A Comprehensive Review on Mac Protocol of Wireless Nanosensor Networks for Intrabody Application

S. Sivapriya
PG Scholar
Department of Electronics & Communication
College of Engineering, Chennai

Dr. D. Sridharan
Professor
Department of Electronics & Communication
College of Engineering, Chennai

Abstract

Nanotechnology has led to the evolution of nano-machines which are tiny components comprising of arranged set of molecules performing pre-determined tasks. The interconnection of nanosensors and nanodevices with Internet has led to development of next evolutionary step towards IoT called "Internet of Nano Things" (IoNT). WNSN for intrabody application consist of integrated nano-machines, diffused in the human body for collecting diagnostic and prognostic processes and aid in the treatment of patients through accurate tumor and disease detection. Medium Access Control (MAC) protocols are needed for the communication between nano-devices and for the access coordination to the wireless channel. Since classical MAC protocols cannot be used due to the peculiarities of nano-devices and the Terahertz band, they are not suitable for WNSN. The main objective behind this paper is to provide review on so far developed MAC protocols in novel nano-scale communication approaches along with architectural requirements for implementation, communication and networking aspects, significant challenges and security issues.

Keywords: Internet of Nano Things (IoNT), Nanosensors, Nanotechnology, Wireless Nano-Sensor Networks (WNSN)

I. INTRODUCTION

The recent boost in nanotechnology fosters extension of control and networking to nano scale by deployment of nanosensors having a size of one to few hundred nanometers. Being equipped with a nano-antenna, a memory, a CPU, and a power supply, such nanosenors are enabled to perform simple operations and wireless communication in short distances. Such wireless communication among nanosensors bolsters emergence of a new paradigm called wireless nanosensor networks (WNSNs). However, communication in WNSNs is expected to experience different challenges, owing to limitations in capabilities of the nanosensors such as limited transmission range, less processing power, small memory, scarcity of energy, etc. The nano network holds significantly greater communication and processing potential that overcomes the limitations of standalone nanomachines through nanodevices cooperation. This may allow for the provision of advanced services and applications in several fields such as industry, environment, military and health. Nanomachines can monitor inaccessible parts of the human body, such as the aortic heart valve and collect sensory data of the valve. A nano network, in turn, can carry the sensory data to an external device such as a Smartphone or an Internet gateway enabling nanodevices to wirelessly communicate with powerful external processing devices. A nanonetwork connected to internet gateways enables a new network paradigm called the IoNT.

In general, there are four main novel nano-scale communication techniques: nanomechanical, acoustic, chemical or molecular and electromagnetic communications. In nanomechanical communication, the information is transmitted by a mechanical contact between transmitter and receiver. An acoustic communication is defined as the transmission of information through acoustic energy such as pressure variations. In molecular communication, the information is encoded in bio-molecules which move as carriers from the transmitter nano-machine to receiver nano-machine. Electromagnetic communication is based on the modulation and demodulation of electromagnetic waves using components that are made based on novel nano materials [3]. In acoustic communication, the traditional acoustic transducers and radio frequency transceivers cannot be integrated at a nano-scale device because of their size and communication principle. Moreover, in nanomechanical communication, a physical and direct contact is needed between transmitter and receiver nanomachines. Therefore, the molecular and electromagnetic communications are the most promising approaches for nanonetworking [1].

The miniaturization of a conventional metallic antenna to meet the size requirements of the nano-devices would impose the use of very high operating frequencies (several hundreds of Terahertz), thus limiting the feasibility of nanonetworks. Amongst others, ongoing research on the characterization of the EM properties of graphene, points to the Terahertz Band (0.1–10.0 THz) as the radiation frequency band of novel nano-antennas [5].This paper focuses on the electromagnetic communications as most studied nano-scale communication approaches in the Terahertz band. In addition, a qualitative evaluation of the so-far developed WNSNs protocols is presented in terms of their architecture requirements, network and channel models and security issues and challenges.

This paper is organized as follows: Section II will provide a general overview of the ubiquitous healthcare ecosystem and a background on both IoT and IoNT paradigms, by focusing the attention on biomedical applications. Section III discusses about the electromagnetic communication in nano-network, concepts and architecture of nano-sensors, terahertz channel properties and electromagnetic communication challenges in body-centric nano-scale communications. In Section IV, current issues and challenges in protocol stack of WNSN will be discussed. A study on related works of the so far developed MAC protocols for WNSNs is introduced in Section V. Finally, we conclude the paper in Section VI.

II. GENERAL OVERVIEW OF IOT & IONT PARADIGMS

Internet of Things, no doubt has transformed the use of Internet and Device to Device communications in which devices, sensors and objects interact with one another and exchange data and has also given birth to several other domains like Wireless Body Sensor Networks (WBAN), Internet of Nanotechnology-Nano Things (IoNT).

In a more recent form, the IoT is supposed to be capable of managing a potentially very large number of smart wireless devices forming a capillary networking infrastructure that can be connected to the Internet. At this moment, it is widely recognized that IoT can be adopted in the health-care domain for handling a number of tasks, including the remote monitoring of patients [9], the control of drugs [10], and the tracking of medical staff and equipments in their environment [11]. However, all of these solutions do not go beyond the macro scale, thus leaving the nano-medicine applications completely unexplored.

Scientists have started shrinking sensors from millimeters or microns in size to the nanometer scale, small enough to circulate within living bodies and to mix directly into construction materials. This is a crucial first step toward an Internet of Nano Things (IoNT) that could take medicine, energy efficiency and many other sectors to a whole new dimension. As explained in Fig 1 with reference to typical IoT architecture, monitoring devices communicate with the nanointerface and a network coordinator (which provides the connectivity with a remote health-care server through a wireless/wired broadband technology) by using IEEE 802.15.4285 radios.

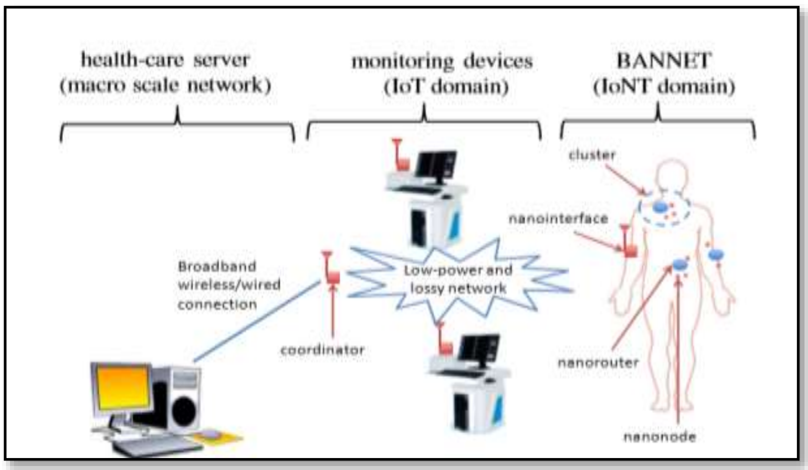

Fig. 1: Complete healthcare system with IoT & IoNT paradigms [7]

The interaction between macro and nano domains can be handled by means of a request/response process. In fact, it is assumed that each monitoring device is configured for tracking some biological functionalities of a given health-care server (macro scale network) patient during the time. To this end, it sends specific request messages to the nanointerface of the BANNET through the IoT network infrastructure. The nanointerface will deliver the received request to all nanorouters, thus allowing them to retrieve an answer from their corresponding clusters. Then, the requests generated by a sub-set of nanonodes are sent back to the monitoring device in the opposite direction. Finally, the monitoring devices will deliver all the collected information to the remote health-care server.

III. ELECTROMAGNETIC COMMUNICATION IN BODY-CENTRIC NANO-NETWORKS

As explained earlier, the molecular communication is based on bio-molecules as a communication medium, while electromagnetic communication is based on communication using electromagnetic waves and wireless technology. Recent advancements in nanotechnology and carbon electronics have paved the way to produce electronic nano-device such as nano-memories, nano-processor, nano-batteries, and nanoantennas. The nano-particles show new behavior in nano-scale that cannot be observed at the microscopic level.

Nanonetworks are not just downscaled networks, but there are several properties stemming from the nanoscale that require us to totally rethink well-established networking concepts. In the following, the main challenges from the communication perspective are discussed in a bottom-up fashion, from the physical nanoscale issues affecting a single nanomachine up to the nanonetworking protocols. The design flow for the development of nanonetworks is shown in Fig.2.

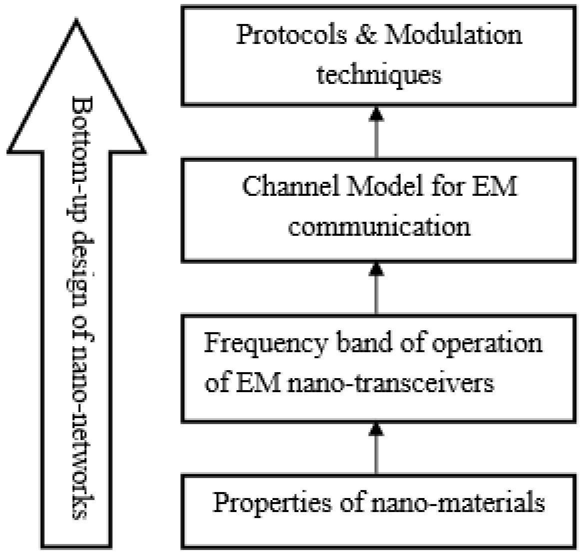

Fig. 2: Bottom-up approach for design of nanonetworks

Properties of nano-materials: Due to the small size of nano-machine, wiring a large number of them is not feasible. One the most known nano carbon structure that is referred it as the wonder material of the 21st century is graphene [7]. Graphene is a one-atom-thick planar sheet that consists of carbon atoms arranged on a honeycomb crystal lattice. Two of the known derivatives of graphene are Carbon Nanotubes (CNT) and Graphene Nanoribbon (GNR). The CNT is a folded nanoribbon. The carbon materials have the electrical and optical characteristics that are analyzed in light of quantum mechanics. These properties include of high current capacity and high thermal conductivity and their mechanical strength is extremely high and they also have a very high sensitivity.

Frequency band of operation of EM communication: Nano-antennas can support EM communications in two possible ranges of frequencies: the terahertz band and the upper part of the megahertz one. Despite the lowest bandwidth ensures the highest transmission ranges, it provides a very limited energy efficiency, which is unacceptable for nano-devices. For this reason, it is preferred to design nano-transceivers working in the terahertz band (i.e., 0.1 to 10.0 THz) and enabling a channel capacity in the order of few terabit/s and a transmission range that cannot exceed few tens of millimeters [5].

Terahertz channel properties: Terahertz channel is seriously affected by the presence of different molecules in the medium. The main characteristics of the terahertz channel are: Path loss and noise [8]. The total noise in the receiver consists of electronic noise and molecular noise. The electronic noise is due to large free path of electrons in graphene. The molecular noise also occurs because of the molecular absorption.

Protocols & Modulation Techniques: Nanomachines require new simple modulation techniques suitable for their limited hardware. Inspired by the huge bandwidth provided by the Terahertz channel, we envision a new communication paradigm based on the exchange of very short pulses, just a few femtoseconds long. The power of a femtosecond-long pulse is contained within the Terahertz frequency band and, thus, it can be radiated by a graphene-based nano antenna. By transmitting these pulses distributed over time rather than in a single continuous packet or burst, the requirements on the power unit of nanomachines are also relaxed.

IV. ISSUES & CHALLENGES IN PROTOCOL STACK OF WIRELESS NANOSENSOR NETWORKS

IoNT is regarded as the most miniaturized nano sensor networks having huge potential to be as such adoptable in real time applications in diverse fields. Services should also be enhanced and new service-oriented architectures needs to be proposed to make nano sensors and nano networks compatible to hold tons of large varieties of data.

A. Application Layer

Application design for healthcare services needs to address requirements for real-time, reliable, and context-aware operation. The critical significance of health services makes real-time or near-real-time operation a fundamental requirement. However, due to the unpredictable transmission medium and the significantly short range of intra-body communication, a random delay is to be expected. Data fusion will, therefore, need to be optimal, dynamic, and delay-tolerant for applications that rely on the integration of diverse data sources [4].

B. Transport Layer:

The nanoscale of the IoNT makes it impractical to have individual network addresses for the individual nanomachines. Addressing can thus be cluster-based instead of node-based. This makes it possible to address a group of nodes based on the health functionality they perform or the biological organ or phenomena they monitor [6].

C. Network Layer:

The limited processing and storage capabilities of nanomachines dictate that routing design should not assume that nodes have knowledge of the network topology. Network topology inside the body can be random and dynamic due to the uncontrolled properties of the biological communication medium. This also affects cooperation between nanomachines, which has to be kept to a minimum. Node mobility inside the body and proximity based opportunistic routing can be suitable solutions.

D. Medium Access Control Layer:

Terahertz band communication provides enormous bandwidth and significantly short transmission time, which leads to fewer collisions and interference than in traditional networks. The high path-loss and low energy of nano-devices coupled with noisy transmission media increase the probability of packet errors regardless of the huge link bandwidth. This promotes the need for error-control MAC protocols that address the necessity of controlling access to the THz-band channel to reduce packets retransmissions.

E. Physical Layer:

Three main requirements are needed by health applications at the PHY layer: a channel capacity that guarantees reliable data delivery, an accurate channel model that accounts for the unique biological transmission medium and its associated noise, and efficient coding schemes that are resilient to errors.

V. RELATED WORKS & COMPARITIVE STUDY OF THE MAC PROTOCOLS IN WNSN

Transparent MAC is a simplified protocol, where the packet received from the network layer is transmitted to the physical interface without handling any flow control, error control or adding any headers to the packet. Terahertz band communication provides enormous bandwidth and significantly short transmission time, which leads to fewer collisions and interference than in traditional networks. The high path-loss and low energy of nano-devices coupled with noisy transmission media increase the probability of packet errors regardless of the huge link bandwidth. This promotes the need for error-control MAC protocols that address the necessity of controlling access to the THz-band channel to reduce packets retransmissions. Fully charged nanodevices are capable of just transmitting a few packets before getting fully depleted. Consequently, nanonodes are required to wait to recharge using energy harvesting before being able to transmit again, which may introduce an unavoidable delay that renders packet retransmission useless.

A. PHLAME (PHysical Layer Aware MAC Protocol for EM Nanonetworks)

PHLAME is based on the joint selection by the transmitter and the receiver of the optimal communication parameters and channel coding scheme which minimize the interference in the nanonetwork and maximize the probability of successfully decoding the received information. Moreover, the fluctuations in the energy of the nano-devices are taken into account. It is a revised version of the communication scheme based on the exchange of femtosecond-long pulses that we introduced in [14], in order to support variable symbol rates.

The protocol is built in two stages, namely, the handshaking process and the data transmission process. First, it allows a receiver to coordinate multiple simultaneous transmissions. Second, it facilitates the joint selection of (i) the transmission symbol rate and (ii) the channel coding scheme which make the data transmission more reliable.

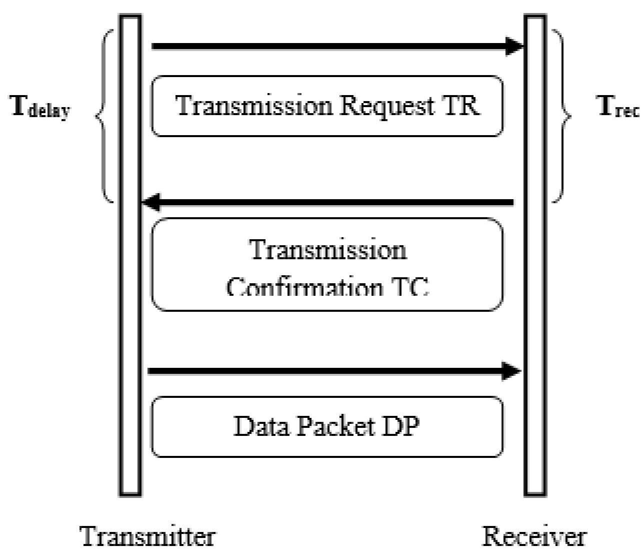

Fig. 3: PHLAME Protocol

The handshaking process is divided into two sub-stages: Initially the transmitter generates Transmission Request (TR) to the intended receiver which contains the transmitting Data Symbol Rate (DSR) and the Error Detecting Code (EDC). In PHLAME, every transmitting node randomly selects a symbol rate from a set of coprime rates, which have been shown to minimize the probability of having catastrophic collisions [16].The TR packet is transmitted using CCS (Common Coding Scheme) which defines pre-defined symbol rate and channel coding scheme. The transmitter waits for T_{delay} time for TR retransmissions.

The handshaking acknowledgment is triggered by the receiver of the TR packet, which uses the CCS to decode the received bit streams when listening to the channel. Due to the energy limitations of nano-devices, after the transmission or the active reception of a packet, a device needs to wait for a certain recovery time T_{rec} in order to restore its energy by means of energy harvesting systems. If the handshake is accepted, the receiver replies to the transmitter with a Transmission Confirmation (TC) packet, which is encoded by using the CCS. . The TC packet contains the transmitting Data Coding Scheme (DCS) and the Error Detecting Code. The DCS is selected by the receiver in order to guarantee a target Packet Error Rate (PER). This depends on the perceived channel quality.

Finally, the data packet (DP) is sent by the transmitter. . If the DP is not detected at the receiver before a time-out the receiver assumes that the handshaking process failed. The protocol have been diagrammatically explained in Fig 3.The main advantage of the protocol is it reduces nano-network interference and maximum decoding of received information. Their main drawbacks include handshaking and not enough computational resources.

B. RIH-MAC: Receiver Initiated Harvesting MAC Protocol

In the receiver-initiated communication schema, the transmission only occurs if the receiver will have adequate energy to complete the reception. Therefore, the transmitter can adaptively select its network participant.

In [12] the author applies the receiver initiated communication schema in centralized and distributed WNSN MAC protocol. In this MAC protocol, the time is split into equal time slots, where two packets are transferred between the sender and one receiver. The receiver nano-nodes announce that it is ready to receive a packet by sending ready to receive (RTR) packet. In addition, the receiver of the RTR packet will send a Data packet which is explained in Fig 4. Two communication models were proposed: a centralized and distributed communication model. In the distributed version of RIH-MAC, the communication between the nano-node can be designed as an edge colouring problem, where the colouring operation occurs in cycles. In a centralized receiver-initiated solution [12], a more powerful nano-controller device is needed for scheduling the communication between nano-devices.

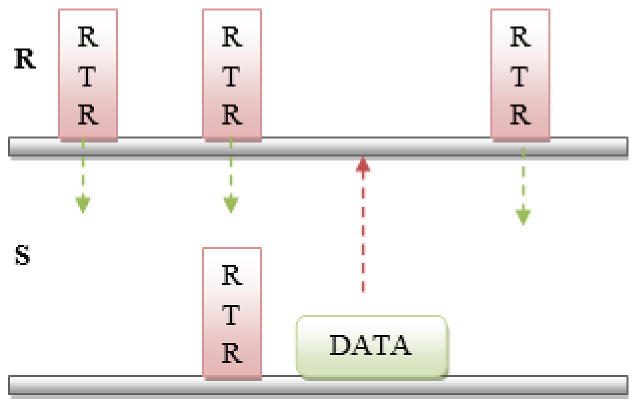

Fig. 4: RTR and DATA Packets between a Receiver (R) and a Sender (S)

RIH-MAC can be run stand-alone if there is no energy limitation on nanonodes. However, a coordinated energy consumption schedule (CECS) between two communicating nanonodes is required to achieve the highest performance of RIH-MAC. When there is no such coordination, many RTR packets would be sent with no DATA packet response. Similarly, transmitters may listen for RTR packets but receive no RTR packets. In both scenarios, energy is wasted. Here, we describe our prediction-based CECS.

The advantage of RIH-MAC over energy aware protocol is less collision probability, scalable with more number of sensor nodes and have high ratio of packet delivery. Besides, in RIH-MAC, some time slots will be wasted. The wasted time slots can occur in the situation where the energy harvesting rate is lower than the energy consumption rate. Additionally, the use of the optimum policy lookup table could also contribute in the energy waste. Furthermore, DRIH-MAC suffers from the hidden terminal problem.

C. TAB-MAC: Assisted Beamforming MAC protocol for Terahertz Communication networks

The protocol exploits two different wireless technologies, namely, Wi-Fi at 2.4 GHz and THz-band communication. In particular, nodes rely on the omni directional 2.4 GHz channel to exchange control information and coordinate their data transmissions (Phase 1), whereas the actual data transfer occurs at THz frequencies only after the nodes have aligned their beams (Phase 2).

The functioning of the TAB-MAC protocol is summarized as follows. When a regular node wants to communicate with another node, it first broadcasts its request by using Wi-Fi technology and exchanges the location information with the intended receiver. Based on the exchanged information, the transmitter and the receiver steer their THz beamforming antennas to point to each other with a specific beam width. Once the coupled regular nodes are facing each other, the data transactions at THz frequencies proceeds. This presents an effective and efficient solution to address the ''facing'' problem in THz communication networks as well as to mitigate interference. However, the time delay introduced by the cooperation between two types of wireless technologies should be comprehensively investigated.

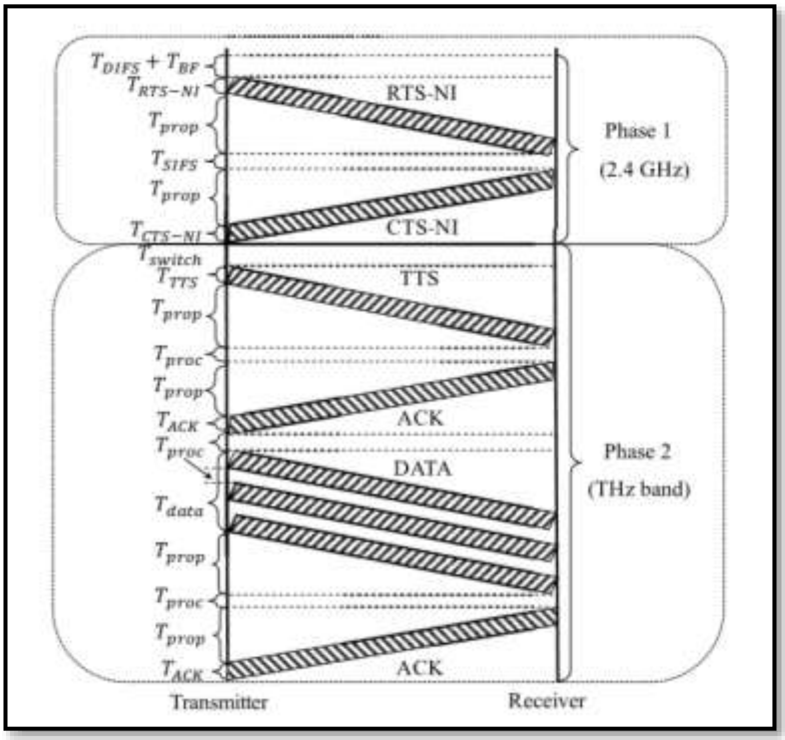

Fig. 5: Assisted beamforming MAC for Terahertz networks [15]

As explained in Fig 5, phase 1 is designed to discover and couple the transmitter and receiver through the benefits of omni directional 2.4 GHz communication. First, the transmitter sends Request-to-send (RTS) with node information which contains the position of node. The receiver will reply an extended Clear-To-Send (CTS) frame with its Node Information, named as CTS-NI, when it is available. Once these two nodes obtained each other's node positions, they can compute the Line-of-Sight (LoS) distance between them, and steer their beamforming antennas pointing to each other with a specific beam width. After Phase 1, the beamforming antennas of the transmitter and receiver have been steered to point each other, i.e., the transmitter is ready to transmit data in the THz band. Firstly, the transmitter will send one TTS frame to make sure that their directional antennas are pointing to each other and the LoS propagation between them is available. Once receiving the Acknowledgement (ACK) from the receiver, the transmitter will begin the data transmission. The total time delay in Phase 2 can be expressed as shown in figure where Tswitch refers to the switching time from 2.4 GHz omni directional antenna to THz beamforming antennas. Tproc refers to the short processing time for high data rate in THz band; TTTS refers to the transmission time for one TTS frame. TACK refers to the transmission time for ACK. TDATA is the required time to transmit all data frames from the transmitter to the receiver.

VI. CONCLUSION

The scenario of application is that each nanosensor node would be placed within each cell and that they will communicate with their immediate neighbor cell according to the protocol preferred. In this paper, the state-of-the-art and comprehensive review in the domain of nano-scale electromagnetic communication for intrabody applications is presented. Various studies on the current works on MAC protocols on WNSN have been analyzed and discussed covering the theoretical basis of communication mechanisms among nano devices, state-of-the-art in antenna design, current issues and challenges in protocol stack of WNSN. Considering the expected future growth of nano technologies and their potential use for the detection and diagnosis of various health related issues, the open research challenges for these potential networks are highlighted and presented to clearly demonstrate the necessary steps the scientific, engineering and wider community needs to take to further enhance the current status.

REFERENCES

[1] I.F. Akyildiz, F. Brunetti, C. Bl´azquez, "Nanonetworks: A New Communication Paradigm", Elsevier Computer Networks Journal, vol. 52, no. 12, pp. 2260-2279, May 2008.
[2] M. Gregori, I.F. Akyildiz, "A New NanoNetwork Architecture Using Flagellated Bacteria and Catalytic Nanomotors", IEEE Journal on Selected Areas in Communications, vol. 28, no. 4, pp. 612-619, May 2010.
[3] B. Atakan, O.B. Akan, "Carbon Nanotube-Based Nanoscale Ad Hoc Networks", IEEE Communications Magazine, vol. 48 , no. 6, pp. 129-135, June 2010.

[4] J.M. Jornet, I.F. Akyildiz, "Information capacity of pulse-based wireless nanosensor networks", in: Proceedings of the 8th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks, SECON, Jun 2011.
[5] J.M. Jornet, I.F. Akyildiz, "Graphene-based nano-antennas for electromagnetic nanocommunications in the terahertz band", in: Proc. of 4th European Conference on Antennas and Propagation, EUCAP, Apr 2010
[6] N. Agoulmine, K. Kim, S. Kim, T. Rim, J.-S. Lee and M. Meyyappan, "Enabling communication and cooperation in bio-nanosensor networks: toward innovative healthcare solutions," IEEE Wireless Communications, vol. 19, no. 5, pp. 42-51, 2012.
[7] Giuseppe Piro, Gennaro Boggia, and Luigi Alfredo Grieco, "On the design of an energy-harvesting protocol stack for Body Area Nano-NETworks", Nano Communication Networks Journal (Elsevier) November 10, 2014.
[8] Ian F.Akyildiz and Joseph Miquel Jornet, "The Internet of Nano-Things", IEEE Wireless Communications ,December 2010 .
[9] H. Furtado, R. Trobec, "Applications of wireless sensors in medicine", in: International Convention MIPRO, 2011, pp. 257–261.
[10] A. Jara, A. Alcolea, M. Zamora, A. Skarmeta, M. Alsaedy, "Drugs interaction checker based on iot", in: Internet of Things (IOT), 2010, pp. 1–8.
[11] A. Dohr, R. Modre-Opsrian, M. Drobics, D. Hayn, G. Schreier, "The Internet of Things for Ambient Assisted Living", in: IEEE Int. Conf. on Infor-600mation Technology: New Generations, ITNG, 2010, pp. 804–809.
[12] J.M. Jornet, I. F. Akyildiz, "Femtosecond-long pulse-based modulation for terahertz band communication in nanonetworks", IEEE Trans. on Commun.62 (5) (2014) 1742–1754.
[13] M. Rosenau da Costa, O. V. Kibis, and M. E. Portnoi, "Carbon Nanotubes as A Basis for Terahertz Emitters and Detectors," Microelectronics J., vol. 40, no. 4–5, Apr. 2009, pp. 776–78.
[14] Balasubramaniam, Sasitharan, and Jussi Kangasharju. "Realizing the internet of nano things: challenges, solutions, and applications." Computer 2 (2013): 62-68.
[15] Xin-Wei Yaoa and Josep Miquel Jornet ," TAB-MAC: Assisted beamforming MAC protocol for Terahertz communication networks", Nano Communication Networks (Elsevier),July 2016.
[16] Josep Miquel Jornet , Joan Capdevila Pujol and Josep Solé Pareta ," PHLAME: A Physical Layer Aware MAC protocol for Electromagnetic nanonetworks in the Terahertz Band" in Nano Communication Networks (Elsevier),January 2013.
[17] S. Mohrehkesh and M. C. Weigle. "RIH-MAC: receiver initiated harvesting-aware mac for nanonetworks." Proceedings of ACM the First Annual International Conference on Nanoscale Computing and Communication. ACM, 2014, pp. 3-9.
[18] Rawan Alsheikh', Nadine Akkari and Etimad Fadel , "MAC Protocols for Wireless Nano-sensor Networks: Performance Analysis and Design Guidelines" in IEEE Trans. On Communication, 2016.
[19] Negar Rikhtegar and Manijeh Keshtgary," A Brief Survey on Molecular and Electromagnetic Communications in Nano-Networks ", in International Journal of Computer Applications (0975 – 8887) Volume 79 – No3, October 2013.