A Hybrid Spectrum Mobility and Handover Protocol in 3GPP Cognitive LTE Systems

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***Abstract*—Many researches show that the current approach of fixed spectrum allocation caused the most of idle resources being unused by other wireless devices. Cognitive Radio (CR) is the novel system that improves the low utilization spectrum, with software-defined radio (SDR) devices of reconfigurable and switching spectrum resources to enhance the appropriate spectrum access and sharing. The new network technology long term evolution (LTE) systems have been proposed and this technique has highly flexible bandwidth and spectrum agile to satisfy the CR network. For the purpose of spectrum selection and mobility, we propose a hybrid spectrum mobility and handover protocol that based on the Poisson distribution of spectrum resources and consider the different spectrum holes characters to compute the expected transmission time of each spectrum hole. The minimum expected transmission time makes an appropriate spectrum holes selection to spectrum mobility and the makes the secondary user to select the adaptive base station to handover. Simulation results have shown that the proposed protocol is able to select spectrum holes adaptively and reduce the spectrum mobility ratio.**

***Index Terms*—Cognitive, mobility, LTE, software defined radio (SDR), handover.**

I. Introduction

In recent years, Internet users a way to use network access technology has been vigorous development of the current wireless network gradually replaced the limited network. Due to the wireless network bandwidth constraints can not fully take advantage of all of the radio spectrum resources for mobile devices and power supply can not continue to use, and the free radio spectrum resources is very frequent. According to Federal Communications Commission (FCC), temporal and geographical variations in the utilization of the assigned spectrum range from 15% to 85% (2)(3). In order to improve the utilization of the overall radio spectrum, the cognitive radio (CR) network is a solution to this low utilization of the radio spectrum.

The concept of CR is first presented by Joseph Mitola III and Gerald Q. Maguire, Jo. (4). In CR networks, there are two types of users; one is to licensed users (primary users, PUs), and the other is unlicensed users (secondary user, SUs). PUs can access the wireless network resources anytime and anywhere. Unlike the PUs, the SUs only take advantage of these radio spectrum resources when PUs unused. When PUs reclaim the radio spectrum resources, the SUs must move away the current radio spectrum resources at once and switch to other idle radio spectrum resources.

With the development of wireless network technology, the wireless mobile access has been progressed by second-generation (2G) and third-generation (3G) cellular systems. In recent years, the Third Generation Partnership Project (3GPP) has proposed a 3G long term evolution (LTE) (6)(5). LTE is based on the universal terrestrial radio access (UTRA) and high speed down-link packet access (HSDPA) and further strengthen its communications capacity to upload in order to enhance its quality of service can be provided. LTE have to coexist with 2G/3G systems, WLAN, WiMAX, etc. Since LTE have highly flexible bandwidth and LTE is have possible to use communication device in many different bands with facility for reprogramming if the operator you are using communication device with has completely different frequency band it is being proposed that Software Defined Radio (SDR) be used with LTE.

SDR is a revolutionary technology (7). SDR may change the wireless industry, and the restrictions on mobile communication system are solved. SDR is the first research and development in order to integrate communication capabilities between U.S. militaries. SDR can dynamic set up different network protocol when mobile terminal with SDR device in different networks. In addition to reconfigurable property, in the CR network the SUs with SDR device use the physical layer of the sensing technology to periodically cycle sense the current signal strength and the idle spectrum resources (or called spectrum holes). With these information, SUs dynamically select a suitable spectrum hole to use without interfering with PUs.

In this paper, to achieve layer two spectrum mobility and layer three handover selection. SUs with SDR device perform the following three phases; (1) environment observation, (2) computation and analysis, and (3) evaluation and transmission. In the environment observation phase, the secondary users (SUs) collect the spectrum bands information and other communication parameters by the SDR device. In the computation and analysis phase, the collected information is analyzed to understand the characters of every spectrum hole. The characters of each spectrum hole are prepared for the next phase. In the evaluation an transmission phase, the secondary users evaluate expected transmission time of each spectrum hole for SUs service data. The spectrum hole with minimum expected transmission time to complete SU service has more opportunity usage without interruption. For layer two purposes, the spectrum hole with minimum expected transmission time of spectrum hole is selected to spectrum mobility. The minimum expected transmission time of spectrum hole make the layer three select the adaptive base station to handover.

The remainder of this paper is organized as follows. In section II, related works are described. section III overviews the system architecture, and the basic ideas of the proposed schemes. section IV describes the proposed hybrid spectrum mobility and handover protocol. Performance evaluation is presented in section V. section VI concludes this paper.

II. Related Work

In layer two solution, the dynamic spectrum allocation (DSA) mainly focuses on how to exploiting temporal and spatial traffic statistics to allocate the spectrum to SUs. In recent years, DSA has been a gate of heat research because of its potential to exploit highly under utilized wireless spectrum resource. DSA make the CR with more frequency agility by sensing the spectrum holes and automatically tuning to the adaptive frequency channels. Many research of DSA has proposed based on the systems that composed of SUs equipped with CR systems that aim to utilize spectrum holes that are not being used by PUs.

Ohyun *et al.*(8) proposed a spectrum matching algorithms which consider the user QoS and spectrum characteristics to efficiently allocate spectrum holes for SUs in the CR base station architecture. For minimizing the probability of spectrum handover and satisfying the service of SUs, the spectrum matching algorithm focus on the different services of SUs and the spectrum hole of different sizes and holding time, according the differences the spectrum matching algorithm select the require time of service that most closest to the spectrum holding time to assign spectrum hole. These spectrum be classified by the similar holding time, each SU should calculate the service require time itself, then the CR base station according to the service require time to select a holding time class and random a spectrum hole in the class to allocate the spectrum hole to SU.

Akbar *et al.*(9) proposed a Markov-based Channel Prediction Algorithm (MCPA) and the channel occupancy of PUs is assumed to be passion distribution, it is based on the hidden Markov model (HMM). HMM is a finite state machine that can predict the appearance of spectrum holes in different spectrum bands. The first of MCPA operation need to observe channel usage patterns and update HMM parameters, then predicting channel availability and occupation using HMM and decide whether the SU should remain in the same spectrum or move to others.

Hoyhtya *et al.*(10) propose a simple classification and learning of predictive channel selection method. In this method the author presents the architecture

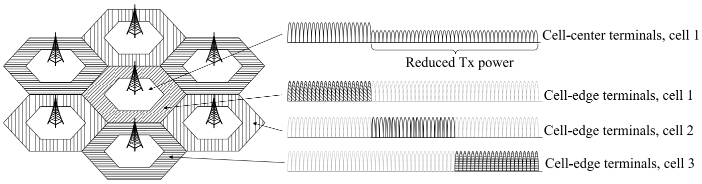


Fig. 1. Example of inter-cell interference coordination.

for predictive CR systems for statistics of spectrum sensing results and the channel history. In order to choose the channel with the largest idle time, the author classifies the network traffic pattern to four types. According to the different types of traffic pattern the predicting results is different in each types. The prediction of idle times with periodic traffic patterns, the history information support to exact predicts future channel idle times. The prediction of idle times with random traffic patterns, the predictive idle times is calculated by the detection of the available idle time. For availability using the idle channels the probability of predictive idle time must be greater than 50%. When the current channel used by SU has been occupied by PU, SU utilize the past channel history information to predict the spectrum availability and select a channel with maximum idle time, and then switch to the channel without interfering the PUs.

III. Preliminary

In this section, we first describe the assumptions, LTE systems architecture, and we proposed system model, and then we explain the challenges, the basic idea and the main contributions of this work.

A. LTE system architecture

The LTE systems provide frequency orthogonality between users in both uplink and downlink within a cell. Therefore, the performance of the LTE systems in terms of available data rates and spectrum efficiency is limited by interference from other cells (inter-cell interference). Inter-cell interference coordination is a scheduling method which the date rate are increased in the cell edge by taking inter-cell interference into account. Inter-cell interference coordination infers certain (frequency domain) restrictions to the uplink and downlink schedulers in a cell to handle the inter-cell interference. By restricting the parts of the spectrum of transmission power in one cell, the interference appeared in the neighboring cells in this part of the spectrum will be reduced. This part of the spectrum can provide

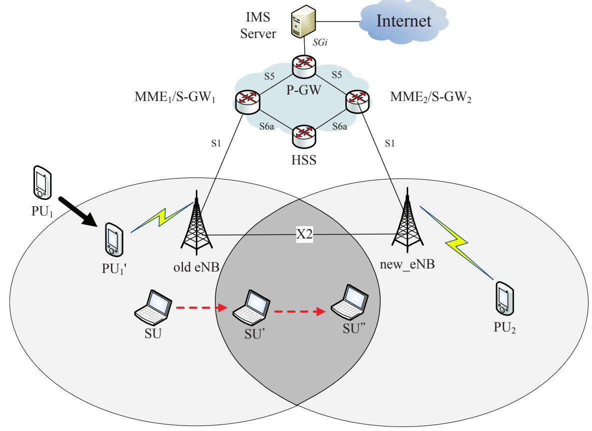


Fig. 2. System model.

higher data rates for user in the neighboring cell. in reality, the frequency reuse factor is different in different parts of the cell, shown as Fig. 1.

The other characteristic of LTE systems is the spectrum agility. The LTE systems support more different bandwidth of channels. This characteristic of LTE systems is similar to the CR network, The proposed scheme presents the LTE systems based on CR to achieve the full frequency spectrum utilization. As shown in Fig. 2, the system model consist of the LTE core systems, PUs and SUs. SUs have opportunity to use the unoccupied spectrum by PUs and connect to the Internet throughout the LTE core systems. In the system model, SU moves as shown in Fig. 2. The initial location of SU is not in the overlapped area. If the PU appeared, SU performs the proposed algorithm and selects an adaptive spectrum hole to spectrum mobility. When the SUs move to the overlapped area. SU moves from SU' to SU", there are two events happened, one is the spectrum mobility, and the other is handover to new_eNB. In the proposed algorithm, the algorithm focus on the mobility of SUs in the overlapped area and non-overlapped area. The proposed scheme aims to decide the adaptive allocation of spectrum holes for SUs.

B. Basic idea and challenge

The proposed scheme observes the spectrum occupied ratio to predict the probability of the resource reclaiming by PUs and the received signal strength to perform handover to an appropriate base station (BS). The proposed scheme to achieve low transmission time, high successful rate, and throughput. In the proposed scheme, the expected transmission time of spectrum hole is mainly considered. Let

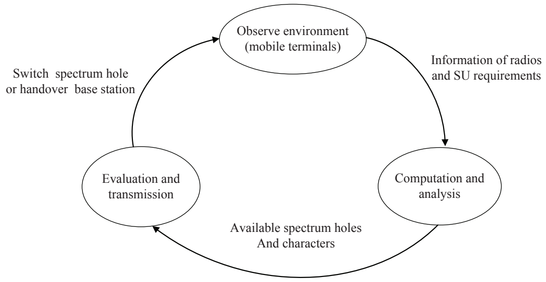


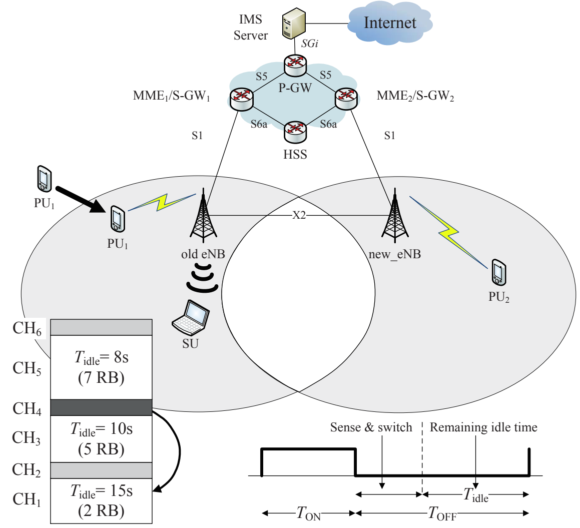
Fig. 3. Cognitive cycle.

$T_E(SH_i)$ denote as the expected transmission time of spectrum hole i for SU's service data. When $T_E(SH_i)$ is large, this represents the expected transmission time of the spectrum hole is higher, and then SUs have to bear greater risks of PUs reclaimed resources. This may cause frequent spectrum mobility and handover. On the other hand, the smaller the $T_E(SH_i)$ has high successful rate of service data transmission without the PUs reclaimed resources. Hence, the minimum $T_E(SH_i)$ is the basis for decision-making.

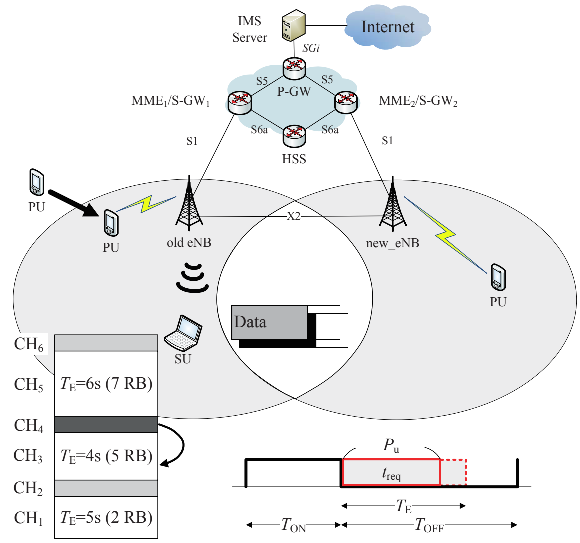
The proposed scheme provides an overview of the cognitive cycle shown in Fig. 3. There are three main steps on the cognitive cycle: environment observation, computation and analysis, and evaluation and transmission. The detail as following.

- Environment observation - in the CR the SUs monitor the spectrum utilization, received signal power, and detect the appearance of PUs.
- Computation and analysis - according to observed information to analyze the spectrum hole characters such as transmission rate, unoccupied rate, etc.
- Evaluation and transmission - evaluate the expected transmission time of SU service transmission by each spectrum hole, and then select one to spectrum mobility and help the layer three decision to handover adaptive base station.

In Hoyhtya *et al.*(10) proposed scheme, shown as Fig. 4(a), let T_{ON} denotes channel be occupied by PU , T_{OFF} denotes the channel is idle, T_{idle} denotes the channel idle time. the scheme divides the time into T_{ON} and T_{OFF}. According to periodically recorded the channel idle time, the next period the channel idle time is acquired, and the channel with maximum T_{idle} is the best choice. In Fig. 4(a) the SU performs spectrum mobility form CH_4 to CH_1 with the maximum T_{idle}. But the channel with the maximum idle time maybe not the appropriate in



(a)



(b)

Fig. 4. (a)The comparative scheme with the maximum idle time, (b)The proposed scheme with expected transmission time.

the proposed system model. Because the channel size is different, the idle channel with the maximum idle time may be the minimum channel size. If the maximum idle time channel with minimum channel size is selected, the data need more time to finish the transmission. But the more time the data transmission need, the higher probability of interrupt. Therefore, in the proposed scheme, the

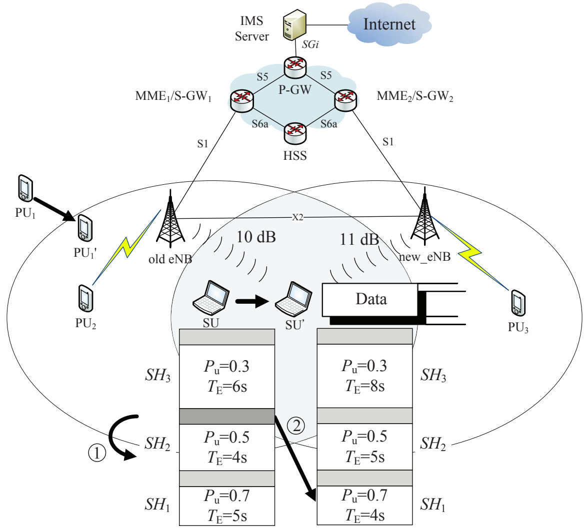


Fig. 5. The proposed scheme with expected transmission time.

number of PU reclaim spectrum hole in unit time is main consideration, shown as Fig. 4(b), we assume the spectrum hole size is equal to Fig. 4(a) channel size, and then compute the SU service needed time. Let t_{req} denotes the SU service required time, SH_i denotes the ith spectrum hole, and $P_u(SH_i, t_{req})$ denotes the probability of spectrum hole unoccupied by PUs. The probability $P_u(SH_i, t_{req})$ is the spectrum hole SH_i unoccupied probability in the t_{req} period. Calculation of the above parameters and consider the element of spectrum mobility, the SU service expected transmission time is evaluated. The proposed scheme supports flexible spectrum hole size, and this characteristic make the proposed algorithm more considered. Because the different spectrum hole size has different occupied probability. Although the large of the spectrum holes have fast transmission rate but the occupied range of frequency bands is wide. When PUs reclaimed spectrum resource, the spectrum resource is easily overlap with the spectrum hole. This cause the spectrum mobility ratio become higher. In stead of the smaller spectrum holes size are not easy to be occupied by PUs. The result of maximum expected transmission time is selected. Then SU moves from current spectrum hole CH_4 to CH_3 with the minimum T_E.

In the proposed scheme, when SU moves to the center area of the overlapped area. The variation of the SNR makes the different BS spectrum holes of transmission rate different. This factor may affect the final outcome T_E. Hence, in Fig. 5, there are two sub cases happened, one performs spectrum mobility in original old_eNB, because of the minimum T_E of old_eNB spectrum hole is lower than the minimum T_E of new_eNB spectrum hole with a layer three handover delay time, SU has a adaptive choice of stay old_eNB to spectrum mobility. If the minimum T_E of old_eNB spectrum hole is greater than the new_eNB spectrum hole with a layer three handover delay time, this represent the spectrum holes of the old_eNB is the worthless choice, and then SU handover to the new_eNB.

IV. Hybrid Spectrum Mobility and Handover Protocol

This section presents the hybrid spectrum mobility and handover protocol in 3GPP cognitive LTE systems. The proposed scheme evaluate the expected transmission time of every spectrum hole to select the minimum expected transmission time of spectrum hole to layer two spectrum mobility, and the decision for layer three to handover an adaptive base station. This scheme is split into three phase; (1) environment observation, (2) computation and analysis, and (3) evaluation an transmission. Let SU_x denotes the xth secondary user in the systems. In the phase of evaluation an transmission , the secondary users (SUs) collect the information by the SDR device. In the phase of computation and analysis, the collected information is analyzed to characters of every spectrum hole. The characters of each spectrum hole prepares for the next phase. In the phase of evaluation an transmission, the secondary users evaluate expected transmission time of each spectrum hole in transmitting the service data.

A. Phase of environment observation

The main task of this phase make use of SDR to observe the signal power from the base station (BS), usage of each resource block, and SU_x requirements. The above information is acquired to know the spectrum distribution and utilization. As shown in Fig. 7, the SU_x periodically senses the spectrum bands of each resource block in order to acquire the information of each resource block occupied frequency and spectrum hole SH_i that consisting of m_i resource blocks. Let λ_{m_i} is number of times that m_ith RB be occupied in the time period. If the λ_{m_i} is large, the PUs frequently occupied the

RB lower the opportunity of RB usage. Otherwise, if the λ_{m_i} is small, SU has more opportunity to use the RB without interrupted by PUs. The signal strength is the basis on the wireless communication systems. The signal information assist SU_x to get the location from BS, and the transmission quality. The observation phase is operated as following.

S1 SU_x sense all RB in the spectrum bands, and the continue idle RB regard as the spectrum holes (SH_1, SH_2,$\cdots$,SH_i). And then each RB occupied frequency λ_{m_i} is also recorded in a time period. The signal strength the SU_x received record in every sensing period.

S2 When SU_x has requirement to spectrum mobility or handover, SU_x evaluates the current service data size d_t and trigger a request to next phase.

B. Phase of computation and analysis

In the computation and analysis phase, due to SU_x detected PU_y appearance, the proposed scheme triggers SU_i to receive the observed information from physical layer and then analyze the observed information in order to acquire the spectrum characters. The spectrum characters such as bandwidth, transmission rate, and signal to noise ratio (SNR) are important to evaluate the expected transmission time of SU_x service. However, SU_x in the overlapped area and the non-overlapped area is different. Hence, the proposed scheme divides the system into two cases, the two cases are illustrated in section 4.2.1 and section 4.2.2, respectively.

1) Secondary users in the non-overlapped area: In the non-overlapped case, SU_x has only one available serving BS, and then analyzes the spectrum characters of the BS. According to SU_x received signal from the BSs. If the received signal strength from BS is greater than the signal threshold, SU_x can get service from the BS. Otherwise, SU_x cannot get any service from the BS. As shown in Fig. **??**, SU_x only receives old_eNB signal, and analyzes the spectrum characters of BS. The procedure of the computation and analysis is developed.

S1 To evaluate the expected transmission time T_E of SU_x' service, the SNR is needed. The SNR is analyzed from the received signal strength α by the transformation equation $dB = 10\log SNR$, where dB is the received signal strength. Hence, the SNR is $SNR = 10^{\frac{\alpha}{10}}$.

S2 SU_x determines the maximum transmission rate for each spectrum hole SH_i and the required transmission time t_{req} of service data d_t. Let R_i denotes the transmission rate in the SH_i. Due to the SH_i is consist of m_i resource blocks RB, the bandwidth of SH_i is $m_i \times RB$. For determining the R_i of SH_i, a formal equation to evaluate the maximum transmission rate proposed by Shannon (11). The maximum transmission rate is evaluated by $C = B \times \log_2(1+SNR)$, where C is the maximum channel capacity, and B is the bandwidth. Hence, the R_i is $m_i \times RB \times \log_2(1 + SNR)$. And the the required transmission time t_{req} of service data d_t is evaluated by data d_t and R_i. The t_{req} is $\frac{d_t}{m_i \times RB \times \log_2(1+SNR)}$.

S3 To predict the availability of spectrum hole SH_i, the probability of SH_i unoccupied is needed to know. Let $P_u(SH_i, t_{req})$ denotes the probability of spectrum hole unoccupied by PUs. The probability $P_u(SH_i, t_{req})$ is the SH_i unoccupied probability in the t_{req} period. To predict the idle SH_i in a service require time t_{req}. The proposed scheme use the Poisson distribution (12) to analyze the SH_i. The formal equation of Poisson distribution is written as $P(k, T) = \frac{(\lambda T)^k}{k!} e^{-(\lambda T)}$, where k is the number of events, T is the period time, and λ is the proportion of average event happened. The $P(k, T)$ means in the time period T, and there are k events happened probability. To analyze the probability that the SH_i is not be used in a service require time t_{req}. The k sets zero, and T sets t_{req}. Hence, if the SH_i is composed of m_i RB, the probability is written as $P_u(m_i, t_{req}) = \prod_{n=1}^{m_i} P_n(0, t_{req}) = e^{-\sum_{n=1}^{m_i} \lambda_n t_{req}}$.

C. Secondary users in the overlapped area

In the overlapped area, SU_x has one or more available serving BS to build connection. The frequency spectrum in old_eNB cell edge do not interfere with the frequency spectrum in new_eNB cell edge because the allocated frequency in the cell edge is divided into different frequency domain. The computation and analysis of these spectrum holes are computed with the more than one BS. The different spectrum hole list in different BS make SU_x has more choice to determine which to use. The procedure is described below.

S1 To evaluate the expected transmission time T_E of SU_x service, the SNR is needed. The SNR can be analyzed form the received signal strength α and β by the transformation equation $dB = 10 \log SNR$. Hence, the SNR is written as $SNR = 10^{\frac{\alpha}{10}}$ and $SNR = 10^{\frac{\beta}{10}}$.

S2 SU_x determines the maximum transmission rate for each spectrum hole SH_i and SH'_j in different BS and the required transmission time t_{req} of service data d_t in each spectrum hole. In old_eNB, the SH_i is consist of m_i resource blocks RB, the bandwidth of SH_i is $m_i \times RB$. To determine the transmission rate of SH_i by Shannon theorem, the maximum transmission rate is evaluated by $C = B \times \log_2(1 + SNR)$. Hence, the R_i is $m_i \times RB \times \log_2(1 + SNR)$. And the the required transmission time t_{req} of service data d_t is evaluated by data d_t and R_i. The t_{req} is $\frac{d_t}{m_i \times RB \times \log_2(1+SNR)}$. In new_eNB, the SH'_j is consist of m'_j resource blocks RB, the bandwidth of SH'_j is $m'_j \times RB$. To determine the transmission rate of SH'_j by Shannon theorem, the maximum transmission rate is evaluated by $C = B \times \log_2(1 + SNR)$. Hence, the R'_j is $m'_j \times RB \times \log_2(1 + SNR)$. And the the required transmission time t_{req} of service data d_t is evaluated by data d_t and R'_j. The t_{req} is $\frac{d_t}{m'_j \times RB \times \log_2(1+SNR)}$.

S3 To predict the availability of spectrum hole SH_i in old_eNB and SH'_j in new_eNB, the unoccupied probability of spectrum hole is needed to evaluate the expected transmission time T_E. Let $P_u(SH_i, t_{req})$ is the unoccupied probability of spectrum hole SH_i and $P'_u(SH'_j, t_{req})$ is the unoccupied probability of spectrum hole SH'_j. In order to predict the SH_i and SH'_j in different BS are not be used in a service require time t_{req}. The proposed scheme use the Poisson distribution to analyze the SH_i and SH'_j. The formal equation of Poisson distribution is written as $P(k, T) = \frac{(\lambda T)^k}{k!} e^{-(\lambda T)}$. In old_eNB, to analyze the probability that the SH_i is not be used in a service require time t_{req}, the event k is setting zero, and time period T is setting t_{req}. Hence, if the SH_i is composed of m_i resource block, the probability is written as $P_u(SH_i, t_{req}) = \prod_{n=1}^{m_i} P_n(0, t_{req}) = e^{-\sum_{n=1}^{m_i} \lambda_{m_i} t_{req}}$. I n new_eNB, to analyze the probability that the SH'_j is not be used in a service require time t_{req}, the probability is written as $P_u(SH'_j, t_{req}) = \prod_{n=1}^{m'_j} P_n(0, t_{req}) = e^{-\sum_{n=1}^{m'_j} \lambda_{m'_j} t_{req}}$.

D. Phase of evaluation and transmission

In evaluation and transmission phase, the main goal is to evaluate the expected transmission time that SU_x service required, and then to selects an adaptive spectrum hole with the minimum T_E. The T_E not only considers the transmission time that SU_x service data d_t required but also the SH_i characters such as bandwidth, SNR, SU_x service data size, and unoccupied ratio. These characters assist the T_E to predict the possibility of the candidate SH_i spectrum mobility, and then add some penalty to increase or decrease the value of T_E. And the minimum T_E is the adaptive selection to spectrum mobility and handover. The detailed operation is developed as follows.

S1 Let $T_E(SH_i)$ denotes the expected transmission time in the SH_i of old_eNB. In non-overlapped area, for each spectrum hole in the old_eNB the equation of $T_E(SH_i)$ is written as equation (1),

$$T_E(SH_i) = \frac{d_t}{P_u(m_i, t_{req}) \times R_i} + (1 - P_u(m_i, t_{req})) \times T_{L2H} \quad (1)$$

The T_{L2H} is layer 2 switch time, and $(1 - P_u(m_i, t_{req}))$ is the probability of SH_i be occupied. In fact the original transmission time should be $\frac{d_t}{R_i}$. But the time may be interrupted when PUs back. The expected transmission time should be added some penalty that $P_u(m_i, t_{req})$ multiples R_i for increasing the transmission time. And the SH_i may interrupt when PUs back, the SU_x should perform spectrum mobility again. Hence, the event is considered by the penalty of possible interrupted and spectrum mobility time, $(1 - P_u(m_i, t_{req})) \times T_{L2H}$. Therefore, the expected transmission time is the sum of data transmission time and the penalty time.

S2 To evaluate the expected transmission time that SU_x service required. Let $T_E(SU'_j)$ denotes the expected transmission time in the SH'_j of new_eNB In overlapped area, the equation of expected transmission time in new_eNB spectrum bands is differ from T_E in old_eNB. The equation of expected transmission time in new_eNB should add a layer 3 handover procedure time, the equation is written as following.

$$T'_E(SH'_j) = T_{L3H} + \frac{d_t}{P'_u(m'_j, t_{req}) \times R'_j} + (1 - P'_u(m'_j, t_{req})) \times T_{L2H} \quad (2)$$

The T_{L3H} is layer 3 handover procedure time. In the overlapped area, SU_x has two selection of BS spectrum bands. If SU_x select the old_eNB spectrum bands, the evaluation of T_E is similar to equation (1). If SU_x select the new_eNB spectrum bands, the expected transmission time should be increasing because the additional handover procedure time T_{L3H}. And then the expected transmission time is the sum of data transmission time , the penalty time, and handover procedure time.

S3 The minimum expected transmission time is an adaptive selection. In the non-overlapped area, SU_x performs the spectrum mobility with the spectrum hole SH_i that has the minimum expected transmission time to data transmission. Due to the expected transmission time has considered the SH_i characters and added some penalty in the transmission time, the $T_E(SH_i)$ with minimum value has high successful rate and the shortest transmission time. In the overlapped area, SU_x selects spectrum holes in which old_eNB or new_eNB. Although the signal strength between SU_x and old_eNB does not meet the signal strength threshold, the value of $T'_E(SH'_j)$ is smaller than $T_E(SH_i)$ should be a proper spectrum hole to perform the handover procedure to the new_eNB.

V. Simulation Results

In this section, we evaluate the performance of the spectrum mobility and handover scheme in cognitive LTE systems. In the proposed scheme, the spectrum holes is similar to channels. The spectrum holes adopt AGWN channel and ignore the channel fading problem. The simulation results are then analyzed.

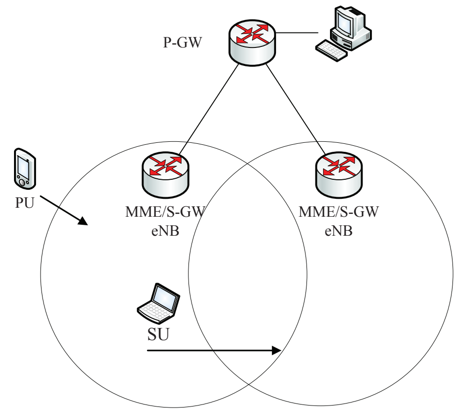


Fig. 6. Simulation architecture.

A. Simulation Setup

This work develop a spectrum mobility and handover protocol in 3GPP cognitive LTE systems. To evaluate the proposed scheme, using the Network Simulator-2 (NS-2) (1), ns-2 Cognitive Radio Network model, and euran module. The simulation architecture is shown as Fig. 6, and the parameter is setting up as Table 1.

Table-1

Parameter	Value
BS transmission range	50 km
Network size	500×500 km
Secondary users speed	0-100 km/hr
Number secondary user	0-20
Spectrum sensing period	40 ms
Spectrum switching delay	10 ms
Handover delay	200 - 350 ms
Packet size	1500 bytes
Simulation time	100-1000 s

The performance metrics that be analyzed in our simulations are shown as follows:

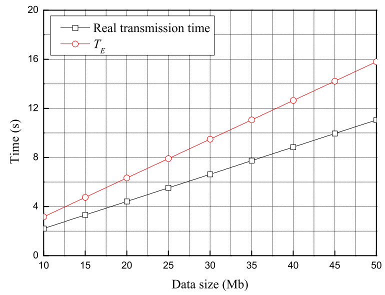


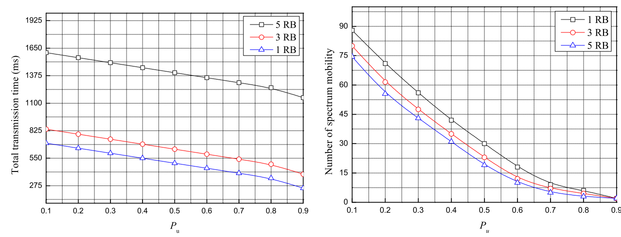
Fig. 7. The expected transmission time vs. real transmission time.

B. *The expected transmission time*

The proposed expected transmission time T_E is the decision parameter. When T_E is large, this represents the expected transmission time of the spectrum hole is higher, and then SUs have to bear greater risks of PUs reclaimed resources. This may cause frequent spectrum mobility and handover. On the other hand, the smaller the T_E has high successful rate of service data transmission without the PUs reclaimed resources. Fig. 7 illustrates the expected transmission time T_E always higher than the real transmission time. Because the expected transmission T_E according to the spectrum hole unoccupied ratio to add some penalty. The real transmission time includes number of spectrum mobility time, and less than the expected transmission time T_E.

C. *The impact of spectrum hole size*

We discuss the impact of spectrum hole size to the total transmission time, spectrum hole unoccupied ratio, and the number of spectrum mobility. Fig. 8(a) illustrates the impact simulation of transmission time and the spectrum hole unoccupied ratio with different spectrum hole size. The total transmission time decrease when the spectrum hole unoccupied ratio increase. Because the unoccupied ratio is increase, the secondary users have more opportunity to use the spectrum hole without interrupted. The spectrum hole 5RB has lowest total transmission time because the transmission rate is higher than others. Fig. 8(b) illustrates the impact number of the spectrum mobility and spectrum hole unoccupied ratio. The number of spectrum mobility decrease when the spectrum hole unoccupied ratio increase. When the spectrum hole unoccupied ratio is less than 0.5, the number of spectrum mobility is increasing violently. The spectrum hole 5RB has lowest number of spectrum mobility because the transmission time is less than other, secondary user use the spectrum hole 5RB encounter less interruption.

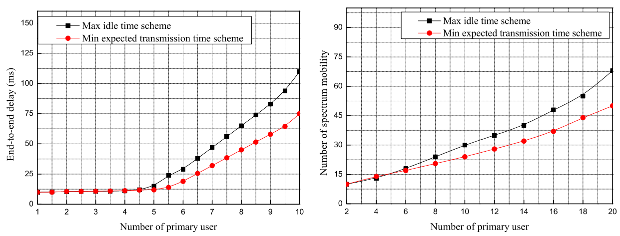


(a) (b)

Fig. 8. (a) Total transmission time vs. spectrum hole unoccupied ratio P_u. (b) number of spectrum mobility vs. spectrum hole unoccupied ratio.

D. *The comparison of layer 2 scheme*

The proposed scheme compares to the other layer 2 scheme. The other layer 2 scheme according to periodically recorded the channel idle time, the next period the channel idle time is acquired, and the channel has maximum idle time is the best choice. Our proposed scheme selects the minimum expected transmission time as the best choice. As the number of spectrum hole is 5. Fig. 9(a) illustrates the impact of end-to-end delay and number of primary user. When the number of spectrum hole is less than 5, the end-to-end delay of these two schemes are almost equal. As he number of primary user is more than 5, the end-to-end delay is violently increasing. Fig. 9(b) illustrates the impact of number of spectrum mobility and number of primary user. At beginning, the primary user is less. The number of spectrum mobility of these two schemes is similar. When the primary user increase more, our number of spectrum mobility in our proposed scheme is less than the max idle time selection scheme. Because the max idle time selection scheme is always selected the spectrum hole with the long idle time, the remain spectrum hole with short idle time may not sufficient time to other user service transmission. Hence, the number of spectrum mobility increase. Our proposed scheme increase flatly. Because our proposed scheme selects adaptive spectrum according to the spectrum hole characters and user conditions.

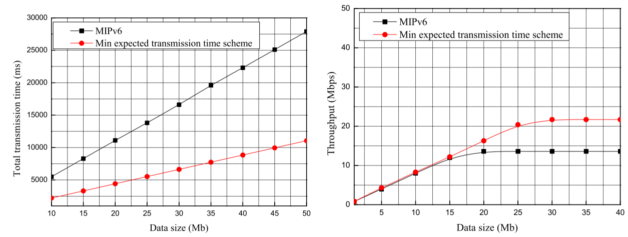


(a) (b)

Fig. 9. (a) The end-to-end delay vs. number of primary user, and (b) number of spectrum mobility vs. number of primary user.

E. The comparison of layer 3 scheme

The proposed scheme compares to the other layer 3 protocol. The compared layer 3 protocol is mobile IPv6. The total transmission time and the throughput is compared. The exist layer 3 protocol is not consider the layer 2 spectrum hole allocation, the layer 3 protocol is always allocated layer 2 the fixed size spectrum resource. For this reason, Fig. 10(a) illustrates the impact of total transmission time and the user service data size in these two protocol. In the same data size, the MIPv6 protocol need more transmission time because the fixed spectrum resource. In our proposed scheme, the layer 2 support the dynamic spectrum holes information to layer 3, and layer 3 may use the spectrum hole with the large size and low occupied ratio to data transmission. Hence, the transmission time of our proposed scheme is less than the MIPv6 protocol. Fig. 10(b) illustrates the impact of throughput and the user service data size in these two protocol. The throughput at the small data size is similar to each protocols. But the data size is increasing, the MIPv6 achieve the maximum throughput. Because the fixed spectrum resource in layer 2. Our proposed scheme is not always selected the large spectrum hole size to secondary user, but the average throughput is higher than the MIPv6 protocol.



(a) (b)

Fig. 10. (a) Total transmission time vs. data size, and (b) throughput vs. data size.

VI. CONCLUSIONS

In this paper, we proposed a spectrum mobility and handover protocol for 3GPP LTE systems. The The secondary users in the systems observe the spectrum bands, analyze the characters of spectrum holes, and evaluate the expected transmission time of spectrum holes. The expected transmission time of spectrum holes is not only for layer 2 switching the spectrum bands, but also for layer 3 to quickly determine the handover base station with the minimum expected transmission time of spectrum hole. The protocol consider the remained service data size and the flexible spectrum hole size. The result of the selected spectrum hole may get more opportunity to finish the data transmission. Finally, the simulation results have shown that our protocol outperforms the existing solutions in terms of spectrum mobility and handover in the systems.

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