Low SAR Path Discovery by Particle Swarm Optimization Algorithm in Wireless Body Area Networks

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Abstract - *Sensor nodes in wireless body area networks are placed on the surface of the human skin or embedded inside the human body. A transmitter sends packets; signals reach the receiver through the human body or skin. However, electric and magnetic field (EMF) radiation generated during packet transmission can lead to a negative influence on human health. The specific absorption rate (SAR) is defined as a measure of the amount of radio frequency energy absorbed by human tissue in units of mass. The higher the human body absorbs the value of the specific absorption rate, the more EMF radiation. Also, the degree of harm to human health is greater. This paper uses the particle swarm optimization algorithm to discover the optimal position of the relay node so that sensor nodes can send packets to the hub via the relay node through a path with the lowest SAR and the success rate of packet transmission thus can be improved the clustered and centered wireless networks in terms of symbol error rate and throughput. The aim of this paper is to find the best position for relay node placement to minimize the influence of SAR on human body during packet transmission.*

***Key Words*: WBAN, SAR, PSO, EMF.**

1.INTRODUCTION

Because of the prevalence of wireless networks and the improvement of micro-sensor technologies in recent years, people have shown great concern for various physiological information and related applications. Thus, it is significant to monitor and retrieve physiological signals at any time. For the retrieval and monitoring of physiological information, the IEEE Standard Group has developed a novel network protocol that is suitable for operation on, in or around the human body: IEEE 802.15.6, also known as Wireless Body Area Networks (WBAN). At present, the closely related WBAN, Wireless Personal Area Network (WPAN), Wireless Sensor Network (WSN) and Mobile Communication all have extensive applications and tremendous market potential. Sensor nodes in WBAN are placed on the surface of the human skin or embedded inside the human body. When a transmitter sends packets, signals reach the receiver through the human body or skin.

However, EMF radiation generated during packet transmission can lead to a negative influence on human health. The amplitude of EMF radiation correlates closely with the operating frequency, power and distance of sensor nodes, and the EMF radiation absorbed by human body can be transformed into heat. Usually, sweating and blood circulation helps to regulate the body temperature. Assume that a great amount of EMF radiation is absorbed by human body in a very short time, the body cannot regulate its temperature immediately and the sudden rise in body temperature may lead to not only skin burns, cardiac arrhythmia and breathing difficulties, but also cell mutation and higher cancer risk. The specific absorption rate (SAR) is defined as a measure of the amount of radio frequency (RF) energy absorbed by human tissue. The higher SAR level means the more EMF radiation the human body absorbs and the higher degree of harm to human health.

In the WBAN studies, most researches have focused on avoiding packet collision [1]–[3], enhancing success rate of transmission [4] and increasing network lifetime [5], [6], but none has paid attention to the impact of SAR on human body during packet transmission. Based on [7], this paper divides the body into several parts and assigns different weight values for each to show the impact of SAR on human body By using the Particle Swarm Optimization (PSO) algorithm, this paper not only discovers the optimal placement of the relay node for sensor nodes to send packets via the relay node to the hub through a path with the lowest SAR, but also attains higher success rate of packet transmission.

The remainder of this paper is structured as follows. Section 2 introduces the background and related work, including WBAN, SAR, and the PSO algorithm. Section 3 describes our proposed method. Section 4 presents the simulation to verify that our proposed method can efficiently reduce the impact of SAR on human body. Section 5 concludes this paper.

2. BACKGROUND AND RELATED WORK

This section introduces Wireless Body Area Network (WBAN), Specific Absorption Rate (SAR) and the Particle Swarm Optimization (PSO) algorithm in order.

2.1 Wireless Body Area Network (WBAN)

Compared with WPAN and WSN, WBAN is a communication standard optimized for short-range, low-power, and highly reliable wireless communication, mainly used in medical applications [8]. In WBAN, wearable sensor nodes are placed on human skin and implant ones are embedded in human body to collect various physiological signals [9]. A hub stores the signals and transmits them through single-hop or two-hop wireless transmission to remote computers via Wi-Fi or 3G for doctors or research organizations to evaluate health conditions of patients and have medical and health related researches [4], [5].

The available frequencies for WBANs vary in different countries and can be generally divided into three frequency bands [10]. Medical Implant Communications Service (MICS) band, defined by the U.S. Federal Communications Commission (FCC) and European Telecommunications Standards Institute (ETSI), uses the frequency band between 402 and 405 MHz for implant communication. Wireless Medical Telemetry Services (WMTS), defined by the U.S. FCC, uses the bands 608-614 MHz, 1395-1400 MHz and 1427-1432MHz, for wireless medical telemetry system. How- ever, neither MICS nor WMTS bandwidths support high data rate applications. Defined by the FCC, Industrial Scientific Medical (ISM) Band in the 2.4GHz range refers to the open frequency bands internationally reserved for industrial, scientific and medical purposes. The ISM bands support high data rates, long distances and low power but there are high chances of interference as many wireless devices including IEEE 802.1 and IEEE802.15.4 operate at ISM band [11].

Three types of network nodes are specified by the IEEE 802.15.6 standard: relayed node, relaying node and hub [12]. Relayed nodes are sensor nodes responsible for collecting various physiological signals. The relaying node (relay node) is responsible for transferring physiological signals collected by relayed nodes to the hub. The hub stores the physiological signals sent by all nodes and sends the data to remote computers or servers.

As defined in the standard, WBAN uses a star topology and provides two types of transmission modes. The first is single-hop transmission the sensor nodes directly communicate with the hub without the relay node. Because WBAN provides a communication range of 0 to 5 meters that can cover the whole body and the distances between nodes are short, single-hop transmission is feasible but affects the body more due to its high transmit power. The other is two-hop communication: the sensor node sends packets to the hub using a relay node. Therefore, the hub needs to com- municate with the sensor node via the relay node. The benefits of two-hop transmission lie in the fact that the sensor node can use lower transmit power and the success rate of packet transmission can be improved because of the relay node.

2.2 *Specific Absorption Rate (SAR)*

Specific Absorption Rate (SAR) [13], as Equation 1 shows, is the rate of absorption of electromagnetic energy (W) per unit mass of tissue in units of watts per kilogram, measured in W/kg.

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) \qquad (1)$$

where

W: power, measured in watts (W)
m: mass, measured in kilograms (Kg) t: time, measured in seconds ($Sec.$)

International SAR measurement standards vary from countries to countries and the SAR limits for the whole body, head/trunk and extremities also differ. Currently, the most generally accepted SAR limit for public exposure from EMF radiation is an SAR level of 1.6 watts per kilogram (1.6 W/kg), specified by the FCC [14]. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) recommends different SAR limits for the whole body and partial body: 2W/kg for head/trunk and 4W/kg for limbs [15].

In most countries, the SAR limits for handheld communication devices ranges between 0.016W/kg and 1.83W/kg. The SAR limit for the ICNIRP standard is 2W/kg. In WBAN, the sensors attached or implanted on the human body can generate heat and electromagnetic radiation, which causes a negative influence on human health. SAR is used to measure the absorption energy of wireless wave unit W/kg over per human body mass unit (1kg). The higher SAR level means the more EMF radiation the human body absorbs and the higher degree of harm to human health. For this reason, by using the PSO algorithm to discover the best placement of the relay node, our proposed scheme enables the sensor nodes to send packets to the hub via the relay node through a path with the lowest SAR.

To this day, many researchers have been involved in SAR-related studies. [19] proposed a swastika slot UWB antenna with the concept of modified ground plane. In this paper, a swastika slot UWB antenna and its radiation characteristics over free space and body-worn (human phantom model) scenarios were simulated for WBAN applications. Also, the authors analyzed the effect of SAR on the human body to adjust the design of UWB antenna.

[20] presented a printed antenna (14mm) with a full ground plane and electromagnetically coupled feed for body area network devices operating in industrial, scientific, and medical (ISM) band at 2.45 GHz and investigated the effect of SAR on human body.

[21]focused on human body communication (HBC) and analyzed the finite difference time domain (FDTD) method with various models of the human body. Various models, including analysis using the Muscle Model, Analysis using

the 2/3-Muscle Model, Analysis using the Layered Human Body Model, etc., were compared.

To reduce the effect of SAR on human health during transmission, [22] presented a MAC protocol that monitors and predicts the channel fluctuations and schedules transmissions opportunistically when the RSS is likely to be higher. The MAC protocol is capable of providing differentiated service and resolves co-channel interference in the event of multiple co-located BANs in vicinity Finally, the authors reported the design and implementation details of BANMAC integrated with the IEEE 802.15.4 protocol stack.

2.3. Particle Swarm Optimization (PSO) Algorithm

1) Theoretical Basis: Proposed by Kennedy and Eberhart in 1995, the Particle Swarm Optimization (PSO) algorithm originated from Kennedy and Eberhart's observations on for- aging behavior of birds and their collective intelligence [16].

While foraging for food, a bird sends and shares information with other companions. Therefore, according to their personal best experiences and the swarm's best experiences, birds keep adjusting their trajectory to find food for each individual as soon as possible. As a result, the swarms of birds fly toward the same direction.

Similar to the Genetic Algorithm (GA), the PSO algorithm is often used on optimization problems. However, the difference between GA and PSO is that each particle in the PSO has its own memory, shares the information with its neighbors and adjusts its behavior according to the swarm's best experiences. Because of the three features, the PSO can achieve convergence rapidly and reach a good solution. The solution found by the PSO may not be the best, but definitely an approximate solution after a number of iterations. At present, the PSO algorithm has been applied to solve Traveling Salesman Problem, industrial load scheduling, routing optimization and complex non-linear optimization problems [23], [24].

2) Initialization in PSO: A PSO begins with generating a large number of initial particles to be distributed randomly across the search space. Also, the PSO is characterized by its ability to handle multiple design variables for finding possible solutions in the space. For the PSO, the typical range for the number of particles is 20-40. Too few particles can lead to particles converging too quickly on the local best while too many particles will slow down the convergence and take more time to find the global best. Each particle has its own location and velocity. Every location in the search space, corresponding to a fitness value, denotes a possible solution to the problem. Velocity represents the speed and direction, based on which a particle changes its location in the next iteration. Below are listed the mathematical expressions:

$V0i$: Initial velocity of particle i $X0i$: Initial location of particle i

3) Fitness Function in PSO: A fitness function is defined as a mathematical expression during the problem solving process. By substituting a particle position into a fitness function, we can obtain a fitness value to determine the merits of a particle. Also, some limitations can be added to speed up the PSO convergence. Below are listed the mathematical expressions:

f : Fitness function

$f(Xik)$: Fitness value of particle i at the kth iteration

4) Search Process in PSO: During the search process, each particle remembers the positions with the better fitness value. Compare the fitness value of the position found by the particle at the k+1th iteration with f(Pik), the fitness value of the local best solution. Supposing the fitness value of the current position is better than that of the local best solution, the position found by the particle and its fitness value will be used to update the fitness value and position of the local best solution. Compare the fitness value of the current position found by the particle at the k+1th iteration with that of the global best solution. Supposing the fitness value of the current position is better than that of the global best solution, the position found by the particle and its fitness value will be used to update the fitness value and the position of the global best solution.

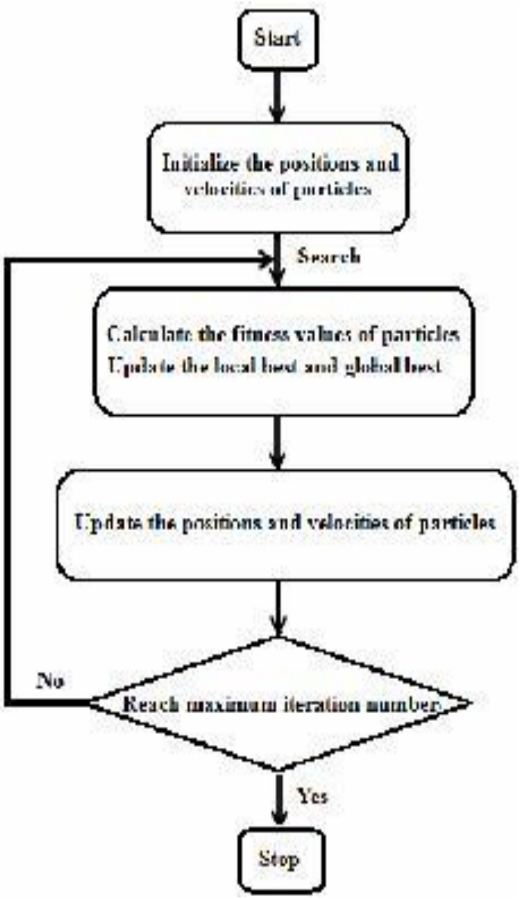

Fig.1. Flowchart of PSO.

Below are listed the mathematical expressions.

$$P_i^{k+1} = \begin{cases} X_i^{k+1}, & f(X_i^{k+1}) \le f(P_i^k) \\ P_i^k, & f(X_i^{k+1}) > f(P_i^k) \end{cases} \quad (2)$$

$$P_g^{k+1} = \begin{cases} P_i^{k+1}, & f(P_i^{k+1}) \le f(P_g^k) \\ P_g^k, & f(P_i^{k+1}) > f(P_g^k) \end{cases} \quad (3)$$

Where
P_{ki} : Local best position of particle i at the *k*th iteration
P_{kg} : Global best positions of all particles at the *k*th iteration

5) Velocity and Position Updates in PSO: In the original PSO, each particle adjusts its own velocity and position according to its current velocity, the positions of the local best and global best solutions. The velocity that is randomly generated toward the local best and the global best positions can determine the velocity of the particle in the next iteration, as shown in the following equations:

$$V_i^{k+1} = V_i^k + c_1r_1(P_i^k - X_i^k) + c_2r_2(P_g^k - X_i^k) \quad (4)$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (5)$$

where

Kth:	the *k*th iteration
V_k :	Velocity of paricle i at the *k*th iteration
X_{ik} :	Location of particle i at the *k*th iteration
P_k :	Personal best position of particle i at *k*th Iteration
P_{gk} :	Global best positions of all particles at the *k*th iteration

c_1, c_2: Coefficients of acceleration in [0, 4]

r_1, r_2: Random numbers in [0, 1]

Equation 4 can be explained from three aspects. Supposing $V_{ki}^{+1} = V_{ki}$, the particle insists on itself and remains its velocity and direction based on the previous iteration. Supposing $V_{ki}^{+1} = V_{ki} + c_1r_1(P_{ik} - X_{ik})$, the particle moves towards its best previous position according to its personal best experience.

Supposing $V_{ki}^{+1} = V_{ki} + c_1r_1(P_{ik} - X_{ik}) + c_2r_2(P_{gk} - X_{ik})$, the particle uses the collective experiences of the swarm: moving toward its best previous position and even toward the best the swarm has met. In Equation 4, c_1 and c_2 are coefficients of acceleration in [0, 4], which control the influence of local best and global best solutions during the search process. Values of c_1 and c_2 could affect how many times the particles search and whether the local best could be avoided. A small acceleration coefficient increases the probability of finding the global best but the computation time increases also due to more iterations. By contrast, a large acceleration coefficient speeds up the convergence and shortens the computation time, which causes the PSO easily trapped into a local best. To get better solutions, [15] sets c_1 and c_2 as the fixed value 2.0. In this paper, we use the fixed value of c_1 and c_2 with 2.0 as well.

Presented by Eberhart et al. in 1998, Constant Inertia Weight [17] is a concept that each particle moves according to its own velocity weight. With the addition of the inertia weight w, velocity and position updates proposed by Kennedy and Eberhart can be modified as:

$$V_{ki}^{+1} = wV_{ki} + c_1r_1(P_{ik} - X_{ik}) + c_2r_2(P_{gk} - X_{ik}) \quad (6)$$

The inertia weight determines the influence of the current particle velocity on the next velocity. When the inertia weight is small, the particle velocity at the $k + 1$th iteration is determined based on the local best and global best. Because a smaller inertia weight facilitates only the local search capability, the PSO is trapped into a local best easily. When the inertia weight is large, the particle velocity at the $k + 1$thiteration tends towards its previous velocity and thus tends to facilitate global search. However, the large exploration through the search space will lead to a slow convergence speed to the global best.

6) Flowchart of PSO (Figure 1):

Step1: Initialize particles with random positions X_{i0} and velocities V_{i0} in a d-dimensional search space.
Step2: Calculate $f(X_{i0})$, the fitness value of each particle, by fitness function and find out P_{i0}, the local best, and P_{g0}, the global best.
Step3: Search.
Step4: Update P_{ik} and P_{gk} .
Step5: Update the new position and velocity of each parti- cle.
Step6: Determine whether the maximum iteration number has been reached or the stopped criteria have been met. If not, go back to Step 3.

3. RELAY NODE PLACEMENT BY THE PSO ALGORITHM

In WBAN, one-hop packet success rate is generally low [18]. Figure 2 displays the experiment scenario of [18], which includes four sensor nodes around the body and one hub around the waist. Figure 2 shows the one-hop packet success rate of the experiment scenario. Figure 6 reveals that in one-hop transmission mode, the packet success rate of Node 1, Node 2 and Node 3 cannot reach 20%, which is unreliable for physiological information monitoring. To increase the packet success rate, [18] chose to place the relay node on the trunk based on the PRNs (Phase Relay Nodes) algorithm. Low-power EMF radiation is easily blocked by human body. The authors therefore utilized the minimum coverage algorithm for relay node placement to prevent the packet loss and improve the packet success rate over human body. However, [7] mentioned that compared with other body parts, the trunk is the most affected region because the major organs are housed within the trunk. Therefore, to place the relay node on the trunk could be harmful to human health. In order to reduce the negative impact of packet transmission on human body, this paper bases itself on the weight values of SAR [7] and uses the PSO algorithm to find the optimal placement of the relay node. Thus, sensor nodes can send packets via the relay node to the hub through a path with the lowest SAR while the transmission success rate can be simultaneously improved.

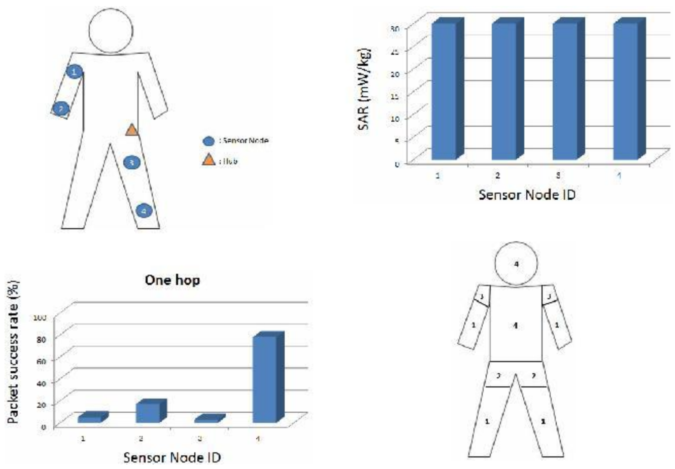

Fig.2. Packet success rate.

In the following, this paper aims at discovering the best position of the relay node. For problem solving, Genetic Algorithms (GA) is one of the algorithms often used to solve optimization problems. In the selection process, two parent chromosomes with the better fitness values are selected,crossed-over and mutated to produce better offspring. GA works iteratively and evenly moves towards the best solution. In the PSO, every particle has its own memory, shares the information with its neighbors and adjust its behavior according to the swarm's best experiences. Because of the three features, particles move rapidly in order to find the global best solution during the initial stage of a search. In the final stages, particles will slow down to reach the region close to the global best. Compared with GA, the PSO can achieve convergence rapidly to reach the best solution. Therefore, we use the PSO in this paper to find the best position of the relay node.

3.1. SAR Weighting

According to the whole-body averaged SAR values given in [7], this paper divides the body into several parts and assigns different weight values to each, as displayed in Figure 8. Each weight value means the degree of damage to the human body and the higher value means the more harm to EMF radiation brings to the human body. Therefore, the placement of sensor nodes on that part should be avoided.

3.2. Finding Solution by PSO

This section describes how to use the PSO algorithm to find the best position of the relay node. The d-dimensional search

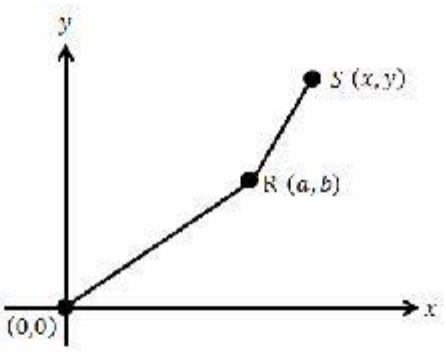

Fig. 3. Nodes in the plane cartesian coordinate system.

space is usually regarded as a plane Cartesian coordinate system and the target is R=(x,y), as shown in Figure 3. However, by converting from a plane Cartesian coordinate system (x,y) to a polar coordinate (r, θ), R point can be denoted as R=($r\cos\theta$,$r\sin\theta$), specifying the position of a particle by its directional velocity. Therefore, in this paper, each particle represents a point in the polar coordinate system, i.e. the possible best position of the relay node. The best placement of the relay node enables the sensor nodes to send packets to the hub via the relay node through a path with the lowest SAR. After a number of iterations, all particles converge to a point, i.e. the optimal position of the relay node on human body. Since number of particles and iterations affect the convergence time and solution quality, the solution found by the PSO may not be the best, but definitely an approximate to the best.

1) Particle Encoding: To employ the PSO algorithm for problem solving, particles must be encoded first. In this paper, each particle is a point in the polar coordinate system and 20 particles means 20 different points running in the polar coordinate system. After many iterations of the PSO algorithm, the 20 points move toward one point, which will be the optimal position of the relay node in this paper. The particle is defined as:

$$X_i^k = a_i^k, b_i^k \quad ,\forall i = 1,...,n \qquad (7)$$

$$a_i^k = r_i^k \cos\theta_i^k, \quad b_i^k = r_i^k \sin\theta_i^k, \quad \forall r_i^k \in [1, m], \forall \theta_i^k \in [0, 2\pi] \qquad (8)$$

2) Fitness Function: The purpose of this paper is to find the optimal position of the relay node for sensor nodes to send packets via the relay node to the hub through a path with the lowest SAR. In the scenario of one sensor node, to multiply the minimum transmission power of the node by the SAR weight value of the area where the node is located, we can find the path with the lowest SAR. By using Equation 11 the signal attenuation equation, the minimum transmission power can be obtained.

$$10 \log_{10} P + 95dB - 25dB = 32.45 + 20 \log_{10} D + 20 \log_{10} F \quad (11)$$

$$D = (x_i - x_j)^2 + (y_i - y_j)^2 \quad (12)$$

where

P: power, in mW
D: distance between two nodes, in kilometers (Km)
F: frequency band for sensor nodes, in MHz
95dB: receive sensitivity of sensor nodes
25dB: signal attenuation caused by air

From Equation 12, we get the minimum transmission power of sensor node s to the relay node, P_s, and the minimum transmission power of the relay node to the hub, P_R, as given in Equation 13 and 14, respectively:

$$P_s = 10^{\frac{32.45 + 20\log_{10} 2400 \sqrt{(x_s - r_{ik}\cos\theta_{ik})^2 + (y_s - r_{ik}\sin\theta_{ik})^2}}{10}} \quad (13)$$

$$P_R = 10^{\frac{32.45 + 20\log_{10} 2400 \sqrt{(r_{ik}\cos\theta_{ik} - 0)^2 + (r_{ik}\sin\theta_{ik} - 0)^2}}{10}} \quad (14)$$

Assume the coordinates of the hub in the polar coordinate system is the origin (0, 0), as displayed in Figure 9. Supposing the coordinates of sensor node s is (x, y), we attempt to find the optimal coordinates of the relay node (a, b), so that packets can be transmitted from (x, y) to (a, b), and forwarded from (a, b) to $(0, 0)$ via a path with the lowest SAR.

Therefore, f, the fitness function of the problem, can be given by Equation 15:

$$f = P_s \times w_s + P_R \times w_R \quad (15)$$

Where

X_{ik} means the coordinates of particle i in the polar coordi nate system at the kth iteration. a_{ik}, b_{ik} refers to the solution in the space, denoted by the coordinates combined by the distance and rotation angle between the hub and the relay node after the kth iteration. r by which the new velocity and direction of the particle is altered and the particle position in the next iteration is changed. r_k is the distance to the hub after the kth iteration

equations can be given by Equations 17 and 18:

$$r_{ik+1} = w r_{ki} + c_1 rand_1 (P_{rki} - r_{ik}) + c_2 rand_2 (P_{rkg} - r_{ik}) \quad (17)$$

$$\theta_{ik+1} = w\theta_{ki} + c_1 rand_1 (P\theta_{ki} - \theta_{ik}) + c_2 rand_2 (P\theta_{kg} - \theta_{ik}) \quad (18)$$

After obtaining r_{ik+1} and θ_{ik+1} from the two equations above, we can find X_{ik+1}, the position of particle i at the k+1th iteration, as shown in Equation 19:

$$X_{ik+1} = (a_{ik+1}, b_{ki+1}) = (r_{ik+1}\cos\theta_{ik+1}, r_{ik+1}\sin\theta_{ik+1}) \quad (19)$$

4 . SIMULATION SCENARIOS AND RESULT ANALYSIS

In this section, we simulate our proposed scheme by PSO for further analysis and use [18] as the control group. Section 4.1 describes the simulation scenarios. Section 4.2 not only investigates the relations between relay node placement and SAR for sensor nodes in two-hop transmission, but also compares the packet success rate of each sensor node after the inclusion of the relay node.

4.1. Simulation Scenario and Parameter Settings

Three simulation scenarios are: (a) both arms stretched down, (b) both arms stretched out to sides, and (c) both arms raised up. In each scenario, there are four sensor nodes around the body and one hub around the waist. The frequency band for sensor nodes is 2.4 GHz

Considerations have been especially made in choosing the number of particles. Many particles can share information with one another and reach a better solution even in less number of iterations. Few particles can converge quickly but the quality solution may not be good enough. The aim of this paper is to find the best position for relay node placement to minimize the influence of SAR on human body during packet transmission. The quality of the solution is important in this paper. Therefore, in order to reach a fast convergence and a good solution, we set the number of particles to 30.

4.2. Result Analysis

In Scenario (a), we use PSO for relay node placement and the chosen position of the relay node leads to the lower SAR level, approximately 3 to 6 times decline, compared with the PRNS algorithm in [18]. In Scenario (b), the SAR level increases a little bit because both arms are stretched out to sides, which increases the distances between nodes and the relay node and thus requires more power to transmit packets. Nevertheless, this is still a low-SAR network compared with [18]. In Scenario (c) in which both arms are raised up, the SAR level of Node 2 is obviously higher than Node 1 because Node 2 is farer from the relay node than Node 1 and therefore more power is required.

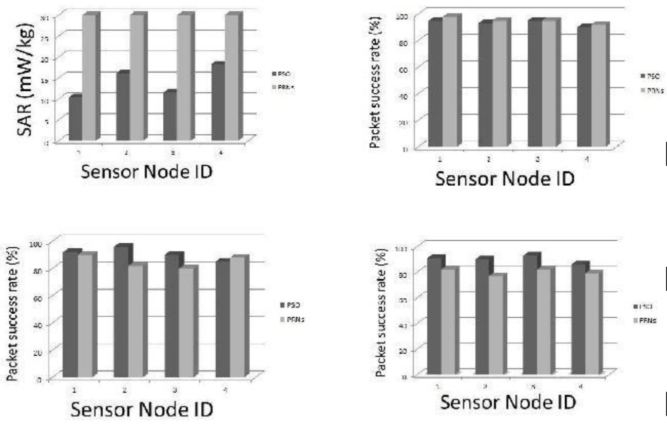

Fig.4. Packet Success rate in scenario (c)

Fig.5. Packet Success rate in scenario (a)

Next, we add the relay node to improve the packet success rate and reach 90 to 95% success rate in each scenario. Compared with the PRNs that aims at packet success rate enhancement, our proposed scheme not only decreases the negative impact of EMF but also improve the reliability.

5. CONCLUSIONS

This paper proposes to us PSO for relay node placement to reduce the influence of EMF radiation on human body during packet transmission. Because EMF radiation is directly proportional to the power of sensor nodes, we adjust the distance between sensor nodes and the relay node so that sensor nodes can complete transmissions within the distance in low transmission power. This scheme not only reduces the negative influence of EMF radiation on human body, but also increases the lifetime of nodes. Also, we propose to place the relay node on the right side between wrist and arm. The simulation results prove that the SAR level is significantly lowered and the packet success rate is obviously improved.

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