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UWB 신호채널을 사용한 분산협력 스펙트럼 센싱의 검출확률 향상

(Enhancement of the Detection Probability for Distributed Cooperative Spectrum Sensing using UWB as a Common Channel)

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요 약

인지전파 기술은 유효한 스펙트럼을 찾기 위하여 면허사용자(주사용자)의 존재를 검출하는 적절한 센싱 기술이 필요하다. 또한 분산형 ad-hoc 네트워크의 경우 검출된 정보는 부사용자 간에 서로 제공될 수 있어야 한다. 동시에 주사용자의 성능은 부사용자에 의하여 열화 되지 않아야 한다. 특히, 주사용자의 검출은 음영지역에서는 매우 어렵다. 이를 위하여 분산형 협력 스펙트럼 센싱 기술이 제안되었는데 이는 검출 성능을 향상하기 위하여 다수의 부사용자에 의하여 검출된 정보를 협력적으로 조합하는 방법이다. 그러나 이 기술은 주사용자를 검출하는 정확성과 신속성 측면에서 성능 향상이 필요하다. 본 논문에서는 UWB를 사용하여 주사용자를 검출하고 또 이를 사용하여 검출된 정보를 부사용자 노드들에게 제공하는 방법을 제안하였다. UWB는 고속의 데이터 전송이 가능한 장점이 있다. 뿐만 아니라 underlay 방법으로 주사용자와 공존하여 전송이 가능한 장점이 있다. 본 논문에서는 UWB를 사용한 주사용자의 검출 확률 측면에서 개선이 됨을 보였다. 또한 throughput을 해석한 결과 제안된 방법은 기존의 방법과 비교하여 개선되었음을 보였다.

Abstract

Cognitive radio should imply a proper sensing technique for detecting the presence of licensed users to identify the unused spectrum holes. Besides this, this information should also be used to opportunistically provide communication among secondary users. At the same time the performance of the primary user should not be declined by the secondary users. The detection of licensed users may be significantly difficult for shadowing effect. To prevail over this problem, cooperative spectrum sensing, in which the combined observation information gained by multiple secondary users is employed to achieve higher performance of detection, has been inspected. However, the primary challenge of cooperative sensing lays in its ability to detect the presence of licensed user quickly and accurately. In this paper, we have used UltraWideBand (UWB) to detect the presence of licensed users and transmit the sensing information among the nodes of the network. UWB has the capability of transmitting data at a very high rate. It is unique in co-existence capability with narrow band systems. Here, we have shown that the detection probability of licensed user is improved by means of transmitting the spectrum sensing information via UWB. We also have analyzed the throughput of the proposed technique and compared the result with existing sensing method.

Keywords : Cognitive radio, cooperative spectrum sensing, UWB supported cognitive radio networks.

Ⅰ. Introduction

New generations of mobile radio communication systems aim at providing higher data rates and a wide variety of applications to the mobile users, while serving as many users as possible. However, this goal must be achieved under the constraint of limited available resources such as power and frequency spectrum. Given the high cost of power

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and scarcity of the spectrum, radio systems must provide higher capacity and performance through a more efficient use of the available resources[1]. Hence, in order not to limit the economic and technological improvement of the wireless world, it is necessary to find immediate solutions regarding the usage of existing resources. A recent solution for this problem is cognitive radio[2].

Cognitive radio aims at a very efficient spectrum utilization employing smart wireless devices with awareness, sensing, learning, and adaptation capabilities. As a solution for the spectrum scarcity problem, cognitive radio proposes an opportunistic spectrum usage approach[3], in which frequency bands that are not being used by their primary (licensed) users are utilized by cognitive radios. However, such spectrum utilization technologies involve problems of interference. So, secondary user must prevent excessive interference with primary users. In this perspective, sensing technique to detect the presence or absence of primary users in the frequency band is important and it corresponds to a sensing problem.

So far, several methods have been inspected to deal with this sensing problem in cognitive radio. Energy detection is one of the practical methods because of its simplicity[4]. In this method it is extensively difficult to always maintain a required sensing performance i.e. detection capability, for the users which experience shadowing. For this problem, cooperative sensing method has been introduced[5~6].

In cooperative spectrum sensing, cooperation occurs among the secondary users. One secondary user communicates with another to exchange the information that it has observed. In this way all the secondary users communicate with others and distribute the information among all other secondary users. Thus higher detection performance with reducing influence of shadowing is gained. The advantages of cooperative sensing have been presented in [5]. Cooperative spectrum sensing aims at detecting the presence or absence of licensed user in a quick and accurate manner. In most of the cooperative sensing techniques, a centralized controller or a separate channel is used to share the sensing information among the secondary users in the cognitive network. In such approach, the centralized controller collects such information, processes it, and transfers it to other cognitive users. This procedure requires high data rate for transmission of information through a traffic channel. We focus on this point of high data rate for transmission of information. If the information transmission among the secondary users can be speeded up then the detection capability of the cognitive network as a whole might increase. We will use the UWB (UltraWideBand) for transmitting the spectrum sensing information among the secondary users as a common channel.

UWB is a promising technology for future short and medium range wireless communication networks with various throughput options including very high data rates. It has many tempting features such as low power consumption, significantly low complexity transceivers, and immunity to multipath effects. The lucrative features of UWB systems that make these systems very tempting for cognitive radio include that - their transmission parameters such as power, pulse shape, and data rate are highly adaptive, in order to utilize the spectrum they don't require license, by employing interference avoidance and cancellation methods they can coexist with licensed communication systems, their practical implementation does not have a high cost[7].

Systems with a spectral allocation similar to UWB are often referred as underlay systems. The transmitted power of UWB devices is controlled by the regulatory agencies, so that narrow band systems are affected from UWB signals only at a negligible level. So, in this way UWB systems are enabled to co-exist with narrow band technologies. By using UWB for sensing information transmission we can increase the detection capability of the network as well as improve the performance of the network.

In this paper, a method of combining underlay UWB with cognitive radio is proposed. A cognitive system that distributes the spectrum sensing information within its network via UWB is anticipated here. The range of cognitive communications in this scenario is inspected. This method aims at increasing the capacity, performance, range, and variety of cognitive communications making use of UWB. The remaining portion of our paper is organized as follows. In section II, the system model is described, which is followed by the practical implementation steps of this system. In section III, the communication scenario, network range and throughput are addressed followed by simulation results, and finally we have concluded in section IV.

II. System Model

There are several things that might be considered while proposing UWB to transmit the sensing information among the secondary users. UWB systems operate over extremely wide frequency bands, where various narrow band technologies also operate with much higher power levels as shown in Figure 1. The unlicensed usage of a very wide spectrum that overlaps with the spectra of narrowband technologies brings about some concerns. Therefore, significant amount of research has been carried out lately to quantify the effect of UWB signals on narrow band systems[8].

The transmitted power of UWB devices is controlled by the regulatory agencies such as the FCC in the United States, so that narrow band systems are affected from UWB signals only at an egligible level. This way, UWB systems are enabled to co-exist with narrow band technologies. However, the fact from the other side is that the influence of narrow band signals on the UWB system can still be significant. The recent studies show that the BER (bit-error-rate) performance of the UWB receivers is greatly degraded due to the impact of narrow band interference[9]. The high processing gain of the UWB signal can cope with the narrow band interferers to some extent. However, where the large processing gain alone is not sufficient to suppress the effect of the high power interferers, the UWB receivers require employing NBI (narrow band interference) suppression techniques to improve the performance, the capacity, and the range of the UWB communications. The most inexpensive and successful way of suppressing NBI can be achieved by employing an adaptive method of combining the avoidance and cancellation approaches. Some of the NBI avoiding techniques are multi-carrier approach, pulse shaping etc[10] and cancellation methods are MMSE (Minimum Mean Square Error) combining etc.

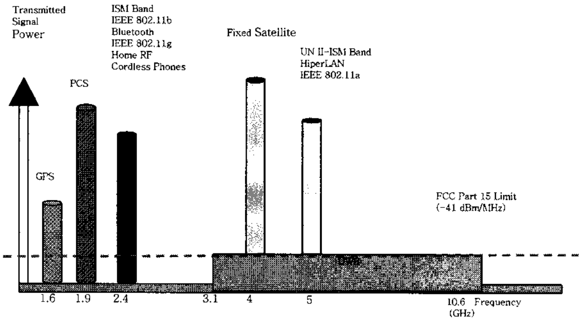

그림 1. UWB 시스템에서 협대역 사용자들의 스펙트럼 중첩

Fig. 1. Spectrum crossover of the narrowband interferers in UWB systems[8].

In this paper, we assume the cognitive system of an ad hoc node has the capability of transmission and reception of the sensing information to and from other ad hoc nodes. In order to match the results of spectrum sensing operation done by both parties, each of them will transmit the information regarding the white spaces they have detected. We propose that

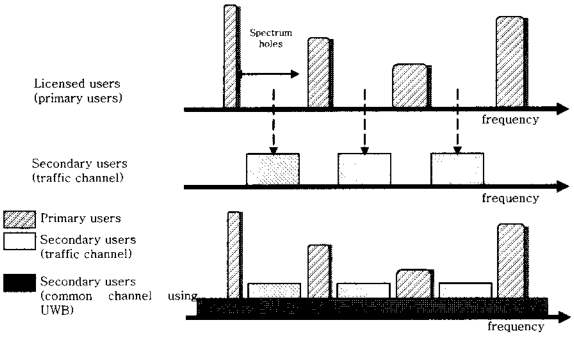

그림 2. 본 논문에서 제안된 방법

Fig. 2. The proposed scheme in this paper.

the information of spectrum holes sensed by UWB can be transmitted via UWB common signaling channels. Since this transmission will be accomplished in an underlay manner, it can be done simultaneously with the real data communication, which is a traffic channel, without affecting each other as shown in Figure 2.

Considering the relatively low throughput needed to transmit the sensing information as well as the low cost transceiver requirement, it turns out to be a proper option to use an uncomplicated non-coherent receiver such as an energy detector, and to employ OOK (On-Off Keying) modulation. OOK is one of the most popular non-coherent modulation options that have been considered for energy detectors. OOK based implementation of energy detectors is achieved by passing the signal through a square law devices, such as a Schottky diode operating in square-region, followed by an integrator and a decision mechanism, where the decisions are made by comparing the outputs of the integrator with a threshold. Two challenging issues for the enhancement of energy detector receivers are the estimation of the optimal threshold, and the determination of synchronization/dump points of the integrator. The implementation issues regarding the OOK based energy detector receivers such as estimating the optimal threshold and determining the optimum integration interval is discussed in [7].

It may not be reliable to consider a white band an opportunity if it is detected by only one single cognitive radio device. The reasons include that the device has a limited sensing range, as well as that it may be experiencing shadowing. Optimally, the spectrum has to be sensed by a number of cognitive nodes over a region that goes well beyond the range of a single cognitive device. A band can be considered a candidate for being a spectrum opportunity only if it is detected as white by many cognitive nodes at different locations that exchange the spectrum sensing information with each other.

Once both parties of communication receive the spectrum sensing information obtained by the other party, they logically 'AND' the white spaces each of them has detected separately. The reason is that if both the parties classify them as white space only then that space can be used for opportunistic usage. Depending on the knowledge about the common white spaces, each party designs a new pulse shape. Since the new pulses designed by both parties will be the same, this method has the very advantageous feature that it enables highly efficient matched filtering during the real data traffic. To be more clear, what the receiving party uses as the template to match the received pulse will be almost the same as the transmitted pulse by the other party, leading to a high correlation between them, and hence, to a successful matched filtering.

The communication scenario as well as the transmission of information as a whole can be summarized as, suppose in a communication environment there are some cognitive users in a particular area and also there are primary users. Now, if two of the cognitive users try to communicate between themselves, they have to be informed about the available spectrum prior to start the communication. The cognitive users always scan the spectrum for availability of usage and pass the information to other cognitive user via the UWB channel at a very high speed. In this way, the cognitive users are aware of the spectrum availability

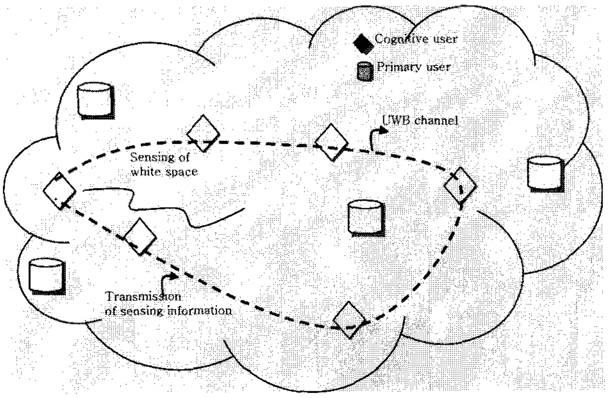

그림 3. UWB 신호채널을 사용한 스펙트럼 홀의 검출과 정보의 협력 전송

Fig. 3. Sensing of spectrum holes and co-operative transmitting the information via UWB common channels.

and they can use that portion successfully. The total scenario of communication and transmission can be depicted in the following Figure 3.

The cognitive or secondary nodes transmit message and spectrum sensing information among them in the communication scenario. The sensing information is transmitted via UWB. The communication scenario as a whole is accomplished through several steps. These steps can be described briefly as, firstly, capturing any signal in the target spectrum (e.g. 2.1-2.3 GHz) by using an appropriate antenna and analog band pass filter, then analyzing the spectral content of the received signal either by analog means or by digital means, after that comparing the bandwidths of the white spaces with a pre-determined minimum bandwidth in order to find out if they are wide enough to be utilized, then transmitting the information regarding the usable white spaces to the other party via UWB signaling, after that receiving the white space data from the other party, then finding the common white spaces, then designing a pulse shape that utilizes as much usable white space as possible and finally initiating the cognitive communication and repeating the entire sensing process at a regular period. These steps are depicted in Figure 4 in the form of flowchart to clearly understand the scenario.

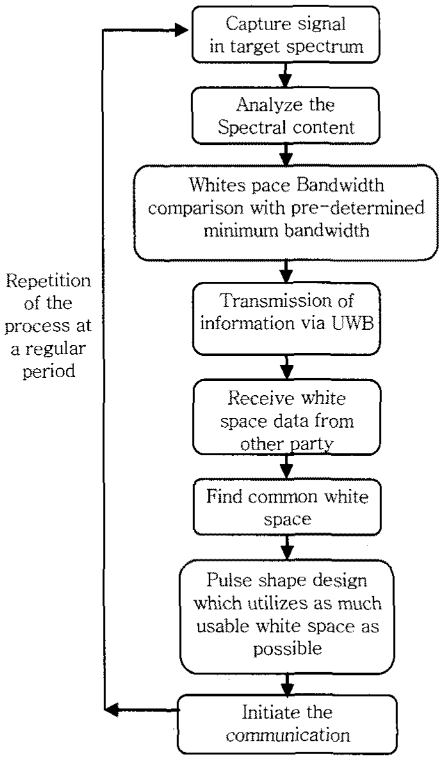

그림 4. 제안 시스템의 구현 흐름도
Fig. 4. Steps of implementation scenario.

Ⅲ. Analysis and Simulation Results

1. Sensing Region and Detection Probability

In cognitive radio communications, in order to make sure that the intended frequency spectrum is not in use, both parties of communication have to scan the spectrum and inform each other about the spectral conditions. Therefore, there should not be a gap between the sensing ranges of them. If the sensing ranges are not at least partially overlapping, there is always a risk that a licensed user located inside the gap between the sensing ranges is not detected. Therefore, the receiving sensitivity of both parties has an integral role in determining the range of communication. Besides this, detection of the licensed user is in accurate and quick manner is another concern. If the probability of detection is increased, the performance of communication as a whole is increased.

For analysis of sensing region we can take a sensitivity range, for example, around -120dBm to -130dBm and free space propagation, in which the transmitted power (P_{tx}) and received power (P_{rx}) are related to each other by the Friis equation (ignoring the system loss and antenna gains)

$$P_{rx} = \frac{P_{tx}\lambda^2}{(4\pi)^2 d^2} \tag{1}$$

where λ is the wavelength, and d is the distance. With these assumptions, the scope of cognitive radio is limited to 50m to 150m, which is comparable to the range of WLANs.

If the targeted range of communications is wider than this level, or if the cognitive devices are experiencing shadowing and are hardly able to detect the existence of licensed users, a network of

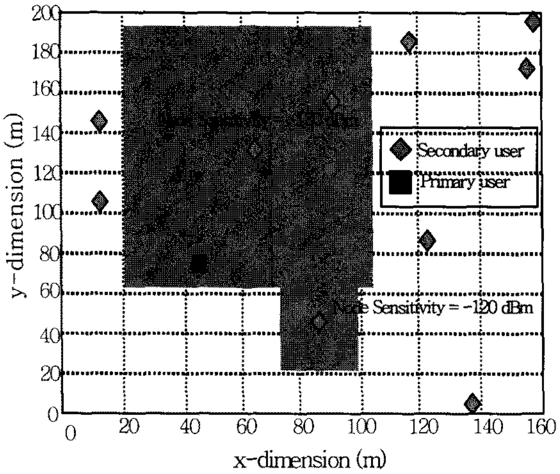

그림 5. 인지 전파 트랜시버 네트워크 (민감도 범위는 스케일링되지 않음)

Fig. 5. Network of cognitive transceivers (sensitivity ranges are not drawn to scale).

collaborating cognitive nodes may be an effective solution.

We consider a cognitive network as shown in Figure 5, in which the nodes communicate with each other using UWB to exchange spectrum information. The proposing of UWB signaling may seem to be contradicting with the aim of increasing the range of cognitive radio because of the limited range of UWB. However, looking at the BER expression for OOK modulated UWB signals

$$Q\left(\sqrt{\frac{N_s A E_p}{2N_o}}\right) \tag{2}$$

where N_s is the number of pulses per symbol, A is the pulse amplitude, E_p is the received pulse energy, and the additive white Gaussian noise (AWGN) has a double sided spectrum of $N_0/2$. So, it is seen that increasing Ns, which can be accomplished by repeated transmission of data, results in lower BER. This piece of information directs to a really useful feature of UWB called the processing gain.

If the necessary amount of processing gain can be employed, it is possible that the farthest nodes in a cognitive network can share the spectrum sensing information. Although this comes at the expense of lowered throughput, it is not a limiting factor in this case because a quite low data rate is enough to transmit the spectrum sensing information.

By enabling all the nodes in a cognitive network to communicate with each other via UWB, there is no need - either to allocate a separate channel for sharing the sensing information or to employ a centralized controller that collects such information, processes it, and transfers it to other cognitive users. The sensing information received from all the other nodes in the network can be combined in each node, and pulse design can be done according to the common white spaces.

For the practical implementation of cognitive radio communications, computer analysis and simulations are performed. These are related to the transmission of spectrum sensing results via UWB, the range of cognitive communications, the capability of a cognitive network to detect a licensed system of the suggested idea.

In the simulations regarding the UWB signaling, the channel model CM3 in [12], which corresponds to an office environment with LOS (Line-Of-Sight), is utilized. The frequency range is 3.1-3.6 GHz, the reference path loss 35.4 dB, the path loss exponent is 1.63, the receiver antenna noise figure is 17 dB, the implementation loss is 3 dB, the throughput is 20 Mbps, and the integration interval is 30ns.

A theoretical analysis was performed to investigate the performance of OOK modulated UWB data transmission depending on the distance between a cognitive transmitter- receiver pair. According to [12], the path loss assumed can be shown as

$$L(d) = L_0 + 10n\log_{10}\left(\frac{d}{d_0}\right) \tag{3}$$

where the reference distance (d_0) is set as 1m, L_0 is the path loss at d_0, and n is the path loss exponent. The average noise power per bit is

$$N = -174 + 10\log_{10}(R_b) \tag{4}$$

where R_b is the throughput.

In Figure 6, the effect of distance on the probability of error is established. The results show

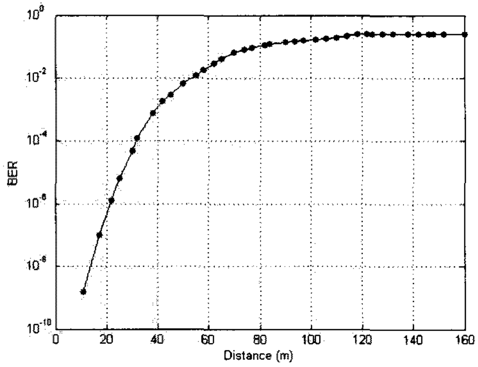

그림 6 UWB 신호 노드 간의 BER과 거리의 관계

Fig. 6. BER vs. distance between the nodes of UWB signalling.

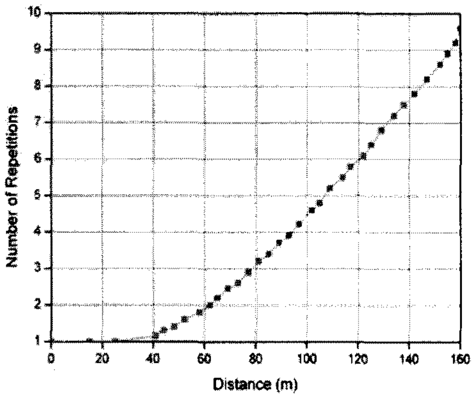

그림 7. 신뢰성 있는 UWB 신호를 위하여 요구된 repetition rate과 거리와의 관계

Fig. 7. Repetition rate required for reliable UWB signaling vs. distance.

that the BERs obtained for up to 40m are still acceptable. For further distances, however, some processing gain is definitely needed. The processing gain is obtained by repeated transmission of the same information.

The following result investigates the number of repetitions required in order not to exceed the BER obtained at 40m, which corresponds to $10^{-3.2}$. The number of repetitions needed vs. the distance is shown in Figure 7.

To examine the effect of the number of nodes on the probability of a licensed system being detected by the cognitive network, a simulation is performed. Figure 5 demonstrates a network composed of cognitive radio devices. The nodes in the network are randomly distributed in a 200m x 200m area inside a building. It is assumed that there is a licensed transmitter, which is transmitting at -60dBm, whose location is random, as well.

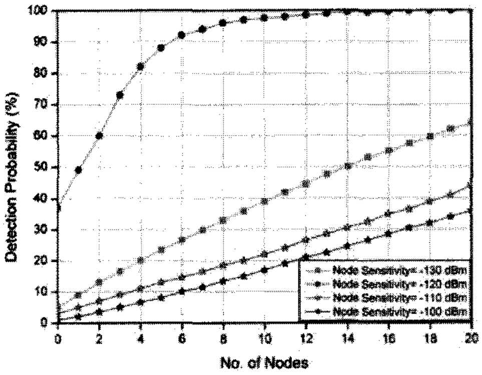

그림 8. 인지 네트워크에서 검출된 주사용자 송신기의 검출 확률

Fig. 8. Probability of a licensed transmitter being detected by the cognitive network.

We have used equation (3), (4) and trial and success method for the simulation result. The simulation result depicts that the detection probability of licensed user is increased with the increase of number of communication nodes when UWB channel is used for transmission of sensing information and hence the efficiency of cognitive radio system is increased as shown in Figure 8.

In order to make a reliable detection, the number of required nodes may vary depending upon the level of the node sensitivity region.

2. Throughput

The cognitive nodes in our system are capable of both transmission and reception. These nodes transmit sensing information through UWB channel and passes message via traffic channel as depicted in Figure 2. For the purpose of comparison of throughput with existing one, we consider the two switch model described in [11]. We proceed with analyzing the throughput of our idea first and then we have compared the throughput.

For throughput analysis we consider a scenario where secondary transmitter and secondary receiver are separated by a distance *d*. Both the transmitter and the receiver have their sensing region denoted by R_S. The activity of secondary transmitter and receiver

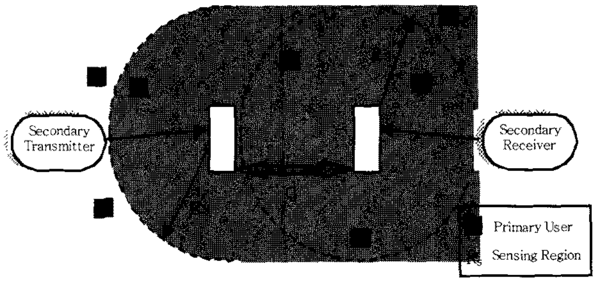

그림 9. 부사용자 송수신기의 검출 반경 Rs의 영역
Fig. 9. Region of sensing of radius Rs around the secondary transmitter and receiver.

is affected by the presence or absence of primary user in the sensing area. This scenario is depicted in the Figure 9.

The locations of the primary users in the system are captured by a Poisson point process with a density of ρ primary nodes per unit area, i.e., the probability of finding n primary in an area A. R^2 is given by,

Prob[n nodes in A] = Prob [N(A) = n]

$$= \frac{e^{-\rho A}(\rho A)^n}{n!} \tag{5}$$

The capacity equation of [11] can be expressed as below:

C(P)=Prob[No Primary User within Secondary Transmitter's and Secondary Receiver's sensing region] log (1 + P/Prob [No Primary User within Secondary Transmitter's sensing region]) (6)

Here, P is average power constraint at the secondary transmitter.

For analyzing the throughput of our system we consider the scenario depicted in the Figure 9.

For the equation (6), we can write in the following way,

Prob [No Primary User within Secondary Transmitter's sensing region]

= Prob[N(πRs^2)]

$=e^{-\rho\pi R_s^2}$[from equation (5) since n=0] (7)

and,

Prob [No Primary User within Secondary Transmitter's and Secondary Receiver's sensing region]

$$= e^{-\rho(2R_s{}^2(\pi-\cos^{-1}(\frac{d}{2R_s}))+dR_s\sqrt{1-\frac{d^2}{4R_s{}^2}})} \tag{8}$$

Now, putting these values in the capacity equation (6) we get,

$$C = e^{-\rho(2R_s{}^2(\pi-\cos^{-1}(\frac{d}{2R_s}))+dR_s\sqrt{1-\frac{d^2}{4R_s{}^2}})}$$

$$\log(1+Pe^{-\rho\pi R_s^2}) \tag{9}$$

Here, P is the secondary transmitter power constraint.

Considering $P=1$ and $d=1$, we get the following throughput versus sensing radius R_s graph. In this graph we have taken different densities of primary user in an area. Figure 10 plots the secondary user throughput against the radius of the sensing regions R_s for different primary user densities ρ. From this figure, we can see that with increase in R_s, the sensitivity of detection increases, the average number of communication opportunities decreases resulting in a lower throughput as expected. The same is true as ρ increases.

Now, for comparing the throughput of our suggested idea with existing method we consider the two-switch model. The communication scenario for comparing our idea with the two-switch model, in

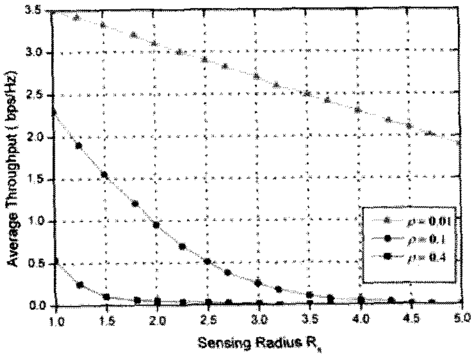

그림 10. ρ 값에 따른 throughput과 검출 반경과의 관계
Fig. 10. Throughput vs. sensing radius for different values of ρ.

which the primary and secondary transmitters are separated by a distance of value x, can be described as, the scenario consists of primary and secondary transmitters and receivers. Primary transmitter can transmit message to primary receiver and secondary transmitter and receiver as well. Secondary transmitter can transmit message to primary and secondary receiver.

The two switch model shows the attribute of distributed spectral environment. Our suggested idea acts like the selfless approach described in [13]. In this approach, the secondary transmitter uses a part of its power to relay the primary user's message to the primary receiver. The remaining power is used to transmit the secondary user's message.

The signal to noise ratio (SNR) can be expressed as,

$$\text{SNR (db)} = 10\log_{10}\left(\frac{P_{signal}}{P_{noise}}\right) \tag{10}$$

Here P is the average power.

The power split is chosen such that the increase in the primary user's SNR due to the relaying is exactly balanced by the decrease in its SNR due to interference caused by secondary transmissions, i.e., the SNR at the primary receiver remains the same with or without the secondary user[13].

For every link in the scenario for comparing the throughput, we assume path-loss exponent of 4 and unit variance AWGN noise. The channel gains are assumed to be known to all the nodes at all instants. The primary user activity follows an i.i.d Bernoulli process with an average on-time of 40%. We consider a short term power constraint of P_p=10 at the primary transmitter and P_s at the secondary transmitter. Upon these assumptions, we compare the throughput of the suggested scheme between the two-switch model and the result is shown in Figure 11.

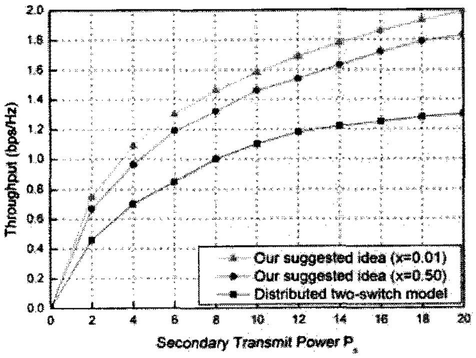

그림 11. 제안된 기법과 two-switch 모델의 throughput 결과비교

Fig. 11. Throughput comparison of the proposed scheme and two-switch model.

For the sake of simplicity, primary user detection is assumed to be error free. The throughput of two-switch model is independent of the value x while the throughput of the proposed idea depends on x. From the Figure 11, it is clear that the throughput improves with the decrease of the value x i.e. when the primary and secondary transmitters are located closer to each other, the throughput improvement is gained.

Ⅳ. Conclusion

The constantly rising need for frequency spectrum demands the increase of efficiency of spectrum usage. Hence, it is necessary to develop adaptable radio access technologies that can take benefit of the existing spectrum in an opportunistic way. A cognitive system is proposed that benefits from UWB in distributing the spectrum sensing information. It is shown that such a system can make use of the processing gain property of UWB to increase the targeted range of cognitive communications and increase the detection probability of the primary users at the same time. Besides this, we have shown that the throughput performance is also improved comparing with existing one. Thus, the proposed idea shows the enhancement of the efficiency of cognitive radio. In the future, more performance metrics will be considered for performance evaluation.

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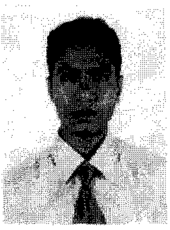

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