NIPES Journal of Science and Technology Research 3(3) 2021 pp. 162-172 pISSN-2682-5821, eISSN-2682-5821

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

State of Internet of Things (IoT) Network and Rising Issues: A Review

Udo, E. U[*a], Iroh, C. U[*a], Nwaorgu, O. A[*a], Okey, D. O[b]

[*a]*Department of Electrical/Electronic Engineering, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria.*
thought.umoren@gmail.com , irohcu@gmail.com and nwaorguokeze@yahoo.com
[b]*Department of Systems Engineering and Automation, Universidade Federal de Lavras, Minas Gerais, Lavras, Brazil.*
ogobuchi.okey@estudante.ufla.br

Article Info

Received 05 August 2021
Revised 13 August 2021
Accepted 19 August 2021
Available online 31 August 2021

***Keywords**:*
Internet of Things, Heterogeneity, Heterogeneous Networks, Wireless Communication

https://doi.org/10.37933/nipes/3.3.2021.16

https://nipesjournals.org.ng

Abstract

This paper presents a review on the state of Internet of Things in heterogeneous networks. Internet of Things is one of the top notch practices in wireless communication nowadays. It has connections of devices in billions linked to the internet through different technologies and communication standards. There are several challenges that can occur which leads to undesired kind of service if not properly managed and then its short fall in spectrum resources will be an obstruction for future IoT development. Heterogeneity is one of the major challenges posing complexity to the practices of IoT and due to different technologies with varying service requirements lead to its emergence. In view of that, several measures have been taken to check the effects and accommodate the surge in IoT. This paper reviewed Internet of Things in a holistic way, discussed shortcomings, standards tools, challenges, advantages and disadvantages that when practiced in heterogeneous networks will help in averting most of the hitches experienced. We believed that the outlined steps and measures of this research work will serve as a great insight to researchers and will provide lasting solution to issues of the network.

1. Introduction

Evolution of internet began by connecting computers and later many computers were connected together which created World Wide Web. Then mobile devices were able to connect to the internet which leads to mobile-internet technique and people started using the internet via social networks. Finally the idea of connecting daily objects to the internet was proposed, which lead to the Internet of Things technology [1]. The advances in wireless communication have given rise to a new advent known as internet of things (IoT) and it presents a network densely populated with devices such as phones, Wireless Access Points (WAPs), sensors and other machines which are used in communication. This population of devices are connected to the internet using various cellular technologies like 2G, 3G, 4G, LTE, 5G and even machine to machine techniques of various radio options [2].

IoT creates a world where all the objects (also called smart objects) around us are connected to the internet and communicate with each other with minimum human intervention. The ultimate goal is to create a better world for human beings where objects around us know what we like, what we want, what we need and act accordingly without explicit instructions [3].

Internet of Things, since its emergence has made a major impact in the present market and still wish to do more, an estimation of 50 billion devices was expected to be connected to network of IoT. This increase the span of IoT and gives rise to research in this field of technology. It supports devices to execute diverse task, utilize cloud for storage and ensure immediate response under emergency situation with the existing internet as its underlying technology. IoT also enhances the already existing devices to function smarter by introduction of technologies such as artificial intelligence, embedded devices, communication standards and technologies, application services and several internet standard [4].

These technologies involved are sophisticated and require dynamic measures that will always enable communication among them stay uninterrupted. Internet of Things relies on several factors such as optimization, architecture, protocol, security aspect and other services associated to discrete application types to give efficient and reliable communication [5]. Data sent over IoT network consist of several heterogeneous devices sent to end users on demand or proactive form and transmission of data in IoT also experience network challenges like congestion and scalability issues, reduced storage capability and energy constrain. For trafficking in IoT to be efficiently done, it has to be in decentralized manner so as to enable individual nodes exchange information with ease and as well as schedule the traffic based on data rate from each source in order to avoid challenges [6].

As we envisage a continued rise in this technology, recent trends on IoT known as internet of future which would consist of more devices through technologies which have similar behaviour but do not share similar spectrum such as LTE, IEEE 802.11 and technologies which do not have similar behaviour but share same spectrum such as IEEE 802.11 and Bluetooth [7].

2. Internet of things state of art and technologies

Internet of Things networks are viable because of their ability to support heterogeneity and managing Internet of Things heterogeneity is becoming more challenging issues that keep rising as devices incorporated expand on daily basis. These occur as result of various technologies supported which are unique in capacity, range, power consumption and these diversifications have led to various issues as stated as follows:

Less multipath routing support across technology. For each of the technology involved in heterogeneous network, packet forwarding and receiving are done individually and thereby excluding load balancing and packet duplication.

No vertical handover of traffic flows across techniques when compared with horizontal handover, instead connections drops until upper layer switches to another technology and this act uses up seconds which is wasteful in practice.

There is no spectrum cooperation among technologies involved. This has a severe effect on performance and throughput. It also increases latency shortage in spectrum resource utilization, though techniques like Cognitive Radio Technology (CRT) exists which supports dynamic sharing of spectrum and its acceptance and deployment by various industries are still difficult to achieve [8].

Poor management among the technologies involved. This encourages all these shortcoming experienced in all kind of heterogeneous network. A typical scenario is where different high end devices like smart TV and smart phones compete for the bandwidth such as Ethernet, IEEE 802.11 and Bluetooth.

With the introduction of LTE-U and LTE – LAA, internet has shifted to LTE and IEEE 802.11. The most commonly used innovations for high throughput in the unlicensed spectrum shows that several works have been done in [9]. The authors indicated that frequency separation required between the technologies is the virtualization of the time domain. This was achieved by proposing two throughput optimization one for each of them and then combined with scheduling algorithm that assigns different slots ratios. The coexistence between LTE and IEEE 802.11 utilized quality of service parameter by considering user association and resource allocation as a singular problem but by adjusting power allocation, transmission time and subcarrier assignment for LTE, fairness can be kept for IEEE 802.11 users [10].

This coexistence was extended to the 5GHz spectrum by introducing Radar Dedicated Short Range Communication (DSRC) and Vehicle-To-Everything (V2X), especially Cellular – V2X (C-V2X) indicating that coexistence problems exists outside of the focus of LTE and IEEE 802.11 technologies. Another very important innovation that supports technology coexistence is Cognitive Radio Technology (CRT). In CRT, adaptive spectrum occupancy detections and spectrum use decision allow a very flexible use of spectrum resources. This concept can be of great benefit in wireless cellular communication and smart grids [11].

3. Standards used in Heterogeneous Networks

3.1 IEEE 802.21 Media Independent Handover (MIH)

This enables for continuation of IP sessions across various technologies and network by allowing of the exchange of inter-layer messages through the Media Independent Handover Function (MIHF). It can be seen between layer 2 and layer 3 of network and it uses SIP and mobile Internet Protocol (IP) to achieve handover while event notification, command and information services are used to manage communication between MHIS of various wireless networks. It however requires adaptation to the underlying technology and IEEE 802.21 also supports handover in mobile IPV6 [12].

3.2 IEEE 1905.1

This addresses inter-technology handover and management issues in Local Area Networks (LANs). Its compliant devices have an abstract layer hiding the underlying diversity in supported technologies like Ethernet, IEEE 82.11, Powerline Homeplug and multimedia over Coax (MaCa). This abstract is the main factor used for user friendliness and Quality of Service (QoS) as struggles with the low-level specifics of technology is not supported among users [13].

Abstraction layer Management Entity (ALME) service access point is used to manage abstract layer and it is an avenue to higher layers. It makes an opportunity to set flow forwarding rules based on Media Access Control (MAC) address. Product like qualcomm Hy-Fi supports this standard and it was not generally used by industries and its internet is limited to applying and making use of a framework for network management [14].

3.3 Orchestral-Virtual MAC Layer

This is intended to tackle the challenges of transport protocol and technology independent management with packet- level control. It constitutes of virtual MAC (VMAC) which is useable in all types of network nodes and a centralized controller. The Virtual MAC is allowed to abstract network access by introducing a virtual layer between data link layer which offer a single virtual data link layer to the network layer with a unified IP address. Virtual Media Access Control (VMAC) offers services like handover, duplication and load balancing when in full control over the data link layer and it also uses packet head matching rules. The central control maintain a global real-time view over the network by gathering monitoring statistics from all VMACs and can send command to each VMAC instance to update rules. It also allows the deployment of algorithm and intelligence to perform network optimization [15].

It can also communicate through Netconf of Open Flow (OF) with existing Software Defined Network (SDN) controllers to manage legacy devices without a VMAC and can be distributed to allow scalability in ever growing networks. The advanced functionality of this standard can also be used in wireless backhaul networks. Other supportive standards deployable in managing heterogeneous are SDN-based solutions, Long Term Evolution(LTE), Licensed Assisted Access(LAA), LTE-Unlicensed (LTE-U), Multifire, 5G new radio, Multipath Transmission Control Protocol (MPTCP), application layer and operating system based solution and lower power base technologies [16].

4. Heterogeneity

The drawbacks experienced as result of several devices and protocol used in IoT network are quiet destructive and these will cause more danger if not properly managed. In the work of [17], heterogeneous OAM (H-OAM) frame work to detect failure, monitor and measure the performance of heterogeneous activities was proposed. It analyzes and trouble shoots the network connectivity, these attributes are achieved by inspecting the data obtained from various layers of communication stack.
Another authors in Ganz *et al* [18] looked into sensor Symbolic Aggregate Approximation (SAX) approach which is based on SAX algorithm and is used to optimize the sensor data. This approach aids in reduction of load on network imposed by large amount of data from heterogeneous IoT devices. As the network grows in size, the deployment of several embedded technologies rises in order to meet up with the ever growing network. This however presents a challenge of managing devices and data generated alongside in order to have an efficient network.

The authors in Jara *et al* [19], presented a mechanism that optimizes IEEE 802.154 network, this mechanism reduces 24% of packet transfer and 35% of data transfer through header compaction which helps in achieving small header. This approach according to the authors helps in deploying large scale devices in the network in order to scale the network.

Authors in Pawlowski *et* al [20] deployed a storage management strategy to maximally utilize the paucity of the storage space accessible in IoT devices. This technique allows individual nodes to maintain limited security information about the subset of the nodes and when this was achieved, it performs similar information to the nodes with the ideal storage space. This helps in scaling trust management scheme for a large number of nodes in the network and as well as meeting the scalability issues.

5. Frequency management

Technologies nowadays are made to share spectrum with one another and they are also categorized. First is the group that do not have any direct access to other technologies and therefore are limited. Example are MPTCP, BGP, SIP and operating system level solution. In this group, interference avoidance or cooperation does not exist as there is no direct information about other wireless network. It also makes coordination with other technologies and throughput optimization difficult but its ease application and less modification are the benefits associated with it.

The second group supports one technology but uses multiple spectrum bands technology, examples are ODIN, 5G-EmPOWER, Wi-5 multefire, LTE-U/LTE-LAA. It is pertinent to know that some of these technologies were not designed with coexistence support for each other technology. The requirement to use an LBT protocol as they only operate in unlicensed spectrum gives them indirect support, this support is derived from the possibility of anybody deploying its wireless network [21].

The third group, is coexistence between different spectra by managing multiple technologies. This is because the management layers of these solutions have access to multiple technologies and their low-level monitoring information can decide on their behaviour. Examples are IEEE 802.21, IEEE 1905.1, Ochestra and LWA.
They support minimum of two technologies either by abstracting the technology or by integrating it into an existing technology. It enables easier management as all information and control over each technology is available. It also comes at the expense of requiring alteration of the devices. It is the only group that supports more advanced functionality like load balancing, duplication and handovers between technologies [22]. This poses an important concern in heterogeneous networks and we can categorize them through the following ways as stated below:

5.1 Small to medium scale

This includes IEEE 802.21, IEEE 1905.1, SDN @ HOME, 5G EmPOWER, Multifire and MDTCP. They are mainly used for small scale development such as home and offices with single Access Points (APs). Their scalability emanated from centralizing management components such as association and client placement in IEEE 802.11 for very low management. The transformation range of this approach is limited but has high throughput therefore it cannot be used for large scaling [23].

5.2 Large scale

This approach consists of Orchestra, Wi-5, LTE-U/LTE-LAA, LWA, NR, BGP and SIP because of design and controller distribution. Apart from Wi-5, all these technologies were designed for large scaling, LTE, NR, Universal Mobile Telecommunication System (UMTS) and Global System for Mobile Communication (GSM) should scale from various local cities to countries and multinational cooperative networks.
Wi-5 scales specific technology previously intended for small scale to large scale, this is possible by federating a multitude of smaller networks into one big network thereby allowing arbitrary scaling on the other hand. Scalability is achieved by BGP through decentralizing the management task. In general, the cost for being scalable to any level requires a centralized management platform that is in itself scalable. This however is complex and hence deployable by large organization. It is pertinent to know that for specific areas, one or more of these approaches are suitable for use and none of them is a universal solution [19].

6. Network routing

This is a process of path selection for sending the data across single or multiple networks. Data are generated by M2M or machine to object communication and routed to pass through the shortest and optimal path to get the destination. This routing process can be reactive when sources are sending data to destination or proactive when a routing table is periodically updated based on fresh destination list. It is also known as driven protocol when reactive and proactive are merged to give hybrid. The content centric routing (CCR) was proposed in [24] are content decides routing. It routes data to achieve outstanding data aggregation for reducing network traffic. Network latency reduction and redundant data elimination are achieved by this method. It is also used for optimizing energy consumption and reliability of network. Improved Ad-hoc on Demand Multipath Distance Vector (ADMDV) for IoT was proposed by (Rahman *et* al [25]. It dynamically selects a stable internet path by steadily updating table connected to internet condition and it reduces end to end delay, packet loss and discovery frequency.

7. Energy conservation

Nowadays, internet consumes more than 5% of generated energy and it will require more than this as internet users increase every day. Some works have been done in that regard to save energy and prolong the life time of network. This includes IEEE 802.11 ah, Zig Bee, Bluetooth Low Energy (BLE) and Lower Power Wide Area Network (LPWAN)

7.1 IEEE 802.11 ah

This is networking protocol intended to optimize energy more than standard IEEE 802.11. The former has twice the communication range than that of later as a result of use of 900 MHz free channel that is licensed. IEEE 802.11 ah consists of two power saving stations which are TIM station where buffered traffic information from the Access Point (AP) is periodically received. Non –TIM station where Target Wake Time (TWT) mechanism is being used to reduce signaling overhead. TWT allows AP to define specific or set time to access the medium by individual stations and the energy consumption of the network is minimized. IEEE 802.11ah makes use of small signals in place of acknowledgement so as to save energy.

7.2 Zig Bee

This is a protocol in IEEE 802.15.4 and is define by layer 3 and above ZigBee has two nodes, the Fully Functional Device (FFD) that acts as coordinator and common node. The other node is known as Reduced Function Device (RFD) that functions only as a common node. The work of authors' in Azevedo *et* al [26] proposed Synchronized Sleeping Technique (SST) to facilitate sleep mode to all the nodes of Zig Bee network. In some applications, routing is required for a little period and SST allows FFDs to enter into sleep state in idle periods thereby saving energy [27].

7.3 Bluetooth Low Energy (BLE)

This is also known as Bluetooth smart and is mostly used in operating system of smart devices for office and homes. Its power is about ten times lesser power than that of standard Bluetooth because BLE uses master/slave architecture. The master defines the wake time of the slave so that slave can enter into sleep after having sent all information to the master. Its attribute makes BLE ideal for IoT application [28].

7.4 Lower Power Wide Area Network (LPWAN)

This is targeted for battery operating devices hence making it ideal for IoT uses. It is used in bidirectional communication, mobility, localization and security required by IoT applications. LPWAN encourages greater number of users thus enhancing scalability issues, energy optimization and harvesting are also facilitated by LPWAN.

8. Congestion Management

The massive deployment of devices connected together in internet is ever increasing. This has resulted in network congestion which requires immediate measures to address and accommodate the future users. Authors in Betzler *et al* [29] proposed a CoCoA mechanism to eliminate the restrictions on message rate and to provide a dynamic congestion management technique with secured protocol guaranteed.

Other authors in [30] handled channels congestion resulting from mass data transmission by proposing a multiple layer approach which hints at the layers comprising spectrum sharing, data

processing architecture, data dimension reduction and data abandon protocol. Data dimension can be reduced by context awareness and granular computing. To manage the congestion issues occurring as a result of great increase in sensor nodes and to monitor the variety of vehicular applications in IoT enabled Intra- Vehicular communication.
This new approach is better when compared to the existing approaches by setting parameters like Back off Exponent (BE) and the Number of Back off (NB) stages when new data need to be sent and it sets these values based on the history of save BE and NB to reduce congestion [31].

9. Quality of service (QoS) and Reliability

Parameters such as bit error rate, bandwidth, packet loss, delay and interference management among others are factors that determine the quality of data received after transmission. Attempts to simultaneously put all these factors to check while transmitting tends to prove abortive as in a bid to manage one sometimes results in suffering of others, hence the tradeoffs that exist. Authors in [32], proposed discontinues reception/transmission (DRX/DTX) technique for 3GPP LTE-A to guarantee the traffic bit rate, packet delay and rate of packet loss with saving energy of user devices in IoT applications in QoS context.
The authors in [33] tested the packet of different size in LTE uplink to maximize the resource of LTE air interface optimally, from the results obtained, it was observed that packet with smaller size achieved almost half of the throughput compared to a larger sized packet.
This outcome gives a way for packet aggregation at the IoT gateway’s mobile edge to optimize various QoS parameter like latency, packet loss, jitter and bandwidth utilization required by a large number of small packets.
This is one of the most parameters of great concern in wired and wireless communication. This is because our network is in most times unmanned and there is need for steady and optimal performance. The authors in [34] decentralized management mechanism for providing reliable and smarter service to IoT network.
It uses situational acquisition, knowledge and analysis strategy to be acquainted with of unfavorable conditions in the network. It also makes use of a technique known as Privelets to provide confidentiality and to protect the personal data.
Another work in [35] proposed what is called PERUM framework built on network protocols and interfaced for hardware. This technique uses privacy-by-design concept which makes data not to be exposed to the third party. It also enhances the existing reliability, security and trust worthiness of IoT network.

10. Challenges and issues

Software Complexity

Since software systems in smart objects work requires minimal resources, there is a need for software infrastructure to support the network and also requires a server on the back ground to manage and support smart objects of the network.

a. Data Interpretation

It is very important to interpret the context that sensor has to sense. Context has important role for generating useful information and to draw a conclusion from the data sent by the sensors.

b. ***Scalability***

Spontaneously various new smart objects or devices are getting connected to the network. So IoT should be capable to solve the issues such as addressing, information management, service management and also should support both small-scale and large-scale environments.

c. ***Self-Configuration***

IoT objects should be programmed for self-configuration to suit particular environment without manual configuration by the user.

d. ***Storage Volume***

Based on the scenario and context, smart objects collect either small amount of data or huge volume of data. So based on amount of data, storage has to be allocated.

e. ***Interoperability***

In IoT, many smart objects are connected and each smart object has its own information collection capability, processing and communication capability. For communication and cooperation between the smart objects of different types, they should have common communication standard.

f. ***Security and Personal Privacy***

Network formed by smart objects via internet make security and privacy difficult. Sometimes users prevent other users to access some particular information at certain time and some transaction to protect secrete information from competitors. So, handling all this situation is a big challenge.

g. Ubiquitous Data Exchange through Wireless Technologies

Issues such as availability, network delays, and congestion of wireless technologies which is used for communication of smart devices are big challenge.

h. ***Energy-optimized solutions Network***

Energy-optimized solutions Network consists of many interconnected devices which requires high energy to keep the network active. So energy optimization is the major aspect in IoT [14].

i. ***Fault Tolerance***

Smart objects or devices are dynamic and rapidly context can change. But still network has to function automatically to adapt to the changed conditions. So IoT has to be structured for fault tolerance and robust.

11. Advantages and Disadvantages of IoT

11.1 Advantages

Better Quality of Life

IoT based applications increases comfort and better management in our daily life, thereby improving the quality of life.

Communication

Since IoT has communication between devices, in which physical devices are able to stay connected and hence the total transparency is available with lesser inefficiencies and greater quality.

a. Monitoring saves money and time

Since IOT uses smart sensors to monitor various aspects in our daily life for various applications which saves money and time.

b. New business opportunities

This creates new business for IoT technology, hence increases economic growth and new jobs.

c. Better Environment

It saves natural resources and helps in creating a smart greener and sustainable planet.

d. Automation and Control

Without human involvement, machines are automating and controlling vast amount of information, which leads faster and timely output.

11.2 Disadvantages

a. Lesser employment of menial staff

With the advent of technology, daily activities are getting automated by using IoT with less human intervention, which in turn causes fewer requirements of human resources. This causes unemployment issue in the society.

b. Compatibility

As devices from different manufacturers will be interconnected in IoT, presently, there is no international standard of compatibility for the tagging and monitoring equipment.

c. Privacy/Security

IoT has involvement of multiple devices and technologies and multiple companies will be monitoring it. Since a lot of data related to the context will be transmitted by the smart sensors, there is a high risk of losing private data.

d. Technology Takes Control of Life

Our lives will be increasingly controlled by technology and will be dependent on it. The younger generation is already addicted to technology for every little thing. With IoT, this dependency will spread amongst generations and in daily routines of users. We have to decide how much of our daily lives are we willing to mechanize and be controlled by technology.

e. Complexity

The IoT is a diverse and complex network. Any failure or bugs in the software or hardware will have serious consequences. Even power failure can cause a lot of inconvenience.

12. Conclusion

Internet of Things network is an ever growing network with billions of devices connected through several technologies of varying service requirements. Heterogeneity among other issues has been observed to be posing challenges in the network because of several communication protocols of the network at any given time.

This paper therefore reviewed IoT networks with a particular concern on heterogeneous network and also discussed possible measures to tackle the present challenges of the networks and it is believed that when practiced, IoT will have its network improved greatly with better services to the users. Internet of Things is a part of future internet that cuts across all domains and various industries, hence should be operated without network challenges. Internet of Things finds its application in safety, security, health sectors and the prompt response that makes delay not to be tolerated in the network but should be robust enough to deliver sent items to the destination within a short period of time.

12.1. Recommendation

We recommend that Internet of Things (IoT) should be used in the field of agriculture to improve its applications by the users and educate same to the agriculturist. This will reduce the dependency on manpower development and improve the yield which leads to increase in economy.
Using IoT in different phases of agriculture will be a solution to some of the problems in real-time information gathering with regards to weather, temperature, humidity, soil composition, soil moisture, water level, predicting pest and air quality. These will provide the farmer with statistical predictive information thereby enabling him to make smarter decisions in crop selection, crop monitoring, fertilizer application, diagnosis of diseases and soil erosion control.

References

[1] C. Perera, C. H. Liu, and S. Jayawardena, "The Emerging Internet of Things Marketplace from an Industrial Perspective: A Survey," *IEEE Trans. Emerg. Top. Comput.*, vol. 3, no. 4, pp. 585–598, 2015, doi: 10.1109/TETC.2015.2390034.

[2] G. Naik, J. Liu, and J. M. J. Park, "Coexistence of wireless technologies in the 5GHz bands: A survey of existing solutions and a roadmap for future research," *IEEE Commun. Surv. Tutorials*, vol. 20, no. 3, pp. 1777–1798, 2018, doi: 10.1109/COMST.2018.2815585.

[3] D. Kyriazis and T. Varvarigou, "Smart, autonomous and reliable Internet of Things," *Procedia Comput. Sci.*, vol. 21, pp. 442–448, 2013, doi: 10.1016/j.procs.2013.09.059.

[4] M. R. Ramli, P. T. Daely, D. Kim, and J. M. Lee, "IoT-based adaptive network mechanism for reliable smart farm system," *Comput. Electron. Agric.*, vol. 170, no. February, pp. 1–8, 2020, doi: 10.1016/j.compag.2020.105287.

[5] N. N. Srinidhi, S. M. Dilip Kumar, and K. R. Venugopal, "Network optimizations in the Internet of Things: A review," *Eng. Sci. Technol. an Int. J.*, vol. 22, no. 1, pp. 1–21, 2019, doi: 10.1016/j.jestch.2018.09.003.

[6] P. Bosch *et al.*, "A Demonstration of Seamless Inter-Technology Mobility in Heterogeneous Networks," in *19th IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks, WoWMoM 2018*, 2018, pp. 14–16, doi: 10.1109/WoWMoM.2018.8449788.

[7] A. Mukherjee *et al.*, "Licensed-Assisted Access LTE: Coexistence with IEEE 802.11 and the evolution toward 5G," *IEEE Commun. Mag.*, vol. 54, no. 6, pp. 50–57, 2016, doi: 10.1109/MCOM.2016.7497766.

[8] T. Sudha, V. Anand, V. G. Kavya, M. K. P. Anagha, K. Selvan, and K. Anilkumar, "Cognitive radio for smart home environment," in *ACM International Conference Proceeding Series*, 2015, vol. 10-13-Augu, pp. 629–634, doi: 10.1145/2791405.2791548.

[9] K. Taniuchi *et al.*, "IEEE 802.21: Media Independent Handover: Features, Applicability, and Realization," *IEEE Commun. Mag.*, vol. 47, no. 1, pp. 112–120, 2009, doi: 10.1109/MCOM.2009.4752687.

[10] S. Zimmo, A. Moubayed, A. Refaey, and A. Shami, "Coexistence of WiFi and LTE in the Unlicensed Band Using Time-Domain Virtualization," in *2018 IEEE Global Communications Conference, GLOBECOM 2018 - Proceedings*, 2018, pp. 1–6, doi: 10.1109/GLOCOM.2018.8648057.

[11] M. M. Bin Tariq, K. Faizan, M. Ali, and F. Qamar, "LTE-Unlicensed and WiFi: Sharing unlicensed spectrum in 5GHz band," in *15th International Conference on Emerging Technologies, ICET 2019*, 2019, pp. 1–6, doi: 10.1109/ICET48972.2019.8994705.

[12] Y. Jin, S. Gormus, P. Kulkarni, and M. Sooriyabandara, "Content centric routing in IoT networks and its integration in RPL," *Comput. Commun.*, vol. 89–90, pp. 87–104, 2016, doi: 10.1016/j.comcom.2016.03.005.

[13] D. Macone, G. Oddi, A. Palo, and V. Suraci, "A dynamic load balancing algorithm for Quality of Service and mobility management in next generation home networks," *Telecommun. Syst.*, vol. 53, no. 3, pp. 265–283, 2013, doi: 10.1007/s11235-013-9697-y.

[14] P. Bosch, T. De Schepper, E. Zeljković, J. Famaey, and S. Latré, "Orchestration of heterogeneous wireless networks: State of the art and remaining challenges," *Comput. Commun.*, vol. 149, pp. 62–77, 2020, doi: 10.1016/j.comcom.2019.10.008.

[15] E. Zeljković *et al.*, "ORCHESTRA: Virtualized and programmable orchestration of heterogeneous WLANs," in *2017 13th International Conference on Network and Service Management, CNSM 2017*, 2017, vol. 2018-Janua, pp. 1–9, doi: 10.23919/CNSM.2017.8255999.

[16] X. Zhao, Y. W. Li, H. Tian, and X. Wu, "Energy Management Strategy of Multiple Supercapacitors in a DC

Microgrid Using Adaptive Virtual Impedance," *IEEE J. Emerg. Sel. Top. Power Electron.*, vol. 4, no. 4, pp. 1174–1185, 2016, doi: 10.1109/JESTPE.2016.2601097.

[17] J. Sterle, U. Sedlar, M. Rugelj, A. Kos, and M. Volk, "Application-Driven OAM Framework for Heterogeneous IoT Environments," *Int. J. Distrib. Sens. Networks*, vol. 2016, no. 1, p. 5649291, 2016, doi: 10.1155/2016/5649291.

[18] F. Ganz, P. Barnaghi, and F. Carrez, "Information abstraction for heterogeneous real world internet data," *IEEE Sens. J.*, vol. 13, no. 10, pp. 3793–3805, 2013, doi: 10.1109/JSEN.2013.2271562.

[19] A. J. Jara, V. P. Kafle, and A. F. Skarmeta, "Secure and scalable mobility management scheme for the Internet of Things integration in the future internet architecture," *Int. J. Ad Hoc Ubiquitous Comput.*, vol. 13, no. 3–4, pp. 228–242, 2013, doi: 10.1504/IJAHUC.2013.055468.

[20] M. P. Pawlowski, A. J. Jara, and M. J. Ogorzalek, "Compact Extensible Authentication Protocol for the Internet of Things: Enabling Scalable and Efficient Security Commissioning," *Mob. Inf. Syst.*, vol. 2015, 2015, doi: 10.1155/2015/506284.

[21] E. De Poorter, I. Moerman, and P. Demeester, "Enabling direct connectivity between heterogeneous objects in the internet of things through a network-service-oriented architecture," *Eurasip J. Wirel. Commun. Netw.*, vol. 2011, no. 1, pp. 1–14, 2011, doi: 10.1186/1687-1499-2011-61.

[22] H. C. Pöhls *et al.*, "RERUM: Building a reliable IoT upon privacy- and security- enabled smart objects," in *2014 IEEE Wireless Communications and Networking Conference Workshops, WCNCW 2014*, 2014, pp. 122–127, doi: 10.1109/WCNCW.2014.6934872.

[23] H. Jiang *et al.*, "TDOCP: A two-dimensional optimization integrating channel assignment and power control for large-scale WLANs with dense users," *Ad Hoc Networks*, vol. 26, pp. 114–127, 2015, doi: 10.1016/j.adhoc.2014.11.015.

[24] Y. Tian and R. Hou, "An improved AOMDV routing protocol for internet of things," in *2010 International Conference on Computational Intelligence and Software Engineering, CiSE 2010*, 2010, pp. 1–4, doi: 10.1109/CISE.2010.5676940.

[25] M. A. Rahman, A. T. Asyhari, L. S. Leong, G. B. Satrya, M. Hai Tao, and M. F. Zolkipli, "Scalable machine learning-based intrusion detection system for IoT-enabled smart cities," *Sustain. Cities Soc.*, vol. 61, no. January, p. 102324, 2020, doi: 10.1016/j.scs.2020.102324.

[26] J. Azevedo, F. Santos, M. Rodrigues, and L. Aguiar, "Sleeping ZigBee networks at the application layer," *IET Wirel. Sens. Syst.*, vol. 4, no. 1, pp. 35–41, 2014, doi: 10.1049/iet-wss.2013.0024.

[27] S. Zhang, Y. Wang, and W. Zhou, "Towards secure 5G networks: A Survey," *Comput. Networks*, vol. 162, p. 106871, 2019, doi: 10.1016/j.comnet.2019.106871.

[28] M. Antonini, S. Cirani, G. Ferrari, P. Medagliani, M. Picone, and L. Veltri, "Lightweight multicast forwarding for service discovery in low-power IoT networks," in *2014 22nd International Conference on Software, Telecommunications and Computer Networks, SoftCOM 2014*, 2014, pp. 133–138, doi: 10.1109/SOFTCOM.2014.7039103.

[29] A. Betzler, C. Gomez, I. Demirkol, and J. Paradells, "CoAP congestion control for the internet of things," *IEEE Commun. Mag.*, vol. 54, no. 7, pp. 154–160, 2016, doi: 10.1109/MCOM.2016.7509394.

[30] J. Wellons and Y. Xue, "The robust joint solution for channel assignment and routing for wireless mesh networks with time partitioning," *Ad Hoc Networks*, vol. 13, no. PART A, pp. 210–221, 2014, doi: 10.1016/j.adhoc.2011.05.002.

[31] M. Bani Younes and A. Boukerche, "A performance evaluation of an efficient traffic congestion detection protocol (ECODE) for intelligent transportation systems," *Ad Hoc Networks*, vol. 24, no. PA, pp. 317–336, 2015, doi: 10.1016/j.adhoc.2014.09.005.

[32] J. M. Liang, J. J. Chen, H. H. Cheng, and Y. C. Tseng, "Energy-efficient sleep scheduling with QoS considerations in 3GPP LTE-advanced networks," *2013 9th Int. Wirel. Commun. Mob. Comput. Conf. IWCMC 2013*, vol. 3, no. 1, pp. 527–531, 2013, doi: 10.1109/IWCMC.2013.6583613.

[33] E. Piri and J. Pinola, "Performance of LTE uplink for IoT backhaul," in *2016 13th IEEE Annual Consumer Communications and Networking Conference, CCNC 2016*, 2016, pp. 6–11, doi: 10.1109/CCNC.2016.7444723.

[34] A. Anvari-Moghaddam, H. Monsef, and A. Rahimi-Kian, "Optimal smart home energy management considering energy saving and a comfortable lifestyle," *IEEE Trans. Smart Grid*, vol. 6, no. 1, pp. 324–332, 2015, doi: 10.1109/TSG.2014.2349352.

[35] A. Balte, A. Kashid, and B. Patil, "Security Issues in Internet of Things (IoT): A Survey," *Int. J. Adv. Res. Comput. Sci. Softw. Eng.*, vol. 5, no. 4, 2015.