SAR Computation and Channel Modeling of Body Area Networks

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Abstract

Body Area Network (BANs) is of importance for telemedicine and telehealth services. Since the wireless sensor nodes adhere to the human body surface, the human body unavoidably absorbs the electromagnetic wave which may be harmful, so investigating the specific absorption rate becomes significant in exploration of BANs. Additionally, the BAN channel is different with the common wireless channel. In this paper, we propose a method to compute SAR values in different frequency bands and provide theoretical analysis for the BAN channel. A path loss model is constructed to represent the wireless channel.

Categories and Subject Descriptors

J.3 [**Computer Applications**]: Life and Medical Sciences – *Health, Medical Information Systems*.

General Terms

Performance, Design

Keywords

Body area network; SAR; Channel model; Path loss

1. INTRODUCTION

With the fast increasing needs of ubiquitous networks and the prevalence of chronic diseases such as hypertension and diabetes, applications of wireless networks around humans cause wide interests. In order to achieve the purpose of medical care in time, the sensors used to collect body parameters need to be placed in many parts of the body and form a wireless network, that is, body area network (BAN) which consists of a number of removable sensors. The data transmissions between these nodes are usually limited in a short range of 2m [1][2].

Applications of BANs must satisfy biosecurity since they may cause the electromagnetic biological effect Specific absorption rate (SAR) is a general indicator to assess the biosecurity when human tissues are exposed in the electromagneticenvironment, so how to precisely calculate SAR value becomes a key problem. Authors in [3] design a human head model and obtain its SAR in different frequencies between 0.5 GHz and 5.5GHz. They conclude that the radiation efficiency is decreasing with the frequency becoming higher. The paper [4] develops a SAR test methodology to provide safety assessment using two antennas in the 900 – 6000MHz frequency band. Three subbands have been devised to minimize uncertainty from the measurements caused by the deviation of the permittivity and conductivity. A scientifically sound method of evaluating human exposure in the reactive near field of a wireless power transfer system is presented in [5] which employs strongly-coupled self- resonant coils. The exposure relies on an anatomical model with variations exceeding 3 dB for the configurations studied. Findlay et al. [6] investigate human exposure to the electromagnetic fields at 2.4 GHz and 5 GHz using a voxel model of a child in schools produced by wireless local area networks. These models or methods mentioned above have disadvantages that the material used for computation is simple and not enough to precisely simulate human tissues.

The study of channel characteristics is a crucial step of building network structure and plays an indispensable role to design the upper network protocol. The complexity of human tissue and body shape, and the diversity of the working environment increase the difficulty of BAN channel modeling. Reusens et al. [7] explore a channel propagation model of human tissues under the multipath condition in 2.45GHz, and calculate the path loss value by using an auto-correction model to retrieve the time domain characteristic. Gupta et al. [8] employ the green function on a cylindrical body model and propose a simple electromagnetic propagation channel model. An analytical expression is presented to compute the signal strength accepted by the human body around. Takizawa et al. [9] consider both the path loss model and power delay model, and obtain the channel model parameter from channel transfer function under the hospital environment. The authors in [10] design a propagation model in the frequency of 915MHz and 2.45GHz, and evaluate the BER in the Rice channel according to the distance of the transmitter and receiver.

In this paper, we design a model to simulate a real human tissue in order to obtain precise SAR in 900MHz and 2.4GHz which can be both used in BANs. Also, a path loss value is calculated based on the model to investigate the BAN wireless channel that is very helpful to decide BAN standard and protocols in the future.

2. THE DESIGNED SAR MODEL

SAR testing is commonly used to provide data on how

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much electromagnetic energy is being absorbed by the human body and helpful to determine the upper value accepted by the body.

Definition 1: Specific absorption rate is the electromagnetic radiation energy absorbed by an organism per unit time and unit mass. The measured unit is W/kg.

SAR can be calculated as the following equation:

$$SAR = \frac{\sigma}{\rho} E^2 \tag{1}$$

Here E represents the electric field intensity. Now we use the following equations which are the electric field differential equation and magnetic field differential equation in the time of $t = (n + 1/2)\Delta$ and grid coordinates of (i+1/2, j, k) to establish the human grid model for calculating the SAR values.

$$E_x^{n+1}(i+\frac{1}{2}, j, k) = \frac{\varepsilon(m) - 0.5\sigma(m)\Delta t}{\varepsilon(m) + 0.5\sigma(m)\Delta t} \times E_x^{n}(i+\frac{1}{2}, j, k)$$

$$+\frac{\Delta t}{\varepsilon(m) + 0.5\sigma(m)\Delta t} \times \left\{ \frac{H_Z^{n+1/2}(i+\frac{1}{2}, j+\frac{1}{2}, k) - H_Z^{n+1/2}(i+\frac{1}{2}, j-\frac{1}{2}, k)}{\Delta y} \right.$$

$$\left. - \frac{H_y^{n+1/2}(i+\frac{1}{2}, j, k+\frac{1}{2}) - H_z^{n+1/2}(i+\frac{1}{2}, j, k+\frac{1}{2})}{\Delta z} \right\}$$

$$H_x^{n+1/2}(i, j+\frac{1}{2}, k+\frac{1}{2}) = \frac{\mu(m) - 0.5\sigma(m)\Delta t}{\mu(m) + 0.5\sigma(m)\Delta t} \times H_x^{n-1/2}(i, j+\frac{1}{2}, k+\frac{1}{2})$$

$$+\frac{\Delta t}{\mu(m) + 0.5\sigma(m)\Delta t} \times \left\{ \frac{E_y^{n}(i, j+\frac{1}{2}, k+1) - E_y^{n}(i, j, k+\frac{1}{2})}{\Delta z} \right.$$

$$\left. - \frac{E_z^{n}(i, j+1, k+\frac{1}{2}) - E_z^{n}(i, j, k+\frac{1}{2})}{\Delta y} \right\}$$

Here E and H represent the electrical field strength and magnetic field intensity respectively. Expanding above equations according to the sphericalcoordinate, Eqn. (1) is obtained:

$$SAR(i,j,k) = \left(1/_{2\rho}\right) \left[\sigma_x(i,j,k) \cdot E_x^2(i,j,k) + \sigma_y(i,j,k) \cdot E_y^2(i,j,k) + \sigma_z(i,j,k) \cdot E_z^2(i,j,k)\right] \tag{2}$$

σ_x, σ_y and σ_z represent the electric conductivity along the direction of X, Y and Z; $\rho(i, j, k)$is the density of human tissues. Because all sorts of human body tissue density are close to water, we set ρ= 1000kg/m^3. The conductivity σ and relative dielectric constant ε_r of human tissues are shown in Table 1 [11].

Table 1. The values of σ and ε_r in different tissues

Human tissue	Thickness (mm)	σ (S/m)	ε_r
Skin	2	1.44	38.06
Fat	5	0.26	10.84
Muscle	10	1.77	53.64
Intestines	10	1.92	47.7

2.1 SAR Calculation for the Model

Based on the data in Table 1, we design a model to approximate human tissues consisted of four layers shown in Figure. 1. The model has the length of 225mm, 115mm width and 27mm height respectively. The bottom layer is skin with thickness of 2mm, and the gray layer represents 5mm thick fat, while the brown layer is 10mm thick muscle and the last layer represents intestine with thickness of 10mm. A dipole antenna sticks to the skin layer with the distance of 4.2mm. Its length is set to 1/2λ (λ is the frequency wavelength).

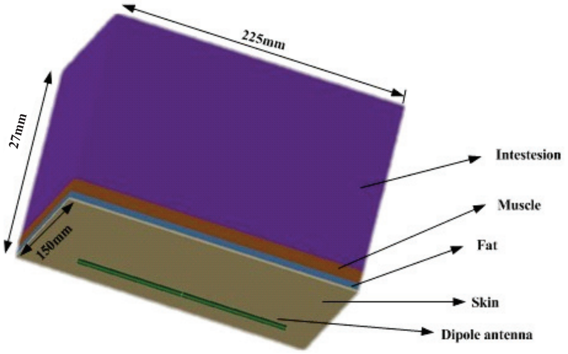


Figure 1.A model of approximating human tissues

We adopt the finite different time domain method to perform numeric calculation of electromagnetic fields because this method adapts to simulate the complex structure such as human tissues and can almost solve all the problem of interaction between electromagnetic field and 3D objects. The required execution time and memory are only proportional to the grid number, so the method is greatly superior to other electromagnetic field numerical calculation methods.

Figure 2 describes the simulation results based on the above model in different frequencies as 900MHz, 24.GHz and 5GHz respectively in a) and b) and c). The power concentrates the tissue around 24mm on the condition of 900MHz while 9mm for 2.4GHz and 5mm for 5GHz. Table 2 lists the maximum SAR value (10-g and 1-g) in the three frequencies with the unit of w/kg.

Table 2. The maximum SAR values in different frequencies

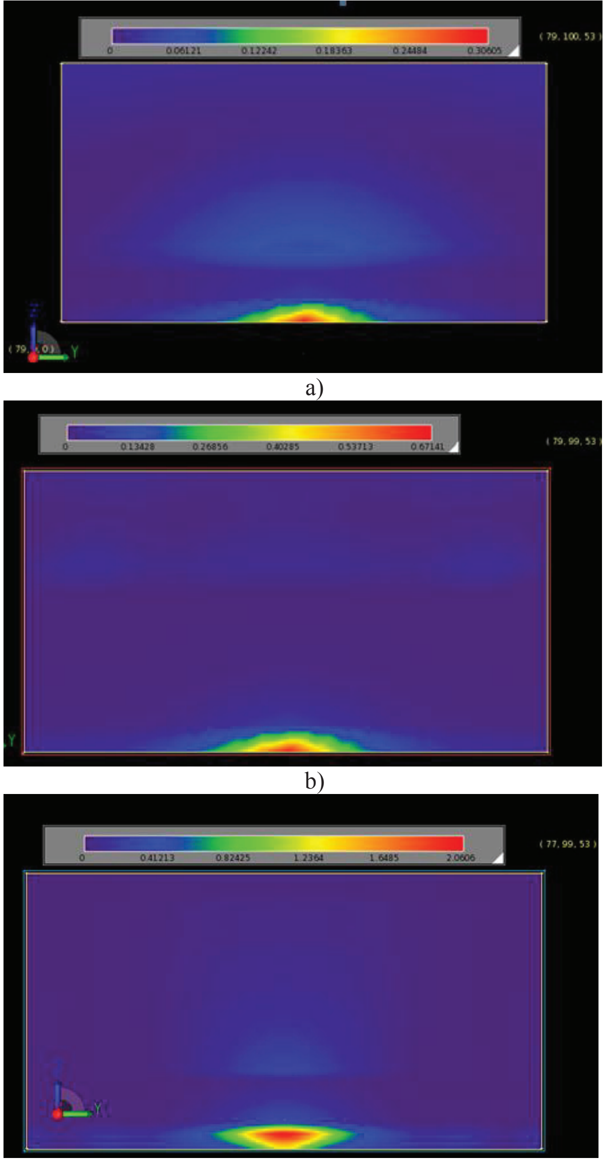
F (GHz)	Max SAR	Max SAR (10-g Average)	Max SAR (1-g Average)
0.9	0.306	0.02779	0.05937
2.45	0.6714	0.02053	0.0642
5	2.061	0.1144	0.3766

2.2 Plane wave irradiation of the human body SAR contribution

Body SAR values can be obtained under the plane wave illumination. Table 3 shows the conductivity and relative dielectric constants of the normal human organs and tissues. According to Table 3, we establish high-precision electromagnetic model of the human body.

The plane wave in 2.45GHz frequency is used to irradiate the human body model, which can calculate the SAR value in the free space under the condition of 1g and

10g respectively.



a)

b)

c)

Figure 2. SAR results in 900MHz, 2.4GHz and 5GHz

In Figure 3, we set the far field radiation source as a uniform plane wave at 2.45GHz. The three calculation results in Figure 3 from the left to the right map the plane wave irradiation coming from the different directions (the back side, front side and sideway). The mesh size of the human model is 5mmwhilethe total number of spatial grid 108×88×260 under the condition of *E*-polarization and the *Z*-axis direction for the electric field strength.

3. BAN CHANNEL MODEL

The study of channel characteristics is a crucial step of building network structure and plays an indispensable role to design the upper network protocol. Three frequency bands can be used in BAN including 900MHz, 2.4GHz and UWB band. In this section we investigate the path loss values based on the given model in Figure 4 under different frequencies.

Table 3. The conductivity and relative dielectric constants of different organ

Human tissues	σ（S/m）	ε_r	Density (kg/m^3)
skin	1.319	38.67	1145
Fat, Yellow marrow	0.08082	4.39	963
Reticular bone	0.6121	16.43	1074
Blood	2.71528	52.26	1070
Muscle, Myocardium, Spleen, Colon	2.35716	56.75	1046
Cerebrospinal fluid	2.03481	51.43	1012

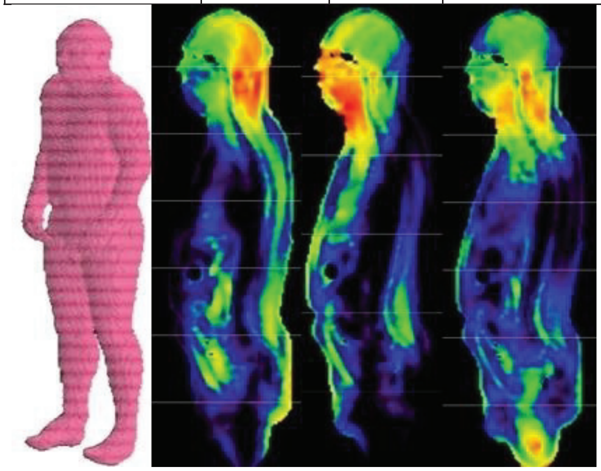


Figure 3. *E*-field distribution of the human model in 2.4GHz

3.1 Path loss model

Two dipole antennas are placed in the skin layer to play the transmitting antenna and receiving antenna. The parameter *d* represents the distance of the two antennas from 70mm to 300mm. *L* is the antenna length which equals to 1/2λ. *T*=3.6mm represents the antenna diameter. The distance of the antennas to the skin layer is 3.6mm. Figure 4 describes the established path loss model.

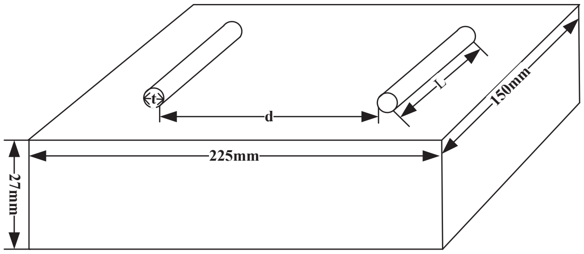


Figure 4. The simulation model for path loss calculation

Path loss at a distance *d* from the transmitting antenna can be defined as:

$$PL(d) = G_R P_T / P_R(d) \qquad (3)$$

where G_R is the receiver antenna gain, P_T is the transmitting power, P_R denotes the received power. Therefore, as defined in above, the path loss would include the transmitter antenna gain, which is usually not the case for channel models in most wireless systems, but for BAN, the transmitting antenna is considered to be part of the channel. The path loss (dB) at some distance d can be statistically modeled by the following equation:

$$PL(d) = PL(d_0) + 10n\log_{10}(d / d_0) + S \qquad (4)$$

where d_0 is the reference distance (i.e. 50 mm) and $PL(d_0)$ is the path loss at d_0. N is the path loss exponent which heavily depends on the environment where the RF signal propagates through. For example, it is well known that for free space, n=2. Human body is an extremely lossy environment and much higher value for the path loss exponent is expected. n is around 4.22 near the human tissue. S represents deviation in dB caused by different materials (for instance bone, muscle, etc.) and the antenna gain in different directions. The value of S can be approximated to nd.

S_{21} is introduced to express the power ratio between the receiver and transmitter defined by the following equation:

$$\frac{P_{rec}}{P_{trans}}(d) = PL(d_0) + 10n\log d / d_0 = |S_{21}|_{dB} \qquad (5)$$

Therefore, the value of $PL(d)$ can be computed by the following equation:

$$PL(d) = S_{21} + nd \qquad (6)$$

Based on Eqn. (4), we can obtain the path loss value in different distance under the three frequencies by calculating S_{21} shown in Table 5. Seen from the above Table 4, the path loss value augments with increase of distance and radio frequency, which denotes that the receiver requires higher sensitivity to detect the signal from its antenna so leading to higher complexity according to the distance and frequency. Therefore, investigating the hardware structure will become a significant job in the coming time.

Table 4. The path loss values in different distance under the condition of 900MHz, 2.4GHz and 5GHz

d *mm*	0.9GHz		2.4GHz		5GHz	
	S_{21}	PL	S_{21}	PL	S_{21}	PL
76	19.73	20.05	45.52	45.84	42.78	43.10
102	21.61	22.04	46.25	46.68	45.12	45.55
127	22.97	23.51	46.77	47.31	46.84	47.38
152	24.08	24.72	47.18	47.93	48.24	48.88
178	25.04	25.79	47.53	48.28	49.45	50.20
203	25.81	26.67	47.79	48.65	50.43	51.29

4. CONCLUSION

BAN is a new technique to be applied in smart health which can ceaselessly monitor vital parameters and delivery the data to remote servers by smart terminals. In order to explore applications of BANs, a necessary step is to investigate SAR values in BAN frequency bands. Also, the characteristics of the short range wireless channel determine the structure of the physical layer so causing wide attention. In this paper, we design a human tissue model to calculate SAR values, and compute the path loss values for three frequency bands based on the model.

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