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Systematic Review of Internet of Nano Things (IoNT) Technology: Taxonomy, Architecture, Open Challenges, Motivation and Recommendations

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Nano Communication;
IoNT architecture;
IoNT applications.

Abstract

Internet of nano things (IoNT) is a new and modern part of the internet of things (IoT). Applications that operate in the field of nano scale show a new advantage in communication networks. IoNT opened the door to many applications in various fields with new features derived from the advantages of nanotechnology. In this work, a description of the IoNT during 2015-2021 was achieved, including taxonomy, architecture, motives, applications and challenges, in addition to recommendations. The architecture of the IoNT and the most important technologies used in Nano communication networks have been identified, with an indication of the advantages of each. This study, we hope, will make a contribution to this field of science, thus contributing to providing assistance to researchers in this emerging field and covering the challenges they face in this way. That would permit communication between nano-devices to be conventional, making these calibrations to be implemented in various IoNT applications. Until the IoNT system is designed without any problems in the near future, which if achieved, will provide great services, especially in medical applications and other applications.

Introduction

IoNT is the field of nanoscale campaigns to the current communication networks. It is one of the requests of nanotechnology with the internet of things (IoT) technology, a combination of the two technologies. The drive of IoNT involves the dimensions to interconnect varied kinds of advanced devices that operate with nano communication network technique, where it permits the group of data in seats with hard admission [1, 2]. In the IoNT technique, multiple nano sensors will

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connect internally with each other through nanonetworks [3]. Thus, it proposes a new model creating predominant networks that improve our daily actions that will recover communication efficacy and rise the communication stations' character and its abilities with minor costs. Temporarily, it protects greater ranges and realizes the unfamiliar and difficult to admission spaces at the molecular level [4]. Most of the critical difficulties have become possible to overcome using this technology, and applications such as reading data based on portable sensors have become available through this technology [5]. The most important factors in the development of IoNT technology are based on low-cost processing capabilities compared to huge storage capacities, as well as smart antennas and smart RFID technology [1]. In this study, the keywords related to this topic have been searched in a systematic way as follows:" Internet of nano things", or "IoNT", or "Nano things" AND "Communication" or "Sensor". The selected digital databases for this study were described as follows: ScienceDirect, IEEE and Web of Science (WoS) database. The research time range is achieved within the years (2015–2021) adopting the English language only. The obtained literature sources are screened and filtered by excluding duplicate articles. The results of the original query exploration of 352 articles were done as follows: 6 articles from ScienceDirect, 10 articles from IEEE and 11 articles from WoS from 2015 to 2021. The final set involved 27 papers, which were separated into two main groups. The first group, which includes 13 articles were reviewed and surveyed. The second group was IoNT architecture limited to 14 articles in three units. The first unit, which covered 8 out of 14 articles, were the IoNT based nano sensor techniques. The second unit, which covered 3 out of 14 articles, described the IoNT gateways, while the last unit included IoNT based servers which covered 2 articles. These results are summarized in figure1.

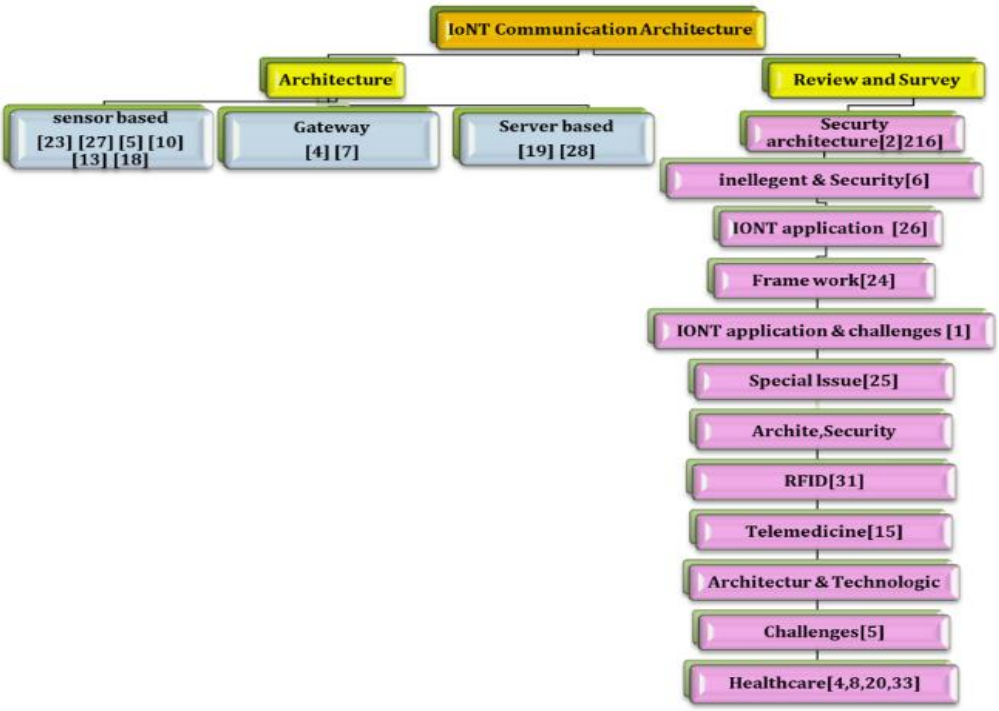

Figure 1. Classification of articles about IoNT technology. The first part includes review and survey, while the second dealt with IoNT architecture which is categorized by three areas: sensor, gateway, and server.

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In order to identify the levels of publication for the aforementioned search engines, the number of articles published during the specified time period was counted, as shown in figure 2. It is very clear how much new topics are understudied in important scientific sites.

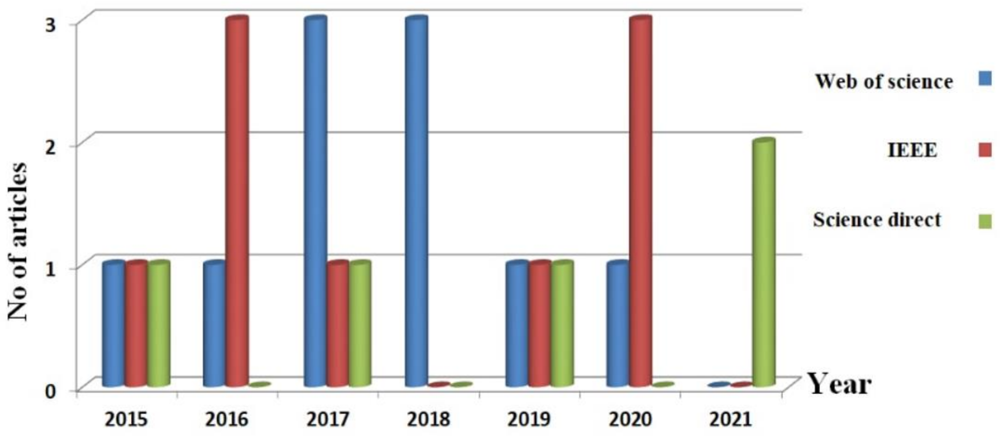

Figure 2 The publication level of IoNT literature through the three search engines during the period 2015-2021, the diagram indicates the low level of publication during this period and the need to increase interest in this topic.

Reviews and Surveys

In [6], several IoNT technology gates were produced to achieve access to one or more nanonets, ensuring accurate processing and reliability. The intended IoNT health care applications with the requirements are recognized by [7], as well as the fundamental health care facility chances. While [8] was studied In-Body Nano Communication Network with the Body Area Network of the IoNT architecture by an overview and major requirements to design gateways. This studied model forms a new level of security where the authors assessed the resultant security challenges with processors. Another study examined the effect of some changing environmental conditions and observed their effect on IoNT communication based on molecular contacts, namely temperature (T) and the relative concentration of physical obstacles (X). When the conductivity (Pconn) of the nano-network was examined, it has been noted that Pconn was less affected when changes occur in T and X [9] while increasing T had a positive effect on the Pconn in the case where there is an interference in the received signal. In [10], the IoNT based telemedicine application was analyzed and the medical information contained in the international publications was obtained, processed, and distributed.

The authors, in [11], have proposed the eNEUTRAL model to monitor the energy factor through the IoNT, which detects and introduces signals about the event that depends on the amount of energy generated by the events. As a result, data will be uploaded to a control location depending on the energy obtained from the event. A new approach in nano grids based IoNT that reduces energy consumption within the grid is an Enhanced Energy-Efficient Algorithm (E^3A) which was proposed by [12]. A new approach named a rational data delivery approach (RDDA) was designed by [13] to provide the extended network lifetime without affecting other QoI features within the IoNT. In [14], a proposal was presented to address the energy problem in the IoNT communication system, this proposal includes synchronization of wireless information and nano-networks which transmit energy in the terahertz (THz) range to ensure improved system performance. The applications, challenges, security objectives, attack cycles, and security challenges of the IoNT network were investigated

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by [15]. A system was developed in [16], to harvest energy through a combination of nano-antenna and ultrafast modulated diode to overcome the challenge of extremely limited power in IoNT networks when used in healthcare applications. This device acts as a generator in the system depending on the broadband characteristics that enable it to generate direct current (DC) with a power of 27.5 nW from input with THz to optical frequencies, which provides low voltage compared to the piezoelectric nanogenerator. The energy problem was also studied by [17] by proposing a system that saves energy using only one short pulse. This system is based on the use of a Uniform Linear Array (ULA) antenna.

A previous study on the meanings, features, and potentials of IoNT are introduced by [1]. This review provides an explanation of the present state of IoNT, technologies, applications and challenges. In order to address the security issue in IoNT, a security model has been proposed by [2] that establishes two levels of communication: the first is based on electromagnetic waves; while the second is based on a molecular conversation. A mathematical model that contributes to the development of transport policy in IoNT technology has been proposed to address some of the limitations [18] by proposing the General Markov Decision Process (MDP) model. It will contribute to reducing the economic cost of this technique and reducing the damages of implants inside the body. Routing protocols have been studied within the IoNT as well as wireless Nano sensor networks WNSN by [4], which contribute to the expansion of the coverage through its integration with the other nano-devices. Another IoNT design included security challenges that have been introduced by [5], the smart communication models due to the increasing number of connected devices which contribute to medical applications were discussed. In [3], the applications of IoNT to modern health care were studied carefully. A comprehensive overview of this technology and an explanation of the communications architecture for IoNT in Healthcare have been provided. By leveraging on the advantage of security advances in the radio physical layer (PLS), the authors in [19] proposed an encryption technique in order to deal with the security challenges of IoNT. This proposal contributes to facilitating the work of the system within a safer environment.

The various layers in IoNT have been studied by [20] with the most important health care applications such as medicine delivery and disease detection. Another study [21] to address the problem of limited energy was conducted because of the size of the nano-nodes during the environmental and medical applications of IoNT. The effect of air velocity and circulation on nano-components has been studied. In [22], improving the intensity of the focused electric field in the nanoantenna of IoNT design as well as increasing its bandwidth was studied. A proposal to solve the lack of microscale communication sub-systems to enable connectivity between individual nanomachines for IoNT was introduced by [23] by using a synthetic molecular communications (SMC) modulator to link the macroworld to the microworld. Finally, the IoNT-based information architecture was developed by [24] based on a vision-oriented concept.

IoNT Architecture Techniques

There are two areas of IoNT: The Multimedia Internet of Nanoscale Things (IoMNT) and the Internet of Nanoscale Bio-Things (IoBNT). Both are the interconnection of nano-devices with existing communication networks. The architectures of the IoNT network depend on the application domain and its specific features. The most important basic components involved in the architecture of the IoNT network are: Nano nodes, nano routers, nano-micro interface devices (gateway), and internet portals [2,4]. The properties of the nanomaterials embedded in the nanodevices (such as graphene nanoribbon (GNR) or carbon nanotubes (CNT) have an important role in making IoNT design challenges. Gates are Wi-Fi access points that provide a specific location of a patient's place, or the location of a patient's smartphone [3].

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The IoNT architecture integrating intrabody nano communication networks with body area networks are shown in figure 3. In this architecture, the nanodevices are distributed in groups, and each group has a group boss who handles the data and sends them to the nano router within a dynamic path that changes according to the setting and availability. These nano paths ingeniously link to the nearest gateway to transmit information. The nanodevices are then connected via networks that are physically separated from each other [3].

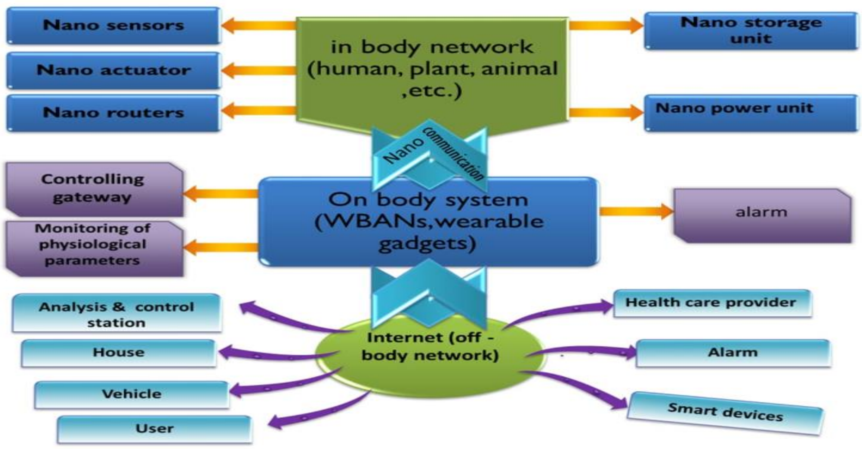

Figure 3: The general IoNT architecture integrating intrabody nano communication networks with body area networks. All communication features are provided through this architecture, implementing various medical applications, storage and processing feature as well as in other applications such as factory work tracking system.

The main nanodevices based IoNT architecture are: sensor and actuation unit, processing unit, a communication unit, storage unit, and power unit [4]. Off-body systems are pervasive from the point of view of the individual, home, car, road, or clinic. These systems can provide extensive health monitoring services. There are three nanonetworks in IoNT architecture depending on the location of the nanodevice: [3]

- On-body systems: they are distributed wirelessly to the same object. View WBANs and wearable tools are used to analyze the received data as well as quickly send health services from and to the private space inside the body.
- In-body systems: they are regularly distributed in different areas within an individual's body, either connected or entrenched in smart screening tools or as internet-connected nanodevices [6].

IoNT Architecture Techniques

IoNT communication utilizes one of these two communication techniques:

- Molecular communications (MC) technique: The transmission and reception information are formed in molecules in this technique. Data are encoded either as a center or as a type of transmitter particle. Messenger particles can be used to hold data through a medium, such as air or liquids. In any case, these atoms are extremely suitable for short-range communications, for example, communications in BANs. The MC technique can be used to create communication systems based on chemical reactions and transport processes, especially those of basic organisms [25].

- Electromagnetic communications (EM) technique: In this type, the transmission and reception of electromagnetic radiation is achieved within the terahertz (THz) range (0.1 THz - 10 THz), which provided super-fast data transfer within IoNT. Data are also exchanged inside and outside the body based on molecular radio communications, audio, or radio frequencies in the terahertz range [6]. Table 1, offers a comparison between these two techniques.

Table 1: Comparison of the different characteristics between each of the molecular communications (MC) and electromagnetic communications (EM) technologies.

Communication Channel	Speed of Information	Physical Data Rate	Environmental Conditions Influence	Activated Molecules	Path Loss	Remote Attacks
Electromagnetic	faster	high	less	more	heavy losses inside the fluid	may occur
Molecular	slower	low	more	less	Less losses inside fluid	may occur

Applications of IoNT

IoNT technology has many promising applications that researchers mentioned in various fields based on the advantages of this modern technology, which has a great impact on various fields in the future.

- Health Care Monitoring
  Nano sensors can be used in health applications through monitoring; where they can monitor most conditions such as temperature, pressure, sugar, fats in the blood and the like. These sensors can also be used to detect cancerous tumors, etc. [10]. In addition, nano sensors can be used to treat nerve cell damage by locating the affected area and using the myelin sheath. IoNT's nano sensors transmit the nerve impulse signal, although this is difficult with other technologies [26].
- Environmental Monitoring
  Most important places such as train stations, airlines, nuclear reactors and other sensitive places can be monitored using this technology. In addition to following up the traffic of cars more efficiently than before, with the follow-up of the pollution rate in the air, and the observation of climate changes and temperatures with extreme accuracy [1].
- Precision Agriculture
  IoNT technology can be used in agricultural applications by building nano-systems that are capable of resisting agricultural pests with high efficiency, which leads to increased production and availability for various species [2]. This technology is also used to monitor agricultural crops through nano-control systems that supervise the stages of plant growth and control them from a distance. Knowing the climatic and environmental conditions and other

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factors such as the condition of the soil and other cases [6]. These data can also be sent to follow-up and monitor stations to take appropriate steps and address emergency cases [26]

- Military

IoNT technology can perform many services with the development and diversity of the weapons industry, such as the presence of chemicals which can be sensed with high accuracy, and the durability of civil and military constructions that can also be examined and infinitesimal defects can be detected. In the field of telecommunications, the IoNT based on THz offers higher capacity with higher throughput, and can rapidly exchange information by integrating nano tools into advanced cell systems related military applications.

- Industrial

Industries can be improved with IoNT technology in different fields. Nano sensors can be used to develop remote sensing devices, and the RFID technology is used to identify some industrial components that can be replaced by IoNT technology as data can be transmitted in huge quantities and at high speed through the Internet. Other areas that can be developed using this promising technique are mentioned in [27].

- Smart Cities

IoT technology plays a distinctive role in the formation of smart cities by communicating with various households and other devices. However, IoNT technology can provide these systems with high-precision nano-sensors and huge storage capacities, which contributes to the development of infrastructure for smart cities, the provision of means for detecting pollution in the atmosphere, the contribution of the economy and providing different facilities [10].

- Oil and Gas

IoNT provides a great opportunity to locate underground oil with high accuracy by taking advantage of the properties of nano-sensors. The traditional method used to detect oil locations is considered less efficient than this technique because it relies on a large magnetic field and a receiver within a specific system to send the nanocomposites to the specified place.

- Biomedical Applications

The most important application based on IoNT technology is the biological applications due to the convergence between nanoparticles and living cells in terms of size, as it is possible to simulate living cells through this technology. It can also be used in many vital applications, for example using nano sensors that can be implanted inside the body or injected into the blood to monitor damaged cells, heart cells, etc., and to diagnose harmful cells, or in other medical applications.

- Functionalized Materials and Fabrics

Using IoNT technology, it is possible to develop materials and fabrics with modern features that contribute to performing new tasks in the textile industry, such as contributing to the development of antibacterial textiles as well as the manufacture of spot pesticides by taking advantage of the advantages of nanomaterials. In addition, IoNT technology can be employed to realize the possibility of adding certain properties to textiles by taking advantage of IoNT technology to create smart textiles with new technologies. These applications have been indicated in figure 4.

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Figure 4: applications of IoNT

Challenges of IoNT

This section provides an overview of the most common challenges based IoNT technology. Since IoNT technology operates within the nanometer scale, this feature, despite its enormous benefits and promising applications, produces many challenges that should be studied by researchers to develop solutions in order to enable this technology to provide its better services to humanity in a way that it is safer and less harmful to societies. Among these challenges that have been studied are the challenges of linking body region networks and other extrinsic gates to nano-devices inside the body by [6]. The challenges of data transmission in IoNT technology are also briefly studied in [3]. The challenge of promise high throughput for distributed scheduling algorithms while maintaining low average delay has been covered by [28] with the challenge of permit data to be carried within hard limits before being released at the time the next package reaches. Below are some of these published challenges:

- Security of IoNT Technique
  One of the most important challenges based IoNT technology is the problem of security and privacy during the work of this technology, which has wide and sensitive applications, as it enters the human body in addition to its work outside it, which increases the sensitivity of the information transmitted by this technology and its need for safety to preserve lives and property. Since IoNT operates within terahertz limits, this requires new security measures compatible with this technology to prevent data theft and harm to users. Among the most important security challenges, according to [6] are eavesdropping and data theft, attempting to disrupt treatment injection procedures, and altering links of nano communication level or a BAN gateway.
- Privacy
  The threat of data theft that IoNT deals with, as a result of its integration with other applications, are phones, home appliances, and the like as these data can be threatened, especially when they are connected to the internet.
- The Nanoscale Communication

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There are challenges facing the implementation of this technology, including those related to the nanoscale size of IoNT devices, which require redesigning and developing new communication models and network concepts that are compatible with these components. Where the terahertz range of frequencies between 100 GHz and 10 THz needs to be studied and modeled for its application on the ground. Figure 5 describes the challenges based on IoNT.

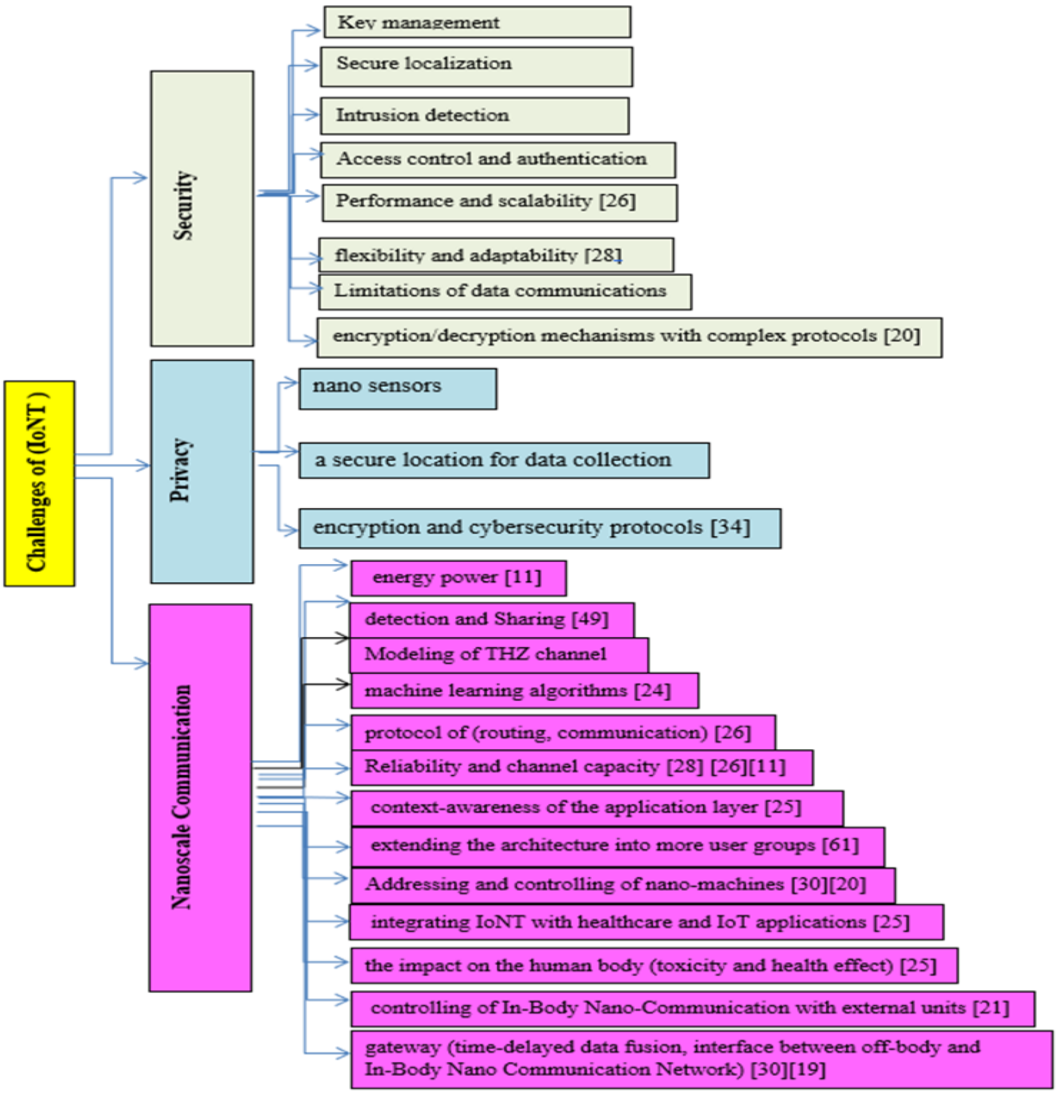

Figure 5: diagram of the current challenges based IoNT technique

Recommendations of IoNT

In this section, a number of recommendations mentioned by researchers for the purpose of developing IoNT technology in the near future, have been mentioned to overcome the challenges based this topic, such as technical problems related to devices for various medical uses.

- Conducting a study based on the data collected from users of different ages, places and genders to determine the security problems in data transfer and their expected effects on the individual and society [29].

- Developing efficient machine learning models through IoNT technology.
- Focusing on IoNT industry applications [1].
- Studying the expected impact of IoNT technology on economy.
- Studying THz based imaging systems.
- Integrating advanced deep learning methods during the study of IoNT in order to develop its performance [30].
- Additional reducing the energy ingesting of forced IoNT nodes by preserving the complete time using a small, portable device that sends time and supplies power-collecting circuits to the nodes [31].
- Investigating the use of IoNT and IoT along with BC for making DMS [32].
- Seamless integration of IoNT with existing IoT systems and networks in health applications [7].
- Investigate security and computing power issues in IoNT technology [24].
- Developing a system to get optimal Pconn under flexible environmental situations [9].
- Integrating MEMS Nano plasmonic surfaces with numerous projects to realize high-performance transmission, reception and dispensation optical signal on a single microsystem on a chip for growing IoNT applications [22].
- Building a self-charging energy system based on the principle of frictional nanogenerators to meet the distributed energy needs of the IoNT network [33].
- Development of an IoNT system in the biofield by coupling paper-based chitin (ChNF) sensors to smartphone technology [34].
- Construction a imitation model of rectilinear devices based on carbon nanotubes (CNTs), and nano-array technology to wirelessly power nano sensors [16].
- Positioning and categorizing different actions in the IoNT when several event nano sensors sense and convey pulses concurrently [17].

Conclusions

In this work, a systematic review in the IoNT techniques was investigated. Also, a review and survey, architecture, communication techniques, applications, challenges and recommendations related to this technique have been presented. The field of study described in scientific engines cab be described as follows: Science Direct, IEEE and Web of Science (WoS) database. The research time range was achieved within the years (2015–2021). The results showed that there are just 27 articles in IoNT techniques during these engines, these articles included 13 articles about review and survey and 14 articles on which IoNT architecture based nano sensors, gateways and servers. IoNT technology needs more attention from researchers in this field. It was concluded that there are wide application areas for this technology in various fields, and there are also many challenges that need more attention in addition to some future recommendations. The results showed that this technology is very useful in developing many scientific and applied fields in the future.

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