Resource Allocation for Relay-Aided Cooperative Hospital Wireless Networks

Jingxian Liu[1], Ke Xiong[1](✉), Yu Zhang[2], and Zhangdui Zhong[3]

[1] School of Computer and Information Technology, Beijing Jiaotong University,
Beijing, China
`xiongke.bjtu.iis@gmail.com`
[2] School of Computer and Communication Engineering,
University of Science and Technology Beijing, Beijing, China
[3] State Key Laboratory of Rail Traffic Control and Safety,
Beijing Jiaotong University, Beijing, China

Abstract. In this paper, we investigate the relay-aided hospital wireless systems in cognitive radio environment, where multiple transmitter-relay pairs desire transmit their collected information to a data center. For the system, we propose a transmission framework, which follows IEEE 802.22 WRAN and adopts the listen-before-talk and geo-location/database methods to protect the primary users. The transmission strategy is presented, where in each subsystem, the wireless sensor device (WSD) with the highest signal-to-noise ratio (SNR) is selected to transmit signals at each time and then, a two-hop half-duplex decode-and forward (DF) relaying transmission is launched among the selected WSD, the corresponding personal wireless hub (PWH) and the data center. To explore the potential system performance, an optimization problem is formulated to maximize the system sum rate via power allocation. We then solve it by using convex optimization theory and KKT condition method and derive a closed-form solution of the optimal power allocation. Simulation results demonstrate the validity of our proposed scheme and also show the effects of the total power, the interference thresholds and the scale of the network on the system performance, which provide some insights for practical hospital wireless system design.

Keywords: Relays · Wireless sensor devices · Hospital environment · Power allocation

1 Introduction

1.1 Background

With the fast development of wireless sensor devices (WSDs), various wireless networks have been developed, which are used for various aspects, including traffic control, healthcare, home automation and habitat monitoring [1]. An emerging paradigm of this kind of network is wireless sensor networks (WSNs), which has

Y. Zhou and T. Kunz (Eds.): ADHOCNETS 2016, LNICST 184, pp. 192–204, 2017.
DOI: 10.1007/978-3-319-51204-4_16

become a very important role in civilian and industrial applications. Besides, the quality of life is becoming a common focus among people all over the world. As a result, WSDs will be used widely in remote and infrastructure-based healthcare facilities [2]. In practice, it is able to reduce workload of staff if to compose a WSN in a hospital. The data of patients can be monitored by a WSN and then these data can be transmitted to their designated doctor or nurses.

The ballistocardiograph (BCG) device is one of the most widely deloped sensor devices, which transmits cardiac respiratory signals, impulse signals and kinetic signals to the health-care center [3]. Another widely deployed sensor device is the Electroencephalography (EEG) monitoring device, which transmits electrophysiological monitoring data of recording electrical activity of the brain. Besides, the device used to transmit ECG traces, metadata and annotations, is called SCP-ECG [4,5]. These WSDs are low-power devices, which cannot transmit signals over a long distance, so relay nodes are employed to help them transmit signals more reliable over a long distance. In hospital wireless networks, personal wireless hubs (PWHs) are commonly used as helping relays, which help forward the signals from WSDs to the data center. PWHs are capable of enhancing the system performance and improving the reliability of the wireless networks in hospital environment [6].

1.2 Related Work

Wireless resource allocation, which is a very effective way to improve the system performance of wireless networks, has been widely studied in the past few years. Wireless networks are resource-limited systems, including spectrum and power. Due to spectrum scarcity, cognitive radio (CR), which allows the unlicensed users (secondary users) to use the spectrum resource of the licensed users (primary users), was raised for solving this problem and its detailed definition can be found in [7]. In WSNs, CR technology was considered for the information transmission in [8–10].

Moreover, power allocation is also a typical issue in relay-aided WSNs. So far, different relaying protocols (e.g., amplify-and-forward (AF) and decode-and-forward (DF)) have been proposed for wireless cooperative communications [11]. So far, power allocation in AF or DF relaying networks in CR environment have been investigated. For source and relay nodes respectively, a power allocation schemes in CR was analysed in [12–14]. Hence, for hospital wireless networks, resource allocation (e.g., power allocation and bandwidth) is very critical.

1.3 Motivations

As much attention has been paid to health-care facilities and hospital environment recently, resource allocation in hospital wireless networks is attracting more and more interests. In [15], a discrete event system model of operating room (OR) was built on a platform named as SIMIO to allocate resource for health-care networks. The author in [16] formulated a dynamic programming problem to allocate bandwidth to enhance the information capacity of patients.

However, relatively few work has been done on power allocation in cooperative relaying hospital wireless networks. In this paper, we investigate a relay-aided hospital wireless systems, which has n subsystems in CR network environment. Our goal is to maximize the sum rate by power allocation for WSDs (transmitters) and PWHs (relays). Some differences between our work and the similar one in [6] is worthy mentioned. Firstly, in [6] multi-relay assignment was investigated with CR technology in hospital environment, which proposed an iterative joint relay assignment and power allocation algorithm for CR. Moreover, in [6], more than one WSDs are allowed to transmit signals at the same time so that each relay can receive signals from more than one WSD. This may cause multi-user interference and consequently deceases the system performance. To meet the data transmission reliability requirement of each patient in one ward, in our work only one WSD (i.e., the one with highest SNR) is selected to transmit at each time, where the PWHs within the wards are regarded as relays. Secondly, in [6], AF relay protocol was considered, while in this paper we adopt the DF relaying protocol, because compared with AF, DF avoids amplifying the noise by decoding information at the relay. Besides, in our work, the channel gain between the transmitter and the relay is good enough to ensure the relay can decode the signals successfully. Thirdly, we consider the power constraint of each ward (i.e., each subsystem), which may keep the fairness for the patients in different wards and each PWH is only allowed to work over its designated frequency so that the interference among PWHs can be avoided, while in [6], these factors were not considered.

1.4 Contributions

In this paper, we investigate the relay-aided hospital wireless systems in CR environment, where multiple transmitter-relay pairs desire transmit the collected information to the data center. Firstly, we propose a transmission framework for the system and our proposed transmission standard follows IEEE 802.22 WRAN, which has listen-before-talk and geo-location/database schemes to protect the primary users [6]. Secondly, we present the detailed transmission strategy for the system, where in each subsystem, the WSD with the highest SNR is selected to transmit signals at each time. Then, a two-hop half-duplex DF relaying transmission is launched among the selected WSD, the corresponding PWH and the data center, where the PWHs and the WSDs are unlicensed users. Thirdly, to explore the potential system performance, we formulate an optimization problem to maximize the sum rate of the system via power allocation, and then solve it by using convex optimization theory and KKT condition method. By doing so, the closed-form solution of the optimal power allocation is provided. Fourthly, we discuss the effects of the total power, the interference thresholds and the scale of the network on the system performance, which provides some insights for practical hospital wireless system design.

The rest of this paper is organized as follows. The system model and transmission protocol are described in Sect. 2. Section 3 presents the problem formulation and solution and Sect. 4 shows the simulation results. Finally, Sect. 5 concludes the paper.

2 System Model and Transmission Protocol

2.1 System Model

We consider a hospital network, which consists of M WSDs and N PWHs as shown in Fig. 1. Low-power WSDs cannot transmit data only by itself to achieve high reliability, so PWHs of patients in the hospital are considered as relays to help WSDs send data from patients to the data center.

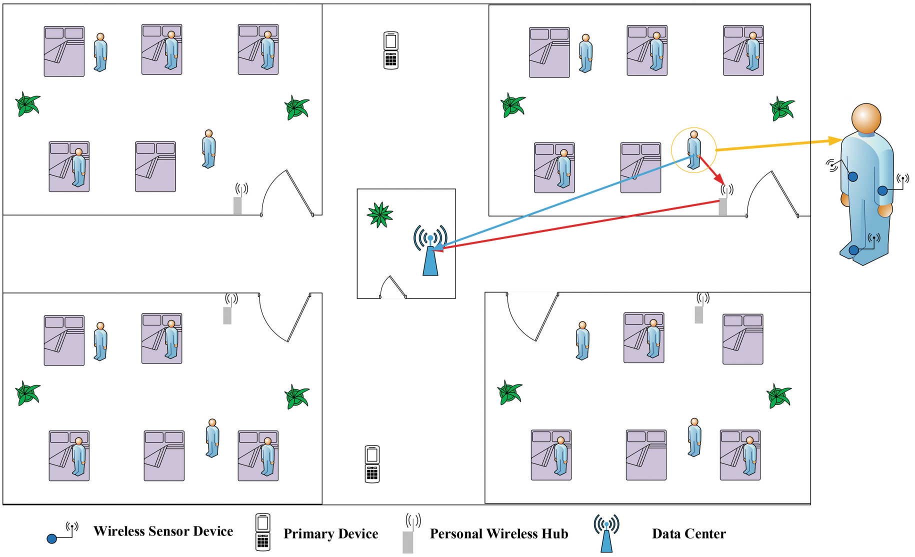

Fig. 1. A part of hospital environment with communication devices.

Considering the limit of spectrum resource, we adopt cognitive radio (CR) to share the spectrum with those licensed wireless devices [6]. In our work, the licensed wireless devices, such as cellphones, are considered as primary wireless devices.

All WSDs and PWHs are unlicensed devices and there are K licensed wireless devices (i.e., primary users) and one data center. There are several patients living together in the same ward, and each of them has several WSDs on his or her body. We assume that one ward only has one PWH. So the number of WSDs are much larger than the related PWHs, i.e., $M > N$. Due to the short distance between the WSDs and their related PWHs, the channel quality between WSDs and their related PWHs are good enough, so the PWH can successfully decode the information transmitted from the sensor devices on the patients. One PWH can only decode signals from one transmitter at some moment. After successfully decoding the information, the PWH re-transmits the data to the data center. p_m and p_n represent the mth WSD's transmission power and the nth PWH's

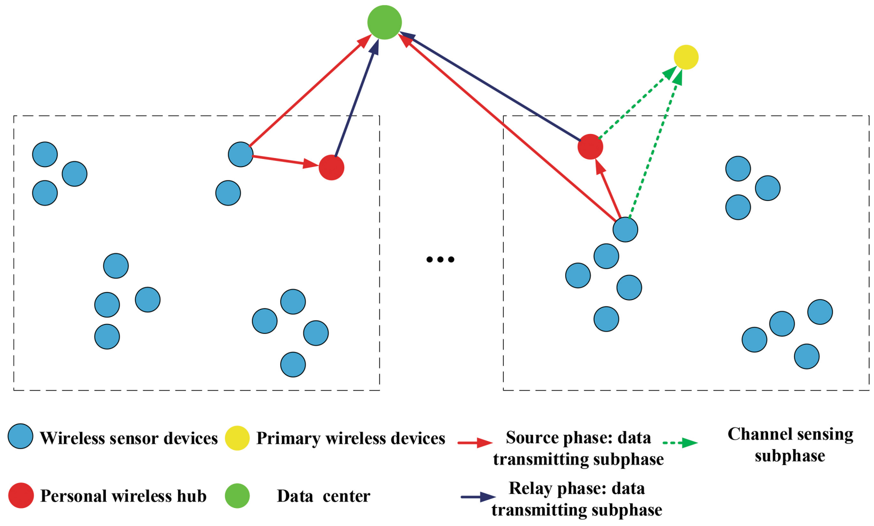

Fig. 2. System communication illustration.

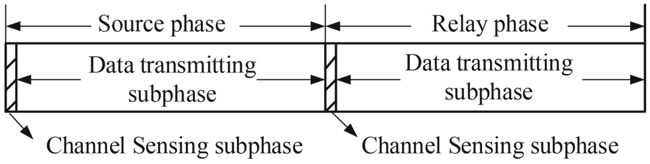

Fig. 3. Transmission protocol structure.

transmission power, respectively. $h_{m,n}$, $h_{m,c}$, $h_{n,c}$ are the channel gains between the mth WSD and the nth PWH, the mth WSD and the data center, and nth PWH and the data center, respectively. The channel gains of the mth WSD and the kth primary wireless device and the nth PWH and the kth primary wireless device are respectively denoted by $g_{m,k}$ and $g_{n,k}$.

2.2 Transmission Protocol

Briefly, the transmission strategy is illustrated as Fig. 2. We consider w WSDs, one PWH and the data center as a subsystem.

We assume that all channels are flat-fading channels. Each PWH only serves for just one WSD and each WSD operates on its separate frequency band, which is not in mutual frequency band with others.

In this paper, time of transmission in every subsystem is divided into two equal parts, which are source phase and relay phase. Source phase is for the WSDs to transmit, while relay phase is for the related PWHs transmitting. Before transmission of the WSDs and the related PWH, they should listen to the primary wireless devices' bands firstly. Secondly, every secondary wireless device should ensure that its transmission power is under a specific threshold. The structure of this protocol is shown in Fig. 3. In the first channel sensing subphase, each WSD should guarantee its interference to the primary devices being under a threshold, i.e.,

$$p_m|g_{m,k}|^2 \leq I_{k,m}, \tag{1}$$

where $I_{k,m}$ represents the interference threshold of mth WSD operating within kth primary device's licensed frequency band. According to the p_m and the channel gain between the mth WSD and related PWH, we let only one WSD in a subsystem transmit its signals and its transmission power is rewritten as $p_{m'}$. m' is in the set $\{1, 2, ..., N\}$. It's easy to see that m' and n are matched. Our selection strategy is a two-stage method. The first stage is, for several WSDs and their related PWH, to sort these WSDs according to their maximum value of achievable transmission power. We assume that a subsystem with w WSDs. According to (1), in a subsystem, for each WSD,

$$p_m = \min\left\{P_S^{\max}, \frac{I_{1,m}}{|g_{m,1}|^2}, \frac{I_{2,m}}{|g_{m,2}|^2}, ..., \frac{I_{K,m}}{|g_{m,K}|^2}\right\} \tag{2}$$

where $P_S^{\max}$ is the maximal transmission power of the transmission device.

The second stage is, for every subsystem, to calculate each SNR at PWH, and choose the WSD with highest SNR at PWH to transmit its data, and then we write $p_{m'}$ as

$$p_{m'} = \arg\max_{p_i}\left\{p_1|h_{1,n}|^2, ..., p_i|h_{i,n}|^2, ..., p_w|h_{w,n}|^2\right\}, \tag{3}$$

which m' starts from 1 to N.

In the first data transmitting subphase, the WSDs broadcast data to related PWHs and the data center. The channel output at nth PWH is

$$Y_n = \sqrt{p_{m'}}h_{m',n}X_{m'} + Z_n, \tag{4}$$

where $X_{m'}$ is complex-valued transmitted signal and Z_n is complex-valued white Guassian noise at nth PWH, which is zero-mean random variable with variance σ^2. And at the data center is

$$\boldsymbol{Y_c^{(1)}} = \boldsymbol{B_1}\boldsymbol{X_1} + \boldsymbol{Z_{c,1}}, \tag{5}$$

where $\boldsymbol{B_1} = \mathrm{diag}[\sqrt{p_1}h_{1,c}, ..., \sqrt{p_{m'}}h_{m',c}, ..., \sqrt{p_N}h_{N,c}]$ and $\boldsymbol{Z_{c,1}}$ is a Guassian noise vector with convariance matrix $\sigma^2\boldsymbol{I_N}$ at the data center and the signal $\boldsymbol{X_1}$ is a vector $[X_1, ...X_{m'}, ..., X_N]^T$. In the second channel sensing subphase, each PWH should guarantee its interference for the primary devices is under a threshold, defined as

$$p_n|g_{n,k}|^2 \leq I_{k,n}, \tag{6}$$

where $I_{k,n}$ represents the interference threshold of nth PWH operating within kth primary device's licensed frequency band. In the second data transmitting subphase, the PWHs transmit signals to the data center. The channel output at the data center is

$$\boldsymbol{Y_c^{(2)}} = \boldsymbol{B_2 X_2} + \boldsymbol{Z_{c,2}}, \tag{7}$$

where $\boldsymbol{B_2} = \mathrm{diag}[\sqrt{p_1}h_{1,c}, ..., \sqrt{p_n}h_{n,c}, ..., \sqrt{p_N}h_{N,c}]$ and $\boldsymbol{Z_{c,2}}$ is a Guassian noise vector with convariance matrix $\sigma^2 \boldsymbol{I_N}$ at the data center. In order to save limited energy and guarantee this system will not be strong interference to other important medical devices, in this paper, we assume that the whole transmission power of this system is limited, and from the perspective of nth subsystem, this constraint is written as

$$\sum\nolimits_{m'=n=1}^{N} (p_{m'} + p_n) \le P_{\mathrm{total}}, \tag{8}$$

where P_{total} presents the transmission power of the whole system. Besides, for nth subsystem, it has its own power control, which means available power for every subsystem is limited in a proper proportion of the whole system for fairness, and this constraint is written as

$$p_{m'} + p_n \le \theta_n P_{\mathrm{total}}, \tag{9}$$

where $0 \le \theta_n \le 1$ is the proportional factor. Obviously, $\sum\nolimits_{\mathrm{n}=1}^{N} \theta_n = 1$ should be met.

3 Problem Formulation and Solution

In this section, we formulate an optimization problem to allocate power of WSDs and PWHs, and then we get the closed-form of optimal power allocation via two-hop half-duplex DF scheme.

We consider DF strategy to transmit, which means the related PWHs should decode the signals from the WSDs correctly. As shown in Fig. 3, we assume the channel sensing subphase is small enough compared with the data transmitting subphase, so we just consider the data transmitting subphase as the main part of the transmission time and the time of the channel sensing subphase is negligible.

For the nth subsystem, in the first data transmission subphase, the achievable rate $C_{1,n}$ is

$$C_{1,n} = \tfrac{1}{2N} \log\left(1 + \tfrac{p_{m'}\left|h_{m',n}\right|^2}{\sigma^2/N}\right). \tag{10}$$

In the second data transmission subphase, the achievable rate $C_{2,n}$ is

$$C_{2,n} = \tfrac{1}{2N} \log\left(1 + \tfrac{p_{m'}\left|h_{m',c}\right|^2}{\sigma^2/N} + \tfrac{p_n|h_{n,c}|^2}{\sigma^2/N}\right). \tag{11}$$

So the achievable rate of the nth subsystem is the minimum of $C_{1,n}$ and $C_{2,n}$, written as

$$C_n = \min\left\{C_{1,n}, C_{2,n}\right\}. \tag{12}$$

And our aim is to achieve maximum of the achieved rate of the whole system

$$\begin{aligned} \max_{p_{m'},p_n} \ \sum\nolimits_{n=1}^{N} \mu_n C_n \\ \text{s.t. } (1),(6),(8),(9) \\ p_{m'},p_n > 0. \end{aligned} \tag{13}$$

The factor $\mu_n > 0$ ensures the fairness of every subsystem.

Proposition 1. *The optimal power allocation in the problem (12) can be achieved by letting* $C_{1,n} = C_{2,n}$.

Proof. The condition of choosing relay is $h_{m',n} > h_{m',c}$ as well as $h_{n,c} > h_{m',c}$. And for a given $p_{m'}$, we can get a corresponding p_n. $C_{1,n}$ is a monotonically increasing function of $p_{m'}$, while $C_{2,n}$ is a monotonically decreasing function of $p_{m'}$. Because $h_{n,c} > h_{m',c}$ and the sum of $p_{m'}$ and p_n is constant. Only if $C_{1,n} = C_{2,n}$, the subsystem can achieve the maximum achieved rate.

So we can obtain that the relationship between $p_{m'}$ and p_n as following:

$$p_n = \frac{\left|h_{m',n}\right|^2 - \left|h_{m',c}\right|^2}{|h_{n,c}|^2} p_{m'}, \tag{14}$$

and we set $\alpha_n = \frac{\left|h_{m',n}\right|^2 - \left|h_{m',c}\right|^2}{|h_{n,c}|^2}$.

Proposition 2. *The problem (13) is a convex optimization.*

Proof. Based on Proposition 1, we already know that $C_{1,n} = C_{2,n}$. Therefore, C_n is equal to $C_{1,n}$ or $C_{2,n}$. For the sake of convenience, we consider C_n is equal to $C_{1,n}$. Obviously, $C_{1,n}$ is a concave function of $p_{m'}$, so the sum of them is also concave. As for (1), (6), (8) and (9), they are all linear functions of $p_{m'}$, which are both convex and concave. So the problem (13) is a convex optimization.

Based on Proposition 2, this problem can be solved by KKT condition after constructing Lagrangian function. The Lagrangian of problem (13) is:

$$L(p_{m'},\lambda) = \sum\nolimits_{n=1}^{N} \mu_n C_n - \lambda \left(\sum\nolimits_{m'=n=1}^{N} (1+\alpha_n) p_{m'} - P_{\text{total}} \right). \tag{15}$$

Applying the KKT condition to this problem, we have that:

$$\frac{\partial L(\mathrm{p}_{m'},\lambda)}{\partial p_{m'}} = 0, \forall m' \in \{1,2,...,N\}. \tag{16}$$

And we get the solution as:

$$\mathrm{p}_{m'} = \left[\frac{\mu_n}{\lambda(1+\alpha_n)} - \frac{\sigma^2/N}{\left|h_{m',n}\right|^2} \right]^{+}. \tag{17}$$

After that, we can add the other constraints into this solution. We firstly introduce a variable $X = \min\{\frac{I_{k,m'}}{|g_{m',k}|^2}, \frac{I_{k,n}}{\alpha_n |g_{n,k}|^2}, \frac{\theta_n P_{total}}{1+\alpha_n}\}, \forall m', n, k$ and we already knew that m' and n are matched. So we finally get the optimal power allocation is as following:

$$p^*_{m'} = \min\{X, p_{m'}\}. \tag{18}$$

Then, we will demonstrate how these parameters represent the sum of achieved rates of the whole system in the following section.

4 Simulation Results

In this section, we provide some simulation results to discuss the system performance.

In all simulations, channel gain is set to be $h = K_A(\frac{d_0}{d})^\beta \varphi$, seen in [17]. K_A is a constant which describes the antenna characteristic and average channel attenuation. d_0 presents the reference distance for antenna far filed, and the distance between transmitter and receiver is d, which is larger than d_0. β is the path loss constant. The parameter φ is a Rayleigh random variable. And the values of them are set as: $K_A = 20$, $d_0 = 1$, $\beta = 3$. Besides, we set the power of noise is 0.1 mW.

Figure 4 shows an example of WSDs assignment. As shown in Fig. 4, there are four wards existing at one floor of the hospital. Each ward has several patients along with several sensor devices, which are represented by red pots. And the blue pots represent the related PWHs. We use MATLAB to simulate the result of choosing proper WSDs. We chose the WSD with the best channel quality within one subsystem. Instinctively, in the subsystem, the selected WSD is the one that with the shortest distance between it and the PWH.

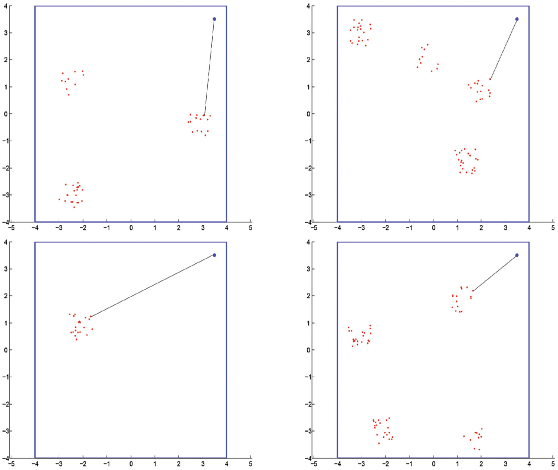

Fig. 4. An example of wireless sensor devices assignment. (Color figure online)

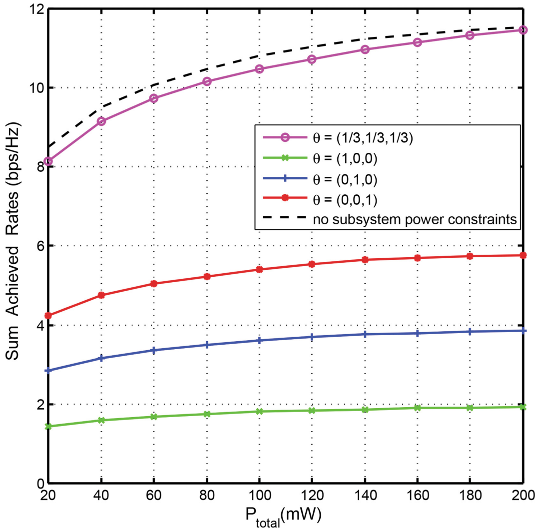

Fig. 5. Sum rate with different P_{total}, when $N = 3$, $K = 2$.

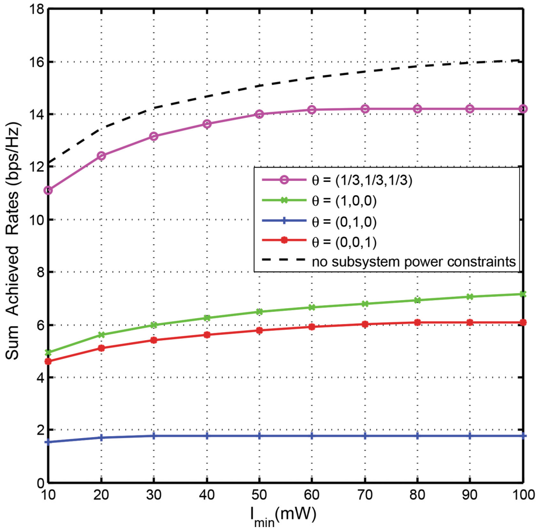

Fig. 6. Sum rates with different $I_{\min}$, when $N = 3$, $K = 2$.

Figures 5 and 6 are simulation results of the system with $N = 3$, $K = 2$. Figure 5 illustrates the sum rate versus θ when P_{total} changes from 20 mW to 200 mW. We set μ randomly and we set $I_1 = 80\,mW$ and $I_2 = 60\,mW$. It shows that, the system with uniformed θ gets higher sum rate than the system with only one subsystem transmitting. It indicates that, to achieve better fairness and spectral efficiency, only one subsystem being permitted to transmit may not

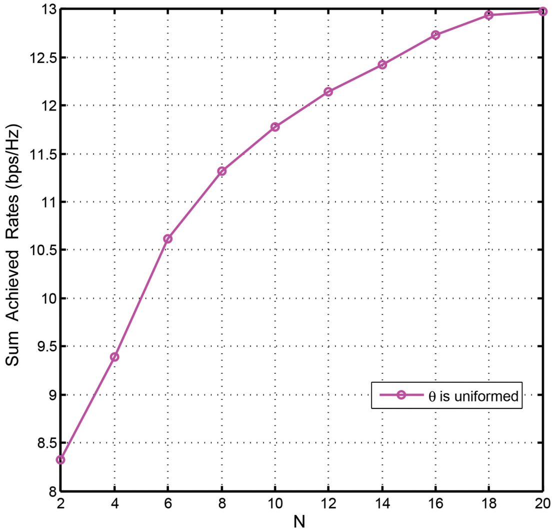

Fig. 7. Sum rates with different N, when $K = 2$, $p_{\text{total}} = 200\,\text{mW}$.

always be the best choice. Moreover, the gap between the system with uniformed θ and the system with no subsystem power constraint is the smallest than the others, and the gap is decreasing when P_{total} increases. It can be concluded that when P_{total} is becoming larger, uniformed θ constrains will not be the main factor on affecting the system sum rate any more. Figure 6 illustrates the sum rate of different θ versus $I_{\min}$ changing from 10 mW to 100 mW. Two different I values limit the optimal values of $p_{m'}$ and the smaller one affects the sum rate more obviously. It can be observed that the gap between the system with uniformed θ and the system with no subsystem power constraint is the smallest than the others, and the gap is increasing when $I_{\min}$ increases, because when $I_{\min}$ is getting larger, uniformed θ will be the main factor, which limits the system sum rate.

Figure 7 shows that the sum rate is increased when N grows, but the increasing rate is declining with the increment of N.

5 Conclusion

This paper studied the relay-aided hospital wireless systems in cognitive radio environment. We proposed a transmission framework and the corresponding transmission strategy. To explore the potential system performance, an optimization problem was formulated to maximize the system sum rate via power allocation. A closed-form solution was derived for the power allocation. Simulation results demonstrated the validity of our proposed scheme and also showed the effects of the total power, the interference thresholds and the scale of the network on the system performance, which provide some insights for practical hospital wireless system design.

Acknowledgement. This work was supported by the Open Research Fund of National Mobile Communications Research Laboratory, Southeast University (no. 2014D03), the Fundamental Research Funds for the Central Universities (no. 2016JBM015), and in part by the Beijing Natural Science Foundation (no. 4162049).

References

1. Zeb, A., Islam, A., Komaki, S., Baharun, S.: Multi-nodes joining for dynamic cluster-based Wireless Sensor Network. In: Informatics, Electronics & Vision (ICIEV), May 2014
2. Naeem, M., Pareek, U., Lee, D.C., Khwaja, A.S., Anpalagan, A.: Efficient multiple personal wireless hub assignment in next generation healthcare facilities. In: IEEE Conference on Wireless Commununication Network (WCNC), March 2015
3. Kim, J.M., Hong, J.H., Cho, M.C., Cha, E.J., Lee, T.S.: Wireless biomedical signal monitoring device on wheelchair using noncontact electro-mechanical film sensor. In: 29th Annual International Conference on IEEE Engineering in Medicine and Biology Society (EMBS), Lyon, pp. 574–577 (2007)
4. Mandellos, G.J., Koukias, M.N., Styliadis, I.S., Lymberopoulos, D.K.: e-SCP-ECG protocol: an expansion on SCP-ECG protocol for health telemonitoring-pilot implementation. Int. J. Telemed. Appl. **2010**, 137201 (2010)
5. Rubel, P., et al.: Toward personal eHealth in cardiology. IEEE Electrocardiol. J. **38**(4), 100–106 (2005)
6. Naeem, M., Pareek, U., Lee, D.C., Khwaja, A.S., Anpalagan, A.: Wireless resource allocation in next generation healthcare facilities. IEEE Sens. J. **15**(3), 1463–1474 (2015)
7. Akyildiz, I.F., Lee, W.Y., Vuran, M.C., Mohanty, S.: A survey on spectrum management in cognitive radio networks. IEEE Commun. Mag. **46**(4), 40–48 (2008)
8. Vijay, G., Bdira, E.B.A., Ibnkahla, M.: Cognition in wireless sensor networks: a perspective. IEEE Sensors J. **11**(3), 582–592 (2011)
9. Rao, R., Cheng, Q., Varshney, P.K.: Subspace-based cooperative spectrum sensing for cognitive radios. IEEE Sensors J. **11**(3), 611–620 (2011)
10. Lee, K.D., Vasilakos, A.V.: Access stratum resource management for reliable u-healthcare service in LTE networks. Wirel. Netw. **17**(7), 1667–1678 (2011)
11. Moubagou, B.D., Chang, Y.Y.: Performance of AF and DF relays by employing Half Duplex and Full Duplex mode. In: International Conference on Measurement, Information and Control (ICMIC), Harbin (2013)
12. Li, Y., Chen, Z., Gong, Y.: Optimal power allocation for coordinated transmission in cognitive radio networks. In: IEEE 81st Vehicular Technology Conference (VTC Spring), Glasgow, pp. 1–5 (2015)
13. Zhang, C., Fan, P., Xiong, K.: Optimal power allocation with delay constraint for signal transmission from moving train to base stations in high-speed railway scenarios. IEEE Trans. Veh. Technol. **64**, 5775–5788 (2015)
14. Xiong, K., Shi, Q., Fan, P., Letaief, K.B.: Resource allocation for two-way relay networks with symmetric data rates: an information theoretic approach. In: IEEE International Conference on Communications (ICC), pp. 6060–6064, June 2013
15. Zheng, Q., Shen, J., Liu, Z.Q., Fang, K., Xiang, W.: Resource allocation simulation on operating rooms of hospital. In: IEEE 18th International Conference on Industrial Engineering and Engineering Management (IE&EM), Changchun, pp. 1744–1748 (2011)

16. Lin, D., Labeau, F.: Bandwidth allocation in view of EMI on medical equipments in healthcare monitoring systems. In: 13th IEEE International Conference on Healthcom, pp. 209–212, June 2011
17. Goldsmith, A.: Wireless Communications. Cambridge University Press, Cambridge (2005)