Studying the Impact of Mobility on the Link Layer Structure of the Mobile Internet of Things

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Abstract

As an exciting new topic in information technology, the Internet of Mobile Things (IoMT) enables any application to allow objects to move freely in designated locations. Also, network lifetime is a major challenge in IoMT, which attempts to increase the lifetime of IoMT. In this regard, mobility is used as an efficient method to reduce the number of transitions between objects. Mobility in IoT leads to increased network lifetime and reduced energy consumption. Although the mobility of sensors and actuators plays a vital role in IoMT, there is no comprehensive and systematic study to analyze its important methods. Therefore, this paper aims to systematically investigate and examine the impact of mobility in the Internet of Things and the specific characteristics of the link layer in the mobile Internet of Things.

Keywords: Internet of Thing, Mobility, Link Layer, lifetime of IoMT

1. Introduction

Internet of Things (IoT)[1] also known as the Internet of objects is a foundation for connecting things, sensors, actuators, and other smart technologies, thus enabling person-to-object and object-to-object communications[2, 3].Currently the system of interconnected computer networks to link devices worldwide, and Internet facilitate the data transferring and sharing[4, 5]. Recently, the IoT has become the important research attention [6-8] by integrating the heterogeneous and pervasive objects to offer information about the physical world[9, 10]. This information is presented by other devices and multiple platforms for using the actuators and sensors [6]. Therefore, the IoT makes feasibilities to offer the new services to end-users from the surroundings monitoring[11-13]. It allows physical things to see, hear, and think by connecting them to share data and to harmonize decisions [14, 15]. The IoT provides smart objects through using its underlying technologies such as pervasive and ubiquitous computing, sensor networks, Internet protocols, communication technologies, and applications[16, 17]. It develops the applications in several domains such as mobile healthcare, industrial automation, home automation, medical aids, traffic management, and many others[18, 19]. The number of physical things connected to the Internet is increased at an unheard rate realizing the ideas of the IoT[20, 21]. According to the[22, 23], more than 75.4 billion devices will be connected to the internet by 2025 and those connections will facilitate the used data to analyze, preplan, manage, and make intelligent decisions autonomously. IoT has three important characteristics: Instrumented objects; interconnected terminals and intelligent services[24]. Ordinary objects are instrumented such that cups, tables, screws, foods and automobile tires can be individually addressed by means of embedded chip, Radio-frequency identification(RFID), bar code and so on[25]. The instrumented physical objects are interconnected as autonomic network terminals. In such an extensively interconnected network, letting every object participate in the service flow to make the pervasive service intelligent[26]. Based on the IT's definition of IoT, it can be said that IoT allows people and to be connected Anytime, Anyplace with Anything and Anyone ideally using Any network and Any Service (6A) which IoT is a sophisticated comprehensive inter-disciplinary technology addressing key elements such as Convergence, Content, Collections (Repositories), Computing, Communication and Connectivity (6C) in the context of IoT[27].

IoT represents interconnected static things such as smart meters in smart grid, smart sensors in advanced water systems, RFID and motion sensors in smart buildings, or traffic cameras at road intersections[28]. But in addition to static IoT, mobility of things is coming forward as mobile phones and vehicles are equipped with more and more advanced sensors. The mobile devices are then able to communicate with each other, with surrounding cyber-physical infrastructures, and represent the Internet of Mobile Things(IoMT)[6]. The difference between IoT and IoMT is that when considering mobility of things, major changes occur in terms of (a) context, e.g., where the mobile device is located, in what hands it is now, (b) Internet access and connectivity, e.g., if the mobile device is connected at all, and when connected to what wireless or wired network, at what bandwidth level, and with what security, (c) energy availability, e.g., where can the mobile device charge again, how much energy does the mobile app need, (d) security and privacy, e.g., what kind of security infrastructure the mobile device encounters when moving among different locations, and what private information do service providers have about user using a mobile device[29, 30]. Hence, when considering IoMT, mobility becomes a first class object and one has to look at the IoMT separately from IoT. It is important to note that mobility of devices has been studied for many past years[29, 31-33], But what changes now is the increased number of sensors per mobile device, the increased density of mobile devices in users' environments, and most importantly, the increased interconnectivity and the increased reliance of users on mobile devices, making mobile devices and their interconnectivity an integral part of users' daily routines and smart environments.

Although the mobility of objects has a vital role in IoT, there is not any organized and general study about examining its significant techniques. Reviewing and investigating the mobility in IoT are considered as the main goals of this paper. Briefly, this study reviews the selected papers systematically, offers the detailed comparison of the methods, and also suggests the guideline for further studies[34]. The main contributions of this paper are as follows:

- Presenting a systematic review and studying the mobility concerns in IoT.
- Exploring the primary challenges and issues about the mobile objects in IoT.

- Dividing objects into two main classes, including static device and mobile device.
- Providing an accurate assessment using some important metrics such as energy availability, security and Internet access and connectivity.
- Describing the important areas to increase the efficiency of IoT through a mobile patterns.

The remainder of this paper is organized as follows. Section 2 considers some related work. In section 3, the background of the Internet of Things is reviewed. The research methodology is provided in Section 4. Section 5 discusses the selected mobility techniques in link layer of mobility IoT and categorizes them, also it offers the classification and comparison of the selected techniques. Lastly, Section 8 provides the limitations and conclusion.

2. Related works

Lots of review papers have been prepared in the field of IoT, including security, middleware, routing, data quality and etc. However, there is not any a comprehensive research about mobility concerns in IoT. In the literature, there are only a few works about mobile IoT. This section refers to some papers in the field of mobility concerns in IoT. Finally, some research about mobility concerns in IoT has been carried out. This section will refer to some review papers that discussed the mobility concerns in the IoT and outlines their main advantageous and disadvantageous.

One of the important studies of the mobility concerns in IoT has been carried out by Ghaleb, Subramaniam [35]. In their survey, various mobility protocols such as MIPv4, MIPv6, FMIPv6, HMIPv6 and etc. were analyzed. Then, a comparative analysis between several mobility protocols in terms of various characteristics has been provided. However, there is a gap for the papers selection mechanism and analyzing the recently published papers. Also, this paper does not focus on common issues such as: minimizing HO latency, packet loss, mobility signaling costs, end-to-end delay, and power consumption.

Also, in [36], future and enabling technologies for mobile IoT including Low Power Wide Area (LPWA) for mobile IoT technologies, 5G, massive IoT, critical IoT , semantic web and IoT have been studied. The issue has been investigated and some articles have been reviewed. Then some Applications including smart cities, transportation and logistics, healthcare have been discussed. However, there exist some gaps for discussing the open issue, recently published papers and papers selection mechanism.

Moffat, Hammoudeh [37] have examined approaches to data security on mobile devices in IoT. The first part of the their survey focuses on Ciphertext-Policy Attribute-based Encryption (CP-ABE) in mobile computing primarily due to the fact that most ABE schemes in mobile computing appear to be based on CP-ABE or extensions to it. The second part of their paper is to assess the research into the application of ABE in IoT and determine whether the schemes from CP-ABE in mobile computing have been translated as potentially applicable - either directly or with some minor enhancements - to data security in IoT. The approach is to describe the schemes' system architectures using consistent notation and terminologies where appropriate and then measure each in terms of performance and security.

business value in accordance with the survey. Mobile applications in feedback and

Table 1. Studied papers in the field of mobility concerns in IoT

Paper	Main categories	Advantages	Disadvantages
[35]	A comparative analysis between several mobility protocols in terms of various characteristics	-various mobility protocols were analyzed -a comparative analysis between several mobility protocols in terms of various characteristics have been provided	- does not focus on common -imprecise papers selection mechanism -recently published papers have not been studied
[36]	IoT Key Enabling and Future Technologies:5G, Mobile IoT and Applications	-future and enabling technologies for mobile IoT have been studied -some applications including smart cities, transportation, healthcare have been discussed	there exist some gaps for -discussing the open issue -recently published papers -papers selection mechanism
[37]	Data Security on Mobile Devices and its Application to IoT	-Steve et al. have examined approaches to data security on mobile devices in IoT -focuses on Ciphertext-Policy Attribute-based Encryption (CP-ABE) in mobile computing	-some challenges like security, connectivity, performance and latency (delay) have not been addressed -imprecise papers selection mechanism -there is a gap for discussion in open issue
[38]	Mobile Sensing	-mobile sensing technologies have been classified -some of the challenges that occur when mobile sensing is combined with the Internet of Things are discussed	-only mobile sensing was included and the mobile device and searching methodology were not discussed especially in IoT. -no specific mechanism forpapers selection
[39]	Mobile computing in IoT	-numerous mobile applications in mobile IoT have been reviewed -some problems and adoption factors ware mentioned	-recently published papers have not been investigated -open issues have not been well described

However, some of the challenges like security, connectivity, performance and latency (delay) have not been addressed.

A review of mobility concerns in the IoT has been presented by [38] in order to study the mobile sensing technologies in eight classes: crowd sensing, control, health, feedback applications, agriculture, games and sports, interaction with surroundings, transportation. Then explained that mobile computing has a great impact in the field of health, transportation, control and games or sports. These applications have the highest

home automation are increasing. Finally, the use of the mobile application in smart farming or agriculture and interaction with things are still slower.In the following, some of the challenges that occur when mobile sensing is combined with the Internet of Things are discussed below: Regular Sensing, Mobile Crowd sensing, Security, Privacy, Congestion, Precise, Personnel, Mood analysis, Cloud storage, Market Cases. However, only mobile sensing was included and the mobile device and searching methodology were not discussed especially in IoT environments.

Finally In [39], numerous mobile applications in mobile IoT such as mobile health (m-health), mobile learning (m-learning) and mobile tourism (M-tourism) have been reviewed. some problems and adoption factors ware mentioned. However, this paper does not contain all applications of mobile IoT. Furthermore, recently published papers have not been investigated and open issues have not been well described.

Briefly, the reviewed articles have some defects that are as follows:

- In some of the papers, few articles have been reviewed.
- The article selection mechanism has not been identified well in many of the papers.
- Mobility concerns in IoT have not been regarded in all of the reviewed survey papers.
- Future works and open issues have not been articulated well.

It is important to consider that these surveys were not prepared a pure systematic literature-based review of the mobility concerns in IoT, future challenges, their classification, and the key role that internet of mobile things could have in the IoT. By responding to each of these questions, this paper formalizes three questions in the next section to choose remarkable studies for evaluation and then accents the significance of mobility mechanisms in IoT, present challenges, and future directions in internet of mobile things.

3. Background

3.1. IoT

IoT has three important characteristics: Instrumented objects; interconnected terminals and intelligent services[40]. (See Figure 1) Ordinary objects are instrumented such that cups, tables, screws, foods and automobile tires can be individually addressed by means of embedded chip, RFID, bar code and so on. The instrumented physical objects are interconnected as autonomic network terminals. In such an extensively interconnected network, letting every object participate in the service flow to make the pervasive service intelligent. Based on the IT‘s definition of IoT, it can be said that IoT allows people and to be connected Anytime, Anyplace with Anything and Anyone ideally using Any network and Any Service (6A) which IoT is a sophisticated comprehensive inter-disciplinary technology addressing key elements such as Convergence, Content, Collections (Repositories), Computing, Communication and Connectivity (6C) in the context of IoT[41, 42].

IoT device that can suitably fit into the IoT network comprise four features: ability to collect and transmit data; actuate devices based on triggers; receive information; and assist in communication. Thus, the main components of IoT device include main control units, the sensors, the communication modules and the power sources[43]. A sensor can measure a physical quality and converts it into a signal that can be read by an instrument or an observer. In IoT, the ability to detect changes in the physical status of things is very essential for recording changes in the environment. Sensor collects data from the environment, such as vibrations, temperature, and pressure, among others, and converts them into data that can be processed and analyzed; allowing the IoT to record any changes in the environment or an object[44]. The communication modules are responsible for connectivity of IoT's platform based on wireless or wired communication protocol they are designed for. In order for things to communicate with one another and the internet, there is need to integrate a wireless (Wi-Fi, Bluetooth or ZigBee) or wired (Ethernet) communication system. The communication technologies include the RFID used in the identification and tracking of objects; Bluetooth used in connection of two small devices with each other; ZigBee for creation of automatic peer networks; Wi-Fi RF Links; and the Cellular Networks[45]. From 1999 till date, a whole range of IoT platforms (Pachube, Things peak, etc), standards (6LoWPAN, Dash7, etc) hardware and software (Contiki, TinyOS, etc) have been developed[46, 47]

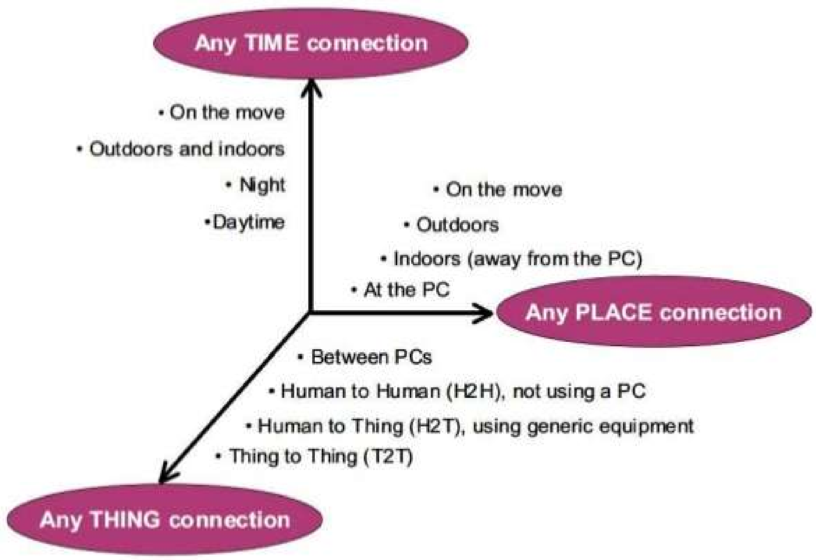

Fig. 1. A new dimension of Information and Communication Technologies (ICTs)

3.2. Hardware/software infrastructures of IoT

IoT scenarios will be characterized by a high-degree of heterogeneity at any level (device, networking, middleware, application service, data and semantics), preventing IoT solutions from interoperating[48]. At the device level, several communication solutions are currently used. Traditional ubiquitous communications (i.e. 3/4/5G cellular communications and Wi-Fi technologies) are evolving to support higher bandwidths and lower cost while other mobile phones, that have already embedded commercial technologies (e.g. Bluetooth, NFC,ANT+), are opening up new possibilities for the IoT (i.e. Bluetooth v4.x and upcoming v5). Alongside these, it is also necessary to consider traditional communication protocols and mechanisms for sensors, actuators and smart objects (e.g. ZigBee, ISA100, Wireless Hart, IEEE802.11ah, Z-Wave, ZigBee Smart, 802.15.4e, ISA100.11a) together with other non-standard proprietary solution (e.g. SIGFOX, LoRa). At the network level there are many solutions for encapsulation (e.g. 6LowPAN, 6TiSCH, 6Lo, Thread) and routing (e.g.

RPL, CORPL, CARP). At the middleware level, the situation is not very different and there are several competing solutions (e.g. FIWARE, Fed Net, Ubicomp, Smart Products, ACOSO, Skynet) also including cloud computing based infrastructures (e.g. Amazon EC2, Google App Engine, Xively, MS Windows Azure). The data and semantics level also presents high heterogeneity (e.g. WSDL, JSON, UD CAP, uCode Relational Model, RDF, OWL, W3C Semantic Sensor Network XG) and the software realm is even richer including many basic software technologies (e.g. TinyOS, Contiki, FreeRTOS, eCos, Android, Ubuntu, Java, WebRTC, REST, WAMP and, Django). Finally, from the hardware perspective, the technological state of the art is also very heterogeneous as many commercial solutions have already been developed (e.g. Arduino, Beagle Board, TelosB sensor mote, Raspberry PI, pc Duino, Cubie board, Libeliumwaspmote) and new digital business opportunities will arise and evolve as software is adapted to meet changing needs by designing interoperable flexible systems based on the Software Defined Radio (SDR) paradigm[49, 50].

3.3.Internet of Mobile things

Internet-wide communication and processing of data from tens of billions of sensors and actuators within devices and smart objects is still a challenge. In particular, very few studies have focused on the Internet of Mobile Things (IoMT), in which the connectable things (or Objects) can be moved or can move independently, and yet remain remotely accessible and controllable from anywhere in the Internet. Mobile Objects (M-OBJs) may have very different size, purpose and complexity - they may range from terrestrial vehicles of any type (cars, busses, etc.), over mobile domestic or industrial robots, aerial robots (UAVs), to very tiny and light-weight wearable devices, badges or sensor tags. In fact, a M-OBJ may be any movable object that carries sensors and/or actuators and provides some means of wireless connectivity[51].

The difference between IoT and IoMT is that when considering mobility of things, major changes occur in terms of (a) context, e.g., where the mobile device is located, in what hands it is now, (b) Internet access and connectivity, e.g., if the mobile device is connected at all, and when connected to what wireless or wired network, at what bandwidth level, and with what security, (c) energy availability, e.g., where can the mobile device charge again, how much energy does the mobile app need, (d) security and privacy, e.g., what kind of security infrastructure the mobile device encounters when moving among different locations, and what private information do service providers have about user using a mobile device. Hence, when considering IoMT, mobility becomes a first class object and one has to look at the IoMT separately from IoT. It is important to note that mobility of devices such as mobile phones and vehicles has been investigated for many years, especially the design of individual devices and their dealings with mobility and usage by users in mobile environments[29, 32, 52, 53].

3.3.1. Energy efficiency

One of the most important issues that face low-power and lossy networks is limited energy, the design of the IEEE 802.15.4 and

Routing Protocol for Low-power networks (RPL) both take energy consumption into account and propose methods to minimize its usage. The problem of energy consumption in RPL is addressed by the trickle timer [54], which aims to minimize the number of unnecessary control messages. However, the trickle timer is proven to have its own disadvantages dealing with dynamic environments[55], resulting in an inefficient transmission of data and high energy loss due to failed packet delivery.

3.3.2. Mobility routing protocol in IoT

Mobility in a LoWPAN sensor network is directly related to the underlying routing protocol[56]. RPL though considered to be the most adequate for 6LoWPAN based WSNs, it has been originally devised for static networks[57]. As such, it originally lacks the support of mobility and many proposals have been made to integrate a mobility support in this routing protocol to make it mobile compliant. However, various weaknesses still persist in terms of performances such as high signaling cost and large handover delay. The signaling cost has a direct impact on the power consumption as well as overloading the different links[58]. The handover delay has a negative impact on the connectivity of the mobile devices and the routing paths and consequently affects the transmission of data.

The main requirements of an efficient mobility support in the RPL protocol concern: 1) Providing a fast mobility detection and a proactive process in order to quickly react against topology changes caused by the mobility of devices and avoid their disconnection by finding new viable attachment points, and 2) decreasing the signaling overhead[59].

3.3.3. Security

One of such problems having key value in computer security is a problem of the IoMT security monitoring. Security monitoring consists in continuous collecting the big arrays of heterogeneous data about security events taken place in IoMT networks. These data are exposed to the further analysis to detect the signs of possible harmful activity for the purpose of framing of timely measures of counteraction to the existing and perspective attacks against the infrastructure of IoMT. Solutions of this problem will promote the substantial enhancement of IoMT security[60].

3.3.3. Mobile Data Collection

Mobile phones and vehicles nowadays come equipped with advanced sensing and communication capabilities. These sensors can capture a wide range of information, including physical, personal, and social contextual information that can be used in data analysis and data management. However, how to leverage and manage these sensors efficiently remains challenging since each of these sensors employs a different technology with distinct tradeoffs in terms of energy consumption, connectivity, and sensing capability. More importantly, the collected sensing traces are only useful if they are clean, complete, and privacy-preserved[61].

3.3.4. Mobile Data Analytics

As sensing data are collected from mobile devices, they can be transferred to a centralized server for storage and analysis. Different from analyzing data of static sensor networks, the analysis of data from mobile devices poses a number of challenges that are centered around the mobility of devices:

- Mobility characterization: How to characterize the mobility of devices?
- Exploiting mobility models: How to leverage the mobility models of IoMT devices to improve the effectiveness of data analysis tasks[6].

4. Research methodology

In order to have a clear picture of the mobility concerns in the IoT, this section provides a systematic literature review (SLR) of mobility concerns with a specific focus on researches related to IoT environments. The first step in conducting a systematic review is to perform a thorough search of the literature for relevant papers[62]. The methodology section of a systematic review will list all of the databases and citation indexes that were searched such as Springer, IEEE, and Science Direct, ACM and any individual journal that was searched. The titles and abstracts of identified articles were checked for their eligibility and relevance investigated in form of our issue. The article classification and selection process as two parts of the search process are discussed in the next subsections.

4.1. Question formalization

In this section, the most related issues and challenges in the field of mobility concerns in the IoT are identified. The evaluation of the selected methods is based on the subsequent Research Questions (RQ):

- RQ 1: What is the internet of mobile things?
- This question was answered in Section 1 and Section 3.
- RQ 2: What is difference between IoT and IoMT?
- This question was answered in Section 1.
- RQ 3: How is the article searching and selecting to evaluate?
- This question will be answered in the next subsection.
- RQ 4: What are the limitations of IoMT?

This question will be answered in Section 5.

4.2. Article selection process

Automated search using keywords and article selection using the title, abstract and quality of the publisher are the steps of choosing articles for the SLR[62]. The online scientific databases based on electronic searching is used to direct the search process. Therefore, first, we use the following databases to find a research paper:

- Springer (http://link.springer.com/)
- Elsevier(www.elsevier.com)
- IEEE explorer (http://ieeexplore.ieee.org/)
- Science Direct (http://www.sciencedirect.com/)
- Sage (http://online.sagepub.com/)
- Taylor rancis(http://www.tandfonline.com/)
- ACM (http://www.acm.org/)
- Scientific (http://www.scientific.net/)
- Emerald (http://www.emeraldinsight.com/)

By adding synonyms and alternative spellings of the main elements, the following search string was defined:

("Mobile" OR "Mobility") AND ("internet of things" OR "IoT")

"Internet of Mobile Things" OR "IoMT"

We found 263 articles using this strategy. Fig. 2 illustrates the classification of the studies by various publishers and Fig. 3

shows the distribution of the articles over time in some famous publishers such as IEEE, Springer, Elsevier and ACM.

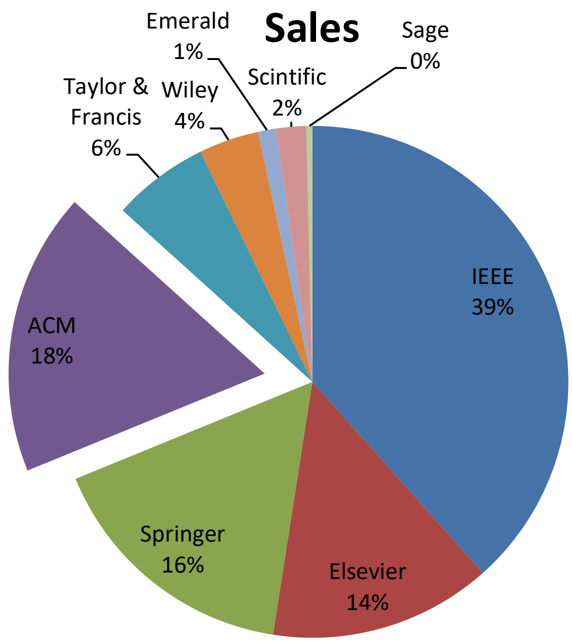

Fig. 2. Percentage of published articles based on different publishers.

Certain practical screening criteria are also used in the next step to assure that only the qualified publications are included from 2013 up to 2024. The following inclusion criteria are applied to select the final papers:

- Studies are published online from 2013 to 2024.
- Studies are retrieved from journal publications and conferences.
- Studies are published in mobility concerns in the IoT field.
- Studies explained the proposed method evidently and clearly.
- Studies focused on internet of mobile things.

The following exclusion criteria are applied to select the final papers:

- Studies regarding survey, systematic literature reviews, reports, and editorial notes.
- Studies are not indexed in the Scopus.
- Studies are published without the peer-reviewed procedure.

After reading abstracts and searching keywords, we eliminated the inappropriate articles. Then, the entire body of the remaining papers was checked and those which were not related to our concerned area were also crossed out. After eliminated inappropriate articles, 21 studies were identified where 43% are related to IEEE, 19% of the articles are related to Springer, 19% are related to Elsevier, 14% are related to IEEE conference and 5% are related to ACM.

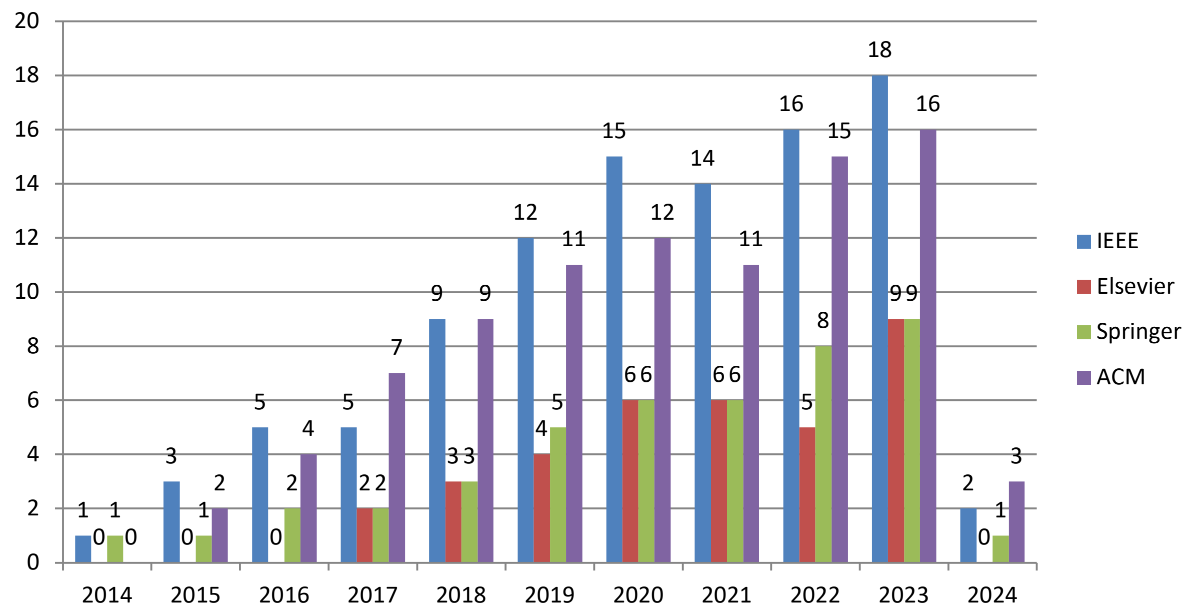

Fig. 3. Percentage of published articles based on different publishers.

5. Link layer mobility support in IoT

5.1. Overview

The link layer has a primary sublayer known as the MAC sublayer that provides channel access control mechanism, enabling several nodes to communicate in a network. The MAC layer provides support for unicast, multicast, anycast and broadcast communication services that one node may use during communication with other nodes in the network. In IoT, MAC protocols need to take into consideration energy efficiency, reliability and low access delay to transmission resources as priorities. One of the biggest means of reducing energy consumption in the IoT is through designing energy efficient MAC protocols. MAC protocols with wake/sleep periods are the most energy efficient MAC protocols[63].

In recent years, researchers have also included in their protocol design data delivery efficiency (delay and throughput) alongside energy efficiency[64]. Besides energy efficiency, a MAC protocol has to be scalable and adaptable to changes in the network[65]. Mobility is one of the changes in the network.

IEEE 802.15.4[66] is a standard which defines the physical layer and the MAC layer for Low-Rate Wireless Personal Area Networks (LR-WPANs). The standard has been used as a basis for different networks, e.g., ZigBee, ISA100.11a, Wireless HART, and 6LoWPAN. The IEEE 802.15.4 defines two types of devices which can participate in the network: a Full-Function Device (FFD), which has full levels of functionality and can serve as a coordinator, and a Reduced-Function Device (RFD) which has more limited functionality. The MAC layer has the following features: beacon management, channel access, Guaranteed Time Slot (GTS) management, frame validation, acknowledged frame delivery, association, and disassociation. The IEEE 802.15.4 defines two types of channel access mechanism: non-beacon enabled, which uses un-slotted CSMA/CA, and beacon enabled mode where slotted CSMA/CA is used.

5.2. Review

In [67], the authors propose a 3-Dimensional Group Management MAC (3-D GM MAC) scheme to maximize energy efficiency for IoT ecosystem environments that include mobile IoT sensor devices. The mobile sensor devices in a target IoT ecosystem gather and collect any required data while moving and transmitting the collected data to a sink node. The proposed scheme is designed to set up node group numbers based on distances from a sink node to mobile sensor devices located in 3-dimensional space which simulates an IoT ecosystem. Energy consumption of the sensor devices depends on the distance from the sink node and also affects overall lifetime of the IoT ecosystems. The proposed 3-D GM MAC scheme groups sensor devices based on the distance (hop) from the sink node and transmits the collected data only to the next higher group level. That is, the data is transmitted only in the direction to the sink node. In addition, the energy efficiency of the entire IoT ecosystem can be improved by transmitting data based on pre-configured buffer threshold values that are set differently for each group and consequently minimizing the energy consumption of sensor devices near the sink node. When any sensor device cannot transmit data to the next higher group level due to movement, it is newly assigned an appropriate group number and transmits data using a new route. They have implemented the proposed 3-D GM MAC scheme and shown that the proposed scheme shows excellent behavior in the aspect of energy efficiency for the target IoT ecosystem by simulation. Therefore, the proposed scheme might be adaptable for mobile sensor devices used in various kinds of computing and networking environments such as IoT, big data, cloud computing, and fog computing. Fine-tuning the criteria for deciding the node group IDs based on the moving speed of sensor devices and configuring buffer threshold values based on traffic generation rates from a target IoT ecosystem are not study. Also, The formula for calculating buffer threshold value for each sensor node group proposed in their paper. So if all the nodes have same buffer threshold, it probably causes the bottleneck phenomenon.

In order to support mobility, an IoT system needs to be equipped with a handover or hand-off mechanism which is responsible for de-registering a sensor node from a source access-point and registering it to a new access-point seamlessly. It is a challenging task to implement an advanced handover mechanism for full mobility support in critical domains such as healthcare[68] due to strict requirements of security, latency, network coverage, and reliability. In fact, the handover mechanism serves to keep the connection between sensor nodes and a gateway with a low latency. In [69], the authors proposed a handover mechanism for mobility support in a remote real-time streaming IoT system. The paper discussed and analyzed metrics for the handover mechanism based on Wi-Fi. In addition, a complete remote real-time e-health monitoring IoT system was implemented for experiments. In order to provide a comprehensive view of a handover mechanism, factors impacting on mobility support in IoT systems using the 802.11 technology have been discussed. These factors are mobility scenarios, handshaking messages for 802.11 connection, and network deployment. The results from evaluating our mobility handover mechanism for mobility support shows that the latency of switching from one gateway to another is 10% - 50% smaller than other state-of-the-art mobility support systems. The main target of the proposed handover mechanism is to achieve both energy efficiency of sensor nodes and a seamless mobility with the minimized handover latency, but packets loss and buffer size has not been considered.

In [70], the authors highlighted that node mobility can degrade the network performance. In fact, whenever a node exits/enters the network, it has to scan the available channels waiting for an EB, in order to join the network and become fully operative again. These scanning times can be very long, given the high number of frequency channels, and, obviously, this affects the latency of mobile nodes' transmissions. This issue is exacerbated by the fact that the beacon and timeslot scheduling mechanisms are not specified by the standard. Hence, the actual joining time of a node depends on the particular beacon/timeslot schedules adopted. In this perspective, the same authors proposed mobility aware Mobile Time Slotted Channel Hopping (MTSCH) [71], a mobility aware framework, based on the concept of passive beacons. Essentially, instead of using Enhanced Beacons (EBs) to advertise the network, nodes in MTSCH exploit ACK messages, used to acknowledge packet reception. Moreover, ACK messages are transmitted on a fixed frequency channel, rather than over all the possible frequencies as defined in Time Slotted Channel Hopping (TSCH). This allows mobile joining nodes to receive synchronization messages (ACKs) more quickly and, hence, to save their energy. In addition, group-ACKs are used. In detail, nodes do not have to send an ACK for every received message, but use a single ACK, at the end of each slot frame, to acknowledge the transmissions of all their neighbors. Thanks to this modification, nodes can save energy due the transmission of individual ACK messages. MTSCH leads to a significant reduction of the duty cycle of mobile nodes, ranging from 7% to 50%, with respect to a standard TSCH network. Also, MTSCH improves the joining time of mobile nodes by a ratio that ranges from 3% to 50%.

The authors of [72], proposed a novel solution to optimize routing method in a TSCH network where mobile nodes may be present. They considered a network composed of many static nodes, called anchor nodes, with a well-known position, and mobile nodes, whose positions are unknown. All nodes in the network need to transmit their data to the central network coordinator. Hence, the best path connecting them with the coordinator must be selected. Links between anchor nodes are constructed using Routing Protocol for Low power and Lossy networks (RPL) protocol[73]. In this case, RPL selects links basing on the Expected Transmission

Count(ETX) metric, that indicates the expected number of times a message must be transmitted to be correctly received by its final destination. However, when considering links between mobile nodes and anchor nodes, the actual position of nodes is also taken into account. Specifically, each node estimates its distance from each anchor node and defines a set of candidate anchors, i.e., a set of nodes that can be selected as parent nodes. Then, a blacklisting process identifies the nodes that should not be selected due to either their unreliability or excessive distance from the mobile node. At this point, the mobile node chooses, as its parent, the node in the set of candidate anchors that minimizes the ETX metric towards the sink. The authors compared their solution with geographical routing [74], where each mobile node forwards its packet to the closest node to the destination. The results show that the solution in [72] offers the best end-to-end link reliability. Also, the blacklisting process allows to alleviate the negative impact of position errors.

5.3. Summary

The MAC layer is one of the most important layers in protocol stack for the IoT. In this subsection, we have presented a survey of MAC layer-based mechanisms for mobility support in IoT to provide the state of the art for the IoT.

6. Conclusion

The state-of-the-art and widely used methods about mobility in the IoT are systematical in this study. In this article, the link layer in the internet of mobile things was specifically and independently examined and explored. The results of the studies, features, and applications of this layer in the Internet of Mobile Things were examined based on the articles studied, and the advantages and disadvantages of each were examined and shown completely and clearly in section 5.2.

Table 2.Studied papers in the field of link layer in IoMT

Approach	Article	Main idea	Advantage
MAC scheme for IoT ecosystem environments	Ryoo, Sun [67]	3-Dimensional group management MAC	-Minimize Energy consumption -Adaptable in various kinds of computing and networking environments
MAC layer mobility support	Gia, Rahmani [69]	Handover mechanism for mobility Support in IoT	-Minimize handover latency -Maximize energy efficiency
MAC Layer (IEEE 802.15.4e)	Al-Nidawi and Kemp [71]	Mobile Time slotted Channel Hopping	-Facilitate the mobile nodes association -Minimize the latency -Low overhead on both of FFD and RFD Nodes -Minimize Energy consumption
MAC Layer (IEEE 802.15.4e)	Barcelo, Correa [72]	Mobile Timeslotted Channel Hopping	-Minimize Energy consumption -Minimize the latency

References

[1] Parihar, A., et al., Role of IOT in healthcare: Applications, security & privacy concerns. Intelligent Pharmacy, 2024. 2(5): p. 707-714.

[2] Anurag, et al. Pervasive health monitoring based on Internet of Things: Two case studies. in 2014 4th International Conference on Wireless Mobile Communication and Healthcare - Transforming Healthcare Through Innovations in Mobile and Wireless Technologies (MOBIHEALTH). 2014.

[3] Li, C., et al., A review of IoT applications in healthcare. Neurocomputing, 2024. 565: p. 127017.

[4] Pourghebleh, B. and N.J. Navimipour, Data aggregation mechanisms in the Internet of things: A systematic review of the literature and recommendations for future research. Journal of Network and Computer Applications, 2017. 97: p. 23-34.

[5] Montori, F., et al., The Curse of Sensing: Survey of techniques and challenges to cope with sparse and dense data in mobile crowd sensing for Internet of Things. Pervasive and Mobile Computing, 2018. 49: p. 111-125.

[6] Nahrstedt, K., et al. Internet of Mobile Things: Mobility-Driven Challenges, Designs and Implementations. in 2016 IEEE First International Conference on Internet-of-Things Design and Implementation (IoTDI). 2016.

[7] Li, S., L.D. Xu, and S. Zhao, 5G Internet of Things: A survey. Journal of Industrial Information Integration, 2018. 10: p. 1-9.

[8] Hernandez-Jaimes, M.L., et al., Artificial intelligence for IoMT security: A review of intrusion detection systems, attacks, datasets and Cloud-Fog-Edge architectures. Internet of Things, 2023: p. 100887.

[9] Iannacci, J., Internet of things (IoT); internet of everything (IoE); tactile internet; 5G – A (not so evanescent) unifying vision empowered by EH-MEMS (energy harvesting MEMS) and RF-MEMS (radio frequency MEMS). Sensors and Actuators A: Physical, 2018. 272: p. 187-198.

[10] Hamzei, M. and N.J. Navimipour, Towards Efficient Service Composition Techniques in the Internet of Things. IEEE Internet of Things Journal, 2018: p. 1-1.

[11] Ray, P.P., A survey on Internet of Things architectures. Journal of King Saud University - Computer and Information Sciences, 2018. 30(3): p. 291-319.

[12] Čolaković, A. and M. Hadžialić, Internet of Things (IoT): A review of enabling technologies, challenges, and open research issues. Computer Networks, 2018. 144: p. 17-39.

[13] Chiregi, M. and N. Jafari Navimipour, Cloud computing and trust evaluation: A systematic literature review of the state-of-the-art mechanisms. Journal of Electrical Systems and Information Technology, 2017.

[14] Yin, Y., et al., The internet of things in healthcare: An overview. Journal of Industrial Information Integration, 2016. 1: p. 3-13.

[15] Srinidhi, N.N., S.M. Dilip Kumar, and K.R. Venugopal, Network optimizations in the Internet of Things: A review. Engineering Science and Technology, an International Journal, 2018.

[16] Zarpelão, B.B., et al., A survey of intrusion detection in Internet of Things. Journal of Network and Computer Applications, 2017. 84: p. 25-37.

[17] Zahoor, S. and R.N. Mir, Resource management in pervasive Internet of Things: A survey. Journal of King Saud University - Computer and Information Sciences, 2018.

[18] Aloi, G., et al., Enabling IoT interoperability through opportunistic smartphone-based mobile gateways. Journal of Network and Computer Applications, 2017. 81: p. 74-84.

[19] Alaba, F.A., et al., Internet of Things security: A survey. Journal of Network and Computer Applications, 2017. 88: p. 10-28.

[20] da Costa, C.A., et al., Internet of Health Things: Toward intelligent vital signs monitoring in hospital wards. Artificial Intelligence in Medicine, 2018. 89: p. 61-69.

[21] Chango, W., T. Olivares, and F. oDelicado, Topologies in the Internet of Medical Things (IoMT), literature review. arXiv preprint arXiv:2404.02908, 2024.

[22] Swamy s, N., An Empirical Study on System Level Aspects of Internet of Things (IoT). IEEE Access, 2020. VOLUME 8: p. 188082-188134.

[23] Subramaniam, E.V.D., et al., Interoperable IoMT approach for remote diagnosis with privacy-preservation perspective in edge systems. Sensors, 2023. 23(17): p. 7474.

[24] Areia, J., et al., IoMT-TrafficData: Dataset and Tools for Benchmarking Intrusion Detection in Internet of Medical Things. IEEE Access, 2024.

[25] Zakeri, F., M. Golsorkhtabaramiri, and M. Hosseinzadeh, Optimizing Radio Frequency Identification Networks Planning by using Particle Swarm Optimization Algorithm with Fuzzy Logic Controller and Mutation. IETE Journal of Research, 2017. 63(5): p. 728-735.

[26] Elijah, O., et al., An Overview of Internet of Things (IoT) and Data Analytics in Agriculture: Benefits and Challenges. IEEE Internet of Things Journal, 2018: p. 1-1.

[27] Dudhe, P.V., et al. Internet of Things (IOT): An overview and its applications. in 2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS). 2017.

[28] Rath, K.C., A. Khang, and D. Roy, The role of Internet of Things (IoT) technology in Industry 4.0 economy, in Advanced IoT technologies and applications in the industry 4.0 digital economy. 2024, CRC Press. p. 1-28.

[29] Do, T.M.T. and D. Gatica-Perez, The Places of Our Lives: Visiting Patterns and Automatic Labeling from Longitudinal Smartphone Data. IEEE Transactions on Mobile Computing, 2014. 13(3): p. 638-648.

[30] Rahmani, A.M., et al., A novel offloading strategy for multi-user optimization in blockchain-enabled Mobile Edge Computing networks for improved Internet of Things performance. Computers and Electrical Engineering, 2024. 119: p. 109514.

[31] Isaacman, S., et al. Identifying Important Places in People's Lives from Cellular Network Data. 2011. Berlin, Heidelberg: Springer Berlin Heidelberg.

[32] Mohimani, G.H., et al., Mobility Modeling, Spatial Traffic Distribution, and Probability of Connectivity for Sparse and Dense Vehicular Ad Hoc Networks. IEEE Transactions on Vehicular Technology, 2009. 58(4): p. 1998-2007.

[33] Calabrese, F., et al., Understanding individual mobility patterns from urban sensing data: A mobile phone trace example. Transportation Research Part C: Emerging Technologies, 2013. 26: p. 301-313.

[34] Aouedi, O., et al., A survey on intelligent Internet of Things: Applications, security, privacy, and future directions. IEEE Communications Surveys & Tutorials, 2024.

[35] Ghaleb, S.M., et al., Mobility management for IoT: a survey. EURASIP Journal on Wireless Communications and Networking, 2016. 2016(1): p. 165.

[36] Goudos, S.K., et al., A Survey of IoT Key Enabling and Future Technologies: 5G, Mobile IoT, Sematic Web and Applications. Wireless Personal Communications, 2017. 97(2): p. 1645-1675.

[37] Moffat, S., M. Hammoudeh, and R. Hegarty, A Survey on Ciphertext-Policy Attribute-based Encryption (CP-ABE) Approaches to Data Security on Mobile Devices and its Application to IoT, in Proceedings of the International Conference on Future Networks and Distributed Systems. 2017, ACM: Cambridge, United Kingdom.

[38] Juyal, S., N. Joshi, and R. Chauhan. Mobile sensing and Internet of Things: A survey. in 2017 International Conference on Emerging Trends in Computing and Communication Technologies (ICETCCT). 2017.

[39] Elazhary, H., Internet of Things (IoT), mobile cloud, cloudlet, mobile IoT, IoT cloud, fog, mobile edge, and edge emerging computing paradigms: Disambiguation and research directions. Journal of Network and Computer Applications, 2018.

[40] Ma, H.-D., Internet of Things: Objectives and Scientific Challenges. Journal of Computer Science and Technology, 2011. 26(6): p. 919-924.

[41] Perera, C., C.H. Liu, and S. Jayawardena, The Emerging Internet of Things Marketplace From an Industrial Perspective: A Survey. IEEE Transactions on Emerging Topics in Computing, 2015. 3(4): p. 585-598.

[42] Perera, C., et al., Context Aware Computing for The Internet of Things: A Survey. IEEE Communications Surveys & Tutorials, 2014. 16(1): p. 414-454.

[43] Adelantado, F., et al., Understanding the Limits of LoRaWAN. IEEE Communications Magazine, 2017. 55(9): p. 34-40.

[44] Ullah, I., M. Sohail Khan, and D. Kim, IoT Services and Virtual Objects Management in

Hyperconnected Things Network. Mobile Information Systems, 2018. 2018: p. 19.
[45] Elkhodr, M., S.A. Shahrestani, and H. Cheung, Emerging Wireless Technologies in the Internet of Things: a Comparative Study. CoRR, 2016. abs/1611.00861.
[46] Vandikas, K. and V. Tsiatsis. Performance Evaluation of an IoT Platform. in 2014 Eighth International Conference on Next Generation Mobile Apps, Services and Technologies. 2014.
[47] da Silva, A.F., et al., A Cloud-based Architecture for the Internet of Things targeting Industrial Devices Remote Monitoring and Control. IFAC-PapersOnLine, 2016. 49(30): p. 108-113.
[48] Al-Fuqaha, A., et al., Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications. IEEE Communications Surveys & Tutorials, 2015. 17(4): p. 2347-2376.
[49] Aloi, G., et al., Software defined radar: synchronization issues and practical implementation. 2011. 48.
[50] Costanzo, S., et al., Potentialities of USRP-based software defined radar systems. Vol. 53. 2013. 417-435.
[51] Talavera, L.E., et al. The Mobile Hub concept: Enabling applications for the Internet of Mobile Things. in 2015 IEEE International Conference on Pervasive Computing and Communication Workshops (PerCom Workshops). 2015.
[52] González, M.C., C.A. Hidalgo, and A.-L. Barabási, Understanding individual human mobility patterns. Nature, 2008. 453: p. 779.
[53] Isaacman, S., et al. Identifying Important Places in People’s Lives from Cellular Network Data. in Pervasive Computing. 2011. Berlin, Heidelberg: Springer Berlin Heidelberg.
[54] Lewis, P., et al., RFC6206: The Trickle Algorithm. 2011.
[55] Cobârzan, C., J. Montavont, and T. Noël. Analysis and performance evaluation of RPL under mobility. in 2014 IEEE Symposium on Computers and Communications (ISCC). 2014.
[56] Oliveira, L.M.L., A.F. de Sousa, and J.J.P.C. Rodrigues, Routing and mobility approaches in IPv6 over LoWPAN mesh networks. International Journal of Communication Systems, 2011. 24(11): p. 1445-1466.
[57] Thubert, P., et al., RPL: IPv6 Routing Protocol for Low power and Lossy Networks. Vol. RFC 6550. 2012.
[58] Iova, O., F. Theoleyre, and T. Noel, Using multiparent routing in RPL to increase the stability and the lifetime of the network. Ad Hoc Networks, 2015. 29: p. 45-62.
[59] Bouaziz, M., A. Rachedi, and A. Belghith, EKF-MRPL: Advanced mobility support routing protocol for internet of mobile things: Movement prediction approach. Future Generation Computer Systems, 2017.
[60] Kotenko, I., I. Saenko, and A. Branitskiy, Framework for Mobile Internet of Things Security Monitoring Based on Big Data Processing and Machine Learning. IEEE Access, 2018. 6: p. 72714-72723.
[61] Aggarwal, C., N. Ashish, and A. Sheth, The Internet of Things: A Survey from the Data-Centric Perspective. 2013. p. 383-428.
[62] Charband, Y. and N. Jafari Navimipour, Knowledge sharing mechanisms in the education: A systematic review of the state of the art literature and recommendations for future research. Kybernetes, 2018. 47(7): p. 1456-1490.
[63] Du, W., F. Mieyeville, and D. Navarro. Modeling Energy Consumption of Wireless Sensor Networks by SystemC. in 2010 Fifth International Conference on Systems and Networks Communications. 2010.
[64] Huang, P., et al., The Evolution of MAC Protocols in Wireless Sensor Networks: A Survey. IEEE Communications Surveys & Tutorials, 2013. 15(1): p. 101-120.
[65] 65. Demirkol, I., C. Ersoy, and F. Alagoz, MAC protocols for wireless sensor networks: a survey. IEEE Communications Magazine, 2006. 44(4): p. 115-121.
[66] IEEE Standard for Low-Rate Wireless Networks. IEEE Std 802.15.4-2015 (Revision of IEEE Std 802.15.4-2011), 2016: p. 1-709.
[67] Ryoo, I., et al., A 3-dimensional group management MAC scheme for mobile IoT devices in wireless sensor networks. Journal of Ambient Intelligence and Humanized Computing, 2018. 9(4): p. 1223-1234.
[68] Francesco, M.D., S.K. Das, and G. Anastasi, Data Collection in Wireless Sensor Networks

with Mobile Elements: A Survey. ACM Trans. Sen. Netw., 2011. 8(1): p. 1-31.
[69] Gia, T.N., et al., Fog Computing Approach for Mobility Support in Internet-of-Things Systems. IEEE Access, 2018. 6: p. 36064-36082.
[70] Al-Nidawi, Y., H. Yahya, and A.H. Kemp. Impact of mobility on the IoT MAC infrastructure: IEEE 802.15.4e TSCH and LLDN platform. in 2015 IEEE 2nd World Forum on Internet of Things (WF-IoT). 2015.
[71] Al-Nidawi, Y. and A.H. Kemp, Mobility Aware Framework for Timeslotted Channel Hopping IEEE 802.15.4e Sensor Networks. IEEE Sensors Journal, 2015. 15(12): p. 7112-7125.
[72] Barcelo, M., et al. Novel Routing Approach for the TSCH Mode of IEEE 802.15.14e in Wireless Sensor Networks with Mobile Nodes. in 2014 IEEE 80th Vehicular Technology Conference (VTC2014-Fall). 2014.
[73] Accettura, N., et al. Performance analysis of the RPL Routing Protocol. in 2011 IEEE International Conference on Mechatronics. 2011.
[74] Peng, B. and A.H. Kemp, Energy-efficient geographic routing in the presence of localization errors. Computer Networks, 2011. 55(3): p. 856-872.
[75] Chowdhury, A.H., et al., Route-over vs mesh-under routing in 6LoWPAN, in Proceedings of the 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly. 2009, ACM: Leipzig, Germany. p. 1208-1212.
[76] Palattella, M.R., et al., Standardized Protocol Stack for the Internet of (Important) Things. IEEE Communications Surveys & Tutorials, 2013. 15(3): p. 1389-1406.
[77] Goyal, S. and T. Chand, Improved Trickle Algorithm for Routing Protocol for Low Power and Lossy Networks. IEEE Sensors Journal, 2018. 18(5): p. 2178-2183.
[78] Ko, J. and M. Chang, MoMoRo: Providing Mobility Support for Low-Power Wireless Applications. IEEE Systems Journal, 2015. 9(2): p. 585-594.
[79] Fotouhi, H., D. Moreira, and M. Alves, mRPL: Boosting mobility in the Internet of Things. Ad Hoc Networks, 2015. 26: p. 17-35.
[80] Fotouhi, H., et al., mRPL+: A mobility management framework in RPL/6LoWPAN. Computer Communications, 2017. 104: p. 34-54.
[81] Ishino, M., Y. Koizumi, and T. Hasegawa, A Routing-Based Mobility Management Scheme for IoT Devices in Wireless Mobile Networks. IEICE Transactions on Communications, 2015. E98.B(12): p. 2376-2381.
[82] Broder, A. and M. Mitzenmacher, Network Applications of Bloom Filters: A Survey. Internet Math., 2003. 1(4): p. 485-509.
[83] Ancillotti, E., et al., A reinforcement learning-based link quality estimation strategy for RPL and its impact on topology management. Computer Communications, 2017. 112: p. 1-13.
[84] Santos, B.P., et al., Mobile Matrix: Routing under mobility in IoT, IoMT, and Social IoT. Ad Hoc Networks, 2018. 78: p. 84-98.
[85] Al-Kashoash, H.A.A., et al., Congestion control in wireless sensor and 6LoWPAN networks: toward the Internet of Things. Wireless Networks, 2018.