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Power optimization of invivo sensor node operating at terahertz band using PSO

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ABSTRACT

The invivo nano-communication links at terahertz (THz) frequencies needs high transmit power because signal suffers radio propagation losses through biological tissues. Less power is received by on body receiving node due to the absorption noise inside the human body. Transmit power of an invivo sensor node needs to be minimized as high transmit power is harmful for biological tissues present inside human body. This paper has been devised with the aim to optimize (using PSO) the transmitted power of invivo sensor node operating at terahertz band. Influence of blood, skin and fat on the communicating signal in invivo communication network has been modelled to critically compare diverse modulation schemes (MFSK, MPSK, and OOK) and compute received power by an on body sensor node. Threshold distance between two communicating nodes is computed using eigen values and is further used as a constrain for PSO to optimize transmitted power of invivo sensor node.

1. Introduction

Wireless Body Area Networks (WBANs) is gaining momentum in human healthcare sector [1]. Recent advancement in WBANs is promoting to move from microscale WBANs to nanoscale WBANs. Nanotechnology makes possible the fabrication of devices in the scale of 1 to 100 nm. Nano devices may be projected as a miniature set of sensor nodes inside the human body (invivo) which is able to perform various tasks like sensing, actuation and computation [2]. Some of the applications of nano devices include internal health monitoring, immune system support and drug delivering system etc. Nano devices are capable of operating inside the cells of human body. Recent advancement of nanotechnology does provide thrust to the internet of nano things (IoNT) paradigm. Low power consumption, low power transmission, low latency, compact size and robustness are basic requirements for invivo BAN [3]. Practices related to power usage inside the human body medical implant communications service (MICS) rules have been established by Federal Communications Commission (FCC). For the 402–405 MHz frequency band MICS protocol allow 25μW (−16 dBm) effective isotropic radiated power (EIRP) only. An implantable device is compact and consist low power transmitter with tiny antenna. These devices are not compatible with IEEE 802.15.1 standards (ZigBee and Bluetooth). Furthermore, because of limit -16 dBm EIRP less interference will be experienced by the other biosensors working in the same frequency band [4]. For transferring information through the Internet of Nano-Things (IoNT) terahertz band is earning popularity as this band is considered a worthwhile technique, since, at these frequencies, (0.1 − 10 THz) biological tissues are not ionized [5]. In body communication also termed as invivo communication at terahertz band incite the analysis of the behavior of the signal when it travels inside the human body. Signal to interference ratio (SINR) evaluation and analysis of terahertz signal for biological tissues (muscles, skin etc.) have been presented in

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[6]. Path loss for intra body communication has been evaluated in [7] by considering various consequences of the spreading and scattering of the propagating wave and molecular absorption from biological tissues inside the human body. Antenna is an integral part of the sensor node. Low power transmission and consumption is the requirement for invivo communication operating at Terahertz band. Various antenna designs have been proposed for terahertz communication. A simple, low cost and compact helix antenna for terahertz applications has been presented in [8].A multibeam radiation antenna has been designed in [9] for terahertz applications with high gain. For high data rate at THz band a portable wideband array antenna is proposed in [10].

In [11] authors have presented a system model for invivo nano-network operating at the terahertz (THz) band. Impact of noise has been analyzed on link quality and information rate for terahertz system model. The maximum achievable information rate of terahertz communication inside human body is inversely proportional to the transmission distance and should be less than 2 mm for invivo nano-network operating in the lower range of THz band. In [12] it has been shown that terahertz band offers good link quality between communicating nodes. Also transmitted power for efficient WBAN at terahertz has been examined in [13]. In in vivo scenario power consumption is a prime concern. The in vivo biosensors are generally self-excited or are driven by an extremely small size battery. Recharging or replacing battery is not feasible [14]. For smart and efficient communication between in body and on body sensor, compression, encoding and modulation are required before the signal is transmitted with the aid of human body as a channel. The complete transmitter and receiver (invivo biosensor) is represented in Fig. 2. Nano devices are highly energy constrained. In nano communication, at terahertz band high power carrier frequency generation is a challenging task for transceiver. Thus, pulse based modulation schemes are best suited for invivo system. [15].

Selection of proper modulation scheme helps in reducing power consumption of invivo network. Research has been conducted for conventional pulse based modulation schemes like Frequency Shift Keying (FSK), Phase Shift Keying (PSK) and On-Off Keying (OOK) for on-body WBAN where the role of human tissues like blood, fat etc. has not been considered. Power analysis for on body WBAN has been done in [16] considering FSK, Binary PSK (BPSK). Since the scenario for invivo communication is different so the power consumption and transmit evaluation will be different in comparison to on body communication.

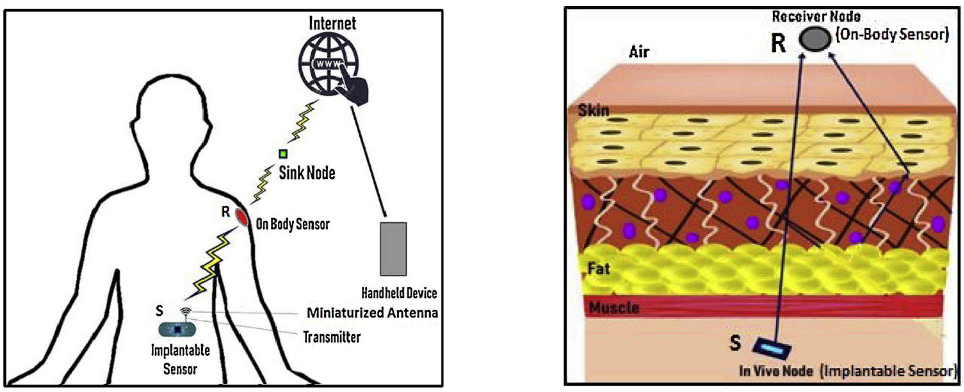
To inspect the effect of modulation schemes on the signal inside the human tissues, a critical comparison of the received power at on body sensor node R is presented in this paper. Further as it has been seen from the literature reviews that transmit power needs to be minimized. Hence transmit power is optimized considering a threshold distance value which will be evaluated using eigen value. The main contributions of the proposed work are:

- To critically compare the performance in terms of received power of modulation schemes at terahertz band for invivo communication.
- To evaluate threshold distance between two communicating nodes using eigen values. The evaluated threshold distance is further used as a constrain to optimiz transmitted power.
- To optimize the transmitted power using Particle Swarm Optimization (PSO).

The rest of the paper is organized as follows: Section II introduces, an invivo system model operating in THz (0.1–10) band. On the basis of received power analysis inside the human body a threshold distance (d^{th}) has been calculated with the help of eigen values in section III. Section IV presents optimization of transmitted power using PSO for efficient invivo communication. Section V highlights the simulation results of the considered scenario. Finally conclusion of the work is described in Section VI.

2. In vivo system model

An in vivo model in which implanted biosensor is operating at THz band (0.1–10 THz) is depicted in Fig. 1 (a). A biosensor (source node S) is implanted at the surgical site to monitor and transmit sensed information to receiver (sensor node R) deployed on the



(a) Human Body Model (b) Simplified Biological Model

Fig. 1. (a) Human body Model and (b) Simplified Biological Model for in vivo Communication System.

Table 1
Permittivity of human tissues at 1 THz [20].

Human Tissues	Blood	Skin	Fat
Permittivity(ε)	.5130	.2625	.1910

human body. Post-surgery monitoring of deep sites inside human body is necessary and difficult. Many times post-surgery complications such as recurrence of life threatening diseases or infections are there. Generally medical experts are altered when symptoms are visible. To avoid such type of delays a biosensor implanted post-surgery for monitoring purpose seems to be a feasible solution. Biosensors sense the particular change in the monitored parameter and further with the aid of transmitter via antenna forward it to the on body sensor. The information received by the receiver (sensor node R) is further transferred to the handheld device. This has been illustrated in Fig. 1 (a).In order to establish the connection between S and R, human body acts like a wireless medium. The wireless medium offered by human body is different from general open space wireless medium as the information signal inside human body has to propagate through various human tissues like blood, fat, skin etc. as shown in Fig. 1(b). The human tissues possess diverse electrical properties and impact the quality of transmitted signal in invivo channel as each human tissue has different permittivity which is given in Table 1. Pathloss is the important parameter which impacts the quality of transmitted signal.

For WBAN various pathloss models have been suggested by IEEE 802.15.6 for different scenarios (on body, off body, implant etc.). The biosensor implants work as per the guidelines laid by MICS. Because of non-ionizing properties of Terahertz band, it has been acknowledged by MICS, IEEE 802.15.6 models are not applicable for terahertz band. To evaluate the pathloss at THz band (0.1–10 THz) in the invivo channel various pathloss model have been proposed. In this paper the pathloss model suggested by authors in [17] has been implemented. The sensed signal with the aid of transmitter and antenna is transmitted in human body as indicated in Fig. 2A low power transmitter aids in transmitting the sensed signal to on body sensor with the help of antenna. The role of transmitter and receiver unit is depicted in Fig. 2. As per the guidelines of MICS the transmitted power of sensor node should be ≤ -16 dBm, which is considerably less in comparison to other wireless communication systems.

With the aim to reduce transmitted power of sensor, modulation schemes applicable for invivo communication are analyzed. Further by using eigen values a threshold distance (d^{th}) is calculated which will be implemented as a constrain in PSO to optimize transmitted power. Fig. 2 shows that modulation plays an important role in establishing invivo communication. By taking into account the biological model (different human tissues) which modulation schemes will require minimum transmit power to establish connection between communicating nodes under the considered scenario is analyzed. For the considered scenario its assumed that S and R are separated by the distance $d_{S,R}$ and power transmitted by the biosensor S is P_t which is prescribed to be less then 1 mW for invivo communication [19] and G_t, G_r are the gain of antenna of transmitting sensor node and receiving sensor node respectively. Source node S is transmitting the data with data rate R where packet length L is 1. For transmission the required energy per bit can be calculated as, [18] and presented in Eq. (1),

$$E_b = \frac{1 \times P_t \times G_t \times G_r \times \left(\frac{c}{\sqrt{\varepsilon \times f}}\right)^2}{N_0 \times R \times (4\pi)^2 \times d_0^{\gamma} \times L} \tag{1}$$

Here, d_0 is the reference distance, γ is the pathloss exponent in human body, ε is the permittivity of the human tissues which have

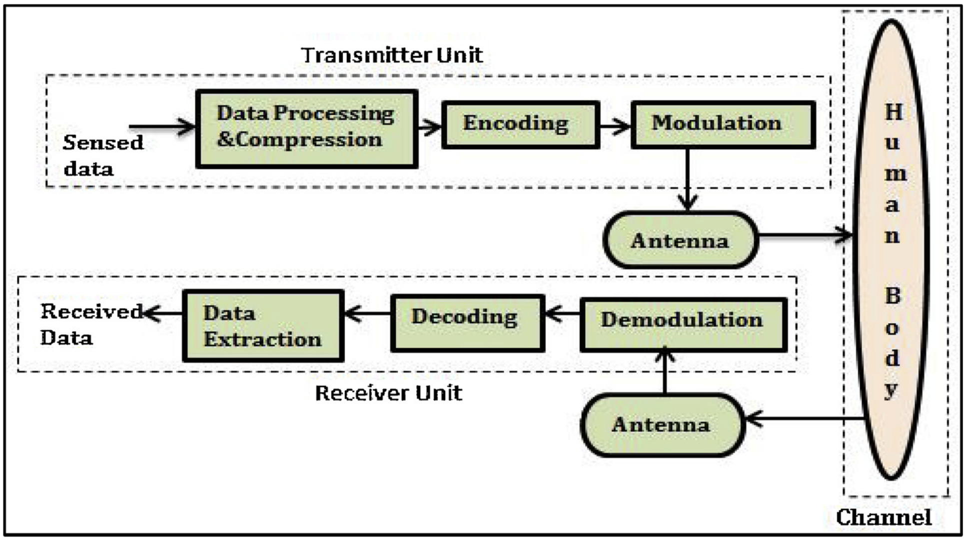


Fig. 2. Basic Block Diagram of invivo communication.

Table 2
E_b/N_0 (dB) values for OOK, MPSK and MFSK.

Modulation Scheme	8 PSK	32PSK	8FSK	32FSK	OOK	Reference
E_b/N_0	14	23.4	9.3	7.5	14	[12] and [14]

available values as indicated in Table 1. f is the frequency of transmitted signal, c is the speed of light.

Power received by the on body sensor node is evaluated by implementing Friis Transmission equation. The equation reflects the linear path loss of the channel as the ratio of transmit power to power received by the receiver. By using the concept from Eq. (1) power received (P_r) can be expressed as,

$$P_r = \frac{\frac{E_b}{N_0} \times N_0 \times R \times G_t \times G_r \times \left(\frac{c}{\sqrt{\varepsilon \times f}}\right)^2}{(4\pi)^2 \times (d_{S,R})^{\gamma} \times PL_{S,R}} \tag{2}$$

Here, $\gamma = 3.5$, $d_0 = 1$ mm and $L = 1$ and the value of E_b/N_0 is given in Table 2

$PL_{S,R}$ is the pathloss suffered by the transmitted signal during its travel from S to R. The information signal suffers severe pathloss contributed by molecular absorption, wave spreading and scattering by human tissues. Pervious research on terahertz communication reveals that at terahertz frequencies pathloss is significantly large even for very small distance [17]. Pathloss suffered by the signal from source node to receiving node inside the human body has been proposed in [17] and given as:

$$PL_{S,R} = -0.2\,N + 3.98 + (0.44\,N + 98.48)d_{S,R}{}^{.65} + (0.068\,N + 2.4)f^{4.07} \tag{3}$$

Where N = 5 is the number of sweat ducts, which are under skin and affects the quality of signal and f is the frequency in THz of the transmitted signal and $d_{S,\,R}$ is the separation distance between S and R. By rearranging the Eq. (2) we get,

$$d_{S,R} = \sqrt[\gamma]{\frac{\frac{E_b}{N_0} \times N_0 \times R \times G_t G_r \times \left(\frac{c}{\sqrt{\varepsilon \times f}}\right)^2}{(4\pi)^2 \times P_r \times PL_{S,R}}} \tag{4}$$

Eq. (4) depicts that for the considered invivo communication scenario, distance between implanted biosensor and on body sensor node ($d_{S,R}$) is inversely proportional to the received power and while pathloss is directly proportional to the antenna gain. Efficient communication in the current scenario requires that the signal should cover maximum distance with minimum transmitted power. High transmitted power may have adverse effect on human tissues. For invivo communication there is permissible limit for transmit power. With low transmit power signal will travel short distance and hence received power will also be less. Therefore with this low transmit power there will be a distance at which received power is maximum under the consideration of pathloss. This distance can be termed as threshold distance. Further transmit power can be optimized with threshold distance as a constrain for PSO. By using Eq. (4) and Table 2, for invivo communication at terahertz band threshold distance for various modulation schemes (OOK, MPSK and MFSK) have been calculated in the following section by eigen values.

3. Computation of threshold distance using eigen values for particle swarm optimization (PSO)

It is clear from Eq. (4) that received power and distance between communicating nodes is impacted by the propagation channel. Presence of human tissues with different dielectric properties will affect the performance of the in vivo network. Power transmission is a constrain for in vivo communication. As per MICS the transmitted power cannot have a high value as it will affect the human tissues and may further impact health of the person under monitoring. There is a need to find the optimal transmit power. In this section using eigen values a threshold distance is computed. Further the computed threshold distance will be used as a constrain for PSO in next section to evaluate optimized transmitted power.

A. Threshold distance calculation Algorithm by using eigen values for PSO

From Eq. (5) a matrix of distance d has been obtained to calculate the threshold distance (d^{th}) for the considered scenario. Following algorithm is proposed to calculate dth:

Algorithm: Threshold distance with minimum eigenvalue detection

Step 1. Obtain covariance matrix of distance d with the help of Eq. (4)

Step 2. Compute the eigen values form the matrix obtained by step 1.

Step 3. Get the minimum eigen value (Λ_{min}) of matrix generated by the step 2.

Step 4. Find the ratio of the maximum transmitted power and minimum Eigen value.

Now, Threshold distance (d^{th}) is stated in [22],

$$d^{th} = \frac{\text{maximum transmitted Power (Pmax)}}{\text{Minimum Eigen value } (\lambda_{min})} \tag{5}$$

Here, $P_{max} = 1$ mW [19]

By using Eqs (1),(4),(5) and the parameters in Table 2, threshold distance for OOK, MPSK and MFSK has been computed respectively and given in Table 3

Table 3
Threshold distance for in vivo communication channel at THz Band.

Frequency	Type of Modulation	Threshold Distance (mm)
1 THz	OOK	38.042
1 THz	MPSK	38.4468
1 THz	MFSK	40.1929

For the considered invivo BAN the threshold distance for the OOK, MPSK and MFSK are 38.042 mm, 38.4468 and 40.1929 respectively as given in Table 3. Computed threshold distances are used as a constrain parameter for optimization process in the next section. Further in section IV, particle swarm optimization (PSO) algorithm is used to optimize the transmitted power for invivo transmitted sensor nodes. From the graphs obtained, optimized output is compared with non-optimized results.

4. Optimization of transmitted power

Formulation: Optimize the transmitted power for invivo sensor nodes operating at terahertz band by the objective function described in Eq. (2).

Particle Swarm Optimization (PSO) Algorithm:

Firstly, Kennedy and Eberhart have proposed particle swarm optimization (PSO) [20]. Inspiration for PSO is taken from the social behavior of bird flocking and fish schooling. In PSO the initialization of system is carried out with the population of particles that 'fly' with given velocities over multi-dimensional search space. The velocity and position of individual particles are generated randomly [21]. Velocity of the particle at each generation is associated with the best historical position of the particle and the neighborhood best position. Fitness evaluation function is used for this purpose. The mobility of every particle acquires an optimal or near-optimal solution. Flow diagram for PSO is shown in Fig. 3 and parameters used for optimization is given in Table 4.

To optimize transmitted power for the considered scenario for in vivo communication PSO is used.

5. Results and discussions

For simulation it has been assumed that a biosensor is placed inside the human body for post-surgery monitoring of the patient to sense the change in concerned parameter. The simulation has been carried out for in vivo channel model, pathloss, and received power with respect to distance to critically compare the performance of different modulation schemes for in vivo communication operating at terahertz band. Further transmitted power has been optimized by using PSO for the considered scenario. To create in

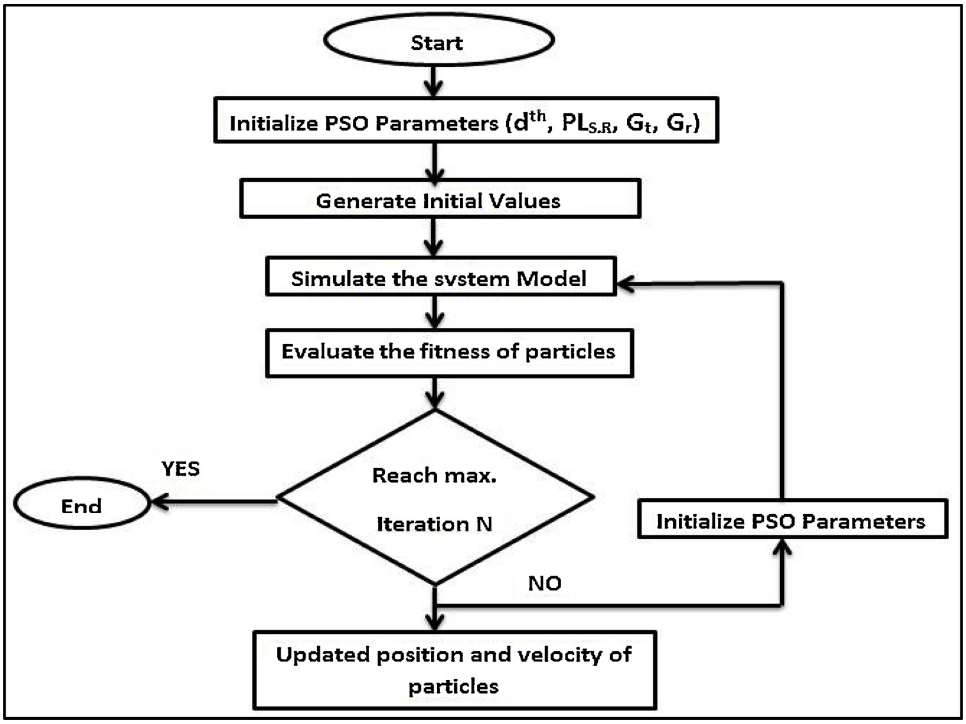


Fig. 3. Flow Chart of particle swarm optimization algorithm.

Table 4
Parameters adopted for PSO.

Parameters	Value
Population size	40
Final weight (wmin)	0.4
Initial weight (wmax)	0.9
Number of iterations (itmax)	100
Acceleration constants(C1, C2)	1.4455, 1.4455
Threshold Distance(d^{th})	38.042, 38.4468, 40.1929

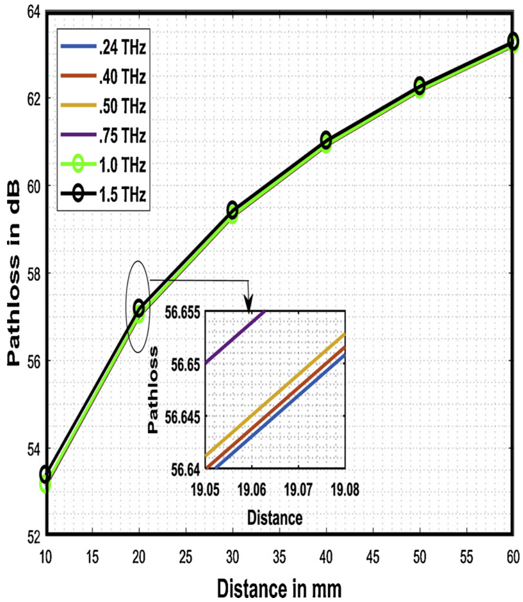


Fig. 4. Pathloss at different Terahertz Frequencies.

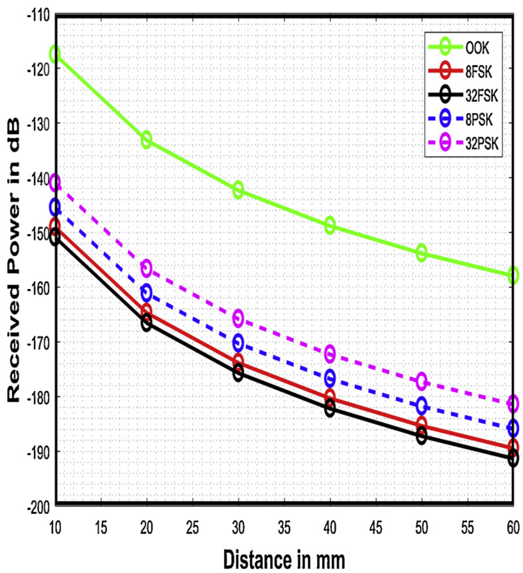


Fig. 5. Comparative Analysis of MFSK,MPSK and OOK in Fat.

vivo scenario permittivity (ε) of blood, skin and fat is taken as 0.5130, 0.2625 and 0.1910 respectively. Terahertz band (0.1–10 THz) is assumed for the operation of sensor nodes, data rate considered for OOK, MPSK and MFSK are 25Gbps and 1Gbps respectively.

Fig. 4 illustrates the effect of distance between the communicating nodes in in vivo on pathloss. Pathloss has been plotted for six

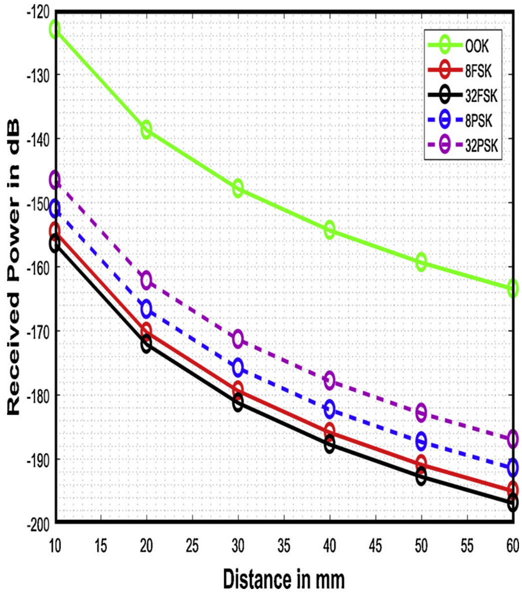


Fig. 6. Comparative Analysis of MFSK,MPSK and OOK in Skin.

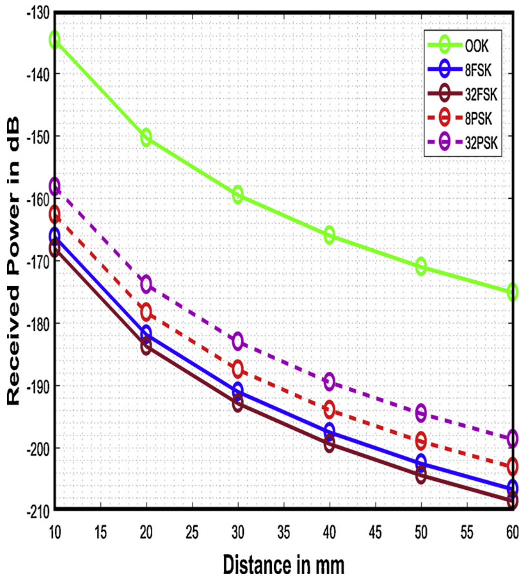


Fig. 7. Comparative Analysis of MFSK, MPSK and OOK in Blood.

different frequencies of operation (0.24 THz, 0.4 THz, 0.5 THz, 0.75 THz, 1.0 THz and 1.5 THz). It is observed from the inset subplot that as the frequency increases pathloss increases. Though the effect is not that much considerable. It may be said that at lower band of terahertz range pathloss will be less.

It is seen from the Figs. 5–7 that received power is maximum for OOK modulation technique in comparison to MPSK and MFSK. It indicates absorption is minimum when OOK modulation scheme is used for the communication channel. Further between MPSK and MFSK, MPSK performs better as received power is slightly higher when MPSK modulation scheme is used. One more interesting observation is that among fat, blood and skin, the signal suffers less attenuation in skin and the high absorption of power is in blood. Hence blood plays the role of main absorber inside the human body. Fig. 8 depicts the critical comparative representation of transmitted power required to establish communication between invivo sensor and on body sensor for the considered scenario. It is observed that by evaluating the threshold distance and further implementing it in PSO the power required for transmission gets reduced by approximately86%

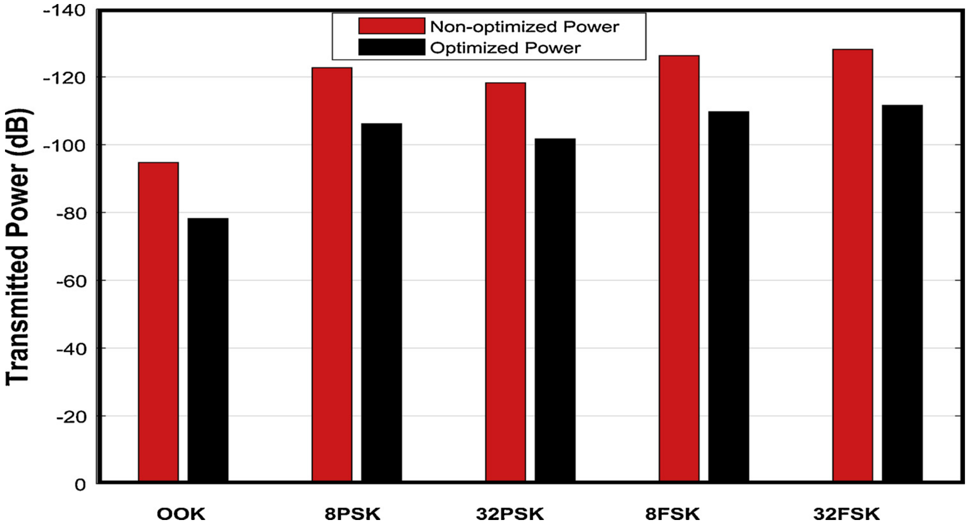


Fig. 8. Optimized transmitted power.

6. Conclusion

In the proposed work an approach to optimize the transmitted power of in vivo sensor node operating at terahertz band is presented. In order to compute received power evaluation critical comparative analysis of various modulation schemes for in vivo communication at terahertz band has been done. It is observed that OOK suffers least absorption in comparison to MPSK and MFSK. It is seen that signal suffers less attenuation in skin in comparison to fat and blood. To optimize transmitted power of implanted sensor node using PSO, threshold distance is computed with the help of eigen values for the considered scenario. It has been shown that using the evaluated threshold distance PSO optimize the transmitted power of implanted sensor node by approximately eighty six percent (86%).

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