THINGS AND EVERYTHING: INTERNET OF NANO-THINGS FUTURE GROWTH TRENDS

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ABSTRACT

The current statuses and future promises of the Internet of Things (IoT), Internet of Everything (IoE) and Internet of Nano-Things (IoNT) are extensively reviewed and a summarized survey is presented. The analysis clearly distinguishes between IoT and IoE, which are wrongly considered to be the same by many commentators. Despite possible negative aspects of these developments, there are grounds for general optimism about the coming technologies. Certainly, many tedious tasks can be taken over by IoT devices. However, the dangers of criminal and other nefarious activities, plus those of hardware and software errors, pose major challenges that are a priority for further research. Major specific priority issues for research are identified. Nanotechnology promises new solutions for many applications in the biomedical, industrial and military fields as well as in consumer and industrial goods. The interconnection of nano scale devices with existing communication networks and ultimately the Internet defines a new networking paradigm that is further referred to as the Internet of Nano-Things. Within this context, this paper discusses the state of the art in electromagnetic communication among nano scale devices.

Keywords: *Internet of Things (IoT), Internet of Everything (IoE), Internet of Nano-Things (IoNT), Nanotechnology.*

1 INTRODUCTION

Nanotechnology is enabling the development of devices in a scale ranging from one to a few hundred nanometers. At this scale, a nano machine is defined as the most basic functional unit, integrated by nano-components and able to perform simple tasks such as sensing or actuation. Coordination and information sharing among several nano machines will expand the potential applications of individual devices both in terms of complexity and range of operation.

The resulting nano networks will be able to cover larger areas, to reach unprecedented locations in a non-invasive way, and to perform additional in-network processing. Moreover, the interconnection of nano scale devices with classical networks and ultimately the Internet defines a new networking paradigm, to which we further refer as the Internet of Nano-Things. Despite several papers on nano-devices and their applications are published every year, it is still not clear how nano machines are going to communicate.

For the time being, we envision two main alternatives for communication in the nano scale, namely, molecular communication and nano-electromagnetic communication:

Molecular communication: this is defined as the transmission and reception of information encoded in molecules. Molecular transceivers are expected to be easily integrated in nano-devices due to their size and domain of operation. These transceivers are able to react to specific molecules, and to release others as a response to an internal command or after performing some type of processing.

Nano-electromagnetic communication: this is defined as the transmission and reception of electromagnetic (EM) radiation from components based on novel nano materials. The unique properties observed in these materials will decide on the specific bandwidth for emission of electromagnetic radiation, the time lag of the emission, or the magnitude of the emitted power for a given input energy.

In this article, we focus on electromagnetic communication among nano-devices and provide an in-depth view of this new networking paradigm from the communication and information theory point of view. We begin our discussion by introducing reference architecture for the

Internet of Nano-Things. We motivate the study of the Terahertz band for nano-electromagnetic communication and outline the main research challenges in terms of channel modeling, information modulation and networking protocols for nano-devices. Finally we conclude the article.

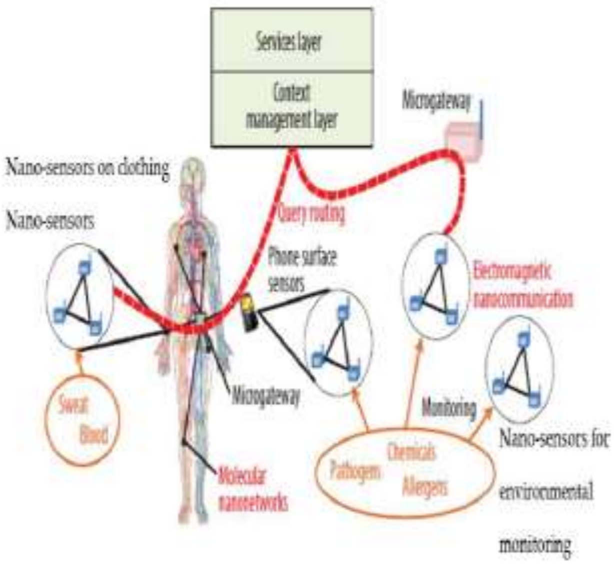

Figure: 1 The Internet of Nano-Things.

Thus, the Internet of Things will not only be deployed in the world that can be seen, but at scales that are invisible to the naked human eye. This will be by the use of IoNT and IoBNT. Their use will not only be medical at the cellular level but industrial, for example in filtration work such as water purification or for dialysis. The overcoming of a major obstruction of IoBNT will follow from the seamless merger of IoNT with existing health-based IoT systems as well as networks. The application of IoBNT, being stemmed from synthetic biology as well as the utilization of nanotechnology tools to enable the engineering of biological embedded computing devices, will reduce the risk of undesired effects on health and/or the environment.

2 LITERATURE REVIEW

The applications and usage of the Internet are multifaceted and expanding daily. The Internet of Things (IoT), Internet of Everything (IoE) and Internet of Nano-Things (IoNT) are new approaches for incorporating the Internet into the generality of personal, professional and societal life, plus the impersonal world of inanimate quasi-intelligent devices. This paper examines the current state of these technologies and their multidimensional applications by surveying the relevant literature.

The paper also evaluates the various possible future applications of these technologies and foresees further developments and how these will both challenge and change the way that future life will be lived. This paper presents an update on our previous work presented at the Internet Technologies and Applications

Conference in 2015 (Wrexham, UK) by extending the survey duration to reflect the current technological advances since 2015.

New dimensions of discussion have also been added such as the future challenges IoT is currently facing. The discussion on IoT, in Section 2, has been further expanded by adding sub-categories of IoT based on the scope of its usage as well as the components of typical IoT systems, with a listing of the top ten IoT segments for 2018 based on a survey of 1600 enterprise IoT projects.

The discussion on IoNT has been augmented by the inclusion of discussion of the Internet of Bio-Nano-Things (IoBNT), limitations and challenges of IoNT and presentation of examples of earlier research advances in the field. The deliberation on "Future Internet" has been extended as well as updated to reflect new research, associated challenges and future trends. Section 6, namely "Challenges and Impediments to IoT", has been added, scrutinizing 21 of the most significant current and future challenges.

The paper first provides a critical discussion on IoT, IoE and IoNT in Sections 2–4 respectively. Section 5 portrays the Future Internet that is predicted to be mediated by adoption of IoT.

3 METHODOLOGIES

The interconnection of nano machines with existing communication networks and eventually the Internet requires the development of new network architectures. In Fig. 1, we introduce the architecture for the Internet of Nano-Things in two different applications, namely, intrabody nano networks for remote healthcare, and the future interconnected office:

In intrabody networks, nano machines such as nano sensors and nano actuators deployed inside the human body are remotely controlled from the macro scale and over the Internet by an external user such as a healthcare provider. The nano scale is the natural domain of molecules, proteins, DNA, organelles and the major components of cells. Amongst others, existing biological nano sensors and nano actuators provide an interface between biological phenomena and electronic nano-devices [2], which can be exploited through this new networking paradigm.

In the interconnected office, every single element normally found in an office and even its internal components are provided of a nano transceiver which allows them to be permanently connected to the Internet. As a result, a user can keep track of the location and status of all its belongings in an effortless fashion. Convenience and almost seamless deployment demand for tiny and non-obtrusive devices. Amongst others, the possibility to harvest irrational, mechanical or even EM energy from the environment [5], ultra-low power consumption and reasonable computing capabilities, motivate the use of new nano materials in the development of these devices. Regardless of the final application, we identify the following components in the network architecture of the Internet of Nano-Things:

Nano-nodes: these are the smallest and simplest nano machines. They are able to perform simple computation, have limited memory, and can only transmit over very short distances, mainly because of their reduced energy and limited communication capabilities. Biological nano sensor nodes inside the human body and nano machines with communication capabilities integrated in all types of things such as books, keys, or paper folders are good examples of nano-nodes.

Nano-routers: these nano-devices have comparatively larger computational resources than nano-nodes and are suitable for aggregating information coming from limited nano machines. In addition, nano-routers can also control the behavior of nano-nodes by exchanging very simple control commands (on/off, sleep, read value, etc.). However, this increase in capabilities involves an increase in their size, and this makes their deployment more invasive.

Nano-micro interface devices: these are able to aggregate the information coming from nano routers, to convey it to the micro scale, and vice versa. We think of nano-micro interfaces as hybrid devices able both to communicate in the nano scale using the aforementioned nano communication 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. For example, in an intrabody network scenario, an advanced cell phone can forward the information it receives from a nano-micro interface in our wrist to our healthcare provider. In the interconnected office, a modem-router can provided this functionality. Despite the interconnection of micro scale devices, the development of gateways and the network management over the Internet are still open research areas, in the remaining of this article we mainly focus on the communication challenges among nano machines.

4 ALGORITHMS

While there are still major open issues in relation to the communication between two nano machines, in the following we provide our initial ideas for the networking of several nano-devices.

Channel Sharing:

Different channel access mechanisms for nanonetworks need to be defined depending on how the information is encoded. For example, carrier sensing based Medium Access Control (MAC) protocols (e.g., CSMA and all its variations) cannot be used in pulse based communications because there is no carrier signal to sense. In addition, achieving synchronization among several nano-nodes also seems quite unlikely.

Moreover, very elaborated protocols cannot be implemented in simple nano machines. Thinking of pulse-based communications in nanonetworks, the fact that the information is transmitted using very short pulses reduces the chances of having collisions among different nano-nodes trying to access the channel at the same time. Because of this, we think of asynchronous MAC protocols, in which a nano node willing to send a packet can just transmit it and wait for some type of acknowledgement.

In addition, if we allow the time between pulses to be much longer than the pulse duration, it can be possible to interleave different pulse streams, allowing a nano machine to follow different user pulse streams at the same time, if feasible for its computational capabilities. Simply stated, a nano-device can start sending an encoded pulse stream when it needs to transmit. Nodes in the transmission range might be able to detect this first pulse with a given probability of detection.

If the time between pulses is fixed and known by all the network members, after the detection of the first pulse, nano devices can to predict when the next pulse is coming. In the meantime, they can decide to transmit their own stream or even to follow different streams from other users. Even if unlikely, collisions between fem to second-long pulses can occur.

Addressing of Nano machines:

In the Internet of Things, every single element in the network requires a unique ID. In nanonetworks and the Internet of Nano-Things, assigning a different address to every nano-node is not a simple task, mainly due to the fact that this would require complex synchronization and coordination between nano machines. Moreover, taking into account that every single nano network will already contain thousands of nano machines, the inter-networking of all them would require the use of very long addresses. However, some simpler and more feasible alternatives are possible.

Information Routing:

Nano machines may have to answer to a specific query from a command center or may need to report new events in a push based fashion. This flow of information requires the establishment of routes. Due to the very limited transmission range of nano machines, multi hop communication will be the standard way to communicate. We cannot even consider that every nano-node will be able to transmit directly to its closest nano-router. In addition, due to the limited resources of nano machines and also their presumably high proneness to failure, we cannot assume that route information can be stored or remembered between transmissions.

Reliability Issues:

End-to-end reliability in nanonetworks and the Internet of Nano-Things has to be guaranteed both for the messages going from a remote command center to the nano nodes, as well as for the packets coming from the nano machines to a common sink. Different aspects that can affect the network reliability include both nano machine failure and transient molecular interference in the channel. Indeed, apart from unexpected errors in nano-nodes, a sudden burst of molecules can create temporal disconnections of the network at different points.

Network Association and Service Discovery:

In the Internet of Nano-Things, every nano-node is expected to be able to seamlessly connect to the network and at the same time inform the other devices about its presence. Taking into account the amount of nano-things that can be involved in such a network, new network association and service discovery solutions are needed. In our vision, the network hierarchy defined earlier, simplifies this task. Indeed, in a majority of applications it will not be necessary to notify the entire network when a new nano-node is in the system, but just the closer nano-router or nano micro interface at most.

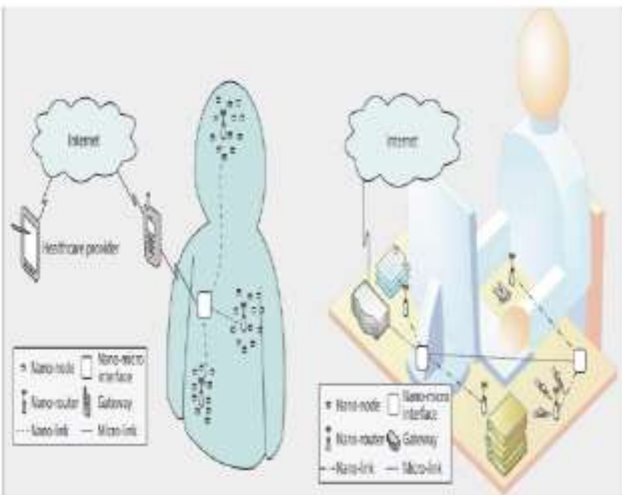

Figure: 2 Network architectures for IoNT

5 CONCLUSIONS

The development of nano machines with communication capabilities and their interconnection with micro- and macro-devices will enable the Internet of Nano-Things. This new networking paradigm will have a great impact in almost every field of our society, ranging from health- care to homeland security or environmental protection. In this article, we have introduced the reference architecture for this new paradigm and discussed the state of the art of research on electromagnetic nanonetworks. Many researchers are currently engaged in developing the hardware underlying future nano machines. The unique properties of the nano scale and the nature of nanonetworks require new solutions for communications that should be provided by the information and communication society. Amongst others, novel nano-antenna designs, nano scale channel models, information encoding and modulations for nano scale networks, and protocols for nanonetworks are contributions expected from the ICT field.

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