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Internet of Nanothings: A Primer

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ABSTRACT

The interconnection of nanodevices with Internet has led to development of a new phase of IoT called Internet of nanothings (IoNT). Thus, Internet of nanothings (IoNT) is essentially the interconnection of nanoscale devices with existing networks. IoNT applications are prevalent everywhere. IoNT has the potential to take medicine, energy, electronics, drug, agriculture, and many other sectors to a whole new dimension. The development of IoNT will have a great impact on almost every field in near future. This paper provides an introduction to the Internet of nanothings, its architecture, applications, benefits, and challenges.

KEYWORDS: *Internet of Things, Nanotechnology, Internet of nanothings, Nano sensors*

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INTRODUCTION

The applications of the Internet are expanding every day and its popularity is increasing.

The Internet is a highly connected global network which promises to connect physical and digital devices. Any individual object or device can become networked to the Internet. Such devices include cameras, smart phones, tablets, desktop, laptop, personal computers, printers, smart TVs, cars, refrigerators, coffee machine, smart light bulbs, etc. The Internet of things (IoT) extends the objective of the internet to many devices and objects from different domains by interconnecting them. IoT connects smart things or devices equipped with sensors. These devices communicate with each other without any human interaction. The central concept of the Internet of things is to connect anything, anytime, and anywhere through Internet. IoT helps people and communities by making their systems smarter and their lives easier, more secure, and safer. IoT transforms ordinary products such as cars, buildings, and machines into smart, connected objects that can communicate with people and each other. These applications have given birth to smart everything, smart cars, smart homes, smart refrigerators, smart cities, etc. The emergence of Internet of things has attracted the attention of governments, research scholars, and business community all over the world [1].

The Internet of Things (IoT), Internet of everything (IoE), Internet of Nano-things (IoNT), and Internet of bio-nanothings (IoBNT) are new approaches for incorporating the Internet into personal, professional, and societal life. As shown in Figure 1, the Internet of things can be regarded as a network of networks [2]. IoE is built upon the four pillars: people, data, process, and things. While IoT is only composed of "things," IoE also extends business and industrial processes to enrich the lives of people. The Internet of nanothings (IoNT) is similar to Internet of things except that the devices connected to it are enough to be termed nanoscale, which is invisible to the naked human eye. This is achieved by incorporating nano-sensors in diverse objects using nano-networks.

NANOTECHNOLOGY

The main building block of Internet of Nanothings (IoNT) is nanotechnology. Nanotechnology (science on the scale of single atoms and molecules) has been called the second Industrial Revolution because of the special properties of materials at the nanoscale. It is a branch of green technology which has the potential to revolutionize many aspects of our lives. It has permeated all sectors of our economy due to the unique properties of materials at the nanoscale. It will not only initiate the next industrial revolution but also it will offer technological solutions.

Nanotechnology is the processes used to make and manipulate materials on the atomic or molecular scale to produce objects which are no more than a few nanometres in diameter.

Such materials or objects themselves are called *nanomaterials*, and the study and discovery of these materials is known as *nanoscience*. Nanotechnology can work from the top down (by reducing the size of the smallest structures to the nanoscale) or the bottom up (by manipulating individual atoms and molecules into nanostructures) [3].

Richard Feymann, the Nobel Prize-winning physicist, introduced the world to nanotechnology in 1959. Nanotechnology involves the manipulation of atoms and molecules at the nanoscale so that materials have new unique properties. Nanotechnology is a multi-disciplinary field that includes biology, chemistry, physics, material science, and engineering. It is the science of small things—at the atomic level or nanoscale level. It is revolutionizing many fields including the military, mechanical industry, electronics, biotechnology, medicine, energy, communication, solar, optics, agriculture, and food [4,5]. Nanotechnology is regarded as a transformative technology, which can stimulate scientific innovation and greatly benefit the society. Research on nanotechnology has skyrocketed over the last decade, leading to numerous applications in virtually every segment of the economy. All potential applications of nanotechnology significantly affect our lives, our health, our convenience, and our environment [6].

With miniaturization of devices via nanotechnology techniques, the end product is termed as nano-machines, which is the foundation for development of nano-bots, nano-processors, nano-memory, and nano-clocks.

INTERNET OF NANOTHINGS

The integration of smart devices on the Internet is known as Internet of Things (IoT). The IoT may be regarded as an interconnection of objects, which can communicate with others as well as with humans. Scientists have started shrinking sensors and devices from millimeters or microns in size to the nanometer scale. As the size of the objects is reduced to nanoscale, there emerges the concept of Internet of nanothings (IoNT). This nanosized objects are used in many fields varying from healthcare, body sensing networks, and environmental monitoring [7]. IoNT is the new evolution that blends IoT with nanotechnology. The Internet of nanothings is based on synthetic biology and nanotechnology tools that allow the engineering of biological embedded computing devices.

The concept of Internet of nanothings was proposed by Ian Akyildiz and Josep Jornet from Georgia Institute of Technology in the paper "The Internet of nano-things." [8].

IoNT uses two broad areas of communication: (1) Terahertz Electromagnetic Nano-Communication, which is regarded as transmission and receiving of electromagnetic radiation from components, (2) Molecular Communication, which is regarded as transmission and receiving of information encoded in molecules. IoNT infrastructure can be implemented by introducing nano devices with other popular technologies like big data, wireless sensor network, cloud computing, and grid computing.

The interconnection of nanomachines with existing communication networks such as Internet requires the development of new network architectures. Regardless of the application areas, the following components are the part of architecture of Internet of nanothings, which is shown in Figure 2 and explained as follows [9,10]

1. **Nano-Nodes:** These are the smallest and simplest nano machines which perform various tasks like computing and processing. They are nano sensor and nano actuator devices which are able to perform simple computation. Networking of nano nodes is possible mainly via electromagnetic communication and molecular communication.
2. **Nano-Routers:** These have larger processing resources than nano-nodes. They act as aggregators of information coming from nano-nodes.
3. **Nano-Micro interface devices:** These are implemented to enable the receive/send information coming from nano-routers to and fro the microscale device.
4. **Gateway:** This facilitates the remote connection of the entire system over the Internet. It enables the remote control of entire nano things network over the Internet.

APPLICATIONS

Most of the potential applications of Internet of nanothings are related to healthcare and smart environments. Other applications are in electronics, military, supply chain management, industry, agriculture/farming, food packaging, oil and gas field, energy, smart cities, drug delivery systems, and Internet bio-nano-things. Some applications of these applications are illustrated in Figure 3 and explained as follows [11].

- **Electronics:** IoNT is used in consumer electronics, such as cellphones, automotive applications (e.g. connected and electric vehicles), and smart home appliances, such as refrigerators, washing machines, and robotic vacuum cleaners [12]. IoNT electronics are sophisticated in design and well-packaged to protect devices from unwanted electromagnetic interference.
- **Environmental Monitoring:** Nano sensors are used in environmental monitoring through deployment in public locations like bus stops, airports, hotels, etc. and real time monitoring of traffic and temperature. In smart factories or farms, nano devices could monitor temperature, humidity, and air quality. IoNT used in precision farming applications leading to efficient environment monitoring, crop growth and even animal monitoring. It is being used to monitor and track the farm animals.
- **Body Sensor Network (BSN):** This comprises of in-body nano sensors playing a crucial role in collecting and monitoring patient's biological activities. Nano sensors being used in BSN to provide real time data on a wearable device. They can be placed in the body and a gateway to communicate with Internet.
- **Healthcare:** Nanonetworks promise to extend medical applications beyond basic monitoring. IoNT is applied in an increasing number of areas inhealthcare, from smart

drug delivery devices to implantable pacemakers. It holds many promises for ubiquitous healthcare, due to the relative ease of mass deployment [13]. The nanosensors can measure the temperature of living cells. This helps doctors to take more accurate decisions while treating a patient. IoNT devices can be fitted in human body to sense biochemical data and transfer it to the external networking device wirelessly. Proper implementation of the Internet of nano-things (IoNT) will revolutionize healthcare systems. It will streamline the diagnostic and prognostic processes and aid in the treatment of patients through localized drug delivery. The devices can be connected to the Internet to enable real-time healthcare monitoring. The IoT and IoNT technologies will definitely be the future of healthcare. Application of IoNT in healthcare is depicted in Figure 4 [14].

- **Internet Bio-Nanothing:** The concept of Internet of nanothings has opened up many possibilities such as the prospective application domain known as Internet of bio-nano things (IoBNT), where very tiny, biocompatible, and non-intrusive devices can communicate through the Internet. In IoBNT, nanomachines are no longer artificial but based on biological cells. Proper implementation of the Internet of nano-things (IoNT) will revolutionize healthcare systems. It will streamline the diagnostic and prognostic processes and aid in the treatment of patients through accurate and localized drug delivery and tumor and disease detection. Embedding nanosensors in human body will enable healthcare providers to remotely control and monitor any unexpected change in the body devices by collecting information through these nanosensors. Figure 5 shows a typical architecture of Internet of bio-nanothings [15].

BENEFITS AND CHALLENGES

When IoNT arrives, it could provide detailed, inexpensive, and up-to-date pictures of our cities, homes, factories, and even our bodies. For example, application of IoNT in medicine through nanomaterials and nanodevices has brought numerous benefits in disease prevention, diagnosis, and treatment. A nano sensor connected to the Internet would be able to travel within the human body and provide more accurate information. Nanodiagnostics, nanosurgery, regenerative medicine, nanodentistry, nanotoxicology, and nanomedicine are expected to be in widespread use in years to come [16].

Some of the challenges that plague the IoT are just as relevant to IoNT. One major challenge is related on how to build a reliable and efficient communication infrastructure and how to exchange data with the Internet. Another challenge is the huge capital investment required for the development of nanotechnology. Working at such a small scale makes some requirements harder to fulfil. For example, the communication and power requirements of such small devices are challenging. As data is being collected by nano sensors, new thorny issues of privacy, security, and safety need to be addressed. These challenges hinder the growth of IoNT market. They need to be addressed so that IoNT can become an indispensable necessity for mankind in near future.

CONCLUSION

The Internet of nanothings is a newly emerging technology that is arriving faster than ever and holds the promise of solving many of the world's most pressing challenges. It will result in various novel applications, such as healthcare and smart environments. It has apparently limitless potential to revolutionize all aspects of our lives. The healthcare sector is expected to have a major share in the application of IoNT. Businesses should also pay close attention to the growth of the Internet of nanothings. The key players have been highlighted on the basis of various business strategies and the marketing tactics. They include Cisco, Intel, IBM, Siemens, Schneider Electric, Juniper Networks, Qualcomm, and Alcatel-Lucent. More information on IoNT can be found in the books in [17,18] and the following journals: *Nanoscience and Nanotechnology*, *Future Internet.*

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