EXPERIMENTAL EVALUATION OF A QOE-ORIENTED NETWORK MANAGEMENT FOR WIRELESS LAN IN SHARED SPECTRUM BAND

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ABSTRACT

We have proposed a new network management mechanism for Wireless LAN on which applications on many terminals can run in high quality even in congested frequency bands such as 2.4 GHz. The system is designed by taking users' Quality of Experience (QoE) as a key metric for network management. In this paper, we present the experimental evaluation of the proposed QoE-oriented wireless LAN, as well as the concept and the design of our prototype of the proposed system. The QoE-oriented wireless LAN consists of four major functional elements: smart spectrum sensing; prediction of achievable application quality; radio channel access management; and network reconfiguration management. The smart spectrum sensing measures available radio resources and estimates radio systems and their traffic types. Using those sensed and estimated results, amount of achievable traffic considering required application quality is calculated by the prediction function. The radio channel access management function decides and allows channel access for applications depending on those priorities. As an outer loop, the network reconfiguration management handles traffic load balancing for maximising QoE. We will show the evaluation results of the proposed QoE-oriented wireless LAN through experiments and simulations. In realistic scenarios with mixed types of applications, traffic types, and data rates, the proposed system significantly improves QoE satisfied throughput.

1. INTRODUCTION

Numerous applications for wireless communications are rapidly being deployed in recent years. Particularly in unlicensed bands such as 2.4 GHz ISM band, various wireless systems operate by sharing the spectrum, e.g, wireless local area network (WLAN), wireless personal area network (WPAN), wireless body area network (WBAN), and so on. The number of wireless nodes is explosively increasing with deployment of machine-to-machine (M2M) and device-to-device (D2D) scenarios. In such circumstances, numerous nodes generate a variety of application traffic in different required communication quality and data size. Since wireless communication resources are limited and access schemes are different among those systems, the system may not operate in required quality for all the traffic. Therefore, it is important for those wireless systems that the limited resources are allocated to satisfy required quality for as much application traffic as possible. It is also important in the resource allocation that usage and utility of applications, required communication quality of applications, priority among applications, etc, should be considered in order that more important applications can run in appropriate quality. A framework for efficient spectrum resource utilisation (SRU) in this aspect is being discussed for standardisation in IEEE 802.15 TG4s [1].

Aiming for achieving these purposes, we have proposed a new Quality of Experience (QoE) -oriented network management for wireless systems operating in unlicensed shared spectrum bands, which supports more applications running with sufficient quality in shared frequency bands [2]-[4]. In the proposed system, users' QoE is introduced as a key metric for network management, and wireless access is controlled so that QoE of each application be right required level. The proposed system consists of four major functional elements: smart spectrum sensing; prediction of achievable application quality; radio channel access management; and network reconfiguration management. The proposed system can be recognised as a wide-sense cognitive radio, as this is an environment-aware smart wireless system.

In this paper, we present an evolved QoE-oriented network management mechanism on the formerly proposed scheme. We also show evaluation results through experiments using developed prototypes (which are also evolved from [4]) as well as simulations. This paper is organised as follows. The section 2 describes overview of the proposed system and practical QoE metrics introduced for the network management. The section 3 describes system architecture and the major functional elements. The developed experimental system is described in the section 4. The section 5 shows performance evaluation results of the proposed system. Finally, conclusions are given in the section 6.

2. THE SYSTEM OVERVIEW AND QOE-ORIENTED NETWORK MANAGEMENT

2.1. General Concept of the Proposed System

A key concept of the proposed QoE-oriented network management is that numerous applications on many terminals can run with sufficient quality even in a congested condition of wireless resources. Since wireless resources are limited, applications may not run properly in a case excessive traffic is generated. It is desired in such conditions that a part of available resources be allocated to prioritised application traffic in order to maximise social utility in overall operational areas. Since resources allocating to applications which run with unacceptable quality are waste, we should avoid such the allocation. In contrast, part of resources allocated to applications running with excessive quality may be reaccommodated other applications. Hence, we focus attention on users' QoE as a key metric for network management.

Figure 1 depicts a functional concept of the proposed QoE-oriented network management. There are four major functional elements for the management: smart spectrum sensing; prediction of achievable application quality; radio channel access management; and network reconfiguration management. The smart spectrum sensing estimates wireless systems (WiFi, Bluetooth, ZigBee, etc) and available wireless resources from measured wide-band signals. Using those sensed and estimated results, amount of supportable applications is calculated considering required application quality by the prediction function. The radio channel access management function decides and allows channel access for applications depending on those priorities. The network reconfiguration management is an outer loop control for balancing among access points (AP) and mobile stations (STA) to maximise users' QoE in the wireless network. Details of each function will be described in section 3.

2.2. The QoE Metrics for Network Management

As has been mentioned, we aim that many applications can run with sufficient quality in the proposed wireless network. In other words, the objective of the proposed system is to

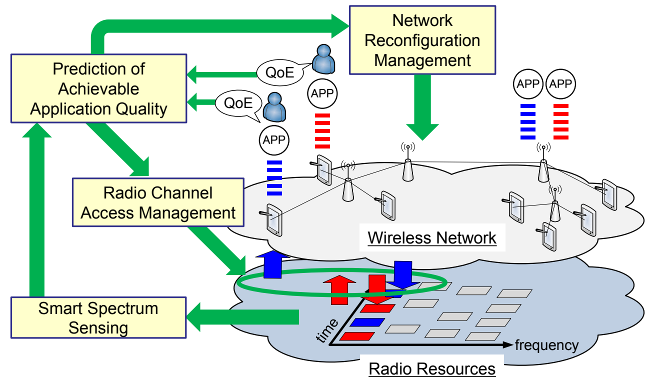


Figure 1 General concept of the proposed system

maximise utility of the system in total. For designing network management with this purpose, it is needed to define metrics of utility and to measure operational quality of each application. We define utility metrics for bothindividual user and for the whole system, as well as QoE and its sufficiency of each running application.

Information types transmitted by applications are in wide variety: motion picture; voice/audio; still image; text message; among the others. Hence, it is needed to set metrics of operational quality individually to each application, considering the types of information transmitted. For real time transmissions such as motion picture or voice/audio applications, QoE has been traditionally used as a measure of operational quality for network management. The QoE is usually converted from quality of service (QoS) metrics on probability of packet loss, latency, mean opinion score (MOS), and so on. For file transfer applications such as images or text messages, throughput and/or goodput have been used as the metrics.

However from users' point of view, individual utility of each user differs highly depending on contents of transmitted information, physical and psychological circumstances of users, and some other factors. For example, when you watch a video for fun in a normal situation, you may feel uncomfortable even if there is only a slightly fuzzy reception. On the contrary in an emergency case, when you watch a news programme for getting information, you may tolerate lower quality if you can understand the context. There may be another situation that you need to save batteries longer by lowering transmission rate. Considering these conditions, the metric of individual utility u is defined, which is gains a user receives from a transmitted information i, of an application a, with a set of communication quality elements q, under a physical and psychological situation for the user s. The individual utility is expressed as follows:

$$u = u_{i,a,s,p}(q).$$

The communication quality elements are throughput, latency, packet loss rate, and so on, depending on applications.

Besides, we also define our QoE Q as an expectation of user's satisfaction on a running application, which is mapped onto real value with a range of 0 to 1.

$$Q = Q_{i,a,s,p}(q)$$

Examples of QoE function for audio voice application are shown in Figure 2, where throughput, transmission delay, and packet loss rate are assumed for the communication quality elements. Note that ITU-T defined QoE as "the overall acceptability of an application or service, as perceived subjectively by the end-user" in [5]. We see that our definition is on this with an assumption that major bottleneck of end-to-end application quality is within wireless networks.

Based on the defined Q, QoE sufficiency η is evaluated comparing estimated Q and required Q_c as follows.

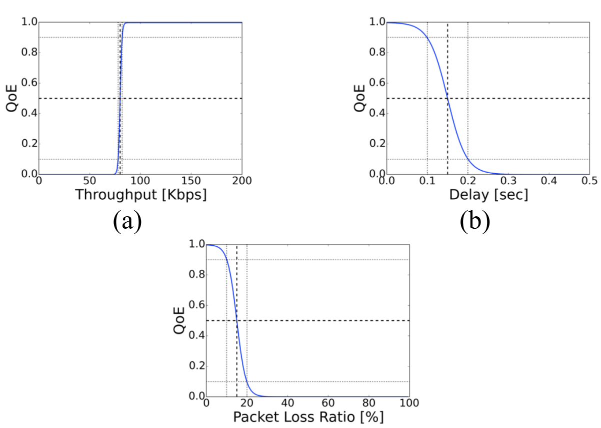
$$\eta_{Q_c}(Q) = \begin{cases} 1 & if \quad Q \geq Q_c \\ 0 & otherwise \end{cases}$$

An effective utility of an application traffic can be judged by a product of u and η. This means that the utility of the traffic running with unsatisfied QoE is none.

For efficient wireless resource utilisation of the total system, priority of each application in social aspects will be considered. Led from the concept, we introduce another new metric, total utility of the system U for network management, which is formulated by

$$U = \sum_{x} \sum_{i_x, a_x} u_{i_x, a_x, s, p_x}\left(q_{i_x, a_x}\right) \cdot \eta\left(Q_{i_x, a_x, s, p_x}\left(q_{i_x, a_x}\right)\right),$$

where the x denotes user index. The efficiency of wireless resource utilisation can be maximised by allocating available resources to applications so that the U be maximum. Where, the priority of individual application can be set in the order of individual utility u per unit resources considering occupied resources (offered load) L and transmission rate R, as $u(q) / \frac{L}{R}$.



(c)

Figure 2 Example of QoE function for audio voice application

3. THE SYSTEM ARCHITECTURE

General functional architecture of the proposed system is shown in Figure 3 [4]. It is a cell-based structure, where an AP manages STAs in a cell, and a network management server manages APs. There is one or more sensing device(s) set in each cell, which performs smart spectrum sensing. The sensing device can be equipped in the AP and/or STA. In each cell, the AP obtains information related to the individual utility u and QoE Q from STAs and sensing devices, and manages resource allocations and access controls for each STA in the cell. The network management server obtains information on running applications, QoE related information from each cell, and makes decisions for setting of channel access policy (usable resource limit, transmit power limit, etc) so that interference among the cells is well coordinated.

In the proposed network management, transmission of each application traffic is controlled in every certain period. General procedure of the proposed network management is the followings:

1. The smart spectrum sensing measures surrounding radio environment by wide-band spectrogram and estimates available resources for the target frequency channel. It also estimates types of wireless system and its traffic running in the channel.
2. Supportable offered traffic for the next transmission slot (= control period) is predicted, based on the estimated available resources, information about application traffic being offered for the next slot, and the effective utility $u\eta$ of each application.
3. Within the limit of the predicted supportable offered load, a decision is made on radio channel access permission to the offered application traffic in the order of priority. Where, the total utility of the system U is to be maximised.
4. Once the several control cycles (steps 1-3), the network management server collects information for each of cells (available channels/resources, in-use channels/resources, offered traffic load, QoE, etc). By processing those information, the network management server controls configuration of the network, if necessary. Some of the connections between AP and STA are changed, so that the total utility of the system are maximised.

3.1. Smart Spectrum Sensing

The smart spectrum sensing provides information about surrounding radio environment for the network management, which includes estimates of available radio resources for the target frequency channel, types of wireless systems and application traffic running in the channel. Our proposed

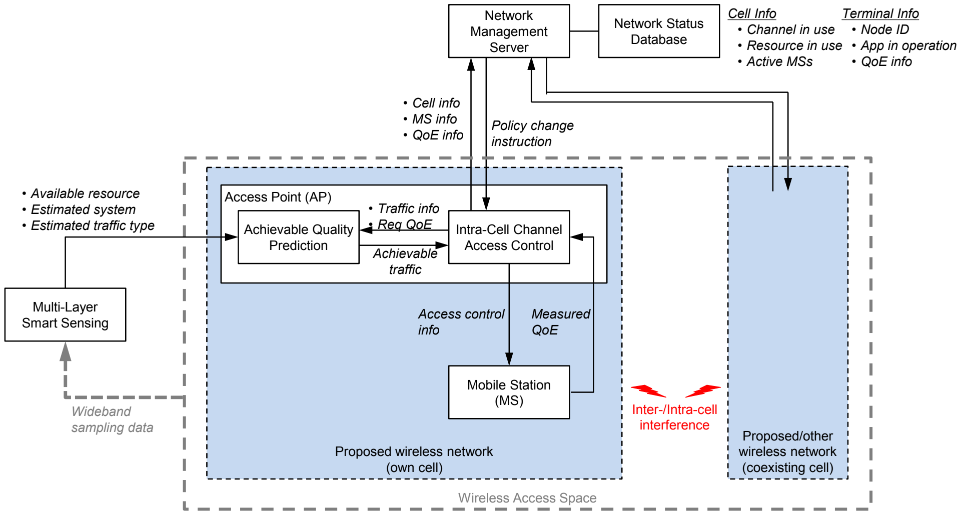


Figure 3 General functional architecture of the proposed system [4]

solution of this function is based on observation of wide-band spectrogram in time and frequency domains, and analyses on it using pattern recognition and data mining techniques. The actual processing steps of the smart spectrum sensing are as follows [6][7].

1. Detect and identify existing wireless systems by extracting the following features in the measured spectrogram: centre frequency; bandwidth; transmission period; signal strength; spectral pattern; cyclostationarity; etc. By applying non-negative matrix factorisation and discriminant analysis on the samples of power in the measured spectrogram, we can extract transmitted signals. Then channel occupancy rate (COR) will be calculated, which is a rate of the channel busy duration to the sensing duration.
2. Detect transmitting nodes and estimate traffic patterns by analysing the multi-dimensional features (obtained in the step 1) referring to MAC protocol for the detected system.
3. Identify individual applications by matching the data traffic pattern to typical behaviour of applications.

3.2. Prediction of Achievable Application Quality and Radio Channel Access Control

The functions for prediction of achievable application quality and radio channel access control are closely related as core of the proposed access control. The general flow of the proposed access control is shown in Figure 4. The basics of the prediction of achievable application quality are depicted in Figure 5. The actual steps are as follows:

1. Calculate the estimated COR of own wireless network from current information about offered load, average packet size, and data rate of each STA.
2. Get information about COR of other network from smart spectrum sensing function.

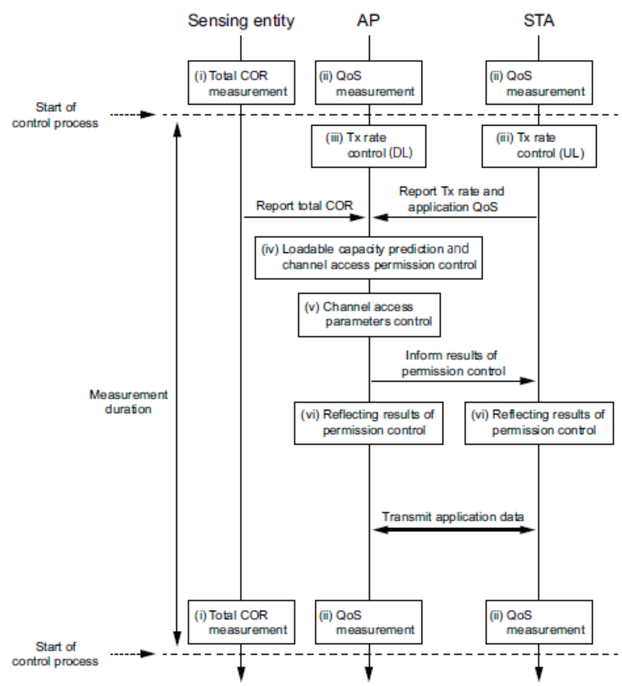


Figure 4 General flow of proposed access control

3. Update the estimated COR of the own network considering additional offered load (applications). Here, the priority of the applications is considered for the additional offered load.
4. Prediction of COR change of other network is obtained. According to the predicted point, one can judge whether or not the traffic of own network would achieve their QoE requirement at the next transmission period.
5. A combination of loadable applications for maximum utility is decided by iterating steps 3-4. Those applications will be allowed for channel access for the next control period.

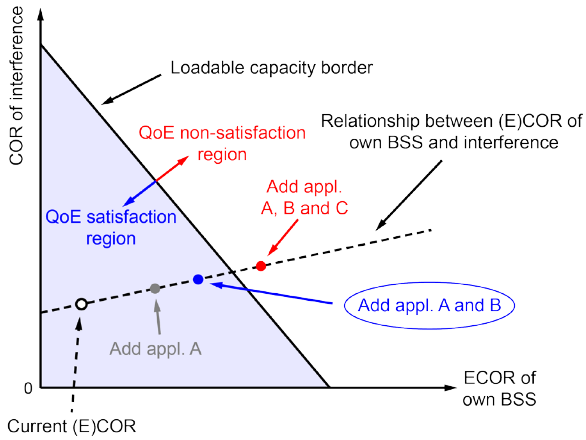


Figure 5 Prediction procedure

The loadable capacity border (whether QoE satisfied or not) can be obtained by the pre-calculation [4][8]. The border can also be adjusted by getting the feedback through the operation of the network management.

3.3. Network Reconfiguration Management

The network reconfiguration management is centralised by the network management server. The server periodically collects the network information from APs (and STAs via APs). The network information includes: radio channel used by each AP; available radio resource for each AP; STA information on connecting/queueing; required radio resource for queueing application.

The network management server decides reconfiguration by analysing the collected information, so that the total utility can be maximised. The reconfiguration can be: handover for a STA to another AP; change of operating channel for an AP.

4. EXPERIMENTAL SYSTEM

An experimental system has been developed for proof of the proposed concept. For setting flexible network configuration, transceivers for AP/STA and sensing nodes are separately implemented. A basic configuration of the system is shown in Figure 6, where the sensing node is connected to the AP via Ethernet. Figure 7 shows the exterior of the transceiver and the sensing node.

4.1. Transceiver

Basic specifications and architecture of the transceiver are respectively shown in Table 1 and Figure 8. The hardware of the transceiver is common for AP and STA, and the transceiver is switchable to AP and STA by the internal software setting.

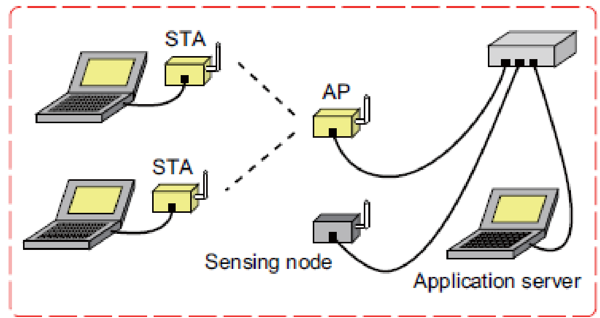


Figure 6 Basic configuration of the experimental system

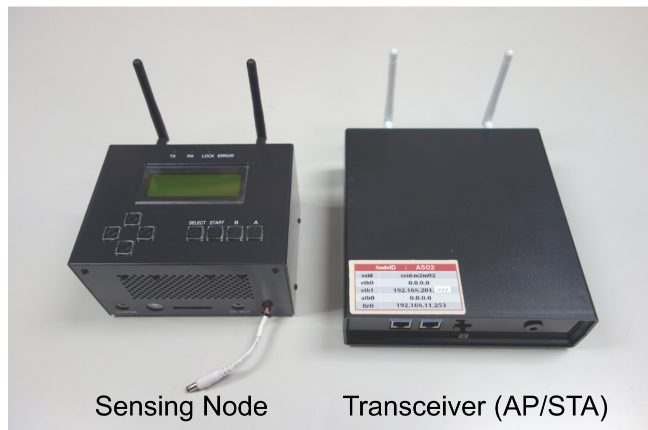


Figure 7 The developed transceiver (AP/STA) and sensing node

Table 1 Specifications of the AP/STA transceiver

MPU	ARM Cortex A8 AM3894
OS	Linux 2.6.37
WLAN module	Silex SX-PCEGN (miniPICe)
WLAN driver	Atheros 9.2

We employ commercial WLAN module as a base, which is compatible with IEEE 802.11b/g/n/e [9]. A driver for the WLAN module is modified based upon the one provided by the chip vendor. We implement “control entity” as an application on the Micro Processing Unit (MPU). The control entity takes the following roles: controlling WLAN module via the driver; collecting information such as communication quality indexes (throughput, transmission delay, packet loss rate, etc), received signal strength indication (RSSI), and so on; processing algorithms for the channel access control.

4.2. Sensing Node

Specifications of the sensing node is shown in Table 2. The sensing node consists of radio frequency (RF) unit, FPGA, and CPU. In the FPGA, fast Fourier transform (FFT) and an algorithm for determining idle/busy of each frequency channel are implemented. Software on the CPU makes configuration and interfaces to external nodes.

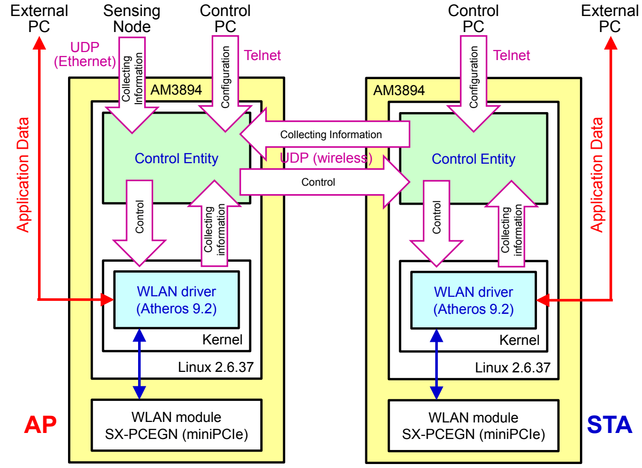


Figure 8 The transceiver architecture

Table 2 Specifications of the sensing node

RF	Centre frequency: 2442 MHz Rx bandwidth: 80 MHz ADC: 14-bit, 125 Msps (operating in 120 Msps)
FPGA	Xilinx Virtex 6
CPU	Renesas SH7763
OS	Linux 2.6

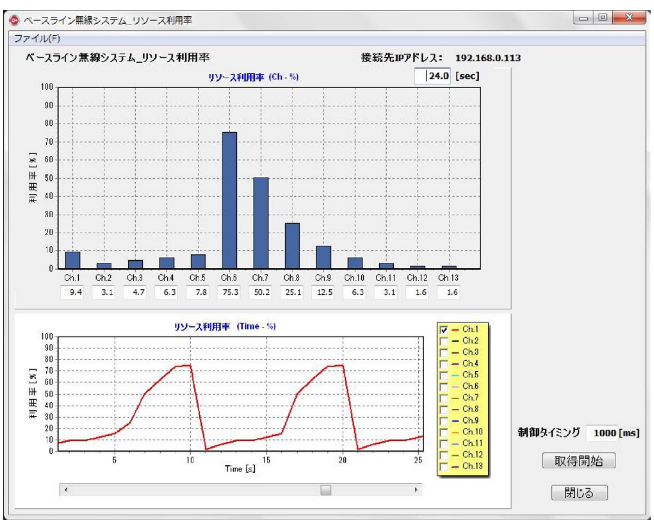


Figure 9 User interface of the sensing node

A snapshot of the sensing node user interface (UI) is shown in Figure 9. In upper part of the screen, COR of each WLAN channel is displayed in real time. The bottom part displays COR transition of the selected channel in time.

5. PERFORMANCE EVALUATIONS

5.1. System Level Simulations

We evaluate effectiveness of the proposed QoE-oriented network management. First we show evaluation results from system level simulations. In the previous study, we showed that the proposed network management improves QoE satisfied ratio and its throughput in a scenario with two WLAN BSSs [4]. Here, we expand the evaluation scenario for a case with mixed wireless systems (WLAN and Bluetooth) coexisting in the same band.

Table 3 shows the simulation parameters. We refer IEEE 802.11g ERP-OFDM [9] as a baseline wireless system for the proposed QoE-oriented network management. In the simulation scenario, there are two WLAN BSSs (BSS1 and BSS2) and up to three Bluetooth piconets in operation in the area of 20m x 20m. One of the WLAN BSSs is assumed to be operating the proposed QoE-oriented network management. On the WLAN, each STA generates uplink CBR traffic. While on the Bluetooth, each Slave generates downlink traffic based on A2DP application. It is assumed that information about offered load, transmission rate, and channel accessibility for each link can be ideally obtained.

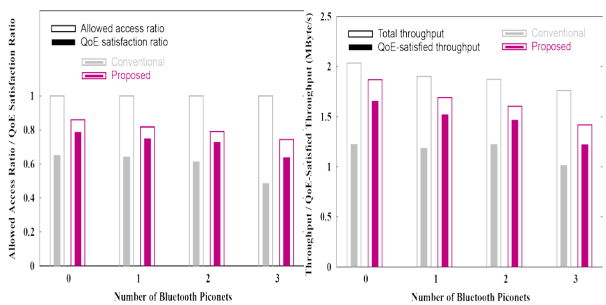
Figure 10 (a) shows a comparison of access allowed ratio and QoE satisfied ratio between proposed network management and ordinary WLAN. Figure (b) shows average throughput in the whole area and throughput of QoE satisfied traffic. Where, “Conventional” denotes the case BSS1 operates as ordinary WLAN, while “Proposed” is the case BSS1 operates with the proposed QoE-oriented network management. The QoE satisfaction is defined as an event where 98% throughput of offered load is achieved [8]. It is seen from these figures that the proposed network management improves QoE satisfaction ratio and QoE-satisfied throughput about 10-15% regardless of the coexisting Bluetooth. This is because the actual traffic in the area is reduced by constraining channel access for QoE-unsatisfied traffic in BSS1.

Figure 11 (a) and (b) respectively show the number of retransmission and total throughput of the Bluetooth links. It is seen that the retransmission of the Bluetooth decreases about 10% while maintaining the throughput, which is because of the effect of the proposed network management for coexisting WLAN. From those results, we confirm that the proposed QoE-oriented network management contributes to improve communication quality and QoE satisfaction for the whole communication area where mixed wireless systems share the same spectrum band.

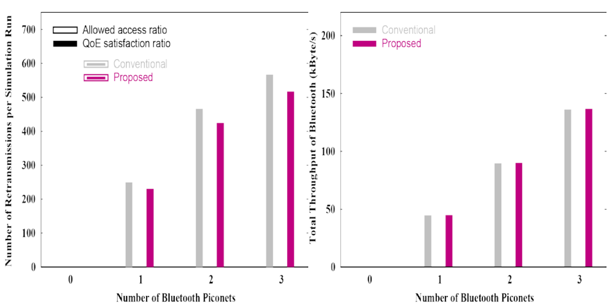
Table 3 Simulation parameters for mixed wireless systems scenario

WLAN system	IEEE 802.11g ERP-OFDM (2 BSSs, 6 STAs / BSS)
Bluetooth system	V2.0 EDR w/o AFH (0 – 3 piconets, 2 Slaves / piconet)
Simulation area	20m x 20m
Channel model	AWGN
WLAN traffic	CBR, UL only, 1500 Byte payload BSS1: 300kByte/s/STA

	BSS2: 100kByte/s/STA
Bluetooth traffic	CBR (A2DP), DL only, 119 Byte payload 41kByte/s/Slave
Transmission power	WLAN: 16 dBm (AP), 12 dBm (STA) Bluetooth: 0 dBm
Number of antennas	2 (WLAN AP), 1 (others)
Noise parameters	NF = 10dB, 300K
Transmission rate	WLAN: fixed to 24 Mb/s Bluetooth: minimum rate on minimum number of slots
Control period	1 s
Spectrum sensing threshold	-88 dBm / 1.25 MHz



(a) (b)
Figure 10 Improvements in WLAN



(a) (b)
Figure 11 Improvements in coexisting Bluetooth

5.2. Experimental Evaluations

We carried out actual radio transmission experiments using the developed experimental system. Table 4 shows the experimentation settings. On each of the links among an AP and STAs, one-way traffic is generated by Iperf: uplink traffic for STA 1 and 2; downlink traffic for other STAs. It is assumed that the traffic for STA with smaller index is highly prioritised. It is again assumed that QoE is satisfied with an event where 98% throughput of offered load is achieved [8].

Figure 12 compares the measured total throughput and QoE-satisfied throughput of the proposed QoE-oriented network management and conventional WLAN. When the links are over-loaded (the number of operating STA becomes 6 or more), only two streams satisfy the required QoE with the conventional WLAN. This is because the transmission opportunities are not enough on the downlink due to severe contentions. On the other hand, the proposed network management can satisfy the required QoE for five streams at any time, thanks to the QoE-based channel access control.

Table 4 Experimentation settings

WLAN system	IEEE 802.11g ERP-OFDM
Application	Iperf (one-way traffic)
Offered load	5.5 Mbps per STA (in application layer)
Number of STAs	Up to 8
Traffic direction	STA 1, 2: uplink STA 3-8: downlink
Tx power	6 dBm
Tx data rate	54 Mbps
Spectrum sensing threshold	-70 dBm / 1.25 MHz

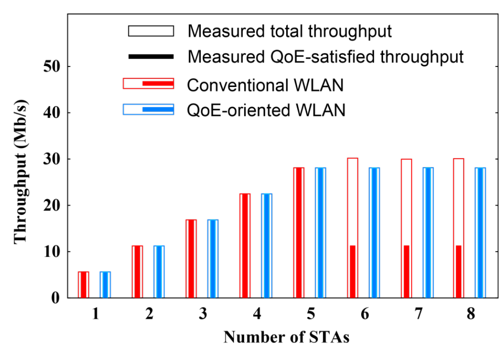


Figure 12 Experimental evaluation of QoE-oriented network management

6. CONCLUSIONS

This paper first presented the concept of the proposed QoE-oriented network management for improving utility of the systems operating in the shared frequency band. Introducing the QoE metrics into the network management, the proposed system can support more applications running with sufficient quality even in conditions mixed wireless systems coexist. We also described design of our developed experimental system. Further, effectiveness of the proposed QoE-based network management is demonstrated by system simulations and experiments.

ACKNOWLEDGEMENT

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