TRANSMISSION POWER CONTROL OF UWB-PAN TO AVOID INTERFERENCE IN THE PRESENCE OF BOTH WIRELESS LAN AND PAN

Marie ENDO and Ryuji KOHNO
(Graduate School of Engineering, Division of Physics, Electrical and Computer Engineering,
Yokohama National University, Yokohama, Kanagawa, JAPAN,
{marie, kohno}@kohnolab.dnj.ynu.ac.jp)

ABSTRACT

This paper assumes an environment where IEEE802.11a and UWB wireless communication systems coexist, and proposes a method to avoid interference from UWB systems to IEEE802.11a. Since both UWB systems and IEEE802.11a utilize a common frequency spectrum, the UWB signal power affects the carrier-sensing of IEEE802.11a. As a result, the throughput of the latter degrades. In this paper, the transmission power of UWB is controlled to avoid interference to IEEE802.11a. By using cognitive radio technique implemented at the base station of IEEE802.11a and monitoring throughput of IEEE802.11a, the transmission power is controlled accordingly. Additionally, the value of each transmission power is optimized in order to maximize total throughput of both IEEE802.11a and UWB, and each throughput and carrier-sense error rate are calculated and compared.

1. INTRODUCTION

Ultra Wideband (UWB) wireless communication systems have attracted attention as a new system which enables low power consumption and high-speed communications, and whose adoption into international standardization of Wireless PAN (Personal Area Network), IEEE802.15.3a, has been discussed [1]. Since UWB uses ultra wideband, 3.1 ~ 10.6GHz frequency band, it influences communications of existing systems such as IEEE802.11a, one of the Wireless LAN (Local Area Network) systems, utilizing 5GHz band. In this paper, an IEEE802.11a network and UWB coexistence is assumed. UWB is prescribed a spectrum mask to limit transmission power by FCC (Federal Communications Commission). However, even if the UWB transmission power is restricted so as to satisfy the limit, it will potentially lead to interference.

Generally, IEEE802.11a uses carrier-sense as medium access control method [2], [3]. In the carrier-sense, a terminal decides whether or not it sends data frames after sensing usage of the channel to avoid collision of frames with other terminals. When the power sensed by terminal is over carrier-sense level, the channel is assumed to be busy and thus the frames are postponed temporally (The algorithm of carrier-sense is briefly shown in Fig. 1). Therefore, when the power of UWB is sensed instead of IEEE802.11a, the carrier-sense error rate increases and thus the opportunity of sending data from IEEE802.11a decreases. As a result, the throughput of IEEE802.11a degrades.

In this paper, monitoring the network on the basis of the cognitive radio concept enables interference avoidance to IEEE802.11a accordingly. Cognitive radio gives the best performance to users flexibly by learning the environment changes [4], [5]. In order to maintain the performance of IEEE802.11a, we control with a cognitive radio technique, the transmission power of UWB terminals if the actual throughput is below the desired level, a new algorithm that maximizes the total throughput of both IEEE802.11a and UWB is introduced in this paper. In more detail, the base station of IEEE802.11a having the capability of cognitive radio controls the transmission power of each UWB terminal when the degradation of throughput of IEEE802.11a is observed. Our proposal is applicable to commercialization since the influence to IEEE802.11a is minimized and spectrum efficiency of IEEE802.11a and UWB is improved only by implementing cognitive radio technique at base station of IEEE802.11a.

In the performance evaluation, we calculate the throughputs of both IEEE802.11a and UWB, as well as the carrier-sense error rates, through computer simulations, showing the effectiveness of the proposed methods. In this paper, throughput is defined as the time spent to send the whole amount of data.

This paper is organized as follows: Section 2 describes the network model assumed in this paper. Section 3 shows an algorithm for avoiding interference to IEEE802.11a with UWB transmission power control. Section 4 presents an optimization method of UWB transmission power. Section 5 evaluates the effectiveness of proposal method. Finally, in Section 6 we draw some conclusions.

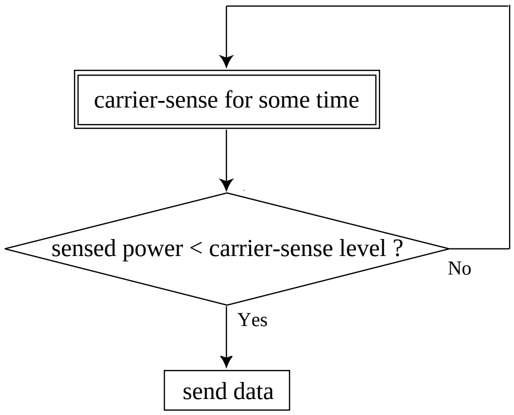

Fig. 1. Algorithm of carrier-sense.

2. NETWORK MODEL

Fig. 2 shows the network model assumed in this paper. In this model, IEEE802.11a and UWB coexist. The network includes a base station of IEEE802.11a (l_0), IEEE802.11a terminals (l_1, l_2, …, l_m, …, l_M) and UWB terminals (p_1, p_2, …, p_n, …, p_N).

In this paper, base station of IEEE802.11a possesses cognitive radio technique and can monitor the throughput of its network. Moreover, it also has a UWB hardware implemented and can control transmission power of UWB terminals. In addition, this base station is able to estimate the distance between each terminal.

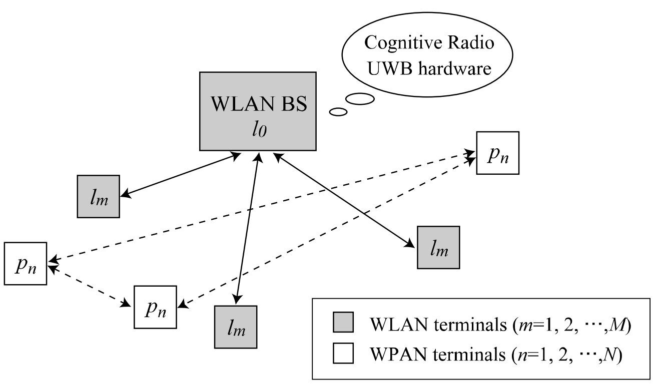

Fig. 2. Network Model.

3. ALGORITHM AVOIDING INTERFERENCE

An algorithm avoiding interference at the base station is shown in the following and Fig. 3.

1. Cognitive radio senses the throughput and the traffic volume of IEEE802.11a network. If the throughput does not satisfy the expected throughput, the base station performs as it follows.
2. The ranging function of UWB equipped at the base station estimates the distance between each terminal.
3. The base station calculates the optimal transmission power values for each UWB terminal as a function of the distance.
4. Finally, after changing each UWB transmission power to the respective optimal values, the communication is restarted.

The method to calculate each optimal value is explained Section 4.

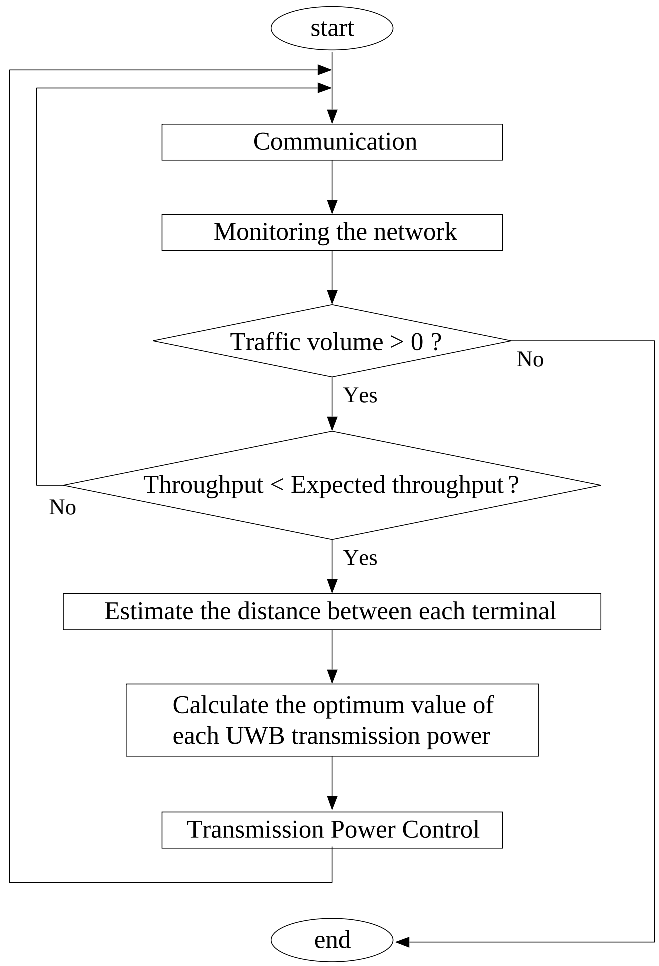

Fig. 3. Algorithm Avoiding Interference.

4. OPTIMIZATION

For throughput optimization of both IEEE802.11a and UWB, the throughput of each system is analyzed theoretically. Moreover, the parameters for optimization are indicated in Table 1.

Table 1. Parameters for Optimization

$d_{m,n}$	Distance between l_m and p_n [m]
$r_{n,n}$	Distance between p_n and p_n [m]
P_{s_n}	Transmission power of p_n [dBm]
λ	Wavelength in 5GHz band [m]
CL_l	Carrier-sense level of IEEE802.11a [dBm]
CL_p	Carrier-sense level of UWB [dBm]
P_{noise_l}	Noise power of IEEE802.11a [dBm]
P_{noise_p}	Noise power of UWB [dBm]
Th_l	Total throughput of IEEE802.11a [Mbps]
Th_p	Total throughput of UWB [Mbps]
$Th_{max\_l_m}$	Maximum total throughput of IEEE802.11a [Mbps]
$Th_{max\_p_n}$	Maximum total throughput of UWB [Mbps]
E_{l_m}	Carrier-sense error rate of l_m
E_{p_n}	Carrier-sense error rate of p_n

4.1. Throughput of IEEE802.11a

When an IEEE802.11a terminal catches the power of UWB terminal and assumes this power to be from its own system's terminal, the carrier-sense error occurs.

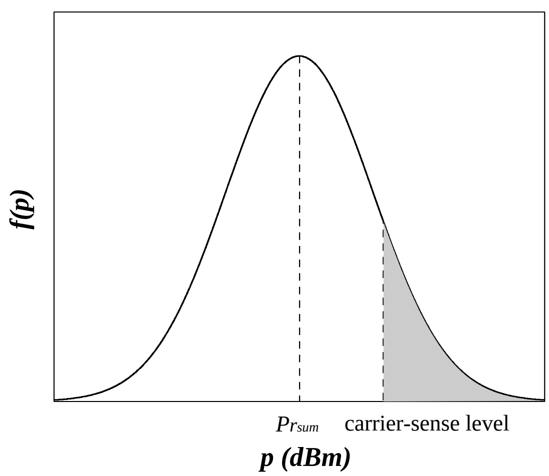

Fig. 4. Probability distribution of noise power.

The probability distribution of UWB power at the base station assumes normal distribution as Fig. 4 shows. The average is the sum of the received power of IEEE802.11a ($P_{r_{sum}}$) and the variance is the squared noise power ($P_{noise\_l}^2$). Since the shadowed area in Fig. 4 is probability that noise power is over the carrier-sense level, the dimension of this area corresponds to the error probability of carrier-sense. Probability density function *f(p)* of the power *p* is shown as follows,

$$f(p) = \frac{1}{\sqrt{2\pi} P_{noise\_l}} e^{\frac{(p-P_{r_{sum}})^2}{2P_{noise\_l}^2}} \qquad (-\infty < p < \infty). \quad (1)$$

Probability distribution function *F(p)* of noise power over the normal distribution is

$$F(p) = \int_p^\infty f(p)dp = \frac{1}{2} erfc\left(\frac{p - P_{r_{sum}}}{\sqrt{2} P_{noise\_l}}\right). \quad (2)$$

Therefore, carrier-sense error rate E_{l_m} of terminal l_m is given by,

$$E_{l_m} = F(CL_l) = \frac{1}{2} erfc\left(\frac{CL_l - \sum_{n=1}^{N}\left(\frac{\lambda}{4\pi d_{m,n}}\right)^2 P_{s_n}}{\sqrt{2} P_{noise\_l}}\right), \quad (3)$$

where complementary error function *erfc(x)* is approximated as follows [6]:

$$erfc(x) \cong 1 - \sqrt{1 - \exp\left(-\frac{4x^2}{\pi}\right)}. \quad (4)$$

Applying (4), (3) can be rewritten as:

$$E_{l_m} \cong \frac{1}{2}\left\{1 - \sqrt{1 - \exp\left[-\frac{4}{\pi}\left(\frac{CL_l - \sum_{n=1}^{N}\left(\frac{\lambda}{4\pi d_{m,n}}\right)^2 P_{s_n}}{\sqrt{2} P_{noise\_l}}\right)^2\right]}\right\}. \quad (5)$$

Finally, throughput of IEEE802.11a Th_l is obtained by,

$$Th_{lan} = \sum_{m=0}^{M} Th_{\max\_l_m}(1 - E_{l_m}). \quad (6)$$

4.2. Throughput of UWB

In this paper, the medium access method of UWB is compliant with IEEE802.11a. In contrast to the case of IEEE802.11a, UWB carrier-sense error occurs when UWB terminal cannot catch the power transmitted from other UWB terminals since the power is lower than the carrier-sense level. The carrier-sense error rate E_{p_n} of terminal p_n can be described as:

$$E_{p_n} = 1 - \frac{1}{2} erfc\left(\frac{CL_p - \left(\frac{\lambda}{4\pi r_{n,n}} \right)^2 P_{s_n}}{\sqrt{2} P_{noise\_p}} \right)$$

$$\cong 1 - \frac{1}{2} \left\{ 1 - \sqrt{1 - \exp\left[-\frac{4}{\pi} \left(\frac{CL_p - \left(\frac{\lambda}{4\pi r_{n,n}} \right)^2 P_{s_n}}{\sqrt{2} P_{noise\_p}} \right)^2 \right]} \right\}. \tag{7}$$

According to (7), the throughput of UWB Th_p is obtained by,

$$Th_p = \sum_{n=0}^{N} Th_{\max\_p_n} (1 - E_{p_n}). \tag{8}$$

4.3. Maximization of Total Throughput of Both IEEE802.11a and UWB

For the optimization of UWB transmission power, total throughput of both IEEE802.11a and UWB is maximized with the following objective function:

$$Th_l + Th_p \tag{9}$$

Each optimal value of UWB transmission power is decided in order to maximize (9) using nonlinear programming.

5. NUMERICAL RESULTS

The proposed algorithm is evaluated by computer simulation. In this paper, cognitive error by the cognitive radio and ranging error by UWB systems are not considered.

5.1. Simulation Parameters

The simulation parameters are shown in Table 2〜4. Terminals are allocated on x-y coordinate at l_0=(0,0), l_1=(5,5), p_1=(0,5), p_2=(5,0) ([m]). The amount of traffic in downlink is equal to the total amount of traffic in uplink. Data size is 1500 octet and other parameters are compliant with IEEE802.11a. The MAC parameters of UWB in this paper are those of IEEE802.11a.

Table 2. System Parameters

M	Number of IEEE802.11a terminals	1
N	Number of UWB terminals	2
P_{noise_l}	Noise power of IEEE802.11a	-63 dBm
P_{noise_p}	Noise power of UWB	-17 dBm
P_{s_1}	Initial value of transmission power	-5 dBm
P_{s_2}	Initial value of transmission power	-5 dBm

Table 3. Parameters for IEEE802.11a

Bit Rate	24 Mbps	MAC header	24 octet
Preamble	16 μ s	FCS	4 octet
PLCP header	4 μ s	Data size	1500 octet
Slot time	9 μ s	ACK size	14 octet
SIFS time	16 μ s	CWmin	15
DIFS time	34 μ s	CWmax	1023
Medium access method		DCF	
Carrier-sense level		-62dBm	

Table 4. Parameters for UWB

Bit Rate	480 Mbps	MAC header	24octet
Preamble	0.8 μ s	FCS	4 octet
PLCP header	0.2 μ s	Data size	1500 octet
Slot time	0.45 μ s	ACK size	14 octet
SIFS time	0.8 μ s	CWmin	15
DIFS time	1.7 μ s	Cwmax	1023
Medium access method		DCF	
Carrier-sense level		-15dBm	

5.2. Simulation Results

Throughput characteristics of IEEE802.11a and UWB are shown in Fig. 5 and 6. The following cases are evaluated in these figures:

- without interference (only in Fig. 5)
- with interference from UWB, without power control
- with interference from UWB, with power control

It is noticeable that, due to the maximization of total throughput of IEEE802.11a and UWB, the throughput of UWB slightly degrades, whereas that of IEEE802.11a is improved about 2Mbps.

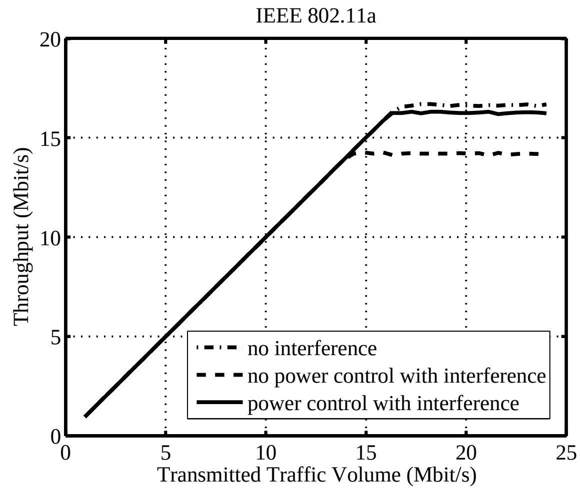

Fig. 5. Throughput of IEEE802.11a.

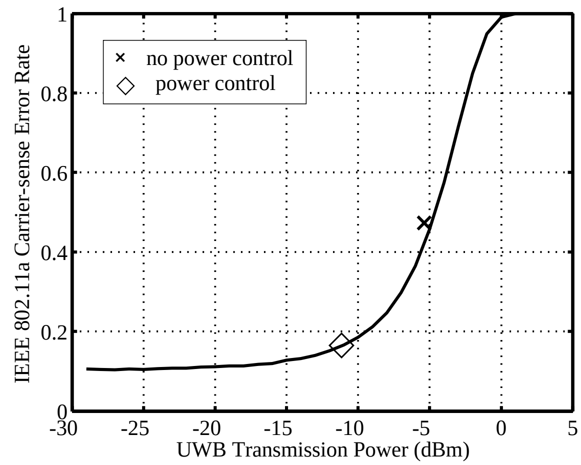

Fig. 7. Carrier-sense error rate of IEEE802.11a.

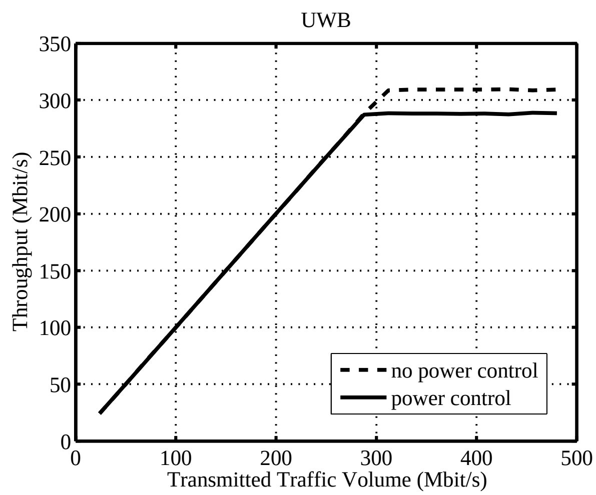

Fig. 6. Throughput of UWB.

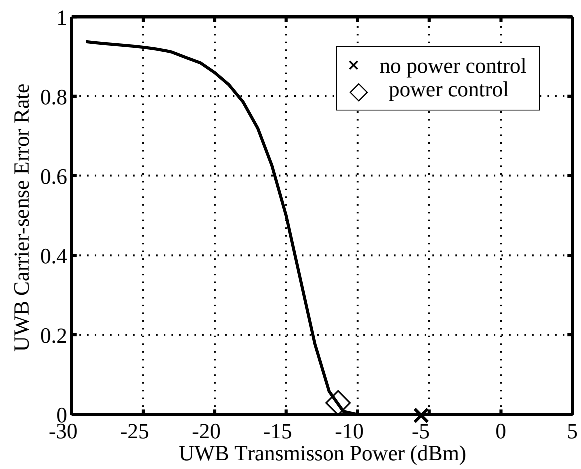

Fig. 8. Carrier-sense error rate of UWB.

The carrier-sense error rates of both systems against the average UWB transmission power are shown in Fig. 7 and 8. Although the UWB carrier-sense error rate slightly increases, the controlled UWB transmission power minimizes the total carrier-sense error rate for both systems, thus the total throughput is maximizes. Consequently, the controlled UWB transmission power can be considered to be an optimal solution.

6. CONCLUSIONS

In this paper, an algorithm avoiding interference from IEEE802.11a to UWB with cognitive radio in an environment where the two systems coexist is proposed. Improvement on the throughputs of both IEEE802.11a and UWB by calculating and controlling optimal value of each UWB terminal's transmission power is shown.

In our future studies, addition of other systems to the proposed network and reduction of the calculation complexity shall be considered. Moreover, cognition error of cognitive radio will also be considered.

7. REFERENCES

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[5] Joseph Mitola III and Gerald Q. Maguire, Jr. “Cognitive Radio: Making Software Radios More Personal,” IEEE Personal Communications, August 1999.

[6] Marie Endo, Kyoichi Obana, Motoko Taniguchi, Kentaro Ikemoto, Ryuji Kohno, "A Study on Transmission Power Control of UWB Terminals to Avoid Interference to Wireless LAN Based on Cognitive Radio Concept," Technical Report of IEICE, SR04-28, pp.51-56, March 2005.

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Yokohama National University

Marie ENDO and Ryuji KOHNO

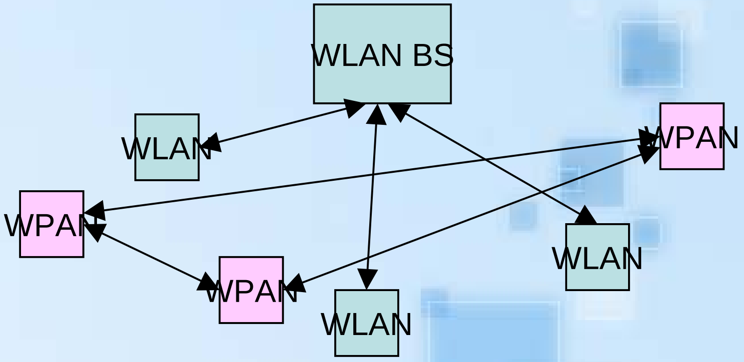
Outline

- Introduction
  - Background
    - WLAN and WPAN coexistence system
    - Problem of this system
      - Interference from WPAN to WLAN
  - Aims of this study
- Algorithm avoiding interference
  - System model
  - Maximization of the network throughput
- Analysis of the proposal algorithm
- Conclusions and Future works

Motivation

- Adoption of Ultra wideband (UWB) into international standardization of WPAN, IEEE802.15.3a, has been discussed.
- UWB enables low power consumption and high-speed communications by using ultra wideband, 3.1-10.6GHz frequency band prescribed by FCC (Federal Communications Commission).
  - ⇒ Interfere to other systems utilizing a common frequency spectrum
- DAA (Detect And Avoid) technologies are considered as a method to avoid interference in Japan and Europe.
  - ⇒ Propose a method avoiding interference

Novelty of this study



Detect

- Cognitive radio
  - Gives the best performance to users flexibly by monitoring and learning the environment changes

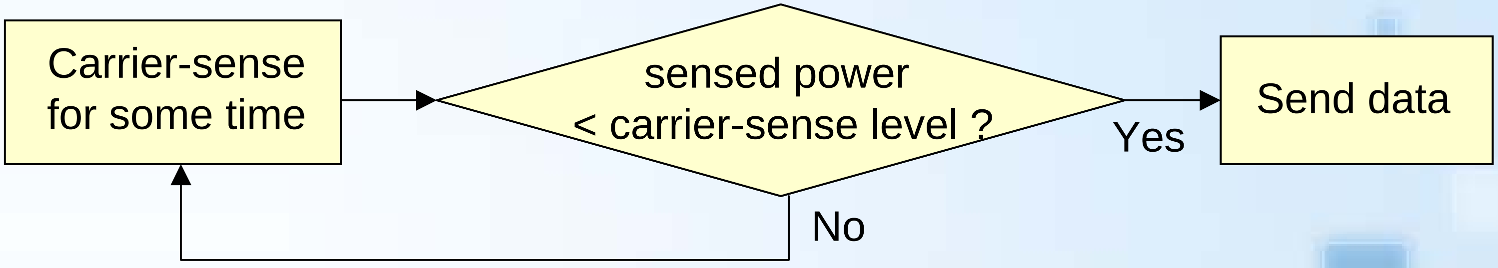
Avoid

- UWB Transmission Power Control

- This paper assumes IEEE802.11a and IEEE802.15.3a coexistence system.
- IEEE802.11a is one of the WLAN systems utilizing 5GHz band.
- UWB signal power affects the carrier-sense of IEEE802.11a.

Carrier-sense of WLAN

- An WLAN terminal decides whether or not it sends data frames after sensing usage of the channel to avoid collision of frames with other terminals.
- When the power sensed by WLAN terminals is over carrier-sense level, the channel is assumed to be busy and thus the frames are postponed temporally.



Problem of this system
-Interference from WPAN to WLAN

- WLAN terminal erroneously senses the power of WPAN

↓

- the carrier-sense error rate of WLAN increases and thus the opportunity of sending data from WLAN decreases

↓

- <u>the throughput of WLAN degrades</u>

Aims of this study

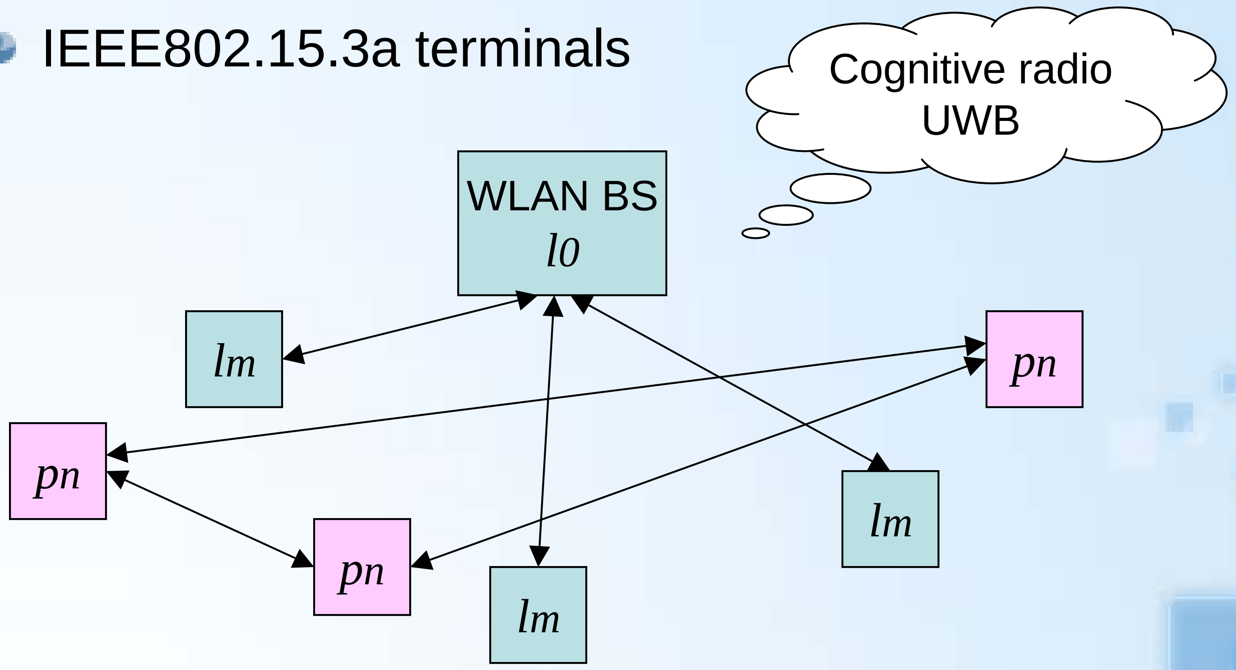
- Avoiding interference to WLAN
  - Reducing WLAN carrier-sense error rate
- Maximization of the total throughput of WLAN and WPAN
  - Optimizing each UWB transmission power

↓

- UWB transmission power control
- Monitoring the network on the basis of the cognitive radio concept
  - Consider only carrier-sense error

Network model

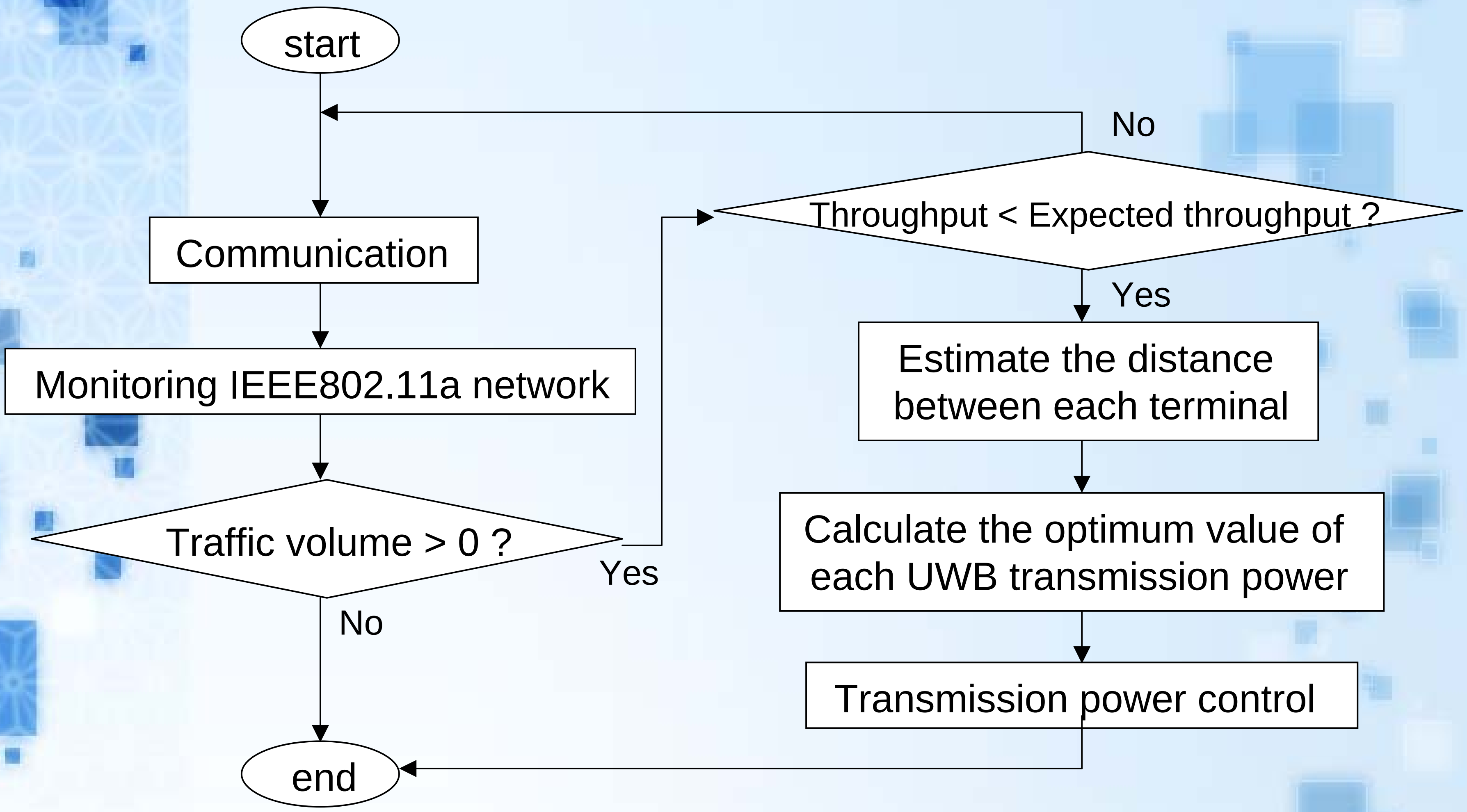
- Single piconet
  - A base station of IEEE802.11a
    - Cognitive radio technique
    - UWB for Transmission Power Control
  - IEEE802.11a terminals
  - IEEE802.15.3a terminals



Proposal of this study

- Cognitive radio technique implemented at the base station of WLAN monitors the throughput of WLAN.
- If the throughput is below the desired level, UWB transmission power is controlled.
- The value of each transmission power is optimized in order to maximize total throughput of both WLAN and WPAN.

Algorithm avoiding interference at IEEE802.11a base station



Maximization of total throughput

- Calculate each optimal value of UWB transmission power(P_{sn}) to maximize total throughput of both WLAN(Th_l) and WPAN(Th_p).

- Nonlinear programming with the following objective function:

$$Th_l + Th_p \quad \rightarrow \max$$

$$\Rightarrow \quad E_{l_m} + E_{p_n} \quad \rightarrow \min$$

Throughput of WLAN

- When an WLAN terminal catches the power of WPAN terminal and assumes this power to be from its own system's terminal, the carrier-sense occurs.
- Carrier-sense error rate of WLAN

$$E_{l_m} \cong \frac{1}{2}\left\{1-\sqrt{1-\exp\left[-\frac{4}{\pi}\left(\frac{CL_l-\sum_{n=1}^{N}\left(\frac{\lambda}{4\pi d_{m,n}}\right)^2 P_{s_n}}{\sqrt{2}P_{noise\_l}}\right)^2\right]}\right\}.$$

- Throughput of WLAN

$$Th_l = \sum_{m=0}^{M} Th_{\max\_l_m}(1-E_{l_m}).$$

p_n : WPAN terminal
E_{l_n} : Carrier-sense error rate of l_m
CL_l : Carrier-sense level of l_m
λ : Wavelength in 5GHz band
$d_{m,n}$: Distance between l_m and p_n
P_{s_n} : Transmission power of p_n
P_{noise_l} : Noise power of WLAN
Th_l : Total throughput of WLAN
$Th_{\max\_l_m}$: Maximum total throughput of WLAN

Throughput of WPAN

- WPAN carrier-sense error occurs when WPAN terminal cannot catch the power transmitted from other WPAN terminals since the power is lower than the carrier-sense level.
- Carrier-sense error rate of WPAN

$$E_{p_n} \cong 1 - \frac{1}{2}\left\{1 - \sqrt{1 - \exp\left[-\frac{4}{\pi}\left(\frac{CL_p - \left(\frac{\lambda}{4\pi r_{n,n}}\right)^2 P_{s_n}}{\sqrt{2}P_{noise\_p}}\right)^2\right]}\right\}.$$

- Throughput of WPAN

$$Th_p = \sum_{n=0}^{N} Th_{\max\_p_n}(1 - E_{p_n}).$$

p_n : WPAN terminal
E_{p_n} : Carrier-sense error rate of p_n
CL_p : Carrier-sense level of p_n
P_{s_n} : Transmission power of p_n
P_{noise_p} : Noise power of WPAN
Th_p : Total throughput of WPAN
$Th_{\max\_p_n}$: Maximum total throughput of WPAN

Simulation parameters (1)

- The amount of traffic downlink is equal to the total amount of traffic in uplink.
  - not considered cognition error and ranging error
- l_0=(0,0), l_1=(5,5), p_1=(0,5), p_2=(5,0) [m]
  - Without interference
  - With interference, without power control
  - With interference, with power control

M	Number of IEEE802.11a terminals	1
N	Number of IEEE802.15.3a terminals	2
Pnoise_l	Noise power of IEEE802.11a	-63 dBm
Pnoise_p	Noise power of IEEE802.15.3a	-17 dBm
Ps1	Initial value of transmission power	-5 dBm
Ps2	Initial value of transmission power	-5 dBm

Simulation parameters (2)

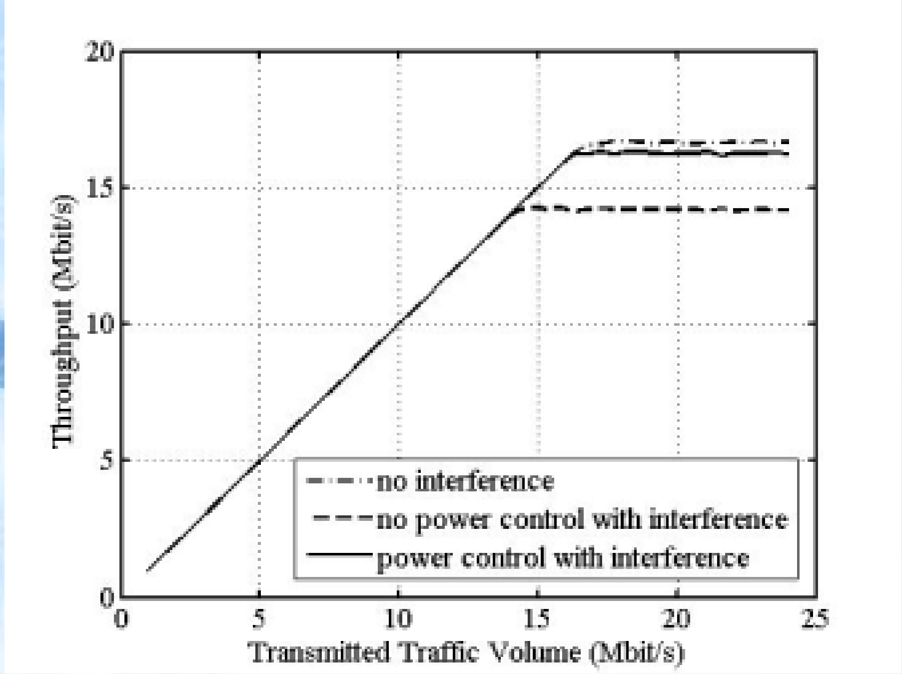
IEEE802.11a

Bit Rate	**24 Mbps**	**MAC header**	**24 octet**
Preamble	**16 μs**	**FCS**	**4 octet**
PLCP header	**4 μs**	**Data size**	**1500octet**
Slot time	**9 μs**	**ACK size**	**14 octet**
SIFS time	**16 μs**	**CWmin**	**15**
DIFS time	**34 μs**	**CWmax**	**1023**
Medium access method		**DCF**	
Carrier-sense level		**-62dBm**	

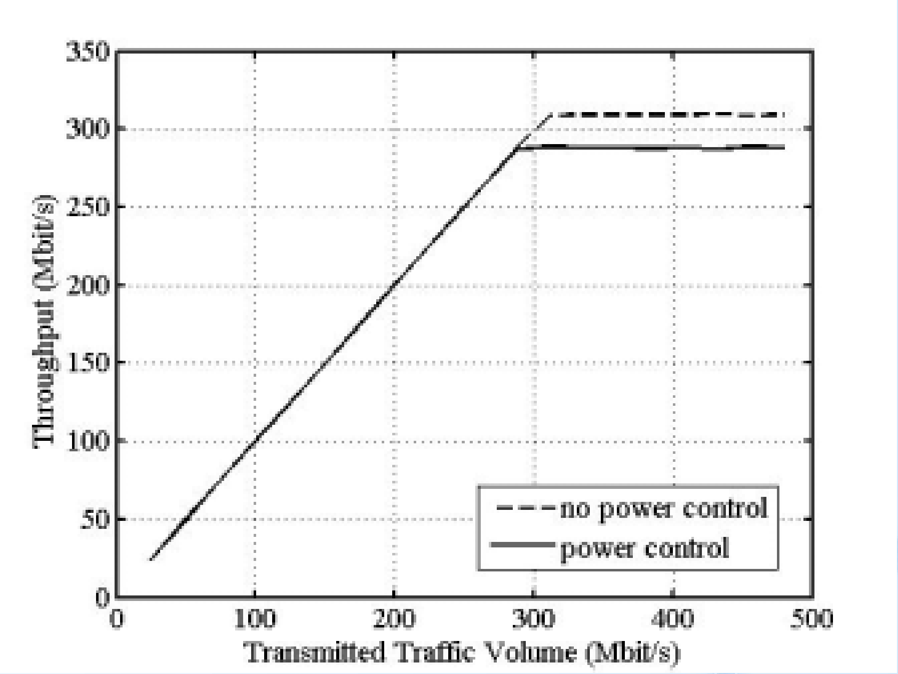
IEEE802.15.3a

Bit Rate	**480 Mbps**	**MAC header**	**24octet**
Preamble	**0.8 μs**	**FCS**	**4 octet**
PLCP header	**0.2 μs**	**Data size**	**1500octet**
Slot time	**0.45 μs**	**ACK size**	**14 octet**
SIFS time	**0.8 μs**	**CWmin**	**15**
DIFS time	**1.7 μs**	**Cwmax**	**1023**
Medium access method		**DCF**	
Carrier-sense level		**-15dBm**	

Numerical result of throughput in each system

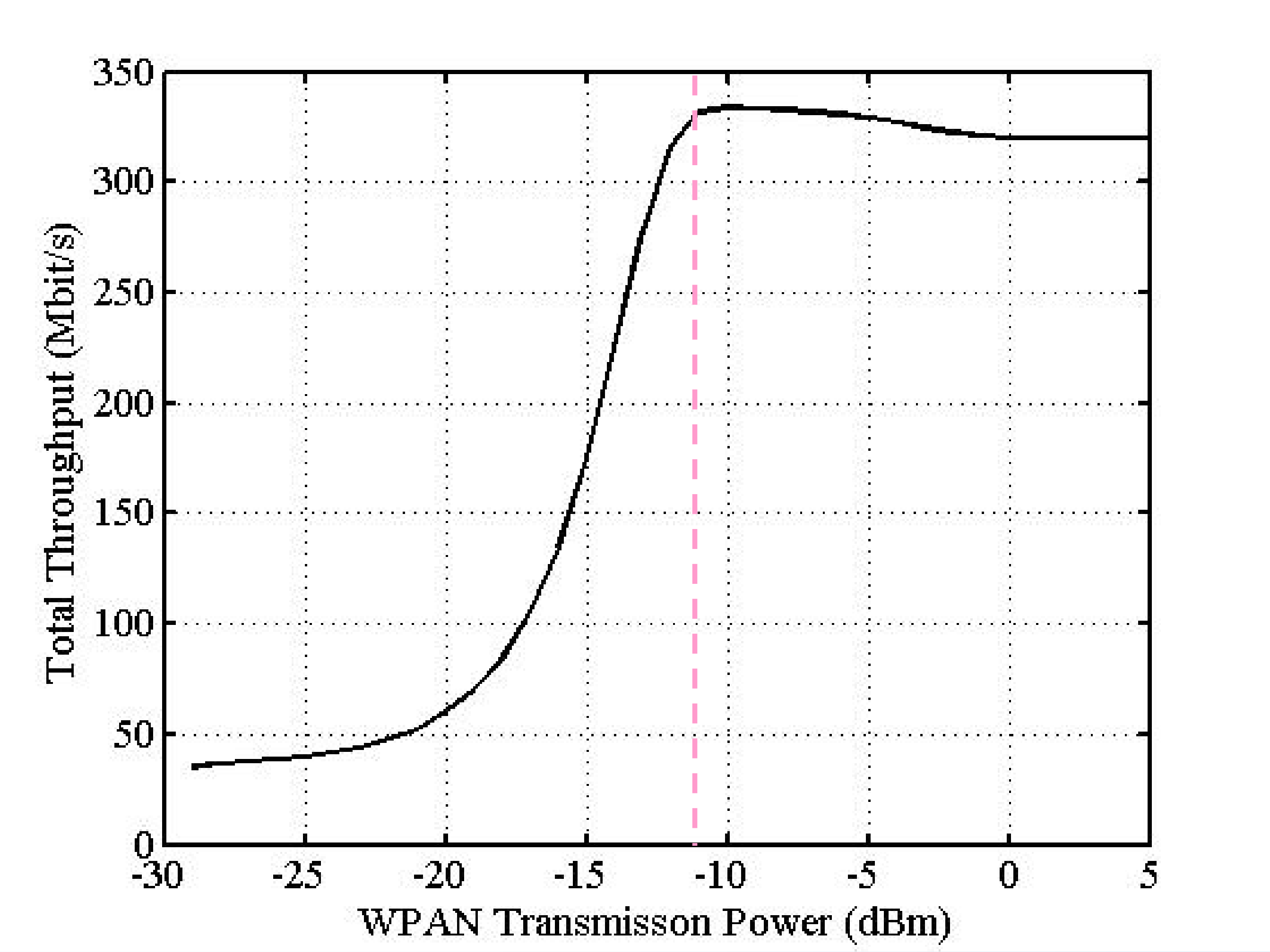


Throughput of WLAN

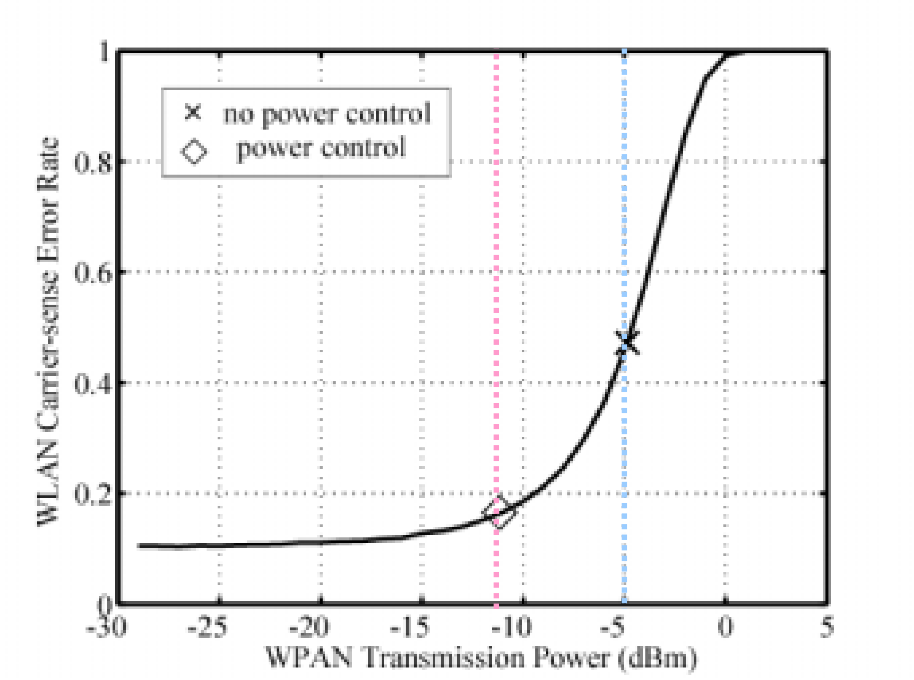


Throughput of WPAN

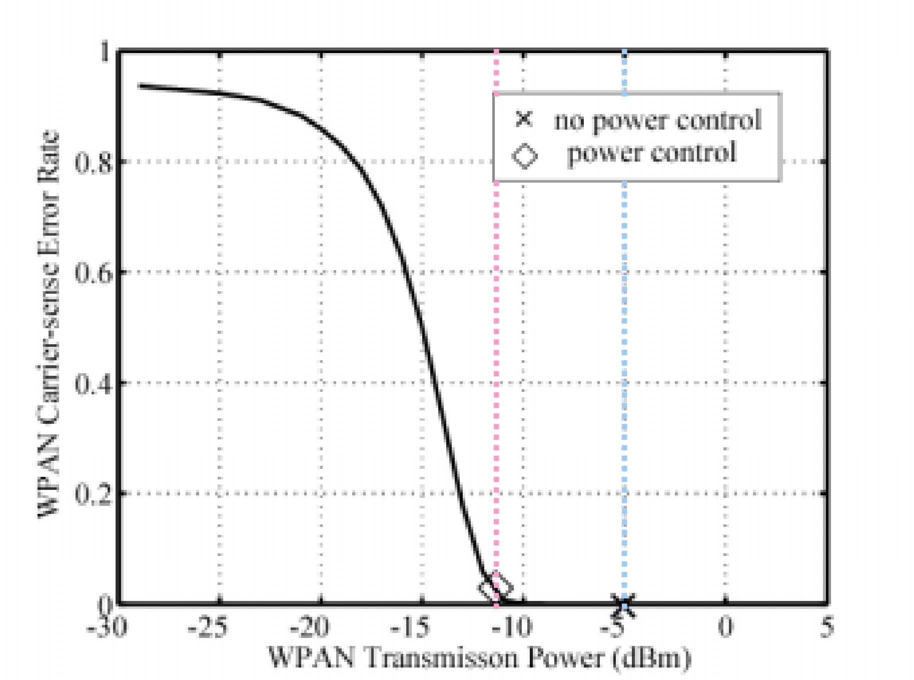
Numerical result of total throughput



Numerical result of carrier-sense error rate in each system



WLAN carrier-sense error rate



WPAN carrier-sense error rate

Discussion

- By the optimization, UWB transmission power is changed from –5dBm to –11dBm, where the total throughput is optimized.
- The throughput of WPAN slightly degrades, whereas that of WLAN is improved about 2Mbps.
- Moreover, it is shown that the controlled transmission power minimizes the total carrier-sense error rate of both systems.
- This controlled UWB transmission power can be considered to be an optimal value.

Conclusions

- An algorithm avoiding interference from WLAN to WPAN with cognitive radio in an environment where the two systems coexist is proposed.
- Improvement on the throughputs of both WLAN and WPAN by calculating and controlling optimal value of each WPAN terminal's transmission power is shown.

- Future works
  - Addition of other systems to the proposed network
  - Reduction of the calculation complexity
    - Iterative algorithm
  - Consideration of cognition error
  - Consideration of other problems