Power Efficient Relay Networking for BANs in Non-Homogeneous Enviroment

Dan Liu†‡, *Member, IEEE,* Mingda Zhou‡, *Student Member, IEEE,*
Yishuang Geng‡, *Student Member, IEEE,* and Kaveh Pahlavan‡, *Fellow, IEEE*

†College of Information Engineering, Dalian Ocean University, DaLian, LiaoNing 116023 China
‡Center for Wireless Information Network Studies, Worcester Polytechnic Institute, Worcester, MA 01609 USA

***Abstract*—Body Area Networks (BANs) has great potential to provide real-time health monitoring of a patient and diagnose many life threatening diseases. The wireless capsule endoscopy (WCE) is one of the promising wireless Body Area Networks (WBANs) applications that provides a noninvasive way to inspect the entire Gastrointestinal (GI) tract. The low operating power of the capsule is the most critical factor to ensure the performance of WCE. In this paper, we investigate the power efficient relay networking in non-homogeneous environment to reduce the transmitting power consumption of WCE which passes through two major digestive organs, small intestine and large intestine, in the human body. According to the deployment of relay sensors, we provide analysis of the maximum and minimum consumed power for the capsule with different relay sensor number and different angle. Simulation results show that when the number of relay sensors on body surface extends to specific numbers (23 for large intestine, 14 for small intestine), the deployment of relay networking has almost no inuence of the power consumption for the capsule. When the number of relay nodes is under some specific number, the angle and number has huge effect on the power consumption. At the same time, we verify the optimal selection and deployment of on-body sensors to minimize the WCE power consumption.**

Keywords*—*Body area networks; Power efficient; Relay networking; Non-homogeneous.

I. INTRODUCTION

With the increasing number of senior citizens all over the world, many countries have to face problems of health monitoring for aging population. Body Area Networks (BANs) have great potential to provide real-time health monitoring of a patient and diagnose many life threatening diseases [1][2]. BANs is a special designed sensor network to connect various medical sensors for health, which emerges as the natural byproduct of existing sensor network technology and biomedical engineering. BANs consists of a number of portable, miniaturized, and autonomously interconnected sensor nodes which are located either inside and outside of a human body. The nodes monitor the body function for sporting, health and emergency applications. Patients equipped with a wireless body area network need not to be physically present at the physician for their diagnostic [3][4].

The wireless capsule endoscopy (WCE) is one part of BANs that provides a noninvasive way to inspect the entire Gastrointestinal (GI) tract. As a critical component of capsule endoscopic examination, physicians need to know the precise position of the endoscopic capsule in order to identify the position of detected intestinal diseases. Some researches for WCE are about computer vision based speed estimation technique to facilitate the localization of WCE inside small intestine [5] and the approach estimating the orientation and displacement of the track of WCE in large intestine [6]. RF waveform transmission based approaches has been also proposed by Yishuang et al., [7] to provide analysis on the effect of human body regarding wireless propagation channel for BANs.

Expect for the above mentioned applications, power consumption of the WCE is another core research topic. As the capsule moves through the intestines, it takes pictures, which are transmitted to a small data recorder that the patient wears on his/her belt. Meanwhile, the capsule will pass anywhere from one to three days after its ingestion, and the capsule is disposable. It is most likely for WCE to consume its total power while it is passing some part of some organ. This may results in a failure of endoscopic examination. And it is not convenient for the patients to swallow the capsule frequently. Hence, the low operating power of the capsule is one of the most important parameters. Presently, much of the ongoing research is focused on the development of the transmitter hardware design for reducing the capsule's power consumption. An IR-UWB wireless telemetry system for medical sensor applications was presented in paper [8]. In [9], the authors presented a high-speed, 450-MHz, transmitter system for WCE applications.

In a relay networking for BANs, as the capsule keeps transmitting signal to the relay sensors on the surface of human body, the deployment of relay nodes is very critical to power consumption for WCE [10]. Currently existing WCE treatments place a single relay sensors on a belt. However, we would like to start our discussion with the question, Is it the best way for relay sensor selection and deployment to minimize WCE power consumption? In this paper, we investigate the maximum and minimum consumed power for the capsule with different relay sensor number and different angle. From the relay networking respect, the transmitting power consumption of WCE is analyzed for BANs in non-homogenous environment.

This paper is organized as follows. We begin in Section II by introducing the system model, which includes WBANs performance evaluation scenario and the implant to body

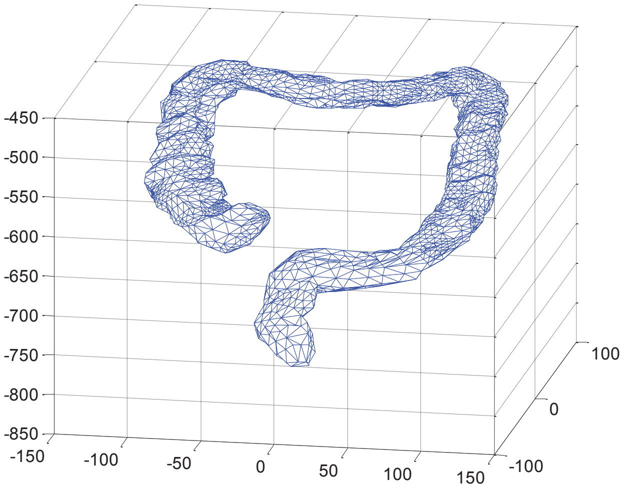


Fig. 1. 3D mesh model of large intestine inside human body.

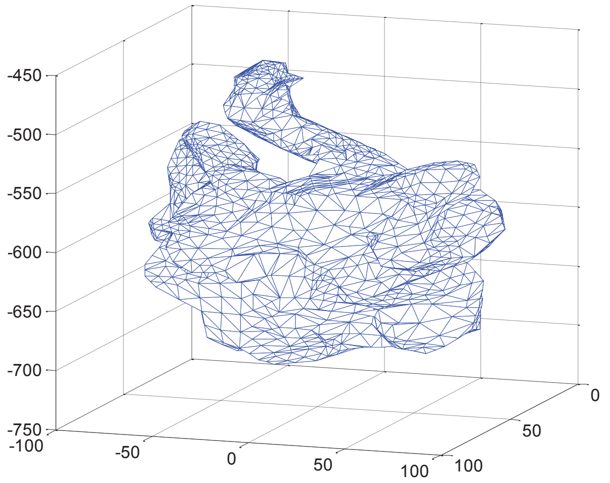


Fig. 2. 3D mesh model of small intestine inside human body.

surface path loss model. After that, we make our problem statement in section III. In section IV, we provide simulation results which highlight the optimal relay node number and node placement that affect the power consumption of WCE. Finally, we conclude the paper in section V.

II. SYSTEM MODEL

In this section, we focus on the setup of software simulation system. First and foremost, we introduce our 3D human body model from full-wave electromagnetic field simulation system, which serves as the geometric bases of the following discussions. After that, we explain the selected in-body RF propagation model, which is the direct constraint of WCE power consumption.

A. *BANs performance evaluation scenario*

In order to create a performance evaluation simulation scenario for wireless capsule as it travels through the human digestive system, we use a 3D mesh model of human body from the three-dimensional full-wave electromagnetic field simulation system (Ansoft [11]). The 3D mesh model includes frequency dependent dielectric properties of 300+ parts in a male human body. We extract the 3D coordinates of large intestine and small intestine from the human body model, which is illustrated in Fig. 1 and Fig. 2. With the mesh model of small and large intestine, a 3D skeletonization algorithm has been applied to extract the movement path of WCE inside the GI tract for the convenience of calculation. The WCE movement paths are shown in Fig. 3 and Fig. 4 for small and large intestine respectively.

For the design of the topology of relay sensors on body, we assume that all the nodes are placed on a belt tied on the patient's waist during the examination. And we also assume that the belt is an ellipse and the center of the ellipse is the relative origin of node coordinates and organ coordinates.

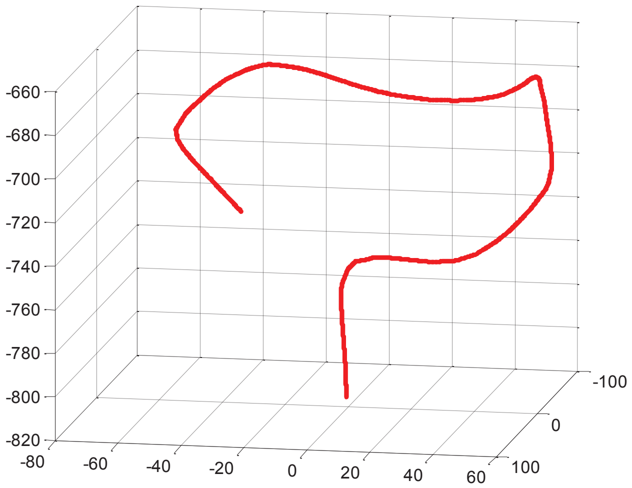


Fig. 3. Movement path of WCE inside large intestine.

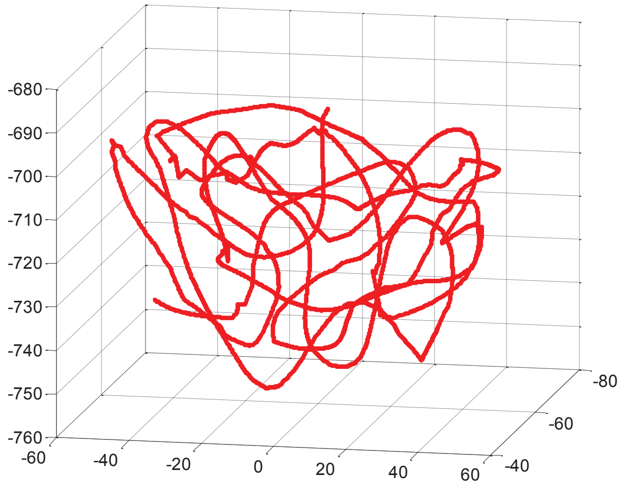


Fig. 4. Movement path of WCE inside small intestine.

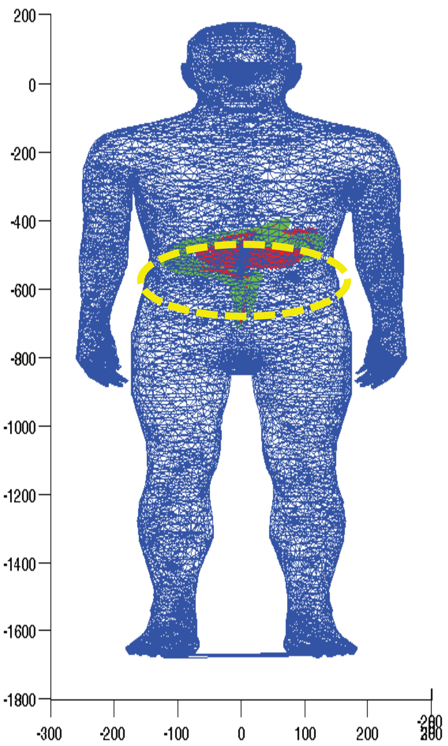


Fig. 5. Full-body mesh model with a belt on the waist.

Every sensor is evenly distributed along the belt. Note that we choose an even-angle sensor placement instead of even-distance placement so that the topology can be easily applied to human subjects with various body size. A human body with a belt is illustrated in Fig. 5.

B. BANs Channel Model

Another important setup of our simulation environment is the RF propagation environment that takes the effect of human body into consideration. Unlike traditional wireless communications, the path loss for body area network system (on-body applications), is both distance and frequency dependent. The frequency dependency of body tissues and organs shall be carefully considered. The path loss model in dB between the transmitting and the receiving antennas are modeled as a function of the distance d based on the Friis formula in free space. It is described by

$$\mathrm{PL}(d) = \mathrm{PL}_0 + 10n\log_{10}(\frac{d}{d_0}) \tag{1}$$

where PL_0 is the path loss at a reference distance d_0, and n is the path-loss gradient. When considering shadowing effect, the total path loss PL is supposed to be modified as,

$$\mathrm{PL} = \mathrm{PL}(d) + S \tag{2}$$

where PL(d) is expressed by the equation (1) and S is a random variable log-normally distributed around the mean which represents the path loss fluctuation caused by shadowing effect of human tissues, human organs and their slight movements.

TABLE I. Implant to Body Surface for 400 MHz

Implant to Body Surface	$\mathrm{PL}(d_0)$ (dB)	n	σ_s (dB)
Deep Tissue	47.14	4.26	7.85
Near Surface	49.81	4.22	6.81

Parameters of a statistical path loss model have been extracted that fits the following equation [12].

$$\mathrm{PL}(d) = \mathrm{PL}_0 + 10n\log_{10}(\frac{d}{d_0}) + S, \qquad d \geq d_0 \tag{3}$$

where $S \sim N(0, \sigma_s)$ and $d_0 = 50mm$.

In our calculation, we can model the path loss of implant to body surface at 400 MHz, as shown in Table I [13]. where $\sigma_s(dB)$ is the standard deviation of shadow fading S.

Note that there are two sets of parameters for path loss from deep and near surface implant to body surface. As the WCE is passing through the large intestine and small intestine, the deep tissue to surface model is used during our simulation.

III. PROBLEM STATEMENT

Intuitively, the relay nodes are evenly placed on the belt [14]. To avoid ambiguity, first sensor node is always fixed at the center of the front side of the belt. According to the human body model, the belt is assumed to be an ellipse whose function can be given as,

$$\begin{cases} x = 75\cos(\theta) \\ y = 145\sin(\theta) \end{cases} \tag{4}$$

In that way, the location of first sensor node can be given as n_1=$(75\cos(\theta_1), 145\sin(\theta_1))$, $\theta_1 = 0^o$. Connectivity is assumed between capsule pills and the relay sensors. The WCE will transmit signal to the node which has the nearest distance to capsule every step for every deployment.

The number of relay nodes is added as $\{n_1, ..., n_k\}, 1 \leq k \leq N$ where $N = 50$ in this paper and n_k represents the k^{th}

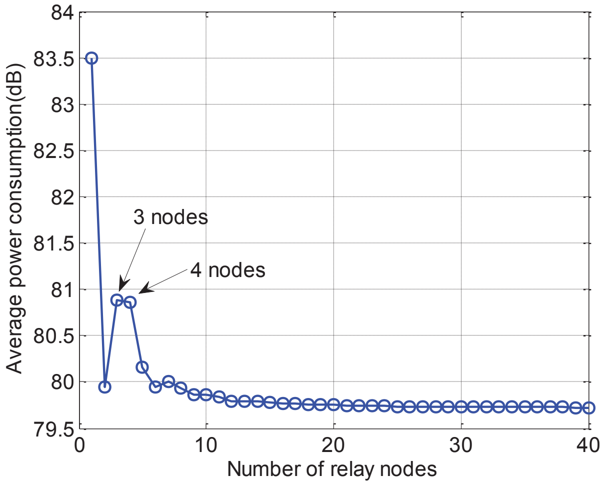
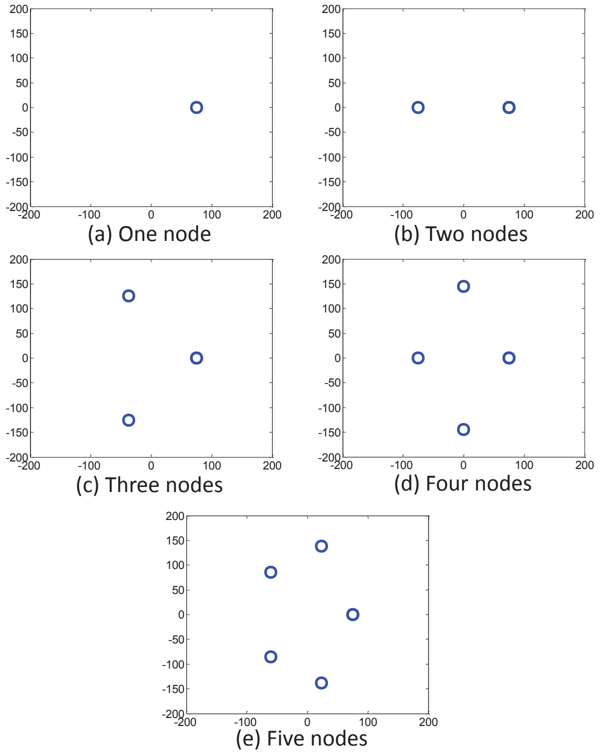


Fig. 6. Power consumption for different number of relay nodes on the belt.

sensor nodes. Then for adjacent sensor pair $\{n_i, n_{i+1}\}, 1 \leq i \leq N$, we connect n_i, n_{i+1} with the coordinate origin to form an angle ϕ as the central angle. For difference number of sensors, we know that $\phi = \frac{2\pi}{N}$. Note that with 1 relay node, the central angle is set to 0 degree and when the number of sensors on the belt is added to 40, the nodes are placed at the intervals of 9 degrees on the ellipse. For this given topology, the relationship of power consumption and the number of sensors is illustrated in Fig. 6. We can find that the power consumption is reduced gradually with the increase of total node number except for the situation of 3, 4 and 5 relay nodes. This is due to the assumption the first relay node is always fixed at the front center of the belt. In this simulation, such deployment for 1, 2, 3, 4, 5 nodes is shown in Fig.7.

When there is only one surface node on the belt, the WCE is always transmitting signal to it, the power consumption is maximum. When there are two nodes, the nodes are located on the center of front and rear of the body respectively whose locations are near to the organs. While the power consumption increases, the deployments for three and four nodes are relatively far from the large and small intestine. When the number of surface nodes increases to more than five nodes, the deployment tends to be uniform. The power consumption decreases. Since first node is always fixed at the center of the front belt for every deployment, with limited sensor node numbers (less than or equal to 5), increasing number of sensor nodes may not results in an optimized power efficiency. Such reality can be a proof of the fact that topologies with 3, 4 and 5 nodes are not better than topology with 2 nodes.



(a) One node
(b) Two nodes
(c) Three nodes
(d) Four nodes
(e) Five nodes

Fig. 7. The deployment for different number of relay nodes.

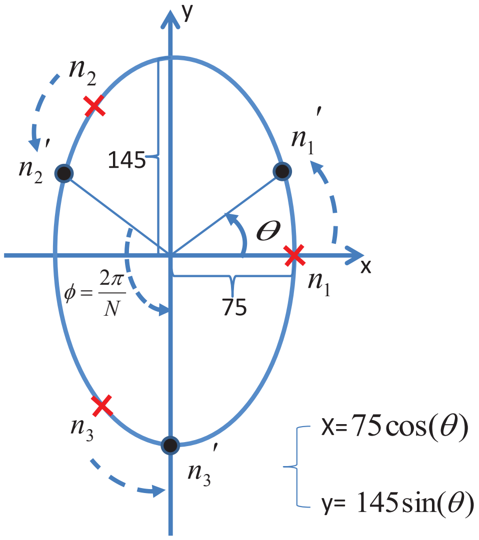


Fig. 8. Deployment of relay nodes with optimal angle.

The above analysis indicates that fixing the first on-body relay sensor at the front center of the belt may not give us an optimal topology. Due to the fact that the power consumption of capsule is tightly coupled with the distance between the capsule and relay nodes, finding the optimal topology with shortest overall transmitting distance is necessary. If the shortest transmitting distance is found, that is to say an optimal placement of the first relay node may be found to minimize the overall power consumption of WCE.

IV. OPTIMAL DEPLOYMENT OF RELAY NODES

According to the problem description in section III, we redefine the connectivity between WCE and relay nodes in small intestine and large intestine environments. We require that the transmit power of WCE can be as low as only the closest on-body relay node can successfully receive the signal. To find the optimal deployment of on-body relay nodes, we rotate every sensor node n_i in a counter-clockwise manner with a step size of 0.1^o from θ_i to $\theta_i + \frac{2\pi}{N}$ during which the θ_{opt} with minimum overall power consumption has been recorded as the optimal location. A typical example of the above mentioned operation has been illustrated in Fig. 8 with 3 on-body relay nodes rotating from original topology $\{n_1, n_2, n_3\}$ to the optimal topology $\{n_1', n_2', n_3'\}$. We also notice that in every organ, the optimal θ_{opt} is found to make the distance between the capsule and the sensors shortest in order to reduce power consumption. In the following simulation, we added the number of receiver sensors one by one and assumed only one single capsule in each organ. Finally, we calculated the optimal θ_{opt} for the entire movement path of WCE inside each organ (83 points along the path for small intestine, 26 points for large intestine and 109 points for total small and large intestine).

TABLE II. OPTIMAL THETA WITH MINIMUM POWER CONSUMPTION FOR DIFFERENT NUMBER OF RELAY NODES

Large Intestine				Small Intestine				Small and Large Instesine			
Number of on-body nodes	Optimal θ_{opt} (^{o})	Minimum power consumption (dB)	PC-max/min difference (dB)	Number of on-body nodes	Optimal θ_{opt} (^{o})	Minimum power consumption (dB)	PC-max/min difference (dB)	Number of on-body nodes	Optimal θ_{opt} (^{o})	Minimum power consumption (dB)	PC-max/min difference (dB)
...	...	...	...	...	...	...	...	...	...	...	...
20	14.8	79.5229	0.0139	11	31.5	79.8091	0.03511	11	31.7	79.7535	0.04215
21	13.8	79.5188	0.0150	12	14.0	79.7951	0.02843	12	8.0	79.7457	0.01775
22	0.1	79.5161	0.0167	13	26.9	79.7867	0.01810	13	0.5	79.7321	0.02096
23	15.6	79.5163	0.0088	14	10.9	79.7797	0.00975	14	7.8	79.7292	0.00528
...	...	...	...	...	...	...	...	...	...	...	...

A. Effect of deployment of relay nodes for power consumption in large intestine

In this subsection, we evaluate the impact of deployment of relay nodes for power consumption in large intestine. Table II shows the optimal θ_{opt} with minimum power consumption for different number of nodes. In the experiment, our simulations were carried out with the number of receiver sensors varied from 1 to 50.

Notice that the difference of maximum and minimum power consumption is apparently smaller when the sensor number is equal to or more than 23. The difference is decreased to 0.0088. At the same time, the maximum power consumption is 79.5251dB. When the number of surface nodes is less than 5, the minimum power consumption fluctuates a lot, especially with 3 nodes. Such fluctuation is again due to the fact that sensor nodes are located on the belt evenly, the deployment of 3 nodes results in larger average distance between WCE and on-body receivers compared with 2 nodes, even though the topology is with smaller angle θ. Power consumption for different number of sensors with optimal angle in large intestine is shown in Fig. 9. When the number of nodes is more than 23, the angle and number have almost no impact on power consumption.

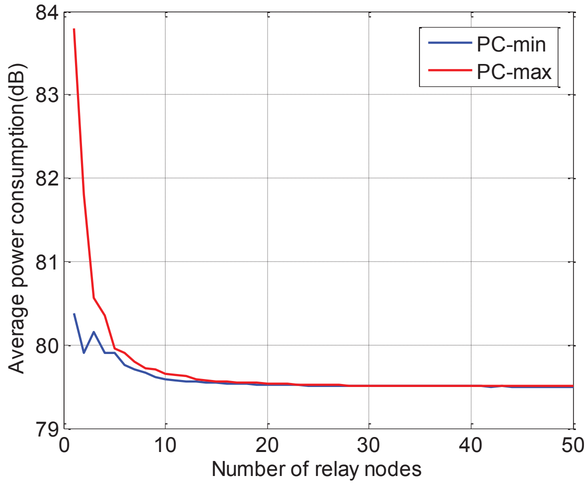


Fig. 9. Power consumption for different number of relay nodes with optimal angle in large intestine.

B. Effect of deployment of relay nodes for power consumption in small intestine

In this subsection, we investigate the impact of deployment of relay nodes for power consumption in small intestine. Table II shows the optimal θ_{opt} with minimum power consumption for different number of on-body sensor nodes in small intestine.

The results show that the difference of maximum and minimum power consumption is apparently smaller when the number is equal to or larger than 14. With 14 on-body sensor nodes, the difference is decreased to 0.00975. At this moment, the maximum power consumption is 79.7894dB. When the number of nodes is more than 14, the angle and number are no little effect on power consumption, as is shown in Fig. 10. That is because there are more points for capsule to travel through inside small intestine, leading to the different optimal sensor selection and deployment.

C. Effect of deployment of relay nodes for power consumption in small and large intestine

Lastly, the small and large intestines are combined and we investigate the impact of deployment of relay nodes on power consumption for the entire intestinal tract. For this simulation, the capsule is assumed to pass through small intestine and

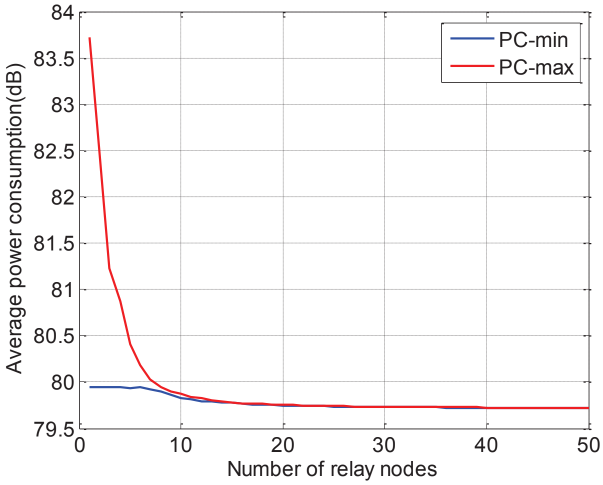


Fig. 10. Power consumption for different number of relay nodes with optimal angle in small intestine.

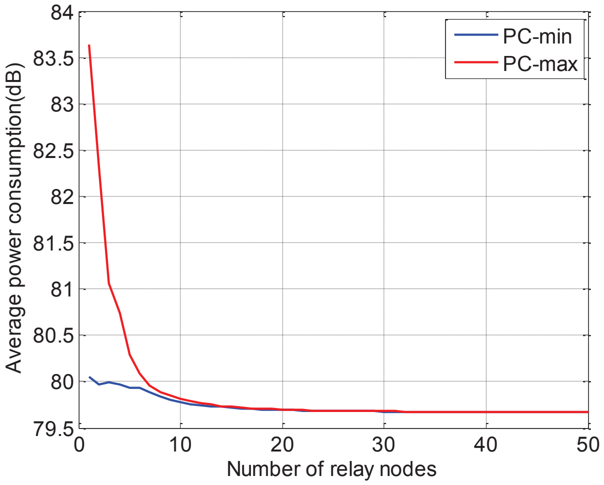


Fig. 11. Power consumption for different number of surface nodes with optimal angle in large and small intestine.

large intestine in the same trip. Table II shows the optimal θ_{opt} with minimum power consumption for different number of relay nodes in small intestine and large intestine.

Notice that the difference of maximum and minimum power consumption is apparently smaller when the number is 14. It is different from small intestine situation mostly because that the large intestine has been taken into consideration and the WCE has a longer path to travel. The difference is decreased to 0.00528 with 14 on-body sensor nodes. Meanwhile, the maximum power consumption is 79.7292dB. For more than 14 nodes, the change of minimum power consumption is trivial, similar to the situation in small intestine. When the number of nodes is more than 14, the angle and number are no little effect on power consumption. The results are presented in Fig. 11. The power consumption is affected by the angle and number of relay sensors while the number is less than 13.

V. CONCLUSION

In this paper, we investigated the effect on deployment of relay nodes for BANs in non-homogeneous environment to reduce the transmitting power consumption of WCE which was passing large and small intestines inside the human body. According to various different deployments, we found the maximum and minimum consumed power for the capsule. Also we veried the optimal deployment angle and number for sensors that were placed on the belt for corresponding minimum power consumption. Simulation results showed that the deployments of more than 23 relay sensors on body surface (for large intestine) and more than 14 nodes (for small intestine, total small and large intestine) have almost no influence on the power consumption for the capsule regardless of angle. We draw the conclusion that when the number of nodes is less than 14(for small intestine, total small and large intestine) or 23(for large intestine), the deployments with optimal angle were very important for less power consumption. While the number is more than 14(for small intestine, total small and large intestine) or 23(for large intestine), the deployment has little impact for power consumption of WCE no matter angle and number.

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