A Proposal of QoE Based Self-Organized Wireless System Considering the Measurement Results in a Major Hospital

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***Abstract*—In this paper, we propose a Quality of Experience based autonomously distributed wireless system for medical and disaster situation. The radio resource assignment and topology are dynamically controlled based on QoE of each application. First of all, we show a situation of 2.4 GHz wireless system environment in a major hospital, and raise some issues of spectrum usage in medical area from the measurement results. The results indicate possible technologies for more efficient spectrum usage with considering application quality. After discussing these aspects, we show the concept of our proposed self-organized wireless system for solving the issues.**

Keywords—Wireless system, Quality of Experience, autonomously distributed system, spectrum sensing, network topology

I. Introduction

Recently the demand for self-organized wireless systems such as wireless local area network (WLAN) and Bluetooth is explosively growing as smartphones and tablet computers are introduced. The trend also leads development of new wireless applications. Medical area is not an exception and the introduction of wireless systems and applications is ongoing in many hospitals. High-tech medical treatments need many sensors and equipments. And it is expected that wireless connectivity among medical sensors, equipments and medical data servers provides higher work efficiency.

A self-organized wireless system in industrial, scientific and medical (ISM) band such as 2.4 GHz and 5 GHz provides freedom of deploying wireless connectivity to users compared to other wireless systems in licensed bands. The users can choose the most suitable wireless system according to the requirements of applications and devices such as data rate, size and power consumption. However, a system in ISM band must share the radio resources of same frequency band with other wireless systems. Even among systems using same wireless technology such as IEEE 802.11 WLAN systems [1], they would be operated independently by different owners or operators. In this case it is not possible to harmonize the usage of the frequency band.

Higher spectrum efficiency is required in ISM band because the insufficiency of radio resource is being exposed due to the trend of increasing wireless applications. The bandwidth of 2.4 GHz ISM band has only 80 MHz whereas the demand of required bandwidth is expected to be comparable or even wider than the bandwidth for connecting several sensors and medical equipments, and high-quality picture transmission in a hospital. Machine-to-machine (M2M) system or sensor network technology has been a hot topic in wireless research area. However, a wireless system deployed in hospital needs to cover from of low-data rate sensors to high-speed applications while sharing same frequency band with other WLAN, Bluetooth and other equipments.

The target of our research is to develop solutions for improving the efficiency of spectrum usage as well as application quality even in crowded frequency band condition. In order to see the actual situation of ISM band in medical area, a measurement campaign of 2.4 GHz ISM band is performed in a major hospital where a huge information and communication technology (ICT) system based on WLAN and Bluetooth systems are introduced.

In this paper, we show the results of the measurement campaign performed in Kyoto University Hospital. After that we analyze and discuss these results for raising issues of spectrum usage in ISM band. Finally we propose a system concept for controlling radio resource assignment and topology of wireless system based on the quality of experience (QoE).

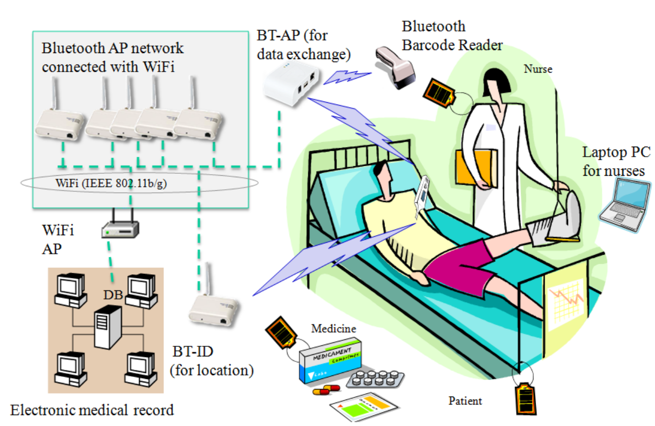

Figure 1. WLAN and Bluetooth based system deployed in Kyoto University Hospital.

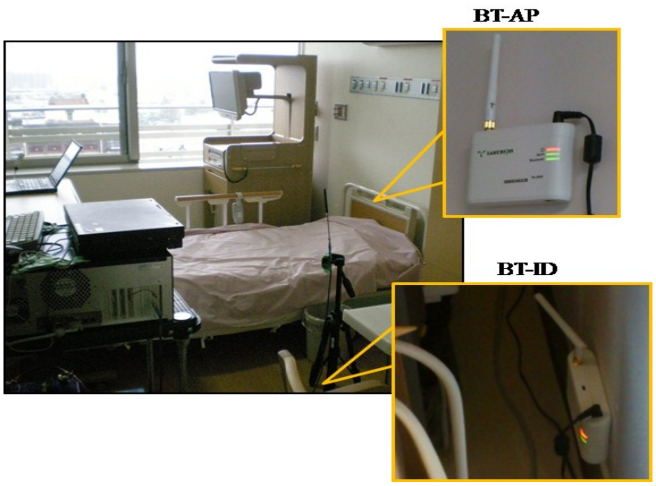

Figure 2. The picture of installed BT-AP and BT-ID in a patient room of a building "Sekitei".

II. OVERVIEW OF KYOTO UNIVERSITY HOSPITAL

We measured the spectrum usage of 2.4 GHz ISM band in Kyoto University Hospital, which has introduced many of WLAN and Bluetooth systems as their ICT system working daily bases. Table 1 shows the overview of the hospital and their system.

Table 1. Overview of Kyoto University Hospital.

Location	Kyoto City
Number of building	6
Number of beds	1182
Number of diagnosis departments	21
Number of medical staff	2700
Number of outpatients (daily)	2600
Number of WLAN APs	650
Notebook PCs with WLAN for medical stuff	1000
Bluetooth-WLAN APs (BT-AP)	600
Bluetooth barcode readers	1500
Bluetooth IDs (BT-ID)	1100
Bluetooth navigation system for patients	2700

WLAN system is introduced for preparing accessibility to a medical database from 1000 of notebook PCs held by medical stuff. And there are several types of Bluetooth devices utilized in the hospital. One is a navigation and communication system for outpatients. The hospital has daily 2300 outpatients and everybody gets the device at the reception. The device indicates the next room an outpatient needs to go, and a medical stuff can check the position of the patient in the building. Voice communication is also possible between medical stuff and the patient. Another introduced device is a wireless bar-code reader for identifying inpatients. Each of the inpatients wears wristband with individual bar-code, and a medical stuff can easily confirm right medicines for right inpatient. In order to connect the Bluetooth devices and backbone, a Bluetooth-WLAN AP is implemented in each patient room as shown in Figure 2. The WLAN connectivity relays the data from Bluetooth devices to WLAN APs connected to backbone. Additionally, Bluetooth ID is implemented beside each bed so as to identify an inpatient.

III. MEASUREMENT METHOD

Several measurement equipments for monitoring the usage of 2.4 GHz ISM band are used in this measurement campaign. Figure 3 shows the overview of Data logger. It measures the spectrogram of whole 80 MHz bandwidth of 2.4 GHz band at once by having 200 M Sample / s analog-to-digital converter (ADC), and stores the sampled data to a 1.1 TB hard disk. The frequency resolution is 125 kHz and the time resolution is 4 µs so as to observe SIFS of WLAN signal in a time domain as well as 270 kHz-width Bluetooth signal in a frequency domain. A removable 1.1 TB hard disk can store 30-minute data. An omni-directional whip antenna is utilized on the data logger to measure the signal from whole directions. Additionally, a protocol analyzer is also used in the measurement.

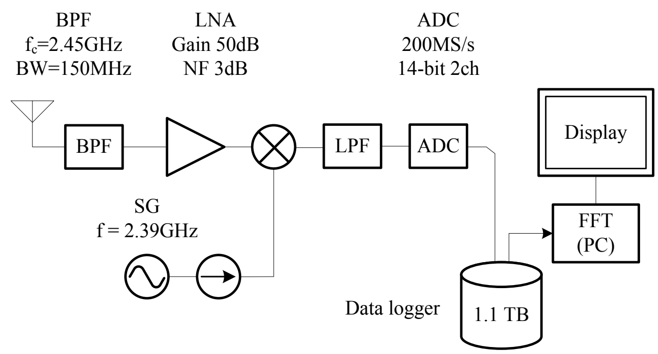

Figure 3. Block diagram of 2.4 GHz ISM Spectrogram measurement equipment (data logger).

IV. MEASUREMENT RESULTS

Figure 5 shows the measurement results observed in a patient room. There are a lot of Bluetooth signals overlapped on WLAN signals in these figures. However, the WLAN signals are not stopped by these Bluetooth signals although WLAN has a carrier sensing mechanism. This means that the Bluetooth signal at the position of the WLAN station (STA) is not enough strong to stop the WLAN transmission.

It is also observed in Figure 5 that an AP at channel 3 generates a vacant radio resource due to WLAN's carrier sensing of other systems. The hospital allocates the frequency channels of their wireless system to channel 1, 5 and 8. However, it is impossible to manage mobile wireless routers, which might be brought by visitors.

Figure 6 shows the spectrogram measured at a corridor. Radio waves from a microwave oven are observed on the spectrogram. There are several microwave ovens on the floor as indicated in Figure 4. In this measurement case, it fortunately doesn't interrupt the transmission of the WLAN system on channel 5. However the electromagnetic wave from microwave ovens must be major reason of interference to the wireless systems.

And Figure 7 shows the result at a corridor. It is reported before the measurement campaign that the WLAN connection from a patient room was not stable. According to the measurement, the reason is coming from metal automatic door between the corridor and stuff area as shown in Figure 4. In this case, there are two neighbor WLAN APs from the patients room. The Bluetooth-WLAN AP (BT-AP) relays the data of Bluetooth devices to the backbone via these WLAN APs outside of the patient's room. It is expected that the BT-AP establish a connection between AP2 or AP1 behind the metal door when the door is open.

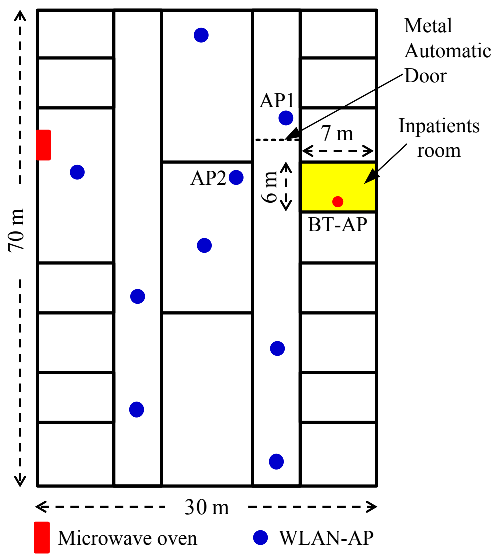

Figure 4. The map of a floor and position of APs in a building "Sekitei" in Kyoto University Hospital.

V. Discussions for efficient Spectrum Usage

In ISM band, it is necessary to share the limited radio resources among APs, STAs and other wireless systems efficiently while keeping the application quality. Each application has different traffic and QoS requirement. For example, a clinical thermometer doesn't need to send the measurement results immediately since the human body temperature would not change quickly. Even the data transmission fails, it is allowed to resend it several times until the packet reaches to a receiver. On the other hand, video streaming data needs to be sent constantly and fluently even though other wireless systems coexist.

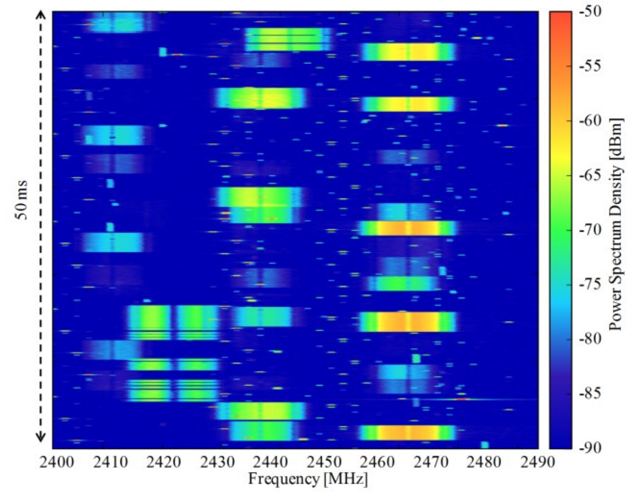

Figure 5. Spectrogram of 2.4 GHz ISM band measured in a patents room.

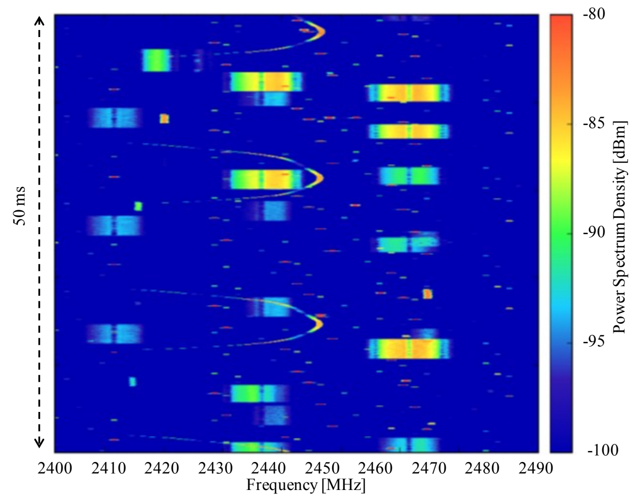

Figure 6. Spectrogram measured in front of the nurse station with a wave from a microwave oven.

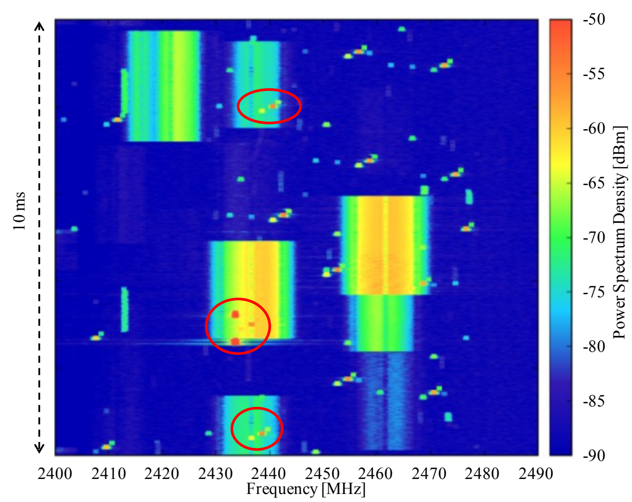

Figure 7. Spectrogram of 2.4 GHz ISM band measured at a corridor.

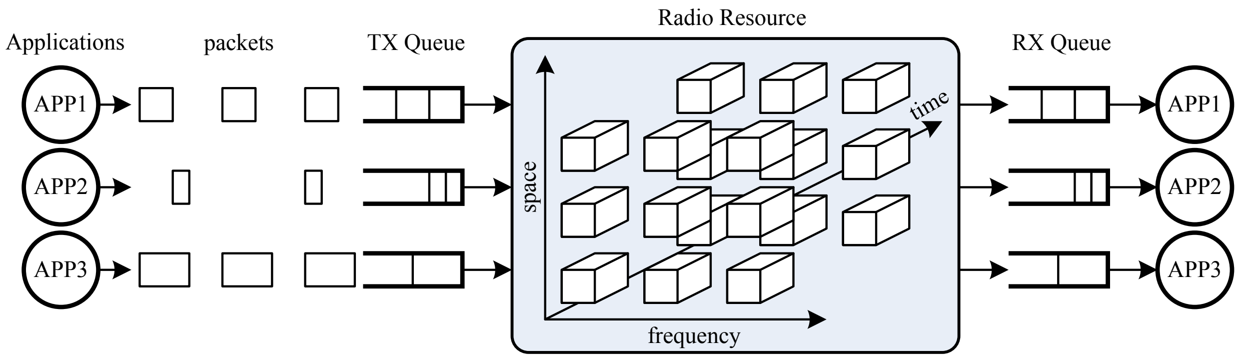

Figure 8. Data flow over radio resources from senders to receivers of applications.

Accordingly, it is important to consider required packet flow and to assign radio resource based on the usage of frequency band in order to improve the application quality. We proposed a QoE based wireless network system [2]. It consists of a spectrum sensing, a radio resource assignment (RR), access control (AC) and a topology control functions (TC). The spectrum sensing function receives whole 80 MHz bandwidth of 2.4 GHz band, and calculates the spectrogram of the frequency band. After that it derives the traffic pattern of each signal from other wireless systems. The function detects vacant radio resources as well as the spectrum usage of other wireless systems. The RR allocates the radio resource for each wireless link. There are three axes of radio resources, frequency, time and space (Figure 8). The function assigns the resources on these axes according to the results of the spectrum sensing and the requirement of an application. The TC manages the network topology for balancing the amount of wireless traffic of in a cell, and controls the interferences and collisions between the signals from APs and STAs. After setting up radio resource and network topology, the AC sends packets in a TX queue. The transmission timing is determined by application type and priority.

According to the measurement campaign, we found several issues to be solved for designing the radio resource management functions. Physical performance of packet transmission such as throughput, jitter, packet error rate (PER) determine the majority of QoE. Therefore the measurement results must be taken into account for achieving higher spectrum efficiency and target QoE.

A. Frequency alignment

For packing the radio signals closely, it is important to align the frequency channels of the systems according to their signal bandwidth. If a part of the frequency channels are not aligned well with other signals as shown in Figure 5, there must be a “hole” of radio resources and it causes inefficient spectrum usage. In case of fixed APs, the frequency channels of APs are equipped very carefully in order to realize stable channel quality. However wireless mobile routers can select the channels freely. Therefore there must be a functionality to align the frequency channel with explicit or inexplicit coordination among APs.

B. Signal bandwidth

Variable signal bandwidth is necessary for filling out vacant and unused radio resources. The modulation type defined by required signal bandwidth, modulation scheme, coding rate must be agreed between an AP and a STA. A control message on a beacon or multicast channel can inform the modulation type, or there must be negotiation scheme between the AP and the STA.

C. Cooperation of APs with explicit / inexplicit information exchange

Coordination among APs is necessary to improve the efficiency of spectrum usage. Among same wireless systems, it is possible to implement messages for coordinating the APs, for example, on a beacon signal. However explicit information exchange consumes other radio resources. Furthermore it is not possible to realize explicit information exchange between different wireless systems. Among different wireless systems, it could try to estimate other systems by receiving signals and analyzing traffic patterns, or try to inform the intention by sending signals for let them avoid signal transmission using their CSMA/CA mechanism.

D. Power control

Transmission power must be adjusted for controlling interference among APs and STAs. Especially the power control including antenna beam steering improves radio resource usage when communication range i.e., distances and direction is limited in some application cases.

E. Frequency assignment according to applications

It is necessary to assign a suitable frequency channel to a communication with an application by considering the usage of a frequency channel. A discrete and small data transmission such as a thermometer can be assigned to a busy-traffic channel whereas video streaming must be assigned to a frequency where certain amount of radio resource is available constantly. A proposal is that an AP monitors the traffic over all frequency channels and suggests STAs to use suitable frequency channel according to their application.

F. Channel quality measurement:

The channel quality must be monitored by APs and STAs, and the results are informed to APs for wireless network management. Some APs manage the network topology by using beacons and control channel. The management interval must be adapted to the speed of network condition change. However, too fast management interval should harm the efficiency of spectrum usage because of too many administrative messages. The speed of network change is determined by several reasons e.g., attach/detach/move of terminals and interaction between signals caused by CSMA/CA manner.

VI. PROPOSED SYSTEM

According to the discussions, we propose a wireless system as shown in Figure 9. The structure of the proposed wireless system includes feedback loop which works to reduce the difference between a target QoE and achieved QoE. For example, if the achieved QoE does not meet the target, RR, AC and TC in the controller try to obtain more radio resources.

The proposed system respected to an application is described in (2).

$$\begin{aligned} \boldsymbol{s}_{n+1} &= A(\boldsymbol{s}_n, u_n) \\ y_n &= C(\boldsymbol{s}_n, u_n) \end{aligned} \tag{2}$$

where u_n is an input data packet from an application at a transmitter and y_n is the output of the wireless system at a receiver. The state of wireless environment $\boldsymbol{s}_n$ includes the situation of the frequency band, i.e., data traffic, interferences and collisions between packets from other nodes and wireless systems. Accordingly by transmitting a packet u_n through the wireless system, the state $\boldsymbol{s}_n$ transit to $\boldsymbol{s}_{n+1}$. From the assumption of wireless systems in ISM band, the proposed system coexists with other wireless systems, and they make influence between each other by transmitting data packet. Therefore $\boldsymbol{s}_n$ is not fully controllable because it must be determined also by other systems' behavior.

The proposed system tries to get radio resources and optimize network topology for transmitting data to obtain enough QoE. The performance of packet transmission, e.g., the flow of data packets can be measured by observing the transmission (TX) queue. And the achieved QoE η is derived by using a function

$$\eta = f(QoS). \tag{3}$$

The achieved QoE η is subtracted from the target QoE η_0,

$$x = \eta_0 - \eta \tag{4}$$

and the controller changes the setting of RR, AC and TC based on the status of wireless system condition so as to minimize x. Here we describe the functionality of the controller as $\pi(x, \boldsymbol{S})$ where $\boldsymbol{S}$ is determined by $\hat{\boldsymbol{s}}_n$ and $\boldsymbol{s}'_n$. The sensing function can observe the situation of the frequency band, but only part of the elements of $\boldsymbol{s}_n$, i.e., $\hat{\boldsymbol{s}}_n \subseteq \boldsymbol{s}_n$. And $\boldsymbol{s}' = \{s'_i\}$ is a parameter vector indicating the user's situation and circumstance. For example, even same application, the required QoE would be changed depend on the situation such as disaster.

The flow of the proposed system is described in Figure 10. In the beginning, the sensing function observes the condition and usage of the frequency band and obtains $\hat{\boldsymbol{s}}_n$. A controller determines the initial setting of the RR, AC and TC, $\boldsymbol{c}_0$ according to a target QoE of the application and the situation of the frequency band observed by the sensing function. And the transmission of data packet starts by going through PHY/MAC and wireless network environment. The QoS Monitoring function observes the flow of the data packets and QoS-QoE function estimates the achieved QoE. Based on the difference between achieved and target QoE values, the control algorithm determines the next settings of $\boldsymbol{c}_n$ (*n=1,2...*) and continue to manage the wireless network by using RR, AC and TC.

The basic policy of RR, AC and TC is to minimize the

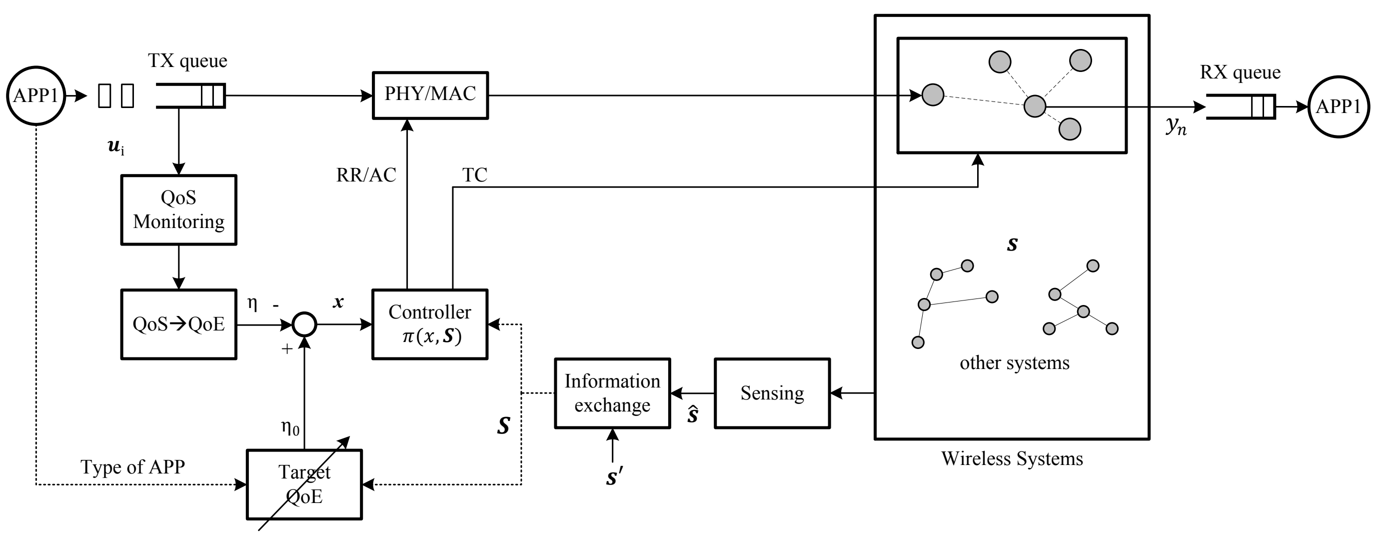

Figure 9. The concept of the proposed system.

"radio resource footprint" of a signal for reducing the possibility of interference between other systems. As discussed previously, it needs to obtain necessary and sufficient amount of radio resources. The control algorithm determines minimum radio resource footprint as S_0 so as to satisfy QoE.

Algorithm *Control of Radio Resource Assignment*

set target QoE η_0
$\hat{\boldsymbol{s}}_0 := Sensing$
$\boldsymbol{S} := \{\hat{\boldsymbol{s}}_0, \boldsymbol{s}'\}$
$\boldsymbol{c}_0 := \arg\min_{\mathrm{c}} \mathrm{footprint}(\pi(0, \boldsymbol{S}))$
do
  packet transmission $(u_n, \boldsymbol{c}_n)$
  $\hat{\boldsymbol{s}}_n := Sensing$
  $\boldsymbol{S} := \{\hat{\boldsymbol{s}}_0, \boldsymbol{s}'\}$
  $\eta_n := f(QoS\ Monitoring)$ // achieved QoE
  $x := \eta_0 - \eta_n$
  $\boldsymbol{c}_{n+1} := \pi(x, \boldsymbol{S})$
while $n < N$

procedure $\pi(x, \boldsymbol{S})$
if $x > 0$ then
  decrease radio resource assignment(RR,AC,TC)
else
  increase radio resource assignment(RR,AC,TC)
end if

Figure 10. The flow of the proposed system.

VII. CONCLUSION

In this paper, we show the measurement results of spectrum usage in Kyoto University Hospital where WLAN and Bluetooth based ICT system are introduced. The results show that the 2.4 GHz ISM band is already congested, and some techniques are required for improving spectrum resource usage since further introduction of new applications in medical area is expected. For this purpose we suggested some viewpoints of new technologies required for the purpose, and we proposed a QoE based wireless system consisting of spectrum sensing, radio resource assignment and network topology control functions. We continue to develop the technologies of and check the quantitative performance of the proposed system.

ACKNOWLEDGEMENT

This work is supported by the Ministry of Internal Affairs and Communications under a grant entitled "Research and development of Dynamic Reconfigurable M2M Wireless Network Technology."

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