The Future of Healthcare: Nanomedicine and Internet of Nano Things

E. Omanović-Mikličanin[1], M. Maksimović[2] and V. Vujović[2]

[1] Faculty of Agriculture and Food Sciences, University of Sarajevo, Sarajevo, Bosnia and Herzegovina
[2] Faculty of Electrical Engineering, University of East Sarajevo, East Sarajevo, Bosnia and Herzegovina

Abstract—**Constant population growth influences of health care demands and needs for new, more advanced scientific solutions. Classical way of providing the health care services could be very robust. It requires new paradigm and technology for more effective solutions. Rapid development information and nano technologies change the health care system in total. It gives to the health care system a new, global domain – Internet of Nano Things (IoNT) and nanomedicine.**

These two concepts are beginning to change the foundations of disease diagnosis, treatment, and prevention. Future healthcare based on IoNT powered e-health systems will make health monitoring, diagnostics and treatment more personalized, timely and convenient. These improvements increase the availability and quality of medical care followed with radically reduced costs. Thus, analysis of this approach is highly important for future development of healthcare.

Keywords— **healthcare, nanomedicine, nanotechnology, Internet of Nano Things.**

I. Introduction

The present tremendous developments in the field of nanotechnology (a technology which is deployed in desired devices within the nanotechnology radius) lead to new nanomachine (the most basic functional unit, integrated by nano-components and able to perform simple tasks such as sensing or actuation) applications that could benefit various industries, including healthcare, industry, as well as the military [1]. In other words, the development of nanoscale electronic and sensor devices has the potential to enable advances in ubiquitous computing and distributed and self-organising network systems [2]. Manufacturing with nanotechnology can solve many of the world's current problems. A more realistic view is that there will not be the aspect of life untouched by nanotechnology. It is expected that nanotechnology will be in widespread use by 2020. Mass applications are likely to have great impact, especially in industry, medicine, new computing systems, and sustainability [3].

The ability of everyday devices to intercommunicate with each other and/or with humans is becoming more prevalent and is known as the Internet of Things (IoT). It is a highly dynamic and radically distributed networked system, composed of a very large number of smart objects. Three main system-level characteristics of IoT are [4]:

- Anything communicates;
- Anything is identified; and
- Anything interacts.

Nowhere does the IoT offer greater promise than in the field of healthcare. McKinsey Global Institute in its report presents predictions and economic feasibility of IoT powered healthcare, which states that by 2025 the largest percentage of the IoT incomes will go to healthcare [5] (Fig. 1).

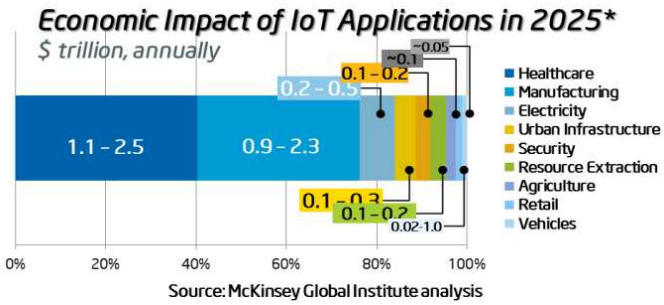


Fig. 1. Economic Impact of IoT Applications in 2025 provided by the McKinsey Global Insitute

Embedding nanomachines in the environment add a new dimension to the Internet of Things, realizing the Internet of Nano Things (IoNT) vision (Fig. 2).



Fig. 2. The Internet of Nano Things possible applications at the global scale [6]

The interconnection of the nanonetworks to the wider Internet will bring along new challenges. These challenges will include acquiring new communication and interface mechanisms between the nano- and micro scale networks as

well as techniques to handle the large amount of data that will emerge from nanonetworks. New service models at the application layer to manage data from the nanonetworks will also be a matter of future research. Thus, the IoNT will open new opportunities for future applications including healthcare, transportation and logistics, defense and aerospace, media and entertainment, manufacturing, energy and utilities, retail, and others services [6]. The application of nanotechnology is most exciting in the biomedical domain, where advances are being made in both diagnostic and treatment areas [3]. This fact ranks nanomedicine as one of the top 5 trends in nanotechnology.

In order to define future healthcare opportunities, this paper presents the possibility of nanotechnology application in medicine as well as the ways and importance of interconnecting nanodevices with the Internet for development a sophisticated medical and expert system for personal health management. The concept and architecture of new IoT paradigm called Internet of Nano Things (IoNT) is presented. Security and ethics issue of applying this technical approach are considered too.

In summary, the perspectives and challenges of both nanomedicine and IoNT are presented in the rest of the paper, which is structured as follows. Section II presents a nanomedicine, therapy and enhancement. The architecture of IoNT is presented in Section III while Section IV presents security and privacy issues of IoNT applications in healthcare. Finally, Section V concludes the paper.

II. NANOMEDICINE, THERAPY AND ENHANCEMENT

Nanotechnology has diverse applications in health care sector, including the development of new diagnostic and imaging applications, more potent pharmaceuticals, and drug delivery mechanisms, implants and devices [2]. Therefore, nanomedicine is the process of diagnosing, treating, and preventing diseases and traumatic injury by using nanoscale-structured materials and simple nanodevices, that can be manufactured today. The core of nanoscale-structured materials and nanodevices is the interaction of these materials with biological systems. In the longer term, perhaps 10-20 years from today, nanomedicine may give molecular machine systems and nanorobots, as a type of nanomachines, which may join the medical armamentarium, finally giving physicians the most potent tools imaginable to conquer human disease, ill-health, and ageing (Fig. 3) [7].

In addition, nanorobots are seen to be instrumental in nanomedicine and cognitive enhancement in future. Several classes of medical nanorobots such as respirocytes, clottocytes, vasculoids, and microbivores are designed till now. They could perform a variety of biophysical clean-up, maintenance, and augmentation functions in the body [8].

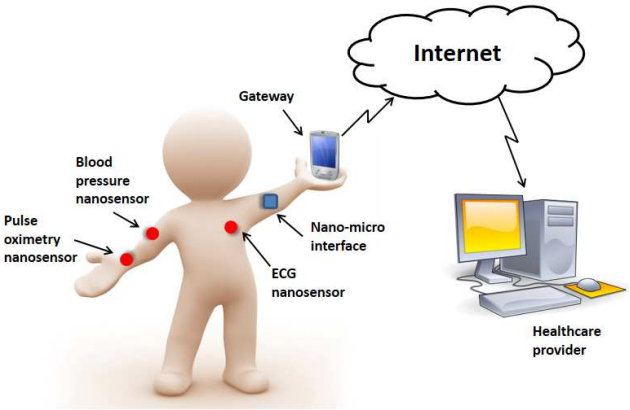


Fig. 3. The Internet of Nano things application in Healthcare

Existing biological nanomachines, such as nanosensors and nanoactuators provide an interface between biological phenomena and electronic nano-devices. In the diagnostics area, nanosensors that can detect, identify, and quantify biological substances in body fluids are leading to early disease detection and earlier treatments as well as the ability to detect environmental contaminants in the body [1]. Nanomachines deployed inside the human body can be remotely controlled from the macroscale and over the Internet by an external user (a healthcare provider), creating in such way a new networking paradigm - the Internet of Nano Things.

The dominant research fields and application in nanomedicine [9] can be summarized into:

A. *Drug Delivery Systems*

Nano-based drug delivery systems aim to improve the bioavailability and pharmacokinetics of pharmaceuticals and to provide non-invasive routes of drug administration. Examples of drug delivery systems in development that use nanomaterials are liposomes, nanosuspensions, polymeric nanoparticles, dendrimers, fullerenes, carbon nanotubes, and inorganic nanoparticles. One of the drug delivery devices undergoing clinical trials is a nanoparticle shell containing a chemotherapy agent [2].

B. *Implants*

Nanomaterials and nano components have increasingly been developed for medical implants. Major application fields are hard tissue implants, bone substitute materials, dental restoratives, soft tissue implants, and antibiotic materials for coating or disinfecting medical equipment. Nano-

materials have been developed for orthopedic implants that have greater biocompatibility, promote new bone growth and which are hoped to have longer life spans [2].

C. Diagnostic Tools and ICT (Information and Communication Technologies) Interfaces

The next generation of medical applications will be made possible through greater and more specific physiological and health data provided by new medical surveillance and diagnostic tools. While this field is still far smaller than that of drug delivery, new information accessed through nano-diagnostics arguably poses the greatest challenges for privacy. Similarly the use of ICT implants for diagnostic purposes has to date attracted little attention [7].

D. Nanobionics

Another emerging field is that of ”nanobionics”, described by some as the convergence between biology and electronics. Nanotechnology does not yet play an important role in the manufacture of commercially available active implants. Nonetheless, there are many examples where nano-structured materials are being used for specific components of active implants, to improve the biocompatibility of implants, and to support more effective electrode-cellular interfaces [2].

III. IONT ARHITECTURE FOR HEALTHCARE APPLICATIONS

Internet-connected devices, brought out to patients in various forms, enable tracking health information what is vital for some patients. This creates an opening for smarter devices to present more valuable data, lessening the demand for direct patient - healthcare professional interaction (Fig. 4) [10]. With faster, better insights, providers can improve patient care, chronic disease management, hospital administration and supply chain efficiencies, and provide medical services to more people at reduced costs [11].

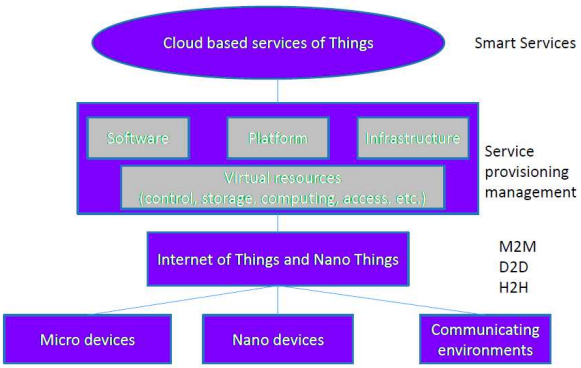


Fig. 4. The Internet of Things architecture [10]

The IoT rapidly change the healthcare scenario by focusing on the way people, devices and applications are connected and interact with each other and offer promising solutions for healthcare, making a more revolutionary archetype for healthcare industry developed on a privacy/security model [12]. Several e-health scenarios are enabled by rapid ICT advancements and with the increasing number of smart things (portable devices and sensors). Such created e-health solutions provide a great wealth of information that can be used to make actionable decisions. By linking information, people, devices, processes and context, Internet powered e-health creates a bunch of chances to improve outcomes, increases efficiency, and makes healthcare affordable.

In order to track and record personal data it is necessary to use sensors or tools which are readily available to the general public. In the IoNT paradigm, the following components are main blocks of the network architecture (Fig. 5) [1]:

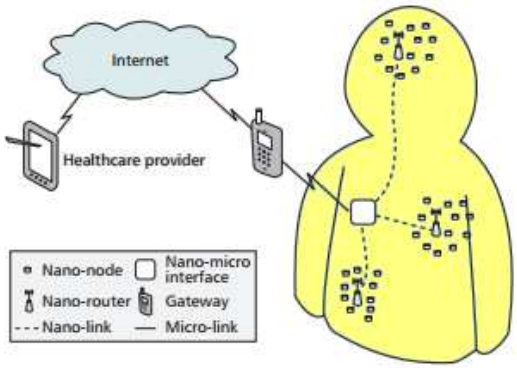
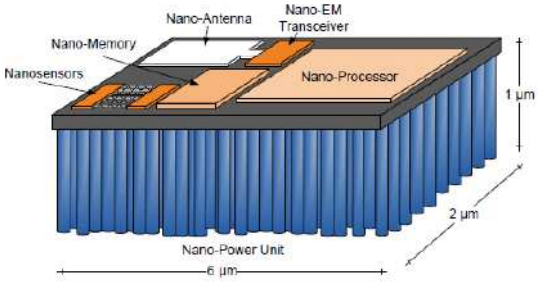
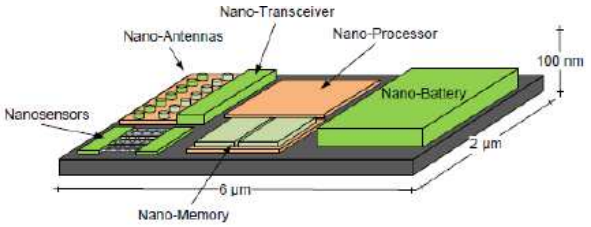


Fig. 5. The Internet of Nano Things architecture in Healthcare application [1]

- Nano-nodes - the smallest and simplest nanomachines which have limited memory and energy, able to perform simple computation, and can only transmit over very short distances. Nano-nodes can be nanomaterial-based designed and bio-inspired designed (Fig. 6).



a) nanomaterial-based design



b) bio-inspired design

Fig. 6. Design principles of nano nodes [10]

In general, nanosensors can be classified into the following types: physical (mechanical, acoustical, thermal and radiation, optical, and magnetic); chemical (atomic and molecular energies); and biological (antibody/antigen interaction, DNA interaction, enzymatic interaction). Approaches for the fabrication and integration of nanosensors are presented in Fig. 7.

- Nano-routers - nano-devices which aggregate information coming from limited nanomachines and can also control the behavior of nano-nodes by exchanging very simple control commands (on/off, sleep, read value, etc.).
- Nano-micro interface devices – these devices aggregate the information coming from nanorouters, to convey it to the microscale, and vice versa. This device are able to communicate in the nanoscale using the nanocommunication techniques and to use classical communication paradigms in conventional communication networks.
- Gateway - this device enables the remote control of the entire system over the Internet.

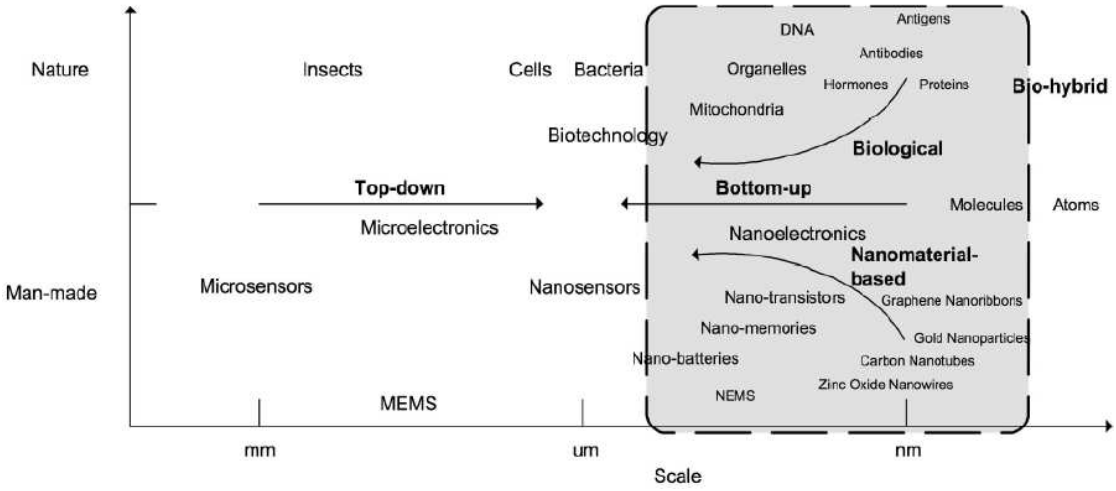


Fig. 7. Approaches for the fabrication and integration of nanosensors [10]

The unique properties of the nanoscale and the nature of nanonetworks require new solutions for communications that should be provided by the information and communication society [1]. As communication is crucial in such networks for extended or permanent health monitoring and diagnostics, author of [13] defined four recognizable near future communication needs of nanotechnology in health applications:

1. Information transfer;
2. Control data transfer;
3. Sensing and Identification; and
4. Localization.

The importance of communication with devices placed in human body also rises as an extensive research and development. On that point is also an impression that adoption of existing communication technology to micro- and nano applications would offer significantly more inexpensive and faster application of nanotechnology in medicine.

IV. IONT HEALTHCARE APPLICATIONS: SECURITY AND PRIVACY ISSUES

Various applications of nanomedicine include the development of novel diagnostic and imaging applications, more potent pharmaceuticals and drug delivery mechanisms, and active implants and devices [2]. For example, diagnostic nanosensors will allow early detection of various diseases, like cancer, at the very onset of the symptoms, before the disease is perceived by the patient. Early detection means higher chances of successfully treating and overcoming the disease. In other words, scale of nanodevices enables reach-

ing hard to access areas and access vital information at a whole new level (molecular information).

The primary and largest benefit of self-monitoring systems is the elimination of the necessity for third party hospitals to run tests, which are both expensive and lengthy. The second advantage is connection with healthcare expert systems which are very important for giving correct information for diagnosis, reducing medical errors and providing immediate medical services [14-16]. These expert systems are usually based on artificial intelligence, and they are added to sensed data.

In other words, the body area networks collect vital patient information and feed this information to service providers' computing systems or expert systems. As a result, it achieves higher accuracy and efficiency in monitoring the health conditions of a great number of patients [17]. Therefore, these systems are an important advancement in the area of personal health management [18].

As the science and technology of nanomedicine speed ahead, ethics, policy and the law are struggling to keep up. It is important to proactively address the ethical, social and regulatory aspects of nanomedicine in order to minimize its adverse impacts on the environment and public health [19]. The computerization of medical information has raised significant concerns about privacy. Critical medical information must be protected from illegal usage for personal advantages and fake acts what implies the importance of security and reliability in IoNT powered e-health solutions. Thus, privacy issues should be well addressed to ensure the appropriate use of the sensitive data collected from personal health monitoring devices. The European Commission's eHealth Action Plan 2012-2020 provides a roadmap to empower patients and healthcare workers, to link up devices and technologies, and to invest in research towards the personalised medicine of the future [20]. Together with this plan, the Commission issued a Staff Working Document on Telemedicine which is the provision of healthcare services, through the use of ICT, in situations where the health professional and the patient are not in the same location. The aim of these regulations is to help dealing with the legal aspects related to data protection rules, privacy matters and reimbursement. In this way, secure transmission of medical data and information, through text, sound, images or other forms needed for the prevention, diagnosis, treatment and follow-up of patients, provides smarter, safer and patient-centered health services.

Discussion and Conclusion

Nanotechnology is a subject area of applied scientific discipline focused on the design, synthesis, characterization and application of materials and devices on the nanoscale. Through the design, characterization, production and application of nano sized, intelligent materials and their application within medicine, there is a possibility to revolutionize the healthcare. In other words, the nanotechnology has become a new advent of medicine (nanomedicine). The use of nanotechnology in medicine offers some exciting possibilities.

Nanotechnology-based therapies, in vitro diagnostics and imaging agents are still in an early stage of development, although it is expected that their importance will grow. Nano drug delivery systems (NDDS) now on the market are first generation products that use nanomaterials to increase the solubility and therefore the bioavailability of drugs, or which concentrate drugs in particular tissues. Just as the understanding of the unintended consequences of exposure to nanomaterials for human health and the environment remains rudimentary, scientists are just beginning to understand the interaction of NDDS with the immune system, cells, and organs.

Nanotechnology provides extraordinary opportunities not only to better materials and medical devices, but also to create new "smart" devices and technologies. IoT with nanomachines have attracted much attention as one of the new research areas. In this way, nanotechnology and the Internet together create a novel vision – Internet of Nano Things (IoNT). Nowhere does the IoNT offer greater promise than in the field of healthcare. The application of IoNT in nanomedicine presents a very significant improvement in nanomedicine - enhancing human health in novel ways, particularly in preventive health, proactive monitoring, follow-up care and chronic care disease management. Nano- and micro-networks of sensors enable continuous health monitoring and logging vital parameters of patients. In other words, these networked systems continuously monitor patients' physiological and physical conditions, and transmit sensed data in real time via either wired or wireless technology to a centralized location where the data can be monitored and processed by trained medical personnel. Having in mind that e-health systems store and process very sensitive data, such systems should have a proper security and privacy framework and mechanisms. Only in this way, the principal goal of Future Healthcare idea - early disease detection and diagnosis, as well as precise and effective therapy tailored to the patient, accompanied with reduced cost is enabled.

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Enisa Omanović-Mikličanin, Faculty of Agriculture and Food Sciences, University of Sarajevo, Zmaja od Bosne 8, 71 000 Sarajevo, Bosnia and Herzegovina (phone: 387-33-653-033; e-mail: enisa.omanovic.miklicanin@gmail.com).