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A Model for QoS – Aware Wireless Communication in Hospitals

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ABSTRACT

In the recent decade, research regarding wireless applications in electronic health (e-Health) services has been increasing. The main benefits of using wireless technologies in e-Health applications are simple communications, fast delivery of medical information, reducing treatment cost and also reducing the medical workers' error rate. However, using wireless communications in sensitive healthcare environment raises electromagnetic interference (EMI). One of the most effective methods to avoid the EMI problem is power management. To this end, some of methods have been proposed in the literature to reduce EMI effects in health care environments. However, using these methods may result in nonaccurate interference avoidance and also may increase network complexity. To overcome these problems, we introduce two approaches based on per-user location and hospital sectoring for power management in sensitive healthcare environments. Although reducing transmission power could avoid EMI, it causes a number of successful message deliveries to the access point to decrease and, hence, the quality of service requirements cannot be meet. In this paper, we propose the use of relays for decreasing the probability of outage in the aforementioned scenario. Relay placement is the main factor to enjoy the usefulness of relay station benefits in the network and, therefore, we use the genetic algorithm to compute the optimum positions of a fixed number of relays. We have considered delay and maximum blind point coverage as two main criteria in relay station problem. The performance of the proposed method in outage reduction is investigated through simulations.

Key words: *EMI problem, outage reduction, power management, wireless communications*

INTRODUCTION

Electronic health (E-Health) is the application of data communications and information technology in the health sector. In the recent decade, e-Health services are acquiring popularity due to the reduced cost and provisioning advanced healthcare services.[1,2]

The use of wireless technology has an important influence on different e-Health applications. The main aim in the healthcare networks is to provide accurate medical information, anytime and anywhere. This may result in dramatic reduction of errors by physicians and other healthcare personnel and also an improved quality of service (QoS).[3,4]

However, electromagnetic interference (EMI) between wireless transmitters and critical medical equipments such as ventilators is a growing problem in the healthcare industry that should be addressed carefully. The main effects of the interference are unexpected automatic shutdown, automatic restart and waveform distortion of sensitive medical devices that can imperil patients who are using those devices.[1,2] The immunity level of critical-care medical devices to the EMI has been defined in the International Electrotechnical Commission (IEC) 60601-1-2 standard.[1,2] Immunity level is the minimum electric field at which the performance of a medical device degrades.[1] As Tikkanen[5], indicates electromagnetic compatibility (EMC) means that "*the device is compatible with its electromagnetic (EM) environment, and it does not emit levels of EM energy that cause EMI in other devices in the vicinity*".[5]

The most critical issues in designing wireless networks for e-Health environments such as a hospital are how to design an effective network to provide guaranteed QoS and to consider the EMI problem. The transmission power of users in the network must be limited to avoid the EMI effect on the medical devices in the vicinity, and this causes the outage probability to increase. As a result of this, the QoS requirements cannot be met. If the received signal strength (RSS) at a specific receiver is less than a predetermined threshold, that receiver is faced with an outage.[1] This threshold is the minimum required RSS that makes the received signal detectable.

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In this paper, to avoid EMI effects, we first investigate the problem of power management in transmitting control data, then propose two approaches for power management to alleviate the EMI problem. After that, we evaluate the outage reduction by using fixed relay stations. These relay stations are optimally placed in healthcare environments such as hospitals. We investigate delay and maximum blind point coverage as two main criteria in the relay station placement.

The rest of the paper is organized as follows: first, an overview of the requirements and challenges in using wireless technology for the e-Health application are presented and then, in the next section, the related work in using wireless LAN (WLAN) in health environments will be reviewed. Then, the system architecture is introduced. The simulation results as well as analysis of two approaches for power management in control transmission messages are discussed. The evaluation and simulation results of our outage reduction method in hospital environment are presented. To this end, we conclude the paper.

REQUIREMENTS AND CHALLENGES IN USING WIRELESS TECHNOLOGY FOR E-HEALTH APPLICATIONS

Advanced information technologies, especially wireless communications, have been considered for delivering medical data and enhancing clinical activities. Several researches have been proposed in the context of improving QoS in healthcare environments.

In different contexts, for using wireless communications in healthcare networking, three different scenarios have been proposed: hospital-integrated networks, residential/home-care networks and anytime–anywhere healthcare networks. Each of these scenarios has various applications.[6]

In order to simplify investigations in such scenarios, the applications in each category, according to their QoS requirements, have been classified into office/medical IT applications, real-time noncritical applications and real-time critical applications.[6] The requirements of each category are summarized in Table 1.

As illustrated in Table 1, each category has distinctive requirements. For example, real-time critical applications (e.g., patient monitoring) have strict requirements as they are both delay-sensitive and loss-sensitive applications. In contrast, office/medical IT applications are just loss sensitive, and some packet loss is usually acceptable. The difference between medical data and other types of traffic is the on-time delivery requirement of medical information according to their QoS requirements.

Some challenges have been proposed in using wireless communications such as wireless personal area network (WPAN), WLAN and wireless metropolitan area network (WMAN) for e-Health applications.[1,3,6]

There are a number of issues that must be addressed when wireless communication is used in e-Health. Some examples are electromagnetic compatibility and EMI requirements,[5] QoS provisioning,[4] coexistence of different wireless technologies,[7] seamless connectivity and security.[8]

WIRELESS LOCAL AREA NETWORKS FOR E-HEALTH

In this section, we study WLAN applications in the healthcare systems. We classify different research works in two categories: research works considering QoS requirements and research works considering the EMI issue.

Research Works Considering the QoS Provisioning

Zvikhachevskaya *et al*[4] have investigated the application of IEEE 802.11 wireless standard for QoS provisioning within e-Health services. They indicated transferring medical information between a clinic and an ambulance, which is moving through different e-Health areas, requires guaranteed QoS. To guarantee QoS between distinctive traffics (patient's

Table 1: Medical application requirements[6]

Applications	Requirements					
	Bandwidth	Delay	Data Loss (MAC Packet error rate)	Reliability	Ubiquity	Security
Remote control apps. (e.g., Control/settings)	low bandwidth, <<1 kb/s	Delays. <3-5 sec	Cannot tolerate data loss. Not detectable	Reliability requirements	Do not require mobility support,	Integrity is required
Real-Time critical apps. (e.g., Waveforms, physiological parameters)	Continuous low bandwidth. 10-100 kb/s	Delays. <300 msec	Cannot tolerate data loss $\sim 10^{-6}$	Very high reliability requirements	Very efficient mobility support	Authentication and confidentiality are required
Real-Time non-critical apps. (e.g., video, audio)	Variable from low (voice) to high (video streaming) bandwidth. 10 kb/s - 1 Mb/s	Moderate delays. 10 mesc-250 msec	Low data loss. $<10^{-4}$	Reliability is important, but not critical	Efficient mobility support	Authentication and confidentiality are required
Office/Medical IT (e.g., Web browsing)	Require high bandwidth. ~1-10 Mb/s	Delays <1 sec	Tolerate data loss, $<10^{-2}$	Reliability is important, but not critical	Pervasive connectivity and mobility support	Authentication, integrity and confidentiality are required

emergency data and medical IT data), a priority scheme for telemedicine/e-Health service is also proposed.[4]

Vergados *et al*[9] have introduced the concept of differentiated services in telemedicine. Differentiated services (DiffServ) can support e-Health applications with different traffic requirements and QoS guarantees. In the introduced Diffserv architecture, medical data corresponds to service classes that include expedited forwarding, assured forwarding and best-effort service classes.

Chigan and Oberoi[10] proposed a resource-efficient mechanism for QoS provisioning in unpredictable emergency data transmission with minimum delay limitation.

Soomro *et al*[6] have introduced an integrated and ubiquitous network for medical environments that have used WLAN and WPAN technologies to meet QoS requirements. Besides that, an adaptive WLAN and bluetooth coexistence mechanism with QoS provisioning for interference management has been investigated.[7]

Research Works Considering the EMI Problem

The EMI control methods can be classified in two groups: policy-based approaches and technology-based approaches.

In policy-based approaches such as what ardavan *et al*[11] proposed, the exceeding risk of immunity level of medical devices has been estimated. This risk can be reduced with an appropriate management policy. The advantages of a management policy are investigated with a quantitative approach[11] by comparing three different policies: unrestricted use of wireless devices, restricted use of them and a ban on wireless devices.

In technology-based approaches, the infrared LAN and illuminating networks was proposed[12,13] for transferring data in a hospital. Hong *et al*[13] have taken the advantage of optical modulation in which high brightness light-emitting diodes (HB-LED) are used as an illuminating source. The information is modulated on the visible light emitted by HB-LED. However, data transmission by visible/invisible light does not allow seamless mobility through a lot of obstacles in the hospital. Hence, Phunchongharn *et al*[1] have proposed an EMI aware scheme for transferring medical information in a hospital with considering QoS requirements based on radio frequency (RF) wireless systems.

SYSTEM ARCHITECTURE

The system architecture and the communication model used in this paper are similar to the models introduced by Phunchongharn *et al*[1,2] The main idea of this system is to avoid harmful EMI to the medical devices and providing differentiated QoS to different e-Health applications. Particularly, two e-Health applications, a real-time application and a nonreal-time hospital information system have been considered. Real-time applications (e.g., remote consultation, remote diagnosis, clinician notification applications and patient information transfer) are sensitive to delay and packet loss and their corresponding users are named high-priority users. On the other hand, the hospital information systems (e.g., medical IT applications) are only sensitive to packet loss, and their corresponding users are named low-priority users.

The location of users can be changed dynamically while the location of sensitive medical devices is assumed to be fixed.

The controller (i.e., access point) manages effective channel allocation and controls wireless access of the users according to a time-slotted request to send/clear to send (RTS/CTS)-based mechanism. Every time, a user who has some data ready for transmission must compete with other users who have data to transmit. The user can transmit its data, if successfully received CTS from the controller, otherwise the collided user must wait for a random time based on exponential backoff.[1,2] To provide priority, high-priority users will wait for a random time based on a constant back off window, while low-priority users will wait for a random time based on exponential back off. In these cases the users are assumed to be in a high priority, and low priority orbits, respectively. To avoid harmful interference to sensitive medical devices, the controller computes the maximum allowable transmit power for each user in the hospital based on the information (e.g. location and status of critical medical devices or users) obtained from an inventory system. The maximum transmitted power can be calculated as follows:

$$P_{max} = \min\left\{\min\left(P_{NLS}(y)\right),\ \min\left(P_{LS}(z)\right),\ P_{transmit}\right\} \quad (1)$$

In equation (1), $P_{transmit}$ is the initial transmission power of the user, min ($P_{LS}(z)$) and min ($P_{NLS}(y)$) are the upper bounds on the user transmit powers that nonlife-supporting device, y, (e.g., infusion pump, electrocardiograph monitor) and life-supporting device, z, (e.g., incubator, defibrillator) can tolerate. P_{NLS} and P_{LS} can be calculated from (2) and (3),

$$P_{NLS}(y) = \left(\frac{D_{NLS}(y).E_{NLS}(y)}{7}\right)^2 \quad (2)$$

$$P_{LS}(z) = \left(\frac{D_{LS}(z).E_{LS}(z)}{23}\right)^2 \quad (3)$$

in which radio frequency ranges can be varied from 800 MHz to 2.5 GHz. $D_{NLS}(y)$ is the distance between nonlife-supporting device, y, and the user. $D_{LS}(z)$ is the distance between the life-supporting device, z, and the user. $E_{NLS}(y)$ and $E_{LS}(z)$ are the EMI immunity levels of the nonlife-supporting device, y, and life-supporting device, z, respectively.[1]

The controller calculates and notifies the upper bound on user transmit power twice: for RTS transmission and for data transmission. Because of simultaneous RTS transmissions, the probability of interference in the RTS transmission is more than that of the data transmission. Hence, the upper bound in the RTS transmission power is less than the upper bound in the data transmission power.

POWER MANAGEMENT APPROACHES

In this section, we investigate two approaches for estimating effective RTS transmission power.

Power Management Based on Every User Location

In the first method, the upper bound on the user transmitted power is calculated and broadcasted to every user by the controller. This method is named as power management based on every user's location. The controller can broadcast this power for every user in the control channel.[1] It is assumed that we have two channels: data channel for data transmission and control channel for control message transmission. The controller can access both channels simultaneously, while the users can access only one channel at a time. In what follows, an upper bound on RTS transmission power is determined.

High- and low-priority users will arrive according to independent Bernoulli processes with arrival probabilities α_1 and α_2, respectively. These users that transmit their RTS massages in the first try are named out of high-priority and out of low-priority orbit users, respectively. The retransmission probability from high-priority orbit and low-priority orbit are shown with θ_1 and θ_2, which can be obtained from the backoff window sizes (in this paper, it is Wmin = 32) and the maximum backoff stage of low-priority users (in this paper, it is m = 5).[14] When collision occurs, the users will go to the orbits, the collision probability of high-priority and low-priority users are illustrated by P_{c1} and P_{c2} [Figure 1].[1]

A discrete-time Markov chain model for estimating the number of high- and low-priority users in the orbits is also used.

In order to calculate an upper bound on RTS transmission power, we have to determine the probability of aggregate transmitted power when multiple users simultaneously transmit RTS messages. The maximum transmission power for RTS transmission by a user can be determined by (4).

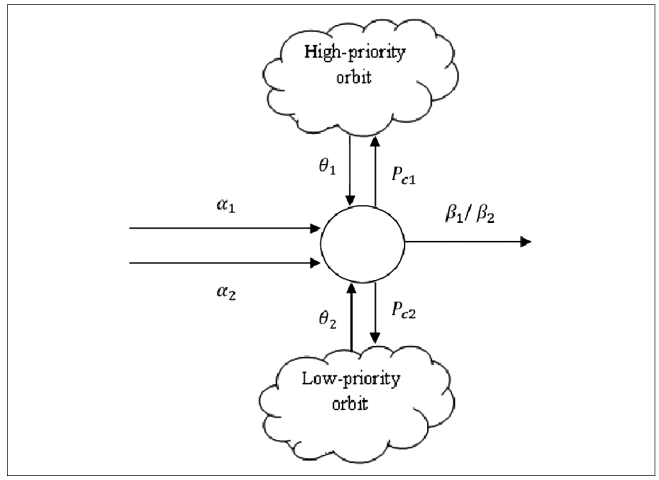

Figure 1: Imaginary orbit model for electromagnetic interference -aware prioritized wireless access system[1]

$$P_{ctr}^{H} = \{\sum_{x=0}^{T_1}\sum_{y=0}^{T_2} \text{max\_arriv\_pro}\,([\tag{4}$$

$$\sum_{n_1=0}^{T_1-1-x}\binom{T_1-1-x}{n_1}\alpha_1^{n_1}(1-\alpha_1)^{T_1-x-1-n_1}$$

$$\sum_{o_1=0}^{x}\binom{x}{o_1}w_1^{o_1}(1-w_1)^{x-o_1}$$

$$\sum_{n_2=0}^{T_2-y}\binom{T_1-y}{n_2}\alpha_2^{n_2}(1-\alpha_2)^{T_2-y-n_2}$$

$$\sum_{o_2=0}^{y}\binom{y}{o_2}w_2^{o_2}(1-w_2)^{y-o_2}\frac{P_{max}}{o_1+o_2+n_1+n_2+1}],$$

$$[\sum_{n_1=0}^{T_1-x}\binom{T_1-x}{n_1}\alpha_1^{n_1}(1-\alpha_1)^{T_1-x-n_1}$$

$$\sum_{o_1=0}^{x-1}\binom{x-1}{o_1}w_1^{o_1}(1-w_1)^{x-1-o_1}$$

$$\sum_{n_2=0}^{T_2-y}\binom{T_1-y}{n_2}\alpha_2^{n_2}(1-\alpha_2)^{T_2-y-n_2}$$

$$\sum_{o_2=0}^{y}\binom{y}{o_2}w_2^{o_2}(1-w_2)^{y-o_2}\frac{P_{max}}{o_1+o_2+n_1+n_2+1}])$$

$$\text{Transition\_p(x,y)}\}$$

where P_{ctr}^{H} indicates the maximum transmission power of high-priority users, Transition_*P*(x,y) represents the probability of the number of users who are in orbits to be x and y, where x and y refer to the number of high-priority and low-priority users in the orbits, respectively. The max_arriv_pro represents the maximum arrival probability of high-priority orbit and out of high-priority orbit in each state of transition matrices. T1 and T2 are the total number of high-priority and low-priority users, respectively. O1 and O2 are the number of high-priority and low-priority user in orbits who have some ready data for transmission; n1 and n_2 represent the number of high-priority and low-priority users in out of orbits who have some data for transmission.

The maximum transmission power of low-priority users can be determined in a way similar to (4).

Power Management Based on Hospital Sectoring

In upper bound power calculation per user method, the controller must have accurate and perfect knowledge of the location and the status of all users in the network, and this information has to be updated with every change in the network. However, this can increase the complexity of the controller in the network.

For simplicity, the hospital area is divided into a number of areas, and the maximum allowable power for each area is calculated based on the proposed algorithm and the network parameters. It is assumed that each user knows his own geographical position.[15] In this case, every user can obtain his own maximum allowable transmission power based on the power of each area and its location.

In this approach, the average interference caused by each area and the mean number of simultaneous transmission requests of each area must be calculated. The average interference caused by area i on sensitive medical device j can be acquired by

$$\overline{EMI(i,j)} = \int_{Xi1}^{Xi2}\int_{Yi1}^{Yi2} Ec(j)\frac{\sqrt{P(i)}}{\sqrt{(x-x(i))^2+(y-y(i))^2}}dxdy \qquad (5)$$

in which, P(i) is the power of the area i, x(j) and y(j) represent the position of the sensitive medical device j, Ec(j) is the immunity level of the sensitive medical device j that has been specified in IEC 60601-1-2 standard. The mean number of simultaneous transmission request in each area can be obtained by

$$\begin{aligned}\overline{num\_a} = \ & \{\sum_{x=0}^{T_1}\sum_{y=0}^{T_2}[\sum_{n_1=0}^{T_1-x}\binom{T_1-x}{n_1}\alpha_1^{n_1}(1-\alpha_1)^{T_1-x-n_1} \\ & \sum_{o_1=0}^{x}\binom{x}{o_1}w_1^{o_1}(1-w_1)^{x-o_1} \\ & \sum_{n_2=0}^{T_2-y}\binom{T_1-y}{n_2}\alpha_2^{n_2}(1-\alpha_2)^{T_2-y-n_2} \\ & \sum_{o_2=0}^{y}\binom{y}{o_2}w_2^{o_2}(1-w_2)^{y-o_2}(\mathrm{n}_1+\mathrm{n}_2+\mathrm{o}_1+\mathrm{o}_2) \\ & \mathrm{area\_pro}\ (\mathrm{n}_1+\mathrm{n}_2+\mathrm{o}_1+\mathrm{o}_2)] \\ & \mathrm{Transition\_p(x,y)}\}\end{aligned} \qquad (6)$$

where area_pro(n) is the probability that n users have located in each area. This probability can be determined from the point Poison process with probability mass function $P(k \in A) = e^{-\lambda A}\ (\lambda A)^k / k!$, in which λ is the density of users in the area A.[16]

The flowchart of power allocation of each area has been shown in Figure 2. In order to avoid EMI effects on each sensitive device, the maximum EMI from each area with and without simultaneous RTS transmission must be lower than the maximum immunity level of that device. In the proposed algorithm, coefficient "a" has been used to adjust the maximum acceptable interference through simultaneous RTS transmissions.

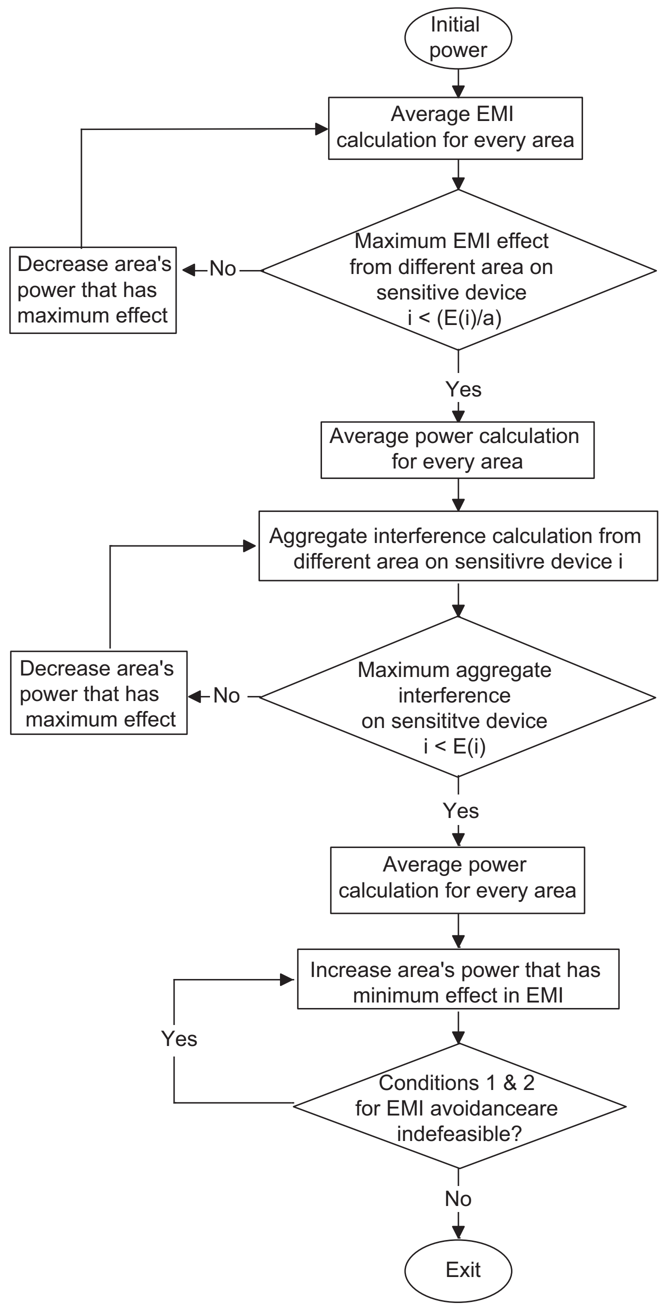

Figure 2: Flowchart of area power allocation method

Performance Comparison in Different Power Management Methods

In order to compare the performance of the proposed methods, a service area over 54 m^2 with six Intensive Care Unit (ICU) rooms, five Cardiac Care Unit (CCU) rooms, four operation rooms, an emergency area, one administration room, patient rooms, one physician room and a hallway in a hospital have been considered. The controller is located in the center of the hospital and 17 nonlife-supporting devices and 15 life-supporting devices have been considered. The service area is divided into 36 areas and is illustrated in Figure 3.

The received signal strength must be greater than −80dBm, otherwise it cannot be decoded by the controller. We assumed that the transmission rate of both high-priority and low-priority users is 1 Mb/s and the medical devices operate in the 2.4 GHz band. We study the case where the following indoor propagation path loss model is applicable:[1]

$$L(d)[\text{in dB}] = L(d_0)[\text{in dB}] + 10n_{SF}\log(d/d_0) + FAF[\text{in dB}] \quad (7)$$

where $L(d_0)$ is the measured line-of-sight (LOS) path loss at d0 = 1 m that equals 37.7 dB, the floor attenuation factor (FAF) is 16.2 dB[17] and n_{SF} (the path-loss exponent) is 3.3.[18]

The simulations are run twice for 10 h (according to each slot time) in MATLAB. It is supposed that the length of data packet is one time slot where the length of each time slot is 18 ms.

We evaluate the interference probability and outage probability with simultaneous RTS transmissions in this section and compare the results with what Phunchongharn, *et al*[1] have introduced for power management in RTS message transmission.

As shown in Figure 4, the interference probability in area power allocation and improved user power allocation methods do not change abruptly because, in these methods, unlike what Phunchongharn *et al*[1] have proposed. RTS transmission requests from each orbit are also considered. The proposed equations[1] for maximum power calculation in simultaneous transmission of high-priority users are as follows (maximum power calculation in simultaneous request transmission of low-priority users can be computed as a way similar to (8)):

$$P_{ctr}^{H} = \sum_{n_1=0}^{T_1-1} \binom{T_1-1}{n_1} \alpha_1^{n_1}(1-\alpha_1)^{(T_1-1-n_1)} \times \sum_{n_2=0}^{T_2} \binom{T_2}{n_2} \alpha_2^{n_2}(1-\alpha_2)^{(T_2-n_2)} \frac{P_{max}}{n_1+n_2+1} \quad (8)$$

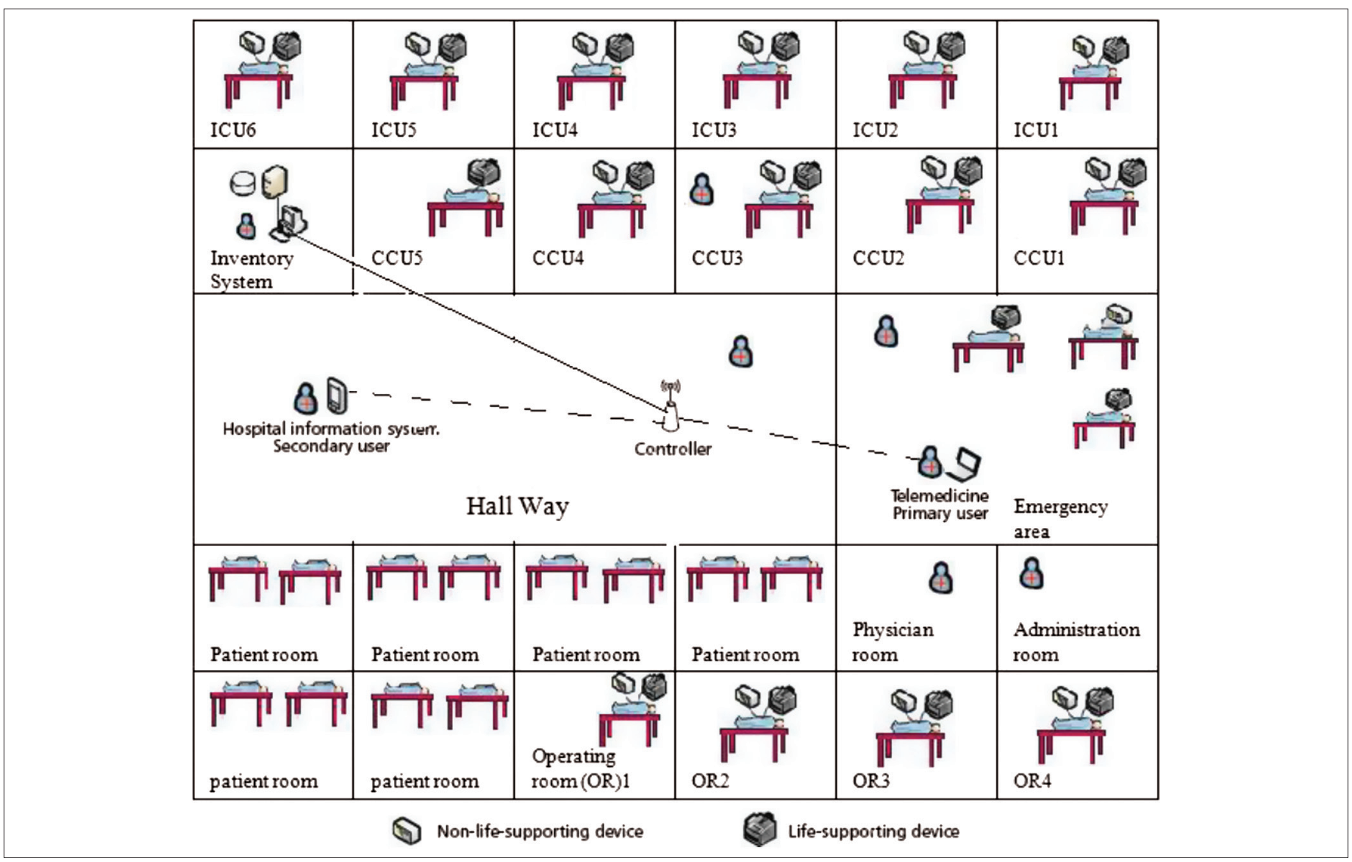

Figure 3: Healthcare scenario

Based on the simulation results [Figure 4], the interference probability with arrival probability of 0.009 is not the same as the other arrival probabilities for equation (8). In this case, the arrival probability from high-priority orbit is about 0.06, which is more than 0.009, and this increases the number of simultaneous RTS transmissions. However, the interference probability in both area power allocation and user power allocation methods changed without any abrupt change. When the arrival probability is 0.0009, the probability of interference decreases compared with a 0.009 arrival probability. In 0.09 arrival probability, most of the secondary users are in orbit that retransmit RTS massages with probability less than 0.06. On the other hand, high-priority users in orbit retransmit RTS with 0.06 arrival probability that is less than 0.09.

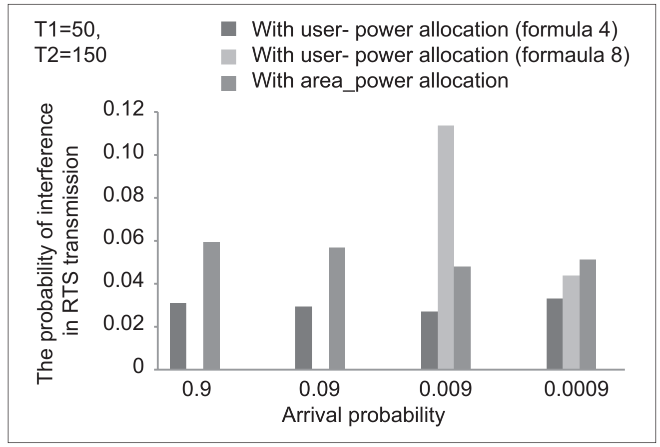

Figure 4: Interference probability versus arrival probability

Similar to the interference probability results, the outage probability [Figure 5] has changed abruptly with different arrival probabilities for the method based on equation (8). Based on the simulation results in Figure 5, in 0.9 arrival probability, the number of users in the high-priority orbit increases, and this causes most of the users to retransmit RTS messages from orbit with 0.06 arrival probability that is less than 0.9.

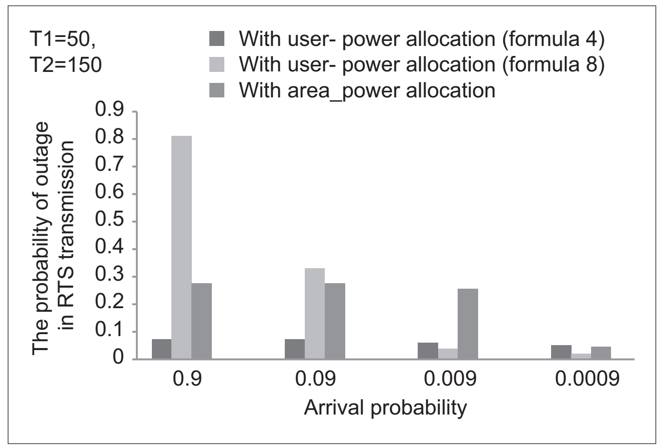

Figure 5: Outage probability versus arrival probability

The effect of coefficient "a" (area–power allocation algorithm) in interference probability is shown in Figure 6. It is evident that with increasing the value of coefficient "a", the probability of interference decreases. These simulations are carried out for RTS power management and there is no interference in data transmission.[1,2]

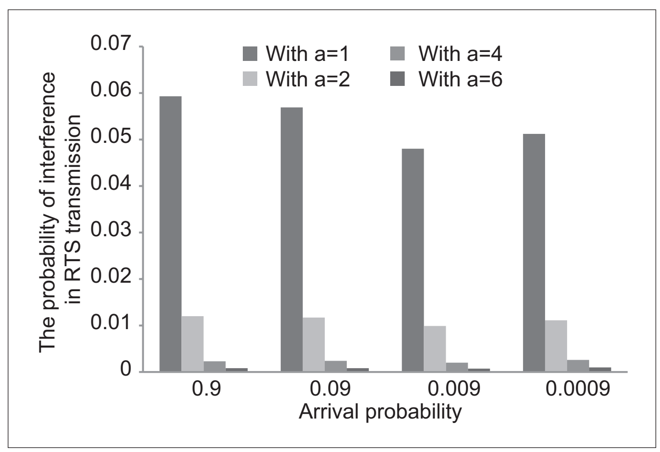

Figure 6: Interference probability with changing parameter "a"

OUTAGE REDUCTION APPROACH

In this paper, we investigate the problem of relay station placement as a solution for outage reduction in a hospital network. As mentioned previously, the users in the network must adaptively tune their transmission power to avoid the harmful interference affecting the medical devices.

Relaying helps convey data packets from the user to the access point (AP) by first receiving the packets from the users and then forwarding them to the AP or vice versa.

In cost-constrained scenarios, such as wireless networks, the use of immobile (fixed) relay station is a very simple and cost-effective solution compared with the cost of installing more APs. In addition, immobile relays unlike mobile relays do not have any limitation of power, through features such as high-capacity battery or access to the power-supply.[19,20]

In a wireless network, distance between transmitter and receiver has an intense correlation with data rate. Therefore, different strategies for the placement of relay stations can affect network performance.[18]

The problem of relay placement has been discussed in different contexts. Previous studies of relay placement have considered various objective functions, e.g. extending coverage,[20] maximizing path diversity,[21] capacity enhancement,[19] optimizing energy usage,[22] minimizing end-to-end delay, maximizing throughput and minimizing error probability.[19] Nevertheless, relay placement problems in e-Health environment have special constraints such as restrictions in relay placement and limitation in maximum relay transmission power, which must be considered.

Genetic algorithm is an optimization technique that can be used to provide approximate solutions to many NP-hard problems in an efficient manner.[21,23,24] The main focus of this section is to determine the optimal placement of a given number of relays in healthcare environments; we investigate the general relay placement optimization problem and show how this problem can be solved by a genetic algorithm.

Genetic Algorithm Principles

In this paper, the basic version of genetic algorithm is employed. An initial population of individual structures or genes is generated (usually randomly), and each gene is evaluated for fitness function. Individuals that have higher fitness value in the prior iteration are chosen as parents to generate new genes in the next iteration. Thus, better genes are given more opportunities to produce offsprings. Then, the genetic operators (usually mutation and crossover) are applied to the individuals. For example, in crossover, the random parts of the parent can be swapped and in mutation, the random bit in a chromosome can be changed. The rates at which mutation and crossover are applied are an implementation decision. If the rates are low enough, it is likely that some of the offsprings produced will be identical to their parents. Other implementation details are the number of offsprings produced by crossover (one or two) and the number of individuals selected and paired in the mating.[25]

Proposed Algorithm for Outage Reduction

We now explain the fitness function and genetic algorithm operators and their parameters for the mentioned problem. A string of binary numbers is used for representation of a chromosome. Each chromosome shows the one-dimension position of a relay. Half of the chromosomes represent the relays position in x-coordination of a Cartesian 2D space, which can vary between [$-x_{max}$, x_{max}]. The other half represent the relays position in y-coordination, which can vary between [$-y_{max}$, y_{max}]. The chromosomes are encoded by the binary encoding scheme. Each chromosome is evaluated by the fitness function. The fitness function is calculated based on the minimum transmission delay and the maximum blind point coverage, and can be determined by (9):

$$\overline{T_r} \cong \frac{1}{M}\sum_{i=1}^{\theta_{max}} \min_{1\le K\le N}[T_r(i,\delta_K,j,\tau_K)] \quad (9)$$

in which $T_r(i,\delta_K,j,\tau_K)$ is the expected transmission time of a user located at the position of (i, j) in order to transmit its data via a relay at (δ,τ), N is the maximum number of relays and M is the number of blind points (users who cannot directly send messages to AP) in a hospital. The roulette wheel selection has been used to select parents. We have applied one-point crossover and random point flip for mutation operation. We have assumed that the genetic algorithm is terminated based on the number of iterations. The population size in our algorithm was fixed to 500, and the number of iterations was fixed to 500.

Performance Evaluation of Outage Reduction Technique

Loss probability and delay are two performance criteria that are usually investigated in different e-Health networks. In the performed simulations, the arrival probabilities of high-priority and low-priority users are assumed to be 0.0002 and 0.0003, respectively. The number of high-priority users is 30 and the number of low-priority users is 80. The size of low-priority orbit is restricted to 3, so to reduce the congestion with high-priority users.[1]

We compare the average waiting time of high-priority users with changing the average size of high-priority data (the size of low-priority data was fixed to 300 kb) for three different methods: with relay placement, with low-priority orbit limited to 3 and without relays or any limitation.

By using relays, the number of outage and also retransmission requests is decreased. Therefore, as shown in Figure 7, the average waiting time in the relaying method is less than the other methods, when the average β_1 is less than 200 kb. However, with increasing the size of transmission data, the average waiting time with relaying increases compared with other methods [Figure 8]. The reason is that in the relaying method, the transmission occurs in two steps; the first step has fixed bit rate equal to 1 Mb/s and the bit rate of the second step depends on the distance between the relay and AP (it is assumed that there is no fading in the channel).

These simulations just demonstrate the waiting time in high-priority orbit. For reduced transmission delay of high-priority users, other approaches can be applied.[1]

When the maximum number of low-priority users in the orbit exceeded a determined threshold, other requests from the low-priority users are dropped (Loss). Hence, as shown in Figure 9, with reducing the probability of β_1 (or with increasing the size of transmission data by the high-priority user), the rate of the dropped requests increases. While in relaying method, there was not any dropped request.

We also investigate the effect of the number of relays in outage reduction in the proposed scenario. Figure 10 represents the outage probability in the network and shows that we can reduce the outage probability by increasing the number of relays. However, installation and maintenance cost of relays

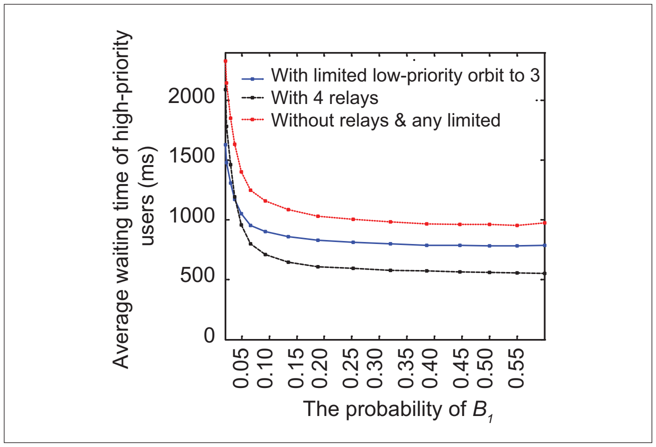

Figure 7: Average waiting time of high-priority users versus high β_1

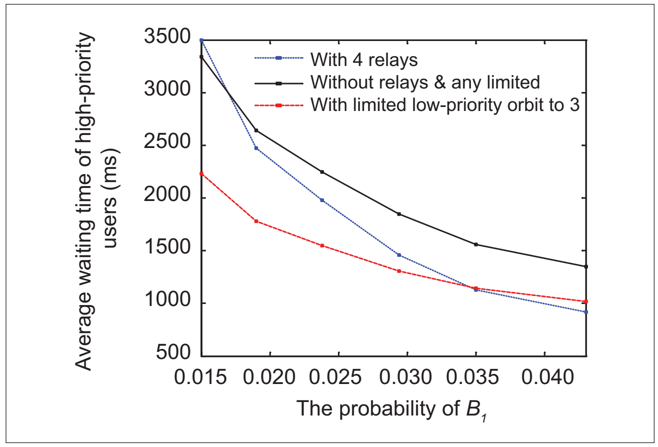

Figure 8: Average waiting time of high-priority users versus low β_1

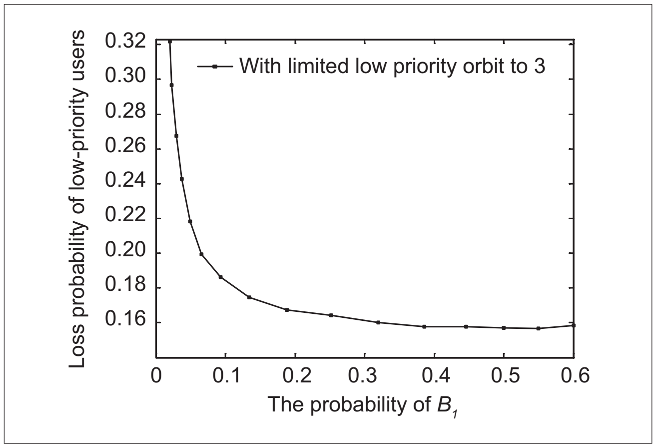

Figure 9: Loss probability of low-priority users versus β_1

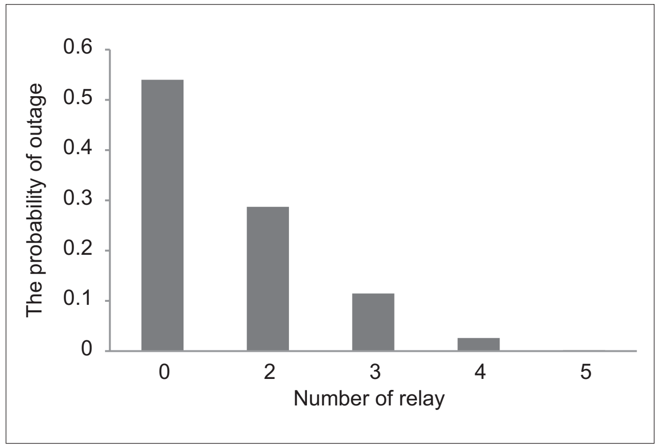

Figure 10: Effect of number of relay in outage reduction

can increase with the number of relays in the hospital. Also, relay usage in the hospital increases the complexity of control massage transmission. Hence, it is essential to define number of relays according to different parameters.

CONCLUSION

In this work, we first investigated two approaches to avoid EMI effects in sensitive healthcare environments such as hospitals. In one approach, the controller must notify the users of their maximum allowable transmission power based on the information about locations, EMI immunity levels, status of sensitive medical devices and the locations of users and sensitive medical devices. To reduce the complexity of the controller in the first approach, the hospital environment is sectored into areas and the maximum allowable power for each area is calculated. To determine maximum allowable transmission power in each area, the average number of users in each area and the aggregated interference probability in different critical points are considered. We then compared interference and outage probabilities for the proposed approaches. Simulation results show that considering network parameters, the interference problem can be alleviated. While, power management methods can control and avoid the EMI problem, they can increase the number of unsuccessful requests. To reduce the outage probability in the aforementioned scenario, the advantages of using relay stations were investigated. We applied genetic algorithm to find optimal positions for relays in the hospital. Performance evaluation results showed that two-hop transferring information using relay stations can reduce the outage probability. In addition, it can reduce delay of high-priority users for small data sizes.

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