Enhancing Wireless Medical Telemetry through Dynamic Spectrum Access

Rahman Doost-Mohammady and Kaushik Roy Chowdhury
Department of Electrical and Computer Engineering, Northeastern University, Boston, USA
Email:{doost,krc}@ece.neu.edu

***Abstract*—Wireless Medical Telemetry Systems (WMTS) currently operate on FCC designated bands for transmitting critical patient health information to distant receivers within hospitals. However, the current devices experience intermittent interference from digital TV transmissions in neighboring channels; are prohibited from transmitting multimedia data; and must operate with a secondary access priority in portions of the WMTS band, also shared with utility metering. We propose a fundamentally new communication paradigm for medical telemetry through dynamic spectrum access technology that adheres to the access rules in the WMTS band, and yet addresses the above concerns. The contributions of the paper are as follows: (i) we undertake a spectrum measurement study at hospital locations in the Boston area to model spectrum usage and activities in the medical band, (ii) we formulate the channel and power allocation task as an optimization problem under constrains of permissible electromagnetic interference to sensitive medical equipment, and latency, bandwidth thresholds of the medical data. Simulation results reveal the potential benefit of the use of dynamic spectrum access to improve medical telemetry and promises long-term improvement in the healthcare domain.**

I. Introduction

Systems that rely on wireless medical telemetry service (WMTS) are an integration of devices that measure vital signs and other health parameters of patients and transmit these parameters through a communication link to a monitoring station [1]. A decade ago, medical telemetry devices were operating on vacant TV channels $7-13$ and $14-46$, or on private land mobile radio in the $450-470\,\mathrm{MHz}$ with a secondary status. In 2000, the FCC in the US designated $14\,\mathrm{MHz}$ of spectrum as the WMTS band for the purpose of medical telemetry covering the ranges $608-614\,\mathrm{MHz}$ (digital television or DTV channel 37), $1395-1400\,\mathrm{MHz}$ (lower-L band), and $1427-1432\,\mathrm{MHz}$ (upper-L band).

Although the FCC has allocated the WMTS bands for medical use, there are several issues that impair free access. First, there are no effective regulations protecting medical telemetry in channel 37 from the harmful interference caused by the power leakage from DTV transmissions in the adjacent channels 36 and 38. In fact, there are many documented cases of interruptions in hospital communication due to this DTV interference [2]. This adjacent channel interference effectively narrows the use of this channel (that represents almost 40% of all WMTS bandwidth). Given the critical nature of hospital communication, this breach must be immediately detected and corrective actions taken [3]. A second cause for concern is the non-uniform access rights in the L bands. Portions of these bands are shared by utility metering telemetry and government radar installations, which have priority access. Thus, the medical telemetry devices must be aware if these primary users or PUs are present in these designated spectrum ranges, and choose different portions of the spectrum, if indeed this is so. The FCC designated the American Society for Healthcare Engineering of the American Hospital Association (ASHE/AHA) to serve as the exclusive WMTS frequency coordinator. Any health care provider who wishes to use WMTS equipment at a given location must first register in advance with ASHE/AHA and provide specified information for the WMTS database. Hence, large hospitals reserve entire bands of the WMTS spectrum for future contingencies, though they typically use very limited portions on a need-basis. Thus, in a region with dense concentration of medical facilities, such as Boston city where our study is based, the WMTS spectrum is used inefficiently under the static database model, and can only support a subset of the demand for spectrum use.

The main contribution of this paper is developing a general communication framework for efficient utilization of the WMTS bands in a medical environment composed of heterogeneous devices with different bandwidth and QoS requirements. We cast the problem of frequency and power allocation in these bands as an optimization problem, subject to the constraints of the medical telemetry and typical hospital applications. Our work is motivated through actual spectrum studies undertaken at the Massachusetts General and Beth Israel hospitals in Boston. As an overview, our framework enables the following:

- It allocates small portions of the spectrum dynamically within the WMTS band to devices based on the type and duration of transmission, thereby increasing the potential for frequency re-use and the resulting channel capacity significantly. Medical telemetry involves transmitting scalar data at set duty cycles, one-shot alarms, streaming information, among others, each with different bandwidth, latency requirements that must be jointly considered [4].
- It protects the existing legacy medical telemetry transmissions that are not equipped with dynamic spectrum access, as well as PUs in the designated portions of the WMTS spectrum. It also regulates transmission power to ensure that electromagnetic interference (EMI) to sensitive medical equipment is within permissible thresholds.

We believe that apart from addressing the spectrum shortage in hospitals, there are other secondary application areas of our work. The FCC currently does not allow home use of WMTS equipment because of the concern that temporary use of such equipment at many dispersed locations would make it difficult to coordinate the operating frequencies, resulting in harmful interference [5]. Our results suggest that it may be possible to revisit this issue of home use of WMTS equipment, also paving the way for mobile hospitals and networked ambulances, which are not permitted under the current rulings.

The rest of this paper is organized as follows: Section III describes spectrum measurements in the WMTS band. Section IV formulates the problem of spectrum and power assignment, and Section V provides a detailed simulation study of our scheme. Finally, Section VI concludes the paper.

II. Network Architecture

The architecture for our proposed scheme is as follows. A central base station (BS) is deployed in the hospital, which admits new data transmission requests made by a node. A "node" here is a medical device that records patient information and transmits it to a remote monitoring agency, caregiver, or to a back-end database that may be different from the BS. The latter is tasked with choosing the optimal amount of bandwidth represented by f_l (frequency at the lower end) and f_u (frequency at the upper end), the modulation level m, and the transmission power p_{tx} for the incoming request. The requests from the node to the BS and the choice of parameters in the reverse direction are made through a common control channel, which could be a designated frequency within the WMTS band or an out-of-band WiFi channel. The proposed optimization scheme is run at the BS, which ensures the node has sufficient bandwidth to meet the QoS requirements, and at the same time is able to transmit with the maximum possible power that does not interfere with sensitive medical equipment. We assume that the locations of such equipment, such as an ECG machine, are fixed and known to the nodes.

We assume three types of medical telemetry applications, as defined in [4]: (i) streaming telemetry, (ii) duty cycle based communication, and (iii) an alarm call, all of which need to be assigned a portion of the frequency band. Before initiating the transmission, the node sends to the BS a request vector $(D_{ij}, d_i, R_{avg}, \ell, BER, EMI)$. Here, D_{ij} is the distance between the two end systems that need to communicate, e.g., the node and the nurse/physician console. d_i is the minimum distance of the node to the sensitive medical equipment in its vicinity. R_{avg} is the average data rate required for the application type. ℓ is the latency requirement for packets transmitted on the link between the communicating node pair. BER is tolerable bit error rate by the application. EMI is threshold level of the sensitive medical devices influenced by the electrical field created around it by wireless radiation. Based on this request vector and the previous choices made by other communicating nodes in the area, the BS runs the optimization problem.

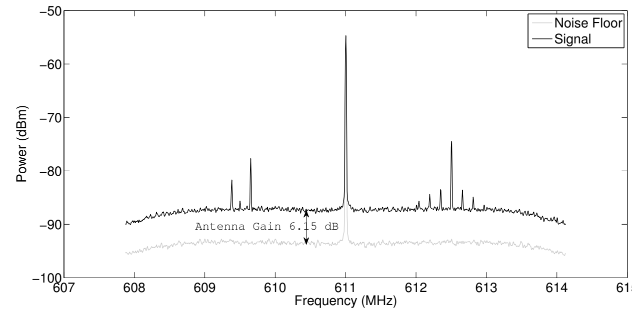

Fig. 1. Frequency domain signal in the UHF Channel 37 vs. the noise floor.

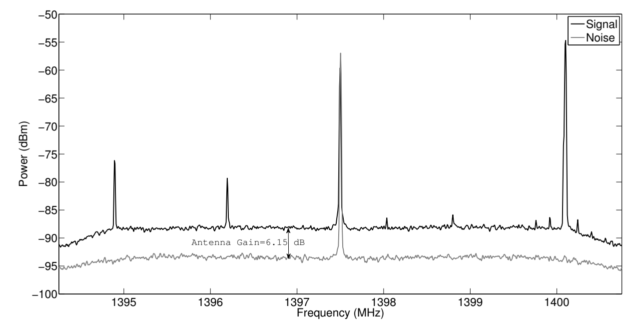

Fig. 2. Frequency domain signal in the Lower L-band vs. the noise floor.

III. Characterizing the WMTS Bands

While several studies have been undertaken in the existing DTV bands, little is known of the PU activity in the WMTS bands. In this section, we describe some experiments undertaken at the Beth Israel hospital on channel 37[1]. Determining the true noise floor in a channel is an open debate, and we first describe our methodology that proved useful in obtaining a statistically significant result on whether a portion of the channel is "active" or "vacant". This is followed by obtaining a PDF of the active times of the channel usage by approximating it with an exponential curve. The channel activity will be subsequently used as an input in the optimization problem that we formulate.

A. Noise Floor Determination

Obtaining a precise measurement of the noise floor is critical in correct decision making, a key concern in the WMTS bands that relies on life-saving communication. The noise floor that we measure includes the thermal white noise incurring at the radio frequency (RF) input plus the noise added by the radio receiving chain due to noise figure of the intermediate frequency (IF) components. We use the USRP2 as a measurement tool [6], and terminate its RF input with a $50\,\Omega$ SMA terminator. We then tune the device to the three portions

[1] We omit similar results obtained at the Massachusetts General Hospital for want of space. The L bands showed similar behavior, though the curve fitting on the raw data exhibited differences based on location and time

of the WMTS bands (37, upper and lower-L) successively, and collect 5×10^5 samples each time. We calculate the FFT from these samples using a bin size of 1024. Each bin records the noise power at a resolution of $\frac{6}{1024}$ MHz for the channel 37, and $\frac{5}{1024}$ MHz for the L bands. At the end, the individual power values in each bin are averaged to obtain the reliable noise floor. Note that this method produces bin-specific noise level, unlike a channel-wide noise level commonly assumed in the literature. We show a plot of the measured noise floor for the channel 37 in Figure 1 and for the lower-L band in Figure 2.

In our measurements, we observe a continuously occurring peak at the center frequency of the channel, which is due to signal leakage from the oscillator at the radio front-end. This artifact is observed for any USRP2 device[2], and is added to the incoming signal. This will cause a problem in correct detection of the present signals in the band when a fixed threshold is used, i.e., the center frequency will always and falsely indicate a present signal. By using the above bin-specific noise floor method, the effect of such RF hardware imperfections can also be eliminated from the spectrum sensing. Figure 1 shows a true frequency domain signal in the channel 37 with several peaks versus noise floor. Our sensing method for the WMTS band, which overcomes the hardware imperfections, involves the following steps:

- Subtract the antenna gain from the bin power ($6.15\,\mathrm{dB}$ in our case).
- Subtract a fixed threshold from the bin power to compensate for signal and noise floor variance ($3\,\mathrm{dB}$ in our case).
- Compare the observed bin power with the previous power of the noise floor and infer the sensing results.

Figures 1 and 3 how these steps are undertaken to extract the true signal from the measured signal. All eight peaks in the signal have been detected in this process, and more importantly, the leakage peak issue described earlier, is not included in the clean, final signal. This is because during noise measurement, the center peak (i.e., error in the noise floor) is greater than the center peak in the signal after subtracting antenna gain and threshold value from the value contained in the FFT bin. Since this center peak is the internal hardware artifact, its power is constant, with or without the antenna on the radio, and it can hence be easily suppressed through the above steps.

B. Channel Activity Model

In this section, we will obtain a probabilistic model for the signal on and off times at each frequency bin. In the following, we describe the measurement study on the WMTS channel 37 on the rooftop of Beth Israel hospital located in Boston's Longwood area, one of the largest healthcare centers in Northeastern America. Similar methodology was followed for the L bands. In this study, we measured the spectrum usage

[2]We tested with 5 different radios, each with the same result and this is widely reported in the USRP2 Community's mailing list.

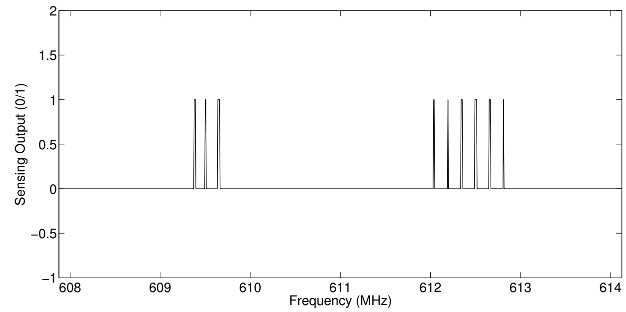

Fig. 3. Spectrum Sensing result via energy detection on UHF Channel 37.

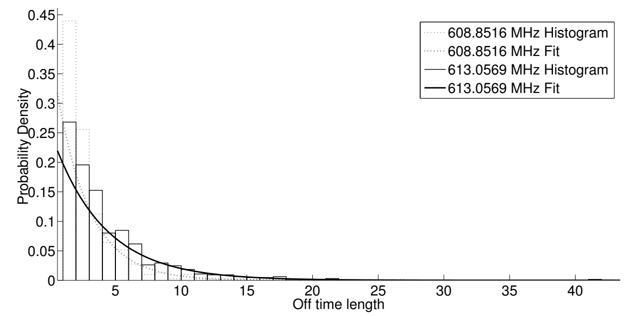

Fig. 4. PDF fitting for the "off" time duration of the bins centered at $608.8516\,\mathrm{MHz}$ and $613.0569\,\mathrm{MHz}$.

on this channel using the USRP2 platform for an hour. We performed 1024-point FFT on the consecutive samples taken in channel 37 (obtaining a $6100\,\mathrm{Hz}$ resolution for each bin). Using the noise floor determination technique in Section III-A, we extracted the active medical telemetry signals for each bin. Since these signals are temporally intermittent, we performed a statistical analysis at each bin on the times that these signals turn on and off. Using the PDF curve fitting function in MATLAB, we fit an exponential PDF function on these "on" and "off" time samples. Therefore, the activity in each bin is captured with two λ_{on} and λ_{off} values, representing the mean values of their respective exponential distribution. Figure 4, shows the histogram of off times at two different bins (frequencies) out of 1024 bins, within the channel 37 and the fitted exponential PDF. Similarly, figure 5 shows such histograms and the fitted exponential PDF for two sample bins in the lower-L band. We obtaind similar result for the upper-L band, but we could not show them here because the lack of space.

This PDF will be used in the next section for determining the channel allocation to the nodes in the network. As this measurement is highly site-specific, it needs to be repeated for each new hospital location. In channel 37, these measurements represent all legacy medical telemetry activity, where devices are not equipped with dynamic spectrum access methods. In the L band, the observed channel activity jointly captures both the existing medical telemetry and utility metering applica-

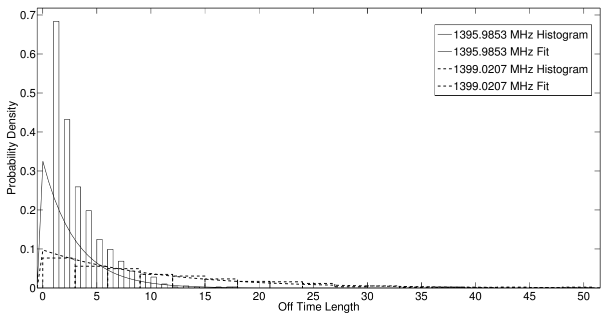

Fig. 5. PDF fitting for the "off" time duration of the bins centered at 1395.9853 MHz and 1399.0207 MHz.

tions.

IV. Problem Formulation

We formulate the problem as a two-step process. The first involves identifying the power and modulation for the requested transmission, and then, we identify the specific frequency range to which it may be allotted.

A. Determining Transmit Power and Modulation

Let the occupancy function $P_{on}(f)$ represent the probability that frequency f is occupied by legacy medical users without dynamic spectrum access ability or utility meter applications (both denoted as PUs) at frequency f. From Section III-B, we obtain two functions $\lambda_{on}(f)$ and $\lambda_{off}(f)$ as the mean "on" and "off" exponential durations, respectively.

Based on the PU activity at each frequency f, the sensing durations may be different. One possible method for determining the sensing time t_s is given in [7].

We begin with the BS computing the power p for the given vector $(D_{ij}, d_i, R_{avg}, \ell, BER, EMI)$ submitted by a node. We consider a single-carrier communication method with MPSK modulation. The combined effect of the modulation in the signal and the signal power must satisfy the BER constraints given in the QoS vector. At the same time, the transmit power of the node is constrained by the EMI threshold level of the sensitive equipment [8]. For a node i,

$$p_i \leq (\frac{d_i EMI_i}{c})^2 \tag{1}$$

where c is constant and EMI_i is the lowest EMI threshold level. The probability of symbol error for MPSK modulation is given as follows [9]:

$$P_E = 2Q\left(\sqrt{\frac{2E_s}{N_0}} \sin\frac{\pi}{M}\right), \tag{2}$$

where $\frac{E_s}{N_0}$ is symbol-energy to noise-power spectral density, $Q(x)$ is the complementary error function and is defined as

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{\infty}^{x} exp\left(-\frac{u^2}{2}\right) du, \tag{3}$$

Also $\frac{E_s}{N_0}$ is related to $\frac{E_b}{N_0}$ (bit-energy to noise-power spectral density) via the following relation:

$$(\log_2 M)\left(\frac{E_b}{N_0}\right) = \left(\frac{E_s}{N_0}\right) \tag{4}$$

Furthermore, $\frac{E_b}{N_0}$ is function of SNR and rate R [10]:

$$\left(\frac{E_b}{N_0}\right)_{dB} = \left(\frac{S}{N_0}\right)_{dB-Hz} - R_{dB-\frac{bit}{sec}} \tag{5}$$

The $\frac{E_s}{N_0}$ in 2 can be replaced with $(\log_2 M)\left(\frac{E_b}{N_0}\right)$.

Considering free-space path loss for transmitted power p, the received power at the receiving node is:

$$p_r = p \times \alpha D_{ij}^{-\beta} \tag{6}$$

Bit error rate P_b and symbol error rate P_E for the case of MPSK are related as [9]:

$$P_b = \frac{1}{k} P_E \tag{7}$$

Combining the above equations, we get:

$$P_b = \frac{2}{k} Q\left(\sqrt{2m\frac{p_i \alpha D_{ij}^{-\beta}}{N_0 R_p}} \sin\frac{\pi}{M}\right), \tag{8}$$

where $m = log_2 M$. To achieve the given BER (p_b),

$$p_i \geq [Q^{-1}(\frac{1}{2m} p_b)]^2 \frac{N_0 R}{2m\alpha D_{ij}^{-\beta}} \tag{9}$$

This is the second constraint for transmit power to be assigned to the application. The selected modulation (M) must satisfy these two constraints integrated in the following optimization problem:

$$\begin{aligned} &\textit{Given}: D_{ij}, d_i, R_p, P_b, EMI \\ &\textit{To find}: m \\ &\textit{To Minimize}: P_{tx} \\ &\textit{Subject to}: \end{aligned} \tag{10}$$

$$P_{tx} \leq (\frac{d_i EMI}{c})^2 \tag{11}$$

$$P_{tx} \geq [Q^{-1}\left(\frac{1}{2m} P_b\right)]^2 \frac{(N_0 + I) R_p}{2m\alpha D_{ij}^{\beta}} \tag{12}$$

The above optimization problem find the minimum transmission power level for the transmission of device i in order to avoid exceeding EMI level for the sensitive medical equipment (11), and also at the same time, satisfy the BER requirement for the corresponding application (12).

Finally, we assume the following simple relation between the allocated bandwidth and the rate of the application:

$$B = \frac{R}{m} \tag{13}$$

B. Determining Frequency Range

To find the best channel in the WMTS band, let the availability function $A(f)$ indicate whether a frequency f is currently assigned for medical telemetry (i.e., $A(f) = 0$) or currently used by the PU (i.e., $A(f) = 1$). With this function, the BS must solve the following optimization problem to get the best channel for the submitted application.

$$\begin{aligned}
&\textit{Given} : R_p, R_a, \ell, L_p \\
&\textit{To find} : f_u, f_l \qquad (14)\\
&\textit{To Minimize} : B = f_u - f_l \\
&\textit{Subject to} :
\end{aligned}$$

$$\int_{f_l}^{f_u} A(f) = 0 \tag{15}$$

$$\int_0^{\infty} t\lambda_{off}^{max}(f)e^{-\lambda_{off}^{max}(f)t}dt \geq \frac{L_p}{R_a} \tag{16}$$

$$\lambda_{off}^{max}(f) = max\lambda_{off}(f)|_{f_l}^{f_u} \tag{17}$$

$$maxt_s(f)|_{f_l}^{f_u} = t_s^{max}(f) \leq \ell \tag{18}$$

$$\frac{T}{T + t_s^{max}(f)}|_{f_l}^{f_u} \times (f_u - f_l)m \geq R_a \tag{19}$$

$$T = \int_{f_l}^{f_u}\int_0^{\infty} t\lambda_{off}(f)e^{-\lambda_{off}(f)t}\mathrm{d}t\mathrm{d}f \tag{20}$$

where ℓ is the Latency in the QoS vector and L_p is the packet length. We define the constraints in (15)-(20) as follows:

- The first constraint (15) on choosing the band is to make sure that it is currently free and not occupied by any other user (either primary or secondary). If the band spans several bins, it means that the summation of the availability function on all bins must be zero.
- When a band containing several bins is picked, the average time left to the first estimated appearance of a PU must be longer than the time needed to send at least one packet (16). At each bin, λ_{off} represents the inverse of the average of the exponential distribution or average time left to next appearance of a primary user. (17) finds the bin with lowest such value among the potential bins to be picked as the solution.
- Since we derive different required sensing times for each bin from [7], among the potential solution bins, the highest sensing time must be picked for the whole band. However, this value must be lower than the latency ℓ permitted by the application (18).
- The effective rate of the application considering the sensing duty cycle and the modulation level must be at least equal to the average required rate by the application (19).
- Finally, (20) calculates the average free time for the potential band.

The node can now immediately begin its transmission with these parameters returned by the BS.

V. Performance Evaluation

To evaluate the performance of the proposed WMTS dynamic spectrum allocation framework, we use the power measurement data of channel 37 and L band collected from the hospital environment. Our measurement data includes one hour of collected data with resolution of every second spanning. A 1024-point FFT is performed on the time-domain signal taken at every second, which provides a resolution of approximately 6100Hz for every bin in the frequency domain. Based on the activity model of the channel, we try to accommodate new dynamic spectrum access nodes (as secondary) in the empty portions of the band. We consider 7 types of telemetry applications with specifications given in the table below [4]:

Application Type	Size Kb/Packet	Avg Rate kb/s	Events per hr	Latency ms
Telemetry	2.6	12.8	Stream	200
Telemetry Diagnostic	5.1	25.6	Stream	200
Telemetry Alarm	1.0	0.1	10/h	-
Clinician Notifier	2.6	0.1	20/h	200
BCMA	0.4	0.1	30/h	500
Infusion Pump Status	1.0	1	Stream	200
Infusion Pump Alarm	1.0	0.1	1/h	200

TABLE I
Application specifications in a hospital case-study [4]

There are different numbers of each application in a hospital, usually a function of the hospital area. For instance, for a typical hospital case study given in [4] with total area of $18580\ \mathrm{m}^2$, these numbers are $(60, 21, 22, 20, 19, 81, 18)$ corresponding to the table I. The streaming applications above must be assigned with their required bandwidth at all times. On the other hand, the alarms and also other applications running on duty cycles must be assigned with adequate bandwidth upon their arrival. We created events of such arrivals with poisson distribution for each duty cycled application with the given rate in the table above in MATLAB, and simulated the power and frequency allocation respectively. For duty cycled and alarm applications, a total on time of $1\,\mathrm{s}$ was considered since these are only sudden bursts of information. We performed the simulation with randomly chosen locations of each application device in an square area of $140 \times 140m$. This is comparable in size to the hospital case study mentioned above.

We compare the performance of the proposed scheme with the classical static allocation case, where every application is assigned with an empty band from the beginning of the simulation. We consider two metrics for such a performance comparison, *residual capacity* (unused spectrum) and *number of interfered PU incidents* during a 1 hour simulation given the number of application mentioned above. Figures 6 and 7 confirm the effectiveness of the dynamic case over the static case. Figure 6 shows that in the dynamic case, the spectrum is used more efficiently than in the static allocation scheme. Also the number of PUs affected by the secondary transmission is remarkably reduced in the dynamic case, indicating that the

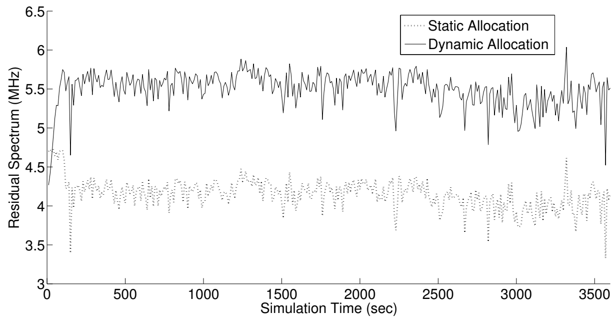

Fig. 6. Residual capacity of WMTS band in static and dynamic spectrum allocation scenarios.

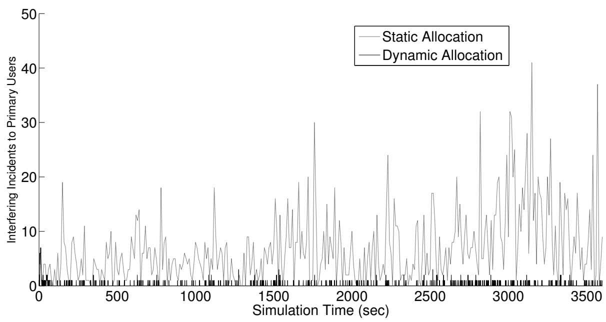

Fig. 7. Number of interfering incidents to primary users in static and dynamic spectrum allocation scenarios.

interference to the PUs is minimized.

Figure 8 compares 3 types of applications (Streaming, Duty Cycled and Alarms) in terms of the interference they cause to the PUs as their number increases from 10 to 100. Non-intuitively, Duty Cycled ones are more hazardous in terms of interference, since they are more frequent than alarms. Moreover in contrast to Streaming, no sensing is done on their assigned spectrum during the second that they use it. As the number of streaming transmissions increases, the amount of interference they cause rises due to their higher bandwidth requirement compared to alarms.

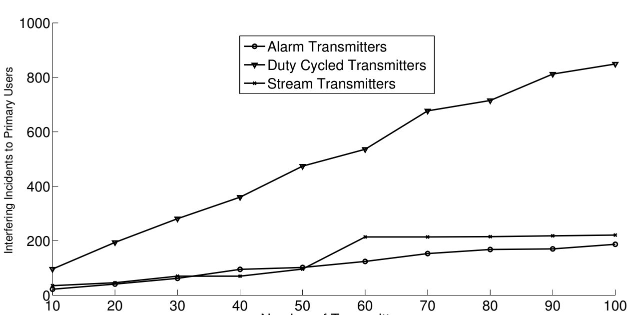

Fig. 8. Number of interfering incidents to primary users in different application types and varying numbers.

VI. Conclusions

In this paper, we have proposed a dynamic spectrum access framework to efficiently utilize the WMTS bands for wireless medical telemetry applications in a hospital environment. The proposed framework assigns optimal bandwidth and power to each medical application device seeking to send data to any other location in the hospital, e.g. telemetry data from a patient to the physician's monitoring station, while avoids interfereing with primary signals of that band also protecting the EMI threshold of sensitive medical equipment. We also performed a measurement study on the WMTS band to derive the activity model of medical telemetry signals in that band. We have used this activity model as a base for the simulation of our optimization framework. Our simulation results indicate the advantages of such a framework for reducing the amount of interference caused to PUs, and also in ensuring the efficient use of the WMTS bands.

Acknowledgement

This material is based upon work supported by the US National Science Foundation under Grant No. CNS-1136027. The authors would like to thank Mr. Rickey Hampton from Partners Healthcare for the helpful discussions on the general problem and for the support during the onsite spectrum measurements.

References

[1] FCC, About Wireless Medical Telemetry. [Online] http://wireless.fcc.gov/services/wmts/about/
[2] R. Hampton, Lessons Learned from Interference to Wireless Medical Telemetry Service Systems. *IT Horizons, published by Association for the Advancement of Medical Instrumentation*, pp. 37–39, 2006.
[3] Medical Connectivity, [Online] http://medicalconnectivity.com/2008/04/27/an-assessment-of-wireless-medical-telemetry-system-wmts/
[4] S. D. Baker, D. H. Hoglund, Medical-Grade Mission-Critical Wireless Networks. *IEEE Engineering in Medicine and Biology Magazine*, pp. 86–95, vol. 27, no. 2, March 2008.
[5] FCC, Equipment and Usage. [Online] http://wireless.fcc.gov/services/wmts/wireless-medical-telemetry/
[6] Ettus Research, USRP2 Datasheet [Online] http://www.ettus.com/downloads/ettus-ds-usrp2-v5.pdf/
[7] W.Y. Lee, I.F. Akyildiz, Optimal Spectrum Sensing Framework for Cognitive Radio Networks. *IEEE Wireless Communications Magazine*, pp. 20–28, vol. 17, no. 1, February 2010.
[8] P. Phunchongharn, E. Hossain, D. Niyato, S. Camorlinga, A Cognitive Radio System for E-Health Applications in a Hospital Environment. *IEEE Wireless Communications Magazine*, pp. 20–28, vol. 17, no. 1, February 2010.
[9] J.G. Proakis, M. Salehi, Digital Communications. *McGraw Hills*, November 2007.
[10] B. Sklar, Defining, Designing, and Evaluating Digital Communication Systems. *IEEE Communications magazine*, pp. 91–101, vol. 31, no. 11, November 1993.