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A Review of Nanotechnology Applications in the Telecommunication Industry

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Abstract: Nanotechnology has evolved into one of the most remarkable topics and active research areas in many sectors, including chemical engineering, electronics, medicine, and sciences. Nanotechnology has the potential as the next industrial revolution in contemporary science to deliver effective solutions for power-efficient computation, sensing, and human-machine interface in telecommunication engineering. With the increasing adoption of mobile gadgets connected with 3G, 4G, and 5G services during the Covid-19 crisis, the telecommunication industry had a tough growth income in many countries. By 2025 the connection of fixed broadband is expected in hundreds of millions. The way nanotechnology impacted the telecommunications industry can become the next industrial revolution since higher computing power is needed to offer higher data rates which consider an unsolvable challenge to current technologies. Nanotechnology in communication systems also enables manufacturers to create smaller computer processors and sensors, higher speed rates, and more energy-efficient associated with the current-generation components. This review presents the principle of operation, the application of nanotechnology, and the benefits of the recent developments in the telecommunication industry.

Keywords: molecular nanotechnology, nanoscale, microelectronic, cellular, encoding

1.0 INTRODUCTION

Throughout the years, nanotechnology continues to evolve in this modern age that is considered a general-purpose solution-oriented technology that operates at the intersection of other enabling technologies in many telecommunications and electronics industry products. As shown in Figure 1, nanotechnology is applied in telecommunications, electronics, computing, biotechnologies, and other sciences. Scientists, engineers, innovators, and others are always on the lookout for new ways to explore the idea of nanotechnology in making something at the smallest size or nanoscale to benefit from the novel structures. The application of nanotechnology brings forward a great revolution. Nanotechnology sometimes known as molecular nanotechnology (MNT), represents the control of matter's structure atom by atom and molecule by molecule to establish a new functionality [1,2]. It is the synthesis and manipulation of atomic-scale matter with extreme accuracy [3,4]. It is a development of material below the nanometer scale, 10^{-9} meters, where it is difficult to imagine the size of these atomic particles and the visibility through the naked human eye.

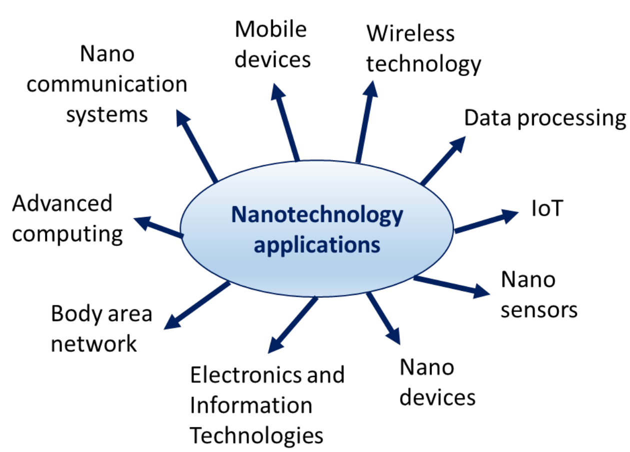

Figure 1: Nanotechnology applications

In today's modern world, nanotechnology is part of the norm to be incorporated into cutting-edge technology with new features. There have been various applications of nanoscale science and technology in the last two decades that have led to the comfort of being surrounded by technological equipment. Researchers [5] discovered new materials in the nanoscale for future evolution in the communication field by the use of molecules to transmit and receive information instead of using electromagnetic waves. This method creates a new communication model leading to a nanonetwork. These advances enable the integration of relevant technologies, the storage of large amounts of data, the use of small storage devices, and the creation of high-performance computers.

Nowadays, smartphone companies are actively expanding the production of mobile phones at a rapid pace. Each of its new releases constantly introduces new features to attract consumers to buy the product. However, this also implies a demand for more memory to store photos, videos, and data. Additional components in a mobile phone can be a challenge to keep costs low and accommodate limited space in a smartphone that should fit in the palm. This is where nanotechnology gains the advantage of following the semiconductor sector which produces transistors with precise dimensions of less than 100 nm by leveraging new nanoscale material designs and innovative data storage methods. Various innovative memory technologies have been researched such as ferroelectric random-access memory (FeRAM), magnetic random-access memory (MRAM), ferroelectric polymer, phase change memory (PCM), resistive random-access memory (RRAM), probe storage, carbon nanotube memory (CNT), and molecular memory [6,7].

Nanotechnology has the potential to be a key driver of technological improvement in the advancement of wireless products such as storage, electronics, antennas, and user interfaces. Nanoscale electrical devices and systems are one of the most important uses of nanotechnology in nanomachines. These nanomachines can be implemented into wireless communication components such as large-scale integration digital processing, RF integrated circuits, and microprocessor control chips, which may have a substantial impact on communication systems in terms of signal transmission, power consumption, and functionality.

2.0 METHODS AND APPLICATIONS

One of the issues with this technology is the lack of agreement on how to define the meaning of nanotechnology. Mostly, the research papers are concerned with the study and method of processes and materials at length scales less than 100 nanometers. Commonly, the structure of nanotechnology is described by making comparisons to human hair, which was in line with the first nanotechnology developed in 1965. Nanotechnology is the processing, separation, consolidation, and deformation of materials by one atom or molecule, which involves the fabrication of devices on a scale ranging from 1 to 100 nanometers [5,7-9].

A general historical outline, basic principles and applications related to nanotechnology in the field of telecommunications are discussed in the following sections.

2.1 General History

According to researchers [10], Richard Feynman was a renowned physicist and Nobel Laureate who predicted the radical downsizing of technology down to the molecular scale in 1959. Half a century later, this field of research has become more centralized, marketable, and self-sufficient. Nanoscale science is categorized into three: nanostructures, nanofabrication, and nano-characterization, through the applications in nano-electronics, biological sciences, and the energy field [11,12]. Thus, nanotechnology manufacturers can make computer processors and sensors which are smaller, quicker, more energy-efficient, and less expensive than their current equivalents.

The evolution of concepts and experimental activities are suitable under the broad category of nanotechnology is traced in the history of nanotechnology. Although nanotechnology is a relatively breakthrough discovery in scientific research, important supporting principles have been developed over a longer period. The emergence of nanotechnology in the 1980s was prompted by the convergence of experimental advances such as the invention of the scanning tunneling microscope in 1981 and the discovery of fullerenes in 1985 [13]. In 1986, the publication of the Engines of Creation book began, this book provides an explanation and dissemination of the conceptual framework for the goals of nanotechnology [13,14].

In the mid-1990s, micromechanical sensors became an integral aspect of automobile technology. In the next ten years, later, increasingly miniaturized micromechanical sensors and embedded sensors based on nanostructures are allowing revolutionary features in consumer electronics and mobile devices [15,16]. Nanorobotics is a new technological discipline that involves building robots or machines with components on a nanometer scale. Nanorobotics is a nanotechnology engineering subject that focuses on creating and fabricating nanorobots with devices ranging from 0.1 to 10 micrometers in size and made up of nanoscale or molecular components [17,18].

In early 2000, the nanotechnology research field drew increasing public attention, controversy, and debates on the potential implications and the feasibility of the applications envisioned by proponents of molecular nanotechnology and governments moving to promote nanotechnology research funds. Commercial uses of nanotechnology began to emerge in the early 2000 but were confined to bulk applications of nanomaterials rather than the revolutionary applications envisioned by the field [19].

Interacting and embedding with other human settings such as the home, business, public places, and mobile devices with high levels of computation and communication requires an intelligent approach to detecting, processing, and communication technologies. These devices must be autonomous and durable, be easily installed without explicit maintenance and the mobility of the devices also requires controlled size and power consumption limits. Intelligent interaction with other devices and surroundings, sensing, context, collective data rates, computational capacity and necessitating additional memory, are further criteria for intelligent mobile systems. All these criteria combine to create a predicament that cannot be solved with existing technology. On the other hand, nanotechnology could help with actuation, sensing, memory, radio, embedding intelligence in the environment, and power-efficient computation.

Nanoscience and nanotechnology are essential in the development of new or improved functional materials that can benefit humans. Nanotechnology material or nanomaterial is the name given to this material where it can be created in various ways. Depending on the constructed nanomaterial, it can serve different purposes in multiple fields. There are three dimensions to classifying nanomaterials. Thin films, tailored surfaces, and surface coatings are examples of one-dimensional nanotechnology materials. Nanowires, biopolymers, inorganic nanotubes, and carbon nanotubes are two-dimensional nanomaterials, while colloids, precipitates, dendrimers, fullerenes/carbon 60, nanoparticles, and quantum dots are examples of three-dimensional nanomaterials [19-21]. Most of these materials are used in the manufacturing of electrical and telecommunications products.

Telecommunication is defined as distant communication, and also as the transmission of information signals over vast distances. The information can include telegraph, radio, telephone calls, or data. In many aspects, nanotechnology influences telecommunications and facilitates communications not just beyond physical boundaries, but also over long-established economic, political, cultural, and even religious obstacles [22,23]. Through this influence on telecommunications, the capability of wireless communication can be enhanced significantly while extending communication around the world. According to [24], the development of nanoscale components that would improve performance, lower power consumption, smaller size device, and novel functionality are the main drivers for employing nanotechnology in wireless communications. It would also increase the use of the RF spectrum in gadgets and devices, hence increasing the trend of wireless communication.

Based on a study by [25], nanotechnology can help radio frequency (RF) operation in frequency ranges and avoid interference for Giga-Hertz (GHz) signal processing by building systems with an abundant number of nanoscale resonators. Furthermore, it opens up new insights for the advancement of antennas. As antennas are one of the essential components in telecommunication, the research covered the potential of nanotechnology to improve performance by optimizing the geometry of an antenna. It can be developed by adopting new materials such as magnetic nanoparticles, reducing the losses, and tuning the electrical transmittance and conductivity to achieve the optimum values.

2.2 Basic Principle of Nano-Communication Systems

Nanomachines are mechanical devices that rely on nanometer-scale components. A nuclear machine is a mechanical device that plays out an accommodating limit employing nanoscale scale fragments and defined sub-nuclear structures capable of transporting, processing, information, sensing, and potentially activating other systems [5,26,27].

The most fundamental technique for interconnecting microelectronic devices is communication-based on electromagnetic waves, which may propagate with low loss either wired or wirelessly [28]. RF systems in nanomachines must be coordinated, to create two-way wireless nano communication and the construction of nano-sized antennas to operate at high frequencies. Molecular communication, which represents the transmission and reception of information contained in the molecules is applied to characterize communication amongst nano-size devices [29]. Molecular communication can be used to connect multiple nanomachines, resulting in nanonetworks that use molecules to encode messages. The molecular coding approach, which uses the intrinsic properties of the molecules to encode information such as chemical structure, the relative placement of molecular parts, or polarization, can be considered to represent information in nanonetworks. The receiver must be able to recognize these specific molecules when decoding the information. This approach is comparable to the use of encrypted packets in communication networks, where the information can only be read by the designated receiver.

Figure 2 shows phenomenal communication, the molecular encoding is utilized with only members of the transmitter species being able to decipher the communicated message. Traditional communication networks are often used to transmit text, voice, and video. However, nanonetworks convey information that is more tied to events, chemical states, and processes since the message is a molecule [5,29,30].

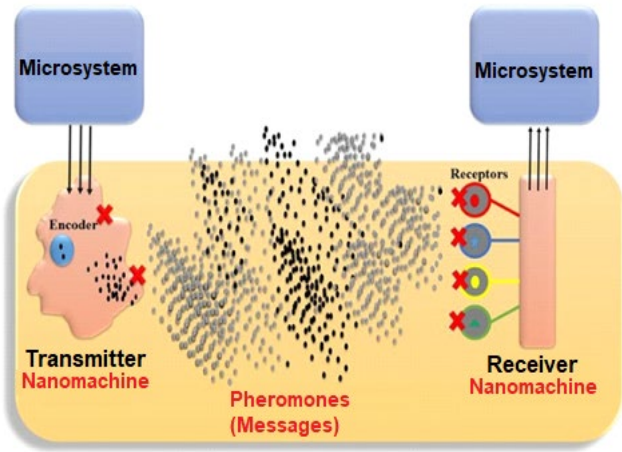

Figure 2: Molecular communication based on pheromones encoding [5,29,30]

The communication between nanomachines is carried out in the same way as traditional communication, which means that the message is transmitted across a carrier to the receiver, then, the information delivered must be encoded on the transmitter side and decoded on the receiver. However, in molecular message communication, the molecule presents a predefined external structure that allows easy recognition by the receiver. When the molecular messages did not react with other molecules in the medium, it means the communication is non-functioning. The molecular messages should be easily eliminated without causing any consequences in the nanomachine. Then, the molecules are decoded at the receiver nanomachine. The carriers are specific molecules capable of transporting chemical signals or molecular structures that hold information data [31].

In biological systems, the molecules are used as information carriers in molecular communication. The molecular motors or calcium ions might be utilized as the carrier. Proteins such as dynein, kinesin, and myosin can create motions using chemical energy and are used to carry a molecule packet of data from the transmitter to the receiver. Figure 3 shows a molecular motor that shows a protein that converts chemical energy into mechanical work on a molecular scale.

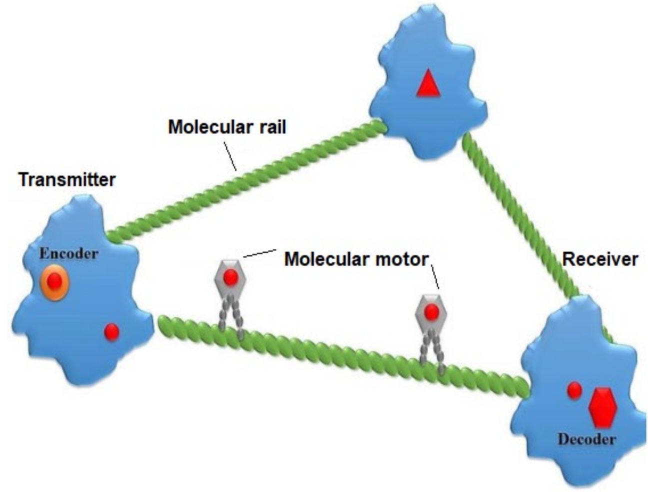

Figure 3: Molecular motors for molecular communication [5,29,30]

The molecular motors can move molecules [32]. The molecule travels or moves along molecular tracks known as microtubules. The molecular motor or calcium ions carrier is employed by the transmitter to encode information by modulating the concentration of ions in terms of amplitude and frequency. The medium in molecular communication, such as in-body or environmental monitoring nanonetworks, can be either wet or dry. The propagation is much reliant on the medium conditions.

2.3 Applications

The advent of nanotechnology could have a significant impact on the telecommunications industry. The nanotechnology on the functioning of both cellular and core networks, as well as improvements in sensor security and performance, has made nanotechnology the most significant advancement over previous technologies. Wireless technology firms have pledged to build intelligent operations that require computation and communication to occur.

Nanodevices may be programmed to do functions like self-powering, sensing the environment, and interfacing intelligently with other systems. Cell phones also include upgraded carbon nanotubes, which fall under the category of nanotechnology. As outfitted with nanotechnology, cell in the fifth generation (5G) of mobile systems is referred to as nanodevices. One of the essential ambitions of the wireless industries is to accomplish a means of nano-intelligent technologies that are ready to assist humans smartly. The demands on network devices and mobile devices, as well as intelligence approaches that be placed in human situations such as the home or public areas, can result in the creation of new sensing and computing methods that are embedded in nano communication systems.

Moreover, in communications systems, a mobile device with a high level of computing and communication needs to be able to interact with other human beings to perform their tasks efficiently. Mobile devices with this capability should be able to operate autonomously and be easily used. These mobile devices or gadgets can be attached to various human situations, such as home, office, and open spaces. One of the requirements for successfully embedding these devices universally is ensuring they are adaptive to the environment. It can aid in the development of new forms of perceptive nanodevices and nanosensors capable of communicating with these organic frameworks for nanotechnology methods.

Nanotechnology will open up options that may be as complex as helping in improving environmental conditions or as simple as determining whether organic products are safe or harmful [33,34]. By incorporating nanotechnology into wireless equipment such as sensing devices, a potential area of research is the advancement of military nanotechnologies. Sensors are considered significant for obtaining information about local circumstances, the growth of enemy soldiers or hardware, surveying continual injury, or undermining the feasibility of an attack. Nanosensors in observation applications may also play a significant role in improving the accuracy of weapon transmission, in such a way by providing data to modify control levels.

In nano communication and networks, the live cells in diverse tissues and species use a variety of ways to establish cell contact [35,36]. Existing cell-cell communication processes might be used to create regulated communication network systems for nanomachines. Furthermore, contemporary molecular engineering methods may allow for the alteration of biological components to construct components suited for communication network systems among nanomachines, besides unique features such as signal amplification and switching mechanisms. Upon sensing a chemical compound in the environment, the transmitter nanomachine initiates a network node or cell signal. Then, the stimulated node transmits the cell signal to the neighbors. When receiving the node-mediated signals, the receiver nanomachines react to the signals by secreting chemicals, creating motion, and emitting light.

The application of nanotechnology can be seen as a technology that brings many benefits. However, nothing is perfect besides this nanotechnology will bring pros and cons [37-40]. The advantages and disadvantages of nanotechnology in the telecommunications industry can be stated as follows:

Advantages:

- Transformation at the cellular level: Nanotechnology can restructure objects at the cellular level. It is as uncertain that waste might be converted into useable stuff. Recycling would take on a new significance.
- Has the potential to develop self-repairing technologies: Once the defect is identified, nanotechnology might be used to correct the problem and prevent the accident.
- Nanotechnology has the potential to end poverty in numerous ways: Nanotechnology has the potential to produce a large number of high-wage new employment.
- Revolutionize a lot of telecommunication products and applications: The development of effective energy storage such as mobile phone batteries can be made smaller and more efficient.
- Growth mechanism, synthesis applications and patentable technology: The development of the synthesis technique of nanomaterials for some applications such as magnetron sputtering, nanostructured thin film and thermal evaporation.
- Nanotechnology has the potential to improve life and work in terms of new technologies to face industrial revolution 4.0 (IR 4.0): Nanotechnology has the potential to enhance the performance of autonomous robotics, the internet of things (IoT), biotechnology and the digital world.
- Nanomaterials and nanoelectronic devices are revolutionizing technological concerns used in the future. Carbon nanotubes could revolutionize car design to improve electrical and thermal capabilities. Micro-vehicles can be developed for deep space exploration and climate research. Nanorobots could assist in the manufacture of microscopic actuators for nano-wireless communication research.

Disadvantages:

- May include different diseases and illnesses: There is no assurance that the issues that may be addressed by nanotechnology will not be followed by other problems that have no solution and are even more difficult in the future.
- Nanomaterials may be risky in the human body's immune system: Nanoparticles materials cannot be filtered behind the human immune system, nanomaterials may slip through skin cell membranes, and carbon nanotubes are harmful to lung cells and may cross the blood-brain barrier.
- Has the potential to develop a new class identity system: One socioeconomic class may retain the technology for their benefit, resulting in a new gap between a rich and poor society.
- Current technologies might become outdated as a result of this: Nanotechnology has the potential to render these technologies obsolete. The consequent change in economic conditions would modify where the value is seen in a population base.
- The development and the equipment can be costly: Nanotechnology systems are difficult to produce and probably the products made with nanotechnology are more expensive.

3.0 DISCUSSION

Advances in electronic, optical, and optoelectronic components in information processing and transmission are expected to result in faster and more accurate communication systems. Photonic crystals might be applied to construct entirely optical circuits as a foundation for information processing based merely on the light. The nanotechnology idea in nanoscale storage devices based on complementary metal-oxide-semiconductor (CMOS) technology and uses quantum dabs and carbon nanotubes have driven to meet high expectations for storing vast amounts of data [41]. The flexible three-dimensional (3D) nanocomputer chip technologies that firmly interconnect memory guarantee rapid and precise data processing by reducing information bottlenecks. With more work, the gain might lead to substantial improvements in execution, competence, and the ability to handle large amounts of data on conventional central processing units (CPUs). A 3D integrated memory and upcoming nanotechnologies such as carbon nanotube (CNT) transistors have promising first steps toward developing ultra-high efficiency and high-performance electronic systems that can handle large quantities of data.

Table 1 shows the range sizes of nanomaterials that can be used in telecommunication applications [37,42-44]. Superior performance, lower power consumption, and smaller communication components are the main reasons for using nanotechnology in wireless devices and systems. Nanotechnology is expected to have a big impact on communication systems, resulting in fewer requests associated with improvements, massive capacity information, and reduced limited devices. Nano networking is a revolutionary concept that enhances the capabilities of nanomachines to be embedded in a single nano core network that can connect to the internet by improving the concept and deployment of the internet of things (IoT) for future nanonetworks.

Table 1: The size range of nanomaterial structures and applications in telecommunication devices

Structures	**Diameter or length (nm)**	**Applications**
Carbon nanotubes (CNT)	1 - 20	Actuators, energy storage, coatings, device modelling, electromagnetic shields
Nanocopper	<50	Conductive ink for radio frequency identification (RFID)
Nanomagnetic	10 - 100	Miniaturize antenna, sensor, radio frequency (RF) devices
Carbon Nanofibres (CNF)	50 - 200	Lithium-ion battery, sensors, metal surface structural, cooling microprocessor chips
Nanosensors	<1000	Nanoelectronics devices, integrated circuits, internet of nano things (IoNT), wireless nanosensor networks (WNSN)

4.0 CONCLUSION

The primary difficulties of future next-generation networks (NGN) research and development are interaction effects related to cognitive radio and software-defined radio. Nanotechnology is projected to transform the mobile telecommunications sector, having a major influence on both terminals and core networks. Besides, worldwide coverage through satellites and high-altitude platforms are feasible transformation pathways for space roaming and NGN radio access expansion. Machine-type communication, wireless sensor networks, and wearable devices, on the other hand, will pave the way for the most emerging NGN applications.

Nanotechnology is not only a reduction of current technologies. However, it is referred to many operating principles and theoretical models from older technologies, including microtechnologies. The use of quantum effect and self-organization processes is a distinguishing feature. Nanotechnology skill and qualification requirements reflect this paradigm shift and translate it into production-relevant applications.

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