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A Review on Wireless Nanosensor Networks Based on Electromagnetic Communication

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Abstract - **Nanotechnology is rapidly gaining the importance in our daily lives and Wireless Nanosensor Networks are now attracts researchers. Among various communication strategies, Electromagnetic communication strategy gives many solutions in many applications and it is really important in building wireless Nanosensor Networks. This paper provides in depth view of Wireless Nanosensor Networks based on Electromagnetic communication. Network architecture for interconnection of Nano devices is provided. Modeling of the network in all possible layers and channel modeling in terms of terahertz band reviewed in depth. There are different parameters like energy, Packet Loss Ratio, information capacity of the channel, packet delays and number of Nanonodes are affect the network efficiency directly or indirectly so they are highlighted here. There are also several research challenges in Wireless Nanosensor Networks which are important to note down for further development of networking paradigm.**

***Keywords*: WNSN, Modeling, TS-OOK, EM Communication, MAC.**

I. INTRODUCTION

As the rapidly changing environment of nanotechnology and progress in the field of Nano technology, wireless nanosensor networks gaining importance in wireless technology. In many applications like bio-medical, environmental, industrial, military nanosensor networks are finding the way to many solutions and paving the way to a better communication paradigm in today's scenario. The research in wireless Nano sensing field is still on going and, for the time being it has been mainly focused on the communication strategies between nanosensor devices. There are mainly four communication strategies for communication between Nano-machines, that are acoustic, Nano-mechanical, molecular and electromagnetic [8]. Among these four communication strategies, molecular and electromagnetic communication are fall into wireless communication. Molecular communication is the transmission and reception of information encoded in molecules while the electromagnetic communication is defined as the transmission and reception of electromagnetic radiation from components based on various nanomaterial [2].At the Nano scale Graphene based Nano antennas are used for propagation of EM wave. Graphene is a one atom thick planner sheet of bonded carbon atoms densely packed in a honeycomb crystal lattice [1]. Interestingly, it is noted that transmitting at lower frequencies, Nanosensor devices would be able to communicate over longer distances and energy efficiency of Nano devices is predictably very low so Nanosensor devices will not communicate themselves by using the megahertz frequencies and also higher energy waves can be used to control large number of nanosensor devices deployed in very large area. So for these several reasons it is concluded that Nanosensor devices potentially communicate among them in the terahertz band (0.1-10.0 THz) [2].

A Wireless Nanosensor Networks are composed by integrated Nano machines which interact through EM communication. Main features of the Wireless Nanosensor Networks are: (i) Size of the Nano-devices are ranging from one to few hundreds of nanometers (ii) Graphene based Nano-antennas are used that supports the EM communication in Terahertz Band (iii) Bit rates are extremely higher(Terabits/s) in WNSN (iv) Very little Transmission Ranges(tens of millimeters).Due to size and energy constraint of Nano devices, it is not feasible to generate high power signals in the Nano scale at terahertz frequency so classical communication paradigm based on the transmission on continuous signal cannot be adopted so for WNSN short pulse based Time Spread On-Off Keying(TS-OOK) modulation technique is used.

II. NETWORK ARCHITECTURE OF WIRELESS NANOSENSOR NETWORKS

Wireless Nanosensor Networks composed by several elements that are: Nano nodes, Nano router, Nano-micro interface and gateway.

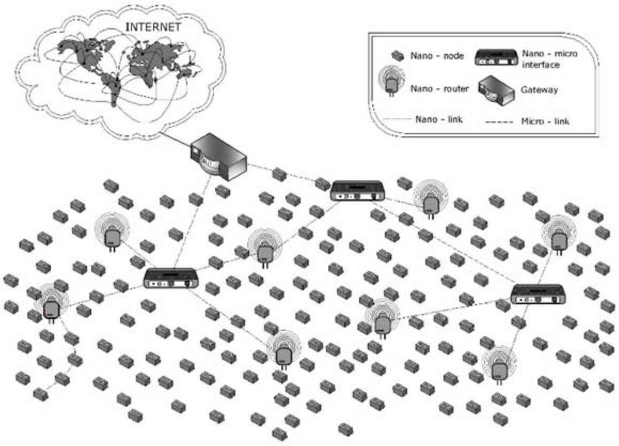

Fig.1 Wireless Nanosensor Network Architecture based on EM communication

A. Nano nodes:

Nano nodes are tiny devices with limited energy, computational, and storage capabilities. They are diffused into a target area for sensing and collecting the information from the environment. Size of the WNSN is mainly defined by these Nano nodes because there are more in numbers to capture all relative information from the target area. The performance of WNSN is influenced by the number of Nano nodes that are used in networks [8].

B. Nano router:

Size of the Nano router is larger than the Nano nodes and having more resources than previous one. They aggregate and process the information coming from Nano nodes and direct this information to Nano-micro interface through Nano-link. Nano router also control the behavior by means of sending short controlling massages.

C. Nano-micro interface:

These devices aggregate the information coming from Nano router and convey these information to the micro scale and vice versa. Nano-micro interfaces are the most complex hybrid devices able both to communicate in the Nano scale using Terahertz Band and to use classical communication paradigm to communicate conventional communication networks.

D. Gateways:

Gateways are micro scale devices that enable the remote control of entire system over the internet. These are the devices that collect the information from the Nano networks and provide these information to the remotely placed monitor through internet.

Nano nodes, Nano router and Nano-micro interface are may be static or dynamic according to the application. For example, in the industrial scenario we can assume that the topology of WNSN is static while in the health-care scenario the topology is dynamic. For all the scenarios, the network configuration, the number of Nano machines, communication and interaction between them and also with the internet still need to be investigated [9].

III. EM BASED WIRELESS NANOSENSOR NETWORKS

Protocol stack of Wireless Nanosensor Networks includes different layers and channel modeling. There are several research challenges for all layers and operations and analysis at all layers are reviewed in the following sections.

A. Physical Layer

As mentioned above due to the size and energy constraint of Nano machines, techniques that based on the transmission of long duration signal cannot be adopted here. Due to the peculiar behavior of noise in the terahertz band and huge bandwidth is available so it is desirable to use technique that depends on very short pulses spread in time over the entire spectrum. This technique is called Time Spread On-Off Keying and it based on asynchronous transmission of femtosecond long pulses. In this technique logical '1' is transmitted by using a short pulse and a logical '0' is encoded as a silence. Only drawback of this technique is that the time between two consecutive pulses (T_s) is much longer than the pulse duration (T_p). This can be made advantage if multiuser can share this channel, several Nanosensor can concurrently use the channel without affecting each other [4],[13].

In [4],[13] information rate or capacity of single user and multi user is defined by developing statistical model of Molecular Absorption Noise. If the silence is transmitted than molecular absorption noise is nonexistent. The capacity of the channel is given by the well-known Shannon Limit Theorem. It is noted that if all the symbols (pulses or silences) are transmitted in burst then the maximum capacity per user is achieved. If β (=$T_s/T_{p)}$ is increased, the single user capacity is reduced but the requirements on the Nano transceiver are greatly relaxed. In [4] the channel capacity is also defined as a function of distance in bit/symbol for different noise power ratios. It is observed that if the distance is increased the capacity diminishes up to a certain point but then it increases again and tends to a constant value. Multi user capacity analysis is also carried out by developing statistical model of interference in TS-OOK. It is shown that multi user interference in TS-OOK occurs when symbols from different Nanosensor reach the receiver at the same time and also the amplitude and shape of the received pulses overlap. When the transmission distance is short, the capacity increases with the number of users up to constant value. This occurs because even when the number of interfering users is drastically increased, the individual probability to transmit silence is much higher than the probability to transmit a pulse. It is interestingly noted that for transmission distance above a few tens of millimeters, there is an optimal number of users for which the network capacity is maximum. From above observation it is concluded that the individual capacity of Nano devices and the aggregate capacity of WNSN can be increased by transmitted more silences rather than pulses.

As stated above that when very large number of Nanomachines are communicate in close proximity, collision between symbols can occur and this collision results into interference and limit the information rate at which the Nanomachines are communicating. To evaluate the performance of interference researchers developed a new model and low weight channel coding scheme that is described in [3]. The probability to transmit a pulse (logical '1') is directly related to interference power. So by controlling the weight of the transmitted code words, probability distribution can be modified and hence interference. By using constant low weight channel codes interference can be reduced but it results into longer massages. For very short transmission distance (bellow 1 mm) interference and noise are negligible. Therefore the maximum achievable information rate is 0.5 which also maximize the source entropy. As the power of the received signal and noise are become comparable to the power of the receive signal, the information rate is decreases suddenly [3],[12].

B. Media Access Control

As the pulse based communication in the Nano networks, and information 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 theses a simple asynchronous MAC protocol is desirable to use which does not handle the acknowledgement and the retransmission of massage. As an asynchronous MAC protocol, transparent MAC and Smart MAC can be used. Transparent MAC is simple which let packets to be transmitted from the network layer to physical interface without any kind of control. In Smart MAC, a packet received from the upper layer is not immediately delivered to the physical interface, but it is stored in a dedicated queue. Before transmitting, the MAC exploits handshaking procedure for discovering Nanomachines in its transmission range [9].

Physical layer aware MAC protocol presented in [6] is based on the joint selection of transmitter and the receiver of the channel coding scheme and optimal communication parameters. This minimizes the interference in the Nanonetworks and maximizes the probability of successfully decoding the received information. This MAC protocol was built on the top of the RD TS-OOK modulation scheme and it split into two stages, namely, handshaking process and data transmission process which are described in [6]. In this protocol, Nanosensors are able to dynamically choose different physical layer parameters based on the channel condition and energy of the Nano-device and these parameters are agreed between the transmitter Nano-device and receiver Nano-device by means of handshaking process. Performance of PHLAME can be described in terms of energy consumption, packet latency and normalized throughput. Results shows that for very dense networks, lowering the code word can reduce the energy consumption by more than half.

As the time going, it is necessary to synchronization and coordination of the transmission of Nano devices and also the energy harvesting system also affect the design of the MAC protocol. New energy and spectrum aware MAC protocol proposed by Pu Wang and other co-authors to achieve fair throughput and lifetime optimal channel access by jointly optimize energy harvesting and consumption process in Nanosensors. For this dynamic scheduling scheme based on TDMA is proposed. In this scheme, variable length transmission time slots are assigned dynamically for each Nanosensors. When the Nanosensor is not transmitting it is called in sleeping state. Energy harvesting process by which the Nanosensor can replenish their batteries is performed in both transmission and sleeping timeslots. If transmission and sleeping timeslots are assigned among Nanosensors in such a way that the harvesting energy and consumed energy are balanced for each Nanosensor thus the lifetime of the network increases.

C. Network Layer

Network layer handles routing operations. In a WNSN, since Nano machine communicate at physical layer with very limited transmission ranges, it should be essential to establish a multi-hop path between the sender and receiver. Hence, the routing algorithm should essentially handle multi-hop connection. At the starting stage simple selective flooding and random routing are proposed in [8],[9]. In selective flooding routing algorithm, simple store and forward mechanism is used in which a packet received from the upper layer spread all neighboring devices within its transmission range. In random routing algorithm packets received by upper layer are transmitted randomly to its neighboring node. This algorithm is suitable for point to point communication. One drawback of this routing is that it creates network loops in multi hop connection. So to solve this each device should avoid to consider as next hop nodes that have already been selected as next hop in the past for a given packet.

Another routing framework for energy harvesting in Wireless Nanosensor Networks is proposed in [14] which uses a hierarchical cluster based architecture that offloads the network operation complexity from the individual Nanosensors towards the cluster heads. To cope up with the limited resources of the Nanosensors, hierarchical cluster based architecture is devised in which more advance device Nano-controller is placed within each cluster it coordinates the Nanosensors and gather the data they communicate. This algorithm is based on based on the evaluation of the probability of saving energy by initiating a multi-hop communication route from a source Nanosensor compared to a direct transmission from the source Nanosensor to the Nano-controller. For short distances of nanosensor and Nano-controller the energy is comparable but as the distance is increases, the energy saved through the multi-hop routing becomes higher in agreement with the values of the probability of energy saving [14].Still the network layer need development for WNSN and better routing algorithm is needed.

D. Terahertz Channel Modeling

To understand the communication among Nanosensors there is need to understand and model the terahertz channel in the very short range. Behavior of terahertz channel can be analyzed by the properties of the terahertz channel which includes Path Loss, Molecular absorption noise, Bandwidth and Channel Capacity.

1) Path Loss:

Radiative transfer theory is used to compute the total path loss that a signal suffers when its travelling distance is up to a few meters from a several tens of millimeters. Total path loss is considered as a n addition of spreading loss and molecular absorption loss as defined in [5].several observations are indicate that total path loss doesn't only depends on transmission distances and system frequency but also on the composition of transmission medium at molecular level.

2) *Noise*

Electronic noise temperature of the system is low due to the electron transport properties of Graphene and this type of noise is only present around the frequencies at which the molecular absorption is high. As a result, main source of the noise in the terahertz band is molecular absorption noise. Molecular noise is neither white not Gaussian but has several peaks because of the different resonance frequency of each type of molecule.

3) *Bandwidth and channel capacity*

The available bandwidth will depend on the molecular composition of the channel and the transmission distance because Molecular Absorption is also determine the usable bandwidth of the terahertz channel. Within a WNSN, it is unlikely to achieve single-hop transmission distances above a few tens of millimeters. Within this range, the available bandwidth is almost the entire band (0.1-10 THz). As a result, the predicted channel capacity of Wireless Nanosensor Networks in the terahertz band is very large, in the order of a few terabits per second.

IV. ENERGY AND OTHER PARAMETERS OF WNSN

As defined earlier that WNSN is made up of small sized Nano-sensing devises having limited energy so energy harvesting process of WNSN and energy efficiency is critical issue in WNSN. Energy harvesting and energy consumption process can be jointly analyzed to increase the life time of the energy harvesting networks. There are several papers are written on energy optimization of the WNSN as different channel codes are defined which minimizes the energy and there are also different energy aware MAC protocols and routing algorithms are proposed [10],[14]. To achieve fair throughput and lifetime optimal channel access jointly optimization of energy harvesting and consumption process is beneficial to consider [10]. To save the energy several mechanisms are proposed in which consumption of energy is reduced by properly adopting channel codes. These types of codes minimizes the energy in order to provide reliability. Minimum energy codes (MEC) maintained the desired hamming distance and minimizes the energy. These code words can be perfectly decoded for large code distance if the source set cardinality is less than the inverse of the symbol error probability [7],[11].

Another parameter that observed in the network is Packet Loss Ratio.it is measured as the percentage of the packets that are not received by the Nanointerface.it is observed that when the number of nodes are less than PLR is unacceptably high so it cannot guarantee the delivery of massages between sensor and remote server.an increase of number of nodes leads to smaller PLR but in it increase the delays.so optimize tradeoff between network size and protocol stack is required to get desirable results[8].

V. RESEARCH CHALLENGES IN WNSN

There are several challenges observed in design and analysis of the wireless Nanosensor networks and summarize as follow:

- Communication between Nanodevices is the major challenge in front of the researchers and it can be handled by choosing proper communication scheme, channel model and routing mechanism.
- Nanosensor device has limited energy so energy harvesting and consumption is big issue in WNSN.
- Size of the network is also affect the network efficiency, as the number of Nanonodes varies, PLR (Packet Loss Ratio) and packet delay have different behavior.
- To manage the size of the network and other parameters of the network, efficient MAC protocol and Routing Algorithm is required.

VI. CONCLUSIONS

The field of Nanotechnology is in early stage of research. There are long way to go for research in various field of Nanotechnology. Energy is limited of the Nanodevices so for that low weight channel codes are used to reduce the interference power and energy consumption so lifetime of the network can be increases. Due to energy constraints and size of the network it is beneficial to adopt communication scheme that is based on short pulses and the information capacity of the network for both single user and multi user are gives the idea of the capacity of the network. There are several research challenges in front of the researchers that includes Size of the network, Channel Modeling, efficient MAC protocol and routing algorithm, Energy harvesting and consumption. These challenges in front of researchers need careful research and evaluation of the network for various applications in all fields.

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