A Fast Frequency Switching Algorithm for Multi-parameter Fusion Decision Mechanism

Kaizhi Peng(✉), Binbin Xu, Rui Fu, and Xiaoling Liu

Wuhan Maritime Communication Research Institute, Wuhan 430079, China
pengkz722@163.com, 490366845@qq.com,
522721238@qq.com, lain_lxl@163.com

Abstract. In order to improve the transmission performance of the cognitive users in the tactical wireless network of warship formations, this paper we focus on the modeling technique and performance analysis for a fast frequency switching algorithm for Multi-parameter fusion decision. By developing a Multi-parameter fusion decision model, the closure expression of the fast frequency switching delay is derived, then the combined effects of the arrival rates of the primary users' connections and the arrival rates of the secondary users' connections on the cumulative handoff delay distribution is simulated. Based on the analytical results, suitable ship scheduling mechanism can be designed.

Keywords: Cognitive radio · Spectrum handoff · Reactive-sensing mechanism

1 Introduction

Cognitive radio (CR) can improve spectrum efficiency by allowing secondary users to temporarily access primary users' unused licensed spectrum [1–3]. However, due to the spectrum-varying nature of CR network, it is necessary to consider not only the access control and operation, but also the handoff timing, the switching procedure and the target channel should be considered, so the continuity and stability of the service transmission of the cognitive user after spectrum switching is ensured.

Both reactive [4–6] and proactive [7, 8] handoff algorithms are studied in existing works with suitable target channel selection (T.C.S.) procedures. When the primary users' businesses are busy, the pre-designed channels can't be used, the secondary users need to switch channels frequently, so the handoff delay increased, in this situation, the reactive is a better choice. If the arrival rates of the primary users' are small, the secondary user doesn't need to spend time to detect the channel, so the proactive is a better choice. The principle of ship communication is to ensure the reliability of communication on the basis of effectiveness, the goal of this paper is to develop a Multi-parameter fusion decision model, derive the closure expression of the fast frequency switching delay and design a suitable ship communication scheduling mechanism.

G. Sun and S. Liu (Eds.): ADHIP 2017, LNICST 219, pp. 25–32, 2018.
https://doi.org/10.1007/978-3-319-73317-3_4

2 System Model

2.1 System Framework

In this paper, the system framework is shown in Fig. 1, the system is consisting of the primary users and the secondary users. The primary users have the preemptive priority to access channels, while the secondary users have the low-priority to access the unused licensed spectrum of the primary users. In order to ensure the reliability of ship communication, and reduce the spectrum handoff delay, we considers the secondary users are equipped with two antennas, One is used for data and control message transmission and the other is used for idle channel detection, so the availability of the switching channel is ensured. In order to effectively short the extended data delivery time under various traffic arrival rates and service time as well as sensing time, we design an intelligent spectrum selection algorithm.

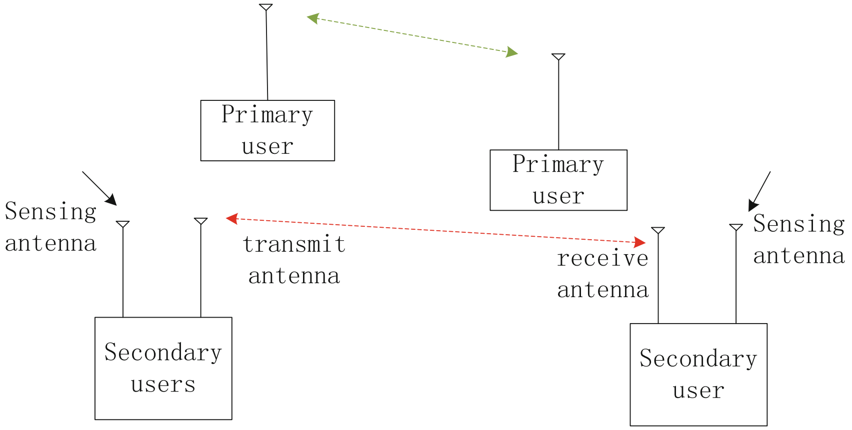

Fig. 1. System framework.

2.2 Multi-parameter Fusion Decision

Compared with two major types of spectrum handoff schemes, Multi-parameter fusion decision reduces the detection time before the data transmission, and then improves the availability of the selected frequencies. The process of the Multi-parameter fusion decision algorithm is as follows (Fig. 2).

The weighted two-threshold spectrum detection algorithm is used to detect whether an primary user arrives. Environment noise module is used to specify local noise detection for channel without service [9]. Primary user occupy channel for a specified time module is used to detect the primary user channel usage in a specified channel and specified time. Secondary user receiver data reception module is used to record the feedback of the channel quality of receiver. Intelligent spectrum selection mechanism module is used to extract the frequency according the different weight factors. Consider various factors to ensure the availability of frequency; the specific formula is as follows:

$$f = f_\varepsilon, \varepsilon = (\max[(\alpha_1 + \beta_1 + \gamma_1 + \theta_1), \ldots (\alpha_M + \beta_M + \gamma_M + \theta_M)]) \ . \tag{1}$$

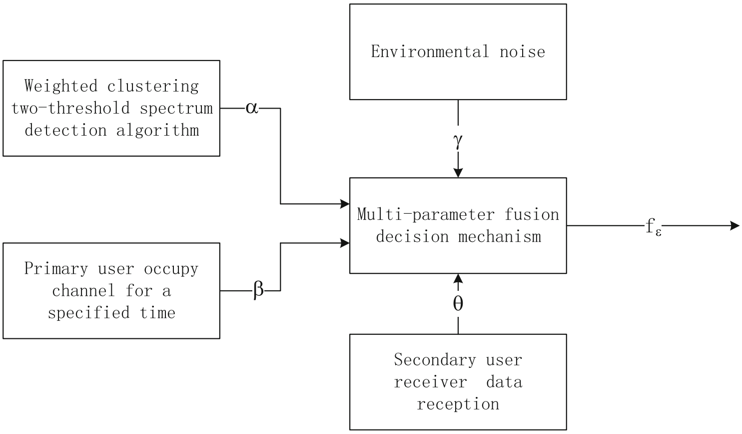

Fig. 2. The Multi-parameter fusion decision algorithm

2.3 Handoff Progress

Spectrum handoff occurs when the primary customers appear in the channel occupied by the secondary customers. In this situation, the secondary customer shall immediately handoff (transit) from the current channel to the target channel. The parameters related to the switching delay are included: (1) the arrival rates and the business duration of the primary user; (2) the arrival rates and the business duration of the secondary user; (3) the duration of the availability of the switching channel. The switching delay consists of the handshaking time and the channel switching time. There is no fixed channel for secondary users, in order to ensure the successful handshake of the secondary user in the initial stage, this paper adopts the common channel way to realize the first handshake of the secondary user. Figure 3 shows an example of Multi-parameter fusion decision spectrum handoff process:

(1) In the beginning, according to the multi-parameter frequency selection algorithm, the secondary users use the historical data and the real-time detection result to select the service initiation frequency, and call the secondary user of the communication object on the common channel, and then complete the first round of communication handshake. For simplicity, assume that the secondary user service is subject to the Poisson distribution, the mean rate is $\lambda_s^{(1)}$, and the service time mean is $E(X_s^1)$.

(2) As shown in Fig. 3, when the secondary user on the channel 1 business is ongoing, while the authorized user, who has the absolutely channel ownership, initiate business. The secondary user detects that the authorized user arrives, the secondary user needs to immediately activate the frequency switching mechanism.

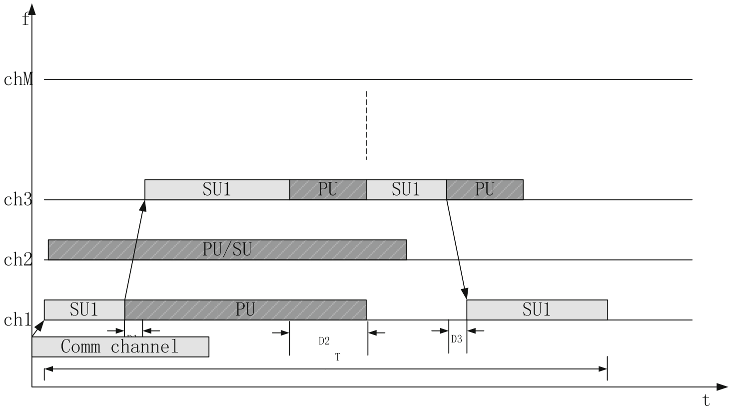

Fig. 3. The Multi-parameter fusion decision handoff progress

After the two parties complete the frequency handover, the handover will switch to channel 3. The main switching delay in this process comes from handshake time and frequency conversion time. For simplicity analysis, assume that the authorized user arrival probability is consistent with the Poisson distribution with mean rates $\lambda_p^{(1)}$ and the business duration is met with mean $E(X_p^1)$.

(3) During the duration of the authorized user service, as shown in Fig. 3, the secondary user can not select the available frequency according to the multi-parameter frequency selection algorithm. The secondary user will remain on channel 3 and immediately start the channel state detection algorithm. When the idle Channel is found, the secondary user will immediately start the frequency switching mechanism to determine whether to switch to new available frequency or not. If the idle channel is of good quality and the idle duration is long, it will switch to the new free channel. Otherwise, the original channel will be maintained until the authorized user has completed the communication.

(4) The above process will continue until the secondary user communication is complete. While after the communication finished, the secondary user will return to the common channel, waiting for the next service.

3 Analysis of Secondary Users' Extended Data Delivery Time

As shown in Fig. 3, the total duration of the secondary user transmission (denoted by ST^k) includes the length of the transmission time (denoted by X_s^k) and the accumulated time of the service (denoted by D^k). The accumulated time is composed of the frequency switching duration and the waiting for the user service time. The formula is shown below:

$$E[ST^k] = E[X_s^k] + E[D^k]\ . \tag{2}$$

In order to calculate the accumulated time of the service (denoted by D^k). On the basis of Fig. 3, The proposed Multi-parameter fusion decision handoff progress is established as an L-order state transition diagram, as shown in Fig. 4. Note that the stage i is the set of all possible states at the ith interruption, and the chk is the channel which the secondary user is select to switch, and the end state indicates the secondary user communication ends.

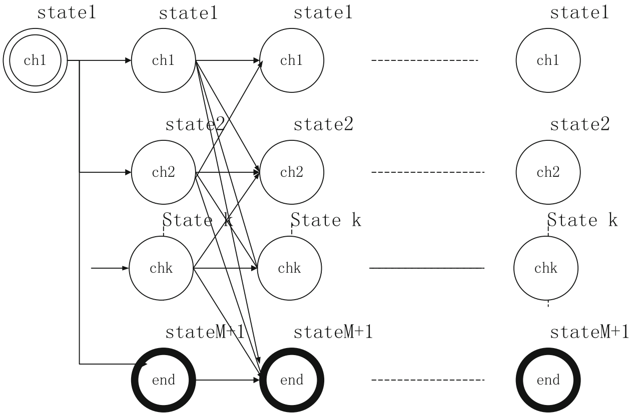

Fig. 4. L-order state transition diagram model

As Fig. 4 shows, for simplified calculations, the secondary user communication duration is consistent with Poisson distribution, the transition probability from states i to j is $P_{i,j}$, and the transition cost from states i to j is $C_{i,j}$. when the target channel is $s_n = (s_1, s_2, \ldots, s_n)$, which default channel is channel $s_0 = k$, the state transition path in Multi-parameter parameter model can be regarded as $(s_0 \rightarrow s_1 \rightarrow s_2 \rightarrow s_3 \rightarrow \cdots \rightarrow s_n \rightarrow M+1)$, so the cumulative handoff delay can be treated as calculating the cumulative transition cost overall possible state transition paths. The specific formula as follows:

$$E[D^k] = \sum_{n=1}^{L} \sum_{\forall s_n \in \Omega^n} [(P_{s_{n,M+1}} \prod_{i=0}^{n-1} P_{s_i, s_{i+1}})(C_{s_{n,M+1}} + \sum_{i=0}^{n-1} C_{s_i, s_{i+1}})]\ , \tag{3}$$

where $\Omega = \{1, 2, \cdots, M\}$.

According to Fig. 3, the secondary user initiates a service on channel 3, and then the primary user arrives at probability p. when the primary user arrives, the secondary user will change its channel according to the proposed frequency selection algorithm. As shown is Fig. 3, there is no available channel, so the secondary user will state on channel 3 until the primary user service is completed. Then, the primary user arrives again, the frequency selection algorithm proposes to switch to channel 1 and finally complete the communication process on channel 1. Hence, the state transition probability matrix of the Multi-parameter fusion decision model can be expressed as follows:

$$P = \begin{bmatrix} p^{(1)}\rho^{(3)} & p^{(1)}(1-\rho^{(3)}) & 1-p^{(1)} \\ 0 & 0 & 0 \\ p^{3}(1-\rho^{(1)}) & p^{(3)}\rho^{(1)} & 1-p^{(3)} \end{bmatrix}. \tag{4}$$

The cumulative transition cost is composed of the frequency switching duration and the waiting for the user service time. σ_c and σ_s are the total processing time for executing spectrum handoff procedures when the secondary users change to another channel and stay on the current channel. The duration resulting from the transmissions of multiple primary connections at channel k and denoted by Y_p^1. Then, we can have $C_{i,j}$ as follows:

$$C_{i,j} = \begin{bmatrix} \sigma_s + E[Y_p^1] & \sigma_c & 0 \\ 0 & 0 & 0 \\ \sigma_c & \sigma_s + E[Y_p^3] & 0 \end{bmatrix}. \tag{5}$$

According to the Poisson distribution parameters assumed above, the $E[Y_p]$ can be expressed as:

$$E[Y_p] = \frac{E[X_p]}{1 - \lambda_p E[X_p]} . \tag{6}$$

Then

$$p = \frac{\lambda_p}{\lambda_p + \mu_s} . \tag{7}$$

$$\rho = \lambda_p E[X_p] + \frac{\lambda_s}{\lambda_p + \mu_s}(1 + \frac{\lambda_p}{\mu_s}) . \tag{8}$$

According to (3)–(8), the closed-form expression for E[D^k] can be expressed as follows

$$E[D] = \frac{\lambda_p[\sigma_s\mu_s + (E[X_p])^2\lambda_p\mu_s + E[X_p](\lambda_s - \sigma_c\lambda_p\mu_s)]}{(1 - \lambda_p E[X_p])\mu_s^2} . \tag{9}$$

4 Numerical Results

Figure 5 simulates the impact of the primary user arrival probability and the business duration on the cumulative delay of the secondary user transmission. Figure 5 shows the cumulative time of the secondary user increases as the arrive probability λ_p of the primary user increases. The main reason is that the increase in the probability of primary users to arrive, it will lead to secondary user to stop service, and to enable the frequency switch mechanism to determine whether to switch frequency or not. At the same time, it also simulates the influence of the duration of primary user $E[X_p]$ on the cumulative delay of the secondary user. The longer the primary user service time is, the longer the cumulative delay of the secondary users is, due to the increase of the channel occupied by the primary user, and so the secondary users will spend more time to wait or frequently enable the channel selection mechanism.

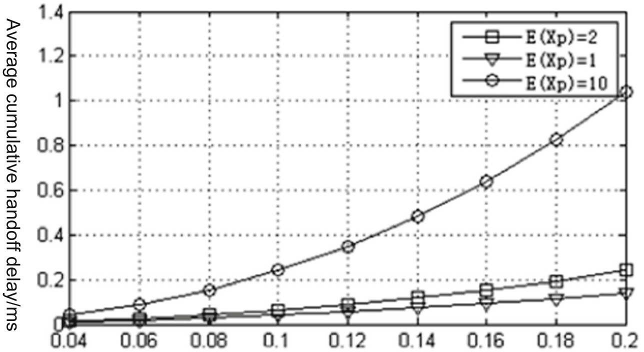

Fig. 5. Average cumulative handoff delay

Figure 6 shows the combined effects of the arrival rates of the primary users' connections and the arrival rates of the secondary users' connections on the cumulative

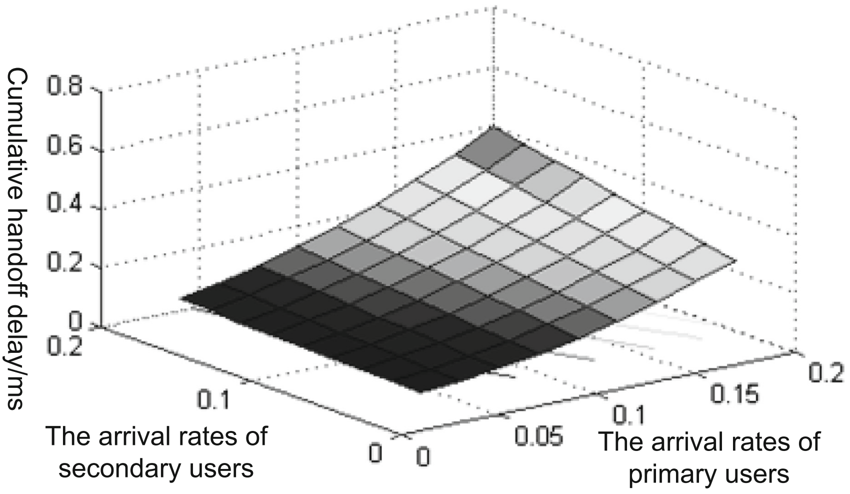

Fig. 6. Cumulative handoff delay

handoff delay distribution. It can be seen from Fig. 5 that the behavior of the primary user' communication has a great influence on the secondary users' performance, with the increase of the primary users' arrival rates, the cumulative handoff delay increase, which is mainly caused by the switching channel cost of the secondary user. The analytical results provide the useful insight for the effect of increasing the efficient time on the transmission performance of the secondary users.

5 Conclusions

In this paper, we also provide a framework to short the extended data delivery time under various traffic arrival rates and service time as well as sensing time. Then, a Multi-parameter parameter model for modeling the connections is developed, and the closed-form expression for handoff delay is expressed, at last the combined effects of the arrival rates of the primary users' connections and the arrival rates of the secondary users' connections on the cumulative handoff delay distribution is simulated. Based on the analytical results, suitable ship scheduling mechanism can be designed. However, the influence of spectral switching on channel capacity gain and system performance degradation has not been studied deeply. Therefore, it is necessary to further explore the influence of cognitive user spectrum switching in future work to achieve the relationship between channel capacity gain and system performance degradation balance.

References

1. Mitola III, J., Maguire, G.Q.: Cognitive radio: making software radios more personal. IEEE Pers. Commun. **6**, 3–18 (1999)
2. Mitola, J.: Cognitive Radio: An integrated Agent Architecture for Software Defined Radio (Ph.D. dissertation). Royal Institute of Technology, Sweden (2002)
3. Haykin, S.: Cognitive radio: brain-empowered wireless communications. IEEE J. Sel. Areas Commun. **23**, 201–220 (2005)
4. Kong, X., Petre, P., Matic, R., Gilbert, A.C., Strauss, M.J.: An analog-to-information converter for wideband signals using a time encoding machine. In: Digital Signal Processing Workshop and IEEE Signal Processing Education Workshop (DSP/SPE), Sedona, AZ, vol. 47, pp. 414–419 (2011)
5. Ning, Z., Song, Q., Peng, Y., Zhang, B.: Interference-aware spectrum sensing mechanisms in cognitive radio networks. Comput. Electr. Eng. **42**(C), 193–206 (2015)
6. Wang, L.: Optimization of MAC-layer multi-user cooperative spectrum sensing mechanism in cognitive radio. Sig. Process. **27**(4), 508–513 (2011)
7. Sasirekha, G.V.K., Bapat, J.: Adaptive model based on proactive spectrum sensing for Emergency Cognitive Ad hoc Networks. In: International ICST Conference on Cognitive Radio Oriented Wireless Networks and Communications, pp. 89–94. IEEE (2012)
8. Chamberl, J.F., Veercivalli, V.V.: The impact of fading on decentralized detection in power constrained wireless sensor networks. In: Proceedings of IEEE ICASSP, Montreal, Cananda, pp. 1286–1290 (2010)
9. Charles Clancy, T., Arbaugh, W.: Measuring interference temperature model. In: IEEE ISIT (2006)