International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 12 Issue: 2
***Article Received:** 25 November2023 **Revised:** 12 December 2023 **Accepted:** 30 January 2024*

Advanced IoT Technology and Protocols: Review and Future Perspectives

Mohsen S. Alsaadi
Department of Electrical and Computer, Faculty of Engineering,King abdulaziz university,
Saudi Arabia
msm_alsaadi@hotmail.com

Naif D. Alotaibi
Department of Electrical and Computer, Faculty of Engineering,King abdulaziz university,
Saudi Arabia
ndalotabi@kau.edu.sa

Wasim A. Ali
Department of Electrical and Information Engineering, Politecnico di Bari,
Bari, Italy.
wasim.ali@poliba.it .
(corresponding author)

Abstract— The Internet of Things (IoT) has emerged as a disruptive paradigm, altering how we interact with our surroundings and enabling a plethora of novel applications across multiple sectors. This literature review provides a complete overview of the Internet of Things, including applications, technology, protocols, modeling tools, and future directions. The assessment begins by looking at a wide range of IoT applications, such as smart cities, healthcare, industrial automation, smart homes, and more. It then looks into the underlying technologies that enable IoT deployments, including low-power wireless communication protocols, edge computing, and sensor networks. Protocols and routing methods designed expressly for IoT networks are also described, as well as simulation tools used to simulate and evaluate IoT systems. The discussion focuses on critical insights and consequences for the future of IoT, including challenges and potential in security, interoperability, edge intelligence, and sustainability. By tackling these obstacles and using emerging technologies, IoT can create disruptive change across businesses while also improving quality of life. This review seeks to give scholars, practitioners, and stakeholders a thorough grasp of IoT and its implications for the future.

Keywords- IoT Application, IoT protocols, Routing protocol, Smart cities, Simulation tools**.**

I. INTRODUCTION

The Internet has become an indispensable tool in various facets of daily life in recent years. The emergence of a global network infrastructure centered on intelligent object communication has made significant strides. The Internet of Things (IoT) concept has become increasingly pertinent to modern society, facilitating the integration of individuals and objects into information systems via wireless sensor nodes and interconnected networks [1]. This technological progression is anticipated to pave the way for novel applications and services leveraging the connectivity between physical and virtual entities [2].

The IoT landscape relies on established communication technologies such as Bluetooth, ZigBee, WiFi, and Long Term Evolution-Advanced (LTE-A). However, integrating these diverse technologies into a cohesive and functional IoT system poses a multifaceted challenge [3]. Standardization within the IoT sphere is paramount to ensure seamless interoperability among sensor devices and objects, necessitating robust identity management systems. Furthermore, network security and data privacy concerns loom large [4]. Developing efficient energy and data management mechanisms is also imperative to promote sustainability in IoT ecosystems. Addressing these challenges necessitates thoroughly examining the networking technologies underpinning IoT deployments.

While numerous studies have explored IoT communication technologies, there is a gap in addressing the IoT network layer, the transmission layer, and its associated technologies. Existing research has focused on various aspects such as Machine-to-

Machine (M2M) networks [5], IoT standards for data communications, M2M/IoT applications, enabling applications, services, protocols, technologies, IETF protocol suite support for IoT devices and applications, as well as standards offered by organizations like IETF, IEEE, and ITU for IoT [6].

Advancements in IoT technologies support IoT application proliferation. IoT systems are primarily powered by low-power CPUs, wireless communication protocols, sensor downsizing, and cloud computing infrastructure [7]. In the Internet of Things (IoT) space, for example, sensors with microcontrollers collect data from the real world, while wireless communication protocols like Bluetooth Low Energy (BLE), LoRaWAN, and Zigbee facilitate easy connectivity and data transfer [8]. Real-time insights and decision-making in IoT ecosystems are made possible by cloud-based platforms such as Microsoft Azure and Amazon Web Services (AWS), which offer scalable infrastructure for data processing, analytics, and storage [9]. Hence, integrating these technological elements serves as the foundation for developing and executing a variety of Internet of Things applications. For IoT systems to be interoperable, dependable, and secure, established protocols must be followed throughout effective communication between IoT devices [10]. In IoT networks, communication of data and message delivery is regulated by protocols like MQTT (Message Queuing Telemetry Transport), CoAP (Constrained Application Protocol), and HTTP (Hypertext Transfer Protocol) [11]. MQTT is extensively used in Internet of Things applications for effective communication between resource-constrained devices and centralized servers because of its lightweight and publish-subscribe messaging architecture [12]. CoAP enables seamless integration of IoT devices with web-based applications, facilitating interoperability across diverse networks. The World Wide Web's foundational protocol, HTTP, also offers a recognizable interface for IoT devices to interact with web servers, facilitating safe data transmission and typical request-response paradigms [13]. Therefore, while developing and implementing reliable and scalable Internet of Things systems, choosing and putting into practice the right protocols is essential.

This review paper explores IoT technologies, protocols, and simulation tools as a distinct area of research within the existing literature, which often focuses on specific IoT applications or standardization endeavors across different architectural layers. Additionally, the study moves beyond merely outlining fundamental communication technologies to examine the roles, functionalities, advantages, and disadvantages of key standards, protocols, and schemes within the IoT network layer. It sheds light on prevailing challenges and limitations while underscoring the potential of each standard to embrace the IPv6 protocol for enhanced IoT development. The review also offers recommendations for addressing gaps and shortcomings in each technology to bolster network communication efficiency among IoT devices, aligning with current trends in the IoT domain. The overarching goal of this survey is to motivate scholars and professionals to devise more effective networking protocols by addressing identified gaps and deficiencies. Figure 1. Shows the paper structure.

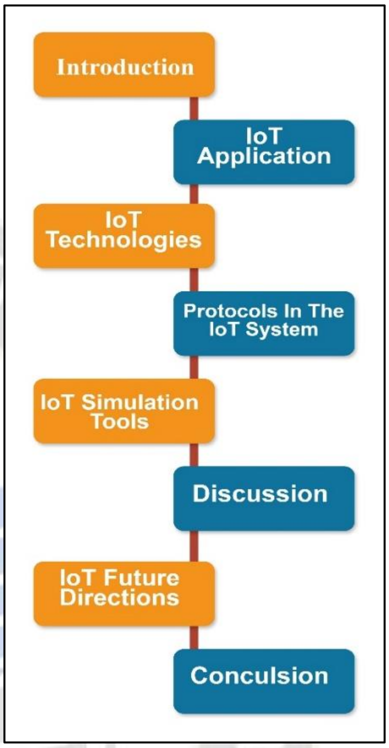

Fig. 1. The paper structure

In Section 2, IoT Application explores various sector applications. Section 3 covers IoT Technologies, focusing on key enabling technologies. Section 4, Protocols In The IoT System, examines protocols. Section 5 introduces IoT Simulation Tools for testing systems. Section 6 discusses current challenges and future trends in IoT. Finally, Section 7, Conclusion, summarizes key points and offers recommendations for further research in the field.

II. IoT Application

This section will delve into various IoT applications, exploring their functionalities, benefits, challenges, and the underlying technologies that power them. By understanding the breadth and depth of IoT applications, we gain insights into the transformative potential of this paradigm shift in our interconnected world. Figure 2. Present the `classification of IoT applications.

Smart Grid: By enabling real-time monitoring, control, and optimization of energy distribution, the integration of IoT into power grids transforms the conventional electrical infrastructure. IoT-enabled smart meters gather detailed information on power outages, voltage levels, and trends in energy consumption. Utilities can use this data to reduce consumer energy costs by implementing demand-response programs, allocating resources effectively, and mitigating peak load demands [14].

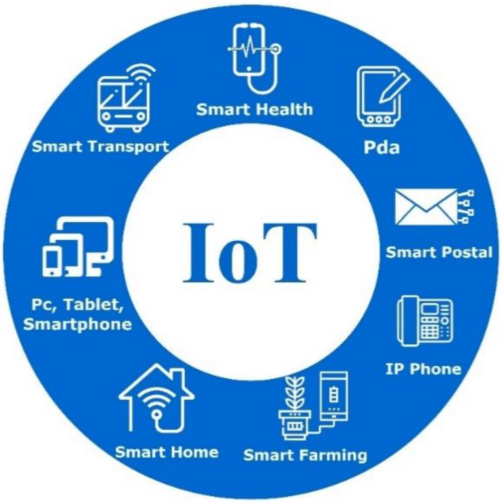

Fig. 2. IoT Applications

Additionally, by offering insights into the intermittent nature of renewable energy sources like solar and wind and enabling dynamic grid balancing, IoT-enabled grid management systems make it easier to integrate these sources. IoT turns traditional power grids into intelligent, adaptable systems that can satisfy the changing needs of contemporary society while advancing sustainability and dependability [15].

Medical & Healthcare: By enabling continuous monitoring, individualized treatment, and better health outcomes, the integration of IoT technology in healthcare is revolutionizing the delivery of patient care. Smartwatches and fitness trackers are examples of wearable technology with biosensors to monitor vital signs, physical activity levels, and even early warning indicators of medical disorders [16]. By managing chronic diseases, keeping an eye on patients' health from a distance, and acting quickly in an emergency, remote patient monitoring systems help lower healthcare expenses and the number of readmissions to hospitals [17]. Additionally, IoT-enabled smart medicine dispensers and adherence monitoring devices improve patients' medication management and treatment compliance, especially for those with complicated pharmaceutical regimens. In general, IoT in healthcare makes it easier to shift to patient-centric, proactive, and personalized healthcare delivery models, eventually improving patient outcomes and quality of life.

Smart Mobility: IoT technologies enable the implementation of smart mobility solutions that improve transportation sustainability, safety, and efficiency. Real-time information sharing between vehicles and infrastructure components is made possible via vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, which promotes proactive traffic management, collision avoidance, and route optimization [18]. Furthermore, IoT-enabled transportation systems combine several forms of transportation, like public transportation, ride-sharing, and bike-sharing, to give travelers smooth, multimodal travel experiences [19]. Advanced traffic management systems use IoT data to prioritize emergency vehicles, manage congestion, and dynamically change traffic signals to improve overall traffic flow and shorten travel times. Moreover, introducing driverless vehicles can completely transform urban transportation by providing safer, more effective, and ecologically friendly alternatives.

Public Safety: A wide range of solutions are available for IoT applications in public safety to improve disaster management, criminal prevention, and emergency response. Real-time monitoring of public areas, important infrastructure, and high-risk regions is made possible by smart surveillance systems outfitted with IoT sensors and video analytics [20]. Law enforcement and first responders may respond quickly and efficiently to security threats, suspicious activity, and emergencies because of these systems' early detection capabilities [21]. Furthermore, environmental sensors installed in urban areas and industrial sites provide early warning of possible risks like air pollution, chemical leaks, and natural disasters, enabling proactive risk mitigation actions and guaranteeing public health and safety [22]. Furthermore, biometric sensor-equipped wearables allow for the surveillance and monitoring of first responders' health and safety in dangerous situations, improving situational awareness and lowering hazards associated with their jobs.

***Article Received:** 25 November2023 **Revised:** 12 December 2023 **Accepted:** 30 January 2024*

Industrial IoT (IIoT): This area combines traditional industrial systems and current IoT technology, allowing for improved automation, optimization, and predictive maintenance in industrial processes [23]. IoT sensors installed in machinery and equipment gather real-time data on operating parameters, performance indicators, and environmental variables, allowing for proactive maintenance and optimization techniques [24]. IIoT also enables the seamless integration and coordination of diverse components in the industrial environment, such as manufacturing plants, supply chain networks, and logistical activities [25]. IIoT provides predictive analytics, anomaly detection, and process optimization by leveraging sophisticated analytics and machine learning algorithms, consequently improving operating efficiency, minimizing downtime, and improving product quality [26].

Smart Home: IoT technologies have transformed residential living by allowing for the building of smart houses that provide greater comfort, convenience, and energy efficiency [27]. Smart home products, including connected appliances, thermostats, lighting systems, and security cameras, can be remotely controlled and automated via smartphone apps or voice commands [28]. These gadgets allow homeowners to monitor and manage many aspects of their houses remotely, such as modifying temperature settings, tracking energy consumption, and receiving alerts for potential security breaches [29]. Furthermore, IoT-enabled smart home ecosystems may learn and adapt to occupant preferences and behaviors over time, resulting in more personalized experiences and better energy efficiency [30]. Smart homes, which use IoT technology, provide increased convenience, security, and energy efficiency while enhancing overall quality of life.

III. IoT Technologies

IoT is supported by diverse dynamic technologies adapted to specific applications. This section focuses on selecting and presenting the most relevant IoT technology. These technologies play critical roles in creating the landscape of IoT applications across industries by promoting innovation, efficiency, and connectivity. The next sections explore the compilation technologies.

Bluetooth: Bluetooth technology has advanced greatly since its conception, especially with the advent of Bluetooth Low Energy (BLE). BLE improves power efficiency, making it excellent for IoT devices that run on batteries or use energy harvesting [31]. Furthermore, the most recent versions of Bluetooth support mesh networking, allowing seamless communication between several devices over long distances. This functionality is especially useful in smart home settings, where several IoT devices must connect and with a central hub. Bluetooth's connectivity with smartphones and other consumer electronics devices makes it an attractive option for IoT applications that require user involvement and control [32].

Zigbee: With its mesh networking capability, Zigbee is an ideal solution for IoT deployments where scalability, dependability, and low power consumption are critical [33]. Zigbee networks are capable of self-organization and self-healing, which guarantees reliable communication even in difficult settings. Furthermore, Zigbee allows for a variety of topologies, such as star, mesh, and cluster tree, providing network designers options [34]. Zigbee is preferred in industrial Internet of things applications because it can connect a lot of sensors and actuators while using less energy. Zigbee's appropriateness for smart grid and smart city installations is further enhanced by its support for interoperability standards like the Thread protocol and the Zigbee Alliance's Smart Energy Profile.

Wi-Fi: In response to the growing needs of Internet of Things applications for greater data rates, enhanced coverage, and enhanced security, Wi-Fi technology is still developing [35]. The most recent Wi-Fi protocols, such as Wi-Fi 6 (802.11ax), are ideal for bandwidth-intensive Internet of Things applications because they improve throughput, latency, and capacity [36]. Better performance in dense IoT installations and more effective spectrum use are made possible by Wi-Fi 6's support for multi-user multiple-input multiple-output (MU-MIMO) and orthogonal frequency-division multiple access (OFDMA) [37]. Furthermore, the widespread availability of Wi-Fi in public areas, workplaces, and households facilitates smooth connectivity for Internet of Things devices, streamlining their setup and upkeep.

Mobile Generations (3G, 4G, and 5G): Mobile cellular technologies are especially important for IoT connectivity in applications that demand wide-area coverage and mobility assistance [38]. With its ultra-low latency, high dependability, and vast device connectivity capabilities, 5G promises to revolutionize IoT connectivity, even though 3G and 4G LTE technologies have been widely used for IoT applications [39]. The ability to create specialized IoT networks for certain use cases is made possible by 5G's support for network slicing, which ensures optimal performance and security. Moreover, 5G creates new opportunities for IoT-enabled innovations by supporting mission-critical applications in manufacturing, transportation, and healthcare sectors [40].

RFID (Radio Frequency Identification): With advancements in communication protocols, chip design, and antenna technology, RFID technology is still developing [41]. RFID becomes more applicable in wider sectors and use cases when integrated with other Internet of Things technologies, like sensors and connectivity modules. For instance, passive RFID tags equipped with sensors can monitor temperature, humidity, and pressure while transporting perishable items. Active RFID tags with GPS modules allow for real-time asset tracking and inventory control in logistics and supply chain operations [42]. Developments further improve the scalability and interoperability of RFID systems in intricate IoT environments in RFID reader technology, such as long-range and multi-protocol support.

LoRaWAN: LoRaWAN technology is still gaining attraction in IoT applications that need low power consumption, long-range communication, and affordable connection [43]. Because of its adaptive data rate optimization and star-of-stars network architecture, LoRaWAN can communicate effectively over great distances, which makes it a good fit for applications like smart utilities, smart agriculture, and environmental monitoring. LoRaWAN's adaptability in asset tracking, smart city, and industrial Internet of Things applications is further enhanced by its capability for bi-directional communication and geolocation services [44]. The adoption of this technology is accelerated by the rise of LoRaWAN-based platforms and ecosystems, which make it possible for IoT solutions to be rapidly prototyped and deployed.

NFC (Near Field Communication): NFC technology allows devices to communicate with each other across short distances, usually a few centimeters [45]. It enables contactless data exchange between an NFC-enabled device (such as a smartphone or tag) and an NFC reader at frequencies of 13.56 MHz. NFC is frequently employed in Internet of Things applications, including contactless payments, access control, and smart packaging. For instance, NFC-enabled cards or smartphones can make contactless payments by only tapping them against NFC-enabled terminals. NFC is a popular option for various IoT use cases due to its simplicity, low power consumption, and ease of integration [46].

Sigfox: Sigfox is a low-power wide-area network (LPWAN) technology for low-speed, long-range communication. Sigfox uses a star network architecture, in which devices connect with base stations directly and run in unlicensed frequency bands [47. Sigfox is especially well suited for Internet of Things applications requiring minimum infrastructure, high battery life, and extended range. Sigfox has applications in asset tracking, smart metering, environmental monitoring, and agricultural telemetry. Sigfox is an appealing choice for IoT installations across various industries due to its affordability, scalability, and simplicity [48].

EnOcean: EnOcean technology's cutting-edge approach to wireless networking is revolutionizing IoT. EnOcean devices run on energy harvested from their environment, not batteries, in contrast to conventional wireless protocols [49]. EnOcean is the perfect choice for Internet of Things applications where sustainability and power efficiency are crucial because of its energy harvesting capability. Wireless communication allows EnOcean-enabled devices—such as switches, controls, and sensors—to integrate seamlessly into smart homes and building automation systems. EnOcean optimizes efficiency and lowers operating costs by guaranteeing dependable and maintenance-free operation with its ultra-low-power wireless connection protocols [50]. The technology EnOcean is compatible with current building automation standards, which makes it easier for different applications to use.

NB-IoT (Narrowband IoT): NB-IoT is a cellular technology developed by the Third Generation Partnership Project (3GPP) for low-power, wide-area IoT deployments [51]. NB-IoT runs in permitted spectrum bands and is best suited for IoT applications that demand long battery life, extensive coverage, and device compatibility. NB-IoT is widely used in smart metering, asset tracking, and agricultural monitoring applications. NB-IoT has benefits such as improved coverage in tough settings, more efficient spectrum utilization, and easier interaction with existing cellular networks [52].

IV. Protocols In The IoT System

The network layer is a vital part of IoT systems that enables connected devices to communicate and exchange data. This layer is composed of different protocols that play a pivotal role in ensuring efficient and reliable communication, as well as resolving the unique requirements and challenges in deploying IoT [53]. In this section, we discuss the important protocols at play in the networking layer of IoT systems as shown in figure 3, which include 6LoWPAN, Zigbee IP, 6TiSCH, 6Lo, 6LoBAC, and IPv6 over NFC. These protocols ensure that devices can flawlessly interoperate and integrate to extend connectivity to different types of applications in diverse environments. We also delve into the various routing protocols that are specifically tailored for IoT networks, such as RPL, CORPL, CARP, AODV, and AODVv2, which guarantee that optimal data transmission and routing decisions are made, especially in dynamic and challenging IoT environments [54]. By understanding these protocols, we gain insights into the architectural foundations and communication mechanisms that underpin IoT systems, driving innovation and connectivity in the IoT ecosystem.

Protocols in the Network Layer of IoT:

Several protocols are critical at the network layer of IoT for simplifying communication and data exchange among interconnected devices. These protocols are intended to meet the specific needs and limits of IoT deployments, such as low-power operation, resource efficiency, and compatibility. Here are some important protocols widely used in the network layer of IoT systems:

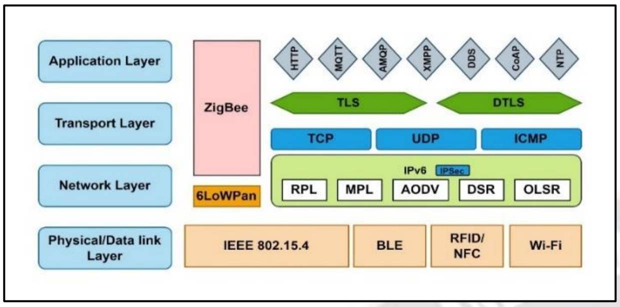

Fig. 3. The IoT protocol stack

1. 6LoWPAN (IPv6 over Low-Power Wireless Personal Area Networks): 6LoWPAN is a protocol for sending IPv6 packets over low-power wireless networks, such as IEEE 802.15.4-based networks [55]. It improves IPv6 packet size and header compression to reduce overhead and bandwidth consumption, making it ideal for resource-constrained IoT devices.
2. Zigbee IP: Zigbee IP expands the Zigbee protocol stack to include IPv6 networking, allowing Zigbee devices to communicate directly with IP-based networks [56]. It allows for the smooth integration of Zigbee devices into existing IP infrastructure, facilitating interoperability and communication with other IP-enabled devices and services.
3. 6TiSCH (IPv6 over the TSCH mode of IEEE 802.15.4e): 6TiSCH is an IPv6 extension designed for use with the IEEE 802.15.4e standard's Time-Slotted Channel Hopping (TSCH) [57]. It ensures deterministic and reliable communication in industrial IoT deployments by arranging transmission time slots and switching between several channels to reduce interference and improve reliability.
4. 6Lo (IPv6 over Networks with Resource-restricted Nodes): 6Lo is a protocol that allows IPv6 communication across restricted networks including low-power wireless networks and sensor networks [58]. It includes mechanisms for header compression, fragmentation, and adaptation to account for the constrained resources and communication capabilities of IoT devices.
5. IPv6 over MS/TP (6LoBAC): IPv6 over Master-Slave/Token-Passing (MS/TP), also known as 6LoBAC, allows IPv6 packets to be transmitted over low-speed serial networks, such as those used in building automation and control systems [59]. It enables IPv6-enabled devices to interact across traditional building automation networks, broadening IPv6's reach to a wide range of IoT contexts.
6. IPv6 over NFC (Near Field Communication): IPv6 over NFC allows IPv6 communication between devices that use NFC technology, which functions via short-range wireless connections. It enables NFC-enabled IoT devices to safely and efficiently exchange IPv6 packets, hence enhancing peer-to-peer communication and service discovery in IoT environments.

Routing Protocols in IoT:
Routing protocols are critical for facilitating data transmission and routing decisions in IoT networks, ensuring efficient and reliable communication among networked devices. Several routing protocols have been specifically developed to solve the challenges and requirements of IoT installations, such as low-power operation, dynamic network topologies, and resource limits. Here are some main routing protocols widely used in IoT:

1. RPL (IPv6 Routing Protocol for Low-Power and Lossy Networks): RPL (IPv6 Routing Protocol for Low-Power and Lossy Networks): RPL is a robust routing protocol specifically designed to address the challenges posed by low-power and lossy networks (LLNs) in IoT environments. By employing directed acyclic graphs (DAGs) and leveraging network parameters such as link quality and energy usage, RPL optimizes routing paths to maximize efficiency and reliability [61]. This protocol plays a crucial role in promoting energy conservation and extending the battery life of IoT devices, which is essential for prolonged operation in resource-constrained environments [62]. Moreover, RPL facilitates seamless communication by dynamically adapting to network changes and ensuring dependable data transmission, even in challenging and dynamic deployment scenarios. As IoT deployments continue to increase across diverse industries, the optimization and enhancement of RPL present promising avenues for research and innovation, paving the way for more efficient and resilient IoT networks [63].
2. CORPL (collecting-Oriented Routing Protocol for Low-Power and Lossy Networks): CORPL builds on RPL's capabilities to improve data collecting and aggregation in LLNs [64]. CORPL improves communication and resource utilization in multi-hop networks by offering approaches for effective data forwarding, storage, and retrieval, responding to the special demands of data-centric IoT applications.
3. CARP (Congestion-Aware Routing Protocol): CARP dynamically adapts routing paths depending on network congestion and connection quality measurements, reducing congestion and optimizing traffic distribution in IoT networks [65]. CARP improves IoT deployment dependability and performance by assuring efficient data transfer while preventing packet loss or delays caused by network congestion.
4. AODV (Ad Hoc On-Demand Distance Vector): AODV is a reactive routing protocol that is well-suited to dynamic IoT

situations with frequent network topology changes [66]. By constructing routes on-demand and maintaining routing tables, AODV effectively passes data packets to their destinations, ensuring timely and reliable communication in mobile ad hoc networks and IoT deployments [67].

5. AODVv2 (Ad Hoc On-Demand Distance Vector, Version 2): AODVv2 enhances AODV's scalability and security in large-scale IoT networks by integrating features including route aggregation, path diversity, and secure routing techniques [68]. These innovations improve routing efficiency and robustness, addressing the changing demands of difficult IoT environments and supporting strong communication among networked devices.

These routing protocols provide the foundation for efficient and dependable data transfer in IoT networks, facilitating seamless communication and connectivity among networked devices in a variety of deployment scenarios. These protocols provide for reliable data transfer by dynamically adapting to changing network conditions and improving routing methods, enabling the uninterrupted flow of information required for IoT applications. Understanding these protocols not only makes them easier to adopt but also highlights their importance as a hot topic for research and the potential to improve IoT connectivity and efficiency.

V. IoT Simulation Tools

Simulation tools are critical in the development and evaluation of IoT systems because they enable researchers and practitioners to evaluate system behavior, test algorithms, and assess performance under varied scenarios. Here, we review many prominent simulation tools utilized in the field of the Internet of Things as shown in figure 4 :

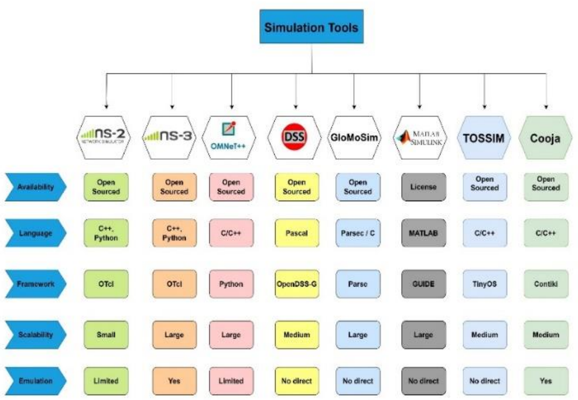

Fig. 4. Different Iot Simulation Tools

NS-2 and NS-3 (Network Simulators 2 and 3) are discrete event network simulators used in academia and industry to analyze communication networks, including IoT systems [69]. NS-2, created in C++, supports both wired and wireless networks and offers a large number of network modules and protocols [70]. Meanwhile, C++-based NS-3 provides enhanced architecture and capabilities, including support for complex network models and simulation scenarios. These simulators allow researchers to conduct detailed simulation tests on IoT protocols, network architectures, and applications, providing information about network performance, scalability, and dependability.

OMNeT++ is a modular, component-based simulation framework that is widely used to describe and simulate complex communication networks and distributed systems [71]. It offers a diverse framework for building and analyzing IoT applications, protocols, and architectures by making it easier to create modular simulation models. With its extensive library of network components and support for a variety of network protocols, OMNeT++ allows researchers to simulate numerous IoT scenarios and examine network behavior under different situations, assisting in the creation and optimization of IoT solutions.

OpenDSS (Open Distribution System Simulator) is a simulation tool for modeling and analyzing electrical distribution systems, especially in IoT applications like smart grids and energy management [72]. It enables researchers and engineers to simulate power distribution networks that incorporate renewable energy sources, energy storage systems, and IoT-enabled devices. Users can use OpenDSS to simulate the influence of IoT technologies on grid performance, optimize energy distribution techniques, and increase power system reliability and efficiency.

MATLAB/Simulink is a popular simulation environment for designing and simulating dynamic systems, including IoT applications. MATLAB/Simulink's intuitive graphical interface and broad block library make it easy to create and analyze IoT systems, algorithms, and control techniques [73]. Researchers can create models of IoT devices, communication protocols, and network architectures to simulate their behavior and performance under various operating scenarios. The combination of MATLAB/Simulink and MATLAB's extensive computational capabilities allows for sophisticated analysis and optimization of IoT solutions, fostering innovation and advancement in the sector [74].

GloMoSim is a scalable simulation tool designed to model and simulate wireless and mobile networks, making it suitable for IoT deployments, including mobile and wireless devices [75]. It facilitates the simulation of large-scale IoT situations, allowing researchers to monitor network performance, assess mobility trends, and investigate protocol behavior. GloMoSim's modular architecture and flexible modeling environment enable researchers to examine a wide range of IoT applications, including smart cities, vehicular networks, and mobile health systems, thereby advancing IoT technologies and services.

TOSSIM is a customized simulation tool for designing and simulating wireless sensor networks (WSNs) that run on TinyOS. It enables academics to assess the performance of IoT applications and protocols in resource-constrained conditions common to WSNs [76]. TOSSIM's support for precise radio and sensor models enables researchers to evaluate the impact of network circumstances, node placement, and communication protocols on the overall performance of IoT systems. TOSSIM's connection with TinyOS enables realistic simulations of IoT deployments, which aids in the creation and optimization of WSN-based IoT applications.

Cooja is a widely recognized network simulator designed primarily for modeling and simulating IoT systems based on the Contiki operating system, which is a popular choice for IoT devices with few resources [77]. Cooja's extensive and versatile simulation environment allows researchers to reproduce real-world IoT deployments precisely. Cooja allows for the simulation of complicated scenarios involving thousands of interconnected devices by emulating large-scale IoT networks. It fully supports a variety of wireless communication methods, including IEEE 802.15.4, making it perfect for modeling wireless sensor networks and other low-power wireless IoT installations [78].

Moreover, Cooja provides a diverse set of visualization tools and debugging capabilities, allowing academics to undertake in-depth analyses and evaluations of IoT systems. Its simple user interface enables users to explore network topologies, monitor communication patterns, and evaluate data exchange between IoT devices in real time [79]. Researchers may evaluate critical performance indicators, including network latency, throughput, and packet loss, allowing them to discover bottlenecks and modify algorithms for greater efficiency and dependability.

Furthermore, Cooja allows researchers to examine energy consumption trends in IoT systems, which is critical for improving the power efficiency of battery-powered devices [78]. By simulating actual usage scenarios and monitoring energy consumption at the device level, researchers may uncover opportunities for energy conservation and develop techniques to extend the battery life of IoT devices.

In our future work, we intend to use Cooja as a crucial tool for modeling and assessing IoT systems. Using Cooja, we intend to examine many aspects of IoT deployments, such as network scalability, protocol performance, and energy efficiency. Furthermore, we want to investigate unique algorithms and strategies for addressing upcoming IoT concerns like as security, interoperability, and resilience. Using Cooja, we hope to advance the state-of-the-art in IoT research and contribute to the creation of novel solutions for real-world applications.

VI. DISCUSSION AND IOT FUTURE DIRECTIONS

The previous sections covered various aspects of IoT, including applications, technology, protocols, simulation tools, and routing strategies. This extensive research revealed several critical discoveries and implications for the future of IoT.

To begin, IoT's widespread adoption across a variety of industries, including smart cities, healthcare, industrial automation, and smart homes, demonstrates its transformative potential in transforming how we interact with our surroundings. The proliferation of connected devices, as well as the exponential growth of data generated by these devices, creates both opportunities and challenges for IoT stakeholders.

Technological improvements in IoT technologies, such as low-power wireless communication protocols (e.g., Bluetooth, Zigbee, LoRaWAN) and edge computing, have the potential to improve the efficiency, scalability, and reliability of IoT installations. These improvements enable the creation of more sophisticated and intelligent IoT solutions that can process data in real-time, do predictive analytics, and make autonomous decisions.

Moreover, the introduction of new simulation tools, such as Cooja and NS-3, has given researchers and practitioners robust platforms for modeling, analyzing, and optimizing IoT systems. Using these simulation tools, researchers may investigate complicated IoT situations, assess the performance of IoT applications and protocols, and validate innovative concepts before deploying them in real-world contexts.

In terms of protocols and routing mechanisms, continuing research efforts are aimed at tackling the unique issues that IoT installations present, such as energy efficiency, scalability, and security. Protocols like RPL and routing methods like CARP and AODVv2 are constantly improving to meet the changing needs of IoT networks, ensuring dependable and efficient communication between networked devices.

Looking ahead, numerous significant issues demand more investigation and research in the realm of IoT. This includes:

1. Security and Privacy: As the number of connected devices grows, the security and privacy of IoT data become increasingly important. Future research should focus on building strong security mechanisms, encryption algorithms, and access control regulations to protect IoT ecosystems from cyber attacks and privacy violations.
2. Interoperability and Standards: Ensuring seamless interoperability among diverse IoT devices and platforms remains a big problem. Future efforts should focus on developing common standards and protocols that enable plug-and-play interoperability, hence enabling the integration and interoperability of IoT systems across domains.
3. Edge Intelligence and Fog Computing: As the number of edge devices and sensors grows, so does the demand for

network edge intelligence. Future research should look into edge computing architectures, distributed machine learning algorithms, and edge analytics techniques that can enable real-time processing and decision-making at the network edge while minimizing latency and bandwidth consumption.

4. Sustainability and Energy Efficiency: As IoT deployments grow, the energy consumption of linked devices becomes a major concern. Future research should focus on building energy-efficient IoT solutions that use techniques like energy harvesting, low-power communication protocols, and adaptive resource management to extend battery life and reduce environmental effects.

Finally, advances in technology, research, and creativity are propelling IoT forward at a rapid pace. By addressing the difficulties and opportunities identified in this assessment, IoT has the potential to revolutionize sectors, improve quality of life, and address global challenges. We may achieve the transformative influence of IoT on society by collaborating interdisciplinaryly and conducting concerted research endeavors.

VII. Conclustion

In this comprehensive literature review, we studied the diverse environment of the Internet of Things (IoT), including its applications, technologies, protocols, simulation tools, and future directions. From smart cities that optimize resource allocation to healthcare systems that revolutionize patient care, the Internet of Things has proved its ability to disrupt industries and improve quality of life.

The assessment focused on the basic technologies that drive IoT deployments, such as low-power wireless communication protocols, edge computing, and sensor networks. Additionally, specific protocols and simulation tools such as Cooja and NS-3 were highlighted, which provide researchers with critical platforms for modeling, analyzing, and optimizing IoT systems. Looking ahead, the future of IoT holds both great potential and severe challenges. To fully achieve the potential of the Internet of Things, security risks, interoperability challenges, and sustainability concerns must be addressed. We can overcome these challenges and unleash the revolutionary power of the Internet of Things by encouraging cooperation, creativity, and interdisciplinary partnerships.

In conclusion, this paper provides a complete overview of the current state of IoT research and development. By seizing possibilities and overcoming obstacles, we can create a smarter, more connected future in which IoT improves people's lives, drives economic growth, and promotes global sustainability.

References

Chahal, R. K., Kumar, N., & Batra, S. (2020). Trust management in social Internet of Things: A taxonomy, open issues, and challenges. Computer Communications, 150, 13-46.

[1] Nižetić, S., Šolić, P., Gonzalez-De, D. L. D. I., & Patrono, L. (2020). Internet of Things (IoT): Opportunities, issues and challenges towards a smart and sustainable future. Journal of cleaner production, 274, 122877.

[2] Peng, S. L., Pal, S., & Huang, L. (Eds.). (2020). Principles of internet of things (IoT) ecosystem: Insight paradigm (pp. 263-276). Springer International Publishing.

[3] Furstenau, L. B., Rodrigues, Y. P. R., Sott, M. K., Leivas, P., Dohan, M. S., López-Robles, J. R., ... & Choo, K. K. R. (2023). Internet of things: Conceptual network structure, main challenges and future directions. Digital Communications and Networks, 9(3), 677-687.

[4] Gazis, V. (2016). A Survey of Standards for Machine-to-Machine and the Internet of Things. IEEE Communications Surveys & Tutorials, 19(1), 482-511.

[5] Kumar, S., Verma, P. K., Verma, R., Alsabaan, M., & Abdelkader, T. (2024). Internet of Things: Classification, Challenges, and Their Solutions. In Applications of Computational Intelligence Techniques in Communications (pp. 137-172). CRC Press.

[6] Malhotra, P., Singh, Y., Anand, P., Bangotra, D. K., Singh, P. K., & Hong, W. C. (2021). Internet of things: Evolution, concerns and security challenges. Sensors, 21(5), 1809.

[7] Al mojamed, M. (2021). On the use of LoRaWAN for mobile Internet of Things: The impact of mobility. Applied System Innovation, 5(1), 5.

[8] Falah, M. F., Panduman, Y. Y. F., Sukaridhoto, S., Tirie, A. W. C., Kriswantoro, M. C., Satria, B. D., & Usman, S. (2021). Comparison of cloud computing providers for development of big data and internet of things application. Indonesian Journal of Electrical Engineering and Computer Science, 22(3), 1723-1730.

[9] Rachit, Bhatt, S., & Ragiri, P. R. (2021). Security trends in Internet of Things: A survey. SN Applied Sciences, 3, 1-14.

[10] Silva, D., Carvalho, L. I., Soares, J., & Sofia, R. C. (2021). A performance analysis of internet of things networking protocols: Evaluating MQTT, CoAP, OPC UA. Applied Sciences, 11(11), 4879.

[11] Yakupov, D. (2022). Overview and comparison of protocols Internet of Things: MQTT and AMQP. International Journal of Open Information Technologies, 10(9), 90-98.

[12] Gupta, P. (2021, June). A survey of application layer protocols for Internet of Things. In 2021 International Conference on Communication information and Computing Technology (ICCICT) (pp. 1-6). IEEE.

[13] Farhangi, H. (2010). The path of the smart grid. IEEE Power and Energy Magazine, 8(1), 18-28.

[14] Gungor, V. C., Sahin, D., Kocak, T., Ergut, S., Buccella, C., Cecati, C., & Hancke, G. P. (2011). Smart grid technologies: Communication technologies and standards. IEEE transactions on Industrial informatics, 7(4), 529-539.

[15] Dhiman, R., Mukherjee, R., Ghousepeer, G. D., & Priyadarshini, A. (2022). Application of Artificial Intelligence in IoT-Based Healthcare Systems. In Deep Learning, Machine Learning and IoT in Biomedical and Health Informatics (pp. 271-296). CRC Press.

[16] Akash, M. R. R., & Shikder, K. (2020, February). IoT based real time health monitoring system. In 2020 Research, Innovation, Knowledge Management and Technology Application for Business Sustainability (INBUSH) (pp. 167-171). IEEE.

[17] Zhang, H., & Lu, X. (2020). Vehicle communication network in intelligent transportation system based on Internet of Things. Computer Communications, 160, 799-806.

[18] Zhu, F., Lv, Y., Chen, Y., Wang, X., Xiong, G., & Wang, F. Y. (2019). Parallel transportation systems: Toward IoT-enabled smart urban traffic control and management. IEEE Transactions on Intelligent Transportation Systems, 21(10), 4063-4071.

[19] Verma, P., Tiwari, R., Hong, W. C., Upadhyay, S., & Yeh, Y. H. (2022). FETCH: a deep learning-based fog computing and IoT integrated environment for healthcare monitoring and diagnosis. IEEE Access, 10, 12548-12563.

[20] Srivastava, A., Gupta, S., Quamara, M., Chaudhary, P., & Aski, V. J. (2020). Future IoT-enabled threats and vulnerabilities: State of the art, challenges, and future prospects. International Journal of Communication Systems, 33(12), e4443.

[21] Ejaz, W., & Anpalagan, A. (2019). Internet of things for smart cities: technologies, big data and security (pp. 1-15). Berlin/Heidelberg, Germany: Springer International Publishing.

[22] Tao, F., Wang, Y., Zuo, Y., Yang, H., & Zhang, M. (2016). Internet of Things in product life-cycle energy management. Journal of Industrial Information Integration, 1, 26-39.

[23] Lee, J., Davari, H., Singh, J., & Pandhare, V. (2018). Industrial Artificial Intelligence for industry 4.0-based manufacturing systems. Manufacturing letters, 18, 20-23.

[24] Saqlain, M., Piao, M., Shim, Y., & Lee, J. Y. (2019). Framework of an IoT-based industrial data management for smart manufacturing. Journal of Sensor and Actuator Networks, 8(2), 25.

[25] Li, X., Li, D., Wan, J., Vasilakos, A. V., Lai, C. F., & Wang, S. (2017). A review of industrial wireless networks in the context of Industry 4.0. Wireless networks, 23, 23-41.

[26] Queirós, A., Silva, A. G., Alvarelhão, J., Teixeira, A., & da Rocha, N. P. (2012, February). Ambient assisted living technologies, systems and services: a systematic literature review. In International Living Usability Lab Workshop on AAL Latest Solutions, Trends and Applications (Vol. 2, pp. 14-26). SCITEPRESS.

[27] Orfanos, V. A., Kaminaris, S. D., Papageorgas, P., Piromalis, D., & Kandris, D. (2023). A Comprehensive Review of IoT Networking Technologies for Smart Home Automation Applications. Journal of Sensor and Actuator Networks, 12(2), 30.

[28] Ali, W., Dustgeer, G., Awais, M., & Shah, M. A. (2017, September). IoT based smart home: Security challenges, security requirements and solutions. In 2017 23rd International Conference on Automation and Computing (ICAC) (pp. 1-6). IEEE.

[29] Liu, L., Stroulia, E., Nikolaidis, I., Miguel-Cruz, A., & Rincon, A. R. (2016). Smart homes and home health monitoring technologies for older adults: A systematic review. International journal of medical informatics, 91, 44-59.

[30] Raza, S., Misra, P., He, Z., & Voigt, T. (2017). Building the Internet of Things with bluetooth smart. Ad Hoc Networks, 57, 19-31.

[31] Oliveira, L. P., Silva, C. A., Sadok, D. F. H., Silva, T. D., Silva, A., & Kelner, J. (2023, March). BAIN: Bluetooth Adaption for IoT Device. In International Conference on Advanced Information Networking and Applications (pp. 421-433). Cham: Springer International Publishing.

[32] Komilov, D. R. (2023). Application of zigbee technology in IOT. International Journal of Advance Scientific Research, 3(09), 343-349.

[33] Zohourian, A., Dadkhah, S., Neto, E. C. P., Mahdikhani, H., Danso, P. K., Molyneaux, H., & Ghorbani, A. A. (2023). IoT Zigbee device security: A comprehensive review. Internet of Things, 100791.

[34] Alyami, M., Alharbi, I., Zou, C., Solihin, Y., & Ackerman, K. (2022, January). WiFi-based IoT devices profiling attack based on eavesdropping of encrypted wifi traffic. In 2022 IEEE 19th Annual Consumer Communications & Networking Conference (CCNC) (pp. 385-392). IEEE.

[35] Chen, C., Li, J., Balasubramaniam, V., Wu, Y., Zhang, Y., & Wan, S. (2020). Contention resolution in Wi-Fi 6-enabled Internet of Things based on deep learning. IEEE Internet of Things Journal, 8(7), 5309-5320.

[36] Vasumathi, K., & Biradar, R. L. (2023, February). MU-MIMO User Selection & OFDMA in 802.11 AX-Based WI-FI Networks. In 2023 Fifth International Conference on Electrical, Computer and Communication Technologies (ICECCT) (pp. 1-10). IEEE.

[37] Muppavaram, K., Govathoti, S., Kamidi, D., & Bhaskar, T. (2023). Exploring the Generations: A Comparative Study of Mobile Technology from 1G to 5G. Int. J. Electron. Commun. Eng, 10, 54-62.

[38] Yadav, P., Upadhyay, A., Prasath, V. S., Ali, Z., & Khare, B. B. (2020, March). Evolution of wireless communications with 3G, 4G, 5G, and next generation technologies in India. In International Conference on Emerging Trends and Advances in Electrical Engineering and Renewable Energy (pp. 355-359). Singapore: Springer Nature Singapore.

[39] Ullah, R., Ullah, S., Faisal, F., Ullah, R., Mabrouk, I. B., Al Hasan, M. J., & Kamal, B. (2021). A novel multi-band and multi-generation (2G, 3G, 4G, and 5G) 9-elements MIMO antenna system for 5G smartphone applications. Wireless Networks, 27, 4825-4837.

[40] Tan, W. C., & Sidhu, M. S. (2022). Review of RFID and IoT integration in supply chain management. Operations Research Perspectives, 9, 100229.

[41] Shrivastava, A., Suji Prasad, S. J., Yeruva, A. R., Mani, P., Nagpal, P., & Chaturvedi, A. (2023). IoT Based RFID Attendance Monitoring System of Students using Arduino ESP8266 & Adafruit. io on Defined Area. Cybernetics and Systems, 1-12.

[42] Manzano, L. G., Boukabache, H., Danzeca, S., Heracleous, N., Murtas, F., Perrin, D., ... & Silari, M. (2021). An IoT LoRaWAN network for environmental radiation monitoring. IEEE Transactions on Instrumentation and Measurement, 70, 1-12.

[43] Alenezi, M., Chai, K. K., Chen, Y., & Jimaa, S. (2020). Ultra-dense LoRaWAN: Reviews and challenges. IET Communications, 14(9), 1361-1371.

[44] Lazaro, A., Villarino, R., & Girbau, D. (2018). A survey of NFC sensors based on energy harvesting for IoT applications. Sensors, 18(11), 3746.

[45] Kumar, R. (2024). Application of Smart Connected-Home Sensors Towards IoT Service. In AIoT and Smart Sensing Technologies for Smart Devices (pp. 103-126). IGI Global.

[46] Mekki, K., Bajic, E., Chaxel, F., & Meyer, F. (2018, March). Overview of cellular LPWAN technologies for IoT deployment: Sigfox, LoRaWAN, and NB-IoT. In 2018 ieee international conference on pervasive computing and communications workshops (percom workshops) (pp. 197-202). IEEE.

[47] Wild, T. A., van Schalkwyk, L., Viljoen, P., Heine, G., Richter, N., Vorneweg, B., ... & Wikelski, M. (2023). A multi-species evaluation of digital wildlife monitoring using the Sigfox IoT network. Animal Biotelemetry, 11(1), 1-17.

[48] Bovet, G., & Hennebert, J. (2013, September). Web-of-Things Gateways for KNX and EnOcean Networks. In International Conference on Cleantech for Smart Cities & Buildings from Nano to Urban Scale (CISBAT 2013).

[49] Wu, Y., & Feng, T. (2022). An Anonymous Authentication and Key Update Mechanism for IoT Devices Based on EnOcean Protocol. Sensors, 22(17), 6713.

[50] Migabo, E. M., Djouani, K. D., & Kurien, A. M. (2020). The narrowband Internet of Things (NB-IoT) resources management performance state of art, challenges, and opportunities. IEEE Access, 8, 97658-97675.

[51] Dangana, M., Hussain, S., Ansari, S., Imran, M., & Zoha, A. (2024). A Digital Twin (DT) approach to Narrow-Band Internet of Things (NB-IoT) wireless communication optimization in an industrial scenario. Internet of Things, 101113.

[52] Qays, M. O., Ahmad, I., Abu-Siada, A., Hossain, M. L., & Yasmin, F. (2023). Key communication technologies, applications, protocols and future guides for IoT-assisted smart grid systems: A review. Energy Reports, 9, 2440-2452.

[53] Zikria, Y. B., Yu, H., Afzal, M. K., Rehmani, M. H., & Hahm, O. (2018). Internet of things (IoT): Operating system, applications and protocols design, and validation techniques. Future Generation Computer Systems, 88, 699-706.

[54] Yang, Z., & Chang, C. H. (2019, February). 6LoWPAN Overview and Implementations. In EWSN (pp. 357-361).

[55] Babun, L., Aksu, H., Ryan, L., Akkaya, K., Bentley, E. S., & Uluagac, A. S. (2020, June). Z-iot: Passive device-class fingerprinting of zigbee and z-wave iot devices. In ICC 2020-2020 IEEE International Conference on Communications (ICC) (pp. 1-7). IEEE.

[56] Kalita, A., & Khatua, M. (2022). 6tisch–ipv6 enabled open stack iot network formation: A review. ACM Transactions on Internet of Things, 3(3), 1-36.

[57] Mou, T. D., & Srivastava, G. (2022). Network Protocols for the Internet of Health Things. In Intelligent Internet of Things for Healthcare and Industry (pp. 21-66). Cham: Springer International Publishing.

[58] Hong, Y. G., Gomez, C., Choi, Y., Sangi, A., & Chakrabarti, S. (2023). RFC 9453 Applicability and Use Cases for IPv6 over Networks of Resource-constrained Nodes (6lo).

[59] Herrero, R. (2022). IPv6 Adaptation in Ultrasonic NFC IoT Communications. In Futuristic Research Trends and Applications of Internet of Things (pp. 159-181). CRC Press.

[60] Rana, A. K., & Sharma, S. (2021). Contiki Cooja Security Solution (CCSS) with IPv6 routing protocol for low-power and lossy networks (RPL) in Internet of Things applications. In Mobile Radio Communications and 5G Networks: Proceedings of MRCN 2020 (pp. 251-259). Springer Singapore.

[61] Kharrufa, H., Al-Kashoash, H. A., & Kemp, A. H. (2019). RPL-based routing protocols in IoT applications: A review. IEEE Sensors Journal, 19(15), 5952-5967.

[62] Raoof, A., Matrawy, A., & Lung, C. H. (2018). Routing attacks and mitigation methods for RPL-based Internet of Things. IEEE Communications Surveys & Tutorials, 21(2), 1582-1606.

[63] Vaigandla, K. K., Karne, R. K., & Rao, A. S. (2021). A Study on IoT Technologies, Standards and Protocols. IBMRD's Journal of Management & Research, 7-14.

[64] Sandhiyaa, S., & Gomathy, C. (2023). Efficient Routing Protocol with Localization Based Priority & Congestion Control for UWSN. Computers, Materials & Continua, 74(3).

[65] Soomro, M. A., Hussain, Z., Channa, M. I., & Ahmed, M. (2020). EPLAODV: Energy Priority and Link Aware Ad-hoc On-demand Distance Vector Routing Protocol for Post-disaster Communication Networks. Engineering, Technology & Applied Science Research, 10(1).

[66] Alsaadi, M. S., & Alotaibi, N. D. (2019). Routing protocols design and performance evaluation in wireless mesh networks. International Journal of Technology Diffusion (IJTD), 10(1), 60-74.

[67] Zola, E., Martin-Escalona, I., Barceló-Arroyo, F., & Machado, S. (2021, October). Implementation and analysis of the AODVv2 Routing Protocol in ARM devices. In 2021 International Symposium on Networks, Computers and Communications (ISNCC) (pp. 1-6). IEEE.

[68] Kamoltham, N., Nakorn, K. N., & Rojviboonchai, K. (2012, January). From NS-2 to NS-3-Implementation and evaluation. In 2012 Computing, Communications and Applications Conference (pp. 35-40). IEEE.

[69] Singh, S. P., & Sharma, S. C. (2017). A novel energy efficient clustering algorithm for wireless sensor networks. Engineering, Technology & Applied Science Research, 7(4), 1775-1780.

[70] Varga, A., & Hornig, R. (2010, May). An overview of the OMNeT++ simulation environment. In 1st International ICST Conference on Simulation Tools and Techniques for Communications, Networks and Systems.

[71] Montenegro, D., & Dugan, R. C. (2017, May). OpenDSS and OpenDSS-PM open source libraries for NI LabVIEW. In 2017 IEEE Workshop on Power Electronics and Power Quality Applications (PEPQA) (pp. 1-5). IEEE.

[72] Xue, D., & Chen, Y. (2013). System simulation techniques with MATLAB and Simulink. John Wiley & Sons.

[73] Yildirim, M., Catalbas, M. C., Gulten, A., & Kurum, H. (2016). Computation of the speed of four in-wheel motors of an electric vehicle using a radial basis neural network. Engineering, Technology & Applied Science Research, 6(6), 1288-1293.

[74] Bajaj, L., Takai, M., Ahuja, R., Tang, K., Bagrodia, R., & Gerla, M. (1999). Glomosim: A scalable network simulation environment. UCLA computer science department technical report, 990027(1999), 213.

[75] Levis, P., Lee, N., Welsh, M., & Culler, D. (2003, November). TOSSIM: Accurate and scalable simulation of entire TinyOS applications. In Proceedings of the 1st international conference on Embedded networked sensor systems (pp. 126-137).

[76] Thomson, C., Romdhani, I., Al-Dubai, A., Qasem, M., Ghaleb, B., & Wadhaj, I. (2016). Cooja simulator manual.

[77] Osterlind, F., Dunkels, A., Eriksson, J., Finne, N., & Voigt, T. (2006, November). Cross-level sensor network simulation with cooja. In Proceedings. 2006 31st IEEE conference on local computer networks (pp. 641-648). IEEE.

[78] Charles, A. J., & Kalavathi, P. (2018). QoS measurement of RPL using Cooja simulator and Wireshark network analyser. International Journal of Computer Sciences and Engineering, 6(4), 283-291.

[79] Behal, A., Sandhu, J. K., & Gupta, G. (2023, February). Using The Cooja Simulator, Analysing The Routing Protocol (RPL) For Low Power And Lossy Networks In IoT. In 2023 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS) (pp. 1-4). IEEE.