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The Performance of Dynamic-static Spectrum Access Based on Markov Transfer Model

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Abstract

This study presented a non-synchronized random access mechanism that supports dynamic-static spectrum.Generally, the authorized users of two networks (network A and network B) with different frequency bands communicate with each other by using static spectrum. When congestion happened, spectrum holes in their networkscan be detected by the opposite networksand then utilized to communicate. Based on queuing theory and Markov transfer model, a user behavior characterized by dynamic-static spectrum access was proposed, and the feasibility of this theoretical model was validated through analog simulation. Thereafter, the theoretical parameters of system performance, like blocking possibility, forced drop-call possibility, and throughput, were measured and compared betweendynamic-static mode and unconjugatedmode.

Keywords*: Dynamic-static spectrum, Markov transfer model, non-synchronized random access, queuing model*

1. Introduction

Strict international rules have been established for the usage of wireless spectrum resources. According to the current practical usage and researches, there are three spectrum patterns when communication control center communicate with terminal: (1) static spectrum; (2) semi-dynamic spectrum; and (3) dynamic spectrum. Generally, static spectrum is fixedly assigned by the state according to national spectrum resources, and it belongs to the unassigned and shared spectrums. Besides, semi-dynamic spectrum is generated via auction, and dynamic spectrum is obtained through dynamic perception. In this study, static resource stands for static spectrum, while dynamic resource represents both semi-dynamic and dynamic spectrums.

The majority of traditional cognitive radio technologies focus on the sharing of spectrums with same frequency band, while few studies have been conducted for the combined access of authorized and unauthorized spectrums. In order to meet the service demand of low delay, large bandwidth, and broad data service scope, future network should allow the access of spectrums with different frequency band. However, the usage of dynamic spectrum is different from that of static spectrum. Therefore, an effective model that represents dynamic-static spectrum access is of great significance.

2. Research Status

Dynamic spectrum access is the basis for the combination of dynamic and static resources. However, the previous researches about spectrum access generally study the access strategy of dynamic spectrum or the behavior of cognitive users in same frequency band. Few studies have been performed on the combined access of authorized and unauthorized spectrums.

Based on the access of dynamic spectrum, Xie et al. have proposed an access model that combines heterogeneous networks, in which main and secondary networks use spectrums with different frequency band [1]. Bian et al have constructed a heterogeneous coexistence structure for cognitive network to solve the potential problems about exchanging and controlling information and interest conflict [2]. Tzelatis and Berberidishave established a system structure for the access of wireless spectrum based on cognition, and it fits the heterogeneous wireless

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network of next generation [3]. Through combining traditional emergency communication technology and cognitive wireless system, Han et al. have constructed Markov transfer model and analyzed some system parameters [4]. Generally, there are many wireless servicers who compete with each other, and secondary users can use their dynamic bidding model to adapt their access to different service providers [5]. Furthermore, cognitive users can be divided into two classes (high priority class and low priority class) according to their service demands when dynamic spectrum access is performed [6]. Li et al. have proposed a joint channel aggregation splitting algorithm, providing a queueing model for dynamic spectrum access [7]. In order to improve the capacity factor of limited channel, Sultana et al. have established an access system structure with multi-priority and multi-user, and set non-preemptive priorities for user time [8]. Moreover, Kumar et al. have measured the performance of dynamic access when primary and secondary users are using IEEE 802.11, a shared frequency band[9]. Jiang et al. have studied the disturbance of dynamic spectrum access to master users whose communication features are unknown to secondary users, and thus designed an access protocol for dynamic spectrum [10].

3. The System Model of Dynamic-static Spectrum Access

3.1. Network Model

It’s assumed that there are only two networks (namely, network A and network B, and their authorized users (namely, U_A and U_B) take spectrums with different frequency bands. If user requests arrive, they will preferentially get access into their own authorized networks via static spectrum. As the networks of U_A and U_B have cognitive ability, they will dynamically percept spectrum holes if there is no available channel in their own networks, and thus utilize these spectrum holes to access dynamic spectrum.

In this study, the available bandwidths of network A and B are represented by channel numbers, which are set equal to facilitate analysis. Authorized users have absolute priority to use the channels in their own networks, in comparison with secondary users. For example, if the request of $U_A$arrives, static spectrums of network A will be firstly checked. If there is idle channel, this request will access channel directly. If there is no idle channel and some channels are taken by U_B, the communication of U_B will be stopped immediately (forced drop-call), and available channels will be provided to U_A. If there is no idle channel and no channel is taken by U_B (namely, all channels in network A are taken by U_A), the request of U_A will be rejected. The access situation of network B is similar to that of network A.

It's assumed that the arrival rates of requests from UA and UB in network A and network B can display the Poisson distribution, while service time can show the negative exponential distribution. This study aims to construct and analyze a model for dynamic-static spectrum access based on queuing theory and Markov transfer model.

3.2. Queuing Model

The major model utilized in the present study is the M/M/m instant-refusing, multi-window, and hybrid-queuing model. Taking the analysis of U_A behavior characters as an example, it's assumed that: (1) there are m channels in network A, while n channels in network B; (2) the channel number required by one request in network A or network B is 1; (3) the arrival rate of new request can display the Poisson distribution (intensity: λ); (4) service time of one channel can show the negative exponential distribution (parameter: μ). As a result, a queuing model is established for the combined access of dynamic-static spectrum (Figure 1).

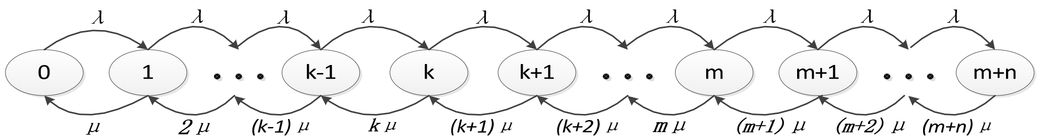


Figure 1. The queuing model for the combined access of dynamic-static spectrum

Number in cycle: number of users in network; users from 0 to m use static spectrum in network A, while users from m+1 to m+n utilize available channels in network B via dynamic perception.

If k users transfer their status, transition probability will be marked as P_k. When stable state is achieved, the function for status transition is:

$$\left.\begin{array}{ll} k=0, & \mu P_1-\lambda P_0=0 \\ 0<k<m+n, & \lambda P_{k-1}+\mu(k+1)P_{k+1}-(\lambda+k\mu)P_k=0 \\ k=m+n, & \lambda P_{m+n-1}-\mu(m+n)P_{m+n}=0 \end{array}\right\} \quad (1)$$

The load parameter of a single channel, ρ, is defined as $\rho = \lambda/\mu$. According to the features of Markov transfer, P_k has polarity. Therefore, result of the above function is:

$$P_0=\frac{1}{\sum_{k=0}^{m+n}\frac{\rho^k}{k!}} \quad (2)$$

By utilizing 0 < k < m+n, it is recursively obtained that:

$$\left.\begin{array}{c} p_1=\rho p_0 \\ P_2=\frac{1}{2}[(\rho+1)\rho P_0-\rho P_0]=\frac{1}{2}\rho^2 p_0 \\ P_3=\frac{1}{3}\left[(\rho+2)\frac{1}{2}\rho^2 P_0-\rho^2 P_0\right]=\frac{1}{6}\rho^3 p_0 \\ \dots\dots \end{array}\right\} \quad (3)$$

Therefore, the general solution of state probability P_k is:

$$P_k=\frac{\rho^k}{k!}P_0 \quad (4)$$

The queuing model for the combined access of dynamic-static spectrum in network B is similar to that in network A.

3.3. Access Strategy

Before the access of U_A request or U_B request, the authorized frequency bands (namely, static spectrums) of network A and B will be firstly checked. Network A is taken as example. If there is idle channel in network A, U_A request will access channel in network A in a static manner. If there is no idle channel in network A, the channels in network B will be checked. Furthermore, if there is idle channel in network B, U_A request will access channel in network B in a dynamic manner. The priority of authorized users is higher than that of cognitive users in both network A and B, namely, priority of U_A> priority of U_B in network A, while priority of U_B> priority of U_A in network B. Therefore, if U_B request arrives and there is no other idle channel in network B, the communication of $U_A$will bestopped (forced drop-call), and the corresponding channel taken by U_A will be provided to U_B, avoiding interference to U_B communication. The access situation of network B is similar to that of network A.

In the combined access of dynamic-static spectrum proposed in this study, requests of U_A and $U_B$can get access into networks in a non-random manner. Again, network A is taken as example. The channels in network A are sequentially marked by numbers from 1 to m (from low frequency band to high frequency band), while the channels in network B are sequentially marked by numbers from 1 to n (from low frequency band to high frequency band). If there is idle channel in network A, U_A request will access the first idle channel in channel 1-m. If there is no idle channel in network A and there is idle channel in network B, U_A request will access the first idle channel in channel n-1 of network B (Figure 2). The access process of network B is similar to that of network A (Figure 2). In other words, authorized users access communication system preferentially via channels with low frequency bands other than that with high frequency bands, while cognitive users access communication system preferentially via channels with high frequency bands.

(1) If static spectrum can meet user demand, request of authorized user will access idle static spectrum/channel (priority: low frequency band > high frequency band) in a non-random manner (Figure 2a, 2b, and 2c).

(2) If there is no idle channel in network A (namely, all the channels in network A are

taken by U_A) and there is idle channel in network B, U_A request will dynamically access idle channel of network B (priority: high frequency band> low frequency band) (Figure 2d). Similarly, the access process of U_B in network B is shown in Figure 2e.

(3) After completing U_A request in network A, the corresponding channel is released, providing an additional idle channel in network A. Then, the cognitive user of network B will switch the spectrum to its authorized frequency band in network A (priority: low frequency band > high frequency band) (Figure 2f).

(4) It's assumed that all the channels in network A are taken by U_A, some channels in network B are taken by U_A, and there is no other idle channel in network B. If U_B request arrives, the communication of U_A will be stopped (forced drop-call), and the corresponding channel taken by U_A will be released and provided to U_B, as priority of U_B> priority of U_A in network B (Figure 2h).

(5) If all the channels in network A are taken by U_A and there is no idle channel in network B, call blocking will happen to U_A (Figure 2i). Similarly, call blocking can also happen to U_B (Figure 2j).

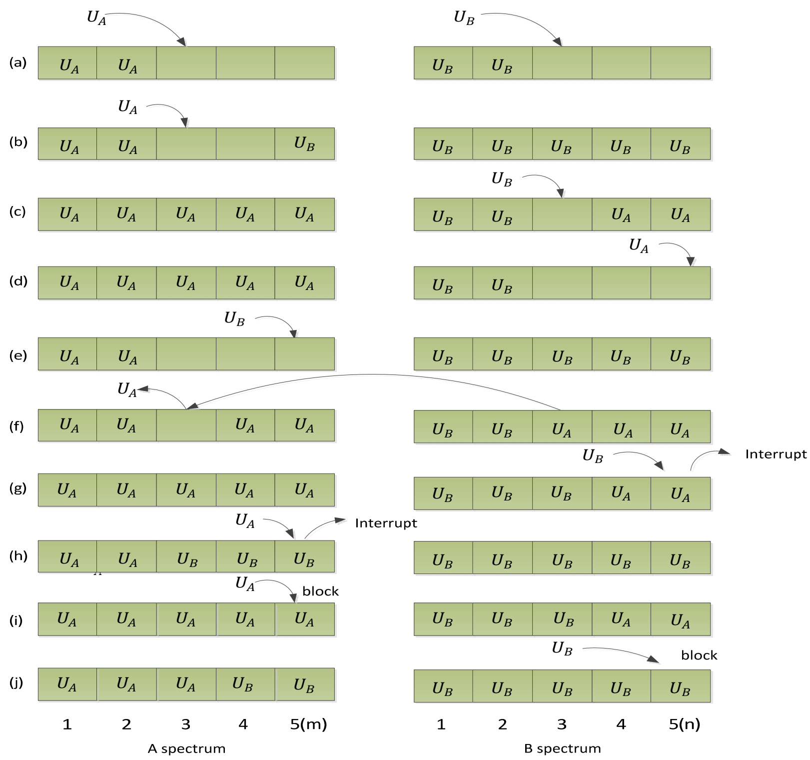


Figure 2. The access process of network A and B (m = n = 5)

4. The Transfer Model of Dynamic-static Spectrum Access

4.1. Markov Transfer Model

It's assumed that the arrival rate of requests from U_A and U_B can display the Poisson distribution, while their service time can show the negative exponential distributions with parametersμ_A and μ_B, respectively. In addition,there are m and n available channels in network A and B, respectively. The user numbers of U_A and $U_B$are represented by integer pair (i, j), while their corresponding possibilities are shown as P(i, j). Besides, state space (i, j) should meet the following formula:

$$\Gamma = \{(i,j)|0 \le i \le m+n, 0 \le j \le m+n, 0 \le i+j \le m+n\} \quad (5)$$

Then, the Markov transfer model of dynamic-static spectrum access is constructed, supporting m and n available channels in network A and B, respectively (Figure 3).

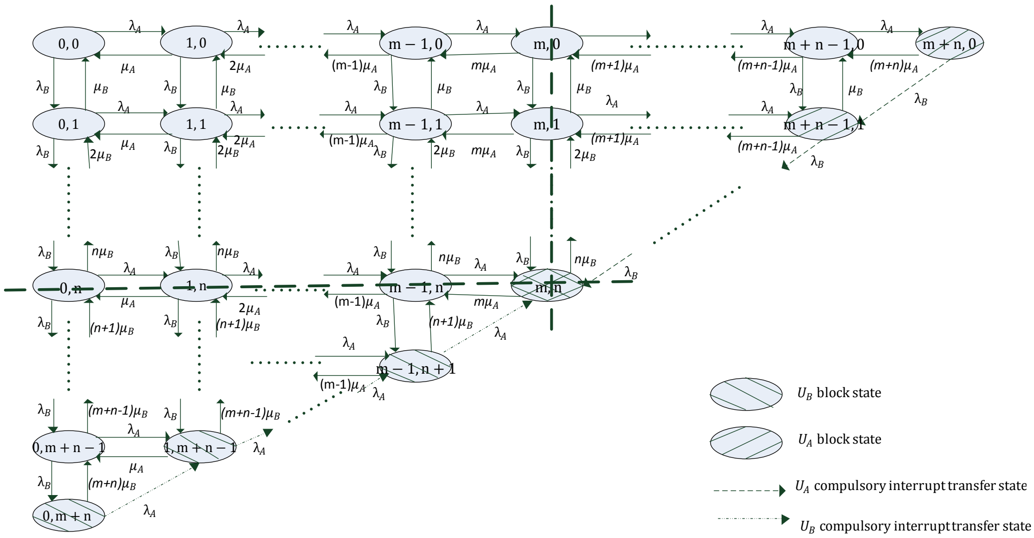


Figure 3. Markov transfer model of dynamic-static spectrum access

In Figure 3, the region between two dotted lines represents static access. State (0, 0) means that neither $U_A$nor U_B is in communication, while state (1, 0) means that U_A is in communication and requestsget access into system in a non-random manner (priority: low frequency band > high frequency band). The arrow from state (0, 0) to state (1, 0) andλ_A(or λ_B) stands for the accession of U_A (or U_B), while the arrow from state (1, 0) to state (0, 0) and μ_A(or μ_B) stands for the departure of U_A(or U_B) after answeringthe request of U_A (or U_B).

In Figure 3, the regions on the right of vertical dotted lines represent that U_A dynamically takes un-authorized frequency bands in network B. For example, state (m, 0) means that m $U_A$in system are in communication, and all of the m static channels are taken by U_A, as U_A can preferentially get access into static frequency band in a non-random manner.If a new U_A request arrives, it will get access into network B in a non-random manner (priority: high frequency band > low frequency band), and state (m, 0) will change into state (m+1, 0).In state (m+1, 0), if a certain U_A occupying static channel leaves system, the U_A which is dynamically occupying network B will transfer into this channel in a non-random manner.This process is represented by the arrow from state (m+1, 0) to state (m, 0) and (m+)μ_A.

In the region with slash on the right of dotted lines, $i + j = m + n$. It means that there is no channel available for U_A, and thus, new request from U_A will be rejected and blocking will happen (e.g. state (m+n, 0)).In this circumstance, if a new U_B request arrives, U_A communication will be stopped (forced drop-call) to avoid interference to U_B, as the priority of U_A< the priority of U_B in network B. This forced drop-call is represented by dotted arrow from (m+n, 0) to (m+n-1, 1) and λ_B.

Similarly, the regions under horizontal dotted lines mean that UB dynamically takes the un-authorized frequency band in network A, and the circumstances are consistent with U_A described above.

4.2. Theoretical Analysis

Based on the principle of conservation of energy, the input flow should equal to the output flow when a steady state is achieved. Therefore, the following formulas will be obtained:

When $i = 0\ , 0 \leq\ j \leq m + n - 1$,

$$(\lambda_A + \lambda_B + i\mu_A + ju_B)P(i\ ,j)\ = [1 - \delta(j)]\lambda_B P(i\ ,j - 1) + (j + 1)u_B P(i\ ,j + 1) + (i + 1)u_A P(i + 1\ ,j) \tag{6}$$

When $i = 0\ , j = m + n$,

$$(\lambda_A + ju_B)P(i\ ,j) = \lambda_B P(i\ ,j - 1) \tag{7}$$

When $0 < i < m \ , i + j = m + n$,

$$(\lambda_A + i\mu_A + ju_B)P(i\ ,j) = \lambda_B P(i\ ,j-1) + \lambda_A P(i-1\ ,j) + \lambda_A P(i-1\ ,j+1) \quad (8)$$

When $i = m\ , j = n$,

$$(i\mu_A + ju_B)P(i\ ,j) = \lambda_B P(i\ ,j-1) + \lambda_A P(i-1\ ,j) + \lambda_B P(i+1\ ,j-1) + \lambda_A P(i-1\ ,j+1) \quad (9)$$

When $m < i < m + n\ , i + \ j = m + n$,

$$(\lambda_B + i\mu_A + ju_B)P(i\ ,j) = \lambda_B P(i\ ,j-1) + \lambda_A P(i-1\ ,j) + \lambda_B P(i+1\ ,j-1) \quad (10)$$

When $0 < i < m + n\ ,0 < i + \ j < m + n$,

$$(\lambda_A + \lambda_B + i\mu_A + ju_B)P(i\ ,j) = [1 - \delta(j)]\lambda_B P(i\ ,j-1) + (j+1)u_B P(i\ ,j+1) + (i+1)u_A P(i+1\ ,j) + \lambda_A P(i-1, j) \quad (11)$$

When $i = m + n\ , j = 0$,

$$(\lambda_B + iu_A)P(i\ ,j) = \lambda_A P(i-1\ ,j) \quad (12)$$

In the above formulas, when $x = 0$, $\delta(x) = 1$; or, $\delta(x) = 0$.
The sum of static possibilities of all states is 1, namely:

$$\sum_{(i,j)\ \epsilon\Gamma} P(i\ ,j) = 1 \quad (13)$$

In order to analyze the system performance of dynamic-static spectrum access, it's assumed that mutual interference do not exist between master users and/or secondary users, and there is no delay in channel switch. Under this circumstance, three statuses are determined, including non-blocking state,blocking state, and forced drop-call state.

(1) Non-blocking state is the status of normal communicationwhen the interferences from others are not taken into account.

(2) Blocking state. As shown in Figure 3, blockinghappens in two circumstances: (a) if all of the channelsin network A and B are occupied by their authorized users, new requests from authorized or unauthorized users will be rejected; (b) if all of the channels in network A and B are occupied by their authorized or unauthorized users, new requests from authorized users will not be rejected, while new requests from unauthorized users will be rejected.

(3) Forced drop-call state. As shown in Figure 3, forced drop-call occurs when there is no idle channel. In other words, if an unauthorized user takes the channel of authorized user, the communication of this unauthorized user will be stopped by force and the corresponding channel will be released when authorized user needs this channel.

If there is no available channel in network, system will reject new requests of call service to guarantee the current service quality. Therefore, the probability of call-blocking is defined as:

$$P_{block} = \frac{\text{The number of blocked users}}{\text{The number of all users in communication}}$$

Traditionally, only static spectrum can get access into network, network A and B are independent, and their authorized users cannot percept spectrum holes in the other network through dynamic spectrum access. In this condition, new calling request will be rejected, if there is no available channel. Forced drop-call cannot happen when static spectrum is getting access, as priority does not exist between different users (business priority is not considered in this study). Therefore, the possibilities of blocking and forced drop-call of U_A and U_B are:

$$\left.\begin{aligned} P_{block,A} &= P(m) \\ P_{block,B} &= P(n) \\ P_{forced,A} &= 0 \\ P_{forced,B} &= 0 \end{aligned}\right\} \quad (14)$$

In the present study, dynamic-static spectrum access is available. If all of the static frequency bandsare occupied by authorized users and no channel is available in perceptive frequency band, the requestsfrom authorized users will be rejected. The blocking possibilities of U_A and U_B are:

$$P_{block,A} = \sum_{i=m}^{m+n}\sum_{j=0}^{n}\delta(i+j-m-n)\,P(i,j) \quad (15)$$

$$P_{block,B} = \sum_{i=0}^{m}\sum_{j=n}^{m+n}\delta(i+j-m-n)\,P(i,j) \quad (16)$$

If a user request accesses system dynamically and authorized users need this channel, the communication of unauthorized user will be stopped to avoid influencing the authorized users, as the priority of authorized user > the priority of unauthorized user. Under this circumstance, the possibility of forced drop-call is defined as:

$$P_{forced} = \frac{\text{The number of forced drop−call users}}{\text{The number of all users in communication}}$$

According to Figure 3, the forced drop-call possibilities of U_A and U_B are:

$$P_{forced,A} = \frac{\sum_{i=m}^{m+n}\sum_{j=0}^{n}\delta(i+j-m-n)\lambda_B P(i,j)}{\lambda_A\ (1-P_{block,A})} \quad (17)$$

$$P_{forced,B} = \frac{\sum_{i=0}^{m}\sum_{j=n}^{m+n}\delta(i+j-m-n)\lambda_A P(i,j)}{\lambda_B\ (1-P_{block,B})} \quad (18)$$

In the above formulas, when $x = 0$, $\delta(x) = 1$; or, $\delta(x) = 0$.

In addition to the possibilities of blocking and forced drop-call, the index named business throughput capacity should also be measured to evaluate a system. After the arriving of user requests, only a part of them can obtain services through system, while the other requests are rejected or forced to drop. Being represented by Th, throughput capacity is defined as the number of requests which obtain services through system per unit of time. If all the users in a system have the same rate of data signaling, the throughput of U_A and $U_B$will be:

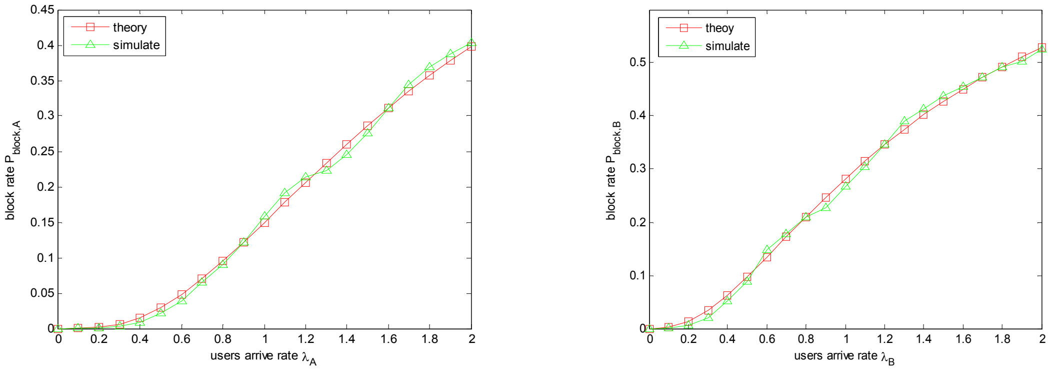
$$Th_A = (1-P_{block,A})(1-P_{forced,A})\lambda_A \quad (19)$$

$$Th_B = (1-P_{block,B})(1-P_{forced,B})\lambda_B \quad (20)$$

5. Result of Simulation and Performance Analysis

5.1. Result of Simulation

In the simulation process, the channel numbers of network A and B were set as $m = 5$and $n = 3$; the service rates of U_A and U_B were set as $\mu_A = 0.3$ and $\mu_B = 0.2$; the request arrival rates of U_A and U_B, namely, λ_A and λ_B were set according to the kind ofperformance analysis.In addition, "theory" stood for the theoretical values obtained by using matlab2010 software and dynamic-static spectrum access based on Markov transfer model, namely, the mathematically computed values derived from mathematical formula (15), (16), (17), and (18). "simulate" represented the system simulation values based on C language, blocking possibility, and forced drop-call possibility. The simulation time was set as T=100s.

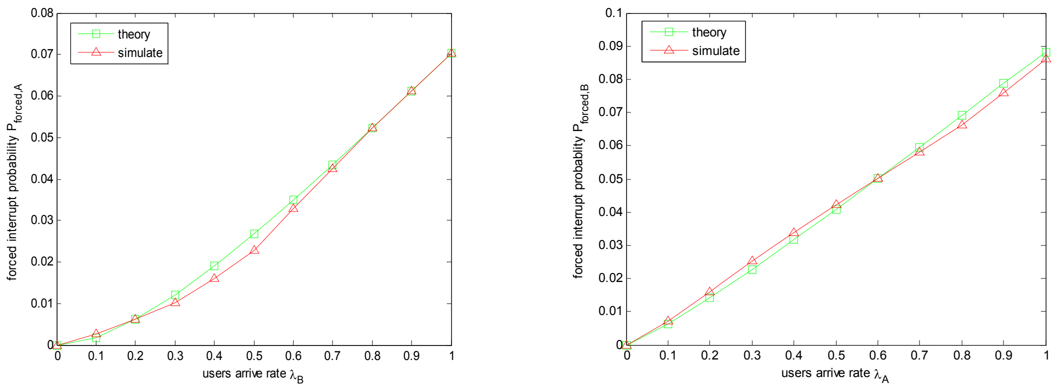


(a) The relationship between blocking possibility P_{blockA} and arrival rate λ_A when $\lambda_B = 0.2$

(b) The relationship between blocking possibilityP_{blockB} and arrival rate λ_B when $\lambda_A = 0.3$

Figure 4. The relationship between blocking possibility and arrival rate

As shown in Figure 4, simulation results were perfectly consistent withmathematically computed values, indicating that it was appropriate to use queueing theory and Markov transform model to analyze the access process of dynamic-static spectrum. Along with the increase in arrival rate of user request, blocking possibility possessed increasing trend. In addition, blocking possibility increased quite gently when the corresponding arrival rate was relatively small, as system resources could meet user demands. Following the increase of arrival rate, system resources could not meet user demands any longer, resulting in the rapid increase in blocking possibility.



(a) The relationship between forced drop-call possibility $P_{forcedA}$ and arrival rate λ_B when $\lambda_A = 0.3$

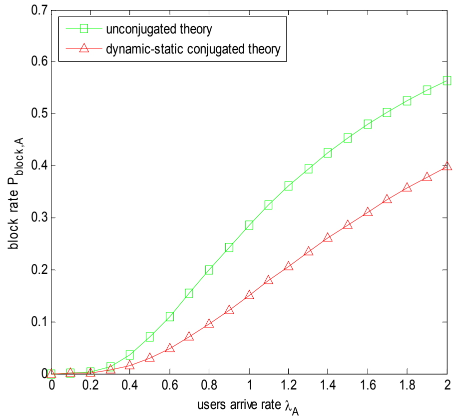
(b) The relationship between forced drop-call possibility $P_{forcedB}$ and arrival rate λ_A when $\lambda_B = 0.2$

Figure 5. The relationship between forced drop-call possibility and arrival rate

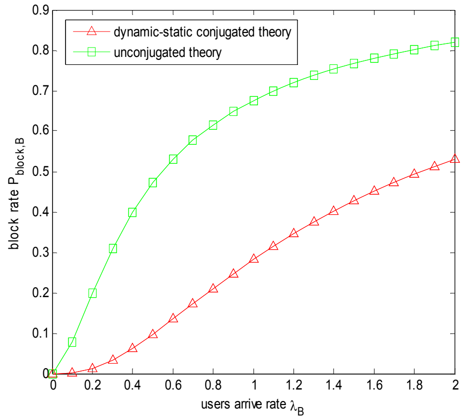
As shown in Figure 5, simulation results were also perfectly consistent with mathematically computed values. Along with the increase in arrival rate of master user requests, the forced drop-call possibility of secondary user also elevated, as forced drop-call happened in the access process of dynamic spectrum.

5.2 Comparison of Mathematically Computed Values

In this section, Matlab2010 was utilized to calculate and compare the theoretical parameters of system performance between dynamic-static mode and unconjugated mode, including blocking possibility, forced drop-call possibility, and throughput.



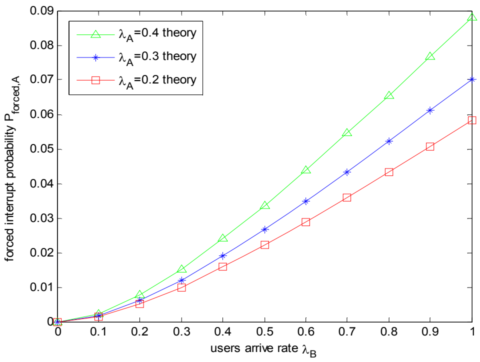
(a) The relationship between blocking possibility P_{blockA} and arrival rate λ_A when $\lambda_B = 0.2$



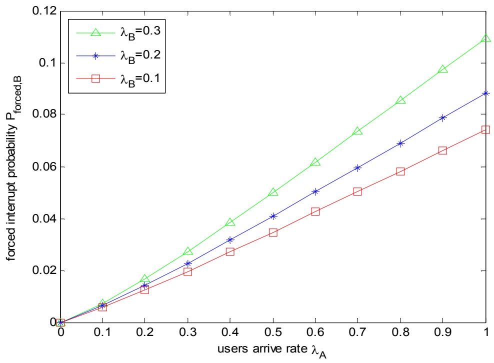
(b) The relationship between blocking possibility P_{blockB} and arrival rate λ_B when $\lambda_A = 0.3$

Figure 6. The relationship between theoretical blocking possibility and arrival rate

Red triangle: dynamic-static access; green square: static access only. As shown in Figure 6, along with the increase in arrival rate of user request, blocking possibility possessed increasing trend in both modes. However, the blocking possibility of U_A (or U_B) in dynamic-static access was much lower than that in static access with the same λ_A (or λ_B), asspectrum holes could be perceived and utilized to communicate in the access process of dynamic-static spectrum.



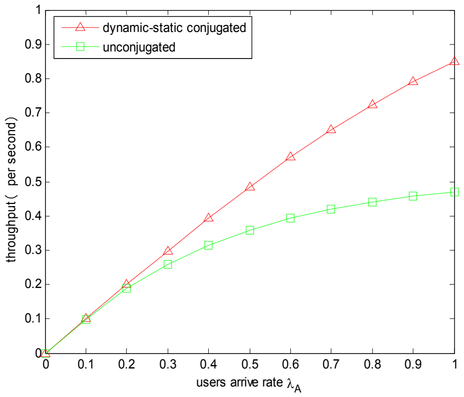
(a) The relationship between theoretical possibility of forced drop-call $P_{forcedA}$ and arrival rate λ_B



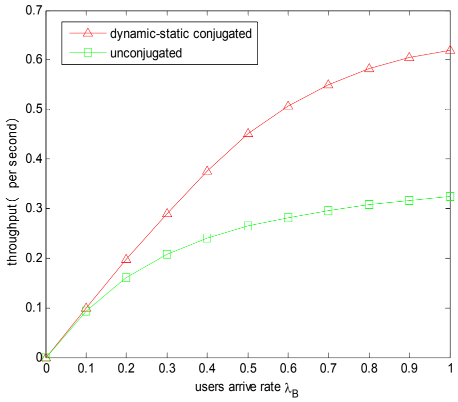
(b) The relationship between theoretical possibility of forced drop-call $P_{forcedB}$ and arrival rate λ_A

Figure 7. The relationship between theoretical possibility of forced drop-call and arrival rate

For the access of dynamic spectrum, forced drop-call happens in the access process of dynamic-static spectrum, while forced drop-callpossibility is 0 in the access process of static spectrum. As shown in Figure 7, along with the increase inλ_A and λ_B, theoretical possibility of U_A(or U_B) forced drop-call elevated. As priority of U_B> priority of U_A in the access process of dynamic spectrum, theoretical possibility of U_A forced drop-call significantly increased when λ_B increased. When λ_B was fixed, users using dynamic spectrum increased along with the increase in λ_A, and thus, theoretical possibility of U_A forced drop-call elevated.



(a) The relationship between theoretical throughput of U_A and arrival rate λ_A when $\lambda_B = 0.2$



(b) The relationship between theoretical throughput of U_B and arrival rate λ_B when $\lambda_A = 0.3$

Figure 8. The relationship between theoretical throughput and arrival rate

Red triangle: dynamic-static access; green square: static access only. As shown in Figure 8, the theoretical throughput in dynamic-static access was similar to that in static access when λ was small, as authorized channels could meet user demand with limited users. However, along with the increase in arrival rate, the theoretical throughput in dynamic-static access was markedly higher than that in static access with a same arrival rate.

6. Conclusion

Based on non-random access, this study simulated the access process of dynamic-static spectrum by using queuing theory and Markov transfer model, and then obtained the formulas of performance parameters, including blocking possibility, forced drop-call possibility, and throughput. The feasibility and reliability of our model were validated by comparing theoretical values with simulative values. The performance parameters of dynamic-static spectrum access were calculated through simulation, including blocking possibility, forced drop-call possibility, and throughput, which were further compared with that of static spectrum access. However, the interferences between different networks were not considered in this model, neither was buffer queue length. As these factors exist in the reality, modification is required to couple with the actual situation.

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