AN ALGORITHM TO AVOID INTERFERENCE BETWEEN WLAN AND WPAN BASED ON COGNITIVE RADIO TECHNIQUE

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ABSTRACT

With the practical use of UWB, the concept of spectrum sharing has been established. Therefore, the necessity to use the frequency spectrum efficiently arises and the Cognitive Radio concept has been drawing much attention. In an environment where 5GHz-WLAN and UWB-WPAN coexist, the frequency spectrum can be shared efficiently by avoiding interference from WPAN to WLAN employing the Cognitive Radio concept, as it is shown in this paper. In particular, the proposed WLAN base station model, where both Cognitive Radio technique and UWB transmitter are implemented, made interference avoidance possible by an adaptive WPAN transmission power control depending on the amount of interference from WPAN.

1. INTRODUCTION

Recently, Ultra Wideband (UWB) wireless communication systems have attracted attention as a new system that enables low power consumption and high-speed communications. UWB wireless communication uses ultra wideband, up to 7.5GHz frequency band (3.1～10.6GHz) and is one type of WPAN (Wireless Personal Area Network). In Japan, the technical conditions about usage of UWB wireless system were set up by the Ministry of Internal Affairs and Communications on March 2006. In the conditions, UWB systems with the DAA (Detect And Avoid) technology implemented have to transmit on up to –41.3dBm/MHz of power and those without the implementation must transmit on up to –70dBm/MHz [1]. DAA is a technology to sense and avoid system interference. Therefore, instead of the traditional concept that frequency spectrums are assigned with each wireless system, spectrum sharing has become possible technologically. As a result, the need to use frequency efficiently has increased and the Cognitive Radio concept has been drawing attention. Cognitive Radio is a radio system that can sense the surrounding radio wave environment and use the radio resources efficiently by flexible reconfiguration of the system as a function of the environment changes [2][3]. It is said to be a concept that extended Software Defined Radio (SDR) in terms of system reconfiguration. This paper aims at the establishment of a method to apply Cognitive Radio commercially.

This paper assumes an environment where 5GHz-WLAN (Wireless Local Area Network) and UWB-WPAN coexist, and proposes a method to avoid interference from WPAN to WLAN so as these systems can coexist by using Cognitive Radio technique. In this scenario, since both 5GHz-WLAN and UWB-WPAN utilize a common frequency spectrum, the WPAN signal power affects the carrier-sensing of WLAN. As a result, the throughput of the latter degrades. This paper proposes to add both Cognitive Radio technique and UWB transmitter to the base station of WLAN. The base station controls the transmission power of WPAN terminals to avoid interference to WLAN when it recognizes the degradation of its throughput. In this paper, a method to calculate the transmission power of WPAN terminals is proposed and evaluated in terms of throughput and carrier-sense error rate.

This paper is organized as follows: Section 2 describes an interference problem in an environment where WLAN and WPAN coexist. Section 3 shows an algorithm for avoiding interference to WLAN with WPAN transmission power control. Section 4 presents a calculation method of WPAN transmission power. Section 5 evaluates the effectiveness of proposal method. Finally, in Section 6 we draw some conclusions.

2. INTERFERENCE FROM WPAN TO WLAN

In this section, an interference problem in an environment where WLAN and WPAN coexist is described.

2.1. Carrier-sense

Generally, WLAN uses carrier-sense as medium access control method [4][5]. 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 a certain level (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.

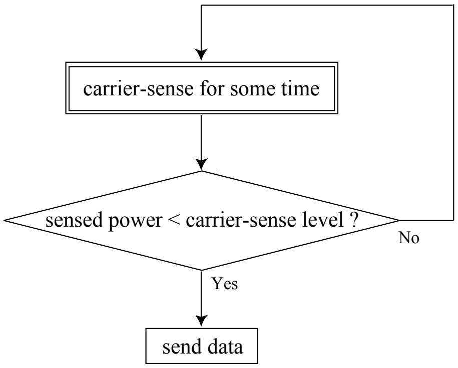

Fig. 1. Algorithm of carrier-sense.

2.2. An Environment where WLAN and WPAN Coexist

In an environment where 5GHz-WLAN and UWB-WPAN, WPAN signal power affects the carrier-sensing of WLAN. In particular, when the power of WPAN is sensed instead of WLAN, the carrier-sense error rate increases and thus the opportunity of sending data from WLAN decreases. As a result, the throughput of WLAN degrades (Fig. 2).

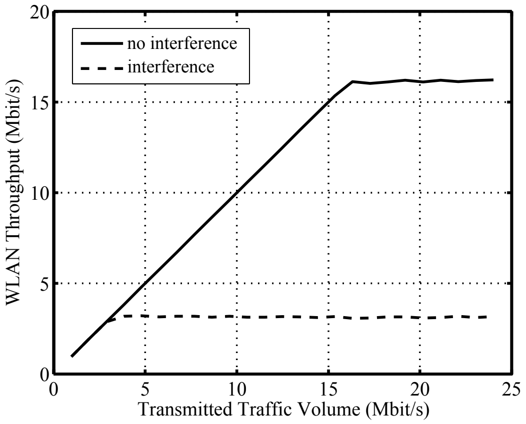

Fig. 2. Degradation of WLAN throughput in the presence of WPAN.

3. ALGORITHM TO AVOID INTERFERENCE

In this section, an algorithm for avoiding interference to WLAN by using WPAN transmission power control is proposed.

3.1. System Model

Fig. 3 shows the system model assumed in this paper. In this model, WLAN that has a cover-area in the range about 100m and WPAN that has it in the range about 10m coexist. The network includes one base station of WLAN, *M* WLAN terminals and *N* WPAN terminals. This paper assumes that WLAN communicates by both uplink and downlink in infrastructure mode. Meanwhile, WPAN communicates without base station generally, one WPAN coordinator is assumed to comport oneself as a base station and communicate with other WPAN terminals in this paper.

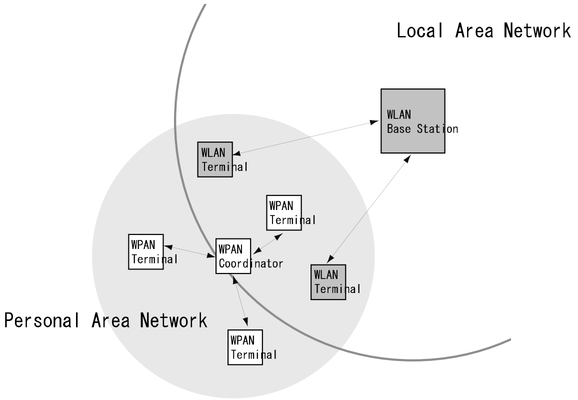

Fig. 3. System model.

3.2. Algorithm to Avoid Interference

It is preferable that interference avoidance is done only when the amount of interference is high so as to also keep the communication quality of WPAN. In this paper, interference avoidance assumes to be done accordingly only when the throughput of WLAN monitored by Cognitive Radio does not satisfy the desired level.

In particular, the base station of WLAN possessing both Cognitive Radio technique and UWB transmitter can monitor the throughput of WLAN and control the WPAN transmission power to avoid interference from WPAN. The proposed algorithm to avoid interference is shown in the following and Fig. 4.

1. All terminals communicate for a given length of time.
2. The base station monitors the throughput of WLAN by using its Cognitive Radio technique. If the monitored throughput satisfies the expected level, go to 5. If not, go to 3.
3. The base station calculates the optimal transmission power for each WPAN terminals as a function of the location.

4. The base station changes the transmission power of each WPAN terminal to the respective optimal values calculated in 4. by using its UWB transmitter.
5. The communication is restarted.

In this paper, however, the base station knows the location of each terminal of both WLAN and WPAN. A method to calculate each WPAN transmission power is described in Section 5.

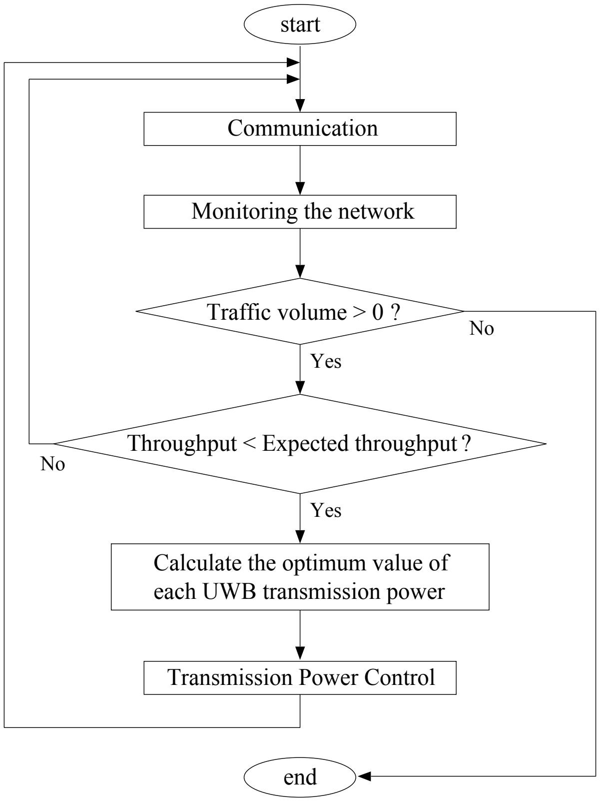

Fig. 4. Algorithm to avoid interference.

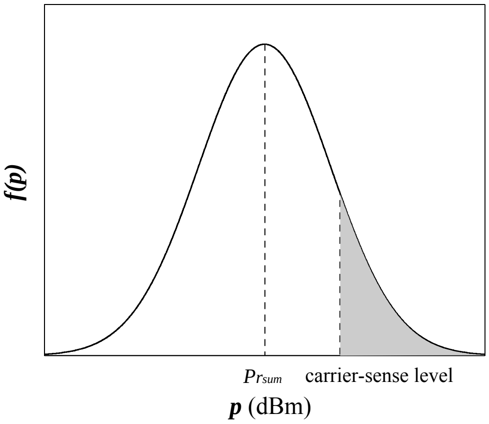

Fig. 5. Probability distribution of interference power.

4. A METHOD TO CALCULATE WPAN TRANSMISSION POWER

In terms of calculation of optimal WPAN transmission power, the throughput of WPAN as well as WLAN needs to be kept. Therefore,

- The throughput of WLAN after controlling is not worse than before controlling.
- The carrier-sense error rate of WLAN terminal that is most interfered is not over an acceptable maximal value α.
- WPAN transmission power satisfies a spectrum mask, which ranges from –70 to –41.3dBm/MHz.

WPAN transmission power needs to be calculated so as to improve the throughput of WLAN on above conditions.

The probability distribution of interference power (noise power + WPAN power) at a WLAN terminal WL$_i$ assumes normal distribution as Fig. 5 shows. The average is $P^R_{\mathrm{WL}_i}$ and the variance is ${P^N_{\mathrm{WL}_i}}^2$. $P^R_{\mathrm{WL}_i}$ is the sum of the received power of WL$_i$, $P^N_{\mathrm{WL}_i}$ is the noise power of WL$_i$ and CL is the carrier-sense level of WLAN. Since the shadowed area in Fig. 5. is probability that noise power is over the carrier-sense level, the dimension of this area corresponds to the error probability of carrier-sense CER_{WL_i}. Probability density function *f(p)* of the power *p* is shown as follows,

$$f(p) = \frac{1}{\sqrt{2\pi} P^N_{\mathrm{WL}_i}} \exp\left(\frac{p - P^R_{\mathrm{WL}_i}}{\sqrt{2} P^N_{\mathrm{WL}_i}} \right)^2 \qquad \left(-\infty < p < \infty \right). \tag{1}$$

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

$$\begin{aligned} F(p) &= \int_p^\infty f(p)dp \\ &= \frac{1}{\sqrt{2\pi} P^N_{\mathrm{WL}_i}} \int_p^\infty \exp\left(\frac{p - P^R_{\mathrm{WL}_i}}{\sqrt{2} P^N_{\mathrm{WL}_i}} \right)^2 dp \\ &= \frac{1}{2} erfc\left(\frac{p - P^R_{\mathrm{WL}_i}}{\sqrt{2} P^N_{\mathrm{WL}_i}} \right). \end{aligned} \tag{2}$$

Where the path-loss L [dB] on indoor propagation is shown as follows [5],

$$L(d) = 10\log f + N\log d + L_f - 28. \tag{3}$$

d: distance between transmitter and receiver [m]
N: damping coefficient of distance
f: frequency [MHz]
L_f: loss by passing shielding

This paper assumes indoor environment without shielding like floor, ceiling and wall and sets L_f=0. Moreover, N=2 is set as a path-loss model of UWB [6].

Meanwhile, the power that is transmitted on $P^S_{\mathrm{WP}_j}$ by WPAN terminal WP$_j$ attenuates to $P^S_{\mathrm{WP}_j} - L(d_{\mathrm{WL}_i,\mathrm{WP}_j})$ at WL$_i$ located $d_{\mathrm{WL}_i,\mathrm{WP}_j}$ away from WP$_j$. $d_{\mathrm{WL}_i,\mathrm{WP}_j}$ is the distance between WL$_i$ and WP$_j$. Therefore, CER_{WL_i} of WL$_i$ is given by,

$$CER_{\mathrm{WL}_i} = F(CL) = \frac{1}{2} erfc\left\{\frac{CL - \sum_{j=1}^{N_{\mathrm{WP}}}\left\{P^S_{\mathrm{WP}_j} - L\left(d_{\mathrm{WL}_i,\mathrm{WP}_j}\right)\right\}}{\sqrt{2}P^N_{\mathrm{WL}_i}}\right\}, \quad (4)$$

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

$$erfc(x) \cong 1 - \sqrt{1 - \exp\left(-\frac{4x^2}{\pi}\right)}. \quad (5)$$

Applying (5), (4) can be rewritten as:

$$\frac{1}{2}\left\{1 - \sqrt{1 - \exp\left[-\frac{2}{{P^N_{\mathrm{WL}_i}}^2\pi}\left\{CL - \sum_{j=1}^{N_{\mathrm{WP}}} P^S_{\mathrm{WP}_j} + \sum_{j=1}^{N_{\mathrm{WP}}} L\left(d_{\mathrm{WL}_i,\mathrm{WP}_j}\right)\right\}^2\right]}\right\}. \quad (6)$$

The carrier-sense error rate of a WLAN terminal that is most interfered by WPAN should be equal to an acceptable maximal value α so that the transmission power of WPAN terminals are degraded at once, as the carrier-sense error rates of all WLAN terminals are not over α. Therefore, each transmission power of WPAN should increase β times so that the sum of the transmission power of all WPAN terminals after controlling is equal to the power that is increased β times the sum of the power before controlling:

$$-\sqrt{-\frac{{P^N_{\mathrm{WL}_i}}^2}{2}\log_e\left\{1-(1-2\alpha)^2\right\}} + CL + \sum_{j=1}^{N_{\mathrm{WP}}} L\left(d_{\mathrm{WL}_i,\mathrm{WP}_j}\right). \quad (7)$$

where $0 \le \alpha \le 1$.

5. PERFORMANCE EVALUATION

In this section, the availability of above algorithm is evaluated by calculating the throughputs of each network with the computer simulation. This paper defines the throughput as:

$$\frac{\textit{Transmitted traffic volume}\,[\mathrm{Mbps}]}{\textit{Time to transmit all traffic volume}\,[\mathrm{s}]}. \quad (8)$$

5.1. Simulation Model

Fig. 6 shows the simulation model assumed in this paper. In this model, both WLAN and WPAN terminals are uniformly distributed within x-m-square on a plane surface. The throughputs of all terminals and base station located in this area are calculated.

Moreover, each traffic volume of one WLAN terminal by uplink is equal and its summation is equal to the traffic volume of the WLAN base station by downlink. In terms of WPAN, the throughputs of all terminals including coordinator are equal.

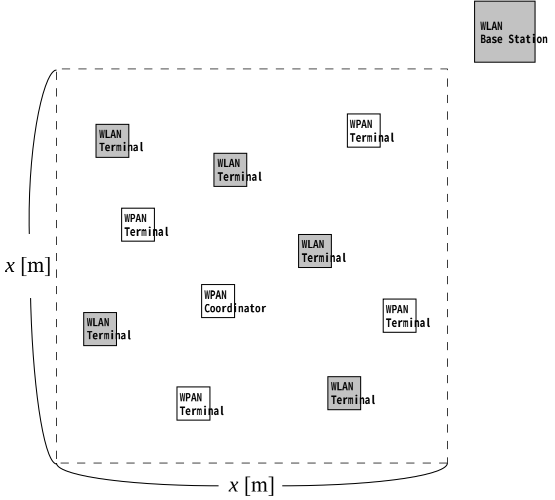

Fig. 6. Simulation model.

5.2. Simulation Parameters

The simulation parameters are shown in Tables 1〜3. Data size is 1500 octet and other parameters are compliant with IEEE802.11a. The MAC parameters of WPAN in this paper are those of IEEE802.11.

Table 1. System parameters.

Number of WLAN terminals	5
Number of WPAN terminals	5
x	10m
Bit rate of WLAN	24Mbps
Initial value of WPAN transmission power	-50dBm/MHz
SNR	3dB
α	0.5

Table 2. Parameters for 5GHz-WLAN.

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

Table 3. Parameters for UWB-WPAN.

Bit rate	480Mbps	MAC header	24octet
Preamble	0.8 μ s	FCS	4octet
PLCP header	0.2 μ s	Data size	1500octet
Slot time	0.45 μ s	ACK size	14octet
SIFS time	0.8 μ s	CWmin	15
DIFS time	1.7 μ s	CWmax	1023
Carrier-sense level		-100dBm	
Medium access method		DCF	

5.3. Time Assignment

In this paper, the throughputs are calculated as one control cycle in Fig. 7. After communication for a certain time (T_{com_1}), the terminals control the WPAN transmission power for a DAA time (T_{DAA}) and the communication is restarted. T_{DAA} is a time including T_{cog} for monitoring throughput by Cognitive Radio, T_{cal} for calculating WPAN transmission power and T_{ctrl} for controlling WPAN transmission power.

If T_{DAA} is too long, the WLAN throughput may degrade more than in the case with no control. Total throughput of WLAN *Th* is shown as:

$$Th = \sum_{i=0}^{N_{\mathrm{WL}}} Th_{\mathrm{WL}_i}^{\max}\left(1 - CER_{\mathrm{WL}_i}\right). \qquad (9)$$

$Th_{\mathrm{WL}_i}^{\max}$ is the maximal value of the throughput of *Th*. Therefore, applying (8), T_{DAA} that has effect to avoid interference has not to be over the following formula:

$$Th_{Tr_1+Tr_2}^{\max}\left(1 - CER_1\right) - \frac{Tr_1}{Th_{Tr_1}^{\max}\left(1 - CER_1\right)} - \frac{Tr_2}{Th_{Tr_2}^{\max}\left(1 - CER_2\right)}. \qquad (10)$$

Where *Tr* is total traffic volume of WLAN.

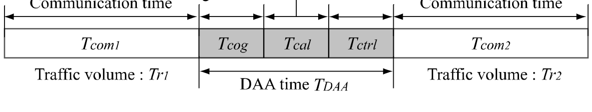

Fig. 7. Time assignment for DAA.

5.4. Simulation Results

WLAN throughput characteristic against T_{DAA} is shown in Fig. 8. The traffic volume is 24Mbps. From the figure, it is clear that T_{DAA} can have effect to avoid interference if it is less than about 4.5Ms.

Next, in the case of T_{DAA}=1Ms, which can have effect to avoid interference, the throughput of WLAN against traffic volume is calculated (Fig. 9). From the figure, it is shown that the throughput of WLAN is improved about double by WPAN transmission power control.

Moreover, the WLAN carrier-sense error rates of around control are compared (Fig. 10). From the figure, there is a terminal whose carrier-sense error rate is over an acceptable maximal value α=0.5 before control. Meanwhile, the carrier-sense error rate of the terminal that is most interfered cannot be over α after control.

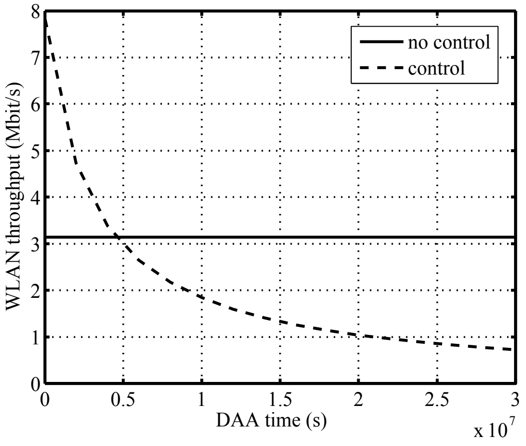

Fig. 8. Throughput of WLAN against DAA time.

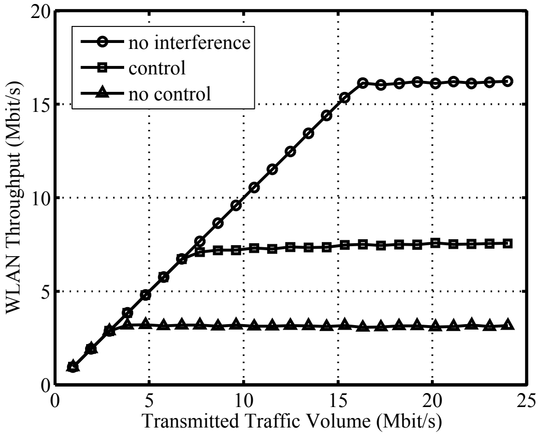

Fig. 9. Throughput of WLAN against traffic volume.

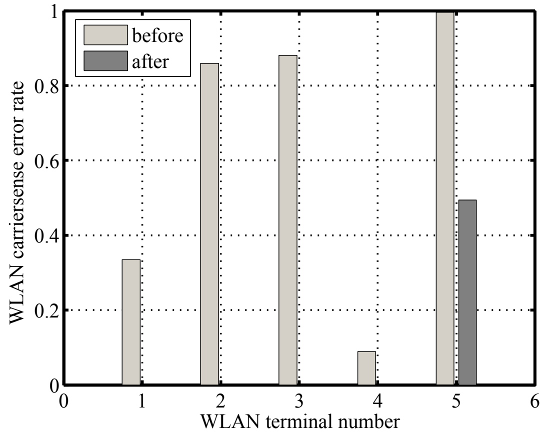

Fig. 10. Carrier-sense error rate of each WLAN terminal.

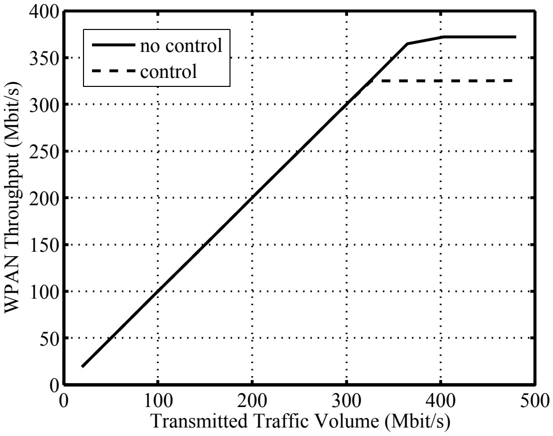

Fig. 11. Throughput of WPAN against traffic volume.

In the same way, the throughput of WPAN against traffic volume around control is calculated (Fig. 11). From the figure, the throughput of WPAN degrades a little bit by WPAN transmission power control, however, the amount of degradation is only about 13%.

6. CONCLUSIONS

In this paper, an algorithm avoiding interference from WPAN to WLAN with Cognitive Radio in an environment where the two systems coexist is proposed. Improvement on the throughputs of WLAN without significant degradation of the throughput of WPAN is shown.

In this paper, each WPAN transmission power is controlled without variation, however, each power is controlled individually and both methods are compared in terms of throughput and number of operations in our future studies. Moreover, more efficient method is proposed with both methods.

7. REFERENCES

[1] http://www.soumu.go.jp/joho_tsusin/policyreports/joho_tsusin/

[2] John Polson, “Cognitive Radio Applications in Software Defined Radio,” *in Proceedings of Software Defined Radio Technical Conference*, November 2004.

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

[4] ANSI/IEEE Std 802.11, “Information technology- Telecommunications and information exchange between systems- Local and metropolitan area networks- Specific requirements- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications,” 1999.

[5] Hideaki Matsue and Masahiro Morikura, *802.11 High-speed Wireless LAN Textbook*, IDG JAPAN.

[6] Shunsuke Sato and Takehiko Kobayashi, “Path-Loss Exponents of Ultra Wideband Signals in Line-of-Sight Environments,” *Technical Report of IEICE, WBS 2003-57*, October 2003.