THE IEEE 1906.1 STANDARD: NANOCOMMUNICATIONS AS A NEW SOURCE OF DATA

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ABSTRACT

*Nanoscale communications is a new paradigm encompassing all those concerns related to the exchange of information among devices at the nanometer scale. A network infrastructure consisting of a huge amount of nano-devices is envisaged to ensure robust, reliable and coordinated data transmission. This will enable a plethora of forthcoming applications and services in many different research fields, such as personalized medicine, synthetic biology, environmental science or industry, which will lead to outstanding and unprecedented advances. The IEEE P1906.1 standard provides a conceptual and general framework to set the starting point for future developments in nanoscale communication networks. This paper reviews the latest IEEE P1906.1 recommendations, observing their main features when applied to the electromagnetic (*EM*) nanocommunication area. We contribute by identifying and discussing the principal shortcomings of the standard, to which further research efforts must be devoted. We also provide interesting guidelines for focusing the object of future investigations.*

Keywords— Nanoscale communication networks, nanodevices, EM nanocommunications, terahertz band, IEEE standards.

1. INTRODUCTION

In the emerging Internet of Things (IoT), objects are expected to be able to sense and capture the physical variables of their surroundings (e.g. temperature, humidity, pressure, etc.) as well as to process the acquired information and communicate it wirelessly to any other object/node in their network. These enhanced objects integrate small sensing/computing/communicating devices in a varied range of sizes, including the nanoscale. Moreover, devices in IoT constitute a network infrastructure connecting both physical and virtual worlds by means of all sorts of innovative applications and services, some of them currently unimaginable. In this context, a huge amount of data will be generated and should be properly managed to extract useful information. Nowadays, the IoT relies on the well-known Wireless Sensor Networks (WSN), in which numerous devices with limited resources are connected, in order to provide feasible solutions in multiple heterogeneous fields, such as agriculture, industry, smart cities, etc. Keeping in mind the way WSN operate and due to incessant technological advances, novel devices with progressively smaller dimensions are being developed, to ease their integration into the environment. However, as they become smaller, many concerns, such as available energy, transmission range or data processing capacity are far more restricted than in traditional WSN. Thus, when the scale of these tiny devices decreases to nanometers, a new paradigm arises, nanoscale communications between nanomachines, and between nanomachines and more conventional devices in the network.

These data-driven nanodevices have become a topic of increasing interest for the scientific community, since they would be able to gather physical parameters at the nanoscale with outstanding accuracy. This capacity would allow the monitoring of scenarios not explored to date, enabling a plethora of potential applications in fields as varied as biomedicine, synthetic biology, environmental science or industry, among many others. Indeed, one of the most promising applications of these nanodevices is aimed at improving medicine, because diverse medical tests, such as blood pressure, virus detection or oxygen levels in blood (Figure 1), could be collected in vivo and directly transmitted to medical personnel (e.g. information about the variation in number and size of cancer cells will be received by the oncologist).

Several works have dealt with how nanodevices should communicate with each other. This is becoming a critical issue, since the extremely limited resources of nanodevices require them to work cooperatively to carry out a useful application. Two main alternatives for communicating at the nanoscale have been envisaged so far, electromagnetic (EM) and molecular communication.

EM communication is based on the use of electromagnetic waves to transmit a message between two nanodevices. Advancements in carbon electronics, mainly those devices made of graphene and carbon nanotubes (CNT), have played a key role in the development of a new generation of electronic nanocomponents, such as nanoantennas or

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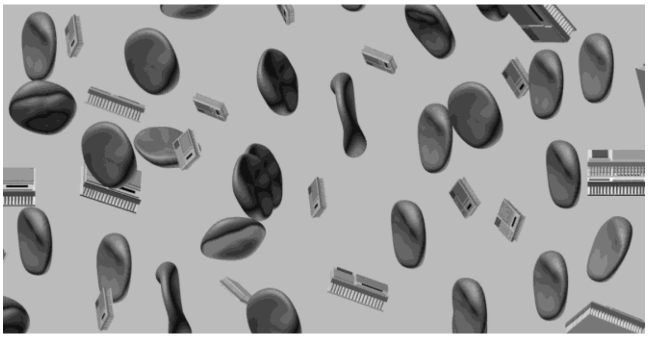

Figure 1. Picture of a nanoscale communication network deployed in the bloodstream

nanotransceivers [1]–[3]. These novel radiocommunication nanocomponents possess unbeatable properties, which allow the radiation of EM waves at THz frequencies with antennas of just a few micrometers in length, i.e. two orders of magnitude lower than their metallic counterparts. Even so, this radiation frequency exhibits high propagation losses, which require a thorough nanoscale communication network design, also known as a nanonetwork. On the other hand, molecular communication is defined as the transmission and reception of information encoded in organic molecules [4], [5]. Molecular transceivers are envisioned to facilitate their integration into nanodevices due to their extremely small size and limited domain of operation. These transceivers can react when receiving certain molecules and release others (as a response to stimulation or after executing some process). The molecules transmitted are propagated in three different ways: moving through a fluidic medium by free diffusion (diffusion-based); moving through a fluidic medium with a guided flow (flow-based); or through pre-defined pathways by using carrier substances (walkway-based).

Both EM and molecular, nanocommunications are considered by the IEEE P1906.1 standard; the first approach to normalize diverse aspects related to communications at the nanoscale, released in December 2015. Under this general premise, this standard first defines the concept of a nanoscale communication network itself, to later propose a conceptual framework for developing communications. Studies using the guidelines of this standard would implement a similar protocol stack for each nanodevice; it is recommended that this stack be based on the components and procedures specified by the IEEE P1906.1 to share and compare results from a common set of performance metrics as defined by the standard.

This paper reviews the IEEE P1906.1 standard, focusing on EM communications; an area in which remarkable technological advances are leading to the first realistic approaches at the nanoscale. In particular, we analyze the standard definition, its pros and cons, describe the framework offered along with its components and, finally, introduce the main metrics which will be taken into consideration to evaluate the performance of a nanoscale communication network. Furthermore, we provide a functional EM communication scheme in which all the steps required to send/receive a message between a transmitter/receiver pair are explained in detail. Analyzing the standard completely, we have identified some lacks and weaknesses, which are further addressed and discussed in this work. These shortcomings pose important challenges. A few of them have been dealt with in previous works [6]–[9], but most of them are still unexplored, which will undoubtedly be the starting point for future investigation.

The rest of the paper is organized as follows. In section 2, we review the IEEE P1906.1 standard from the perspective of EM communications. Section 3 is devoted to pointing out some weaknesses of the standard for the design of EM nanonetworks. In section 4, we indicate how to tackle each detected weakness. Section 5 concludes the paper.

2. IEEE P1906.1 STANDARD DESCRIPTION UNDER EM COMMUNICATIONS

As interdisciplinary research groups are becoming more and more involved in the development of nanoscale communications, the lack of a clear common scope has been confirmed, leading to isolated developments and unrelated knowledge islands. In this sense, the different cases of study proposed in the open scientific literature have been thought about and evaluated under very specific conditions, which differ for each work. This negatively impacts the exchange of information at the nanoscale, since nanonetwork performance depends on the particular working conditions and capabilities of nanodevices. Thus, the IEEE P1906.1 standard [10] is aimed at providing a common framework, in order to join efforts and promote future advances in nanoscale communications. In addition, another significant contribution of this standard is allowing sufficient precision for the development of interoperable and reusable components. To achieve these goals, we examine the following four aspects of the standard structure: (i) *definitions*, (ii) *framework*, (iii) *metrics*, and (iv) *EM communication reference model*.

2.1. Definitions

The first part of the standard provides a complete and detailed definition of “nanoscale communication network”, which should pave the way for future studies in this emerging research field. This definition intends to strictly establish the scope of this concept but, keeping it general enough to cover both molecular and EM communications. The range chosen to delimit the nanoscale is quite narrow (from 1 nm to 100 nm), extracted from the definition of nanoscale provided in [11]. The lower limit is simply selected to exclude the use of single atoms as nanoscale systems. In contrast, the upper limit is the size at which material properties change substantially from the macroscale. This limit could cause controversy, since most of the scientific papers related to EM nanoscale communications consider nanodevices at larger scales. Nevertheless, the sentence “at or with the nanoscale” contained in the definition leaves the door open to different considerations, in particular, those concerning the size of the nanoscale object under study. Therefore, the nanodevices proposed in these papers would support the standard whenever they include a communication element at the nanoscale. These communication elements (transmitter, receiver, medium, message, and message carrier) are also named in the definition, even though they are not described in detail.

2.2. Framework

The second block defined by the standard provides a conceptual, general and small-scale framework consisting of an appropriate number of components comprising well-defined functions and with interoperability among them. The framework offers the organization and structure required to implement procedures and models. To this end, a set of interconnecting components is introduced, namely: (i) *message carrier*, (ii) *motion*, (iii) *field*, (iv) *perturbation*, and (v) *specificity*.

The *message carrier* is described as the physical entity which transports the message across the medium. In particular, in EM nanocommunications, *message carrier* would indicate the EM wave. The *motion* component represents the physical phenomenon that enables the *message carrier* to move (in EM, the wave propagation and phase velocity). This component may be randomly propagated through the medium, which would hamper the propagation of the wave. To avoid this concern, the *field* component organizes and guides the movement of the *motion* component. Concerning the EM nanocommunication system, this would correspond to the omni/directional antenna. The *perturbation* component refers to the mechanism required to accommodate the *message carrier* to the medium in order to transmit the signal that contains the message (equivalent to a modulation). Finally, *specificity* makes reference to the reception of the *message carrier* by a specific receiver (receptor sensitivity/antenna aperture).

This framework is compared to the Open System Interconnection (OSI) model in order to place the five aforementioned components in the traditional communication protocol stack, as specified in Table 1 (extracted from [10]). Due to their tiny size and their close relation to physical aspects, the nanoscale framework components are situated in the lower layers of the OSI stack, even breaching the separation between them. In section 3, we will discuss this issue, analyzing the functions and requirements of each component.

2.3. Metrics

The third section of the standard addresses the definition of common metrics to give information about the interoperability among system components, together with the computation and comparison of performance in a nanoscale communication network. Evaluating networks by using these metrics, researchers can measure and objectively compare the grade of improvement or deterioration that different nanoscale network designs experience.

Table 1. OSI to nanoscale communication network mapping

<table>
<tr><th>OSI protocol layer</th><th colspan="3">Framework nanoscale component</th></tr>
<tr><td>Application</td><td colspan="3">-</td></tr>
<tr><td>Presentation</td><td colspan="3">-</td></tr>
<tr><td>Session</td><td colspan="3">-</td></tr>
<tr><td>Transport</td><td colspan="3">-</td></tr>
<tr><td>Network</td><td></td><td rowspan="2">Field</td><td></td></tr>
<tr><td rowspan="2">Data Link</td><td rowspan="2">Specificity</td><td rowspan="2"></td></tr>
<tr><td rowspan="2">Motion</td></tr>
<tr><td>Physical</td><td>Message Carrier</td><td>Perturbation</td></tr>
</table>

The standard classifies the metrics in function of each component. So, metrics related to the *message carrier* measure how the transmitted information is influenced by the radio channel. Typical network metrics, such as *message lifetime* (a *message carrier* is discarded when exceeding a given time-to-live [TTL]) or *information and communication energy* (the energy required to move and steer a *message carrier*) are proposed for this component. On the other hand, metrics referring to the *motion* component differ from usual network metrics and focus on the physics behind the *message carrier* transmission through the medium. Note that these metrics mainly evaluate molecular communications. Something similar occurs with the metrics related to the *field* component, which copes with the extent to which the *message carrier* motion can be controlled, evaluating whether it follows an intended gradient. *Specificity* metrics point to the capacity of the *message carrier* to deliver a message to a specific destination. These metrics, in fact, are quite similar to those used in conventional EM links. *Specificity* (percentage of *message carriers* not addressed to an intended nanodevice which are not accepted by the intended nanodevice), *sensitivity* (percentage of *message carriers* addressed to an intended nanodevice which are checked and processed by the correct intended nanodevice), or *angular spectrum* (quantifying the distribution of the intensity of nanoscale communication signals received at each nanodevice as a function of angle-of-arrival), are some of the metrics suggested for this component.

Finally, the standard offers some other general metrics to assess the performance of the entire nanoscale network. For instance, the metric *bandwidth-volume ratio*, included in this segment, is employed to evaluate the total amount of information exchanged by nanodevices belonging to the nanoscale network, divided by the total system volume.

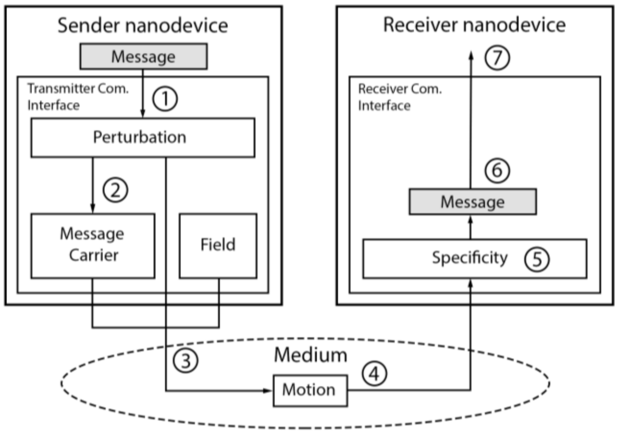

Figure 2. EM communication reference model

2.4. EM communication reference model

Figure 2 illustrates the general communication reference model of the standard extended to EM communications. Also, the sequence of steps followed to carry out a communication between two nanodevices (in that order) is displayed. They are enumerated and commented on in the following paragraphs.

1) The sender nanodevice receives a message from the upper layers, in particular, a string of bits encoding the message to be dispatched. This message is delivered to the *Transmitter Communication Interface*.

2) The *Perturbation* component generates the *message carrier*, considering parameters characterizing the EM transmission, for instance, the central frequency in the THz band to transmit, the bandwidth (usually from 0.55 THz to 1.55 THz), the transmission power, pulse features, type of modulation, etc. Regarding modulation, the Time-Spread On-Off Keying (TS-OOK) modulation is the most widely extended because it is a straightforward scheme that sharply decreases the implementation complexity, alleviating the processing and computing tasks of nanodevices.

3) The *Transmitter Communication Interface* triggers the propagation in the physical medium by passing through the Message Carrier, Perturbation, and Field components. Regarding this last component, an omnidirectional antenna is employed.

4) The *Motion* component is created in function of the propagation model in the scenario under consideration (e.g. the human body), and takes into account requirements such as path loss or background noise [12] to modify properties of the *message carrier,* for instance, propagation loss or end-to-end delay.

5) The receiver *Specificity* component checks and verifies that all the aforementioned parameters stored within the received *message carrier* are the same as those contained in the receiver *Perturbation* component.

6) In the case that step 5) is correctly carried out, the *message carrier* is delivered to the receiver nanodevice.

7) Finally, the message is dispatched to the upper layers of the receiver.

In order to provide a common development environment, the standard proposes the discrete-event and open source network simulator denoted as NS-3 to integrate all the aforementioned steps and components. The objective is that future investigation in the field of nanoscale communications has a starting point for exploiting all the power of the IEEE P1906.1 standard. To this purpose, the simulator follows a hierarchical modular structure, dividing the EM communication implementation into two groups; both taking into account the guidelines of the standard. Specifically, the first group develops the five main framework components, while the second implements other secondary entities involved in the communication process but not classified as "components" (i.e., communication interface, transmitter communication interface, receiver communication interface, medium, and net nanodevice). It is worth remarking that the software developed under the NS3 simulator supports the interaction of all these modules, offering a complete communication scheme.

3. IEEE P1906.1 STANDARD WEAKNESSES IDENTIFIED FOR EM COMMUNICATIONS

Once the main features of the IEEE P1906.1 standard have been introduced, we identified several aspects which make the standard excessively open or even a not well-defined approach. In this section, we discuss some of the issues not thoroughly covered by the standard.

First of all, we should indicate the difficulty of giving a general definition of the concept "nanoscale communication network", since it requires the inclusion of requirements from two different scientific fields, namely Molecular and EM. They are so different, that concepts such as "network" and "communication" may have different meanings in each discipline. In addition, in order to maintain the generality of the definition, a communication system is considered at the nanoscale when one or more essential system components are sized at nanometers in at least one dimension. Actually, following the guidelines of this definition, most works already published about EM nanocommunications [6], [8], [9], [13] (and therefore, prior to the IEEE P1906.1 standard -draft- was launched) would be included under the umbrella of the standard, since antennas employed in these studies are at the nanoscale. In detail, as can be seen in Table 2 (extracted from [10]), the THz waves radiated by graphene or CNT antennas are both considered "components below 100 nm" and therefore "non-standard physics". So, although these studies built their designs from microscale electronic devices (and thus, the resulting design is at the microscale), the employment of THz waves as message carriers is enough to consider the communication at the nanoscale. As can be observed, the concept of "nanoscale communication network", is diffuse enough to consider microdevices operating in a nanonetwork.

Concerning the physical level, the restrictions on the amount of available energy in each nanodevice (we name them nanodevices, although their dimensions may be at the microscale) has an important impact on the communication scheme. The most accepted solution for powering nanodevices involves the use of piezoelectric nanogenerators [6], [8], [13], which are able to convert mechanical strains (e.g. bloodstream movement) into electric energy. The energy harvested is stored in a nanocapacitor to feed the nanodevice components when the energy level exceeds a given threshold. Nevertheless, the main drawback to these nanogenerators is the scarce amount of energy harvested per unit of area, which strictly limits the communication capabilities of nanodevices. In addition, the available energy depends on the physical medium in which nanodevices are deployed (if nanodevices take advantage of environmental movement, the energy harvested will be greater than in a static medium) and the area of the nanogenerator. On the other hand, parameters related to the transmission and reception of EM waves, such as power transmission or signal to noise ratio (SNR), are not treated by the IEEE P1906.1 standard. This recommendation should attract even more attention when human bodies are involved, since the high transmission power envisaged for nanodevices [9] could affect health. The SNR at reception is also an important parameter to consider in order to ensure robust and reliable nanoscale communications. Although the standard deals with the channel capacity (computed by using the Shannon theorem), and therefore, calculating the upper limit for the physical data rate, in the case of a low SNR value, the receiver would not be able to demodulate the radio signal.

Aside from the shortcomings concerning the physical layer, we have also noticed a remarkable insufficiency of the IEEE P1906.1 standard to give some recommendations about the data link layer. As can be observed in Table 1, the standard places the framework components *specificity* and *motion* at the data link layer. In EM communications, these components are identified with signal radiation (*motion*) and antenna aperture in reception (*specificity*) -see Table 2-. However, as EM nanoscale communication networks must contain a huge number of nanodevices due to their extremely limited transmission range (derived from the high path loss suffered in the THz band [12], [14]), some techniques are required to enhance the data transmission robustness between adjacent nanodevices. Specifically, medium control access to arbitrate transmissions and avoid message collisions, flow control to encompass the bitrate of the communication link, or error detection mechanisms would be required. In addition, the number of fields and control/payload/footer length of the reference message is not defined by the standard, which could lead to the design of different and even non-interoperable data link layers.

Concerning the network layer, nanodevices may have to reply to a request from an external macroscale device or may need to immediately report new events to external end personnel (e.g. a doctor). Due to the very limited transmission range of nanodevices, this information flow could require the creation of multi-hop routes. The IEEE P1906.1 standard establishes the *field* component as a piece/part of the network layer, but it does not cover the functionalities related to multi-hop end-to-end communications. In addition, the interconnection of the nanoscale communication network with the macro world is an issue not considered by the standard.

Table 2. Example of the equivalence between EM nanoscale network components and the IEEE P1906.1 framework

IEEE P1906.1 component	**Implemented component**
Transmitter	CNT-based nanoantenna
Receiver	CNT-based nanoantenna
Message	Sodium concentration
Medium	Air
Message carrier	Electromagnetic (EM) wave
Component < 100 nm	Sensor, message carrier (THz frequency wave)
Non-standard physics	Impact of scale on resonance
Motion	Radiation and waveguide
Field	Intensity/directional antenna
Perturbation	RF modulation
Specificity	Receptor sensitivity/antenna aperture

Higher OSI layers could be implemented, including traditional functions (e.g. security techniques to improve the privacy of data); however, due to extremely restricted nanodevice capabilities regarding processing, energy harvesting or memory, serious doubts have been posed about their feasibility.

4. IEEE P1906.1 STANDARD OPEN ISSUES ON EM COMMUNICATIONS

Analyzing the shortcomings identified in the IEEE P1906.1 standard, we suggest some tips that should be considered in future EM nanoscale communications studies in order to offer the scientific community ways of confronting open research challenges not treated by the standard.

As previously mentioned, one of the main goals of the IEEE P1906.1 standard is to join efforts towards the development of nanoscale communications, so the lack of a strict definition leaves the door open to different considerations. The ambiguity of the definition may be a practical reason why the IEEE P1906.1 standard has not been taken into account in recent nanoscale communication works [15]–[18]. Therefore, we believe that a more detailed standard definition should be elaborated to better define the appropriate setting for developing future interoperable nanoscale communication networks, subject to common conditions. In particular, the definition should include, firstly, the concept of a nanodevice as a device at the nanoscale, and, secondly, the division of the standard into two clearly separated parts, one focused on EM communications and the other specifically for molecular nanoscale communications. The result would be a suitable definition in order to provide a more complete standardization, encompassing the true dimension of communication nanonetworks.

Regarding the reference energy model, more effort should be devoted to characterizing the functions of a nanoscale energy generator and its operating conditions. Thus, we believe that the standard should include a reference energy model, considering the energy harvesting restrictions of nanodevices due to their tiny size (and, therefore, pointing to the available area in the nanodevice for the nanogenerator) and the environment under study. So, this reference model would establish a more solid starting point to quantifying important aspects of communication, such as coverage area, size of the message to transmit, etc., which can be consistently used to develop realistic communication protocols. Furthermore, from our point of view, the standardization of both maximum and recommended power transmission values would be relevant, in order to set a common power consumption model for nanodevices forming the nanonetwork. If these power transmission values could be set, it would be possible to estimate the amount of energy that a nanodevice can waste (most of the required energy is dedicated to transmitting a message [6]). These values could vary depending on the application environment of the nanonetwork. In addition, an SNR value recommendation should be taken into consideration by the standard, to appropriately demodulate the signal arriving to the receiver. Power transmission and SNR, together with the path loss model obtained for each physical medium (e.g. human body tissues) would clearly determine the transmission range of each nanodevice for the scenario under study, which would be useful, for instance, in the planning of the required number of nanodevices deployed to cover a particular area.

As regards the data link layer, some techniques are needed to improve the data transmission robustness between neighboring nanodevices. We divide them into four subgroups: (i) media access, (ii) flow control, (iii) addressing, and (iv) error detection/correction. Firstly, due to the very high density of nanodevices expected for nanonetwork deployment, straightforward media access control should regulate the access to the radio channel, to manage simultaneous transmissions in the transmission medium. For instance, by using random seeds to activate the nanodevice transceiver and listen to the medium, message collisions will be mitigated. In the case that a medium access control technique is not employed, messages dispatched by neighbors could collide, corrupting a high percentage of the transmitted data. Secondly, for the same reason, a flow control mechanism is essential to coordinate the communication between nanodevices. For example, a simple acknowledgement reply to confirm the reception of a message, together with a waiting timer for retransmissions (when collisions occur) could be enough to control the traffic load in the network. Thirdly, every single nanodevice in the network requires a unique ID to be identified, facilitating the transmissions from a source nanodevice to a remote destination. Finally, error detection methods are mandatory to evaluate the standard metrics, such as *sensitivity* or *specificity,* since false positives must be properly detected. Hence, we believe the standard should include these data link layer aspects, to provide a more robust and reliable nanoscale communication framework.

Table 3. Weaknesses and open issues for the IEEE P1906.1 standard for EM communications

Standard weaknesses for EM communications	**Open issues**
Excessively open definition of nanoscale communication network.	More detailed definition of nanoscale EM communication devices. Two separate chapters for molecular and EM nanocommunication are suggested.
Lack of a reference energy model.	Definition of a general enough energy model, but easily adapted to the technology employed. Energy restrictions should be better quantified to design a nanonetwork offering a real service.
SNR is not contemplated in the reference communication model.	Standardization of SNR values expected at reception to calculate appropriate receiver sensitivity thresholds.
Lack of layer 2 techniques to enhance communication robustness.	Recommendation of techniques referring to media access control, addressing scheme, flow control and error detection.
Equivalent layer 3 OSI reference model functions are not rigorously addressed.	Definition of routing procedures to allow multi-hop end-to-end communications. Design of a complete network topology.
Interconnections between a nanoscale communication network and macroscale devices are not addressed.	Design and development of a link between the nano and macroscale worlds.

The interconnection of nanodevices and their respective links with existing communication networks entails the design of network architectures that have to be properly planned. So far, we think that the tree-based topology is the most appropriate for EM nanonetworks, which should be further divided into different hierarchical layers [19]. The lowest level is composed of nanodevices grouped into clusters. Each cluster is connected to a larger and more powerful device (in terms of processing, memory, and energy consumption), which belongs to the upper level (e.g. a nano-router). Finally, in the top layer is the *gateway* which interconnects the nanonetwork with the macro world. With this topology, a straightforward multi-hop routing algorithm should be designed to convey the data collected by the nanodevices in the lowest level, ultimately, to the Internet.

Table 3 summarizes the identified limitations of current standard and associates them with their corresponding open issues. Note that even a simple solution to these open issues is a real research challenge at the nanoscale.

5. CONCLUSIONS

The IEEE P1906.1 standard establishes a set of recommended practices with the aim of allowing researchers to advance in the development of effective nanoscale communication systems. Even though it supposes a sound step forward, more concreteness is necessary to envisage a common framework which can become a solid foundation for designing forthcoming EM nanonetworks. Keeping this premise in mind, we have first reviewed the main body of the standard, highlighting those definitions, metrics, and components related to EM communications. In addition, we have taken advantage of the general communication model proposed by the standard, and contributed with a refined reference communication model adapted to EM communications. Secondly, we have identified some relevant shortcomings of the standard, dividing them into four main groups. The first discusses the generality of the definition of the term "nanoscale communication network" itself, while the three remaining groups reveal important deficiencies in each of the three lowest layers of the OSI reference model (physical, data link and network layers). Finally, we have offered possible guidelines for addressing each detected weakness in order to enhance the feasibility and capabilities of EM nanoscale communications.

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