based is more endorsed since it reduces the overhead of user equipment and transmission is also more secure as only one target IP is supported.

D. NBIoT FRAME STRUCTURE

Downlink: The frame structure of NBIoT DL is identical to LTE. *In Time domain* a radio frame is comprised of 10 Subframes, each having length of 1ms and each subframe consists of 2 slots with a time slot of seven OFDM symbols (Fig.6 A) Here each OFDM symbol with in a frame is denoted by a number in the range 0 to 13. Further, the number of these radio frames is referred as the system frame number (SFN) which ranges from 0 to 1023. Once the SFN counter reaches the value of 1023, the counter is reset to 0 and thereafter the hyper SFN counter is increased. The hyper SFN ranges between 0 and 1023. Within each radio frame, the sub frames are labeled as 0 to 9 and the slots as 0 to 19. *In Frequency* domain, one physical resource block consists of 12 consecutive subcarriers with a spacing of 15 kHz [40].

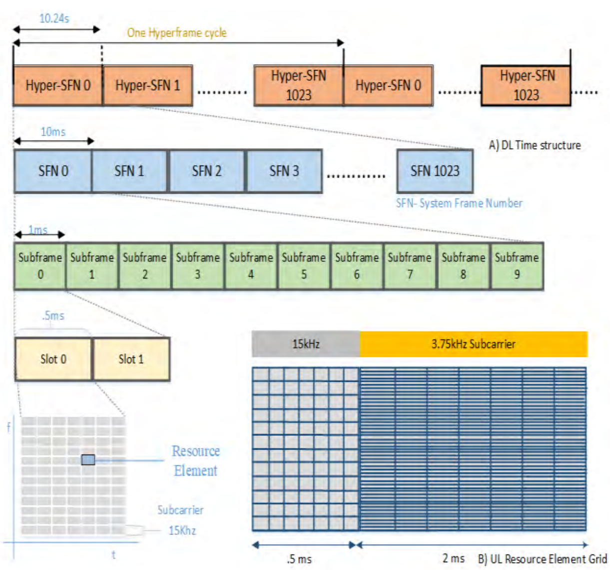

FIGURE 6. Frame structure of NBIoT [59].

Uplink: The UL resource grid has two subcarrier spacing options i.e.15 kHz and 3.75 kHz. *In time domain*: with a subcarrier spacing of 15 kHz each slot has a duration of .5ms, the number of subcarriers will be 12 which is similar to the time domain. However, for the 3.75 kHz subcarrier spacing, total number of subcarriers in the frequency domain is 4 times i.e. 12∗4=48 subcarriers. The slot duration will be of 2ms [40].

E. PHYSICAL CHANNELS AND SIGNALS

1) UPLINK CHANNELS AND SIGNALS

Since NBIoT enabled UE's operates in extreme coverage areas and have limited power to operate. Pertaining to this, to reduce the power consumption and complexity UE is no longer asked to report a channel, thus their functionality reduced to send acknowledgment and No- acknowledgment. Apart from this the need of control channel is also obsoleted and only two UL channels are supported namely NPRACH, NPUSCH.

a: NPRACH: NARROWBAND PHYSICAL RANDOM-ACCESS CHANNEL

NPRACH refers to the time frequency resource which occupies contiguous set of subcarriers either 12, 24, 36 or 48 and used to transmit random access preambles. This preamble consist of four symbol groups, each group comprised of one Cycle Prefix (CP) and 5 symbols [48]. These preambles are repeated with a periodicity from 0.04 s to 2.56 s. The eNB uses the random access preamble sent by a user terminal to estimate the uplink timing. To start the random access process the preamble is transmitted with a duration of 5.6ms or 6.4ms. Further in order to support different cell size two CP lengths are specified in NPRACH, 66.67 μs and 266.7 μs. Where 66.67 μs is used for cells with radii not more than 8 km and 266.7μs is used for cell with radii range of $8 - 35$ km. Each symbol is modulated on a 3.75 kHz tone, which hops from one tone to another within twelve contiguous subcarriers. Further for efficient estimation of TOA (Time of Arrival) and to achieve improved synchronization between UE and eNB, frequency hopping is used. For this two layer hopping pattern is defined i.e. inner hopping & output hopping. In order to provide wide TOA range, inner hopping is used with fixed (for simplicity) and small values. However, an output hopping layer accounts to improve the accuracy of TOA estimation. Furthermore to alleviate cell interference between neighboring cells, the pseudo random hopping pattern is also used which has been inherited from the LTE PUSCH hopping. Finally to support coverage extension of +20dB GPRS, the preamble of four symbol groups can be repeated up to 128 times [59].

b: NPUSCH: NARROWBAND PHYSICAL UPLINK SHARED CHANNEL

The NPUSCH supports single tone transmission with either 3.75 kHz or 15 kHz and multitone bandwidth using 15 kHz subcarrier spacing. The NPUSCH has two formats. Format 1 carries the actual data in the uplink with maximum transmission block size of 1000 bits. Format1 facilitate multitone transmission with 3,6,12 tones. Other than this to decrease the PAPR (Peak to Average Power ratio the modulation scheme π/2-BPSK or π/4-QPSK is used for single-tone and QPSK is used for multi-tone for NPUSCH Format 1. Furthermore, Format 2 carries control information, supports single-tone transmission only and carries 1-bit UCI that corresponds to hybrid automatic repeat request (HARQ) feedback for NB-PDSCH transmission block. Table 3 describes the format 1 and format 2. Typically the NPUSCH is designed to provide long battery life, massive capacity and extended coverage [14], [59].

TABLE 3. NPUSCH Format [59].

Format	Sub spaci ng	Sub carrier s	Slot s	Slot tim e	Resource Unit time	Chann el coding	Modulati on scheme
Format 1	3.75 kHz	1	16	2	32	Turbo 1/3	$\pi/2$-BPSK $\pi/4$-QPSK
	15k Hz	1	16	.5	8		QPSK
		3	8	.5	4		
		6	4	.5	2		
		12	2	.5	1		
Format 2	3.75 kHz	1	4	2	8	Block 1/16	$\pi/2$-BPSK
	15	1	4	.5	2		

c: DMRS: DEMODULATION REFERENCE SIGNAL

In LTE, DMRS is used to obtain channel response for PUSCH. Similar to enable eNB to estimate the UL channel, the NBIoT-UE transmits a demodulation reference signal (DMRS) which is multiplexed with the NPUSCH symbols. Thereby depending on Format of NPUSCH (ie. Format 1or Format 2), (Fig.7) 1or 3 symbols per SC-FDMA slot are utilized to transmit the DMRS. With 15 kHz subcarrier spacing DMRS is allocated to symbol #3 of every 7 symbols and for 3.75 kHz subcarrier spacing. DMRS is allocated to 5th symbol of every 7 symbols for data transmission [40].

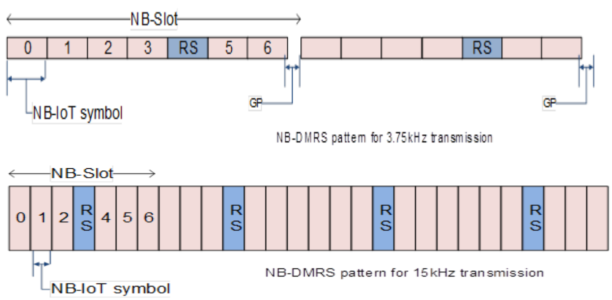

FIGURE 7. DMRS allocation in 15 kHz &3.75 kHz subcarrier spacing [60].

2) DOWNLINK CHANNELS AND SIGNALS

The NBIoT physical downlink channels are QPSK modulated. The downlink designs of NB-IoT MAC and PHY are analogous to the LTE. However, NB-IoT has fewer downlink physical channels as compared to LTE. For example, NBIoT doesn't use PMCH (Physical Multicast Channel) as it doesn't support multimedia broadcast/multicast services (till Rel-13) [61], [62].

a: DL SYNCHRONIZATION SIGNALS

The downlink synchronization signals allow a device to synchronize to NBIoT cell. However, the detection of these

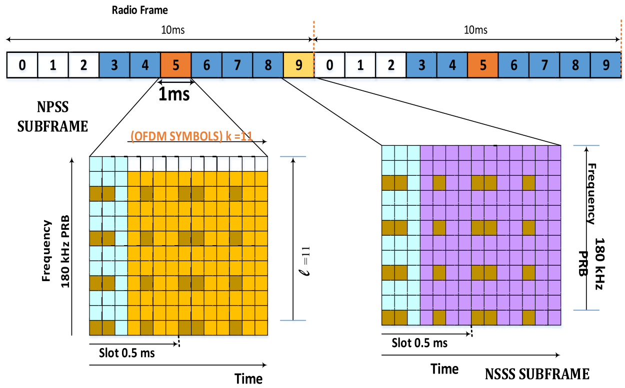

FIGURE 8. NPSS & NSSS subframe [61].

signals is a challenging task. As when a device with low-power oscillator wakes up after a long period of deep sleep, the time base will not have a valid reference then, and the frequency base perhaps off by as ~20 ppm. Hence a large offset may exist between the device and the network time and frequency, which will seriously harm the acquisition performance. The frequency offset is due to factors such as temperature, crystal aging, etc. Out of all "temperature" is the crucial factor that majorly affects the accuracy, and hence required to be compensated in real time. Depending on the quality of the crystal the offset ranges from ±5 ppm to ±100 ppm [63], [64]. Hence to detect with large frequency offset NBIoT new Synchronization signals NPSS (Narrowband Primary Synchronization Signal) is designed which is transmitted in Subframe 5 of duration 1 ms with a sequence pattern periodicity of 10 ms and subcarrier spaced at 15 kHz. The hierarchical sequence of NPSS is generated using (1) [65]

$$P_k(l) = Q(k)\, e^{-j\pi u l(l+1)/11}, \tag{1}$$

Where $Q(k) = \{1, 1, 1, 1, -1, -1, 1, 1, -1, 1\}$ is the modulation sequence, $1 \leq l \leq 11$ (length), $3 \leq k \leq 14$ (OFDM symbols) and $u = 5$ is the root sequence. Its detection is a demanding computational operation from UE perspective. This detection may account for at least 24% of the power consumption. However, to keep the device complexity low, devices are required to search for only one NPSS as all the cells use the same NPSS in NB-IoT network. In contrast to this LTE network uses three PSSs. Although, in order to get one copy of NPSS, 19,200 samples need to be captured with a sub-frame of the length of 10 ms, with 1.92 MHz sampling rate.

Hereafter to ascertain the cell identity out of 504 cell-ids available and to acquire additional information about the frame structure NSSS (Narrowband Secondary Synchronization Signal) is used. It is transmitted in subframe 9 with a subframe periodicity of 20ms. Hence NSSS sequences are transmitted four times in 80-ms repetition interval are differentiated by the phase shift. It uses the last 11 OFDM symbols that consist of 132 resource elements overall. Unlike legacy

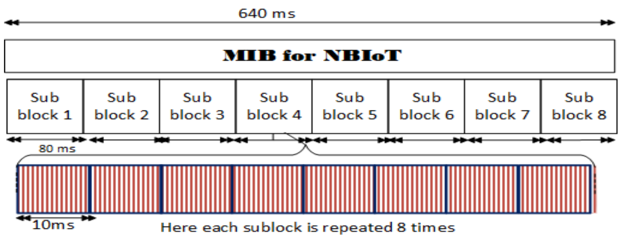

FIGURE 9. Mapping of NBPBCH [59].

LTE, cell ID is enclosed in the secondary sequence without including the primary sequence. NSSS, ZC 131 (Zadoff-Chu sequence) is constructed to indicate cell-ids [65]

$$R(m) = b_q(n)\, e^{-j2\pi\theta_f m} e^{-j\frac{\pi u m'(m'+1)}{131}} \quad (2)$$

Where

$m \quad = 0, 1, \ldots.., 131,$
$m' \quad = m\,mod\,131,$
$n \quad = n\,mod\,128$ the root sequence,
$u \quad = N_{ID}^{Ncell}\,mod\,126 + 3,$
$q \quad = \left\lfloor \frac{N_{ID}^{Ncell}}{126} \right\rfloor$, is cell specific parameter
$\theta_f \quad = \frac{31}{132}(n_f/2)mod4$, the cyclic shift, here n_f is SFN,

b_q, binary scrambling sequence of 128-bits which is obtained based on length-128 WalsheHadamard. Hereafter NSSS is mapped to in radio frames having $n_f mod 2 = 0$.

b: PHYSICAL CHANNELS

i) NBPBCH: NARROW-BAND PHYSICAL BROADCAST CHANNEL

NB-PBCH reside in subframe 0 in every radio frame and carries the MIB (Master Information Block). It provide information about system bandwidth, SFN (system Frame Number), No of antenna ports. NB-PBCH, MIB consists of 8 independently decodable blocks of each of 80 ms duration. Where each block is repeated 8 times consecutively to manage with extreme coverage conditions. Hence MIB remains unchanged for the time span of 640 ms (Fig.9). The NB-IOT determines the number of cell antenna ports whilst demodulating MIB information. Other than this MIB also provide information about operation mode. NB-PBCH reuses the functionalities from legacy LTE PBCH such as CRC generation and attachment, Tail biting convolutional encoding, Rate matching, Scrambling, Modulation, Layer mapping.

ii) NPDCCH: NARROWBAND PHYSICAL DOWNLINK CONTROL CHANNEL

The NPDCCH is used to carry DCI (Downlink Control Information). Basically, a device needs to monitor NPDCCH to obtain three types of information mentioned below. NBIoT has own control channel different from LTE-MTC system, although some features have been inherited. Typically NPDCCH is apt for transporting scheduling information. Moreover, as NBIoT supports only HDD mode thus transmission of NPDCCH is packet based [63]. Besides this to keep the power consumption low on UE side, the payload size of DCI (downlink control information) is kept up to 23 bits for UL grant or DL assignment for NPDCCH. Hence three new DCI formats have been defined as Format N0, Format N1, and Format N2. The usage of these formats is specified in Table 4. Further, NPDCCH consists of Narrowband control channel elements (NCCEs) where resource elements are mapped. A subframe has two NCCEs, analogous to the upper six and lower six subcarriers and for NCCE mapping (Fig. 10).

TABLE 4. DCI Formats [14], [61].

Format	Usage
Format N0	Used for scheduling of NPUSCH in one UL cell with necessary information about assignment of resource, repetition, modulation and coding.
Format N1	Used for scheduling of NPDSCH code-word in a cell. Its size is similar to N0. It inform user informs when to expect data on the NPDSCH
Format N2	Used for paging and direction

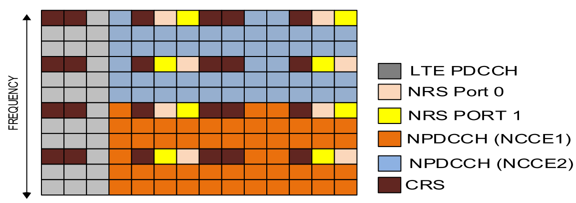

FIGURE 10. NPDCCH subframe structure [62].

iii) NARROWBAND PHYSICAL DOWNLINK SHARED CHANNEL (NPDSCH)

The NPDSCH is the core data bearing channel used for transmission of unicast data, broadcast information such as SI (System Information) messages. It segments the data packet received from higher layer into transmission blocks and transmits one at a time. The resource mapping is done in an almost similar manner as NPDCCH beside two differences. One, that NPDSCH carry only one TB (maximum TB size is limited to 680 bits) though NPDCCH can multiplex resources in a subframe to transmit two DCI messages. Secondly, if the subframe transmits the SIB1-NB then starting OFDM symbol in an NPDCCH subframe will be different from NPDSCH subframe in the in-band mode.

The NPDSCH TB is processed as follows. Firstly, the CRC of 24-bit is evaluated and then attached to the TB. Then TB is encoded via the tail biting convolutional coding encoder and rate-matched owing to code-word length deduced collectively from the number of NPDSCH sub-frames assigned to the TB and on the basis of the number of REs per subframe. Accordingly, the coding rate is determined by size of TB and the number of NPDSCH Subframes allotted to the TB combination. Henceforward before mapping the encoded TB bits to QPSK symbols, the bits are scrambled i.e. the subframe is repeated min (NREP, 4) times before the mapping of the code word continues. For each repetition, the scrambling code differs. The maximum no of repetitions allowed are 2048 to achieve the SNR of −12.6dB. The repeated Subframes allow a device to decode the code word before the transmission completes [64].

F. NBIoT CONNECTION PROCESS

1) CELL SELECTION PROCESS

A device can be in idle or connected mode while looking for the cell to camp on. If the device wakes up from a deep sleep then it obtains the information about most recently used (MRU) cells using cell selection protocols. In case none of the cell is found suitable or if device is powered on for the first time, it is required to perform a full frequency scan to find a new cell to camp on. The fundamental purpose of cell selection is to identify and synchronize to a suitable NB-IoT cell. In this context, the first foremost step is to time synchronize and then obtain a CFO estimated value. In order to achieve NPSS synchronization, its autocorrelation properties must be exploited. Hence when device achieves the time synchronization, then using next frames it determines the CFO. For device located in extreme coverage conditions, large number of NPSS frames are required to be detected. Once the symbol time is determined and the CFO is compensated for in-band or guard-band, still, an additional raster offset will exist up to 7.5 kHz. Consequently, this raster offset drifts the symbol time either in the forward or backward direction due to overcompensation or under compensation of the carrier frequency respectively. As a result, there is severe degradation in the performance of NPBCH detection, which may introduce latency greater than the length of CP (Cyclic Prefix) and subsequently leading to loss of orthogonality of OFDM symbol lost in the downlink. Hence to improve the detection performance device complexity must be increased so that it may do hypothesis testing of set of raster offset. Once the NPSS synchronization is achieved the device has the knowledge of subframe #9, however, a device has information, whether the radio frame is odd or even numbered. As NBIoT has 504 Cell-ids, thus NSSS detection algorithm will form 4032 hypothesis in total. Thereafter correlating the received signal corresponding to each hypothesis with NSSS waveform allow a device to detect the Cell-id. Hereafter device has Cell-id and also has information about the placement of NRS. Now the NBPCH is demodulated to obtain MIB-NB for this the device needs to form eight hypotheses hence also referred as blind decoding. The MIB-NB contains 34 bits and is transmitted over 64 radio frames. The foremost information acquired from MIB are a) Operation mode indicated by 7 bits i.e. stand-alone, in-band, guard-band. b) Information about SIB1 scheduling indicated by 4 bits. c) SI value tag indicated by 5 bits d) Access barring (AB) information enabled or not is indicated by 1 bit. e) System Timing: 4 MSBs of the SFN and 2 LSBs of the H-SFN. f) 11 spare bits used for future extensions. In addition to this, the transport block size and the number of repetitions is also indicated in the MIB. Hence acquiring the MIB-NB, a device can locate and decode SIB1-NB. An SIB1-NB carries 8 MSBs of the H-SFN, tracking area, a 28-bit long cell-id, and scheduling information regarding other SIB to unambiguously ascertain a cell within a PLMN. The SIB1-NB transmitted in subframe #4 of every other frame in 16 continuous frames. Beside this, it is transmitted at a fixed schedule with a periodicity of 2560 ms (256 Radio Frames). To determine the first frame for transmission of SIB1, cell-id is used. Hereafter acquiring SIB1-NB, the device achieves the complete synchronization. If any change occurs it will be indicated either by paging or by changing the tag values. In a manner, the device has accomplished time and frequency synchronization with errors that will not significantly degrade the performance in successive transmissions and receptions during connected or idle mode operations [65], [66]. Fig.11 (a) describes the cell acquisition process.

2) RANDOM ACCESS PROCEDURE

Random Access procedure is initiated by the MAC layer itself or by its sublayer RRC. Before initialization of this process, UE has information about the available set of PRACH resources. The principles to select PRACH resource is based on received signal received power (RSRP) measurement that specify the enhanced coverage level supported by the Serving Cell. A device uses two threshold values supported by serving cell to determine the NPRACH configuration. Besides this, the RSRP thresholds are used by the network to analyze the maximum coupling loss corresponding to different coverage levels. In NBIoT the eNB can support max 3 number of NPRACH repetitions out of {1, 2, 4, 8, 16, 32, and 64}. Hereafter acquiring the CE level information UE instructs the physical layer to transmit a preamble while specifying the number of repetitions required for transmission per preamble, preamble index and preamble received target power. For CE level 0, the preamble received target power (PRTP) is set to *PRTP-10 ∗ log10 (number-of-Repetition-Per-Preamble-Attempt)* whereas for other CE levels PRTP is set to the UE maximum output power [67], [68].

In NPRACH, RA preamble is transmitted to determine the transmission time of the device to eNodeB. On each symbol group of RA preamble frequency hopping is applied so that individual group is transmitted on a different subcarrier. Hereafter transmitting the preamble, RA-RNTI (Random Access-Radio Network Temporary Identifier) is computed using *RA-RNTI=1+ floor (SFN_id/4)*, here SFN_id is the index of the first radio frame, then it looks for RAR (Random Access Response) message indicated in DCI format N1 scrambled with RA-RNTI transmitted in PDCCH. Nevertheless, if RAR (random Access Response) is not received then UE retransmits the preamble. As stated above number of retransmissions depend on CE level. However, if the number of attempt saturates an associated failure is reported to RRC. Now eNB on receiving the preamble sequence transmits the

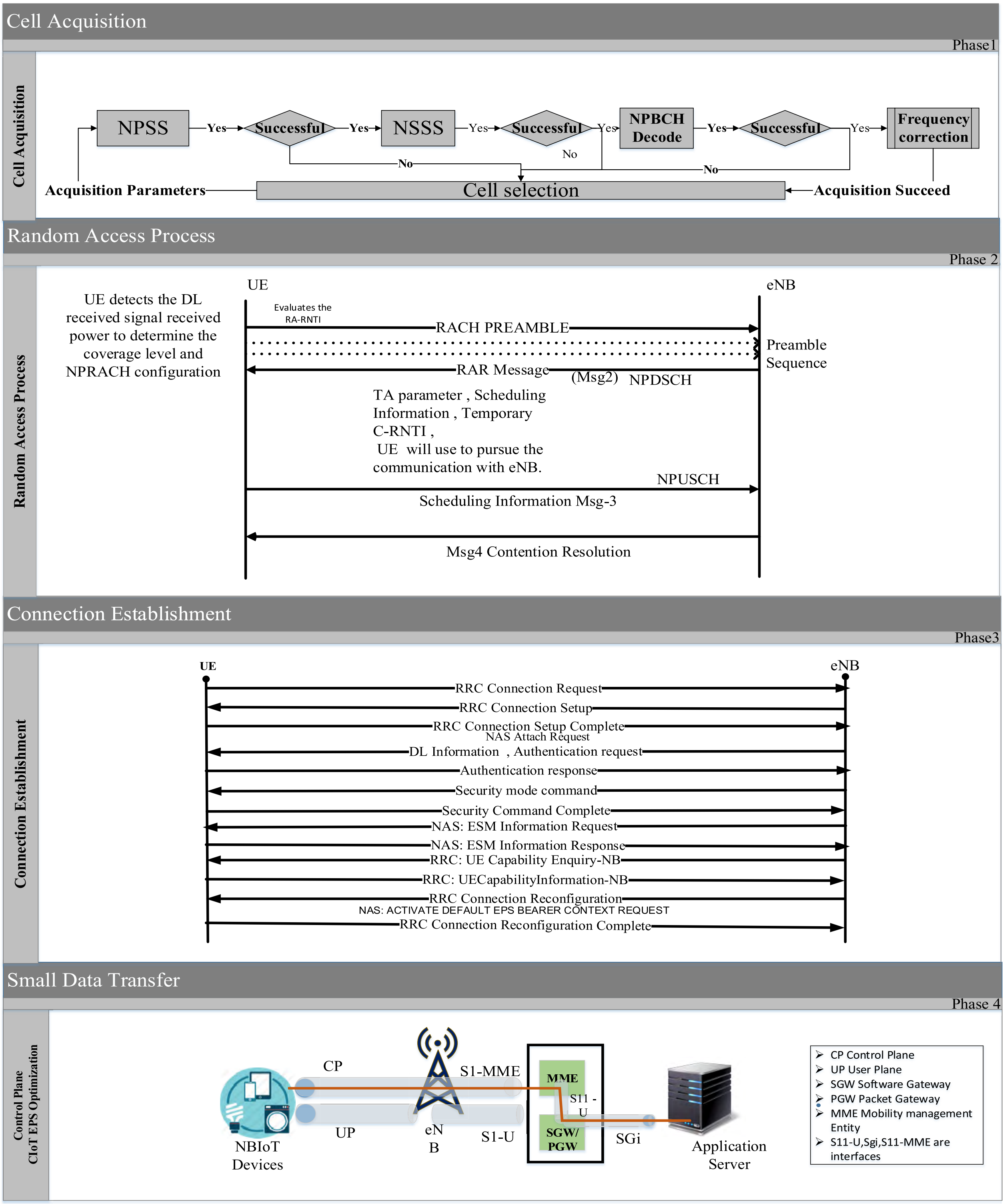

FIGURE 11. (a) Cell acquisition process [66]. (b) Random access procedure [69]. (c) Connection Establishment [70]. (d) Data transmission [73].

RAR message also referred as Msg 2, to UE which provide information about TA (Timing Advance), scheduling information about radio resource that device can use to transmit the request for connection, C-RNTI (Cell radius Network Temporary identification) as shown in Fig.11 (b) [69] Now UE transmits Msg 3 to eNB on NPUSCH including its identity, C-RNTI MAC CE, submitted from the upper layer and start the contention resolution process. In addition to this data, the volume parameter is sent to indicate the amount of data present in UE buffer. All together will facilitate the BS to take power allocation and scheduling decision for subsequent UL transmission.

3) CONNECTION ESTABLISHMENT

UE indicates that it wants to connect to the network by sending RRC-Connection-Request. In addition to the establishment cause, the UE also indicates its capability to support multi-tone traffic and multi carrier support. The eNB on receiving connection request, send RRC-Connection-Setup message Thereafter UE acknowledges by sending the Connection-setup- -complete message and send NAS attach request. The PDN-CONNECTIVITY-REQUEST message is piggy-backed in NAS ATTACH REQUEST [70], [71].

The PDN connection is novel capability introduced in 3GPP Rel-13 that allow UE to remain attached without PDN connection that support CIoT optimization. In this UE is not required to establish a PDN connection as part of attach procedure. Moreover UE and MME can release the connection without releasing EPS connection. Hence enables large number of devices to keep their connection inactive for long duration and seldom transmit data over it [72]. Hereafter the EPS authentication process is initiated. After that to activate the default EPS bearer CONTEXT REQUEST message is piggybacked in NAS: ATTACH ACCEPT. The follow of above discussed steps are discussed in Fig.11(c).

4) SMALL DATA TRANSFER

In Rel-13, 3GPP added an ability to send data over control Plane. As NBIoT require to transmit the small data sporadically, hence to send it in optimized way CIoT EPS optimizations are used which include Control Plane and User Plane optimization.

In Control Plane optimization, UE sends the data packets encapsulated in NAS (Non Access Stratum) to convey non radio signal to MME for a service request. In NAS message RAI (Release Assistance Information) field indicate the MME that any further UL/DL transmissions are expected. In case no further transmission is expected than MME immediately triggers the S1 Release procedure. Hence enable MME to reduce the device DRX waiting period during which it waits for additional transmission. Besides this, if the size of the data transferred via Control Plane exceeds then UE/MME triggers the establishment of User Plane bearer between eNB and SGW.

User Plane CIoT EPS optimization is an alternative procedure which is suitable for short as well as large data transaction. However, it requires first to establish RRC connection and create Access Stratum and radio bearer between the network and UE. Once the RRC connection is established two control procedures Connection suspend and Resume are used [74]

G. MODES OF OPERATION OF NBIoT

NBIoT carrier can be deployed in three modes standalone, in-band, and guard band.

1) Standalone Operation: In this mode, a separate spectrum is either reserved for radio access technology like GSM/UMTS or a dedicated spectrum is used for deployment of NBIoT carrier. However, this will escalate the implementation cost as software and hardware upgradation will be required for spectrum reframing.

2) In Band Operation: In this mode NBIoT carrier is deployed within LTE carrier. Sharing of resource block would definitely result in the more efficient use of spectrum which in turn will increase the capacity. The LTE bands not utilized to carry system information block −1 are used for inband deployment of NBIoT.

In single tone transmission mode in uplink, there will be interference between NB-IoT and LTE (3.75 kHz subcarrier spacing). Although this interference could be minimized by scheduling users with similar SNR requirements in NB-IoT and nearby LTE PRBs. It's also a cost effective way as no hardware modifications are required.

3) In Guard Band Operation: In this mode NBIoT carrier will be located within guard band of LTE carrier to avoid interference. This mode delivers better downlink throughput in comparison to in band as more downlink resource is available [75].

NB-IoT deployment modes offer high flexibility as carrier deployed in one mode can continue working via either of the other modes if spectrum migrates to LTE. Fig.12 describes the scenario of different modes.

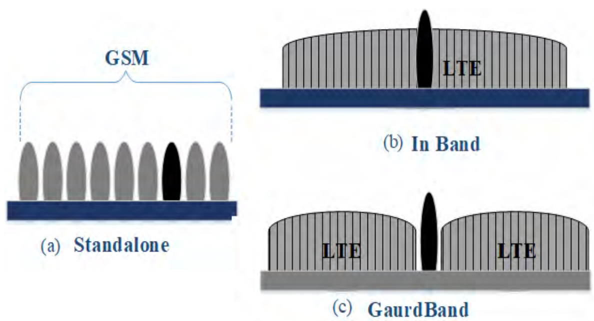

FIGURE 12. Modes of operation of NBIoT [75].

H. LOW POWER CONSUMPTION USING NBIoT

Saving power of the battery powered device is a crucial factor for the realization of LPWAN applications. Two main features Power saving mode (introduced in Rel-12) and Extended Discontinuous reception RX (introduced in Rel-13) are used to extend the battery life of device up to ten or more years (Fig. 13(A) shows the PSM and Fig. 13(B) eDRX mode) [76].

A device in PSM goes into deep sleep mode and could not receive any signal. Although whilst this mode device can't be reached but remain registered with the network. Thereby PSM eradicates the need for re-establishment of a connection when the device wakes up. Hence will not only result in saving power but also help in avoiding network congestion (due to different wake-up time). Thus it is suitable

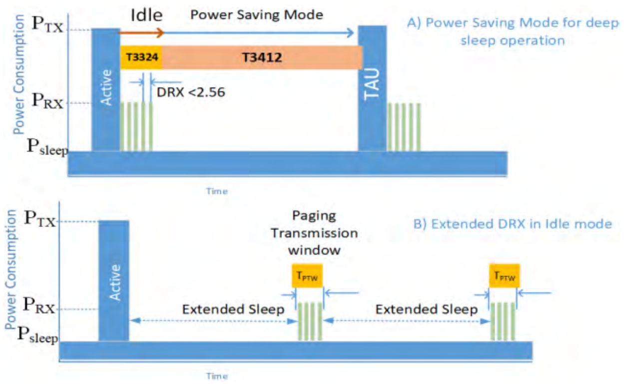

FIGURE 13. PSM and eDRX modes to save power, [Source: https://www.rohde-schwarz.comRohde &Schwarz].

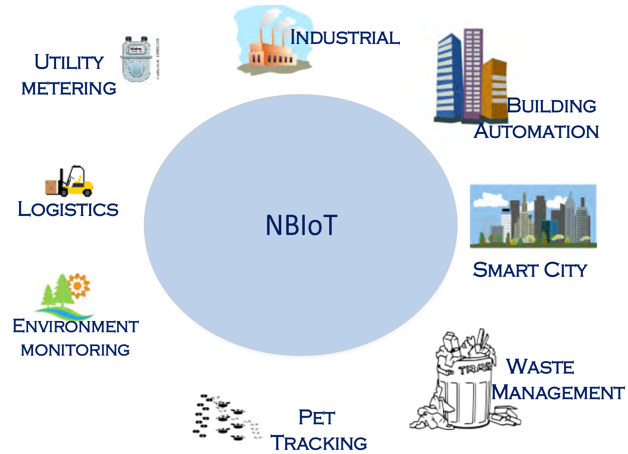

FIGURE 14. Applications of NBIoT.

for application that requires sporadic transmission (e.g. Once a day). A device can switch to PSM, proposing two timers T3324 (active timer) and T3412 (extended timer) and it is attached to TAU. (The maximum time a device could remain in the active state is 186 minutes (~T3324) & max sleeping time for a device would be 413 days defined by T3412.) However, it's up to the network to accept the proposed timer values or not. Despite this, there is one challenge of using PSM is non reachability of device for a long period that needs to be taken care of by opting an optimal value to get a good balance between responsiveness and time for the device to stay in PSM.

Another main feature is eDRX to save power, this in comparison to PSM supports DL accessibility significantly. eDRX reduces the periodicity of a device to switch in receiving mode and extends the sleep cycle more in idle mode than in connected mode. Currently, in LTE, DRX can extend up to 10.24 s whereas using eDRX it can be extended for minutes and hours. Thus for synchronization between network and device a new clock H-SFN (Hyper System Frame Number) is used. A power saving of 43% can be achieved using eDRX with small paging transmission window. As power consumption after PTW during deep sleep mode would be extremely low. Hence longer the eDRX more would be power saving. In addition to this other feature like reduced complexity and reduced overhead of channel measurement also reduce the power consumption, hence extends battery life [77].

I. APPLICATIONS OF NBIoT

The cost effectiveness of NBIoT-network (due to the implementation of new software on an existing LTE infrastructure) has inspired several market analyst organizations to predict the revenue in the future.

NBIoT being a promising technology, could support a wide range of applications with increased efficiency. Some of the important applications sectors of NBIoT with notable market perspective are utility-meter, industry automation, smart logistics, smart cities, waste management, environmental monitoring, agriculture and in personal sector like wearables, pet tracking, kids monitoring, white goods monitoring (Fig. 14) which provide convenience to remotely access of water, gas, electricity, and heat readings even when they are located in weak coverage areas like basements. Currently, a Germany based company, ista-International GmBH in collaboration with Deutsche Telekom is proving a solution for smart buildings by providing smart utility services using NBIoT [26]. Other companies such as Eco Mobile from Zagreb, Croatia in collaboration with Deutsche Telekom are providing IoT solutions for waste management using NBIoT. Here the sensors are used to measure the level of the trash bin and thereafter the sensed data using NBIoT sent to cloud, to determine the optimal route. Hence reduce logistic cost. Another important application of NBIoT is smart parking. Here occupancy [55]. Prime use case /application of NBIoT is utility meters information is collected and hence provide the availability of parking space throughout the city. Hamburg will be first to offer using this service of IoT using NBIoT. Huawei with China Unicom collaboratively launched smart parking in China also in 2017. Apart from this NBIoT can also monitor the environment effectively [16]. For example, XMM7115,

NBIoT-intel chip is used for environmental monitoring. Currently, in Greece Patras, NBIoT based monitoring service is being offered by Deutsche Telekom to effectively measure environment pollution, noise and air quality to take necessary actions. Automation and digitization is the need of the hour and list of possible application are endless. The technical view of current IoT applications related to four particular sectors Health monitoring, Social monitoring, Agriculture monitoring and defense that are ruling the market are given in Table 5.

V. EFFICIENT RESOURCE ALLOCATION TECHNIQUES

Due to massive connections, IoT system will be extremely dense thus the use of efficient resource allocation techniques is of vital importance. As incompetent resource allocation will drastically degrade the performance of IoT systems.

TABLE 5. Different Applications of IoT.

Category	Application	Technique Applied	Objective	Ref. No
Health Care	Monitoring of Wearable Sensor Network	BLE for transmission of data from sensors implanted on body and for energy harvesting (EH) maximum power point tracking technique is used	To extend the life time of sensor using energy harvesting and automate the system using smart phone application	[78]
	Sleep Monitoring	For communication Bluetooth is used. To save bio signal JDK6 supported sleep monitoring program is used, A lithium battery is used for power support	To monitor the sleep pattern of patient	[79]
	Monitoring Voice pathology	Bluetooth for communication to smart phone, watermark used for authentication, signal sampled at 11.25KHz. For classification learning mechanism is used and together with this Binary pattern is considered for detection.	To detect the voice pathology	[80]
	Heart monitoring	Bluetooth and Wi-Fi used for communication Quality assessment of signal is done for this smart phone is used (android based)	To monitor the real time signal of ECG i.e. noise presence will be there in different scenario resting , physical activity ,in ambulance	[81]
	Advance Prediction of :ventricular arrhythmia(VA) a Heart Disease .	Direct access the signal (no storing) .For extraction of parameters it uses two continuous heart signals and then classified using linear classifier, which classify into normal/abnormal cases. To provide security against security attack used Diverse keys.	To reduce power consumption and provide secure health service monitoring	[82]
	Diabetes monitoring	Two communication is supported. GPRS used for communicating data to doctors. Compare it with threshold value, passes data asynchronously. MQTT is used for informing family member	To provide two way communication, in case abnormal blood sugar is detected	[83]
	Glucose Control	Game theory is used for proposed framework, for security compared against threshold value to avoid risk of wrong dosage of insulin.	To reduce the attack probability in cloud based application	[84]
	Cow Health monitoring	LoRa is used for energy efficiency, Raspberry pi is used for transferring the captured data.	To determine path loss and fading using LoRa technology in dairy farm	[85]
	Gesture and Activity recognition	Microsoft Kinetic sensors used for capturing joint movement ,CNN used for cognitive learning	To determine the gesture and activity using low cost	[86]
	Human activity recognition	Used deep learning with kernel method to reduce the computation overhead.	To determine the real time activity signals for low powered devices	[87]
Agriculture Monitoring	Uniform water distribution	Used Satellite and drone data .For segregation /classification using AI i.e. applying gridding, masking	Classification of dense and sparse region	[88]
	Crop yield mapper	SYCM is used for fine scale resolution where image and weather conditions were considered using Google Earth Engine	For fine scale analysis of crop yield.	[89] [90]
	Drought duration and acuteness measurement	Considered VTCI index and converted the image from satellite LANSAT to a coarser image and applied multiple regression on to it	To get scaled information	[91]
	Crop classification	3D based Kernel method (which is a shallow technique),convolution neural network used	To classify the crop in more efficient manner	[92]
		Used Deep learning for classification		[93]
	Biomass estimation and managing grassland	ANFIS model is used which is combination of artificial neural network and fuzzy logic to reduce the error in estimation.	Tracking the growth on weekly basis for estimation of biomass.	[94]
	Maintenance of cutting blades	Sound of blade was monitored	To know the estimated time for regrinding	[95]
	Irrigation monitoring	Cloud and thermal pattern are used for decision making	For uniform distribution of water to reduce water stress	[96]
	Water Saving and monitoring	Fuzzy logic with sensors are used	To provide required amount of water for irrigation	[97]
	Monitoring the Nitrate concentration in water	Temperature based sensing system used which measure impedance	For checking the adulteration level in water via Nitrate	[98]
Defense monitoring	Defend against International attacks	Percolation theory used to determine whether network is connected or not (used 1 bit for each node), game theory is used where a payoff matrix is prepared for adversary and defender. Finally Nash equilibrium is achieved if payoff of both the actors would be same	To defend against international attacks	[99]
	Smart grid Defense against data injection	Remote sensor used for measuring the power in transmission and buses .A host node is used for surveillance of data acquisition and controlling the attacks i.e. SCADA.	To able to detect stealthy attack which is very hazardous for Smart grid	[100]
	General Internet of things defense	Uses MTD technique which changes the address of devices with IPV6	To defend against the attack	[101]
	Exploring the usage of Genetic programming in Defense	Using Genetic programming(GP) created attackers , Improved immune system is used for sensor network	To find the security mechanism against the more powered attackers generated through GP.	[102]
	Security Game	Game theory used	To defend against the attacks while reducing the false detection thus reduced EC	[103]
Social Monitoring	SmartBuddy	Hadoop technology is used for studying huge data generated from the various sub system considered.	To determine the human behavior	[104]
	Teaching and learning system	Wearable sensors used and for communication WIFI and Bluetooth used	To find the usage of IoT in learning for tots	[105]
	Smart Home	Wi-Fi used for communication ,filters used to remove noise impact on RSSI	To reduce the human involvement	[106]

Moreover, there are miscellaneous factors that further aids in increasing the complicacy of efficient resource allocation such as limited network bandwidth, limited device computation power, diverse user requirement, heterogeneous device configurations. Broadly these resource allocation techniques can be classified into the following categories: Power allocation, Spectrum allocation, Computing & Storage resources allocation in the cloud and Scheduling based (Fig. 15). Other than this all techniques that assure the reduction in latency and packet error are categorized under QoS resource allocation techniques. As per now, few resource allocation schemes (RAS) have been proposed for NBIoT system. Immense research is required to be carried out for the practical implication of NBIoT as the IoT devices have limited resources. In this section, a review of resource allocation schemes for NBIoT and IoT system is presented.

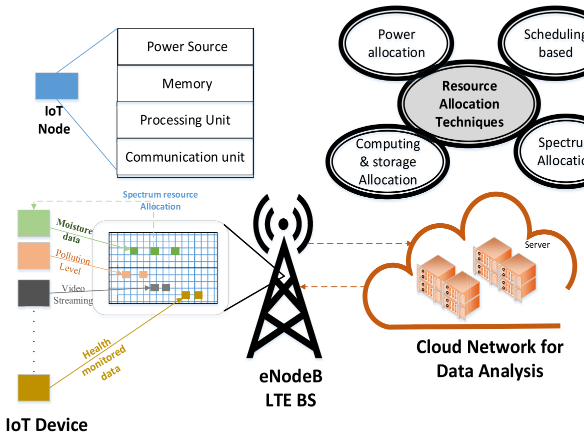

FIGURE 15. Resource allocation in IoT [107].

A. NBIoT RESOURCE ALLOCATION TECHNIQUES

Yu *et al.* [108] proposed a UL *link adaptation scheme* with consideration of repletion factor to address two important aspects of throughput and reliability. This scheme worked in two loops inner and outer. The inner one modifies the repletion factor to improve block error ratio whereas outer concentrate on the selection of modulation and coding scheme level In addition to this outer loop also decides the repetition factor accounting acknowledgment or no acknowledgment packets. As a result, the authors observed that the proposed technique can save 46% more resource allocation and active time in comparison of straightforward techniques. However, they have not considered the effect of inter-channel interference during evaluation.

In order to handle massive connection effectively in NBIoT multi PRB design is used. Where most of UE's use Anchor-PRB (that satisfy the channel raster condition) to get paging and system information block. This leads to overloading of anchor-PRB. Hence the overloading of narrowband resource leads to underutilization of resources and increase power consumption. To overcome this issue Liu *et al.* [109] suggested a resource allocation technique to balance the paging load by using non-Anchor PRB. In the proposed technique existing user will use the Anchor PRB and the new NBIoT user will make use of non-Anchor PRB for paging in idle mode. As a result, it was observed that resource utilization improved by 30% and power consumption was reduced by 80%.

Malik *et al*. [110] proposed an *interference aware RAS* that accounts for the repetition number & time offset. The linear modulation scheme is used in NBIoT (QPSK), therefore spectral efficiency is low. Firstly they evaluated the max attainable data rate for downlink is 89.2 kbps and 92kbps for uplink (theoretically). In addition to this, the authors analyzed the performance of cooperative scheme in comparison of non-cooperative and optimal scheme. They found that cooperative scheme can reduce the energy consumption by 17% and can improve the data rate up to 8%.

B. IoT BASED RESOURCE ALLOCATION TECHNIQUES

Liu and Ansari [111] proposed a green approach by developing an overlay based architecture that uses relay BS powered by solar energy. These relay BS stores the harvested energy in two batteries and each one is used in alternatively when one exhaust. Thus omits the grid based energy utilization and cuts cost for transmission of power also. Here in this approach, the SD (source destination) pairs are classified into two groups based on CSI. Where one is direct D2D which doesn't use relay for transmission and another one that uses relay BS for transmission of information. However, while allocating bandwidth direct D2D pair is given more preference in comparison to relay based D2D transmissions. As a result, authors observed that as the number of SD pair increases with D2D communication very less bandwidth left for relay based pairs which deteriorates their performance. In addition to this due to large no of direct D2D pairs green energy will exhaust quickly and to balance the leftover/residual energy the relay BSs with enough left over green energy will transmit their electricity via electric transmission lines to the relay BSs which run out of green energy. Hence proposed architecture maximizes the green energy utilization and further saves the on-grid energy.

Further, Kotagi *et al.* [112] proposed a breathing technique to reduce the BS energy consumption by assigning the T_x(Transmission) power efficiently. Firstly the SINR of the user is compared with pre-specified SINR threshold value and if found greater Tx Power has modified accordingly. Thereupon resource is allocated, according to breathing pattern i.e. IoT devices are arranged in increasing (inhaling) /decreasing (exhaling) order on the basis required Tx Power and then mapped to resource block. In addition to this if available resources are less as compare to required, the user/device with a heavy request and highest Tx power was blocked. Apart from this transmission power is reduced if SINR of device is greater than the threshold value, which in turn improves the co-channel interference. Authors found that overall energy consumption of BS reduced and throughput is improved using the proposed approach.

Further Samie *et al.* [113] enlighten the issue of underutilization of bandwidth of gateway. As IoT device have limited computation capability thus it is offloaded to the edge nodes i.e. gateway. However, due to limited bandwidth and diverse offloading levels, gateway bandwidth resource remain underutilized. Hence authors developed an algorithm that allocates or take away bandwidth from a device depending on its battery level. As a result, they found that battery life extended by 1.5 hour max and bandwidth utilization improved by 40%.

Ejaz and Ibnkahla [114] proposed a framework for C-5GN. In the proposed framework, multiband sensing approach is used such that sensing is done in shared mode where each node is required to sense equal and reduced number of channels, thus reduced energy consumption. Although it is assured that all channels get processed once at least by a node. Apart from this, a game based CLRS (Cross Layer Reconfiguration) scheme is used to satisfy the diverse QoS requirement (latency, data rate, etc.) for each node. Hence, authors observed that the proposed technique reduced energy consumed during spectrum sensing and QoS is offered economically.

Pang *et al.* [115] proposed a complete contention resolution approach based on the principle of context-aware and dynamic allocation of resource (CADRA). Overload scenario is first detected by analyzing the no of nonempty preambles. If detected, CADRA is called. This works in two phases firstly it determines the estimated number of RACH attempts by observing the preambles received successfully and empty preambles. After that in the second phase resource allocation is done. As a result, authors observed that throughput increased with moderate packet delay. Jang *et al.* [116] proposed Non orthogonal resource allocation collaborated with spatial group resource allocation scheme (SGRA). SGRA divides the cell into spatial groups. After dividing the cell region, it detects the preambles transmitted from the user in a certain spatial group by zadoff-chu sequence (which is shifted by spatial group number). Once the preambles utilized by a spatial group was determined using the ordered time delay metric, subgroups were formed. Authors found that using the proposed approach the probability of success of random access has increased a lot.

Further, Morvari and Ghasemi [117] proposed a resource allocation scheme that works in two stage by efficacious use of resource available in UL. During the first phase, users are required to pass the access class bearing test. If a user manages to pass only then permitted to select the preamble (PA) and use physical uplink shared channel opportunity else has to select the special PA. Finally, in the second stage the secondary users are allowed to take access class bearing test again if passed allowed to request for UL shared channel. Hence it is inferred that the number of request that can be handled with proposed technique whilst dropping the wastage that occurs due to the collision of PA's.

Another extended RA scheme with spatial group resource allocation is proposed in [118]. This scheme reuses the allocated preamble if the distance between the two nodes belonging to a different spatial group is greater than pre-specified minimum distance. In addition to this, access delay is also reduced. The proposed approach will utilize the unused bandwidth. Beside this collision probability is also tapered by using distinct UL resources for transmission.

As interference is also a prevalent challenge for IoT device communication. Taking into consideration Iqbal *et al.* [119] proposed a constraint specific approach to improve the performance of IoT networks For solving the RA problem authors have used backtracking search algorithm named Soft-GORA .Where firstly channel is selected with minimum cost for tentative allocation to link, at the top in the ordered list and then checked against hard constraint. If it couldn't satisfy the constraint, the allocated channel is removed and the next best option is opted. As a result, authors relaxing few constraints observed that throughput has improved and delay is reduced.

Li *et al.* [120] proposed an architecture using edge computing further, they proposed a scheme to jointly control admission of new packet and allocation of resource together with power control. For this, the resource management controller at fog node uses three information i.e. service, state of the queue, CSI. Using the proposed schemes authors found that tradeoff is achieved between throughput and delay.

Zhang *et al.* [121] proposed a joint optimize framework for the selection and allocation of resource among fog nodes (FN), data service subscribers (DSS) & data service operators.(DSO) They have developed a stakelberg game algorithm, here DSO provides the computing resources (CR) to DSS and if they require more CRB's(Computing Resource Block) DSS competes for them. For this, another matching game algorithm is developed. As a result it was found that the system achieves high performance and optimally utilizes their resources. Further, cognitive 5G network (C-5GN) is expected to play a vital role in IoT success,

Angelakis *et al.* [122] developed two algorithms RAND-INT and Average-cost allocation, to optimally allocate resources for services. These algorithms reduced the total cost of resource utilization and activation of interface. Where RAND-INT algorithm normalizes the demands to get an order in which resource is to be allocated. Henceforth the heaviest demand is served first by comparing the utilization cost of interfaces, thereby other demands are served either by splitting or by not splitting among two or more interfaces. Whereas the second algorithm assigns, the resource by averaging the total cost incurred. Authors have studied the impact of the activation cost on the services' splits and distribution among the interfaces. As a result, they found that for random service with high demand, interface total cost increases linearly with respect to the number of services.

Hence above discussed technique proves that resource technique can enhance communication, connectivity and collaboration of IoT devices. The chief objective of resource allocation technique is to minimize the power consumption per node, BER, Delay and maximize the throughput and network utilization. The above discussed techniques are summarized in Table 6.

TABLE 6. Efficient resource allocation techniques for IoT.

Metric	Ref No.	Algorithm proposed	Objective	Outcomes
Power	[111]	GRA	• To properly allocate bandwidth to each SD pair in direct D2D group. • Decrease the power consumption and increase the data rate	• Power and spectrum efficiency • Divided the spectrum into two parts cellular usage & D2D usage, but its performance deteriorates when no of D2D user increases data rates are affected by the co-channel interference.
	[112]	ABS pattern Design UE grouping strategy	• To increase Energy Efficiency of network of LTE enabled IoT device	• Scalability is achieved • Improves system Throughput • Decreased system blocking • Co-channel interference is reduced
	[113]	Iterative BW Allocation on the Gateway	• Proper utilization of unused, wasted bandwidth. • Increase the battery life time of device	• Extended battery life of device by 1.5 hours(max) • Improve bandwidth utilization by 40%
Spectrum allocation & Throughput enhancement	[114]	Multi band Sensing and Cross layer configuration scheme	• To ascertain the least no of channel need to be sensed by individual node in multi band approach to reduce the energy consumption	• Allocate resource to gratify the QoS requisite Reliably and economically • Reduce the burden of spectrum sensing of each node and hence in turn energy consumption is also reduced.
	[115]	CADRA MECHANISM	• To consider the throughput, delay ,probability of success for removing the contention problem • To collect detail about no of attempts of random access	• Estimated error is reduced • Throughput increases even when traffic is extreme. • Chances of failure are very less.
	[116]	NORA-SGRA Non Orthogonal Resource Allocation	• To provide huge no of preamble during initial step of random access • Non orthogonal resource allocation during 2nd step of random access.	• Has able to increase the success probability of random access procedure by 30% in comparison to conventional system • Could support scalability in resource constrained scenario
	[117]	Extended random Access scheme	• To optimize the uplink resource utilization • Lessen the TST of Traffic burst.	• No of collided preambles decreases significantly • Increase the no of successful request
	[118]	ERA-SGPRA	• To avoid collision by allocating different uplink channel/grant for identical preamble • To reuse the allocated preamble • Creating spatial groups based on distance from eNodeB	• Instead of exponential growth of access delay ,it grows linearly • Same preamble could be used for two nodes who are more than δ km apart • Will work better if cell size would be greater than two times the δ km • But intergroup collision could still occur because of alike preamble selection.
	[119]	Soft-GORA	• To allocate best channel among all the available channels. • To avoid deadlock in case non availability of best channel thus Relaxations opted. To provide approximate optimal solution	• Improved throughput, reduced delay
	[120]	ECIoT Joint admission and resource allocation	• To propose an architecture based on fog computing to reduce burden at server side • To enhance the system efficacy • To improve the system throughput by jointly addressing the admission and resource allocation at fog node	• Improved throughput ,backlogs of packets are also diminished
Computing	[121]	Stakelberg Game model	• To determine the no of CRB'S considering the service delay and the and payment to be made to DSO by DSS • To decide how much DSO must Charge for CRB's to get maximum profit	• When no of DSS increases and Fog nodes remain same, then utility of FN decreases, but DSS increases in terms of revenue services. • Joint optimizations to solve the pricing problem and purchasing problem • The proposed approach is also providing the platform for dynamic computing resource allocation with 3 tier IoT fog networks
	[121]	Many-to many matching problem	• To decide how to pair FN and DSO to get high utility (based on FN rent) • To decide how to pair FN and DSS for to get high utility (based on distance between FN and DSS)	
Cost	[122]	Rand-int-allocation Average -cost Allocation	• To minimize the cost of utilizing the interface resources • Calculate the Cost of splitting the service over multiple interface • Approximate the optimal solution of SIA(system to interface assignment)	Reduces the total utilization cost of interface.

VI. ENERGY CONSUMPTION IN LIFECYCLE OF IoT DEVICES

Sensing device act as the backbone for IoT applications. Different sensors are deployed massively to develop a ubiquitous sensed environment, to offer diverse monitoring and control services. Indeed to avoid service interruptions of critical applications sensing device must operate permissibly for a long time. However, as most of the IoT devices are powered by constrained energy source hence device lifetime longevity is a critical issue. Therefore the device must be monitored precisely for optimal utilization. In this context, the trend of energy consumption during different states of the sensor is studied in [123]. There are five modes among which sensor switches- Mode I: Wake up from Sleep mode, Mode II: After Sleep mode. Mode III: Sensing, Mode IV: Processing, Mode V: Transmission. Hussain [123] studied different case studies to see the trend of energy consumption during different modes. As a conclusion of various trends (Fig.16), it was found that during Processing-Phase energy consumption was least whereas, for Sensing Phase, node consumes the highest power as compare to Transmission Phase. However, energy consumption during Transmission phase depends on the application. For example, consider the applications like Humidity /thermal measurement the power consumption during the wake-up and in getting ready for sensing phase is more as compare to other applications like temperature sensing which require less power for the same. Duty Cycle is the other metric that affects the energy consumption in the sensor node. As the duty cycle increases, energy consumption increases consequently lifetime of the node decreases. There are various factors that affect the lifetime of an IoT device such as duty cycle, the amount of data to be communicated, processing time other factors like aging, self-discharge and temperature [124]. Hence various energy efficiency techniques have been proposed in the literature to improve the lifetime of an IoT device and hence network lifetime. In the next section the recently proposed energy efficiency techniques are discussed in detail.

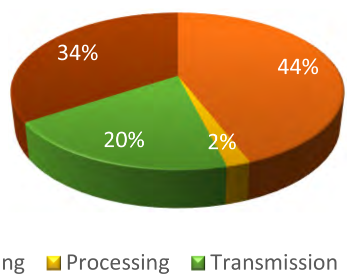

FIGURE 16. Energy consumption during the lifecycle of IoT device [123].

A. ENERGY EFFICIENT TECHNIQUES FOR GREEN COMMUNICATION

The energy budget affects the sensor node processing time, quality of measurement and amount of data it can transmit, thus energy efficiency techniques can a play crucial role to improve QoE. Rault *et al.* [125] classified the energy efficiency techniques classified into five categories of radio optimization, data reduction, sleep/wakeup schemes, energy efficient routing and battery repletion. Where radio optimization techniques would optimize modulation schemes, transmission power, and antenna direction on the other hand data reduction reduces the data transmitted. Furthermore Sleep/Wake-up adaptively switches the node to sleep or active mode to save energy. Other two techniques, energy efficient routing, and battery repletion works on routing efficiency and ways of harvesting energy or finding ways to charge battery automation, respectively. (Fig. 17, discusses briefly the impact of different techniques). In this section, the existing literature on energy efficiency techniques is discussed.

1) SLEEP/WAKEUP TECHNIQUES

Khodr *et al.* [126] enlighten that though the duty cycling technique could reduce power consumption but this will reduce network reactivity. Thus authors proposed a design of sensor based RF wake up technology. This design approach wakes the sensor only when the address decoder detects that whether a received signal address is of IoT device or not. Thereby omits the fake call wakeups hence reduced energy consumption. Perles *et al.* [127] did a case study on cultural heritage and proposed an architecture to improve the lifespan of sensor life up to 20 years using unlicensed LPWAN technologies LoRa &SigFox. In order to keep the energy consumption low, the proposed architecture wakes up the microcontroller whenever a new packet arrives. Apart from this, it uses a cluster management system, Elastic Cloud Computing Cluster (EC3) which can deploy and un-deploy nodes as per demand i.e. nodes will be deployed if load increases and un-deployed if they are idle.

2) COGNITIVE RADIO TECHNIQUES

Further, Qureshi *et al.* [128] discussed cognitive radio approach where unlicensed users opportunistically access the unused spectrum holes that are not used by the licensed user. Hence to achieve good throughput, uninterrupted connectivity, and Reliable communication, for both licensed and unlicensed user the concept of the backup data channel (BDC) was introduced. Where if licensed user return than unlicensed user resumes its communication using BDC. Hence communication time between SUs for task completion will be reduced and thereby the energy consumption of CRAN's will reduce and throughput will increase. Furthermore, Li *et al.* [129] proposed a 5G based framework where the central control unit act as both cloud and central data processor takes the sensed data from the physical world. In addition to this authors, fractionated the resource allocation into two sub problems of power and channel allotment in industrial Cyber physical IoT. These sub-problems are solved separately. For individual channel allotment, the energy efficiency is achieved using game theory and Dinkelbach's algorithm. After this, the Hungarian method was used for channel

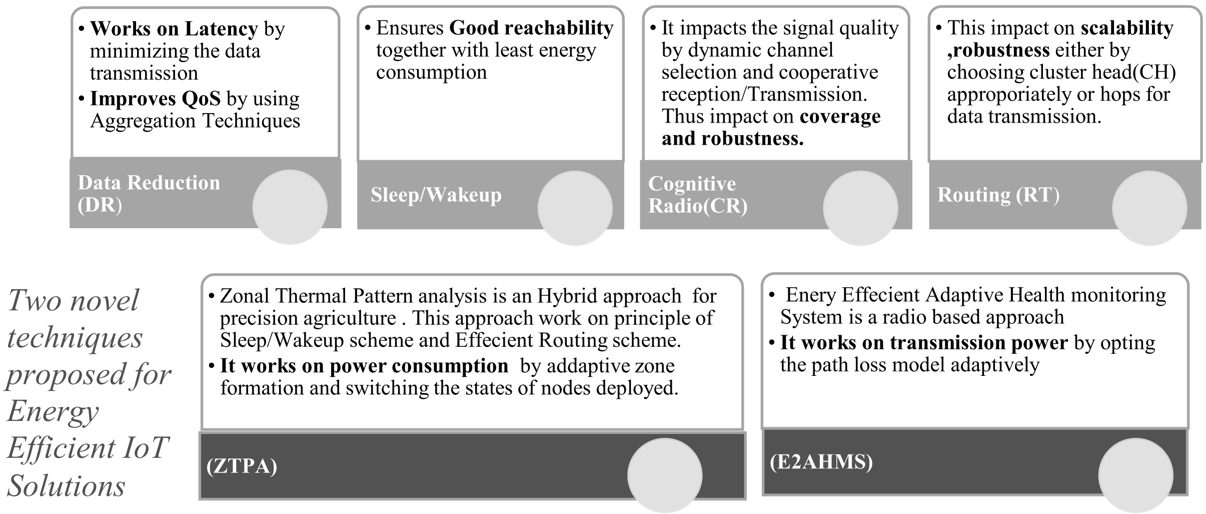

FIGURE 17. Classification of energy efficiency techniques for IoT.

allocation. Authors analyzed that IHM-VD could perform outstandingly.

3) ROUTING TECHNIQUES

Further Yi *et al.* [130] proposed a topology control algorithm in which nodes discover their neighbors asymmetrically. For time synchronization multiple of two is taken as reference point. Authors observed that energy consumption got abridged due to curtailment in wakeup calls required to discover the neighboring node. Further, the utmost drawback of continuous sensing (i.e. nonselective monitoring) is unfiltered data that results in significant energy consumption of sensors. Basnayaka and Haas [131] proposed a physical layer modulation scheme RNM (random number modulation) that operates in two modes energy efficient and low latency. To switch between modes the constellation order and random bit generated by random generator were considered. Proposed approach compromise latency for energy efficiency, as the user was allowed to transmit the data block only when it matches with random sequence generated by a random number generator otherwise the user could not transmit the data.

Shen *et al.* [132] proposed a clustering based protocol EECRP for IoT assisted by WSN to enhance the performance of the network. Firstly a cluster head is opted by comparing the energy of each node with pre-specified energy (threshold value) after this taking the distance from the centroid (energy based) of the network to the node is considered. This leads to uniform energy consumption in the network. After this for optimal result, the max distance value is broadcasted by BS to all the nodes, in order to avoid long distance communication. As a result, it has been found that overall energy consumption of the network is reduced in comparison to proprietary protocols. In extension to this, Tian *et al.* [133] have discussed, when to use network coding concept to reduce the energy consumption. Authors have proposed a network coding and power control based routing (NCPCR) protocol. Using this protocol intermediate node drops the duplicate packets and keep the relevant information in its buffer. Source node selects the path with the minimum distance to transmit the data packets. As a result the energy consumption is reduced as no of packets to be retransmitted is reduced and moreover, it opts for the shortest path also and in addition to this, it can handle scalability.

4) DATA REDUCTION TECHNIQUE

Perera *et al.* [134] proposed a platform C-MOSDEN that performs sensing tasks collaboratively and in a selective manner i.e. adaptive sensing to reduce energy consumption. As sensing would require less computational efforts to drive knowledge from data generated. In addition to this, the storage cost will also be reduced.

5) BATTERY REPLETION TECHNIQUE

Nan *et al.* [135] enlighten that offloading the traffic at fog layer or edge layer has led to increased carbon footprints, thus they have proposed an online algorithm LOTEC (Lyapunov optimization on time and energy cost). The proposed technique suggested using green power source i.e. solar energy and grid power as a standby power source.

The discussed energy efficiency techniques are summarized in tabular form in Table 7. In this paper, two novel application based energy efficient approaches are proposed. For smart agriculture and Smart Healthcare. Where ''ZTPA'' -a hybrid approach, centered on two techniques ''Sleep/wake up'' and ''Energy efficient routing'' is proposed. E^2AHMS is proposed for smart healthcare, which is a radio based approach. These two approaches with their proposed mathematical approach are discussed in detail in section VIII.

VII. OPEN ISSUES

Ascertaining the vision of the NBIoT is not a tranquil task, owing to multiple challenges that are required to be addressed

TABLE 7. Energy effeciency techniques for IoT.

Technique	Algorithm/ Architecture	Objective	Description	Inference	Ref. No
Sleep/ Wakeup	An architecture for optimized power consumption	To reduce the energy consumption using Wake-up radio architecture	Here author have made use of Wakeup radio transceiver ,together with Address decoder (AD) which doesn't interrupt MCU on false call .Hence overall current drawn is reduced	In the proposed architecture instead of scheduled wake up here triggered Wake-up is done on the basis of address decoder .The AD matches the caller address with the stored address and triggers the wakeup call only if matches .therefore leads to efficient energy consumption	[126]
	IoT Architecture	To ensure the lifespan of 20 year of battery life and continuous monitoring of cultural heritage	To monitor the open archaeological sites authors have used UL power microcontroller & general purpose microprocessor. The microprocessor is switched to on mode only when new packet is received by Radio Unit	Improved lifespan of sensor	[127]
CR	RECRMAC	To provide high throughput with optimized energy consumption	In this technique Channels allocated to PU's is used by SU's during the time they turn off. If PU turn on during that time then SU is given an alternative channel which is selected on the basis of PU's action rate To reduce the communication time and frame is also redesigned	For continuous operation Reliable channel and BCD is allocated thereby reduced wait time and also possible collisions .Hence the energy consumption is reduced and also throughput is increased.	[128]
	Dinkelbach's Hungarian Method& 3D matching IHM-VD	To reduce the energy consumption by optimally allocating resources to the device	In these algorithm to establish multiple links central controller is used which act as data cloud and CP also. Author has divided the resource allocation problem in to two sub problem of efficient power and channel allocation For Energy Efficiency Three cases are considered in case I: To optimize the T_x power of sensor. Case II: T_x power of CC need to be optimized Case III: power of sensor & actuator on allocated channel is to be optimized. An iterative DA and game theory used to calculate the q^i_k Further a channel allocation algorithm is used using 3D matching concept used and finally the IHM-VD for resource allocation	The result shows that if number of channels will be less than number of sensor/devices then channels will be used in share mode whereas if greater then each device gets a dedicated channel	[129]
Routing	DAND Algorithm	To reduce the energy consumption by discovering the neighbour node quickly	In this algorithm neighbour nodes are discovered asynchronously and asymmetrically with least wake up slots using combinatorial block design with multiple of 2. Hence discover the neighbour in fast manner with less energy consumption.	To establish the connectivity in distributed network with different device configuration instead of periodic transmission it discovers the neighbour asynchronously by scheduling the wakeup slots according to different duty cycle using combinatorial block design	[130]
	RNM	To reduce the energy Consumption and latency	This modulation scheme works at physical layer. In this two modes are there in which device can operate i.e. energy efficient or reduced latency mode. Random generated number is compared for avoiding collision	Order of constellation and random bit generation helped in overcoming the latency and together with improved energy efficiency.	[131]
	EECRP	To reduce the energy consumption by optimally selecting the CH	In this algorithm there are three phases in phase BS gets the entire details about all the nodes in the cluster then second phase decide which node has maximum energy will be opted as CH and then the distance of opted CH is compared with Maximum distance from BS and then finally opted node transmitting antenna is opened and all other node receiving antenna is opened	The result shows that network has more alive nodes and thereby increasing network lifetime. The number of packets to be transferred from BS is also reduced. Hence the energy is consumed in an efficient manner	[132]
	NCPCR	To reduce the energy consumption by applying derived network coding gain	The proposed routing protocol make use of linear network coding in which node seeks for the optimal path .To take the decision node compares the energy consumption detail in RREP packet , from neighbouring node to destination. Then forwards the packet through optimal path.	The result shows the energy consumption is reduced due to reduction in number of packets to be transmitted.	[133]
Data Reduction	C-MOSDEN	To reduce the memory and energy consumption	In this Authors have proposed a platform for context aware data collection by sensing only relevant data. Thus reduces the amount of data collected but has made much impact on Energy consumption also	Relevant data collection in IoT network can greatly reduce the memory required, As data is collected here for certain activity only therefore radio usage is also reduced which reduces the energy consumption also.	[134]

Although NBIoT offers significant features for LPWA applications, yet a number of critical issues remain unattended that seeks traction from the research community. The technical issues and challenges related to energy are discussed in this section.

A. NON-UNIFORMITY IN RESOURCES ALLOCATION

In the current scenario, resources are allocated on the basis of total available power, coverage range, and demanded applications. Due to non-uniformity in the requirement of resources, a non-uniformity in power consumption persists. This is a critical challenge that seeks redressal as there are no studies/algorithms/techniques available for uniform resource allocation in NBIoT. A unified platform is required for resource allocation so that applications can be handled adaptively in real time scenarios.

B. DIFFICULTY IN ACHIEVING THE DESIRED THROUGHPUT

The prime advantage of NBIoT enabled device is to make use of low power to operate. Therefore the power of the signal transmitted will be low. Beside this due to channel losses, fading & interference (Intra/Inter) SINR will drop drastically. Hence it would be quite difficult to achieve the desired throughput in all condition. Thus proper channel modeling, optimized algorithms/techniques required to be designed /developed to achieve desired throughput

C. INTER-CHANNEL INTERFERENCE

The allocation of frequency in in-band or standalone mode will not be synchronous among all the cells in the network. This results in interference among neighboring cells. Interference within the same cell also exists due to the deployment of small cells in the macro cell. These result in a fall in the SNR. This is a decisive challenge, especially for critical applications like acute healthcare applications, where noise could tamper biological readings. This may lead to the wrong detection and thereby wrong medication. Thus an efficient scheme is required to be developed to reduce interference and provide QoS to the users.

D. SPECTRAL EFFICIENCY

To achieve extended coverage, the concept of multiple repetitions is utilized. Undoubtedly this would improve the T_x Reliability but will lead to loss of spectral efficiency. Thus an efficient resource allocation scheme is required which could optimally decide the repetition factor. Furthermore, to maintain high channel capacity- device consumes more power, consequently reducing its lifetime. This open issue needs to be addressed because it would adversely affect the battery lifetime

E. LATENCY

Different types of latency can occur during NBIoT communication: a) UL/DL latency, b) synchronization latency, c) the latency associated with resource allocation, d) latency associated with packet synchronization. Though NBIoT applications are delay tolerant, yet latency needs to be kept below 10s, especially for real time applications such as health monitoring. Thus the theoretical computational model must be framed to improve the latency analysis.

F. SYNCHRONIZATION WITH THE ACCESS POINT

Consider a scenario where utility meters are positioned close to each other. When all devices would send information to the cluster head, synchronization will be difficult for the access point as there would be interference between devices within its range. Besides this, other factors like the priority of a device, its residual power availability and channel conditions will also affect the synchronization process, raising its complexity. Hence this open issue needs to be addressed by providing techniques/ algorithms for synchronization.

G. SECURITY

The issue of security is very critical for NBIoT. As low power devices have limited resources, they are more vulnerable to security attacks. By exploiting the data integrity or tracking the traffic pattern, passive or active attack can befall at the perception layer. Besides, other security attacks such as the injection of false data by an intruder, transmission of interference signals, etc. can also occur. Thus continuous efforts must be put in by industry, academicians, and researchers to maintain the faith of users in using the services provided by the NBIoT application.

H. CARBON FOOTPRINT INFLATION

The massive connectivity among millions of devices would generate an enormous amount of data. In order to draw an inference from the collected information, servers need to manage data through extensive computations. This will overburden the servers, resulting in rising in energy and subsequently raising carbon emissions. In addition, the factors such as manufacturing of billions of IoT devices, shipments of these devices, excess use of radio access network, etc. will also elevate the carbon footprint. Fig.18 demonstrates the percentage of carbon emissions due to various such activities [136]. Collaboratively, these will have an adverse impact

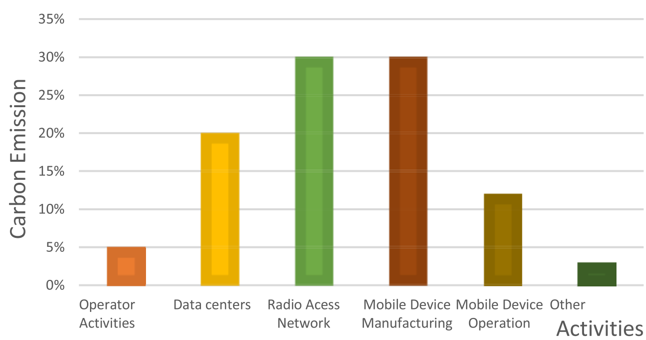

FIGURE 18. Carbon footprint due to various activities.

on pollution levels. Hence, the need for a generic architecture arises to achieve Green IoT, whilst assuring better QoS to all the users.

I. E-WASTE MANAGEMENT

As technology improves, people started procuring additional electronic equipment's like PDA's, desktop computers, smart phones, and gadgets, though might not be required. The complex structure of these e-waste/WEEE (waste electrical and electronic equipment) makes it difficult to destroy. The condition will become even more severe in coming future when millions of sensors and battery operated IoT devices will have to be destroyed and replaced with new ones, either due to reformation in technology or lifetime expiry. Many countries like Japan, Taiwan, and U.S etc. are working on this hot burning issue since 2001. However, together with this research efforts are needed for the development of the green disposable electronic device.

J. CLOUD-RADIO ACCESS NETWORK (C-RAN) OVERHEAD

In C-RAN the virtual centralized BBU (Base Band Unit) is used to reduce the OPEX, generated heat, and latency. Hence, instead of having BBU at each cell site with remote Radio head, they are repositioned in centralized manner in BBU home. In IoT, the users would be monitoring & controlling multiple devices remotely, this would overburden the existing network especially between the RRH and BBU Pool. Moreover, the different types of data i.e. real, non-real, social, sensitive, medical/health data, agriculture related data, etc. would collectively create an extensive overhead for CRAN. Pertaining to this, a huge number of processing units would be required to process the enormous IoT data. This, in turn, generates massive power requirement. Hence "prioritization of data" could be one of the solutions to deal with this open issue.

K. INTERFACE WITH NEXT GENERATION LIKE 5G NETWORK

The journey of IoT from virtual ideology to real time implementation has many milestones to achieve and one of those is interoperability among IoT devices. As we know that 5G operates on the very high frequency range like millimeter waves frequency, ranging from 28 to 32 GHz, whilst IoT devices operate at 2.2 GHz. Thus it's a big challenge for the researchers to interface IoT with 5G Other than this, the high operating frequency in 5G networks escalates power consumption levels to achieve the data rate of the order of Gbps. In contrast to this IoT devices are highly power constrained thus operate at low power levels. This requires technological developments. Including this various other challenges such as [137] Cooperation among millions of devices, Heterogeneous subnet, Anonymous device configuration and Conflicts among semantics of devices exist.

All these will collectively urge for research efforts before 5G specifications are standardized.

L. MIMO/MASSIVE MIMO

Undoubtedly, Multiple Input Multiple Output (MIMO) technique provide a high data rate with high Reliability. In MIMO BS is acquainted with multiple antennas to improve the spectral & energy efficiency. Although, MIMO is an enabler for 5G, yet, it is difficult to employ MIMO in IoT. It is because, in the multi antenna scenario, information transmissions from the sensor nodes will require more processing during the synchronization phase. This results in more power consumption at the sensor end. Since the sensor nodes have limited battery capacity, adaptability of IoT devices in a MIMO environment is an open challenge that needs to be addressed.

M. CHANNEL STATE INFORMATION COLLECTION OVERHEAD

The channel state assessment overhead intensifies linearly with a number of users. If the number of users grows beyond the threshold value then channel block could no longer support the assessment overhead within the narrow coherence time, especially for IoT applications. Moreover, the inaccurate channel estimation results in unreliable transmission. This uncertainty is due to the staleness of information after a certain time gap, due to the collision of pilot signals in UL. Pertaining to this, contention and interference would aggravate. As a result, more retransmissions are required which upraise the power consumption of IoT devices. Moreover, multiple verifications will contribute to more power consumption.

VIII. PROPOSED ARCHITECTURE TOWARDS GREEN COMMUNICATION USING NBIoT

The world population is expected to grow up to 8.025 billion by 2030. Consequently, this growth will inflate the global food demand. Thus meeting the demands of the immense population will be a tough task. The varying climatic conditions, scarcity of water, etc. shall further aggravate the circumstances In addition to this, enhanced health assistance will also be required for projected population, which will be quite difficult to handle using existing infrastructure and services. Thus integration of IoT with Agriculture & Health sector can ensure a resourceful and healthy life for an individual. Despite, all this revolution that IoT is capable to bring in, the biggest stumbling block of its success is to provide energy efficient solution. As most of the IoT devices are constrained in term of energy. Hence this paper is proposing energy efficiency techniques for two prime applications: Smart Agriculture: ***Zonal Thermal Pattern Analysis*** and Smart Health: **Energy Efficiency Adaptive Health Monitoring System.**NBIoT is used for both the application as it offers favorable features like extended coverage with deep indoor penetration, long battery life, supports high density, require the low-cost device, and provide end to end security. Moreover, it would not require the deployment of new infrastructure as compared to proprietary technologies LoRa and SigFox, hence would offer a cost effective solution.

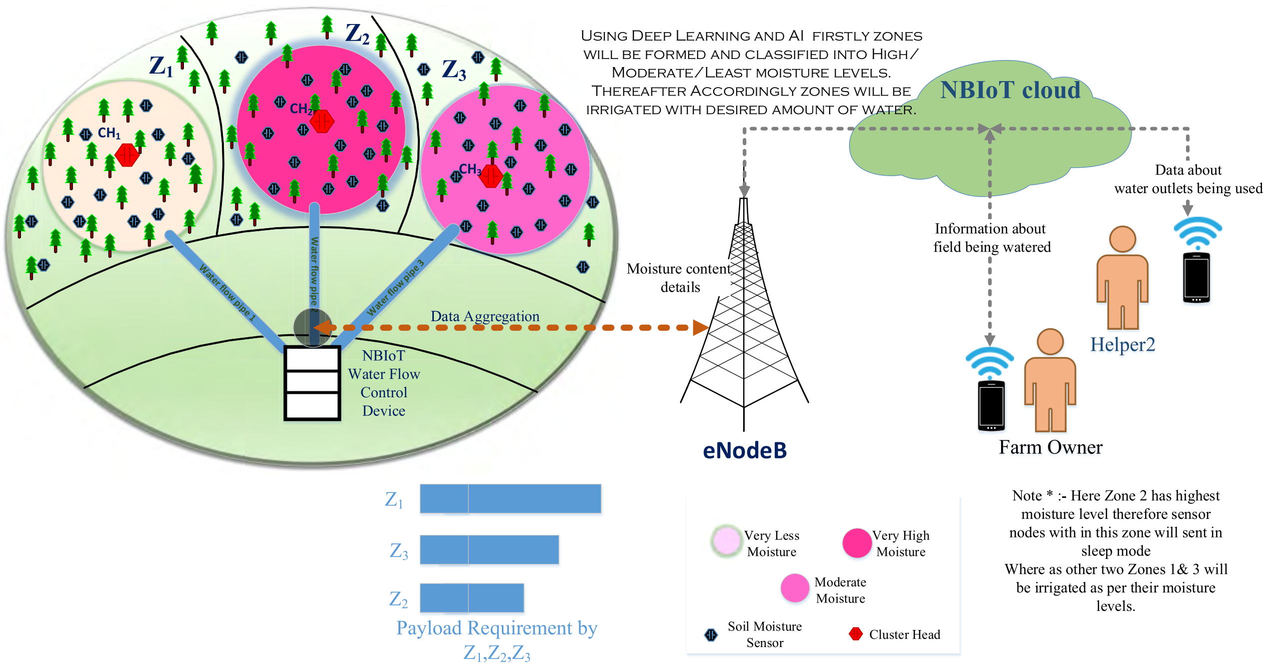

FIGURE 19. **Proposed architecture for energy efficient precision agriculture using NBIoT –toward green communication.**

A. PROPOSED TECHNIQUE FOR SMART AGRICULTURE: ZTPA

1) CASE STUDY 1: ENERGY EFFICIENT AGRICULTURE MONITORING, IRRIGATION SYSTEM FOR GREEN COMMUNICATION

The growing population and climate vagaries are forestalling that in future decades water resources would reduce eminently, especially for agriculture. Since agriculture practices require an ample amount of water, effective utilization of water is an obvious issue to be addressed. This section investigates an energy efficient technique for productive utilization of water. It has been put forth to overcome the disadvantages of conventional irrigation systems like wastage of water (due to percolation, evaporation), abbreviated crop yield. To economize the use of water in agriculture, IoT with Deep Learning could play a significant role. In the proposed scenario, soil moisture sensors are deployed in the farm field under consideration. Thereafter data aggregated from multiple sensors will be passed on to the BS using NBIoT and then to the NBIoT cloud. At the cloud, data (moisture) will be processed using Deep Learning and subsequently, the farm field will be adaptively divided into zones based on moisture level, as shown in Fig.19 (for one iteration which is subjected to change in other iterations). Hereafter depending on the moisture levels i.e. moderate moisture level, high moisture level and least moisture level, zones will be irrigated. To accomplish this, the water pump is attached with smart NBIoT enabled water control device. This device would transmit the water in desired quantity and for the desired time in the zones. This scenario could be well understood by Fig. 19 where zone Z_2 with dark pink color has the highest moisture, Z_1 has the least moisture and Z_3 has moderate moisture level. As Z_2 has good moisture level so no water would be transmitted in that zone. Hence, sensor nodes in Z_2 will enter idle state followed by the sleep state for a long period of time by exploiting eDRX in NBIoT. This will save water along with energy. In addition to this UL traffic will also be reduced, thereby reducing the congestion impact also.

There is another aspect to be considered while designing this scenario i.e. land orientation. Hence this use case study is divided into two sub problems:

a: UNIFORM LAND SURFACE

When land has uniform orientation like in the plain area, there will be no water logging problem. Therefore, farm/agriculture land can be irrigated by classifying the moisture data as discussed previously. Thus watering of the field by the proposed pioneered way could avoid the wastage of water. Also in the plain area, the orientation of land is more or less uniform, thus the pattern of power consumption would not be much diverse. This can be depicted by thermal pattern analysis using drones and satellite captured thermal images.

b: NON-UNIFORM LAND SURFACE

Another case is when agriculture land has non-uniform orientation like in hilly areas, which leads to the uneven power consumption of devices. As in some case, eNB will allocate the resource to the sensor via NBIoT using direct path whereas in some cases using an indirect path. In our proposed approach we have not only considered direct/indirect resource allocation but in addition to this, the overlap condition will also be considered, where one region overlaps with another region.

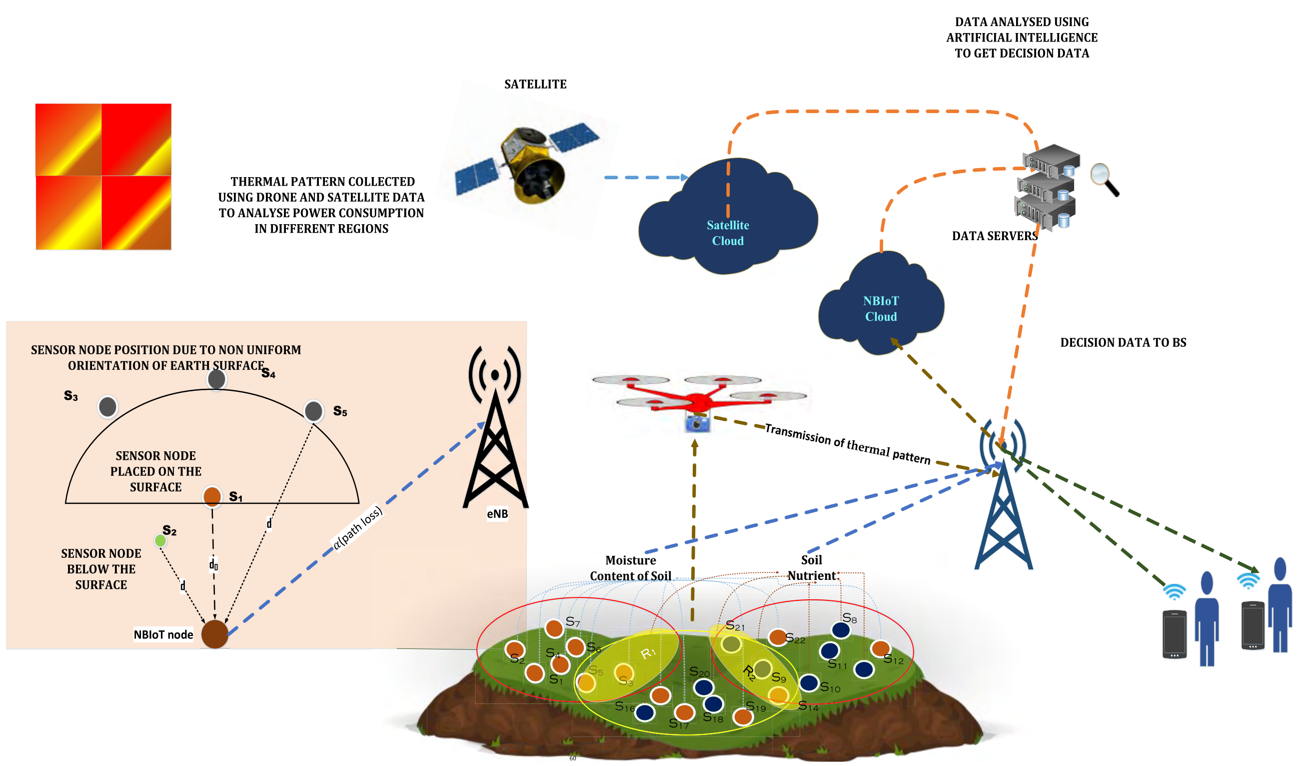

FIGURE 20. **Proposed architecture for energy efficient precision agriculture using NBIoT based on thermal pattern analysis (TPA).**

As shown in Fig.20 regions R_1 and R_2, describes the overlap region. Here the sensor S_3, S_5, S_9, S_{21}, S_{14} suffers from Inter-Interference.

Hence the power consumption pattern will be diverse for node present in this region and node present outside of this region which in turn would affect the network lifetime. In addition to this SNR will also get influenced by interference within inter-interference region.

2) MATHEMATICAL ANALYSIS FOR ENERGY EFFICIENT SMART AGRICULTURE

Sensor nodes $SN_1, SN_2, SN_3, \ldots\ldots, SN_n$ are deployed in the field and as per proposed model, it is assumed CH of disjoint sets of sensors (CH_1, CH_2, and CH3) will communicate with the processing unit (PU). Further, this PU would communicate with BS. Assume that using NBIoT technology k PRB's (physical resource blocks) are required. As the signal propagates from SN_i to NBIoT node path loss (PL) will occur. PL will depend on the position of sensor.

If the sensor is placed under the soil or underground, then soil would absorb the signal and hence leads to path loss which can be evaluated as follows

$$P_C^* = P_C^{real} - j(P^{dipolarloss} + \frac{\sigma}{2\pi f P_D}) \tag{3}$$

Here P_C^* specifies the complex-permittivity (cp),P_C^{real} denotes the real part of cp, $P^{dipolarloss}$ is due to Relaxation and P_D specifies the relative dielectric-permittivity [138], [139].

The permittivity of soil can be affected importantly by parameters like water content, frequency of signal, soil composition and soil conductivity. Hence it is difficult to measure the soil permittivity accurately.

Path loss can be calculated using equation (4) where T_p is Transmission power, T_g Transmission gain, R_g receiver gain,PL_{fs} is path loss due to free space propagation of signal and PL_M is path loss due to medium, α is path loss between NBIoT node and eNB.[1]

$$PL = T_p + T_g + R_g + PL_{fs} - PL_M + \alpha \tag{4}$$

Further path loss due to medium can be evaluated as follows [139]

$$PL_M = WD_s + TL_s \tag{5}$$

Where WD_s is path loss due to difference in wavelength of signal in soil in comparison of free space and TL_s is transmission loss.

If the sensor is placed above the surface (of ground), then plants would act as scatterers and thereby the path loss can be evaluated using equation (6)

$$PL\,(d) = PL\,(d_0) + 10m log\left(\frac{d}{d_0}\right) + OH_{T_i} + \alpha \tag{6}$$

Here OH_{T_i} represent the obstacle height at time $i\varepsilon\{1, 2, 3\}$, where i =1 specifies the phase, when seeds are just

[1] $\alpha*$ depends on the channel conditions between eNB and NBIoT. For power optimized NBIoT it will be standardized in release 16 or later.

sawn, so no plant would be there at that time so no obstacle. Likewise for i =2, specifies that plant has started budding up so it will have certain height. Similarly for i =3 specifies, plant has fully grown to its full height. Thus corresponding to height of plant, obstacle path loss parameter would increase. Here d_0 specifies the reference distance between sensing node and NBIoT node (Refer Fig. 20.). Here α specifies the path loss between NBIoT node and eNB.

Hence the SINR of the sensing node can be expressed as

$$SINR = \frac{S_T G_k}{N + I_T} \tag{7}$$

Where N is thermal noise, I_T total interference,S_T represents the transmitted signal power and G_k is the channel gain between sensor node k and $NBIoT\ node$.

We then express the total interference as

$$I_T = I_{interzone} + I_{intrazone} + I_{Soilreflectivity} \tag{8}$$

Interference that occurs within zone, between zones and also due to soil reflectivity.

Further channel capacity (C) can be evaluated based on Shannon theorem as follows

$$C = Blog_2(1 + \frac{S_k G_k}{N + I_T}) \tag{9}$$

Based on these above formulations we conclude that capacity of a sensor deployed in the agricultural area will be adversely affected by the interference generated by the adjacent sensor nodes, scatterers, etc.

a: ENERGY CONSUMPTION EVALUATION

For electing cluster head out of n sensor node for each disjoint set of sensing nodes. Each node power level is to be determined and one with highest power level is selected. Power level get deteriorates due to energy dissipation. Hence we first evaluate the total energy consumed due to various factors for each node (The energy model used here is given [140].)

$$EC_{Total} = EC_{Sensing} + EC_{Processing} + EC_{Transmission} + EC_{Sleeping} + EC_{Switching} \tag{10}$$

Where energy consumption during sensing could be evaluated using equation (11)

$$EC_{Sensing} = EC_{Sample} * n \tag{11}$$

Here EC_{Sample} specifies the energy consumption during sampling of each sample, n represents the no of samples.

Similarly, energy consumption during transmission ($EC_{Transmission}$) depends on supply voltage S_v, current I and time T required for transmission

$$EC_{Transmission} = S_v * I * T \tag{12}$$

Energy consumed during switching from active to sleep state [141]

$$EC_{Switching} = T_{Swt} * \left(PC_{Active} + PC_{Sleep}\right)/2 \tag{13}$$

Hence total energy consumption can be evaluated (using eq. 10) and using Relation E= P∗T, power levels can be evaluated for each node, where T will include time for switching, sleeping, active, sensing, and processing. Hence CH can be selected for by comparing the power of all the nodes. Here another aspect must also be included that is if the node has acted as CH earlier also then. Hence we evaluate the energy consumption when node act as CH, (EC_{CH}). This will depend on length of message L_{MSG} and energy consumed by transmitter if sending the message to processing point (PP) or energy consumed when receiver receives data by PP [142].

$$EC_{CH} = L_{MSG} * EC_{TX/RX} * D_{PP} \tag{14}$$

Hence total energy consumption equation if node acted as CH could be rewritten as

$$EC_{Total} = EC_{Sensing} + EC_{Processing} + EC_{Transmission} + EC_{Sleeping} + EC_{Switching} + EC_{CH} \tag{15}$$

Finally energy efficiency EE can be evaluated as ratio of total energy consumed , EC_{TOTAL} and energy of sensor at time of deployment , E_{TOTAL}

$$EE = EC_{TOTAL}/E_{TOTAL} \tag{16}$$

Hence using the proposed approach energy efficiency can be improved as EC_{TOTAL} will be reduced by exploiting the eDRX of sensing nodes.

B. PROPOSED TECHNIQUE FOR SMART HEALTH: E^{2}AHMS

1) CASE STUDY: ENERGY EFFICIENT HEALTH MONITORING SYSTEM FOR GREEN COMMUNICATION

IoT provides a big platform to solve medical issues, in real time scenario. Integration of IoT with Wireless Body Area Network (WBAN) is gaining much of the momentum and currently being used for health monitoring of soldiers at battlefields, patients in hospitals, elderly people who could not visit hospitals very often, etc. The performance of WBAN (i.e. reliability, delay, power efficiency) chiefly depends on the physical and medium access control layer. Moreover, as most of the IoT-BAN devices are battery operated, thus power optimization will greatly impact their lifetime and performance. In this context, this paper is proposing a novel approach namely "Energy Efficient Adaptive Health Monitoring System" E^{2}AHMS. This approach will work in an energy efficient manner by adaptively distributing the transmission power required to monitor the patient. In our proposed Health Monitoring system three prospective conditions have been considered Stable, Mono-Stable, Relatively mobile (Fig. 21).

Case B.1: Stable: When a patient lying on the bed i.e. stationary condition

Case B.2: Mono-Stable: When a patient is sitting or standing.

Case B.3: Relatively mobile: When a patient will be moving either by walking or using a wheelchair.

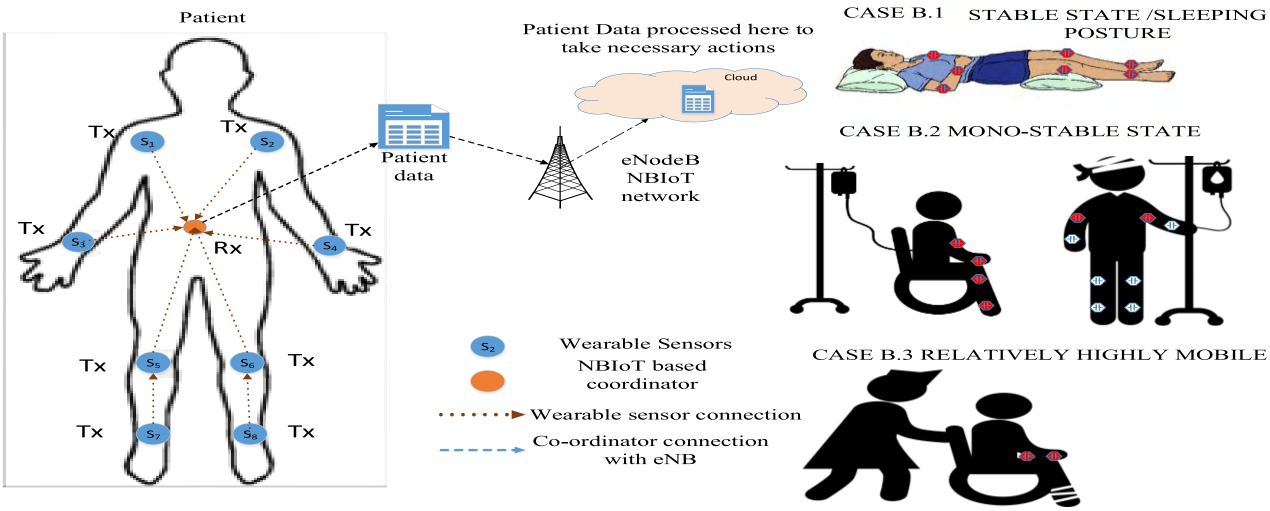

FIGURE 21. Proposed health monitoring system using NBIoT–toward green communication.

Our proposed approach E^2AHMS can not only be used for patients who require continuous monitoring, but also for health monitoring of person who are fit but wants to keep track of their health to prevent themselves from severe disease. As in both the cases, network life time will play a vital role, which can be increased or improved by using proposed optimized energy efficient algorithm.

E^2AHMS will work in an energy efficient manner by adaptively using the transmission, power required during different postural mobility (considered before). To understand this it is required to first understand the difference in energy requirement during different cases under consideration.

CASE B.1 (STABLE): While sleeping it is very likely that the sensors will have LOS communication. Hence, Body Area Network will be in stable state. Thus power required for transmission would be least and hence energy required. As path loss would be minimum between sensing nodes and NBIoT coordinator node. Thus energy consumed during sleeping state $E_i^{c\_s\_st}$ can be given by summation of energy consumption due to factors such as: due to switching from one state to another (On, Off, sleep, idle, Active, idle) $E_i^{st\_tr}$, due to circuit of sensing device E_i^{Crkt}, energy consumption due to processing of signals E_i^{Proc}, energy consumption due to transmission of signal E_i^{Trans}, due to acting as relay/connecting node for other sensors $E_i^{connecting\_node}$ and due to various delays (queuing, propagation, transmission) E_i^{Delays}.

$$E_i^{c\_s\_st} = E_i^{st\_tr} + E_i^{Crkt} + E_i^{Proc} + E_i^{Trans} + E_i^{connecting\_node} + E_i^{Delays} \quad (17)$$

CASE B.2 (MONO-STABLE STATE): In this case the patient could be in a sitting posture or moving his arms or having food. Hence LOS would not be there between sensing nodes. It is very likely that obstacles might interfere with the path of signal transmission thus shadowing would lead to multipath loss and hence energy consumption will be more during this posture.

Energy consumption during mono-stable state $E_i^{c\_ms\_st}$, can be evaluated by equation (18)

$$E_i^{c\_ms\_st} = E_i^{st\_tr} + E_i^{Crkt} + E_i^{Proc} + E_i^{Trans} + E_i^{connecting\_node} + E_i^{Delays} + E_i^{obst} \quad (18)$$

Here E_i^{obst} specifies the energy consumed due to obstacles/ shadowing /multipath effect.

CASE B.3 (RELATIVELY MOBILE): In this state, the patient will be walking or moving with the help of wheel chair or might be doing some routine activities. Therefore it is more likely that NLOS transmission will occur due to various reasons such as obstacles in the surrounding, links between sensors would change rapidly due to body movement, etc. Hence more loss of information and thereby more energy consumption. Energy consumption during mobile state could be given by equation 19.

$$E_i^{c\_m\_st} = E_i^{st\_tr} + E_i^{Crkt} + E_i^{Proc} + E_i^{Trans} + E_i^{connectin\_node} + E_i^{Delays} + n.E_i^{obst} + E_i^{relink} \quad (19)$$

Here E_i^{relink} denotes the energy consumed due to Relinking between sensor nodes and gateway.

Thus, it is clear from the above discussion that due to multipath effect and different channel conditions, different postural movement leads to different energy consumption. Therefore in proposed technique E^2AHMS, depending on postural movement level transmission power will be used adaptively which can be determined using graph theory. Whereas conventionally data was transmitted with equal power without considering LOS communication is possible or not and also channel conditions are good or not. Hence our proposed approach will be an energy efficient approach for Health monitoring application. This proposed approach is also supported by mathematical formulation.

2) MATHEMATICAL FORMULATION

Multiple sensors are positioned on the human body

$$\mathrm{I}=\{i1,\ i2,\ i3\ldots,\ in\} \tag{20}$$

Here each sensor has a coordinate point

$$i1=(\mathrm{x}_1,\mathrm{y}_1) \tag{21.1}$$

$$i2=(\mathrm{x}_2,\mathrm{y}_2) \tag{21.2}$$

Path Loss Analysis As the signal propagates through WBAN this gets attenuated due to multiple factors such as reflection, diffraction, refraction, fading, etc.

To analyze path loss in on-body WBAN, IEEE P802.15, 2009 [143] has given a path loss model.

Using the same as a reference, path loss can be evaluated during different postural mobility.

Case B.1 (Stable/ Sleeping State):

$$PL_{dB}=PL_{d_0}+10n\log_{10}d/d_0+S^{dB} \tag{22}$$

Here d_0 is reference the distance from NBIoT coordinator. S^{dB}, is shadowing factor added to it due to movement of body parts. However, in the sleeping state, it would be negligible.

Case B.2 (Mono-Stable/Sitting State):

During this state, signal could fade due to various obstacle such as table while having food/medicine, legs under the chair or below the table. Moreover due to the movement of body parts effect of shadowing would be high. Hence path loss would be more in comparison to the sleeping state.

$$PL_{dB}=PL_{d_0}+10n\log_{10}d/d_0+(S^{dB}+F_1+F_2) \tag{23}$$

Here F_1+F_2, is addition PL due to factors such as obstacles, interference, surroundings

Case B.3 (Mobile State):

During this state person would be moving from one place to another thus link with access point could change very quickly (From one floor to another, one room to another, walking, etc.). The signal would attenuate n times more in relative mobile state than Sitting/Mono-Stable state.

$$PL_{dB}=PL_{d_0}+10n\log_{10}d/d_0+n(S^{dB}+F_1+F_2+F_3) \tag{24}$$

Here F_3 specifies an additional factor of multipath propagation of signal.

As PL is difference of transmitted power and received power

$$PL=P_{Tx}-P_{RX} \tag{25}$$

Thus received power during different case studies can be evaluated as follows:

Case B.1:

$$P_{Rx}^{S\_ST}\ (dB)=P_{Tx}-PL_{dB}^{S\_ST} \tag{26.1}$$

Case B.2:

$$P_{Rx}^{MS\_ST}\ (dB)=P_{Tx}-PL_{dB}^{MS\_ST} \tag{26.2}$$

Case B.3:

$$P_{Rx}^{M\_ST}\ (dB)=P_{Tx}-PL_{dB}^{M\_ST} \tag{26.3}$$

In the conventional system, same transmission power is used for all the cases whether required or not, but in the proposed technique E^{2}AHMS transmission power would be used adaptively depending on postural mobility. Hence power will be used in an optimized way.

SNR can be evaluated for different considered case studies using received power

$$SNR_{case_i}=\frac{RecivedSignal\_powerP_{Rx}^{case_i}}{Noise\_Power} \tag{27}$$

Thereby channel capacity (C_{case_i}) for considered cases {i=B.1, B.2, B.3} using Shannon theorem could be evaluated for considered case studies as

$$C_{case_i}=B(1+SNR_{case_i}) \tag{28}$$

Hence Energy efficiency can be evaluated using equation

$$EE_{case_i}=\frac{Channel_{case_i}}{P_{Tx}^{case_i}}*100\% \tag{29}$$

It is clear from the above equation the high mobility would result in more energy consumption. Hence using the proposed technique power will be saved and thereby could enhance the battery lifetime. Thus an energy efficient solution.

Using the same theme of the proposed approach real time hardware implementation is done which is discussed in next section.

C. REAL TIME HARDWARE IMPLEMENTATION FOR PROPOSED WORK

1) HARDWARE SYSTEM MODEL

Fig.22 gives an overview of proposed approach real time implementation. Here two axis accelerometer sensors and a pulse sensor is used for real time analysis. To determine the patient postural mobility accelerometer sensors are placed on his right hand and right leg. Apart from this a pulse sensor is used to measure the pulse rate of the patient. Further, in order to send the health information to eNB in energy efficient way. Our proposed approach will differentiate between different postural (Fig. 22 (a), (b), (c), (d), (e)) using edge computing. Such that energy is utilized in an efficiently way by using an optimal amount of transmission power of device as suggested in proposed approach to transmit information to eNB. Hereafter the health information is forwarded to the centralized cloud and then to application server and finally to doctor, who tracks the record of patient, to avoid unwanted situation. Finally, doctor would prescribe some medicine if required otherwise the message will be sent to user that he is fine.

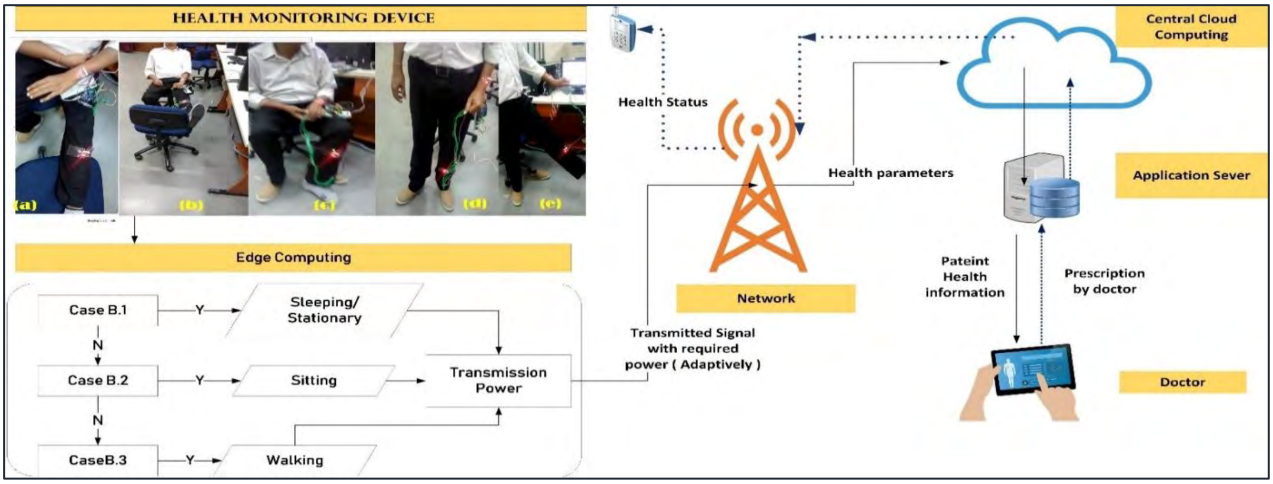

FIGURE 22. Real time health monitoring system model.

2) HARDWARE REQUIREMENT

TABLE 8. Hardware requirement for real time implementatio N of ^{E2}AHMS.

S.No	Hardware	Quantity used	Use
1.	Arduino Uno board	1	Interface
2.	NBIoT Shield	1	To transfer the health parameter to eNB
3.	Accelerometer axis sensor	2	To monitor the mobility of patient
4.	Pulse sensor	1	To measure the pulse of patient
5.	Bread Board	1	To connect all the sensors to Arduino board
6.	Jumper wires	15	Used for connection
7.	Power adapter	1	As power source for Arduino Uno
8.	Data cable	1	To send the information to system for further analysis
9.	Development system with Arduino-IDE	1	Provides an integrated development environment.

3) INTERFACE

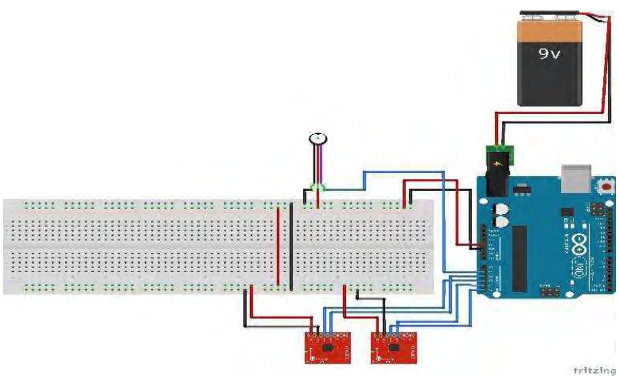

FIGURE 23. Interface of real time health monitoring setup.

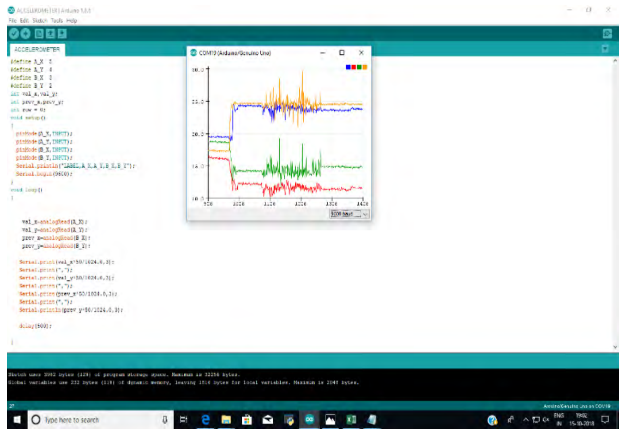

FIGURE 24. Screenshot of plot with arduino IDE.

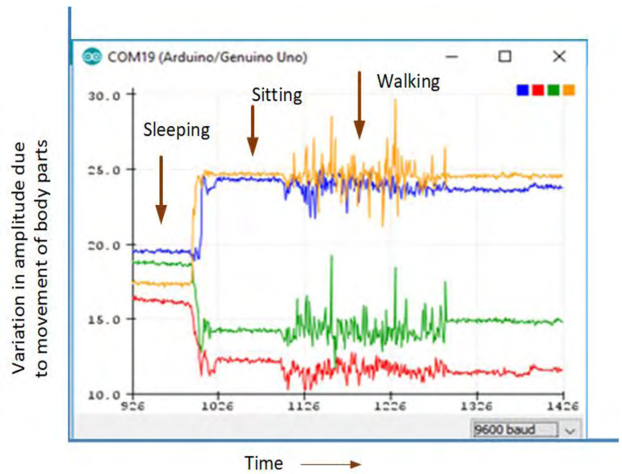

FIGURE 25. A Plot of variation in amplitude vs Time corresponding to Hand and foot movement during different postural mobility, to differentiate between transmission-power to be used (Here blue and Red depicts hand movement whereas Green and orange depicts the leg movement).

4) IMPLEMENTATION

The first step is to setup the connections of all the desired sensors with Arduino Uno. Thereafter the Arduino Uno is connected to development system that has integrated development environment (IDE) with USB. Once the setup is done the code developed for considered case (stable, mono

TABLE 9. Ongoing IOT projects.

S.No	Project Name	Aim of Research	Area of Research	Http Location
1	NMCG	To rejuvenate ganga water, cleanliness and resource conservation.	To control pollution in water bodies	http://theiet.in/The_IET_India_IoT_Panel_consults_with_the_National_Mission_For_Clean_Ganga
2	Photon-recycling for high-efficiency energy harvesting in GaAs photovoltaic devices on silicon	To develop highly-efficient ,cheap GaAs photovoltaic energy harvesters	To harvest energy in photovoltaic devices	http://www.biddetail.com/projects-information/plc
3	High Performance Computing (HPC)	To develop an algorithms to address the Exascale challenges presented by heterogeneous architectures; To achieve scalability and energy efficiency while executing multiscale applications	Computing patterns for HPC	http://www.compat-project.eu/
4	16018 COMPACT	To develop solution for the application based and customer centered realization of very-small IoT nodes with low power consumption.	Software Synthesis	https://itea3.org/project/compact.html
5	SWING	To develop a economical connected power continuity system suitable to implement Industry 4.0	Power availability in Industry 4.0	http://www.adelsystem.com/en/news/horizon-2020/
6	AUTOPILOT	To develop platform for Vehicular IoT for automatic car driving	Smart Vehicle Automation	http://autopilot-project.eu/
7	IoTEE	To provide economical solution for using IoT over entire earth	Cost effective solution in IoT ecosystem	http://www.sat4m2m.com/iotee-ec-smei-phase-2-grant-award/
8	Server Chill	To do the power cooling at server side	Server cooling due to IoT	http://www.fabiodisconzi.com/open-h2020/projects/211143/index.html
9	HEART	To determine the health related activity	Health monitoring	http://heart-itn.eu/
10	ELLIOT	To get wireless connectivity over SSL	Energy saving in IoT	http://www.fabiodisconzi.com/open-h2020/projects/211113/index.html
11	SecIoT	To provide economical & secure solution for IoT	Security in IoT	https://www.openaire.eu/search/project?projectId=corda__h2020::1061a11bd254a4d7d7bf0f99509f6ecd
12	U4IoT	To assist (Large Scale Pilots)LSPs to increase the level of end-user	Pilot scaling	https://u4iot.eu/
13	TREND	To do energy harvesting using Nano wire devices	Energy harvesting in IoT	https://www.openaire.eu/search/project?projectId=corda__h2020::8fce9875518f74c852a35695df46c736
14	ULPIoT	Reconfiguration of IC's of analog block in digital term for scalability	Analog Block	http://www.fabiodisconzi.com/open-h2020/projects/206710/index.html
15	InnoSpace	To design an efficient ultra-high speed fibre, to enhance user connection speed to the Internet and catering short needs of IoT	Multiplexing Technique	https://www.upv.es/noticias-upv/noticia-8612-innospace-es.html
16	REMINDER	To develop a DRAM based low power solution for embedded devices	Power Consumption	http://www.reminder2020.eu/#m-04-2018
17	SENSEI	To develop a low power computation platform and using deep neural network provide useful information	Energy Efficiency	http://www.researchers.polito.it/en/success_stories/progetti_metti_in_rete/smart_sensors_for_the_internet_of_things

stable and walking) is uploaded to Arduino Uno. Hereafter the data is collected related to different postural mobility of person and processed by comparing against the threshold value to determine the postural mobility level. Fig.24, shows the plot of variation in amplitude due to movement of hand and leg (specifically) in developed code. Once the movement is determined thereafter the health information like pulse rate, etc. is sent via NBIoT with required transmitted power to eNB. Hereafter the health information is processed and corresponding actions are than advised to the patients.

5) PERFORMANCE ANALYSIS

As per our proposed architecture, we have done the performance analysis on the basis of a real-time hardware implementation for healthcare monitoring system with all possible case studies. We have deployed sensors on body parts of patients to fetch the information regarding postural mobility as shown in Fig 22. (a), (b), (c), (d), (e). All the data regarding different postural movements saved in the database, which is then processed and compared at the same time. The postural movement is observed for 500 sec from 926sec to 1426 sec (Fig 25 describes the variation of amplitude due to different postural movement.)

Approximately for 94 sec the person has kept his body in sleeping condition as shown in Fig.22 (a),(b), it has been observed that during this period, a variation of the different sensor output is low and smooth, output amplitude is far below as compared to a threshold value. Hereafter the person changed his posture to sitting posture Fig.22(c) and maintained it for 80 sec. For this posture, it was observed that variation is high in comparison to sleeping posture, but get stable after a certain time. Hereafter person changed his posture from sitting to standing (Fig. 22(d), (e)) and did some movement of hand and leg. It can be easily seen that variation is high and fluctuating, some irregular spikes appeared in the process.

On the basis of performance analysis, we have observed that power optimization in all these case studies is very important and because this real time analysis aligns with our proposed approach E^2AHMS. Hence power can be optimized with fair resource allocation to achieve the better quality of service is possible through our proposed approach.

CONCLUSION

IoT is reforming technical industry. This reformation will aid in struggling with global challenges that are budding due to depletion of natural resources, inflated food demand, scarcity of water, etc. Where on one hand IoT is giving hope for resourceful life but on other hand, it will play a crucial role in inflating carbon footprint. Hence solutions must be given to reduce carbon emission. In this study recent work related to energy efficiency techniques has been surveyed and discussed. In contribution toward green-IoT, two novel energy efficient approaches have been proposed - ZTPA for smart agriculture and E^2AHMS for smart healthcare using NBIoT. NBIoT is a new licensed radio technology that guarantees to provide a cost effective, reliable, and low power solution. It can coexist with the existing LTE cellular networks therefore no new infrastructure is required to be setup from scratch, hence installation cost is low. This paper provides a detailed technical view of NBIoT and its state-of-the-art. To spur advance research and speed up the extensive use of the NBIoT systems the research challenges and open issues of NBIoT are also discussed.

APPENDIX

A list of current research projects based on IoT is presented in table 9 In addition to this, an abbreviation list is given in table 10.

TABLE 10. Abbrevation list.

S.No	Abbreviation	Meaning
	3GPP	3rd Generation Partnership Projects
1.	ANN	Artificial neural network
2.	ARP	Access Reservation Protocol
3.	BLE	Bluetooth Energy
4.	CH	Cluster Head
5.	CN	Convolutional Network
6.	CNN	Convolutional neural network
7.	C-RAN	Cloud Radio Access Network
8.	CSI	Channel State Information
9.	D2D	Device To Device
10.	EC-GSM	Extended Coverage GSM
11.	edRx	Extended Discontinuous Reception
12.	eMTC	Enhanced Machine Type Communication
13.	EVDO	Evolution Data Optimized
14.	FDMA	Frequency Division Multiplexing Technique
15.	GSM	Global System for mobile communication
16.	HetNet	Heterogeneous Network
17.	IERC	International Energy Research Center
18.	IMT-A	International Mobile Telecommunication Advance
19.	IoT	Internet Of Things
20.	ITU	International Telecommunication Union
21.	LTE	Long Term Evolution
22.	M2M	Mobile To Mobile
23.	PSM	Power Saving Mode
24.	QAM	Quadrature Amplitude Modulation
25.	QoS	Quality Of Service
26.	RSSI	Received signal strength indication
27.	TTI	Transmission Time Interval
28.	T_x	Transmission
29.	ZTPA	Zonal Thermal Pattern Analysis
30.	E^2AHMS	Energy Effecienct Adaptive Health Monitoring System

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