A STUDY ON COEXISTENCE OF WLAN AND WPAN USING A PAN COORDINATOR WITH AN ARRAY ANTENNA

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ABSTRACT

Cognitive Radio can communicate with minimal interference by using the spectra which is allocated to primary radio systems. Two approaches to spectrum sharing by using cognitive radio have been considered. In this paper, the underlay approach is focused. This approach can be achieved by ultra wideband (UWB). In 3.1-10.6 GHz bands UWB transmission is allowed. However, in these bands, other licensed applications (e.g., IEEE 802.11a) are operating. Therefore, UWB system has some limits in the transmitted power to ensure a negligible impact in terms of interference. In this paper, we focus on the coexistence of wireless personal area networks (WPAN) and IEEE 802.11a for indoor environments. We assume WPAN as UWB system. We propose the access control which can avoid interference from WLAN by using an array antenna. An array antenna is equipped by PAN coordinator to use adaptive beamforming. When WPAN mitigates interference by time domain or space domain technologies, we evaluate each system's total throughput and interference by computer simulations. We show that these algorithms outperform the conventional method by decreasing interference and improving each system's total throughput.

1. INTRODUCTION

Recently, radio communication has developed remarkably. Many wireless communication systems have arrived. As a result, convenient frequency for radio systems is draining. Cognitive Radio has drawn attention as a new technology that improves frequency utilization efficiency and mitigates interference to primary radio system [1]. Cognitive Radio is a radio or system that senses, is aware of its operational environment, dynamically and autonomously adjusts its radio operating parameters, and makes a commission with desired quality of one user of communication possible. By applying this technology, much more users can use wireless system without interference from other systems. On the other hand, UWB wireless communication systems have attracted attention as a new system that enables low power consumption, high speed communications, low costs and accurate locations capability. Since the UWB band overlaps the spectrum of existing narrowband and wideband systems, its worldwide acceptance is mainly conditioned by coexistence issues. Regulatory bodies, such as Federal Communication (FCC) in U.S. [2], have imposed restrictions on UWB transmissions, even though they do not automatically guarantee conflicting free coexistence. Therefore, Detect and Avoid (DAA) are studied to mitigate interference to primary radio system. General interference mitigation methods, which are not limited to UWB only, are presented in [3]. Collaborative and non-collaborative coexistence mechanisms are proposed. In the collaborative scenario, different systems are able to share information and negotiation channel access. In the non-collaborative scenario, different systems do not have the ability to coordinate their transmission. There, wireless systems can only use strategies such as carrier sense multiple access or adaptive frequency hopping. The disadvantage of such strategies is that the channel is not used to its maximum efficiency. However, since existing systems are usually not collaborating, we consider the non-collaborative approach as more promising for UWB systems and use it as basis for our considerations.

Almost conventional DAA technologies are mechanisms on time domain [4] or frequency domain. In the DAA technologies on time domain, the UWB system detects any other wireless system with power detect. The

UWB system transmits in the time between adjacent bursts of existing wireless systems where the channel is not occupied. In the DAA technologies on frequency domain, the UWB system detects frequencies which any other wireless system uses and transmits by using adaptive frequency hopping or pulse which is framed to avoid frequencies used by any other systems. However, these technologies have some issues. The issues on time domain have a risk of losing communication opportunities of UWB and on frequency domain have pulse shape distortion which influence orthogonality of waveform. In this paper, we propose the access control which can avoid interference by using an array antenna. An array antenna is equipped by WPAN coordinator to use adaptive beamforming. This algorithm for access control can not only avoid interference to wireless local area networks (WLAN) nodes but also make an environment in which WPAN nodes can communicate actively.

This paper is organized as follows. The system models which WPAN system and WLAN system coexist is described in Section 2. The Access control based on the DAA technology is detailed in Section 3. The configuration of an array antenna which is equipped by WPAN coordinator is presented in Section 4. The performance of the DAA technologies is evaluated in respect of throughput of each system and interference of each system in Section 5. Finally, conclusions are given in Section 6.

2. NETWORK MODEL

2.1. System Model

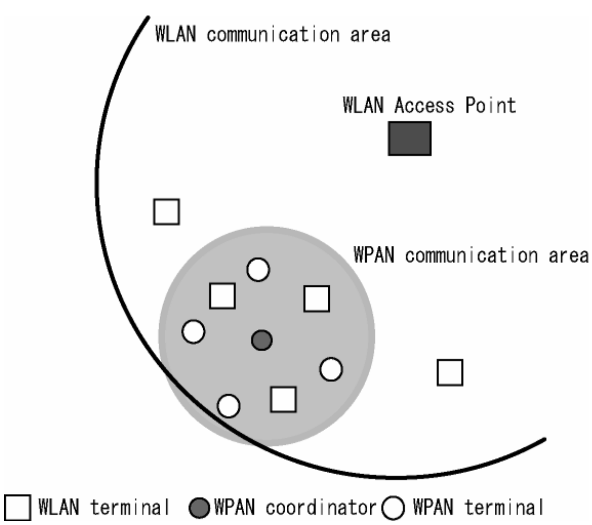

Fig.1. System model

Fig.1. shows the system model assumed in this paper. In this model, WLAN which has a cover-area in the range about 100m and WPAN which has it in range about 10m coexist. WLAN consists of a WLAN access point that is not included in WPAN communication area and *M* WLAN terminals. Network of WLAN communicates by uplink and downlink in infrastructure mode. WPAN consists of a PAN-coordinator which has an array antenna and *N* WPAN terminals. WPAN communicates without base station in general. In this paper, a WPAN coordinator is assumed to comport oneself as abase station and communicate with other WPAN terminals. We consider the uplink and downlink of cognitive radio network in which WPAN communicates with WPAN terminals by using adaptive beamforming technology. The array antenna is uniformly spaced *L*-element antenna array. WLAN base station, WLAN terminals and WPAN terminals are equipped with single antenna. We assume the free space propagation loss channel which is given by

$$L(r) = (\frac{4\pi rf}{c})^2, \qquad (1)$$

where r expresses distance between WPAN coordinator and WPAN terminal, or WPAN coordinator and WLAN terminal. c is the velocity of light and f expresses the frequency.

3. ACCESS CONTROL

In the following access control of WPAN using an array antenna and WLAN is described.

3.1. Access Control of WPAN using an Array Antenna

The WPAN system has to communicate with minimal interference to the WLAN system. The proposed access control to communicate with minimal interference each system is shown in Fig.2.

1. The arrival traffic is modeled as a Poisson random process with rates λ, so the interval time is negative-exponentially distributed with mean time $1/\lambda$.
2. A WPAN terminal which transmits a request of transmission judges whether other WPAN terminals are communicating. If the other WPAN terminals are communicating, Arrival traffic is dropped. If the other WPAN terminals are not communicating, go to 3.
3. A state of the WLAN system is monitored by using Cognitive Radio technique. If it is active, go to 4. If it is idle, the WPAN terminal starts to communicate.
4. WPAN coordinator estimates the directions of arrival (DOA) θ_{PAN}, θ_{LAN} which the WPAN terminal and WLAN terminal communicating. The weight vector using

the minimum mean square error criterion is obtained by the DOA. The SINR of WPAN coordinator or WLAN terminal communicating is estimated. If the SINR is more than the threshold of SINR which is given by desired communication quality, WPAN system starts to communicate. Otherwise, the arrival traffic is dropped.

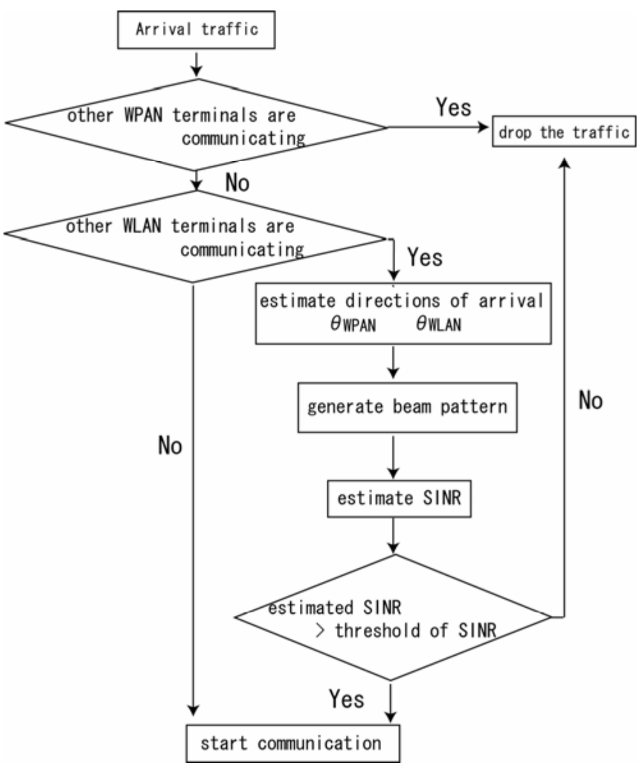

Fig. 2.The access control of WPAN

3.2. Access Control of WLAN

The access control of WLAN is carrier sense multiple access with collision avoidance (CSMA/CA).Fig.3 shows the access control of WLAN.

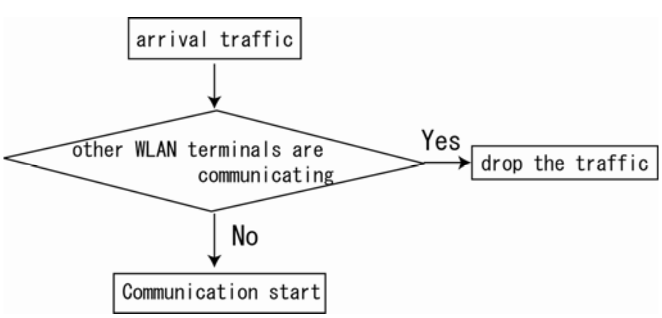

Fig.3. The access control of WLAN

1. The arrival traffic is modeled as a Poisson random process with rates λ, so the interval time is negative-exponentially distributed with mean time $1/\lambda$.
2. A WLAN terminal which transmits a request of transmission judges whether other WLAN terminals are communicating. If the other WLAN terminals are communicating, Arrival traffic is dropped. If the other WLAN terminals are not communicating, the WLAN terminal starts to communicate.

4. THE CONFIGURATION OF AN ARRAY ANTENNA

This section describes the configuration of an array antenna equipped by WPAN coordinator. A directivity beam pattern is derived by using subband signal processing in this paper. Fig.4 shows the configuration of an array antenna. The signal is processed by using band pass filter (BPF). The bandwidth of the each subband has 300 MHz. Denoting the separation distance between two elements as d= $\Lambda/2$ with Λ being the WLAN carrier wavelength. The array response vector from WPAN coordinator to the direction of arrival (θ_{WPAN} , θ_{WLAN}) is $\mathbf{a}(\theta)$. The $\mathbf{a}(\theta)$ can be expressed as

$$\mathbf{a}(f,\theta_{WPAN}) = \left[1, \mathrm{e}^{-\mathrm{j}\frac{2\pi c}{f} d \sin(\theta_{WPAN})}, \cdots, \mathrm{e}^{-\mathrm{j}\frac{2\pi c}{f} d (L-1)\sin(\theta_{WPAN})}\right]^{\mathrm{T}},$$
$$\mathbf{a}(f,\theta_{WLAN}) = \left[1, \mathrm{e}^{-\mathrm{j}\frac{2\pi c}{f} d \sin(\theta_{WLAN})}, \cdots, \mathrm{e}^{-\mathrm{j}\frac{2\pi c}{f} d (L-1)\sin(\theta_{WLAN})}\right]^{\mathrm{T}},$$

(2)

where f is the central frequency of each subband. In this paper, the signal to interference plus noise ratio (SINR) is calculated by considering the frequency bandwidth of each signal:

$$SINR = \frac{\int_{f_{D,low}}^{f_{D,high}} P_D \,|\mathbf{w}^{\mathrm{T}}\mathbf{a}(\nu,\theta_D)|^2\, L(\nu,\theta_D)\, d\nu}{\int_{f_{I,low}}^{f_{I,high}} P_I \,|\mathbf{w}^{\mathrm{T}}\mathbf{a}(\nu,\theta_I)|^2\, L(\nu,\theta_I)\, d\nu + P_n(f_{D,high} - f_{D,low})}.$$

(4)

where P_D and P_I are transmission power of transmitter, which the former is desired transmitter and the latter is interference transmitter. P_n is the density of noise power. The $\mathbf{w} = [w_1,\cdots, w_{L-1}]^{\mathrm{T}}$ is weight vector by calculated by using MMSE criterion.

This array antenna can make wideband directionality to the direction of the WPAN terminal. This is due to the weight vector calculated on the each subband. The directionality of this array antenna is shown in Fig.5. In this case, we assume that the received signals are two signals of which the SNR are 20dB. One signal is the signal of WPAN system. This direction of arrival is 20°. The other is the signal of WLAN system. This direction of arrival is -40°. The number of antennas elements is 3. It is observed that this array antenna generates a directivity beam pattern which has wideband directionality to the direction of WPAN terminal and null to the direction of WLAN terminal in the overlapping frequency with WPAN.

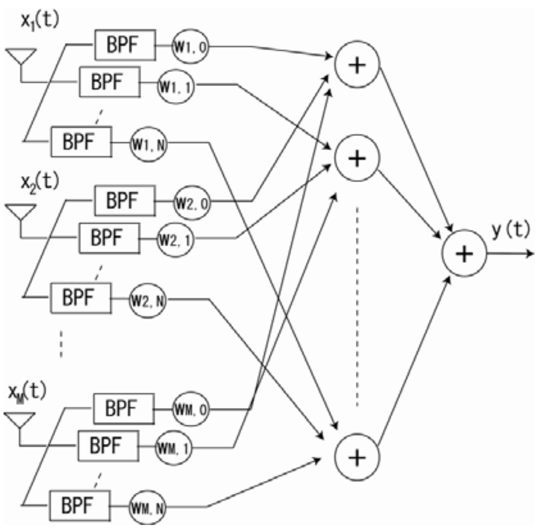

Fig. 4. The configuration of an array antenna

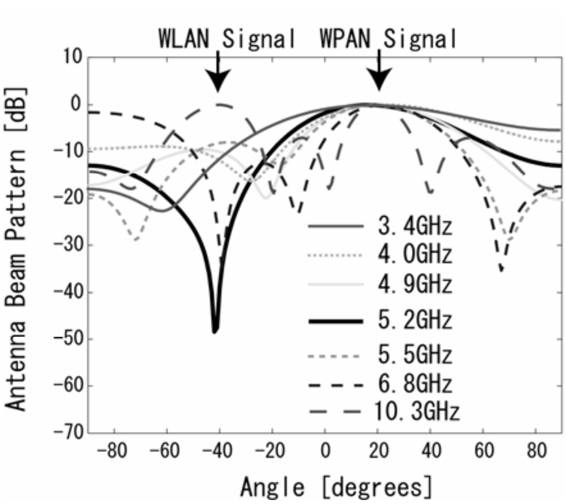

Fig. 5. Beam pattern with subband signal process

5. PERFORMANCE EVALUATION

In this section, we investigate the performance of each system with the access control as described in Section 3 and the array antenna as described in Section 4.

5.1. Simulation Model

Fig.6 shows the simulation model assumed in this paper. Both WLAN and WPAN terminals including WPAN coordinator are uniformly distributed within 10m square on a plane surface. The throughput of the each system is evaluated in this area. The throughput is defined as:

$$\text{Throughput} = \frac{W\sum_{i=1}^{N,M} t_i}{T_{sim}}, \qquad (5)$$

where t_i is a summation of time communicated on a terminal of the each system. W is the bit rate of the each system. T_{sim} is time to simulate this DAA mechanism. In addition, a evaluating the interference is important to investigate this DAA mechanism. In this paper, we assume interference occurs when WLAN terminal starts to communicate during the communication of WPAN system. The interference is recognized when the desired SINR is not obtained. Hence, this paper defines the interference rate as:

$$\text{interference rate} = \frac{\text{count}_{\text{interference}}}{\text{count}_{\text{communication}}}, \qquad (6)$$

where $\text{count}_{\text{interference}}$ means the number of communications in which the desired SINR of the each system is not obtained and $\text{count}_{\text{communication}}$ means the number of communications of the each system in this computer simulation.

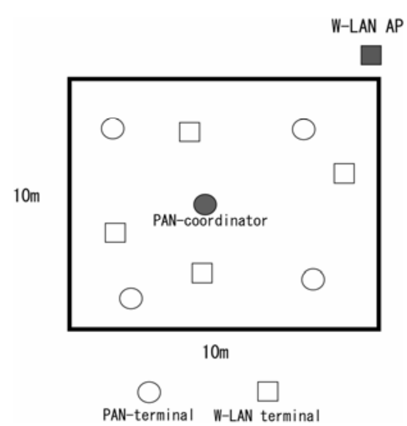

Fig. 6. Simulation Model

5.2. Simulation Results

The simulation parameters are shown in Table 1. The throughput of WPAN and WLAN against λ is shown in Fig.7and Fig.8. The dash lines express the throughput in no interference from other system. From result in Fig.7, we observe that the throughput of the proposed DAA mechanism is nearly double as high as that of temporal DAA mechanism and is slightly high than that of the DAA mechanism using an array antenna without subband signal processing. This is due to the increasing of the opportunity to communicate by using an array antenna and the obtaining the SINR by subband signal processing. Therefore, from result in Fig.8, it is shown that the throughput of the proposed DAA mechanism is improved slightly due to mitigate from WPAN to WLAN by using an array antenna. However, the throughput of the proposed DAA mechanism is same as that of the DAA mechanism using an array antenna without subband signal processing. This is due to broad band of band pass filter compared with bandwidth of WLAN. The interference rate of WPAN and WLAN against λ is shown in Fig.9 and Fig.10. Notice that interference rate of the proposed DAA mechanism reduces about half compared with that of temporal DAA mechanism.

Table 1. System parameter

Number of WPAN terminals	Coordinator 1, terminal 4
Number of WLAN terminals	Terminals 5
Bit rate of WPAN	100Mbps
Bit rate of WLAN	10Mbps
WPAN transmission power	-2.85dBm
WLAN transmission power	15dBm
Desired SINR	20dB
Thermal noise power (300K)	-113.8dBm/MHz
Number of antennas	3

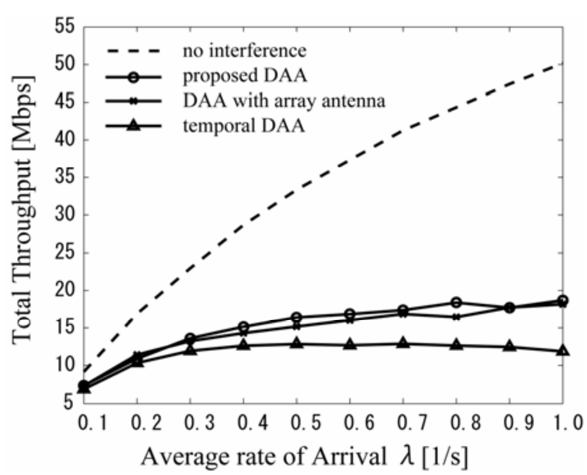

Fig. 7. WPAN Total Throughput

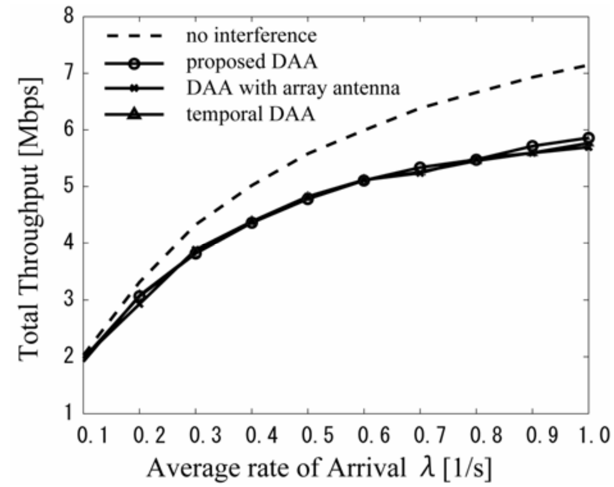

Fig. 8. WLAN Total Throughput

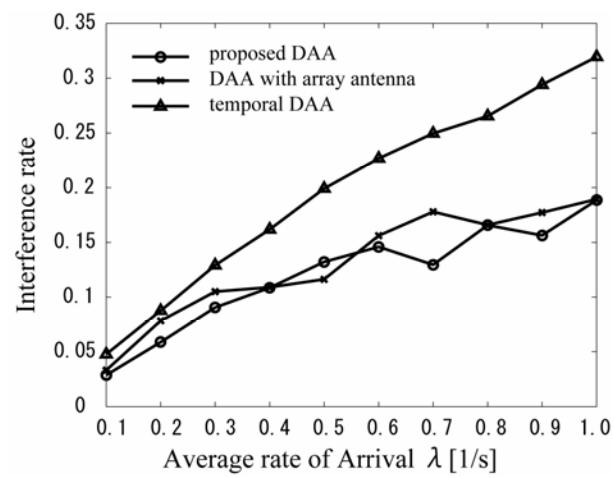

Fig. 9. Interference rate of WPAN

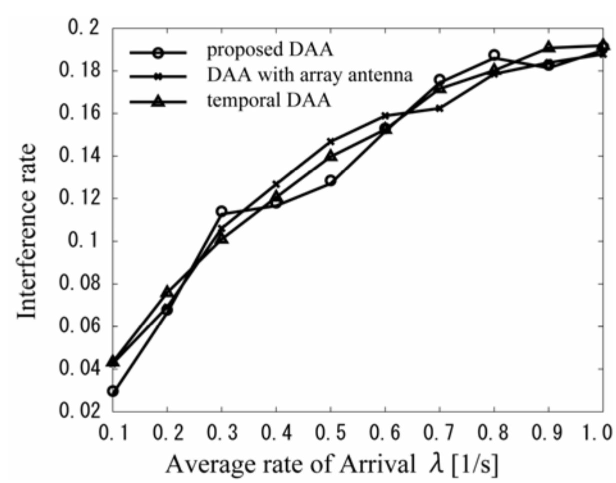

Fig. 10. Interference rate of WLAN

6. CONCLUSIONS

We have presented an access control which can not only avoid interference to WLAN terminals but also make an environment in which WPAN nodes can communicate actively. The proposed access control considers WPAN as secondary system which is can detect the presence of WLAN system in the area. Assuming ideal DOA of the each system and detection of WLAN activity by WPAN, performances of the proposed DAA mechanism, the temporal DAA mechanism and the DAA mechanism using an array antenna without subband signal processing have been evaluated by the computer simulation. It is notable that performances of the algorithm for access control using an array antenna show an improvement of the throughput of the each system and degradation of the interference compared with temporal DAA mechanism.

7. REFERENCES

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