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Error Free Nano Scale Communication

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Abstract: With the advancements in Nano technology the Macro scale devices are being replaced by Nano scale devices which are used in different fields for performing multiple tasks at molecular level. These Nano scale devices gather more accurate and detailed information from the environment where they are deployed, which is then communicated to other Nano scale devices over a Nano scale communication channel (to perform a collaborative analysis of system under study). The major drawback of using Nano scale devices is the availability of extremely low transmission power which results in spreading and molecular absorption loss in the signal propagated from one Nano device to another, thereby causing errors in transmitted message. The solution to this problem can be re-transmission, but this technique is not applicable to Nano scale communication because of the limited availability of energy source at each Nano node. So, the only solution to this problem is the use of error detection-correction or prevention techniques. Also, the already available error detection or prevention techniques cannot be used because of their complex nature, so energy efficient and less complex techniques need to be developed and used for such communication paradigm, making it an error free communication. This Paper presents a brief introduction to Nano scale communication, its applications, and limitations and finally proposes methods to overcome these limitations.

Keywords: Nanotechnology; Nano-scale devices; spreading loss; Molecular absorption loss.

I. INTRODUCTION

Nanotechnology provides us the tools for creating Nano-scale electronic devices [1] which will control molecules and atoms by performing limited tasks and on assembling these Nano components we can create highly efficient machines which can work more efficiently and will have tremendous applications. Also, on connecting these Nano-scale devices with each, they can perform tasks in distributed manner, hence increasing performance and applicability of the device or Nano-machines. Currently the researches on creating Nano-scale devices are being made in medical, engineering, military, industrial and many other fields, which will enhance the working of current techniques, because these Nano-devices can analyse at atomic level, thus formulating a highly efficient detailed description of the system over which they operate.

When we will integrate these Nano-devices using a Nano network, over an internet, then we will be able to control and monitor even a Nano particle, thus giving rise to Internet of Nano-things. As discussed above the Nano-devices work on atomic level, and to make these Nano-devices to communicate with each other we can use molecular communication or Nano-electromagnetic communication.

The molecular communication [2] has been inspired by the molecular communication in human body, a simple example is that when nerves have to send an information to the muscle to contract or relax, they send it by sending a particular type of molecule called: Acetylcholine, which when received by muscle makes it to contract. Similarly for achieving molecular communication, the information from one Nano-machine is encoded in the form of molecules by a transmitter, which reacts with some molecules and releases some molecules to receiver [3], the simple molecular communication between two Nano-devices shown in figure-1.

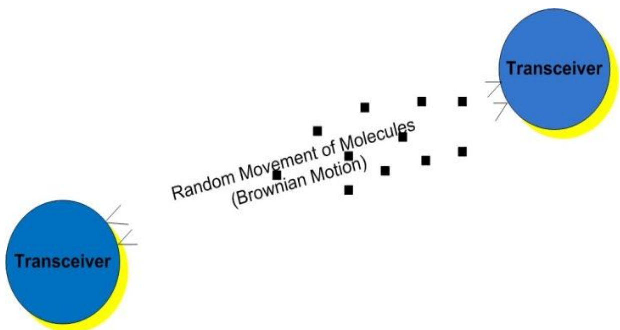

Fig. 1: Basic molecular communication between transmitter and receiver

A. Components of Nano scale communication

The basic components in the communication model are shown in figure-2. The first step in the communication model is encoding, where the information to be sent is transformed into a sequence of zeros & ones, which can be easily sent to receiver through a binary channel. After encoding the transmitter produces molecules or a signal (based on the transmission mechanism employed). If the transmitter is using the molecules as message carriers, then it can use a particular type of molecule to send special information or can use a series of any type of molecule to represent a sequence of zeros and ones. For the propagation of message through a binary channel, there are many methods which are discussed in the upcoming section. At the receiver the first step is the reception of message. If the message is carried by molecules, then the

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receiver can have permeable membrane which will capture the message molecules (same as human cell), or it can use a transceiver which will capture the message molecules of particular type. The final phase at receiver is that of decoding, which is not only responsible for transforming the captured signal into original message, but also is responsible for error detection and correction (if occurred).

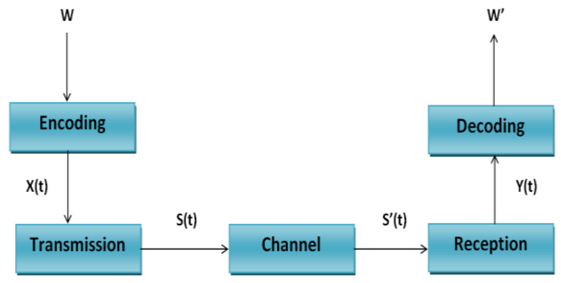

Fig. 2: Five step communication model for molecular communication

B. Propagation methods for Nano Scale Communication
For using Nano-electromagnetic communication, we have to study the properties of Nano-devices [4], which will help us to know what bandwidth can be used for such Nano-devices. Many researches have been made to enable the communication between Nano-devices and all these researches point out to the fact that the Nano scale communication can be achieved by following methods: 1. Communication via diffusion; 2. Calcium signalling; 3. Terahertz signalling. For understanding these modes of communication we will make use of five step communication model, shown in figure-2.

For achieving the communication via diffusion, the transmitter and receiver should be inside the same diffusive environment. The transmitter encodes the message, generates molecules for the message and releases the molecules into the diffusive medium. The information is carried by the environment to the receiver by diffusion dynamics. At the receiver side, the table-1 shows how the information is retrieved from the received molecules. The receiver first captures the molecules and then retrieves the original message from them.

TABLE 1BIT INTERPRETATION

Number of received molecules	Bit is
Greater than or equal to threshold	1
Less than threshold	0

The advantages of using communication via diffusion include:
- It is bio-compatible.
- It is very energy efficient and
- It has broadcast unicast and multi-cast capabilities.

But it has got some disadvantages also, which include:
- Too much path loss.
- Low data rate
- Slow transmission speed.

Another method of molecular communication is the calcium signalling, which is inspired by the ion based communication in human cells. In this molecular transfer method, the transmitter encodes the message in the form of molecules and transmits it on calcium capable channel, where the information is carried by the calcium ions. The bits at the receiver are interpreted in similar manner as in communication via diffusion method, shown in table-1. Thus, this method also requires the transmitter to generate the molecules, either of particulars type or of any type (depending on the type of information sent over the channel), for message transfer between transmitter and receiver. The advantages of using this method in molecular communication include:
- It can have much longer range than communication via diffusion.
- Also it has higher transmission speed than communication via diffusion.

The disadvantages include:
- Here the pre-deployed infrastructure is needed.
- The energy cost of infrastructure can be higher.

The third method used for molecular communication is the use of separate communication band, which is Terahertz band. The Terahertz band falls between microwave and infrared-light waves. Its wave length is: 100μm to 1mm and the frequency is: 0.3 to 3THz. So the frequency of this band is very high and is the meeting point of electronics and optics. The main advantage of using Terahertz ban is the availability of larger bandwidth, which is 10GHz to several THz. But inspite of such a big advantage it has some disadvantages, which include: molecular absorption and reflection loss (more when range > 1m). The major issue in using the Terahertz band for Nano-device communication is to develop the way for signal generation, this has been solved by the researchers by proposing the Graphene [5] as a material to generate the signals in Terahertz band. Graphene is a single atom thick sheet of carbon, which is very much light in weight and has very high heat and electric conductivity. The application of Graphene is shown in figure-3. The researchers show that Graphene-basedplasmonic Nano-antenna (GPN or Graphenna) can operate in Terahertz band [6]. The GPN can support the generation of plasmonic polarities on the surface, which lead to the generation of EM-waves in Terahertz band. The avantages of using Terahertz band for communication include:
- The Terahertz band provides a very high bandwidth.
- The data rates are very high in terahertz band.
- The message transmission using terahertz band is similar to the classical approach of wireless communication.

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But, the disadvantages include:

- The message or signal transmitted using Terahertz band has low range.
- The path loss in the channel of Terahertz band is very high.
- The use of Terahertz band for message transmission has limited bio-compatibility.

With Terahertz band the data rates range from multi Giga-bits per second to even Tera-bits per second, but this comes with the cost of high propagation losses. The limited power constraint for Nano devices affect the THz-band, thus resulting in more error prone connections with low communication range.

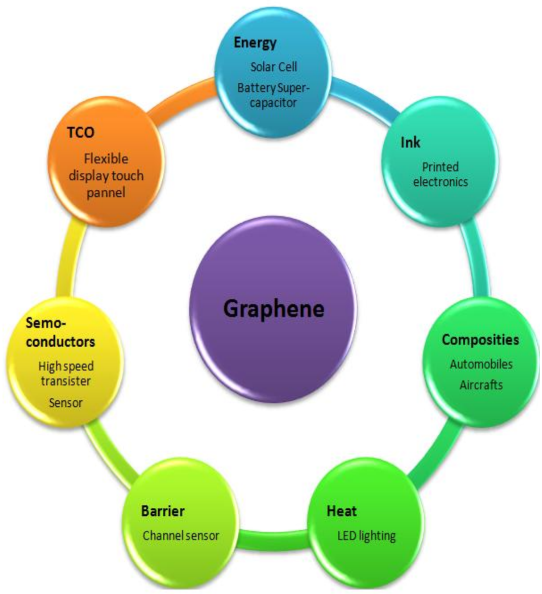

Fig. 3: Applications of Graphene

we need to use a tera-hertz band for Nano-device communication, because the Nano-device are so small that one has to use that antenna whose size should be in Nano-meters and for such a small antenna we need signal frequency in tera-hertz band. Currently, Graphene-based Nano-antennas [7] have been proposed for achieving the communication between Nano-devices, as discussed above.

The electrons of graphene propagate in such a way that they create compact plasmonic component [8] which works under very low frequency, making it suitable for Nano-device communication due to energy constraint.

II. APPLICATIONS OF NANO SCALE COMMUNICATION

With extremely small size and highly specialized performance of Nano devices, the Nano device and the Nano scale communication has limit less applications in almost every field, like applications in medical field, military applications, environmental applications and applications in manufacturing area. The Nano devices when deployed efficiently can monitor even a molecule and can detect slightest variation in the system, thus making the computing more specialized and efficient. Some of the applications are discussed briefly and are collectively presented in figure – 4.

- Medical applications: These include monitoring the health of a patient, complete analysis of a sample by a single chip or set of Nano devices, automatic drug delivery in living organism. One can implant a simple Nano device in a patient, which can gather even the minute information about the patient's body. We can construct a lab on a small chip consisting of many Nano devices, each Nano device capable of performing particular analysis, which can analyse a sample more efficiently and hence reducing the size of the equipment needed for the analysis of the sample. When a Nano device in configured to monitor the health of a person, it can not only detect the disease, but can also cure it by applying medicine on the affected area only, thus providing the cure on-demand and enhancing the healing process.

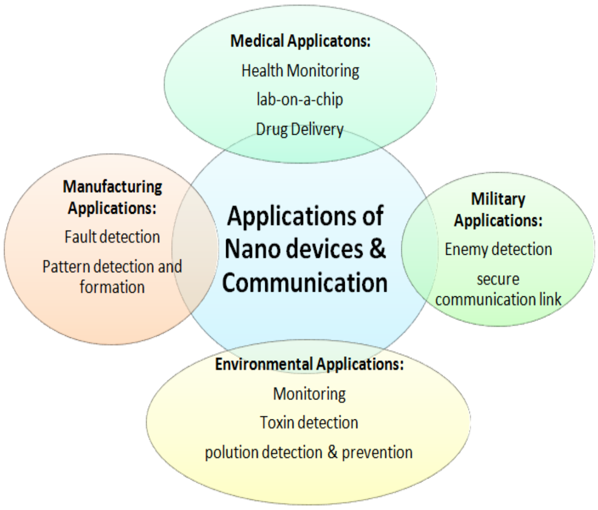

Fig. 4: Applications of Nano devices & Nano scale communication

- Military applications: Nano devices play an important role in military, by using a small sensor whose size in the Nano meter range, we can collect the useful information from any area without being detected by enemy. Nano devices can also be used to create a secure Nano network for the information transfer between different nodes. Nano devices can also be deployed to monitor those areas where it is really difficult for a human being to gather information. They can detect the temperature variation in nuclear or atomic bombs due to their extremely small size.

- Environmental applications: Nano devices can even trace a slightest amount of any toxic material present in the environment, thus provide an efficient way of environmental monitoring. The Nano devices can detect molecules from the environment, analyse it and can detect

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any ill effect by it on the environment. We can create a cluster of Nano devices which will detect any environmental treat and can accordingly inform other Nano devices about the threat to respond and resolve it by producing the antibodies (molecules which kill the infected element in environment).

- Applications in manufacturing area: The Nano devices can detect a minute error or variation in colour or pattern during the manufacturing process due to their extremely small size. We can deploy a Nano device in a manufacturing area which will monitor all the methods and techniques employed. Also a wide variety of patterns can be generated by a Nano device, because they work on molecular level, thus resulting in the formation of numerous structures and patterns for manufacturing new products.

III. MESSAGE PROPAGATION IN NANO SCALE COMMUNICATION AND BASIC ISSUES

The propagation of molecular signal in Tera-hertz band [9] brings many useful opportunities, but the long range communication is limited by the molecular absorption and thus requires a large bandwidth, which is a limitation of Nano-devices. To overcome this, a novel technique has been proposed by the researchers, which transmits 100-femtosecond-long pulse over a particular time called TS-OOK (time sharing on-off keying). In TS-OOK, a binary bit-1 is represented by a 100-femtosecon-long pulse and a bit-0 is represented by not sending anything (silence). For the synchronization purpose we use a preamble initially between transmitter and receiver. Under this scheme, the signal transmitted by Nano-device "x" is given as:

$$S^x(t)=\sum_{i=1}^{k} A_i^x p(t - iT_s - \tau^x)$$

Where, "K" is number of symbols, A_i^x is the amplitude of kth symbol, "p" is pulse with duration Tp, Ts is the time between consecutive transmissions and τ^x is the random transmission delay. Also, $\beta = \frac{T_s}{T_p} >> 1$, i.e. time between transmissions is fixed and is much longer than duration of the transmitted pulse. The signal received by the Nano-device y is:

$$S^y(t) = \sum_{i=1}^{k} A_i^y p(t - iT_s - \tau^x) * r^{x,y}(t) + n_i^{x,y}(t)$$

Where, $r^{x,y}$ is the impulse response of the system between Nano-devices "x" and "y", $n_i^{x,y}$ is the effect of noise on the bit "i" between "x" and "y".

Since the communication between Nano-devices is mainly using binary bits, so we will be considering the binary channel. Then comparing it with the five step communication model for Nano-device communication, the different signals generated are given as:

The signal generated by the transmitter is:

$$S(t) = \begin{cases} n_0 : x(t) = 0 \\ n_1 : x(t) = 1 \end{cases}$$

The message received by the receiver is: (where "τ" is the threshold)

$$Y(t) = \begin{cases} 0 : s'(t) < \tau \\ 1 : s'(t) \geq \tau \end{cases}$$

For the communication using molecular diffusion, let the diffusion process be: $F_{hit}(d, t_s)$, where "d" is the diffusion constant and "ts" is the time instant. Since the message transmission using molecular diffusion is governed by the Brownian motion, so according to Brownian motion the message molecules travel independently, thus $S'(t) \sim \text{Binomial}\ [S(t),\ F_{hit}(d, t_s)]$, then the decoding probabilities $P\{Y(t) = \frac{Y}{X(t)=X}\}$ are calculated in table – 2:

TABLE 2 DECODING PROBABILITIES

Y \ X	0	1
0	$P\{B[n_0, F_{hit}(d, t_s)] < \tau\}$	$P\{B[n_0, F_{hit}(d, t_s)] \geq \tau\}$
1	$P\{B[n_1, F_{hit}(d, t_s)] < \tau\}$	$P\{B[n_1, F_{hit}(d, t_s)] \geq \tau\}$

The basic issues in a binary channel are:

- How to differentiate between the value of symbol 0 and no communication?
- What to do with residual message molecules left over from previous symbol?
- Symbol can represent more than one bit of information, how to resolve it?

In all the upcoming sections of this paper, we will be taking these issues into consideration and will be proposing an efficient binary channel for the Nano-scale devices to transfer the messages between them efficiently an properly. As we have mentioned that the probability of increase in the molecular absorption noise and multi-user interference when using Terahertz band for communication between Nano-scale devices is more. The solution to this problem can be re-transmission, but this solution is not feasible for Nano-communication because of the energy constraint.

When we re-transmit the message again we require same amount of energy as needed before for message transmission, thus increasing the energy requirement of Nano-devices, which is not appropriate.

So, we need to develop the error detection and correction techniques for the Nano-device communication. For this, we need to study already existing error detecting and correcting techniques [10], or develop new techniques to

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have an error free molecular communication between Nano-devices. So, in this paper we propose a technique which can be used to detect and then correct the erroneous message.

Also, the coding technique proposed is so efficient that it will require low energy and will produce codes with less number of ones in it, which will reduce the probability of occurrence of errors, thus making an error free communication of messages between Nano-devices.

IV. PROPOSED METHODOLOGY FOR ACHIEVING ERROR FREE NANO SCALE COMMUNICATION

Due to very low transmission power of Nano scale devices, there is a higher probability of occurrence of errors in the channel. These errors occur due to the molecular absorption noise (if molecules are being used message carriers) and multiuser interference (when using Terahertz band for communication).

The molecular absorption noise is an environmental effect, by which the transmission energy of message molecules is absorbed by the environmental molecules, thus decreasing the range and also increasing the error probability.

Also, when using the terahertz band for Nano device communication, the losses in the channel occur due to multi-user interferences, low transmission power and EM-wave absorption by water vapour molecules.

The probability of occurrence of errors increases with the increase in the transmission range. The use of coding and decoding schemes can reduce errors in the message by encoding the message with redundant bits and transmitting the new signal, which when received can be checked for errors and can be corrected.

The error correcting technique [11] thus developed should have high error detecting and correcting capabilities, and the algorithms used for encoding &decoding should be simple and with least complexity, therefore reducing the need of sophisticated hardware.

In this regard, we have proposed to use LDPC (low density parity codes) for detection and correction of errors [12] occurred during the communication between Nano devices. An LDPC is a block coding scheme whose parity check matrix is sparse i.e. contains very few entries of ones in it.
A LDPC code of length ‘N’ satisfies ‘M’ linear parity check constraints. Thus, LDPC is represented by aMxN parity check matrix (H), where M-rows satisfy N-constraints.Thus, for a parity check code ‘C’

$$C * HT = 0$$

And if ‘r’ = rank (H) <= M, then it gives the number of linearly independent rows in H, and the number of code words are ‘2N - r’ and code dimension is ‘K’ = N – r, and finally the code rate is given as K/N. A regular LDPC codes have exactly same number of ones in each row and column in parity check matrix, where in irregular LDPC codes there are unequal number of ones in each row and column of parity check matrix, but both have less number of ones as compared to zeroes in parity check matrix.

The decoding of such codes can be achieved by using iterative scheme whose complexity increases only linearly with length of block.

LDPC provides better performance and lower decoding complexities (especially with irregular). We have proposed to use irregular LDPC codes for error detection and correction for Nano scale communication, because Nano scale communication uses OOK-modulation scheme, where the signal is only used for the transmission of ones in a message, no signal is used for transmission of zero.

As the parity check matrix for LDPC is sparse, so there are very less number of ones in it, and the codes thus generated will have less number of ones in it, thus reducing the probability of occurrence of errors in message because the signal transmission is only used for carrying ones of message and not zeros in OOK-modulation scheme.

Also, as mentioned earlier that LDPC have lesser complexity in coding and decoding process and thus provide better performance for message transmission for Nano scale communication.

V. CONCLUSION AND FUTURE WORK

Nano scale communication is a new era of communication with tremendous applications. The paper has presented this new type of communication paradigm in detail with its scope and applications in different fields. The paper also highlighted some of the major challenges and issues in Nano scale communication.

Finally at the end we have proposed the use of low density parity check codes for solving the basic problem (occurrence of errors in messages passed over Nano scale communication channel) in Nano scale communication.

The use of proposed coding technique will not only secure the communication channel but also will save the energy of Nano nodes which otherwise gets lost in retransmission of bugged messages. Also these codes are less complex and have lesser overhead, which again favours them to be used for Nano scale communication.

In future the proposed technique will be implemented and analysed in detail, after which the real time data can further prove its applicability for Nano scale communication.

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