랑데부 알고리즘에서의 다중 사용자의 영향에 관한 분석

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Analysis of the Impact of Multiple Users on the Rendezvous Algorithm

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요 약

인지 무선 네트워크(CRN, cognitive radio networks)에서의 랑데부 알고리즘 기술은 다양한 유형의 복잡한 알고리즘들이 제안되고 있다. 본 논문에서는 FRARS(Fast and Robust Asynchronous Rendezvous Scheme) 랑데부 알고리즘을 선택하여 그 특성을 세부적으로 분석하고자 한다. 기존 연구에서는 하나의 송신자와 하나의 수신자로 구성된 단순한 인지 무선 네트워크의 환경에서 그 특성을 보여주었기 때문에 본 논문에서는 네트워크가 하나의 송신자와 다양한 수의 수신자로 구성될 때에는 어떤 현상이 발생하고, 원인이 무엇인지 분석하는 것을 목표로 한다. 본 연구를 통해 향후 FRARS 알고리즘이 다양한 인지 무선 네트워크 분야에 활용될 수 있도록 충분한 정보를 제공할 수 있을 것으로 기대된다.

Key Words : Cognitive Radio, Channel-Hopping, Rendezvous Algorithm, Multi users

ABSTRACT

Rendezvous algorithm technology in CRN (cognitive radio networks) is a complex field in which various types of algorithms are used. In this study, we will focus on the analysis of FRARS(Fast and Robust Asynchronous Rendezvous Scheme), as previous work has already shown its characteristics in the simple case of a network with one sender and one receiver. In this study, we aim to analyze what phenomenon occurs and what causes it when a network consists of one sender and a diverse number of receivers. This study is expected to provide sufficient information so that the FRARS algorithm can be used in various practical fields in the future.

Ⅰ. Introduction

Nowadays, wireless communications are a common part of our lives, from major defense issues to the connectivity of earphones and smartphones. However, the spectrum of frequencies used has its limits, and we will soon need to find sustainable solutions to prevent this overcrowding. Cognitive radio networks (CRNs) provide a solution to this problem[8,9]. Indeed, with this technology, secondary users (SU) can create a network when the primary users (PU) are not using the band allocated to them. Depending on the context of the application, different criteria can be chosen to select the better algorithm to use CRN[3]. For example, in a military context, we can analyze the jamming resistance of different algorithms. It is in this context

that the FRARS (Fast and Robust Asynchronous Rendezvous Scheme) algorithm proposed in [2] has stood out. However, this algorithm was studied in the simple case of two users (one sender and one receiver)[5]. This setup simplifies comparisons between algorithms and allows for the identification of certain characteristics[6].

In the military field, the use of CRNs is already being considered and its importance is increasing. We have chosen FRARS as a suitable algorithm for military applications due to its strong resistance to jamming[1]. However, as mentioned earlier, the analysis of this algorithm has only been conducted for the case of one sender and one receiver, with no performance metrics provided for scenarios involving multiple receivers. Therefore, the aim of this paper is to analyze the performance of the FRARS algorithm in situations with multiple receivers, considering more realistic scenarios. It aims to identify and analyze in detail the issues arising as the number of receivers increases and the underlying causes.

To achieve this goal, we will first explain the operation of the FRARS algorithm and analyze how the time required for rendezvous changes as the number of receivers increases. We will conduct simulations to thoroughly examine the collision phenomena among receivers that affect performance, and separately analyze the performance in synchronized and asynchronous scenarios between senders and receivers. The structure of this paper is organized as follows. In Section 2, we review cognitive radio networks, followed by the introduction of the FRARS algorithm in Section 3. The impact of multiuser scenarios is discussed in both synchronous contexts in Section 4. The asynchronous contexts are then examined in Section 5. Section 6 provides the conclusion of this paper.

Ⅱ. Cognitive Radio

The topic of Cognitive Radio was first introduced by Joseph Mitola III in a seminar at the KTH Royal Institute of Technology in Stockholm in 1998. He defined this innovative approach to wireless communication as follows: "The point at which wireless personal digital assistants and related networks exhibit sufficient computational intelligence regarding radio resources and related computer-to-computer communications to detect user communication needs based on usage context, and to provide radio resources and wireless services most appropriate for those needs."

According to Mitola, cognitive radio networks represent a paradigm shift in wireless communication. Indeed, a significant portion of the spectrum remains underutilized, while other parts are congested. The challenge lies not only in spectrum allocation, as certain bands may experience user saturation only at specific times. For example, the military requires dedicated bands for communication when necessary, particularly due to the critical nature of their operations, which must remain undisturbed.

Therefore, it would be compelling to utilize available free channels and allow primary users to access their bands when needed. The objective is to fully exploit the spectrum. Cognitive radio networks analyze their electromagnetic environment to identify vacant channels. However, for data transfer to occur, a secondary user must rendezvous with another secondary user on the same channel simultaneously. This event is termed a rendezvous. Each user hops across channels in hopes of finding a rendezvous with another user. The duration required to achieve this rendezvous is known as the time to rendezvous (TTR). The hopping scheme used by secondary users between channels is a defining characteristic of an algorithm and facilitates their classification. Once rendezvous occurs, as illustrated in Figure 1, data exchange can commence, while secondary users continuously monitor for any primary user activity on the channel. Should interference occur, both users relocate, seeking
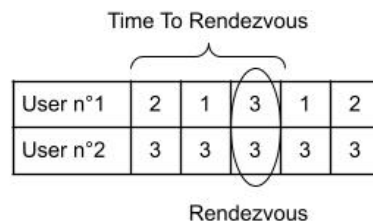

Fig. 1. Rendezvous between two users.

another available channel for communication.

Ⅲ. FRARS algorithm

In the context of CRNs, various rendezvous algorithms have been proposed over the years. We have selected FRARS algorithm as a prominent rendezvous algorithm because, compared to many others, it ensures robust resistance against jamming attacks while guaranteeing efficient rendezvous. The FRARS algorithm, proposed in [2], presents a potential alternative to or competitor with established algorithms such as ACH and EJS[4,7]. In this algorithm, which operates with a periodicity of 2N-1, users are categorized as either Senders or Receivers. Each category employs distinct sequences designed to facilitate rendezvous. Senders construct a sequence of size 2N-1 by initially permutating N available bands randomly, assigning the first N channels to their search sequence. The remaining N-1 channels utilize the last channel as a pivot for symmetry, aiding in locating a rendezvous across these bands. Receivers, on the other hand, randomly select one channel from the N available options and monitor it throughout the period. Figure 2 shows an illustration of rendezvous in FRARS when the number of available channels is 3. The sending sequence shows three periods, and the receiving sequence shows two periods. The shaded timeslots in the sending sequence represent the permutation parts, and the rest are the reversed repetition parts.

Most rendezvous algorithms proposed various methods to minimize rendezvous time. Time synchronization is a factor that can help reduce the Time To Rendezvous (TTR). In fact, when secondary users are sea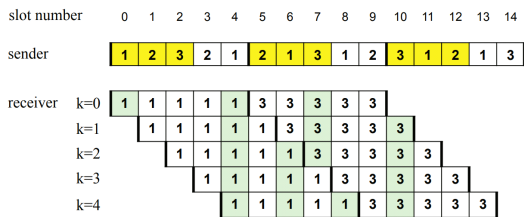rching for another user, they hop between their available channels. The scheme on which they hop is usually common for users within the same network. However, since users are not connected, they do not share the same clock and therefore do not start hopping cycles at the same time. This is where synchronization could be beneficial. The primary challenge is that synchronization requires a preliminary operation, which can reduce the network's adaptability. Nevertheless, it can significantly decrease the time needed to find a rendezvous. An illustration of these two cases (synchronous and asynchronous) is shown in Figure 3.

Many rendezvous algorithms proposed by researchers to minimize time to rendezvous (TTR) in both synchronous and asynchronous scenarios have primarily considered cases involving only two users, typically one sender and one receiver. As a result, the impact of user collisions on performance has been difficult to assess. Therefore, this study aims to address the scenario involving multiple users. To achieve this objective, we must precisely define what will be considered as the Time to Rendezvous (TTR), which corresponds to the meeting time between a sender and a receiver. As stated later in the study, we will consider the simple case of one sender and multiple receivers and analyze the effect of the number of receivers. We will then introduce a new term: the Time To Full Rendezvous (TTFR). This refers to the duration required for the network to have

Fig. 2. Illustration of FRARS when the number of available channel is 3
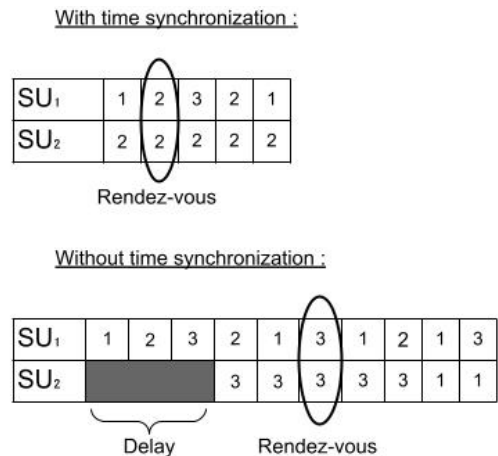

Fig. 3. Difference between algorithms with time synchronization and without time synchronization.

all receivers connected with the sender, meaning that all network users are connected. We will simply have to observe the time when the last receiver establishes a rendezvous with the sender. In Figure 4 below, we see that this occurs in the 4th search time with the rendezvous represented in blue between the sender and receiver No. 2.

In a multi-user scenario, another problem, collision, inevitably arises. This occurs when more than two users end up on the same channel at the same time, we can see a simple example in Figure 5.

There will be two ways to consider this problem. The first approach (without collision) assumes that the systems used are capable of recognizing who wants to communicate with whom, even if there are multiple users at the same time. The second approach (with collision) considers the case where the systems are not able to make this distinction and are therefore unable to determine who has a rendezvous with whom in this situation. In such cases, it is considered that there is no rendezvous at that time. After initial consideration, we can already assert that the TTFR will be shorter, hence better, in the without collision situations since there can be several meetings or, in the extreme case, all meetings occurring at the same
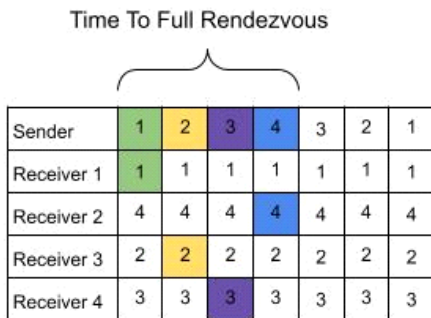

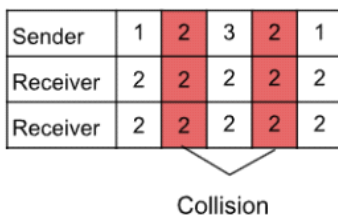Fig. 4. Example of Time To Full Rendezvous
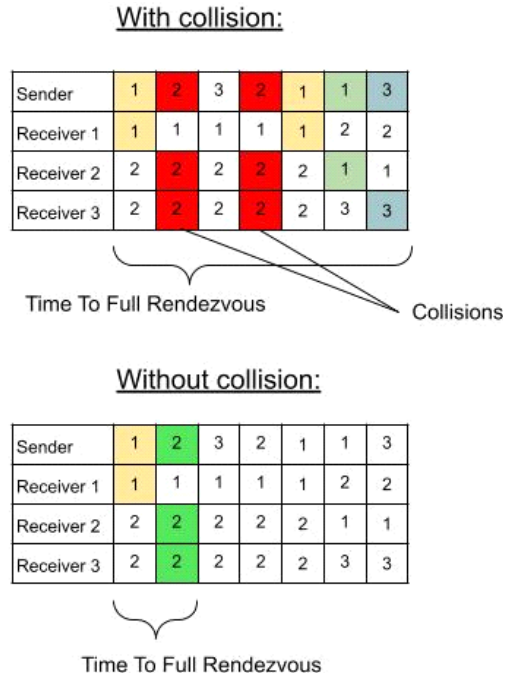

Fig. 5. Simple case of collision

Fig. 6. TTFR for both cases.

time. The bellow example, the Figure 6, shown this difference, with collision the TTFR occurs at the 7th time and without collision it occurs at the 2nd time.

Ⅳ. Impact of Multiple Users

The objective of this study is to determine the evolution of the TTFR as the number of receivers varies. To do this, we use MATLAB simulations that allows us to reconstruct the sequences of senders or receivers using the FRARS algorithm. With these sequences, we can obtain the TTFR for each simulation. It will then be interesting to vary the number of available channels (N) and observe the evolution of the TTFR for different configurations. We will start by studying the synchronous case and then compare the results in both synchronous and asynchronous cases, considering whether or not the phenomenon of collision for each situation.

In this simulation, we plot the TTFR as a function of the number of available channels for a network composed of 1 sender and 1 to 5 receivers.

Figure 7 shows that the more receivers we have in our system, the higher the slope of the line. However, as the number of users increases, the gap is gradually narrowing. Indeed, we observe that for a fixed N, the difference between the 1S1R (1 sender and 1 receiver) curve and 1S2R (1 sender and 2 receivers) curve is much more significant than the difference between the 1S4R curve and 1S5R. When this interval narrows, it can be seen that a convergence value exists for a fixed N. Figure 8 shows that regardless of the number of users, the TTFR will reach a limit that is equal to N, the number of available channels.

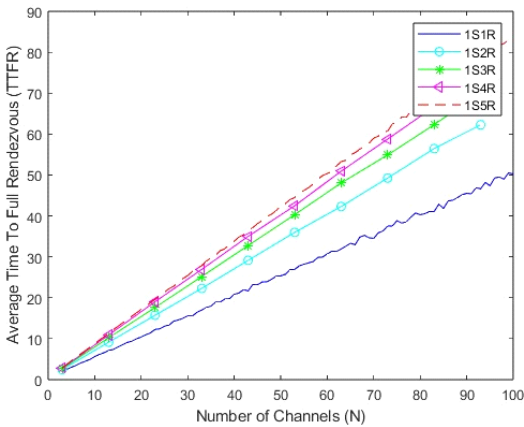These were the results of not considering the collision problem until now. If we do the same simulation considering the collision problem, we can get the following results. Figure 9 shows the average TTFR as a function of the number of available channels. In this figure, two things are noteworthy. First, we observe an inverse relationship in the TTFR when the number of available channels N is less than twice the number of receivers, where the TTFR decreases as the number of channels increases. In this particular situation, the TTFR increases because the probability of collision between users is very high. Secondly, it can be observed that the slope of the line slightly increases as the number of receivers increases. However, the gap between different configurations appears to remain consistent.

Figure 10 shows a comparison between the 1S2R and 1S5R configurations, considering whether collisions occur or not. The major difference between simulations with and without collisions is the emergence of an inverse relationship in certain intervals when collisions are considered. In the presence of collisions, except for the intervals with the inverse relationship, the TTFR value increases with the number of channels, similar to the case without collisions. In the absence of collisions, the TTFR value increases linearly, and the only difference is in the slope of the line. Examining the gap between the scenarios with and without collisions, we observe that in the case of 1S2R, the difference is minimal, whereas in the case of 1S5R, the difference increases significantly. This is because, as the number of users

Fig. 7. Average TTFR in synchronous case without collisions.

Fig. 8. TTFR as a function of the number of receivers with N fixed.
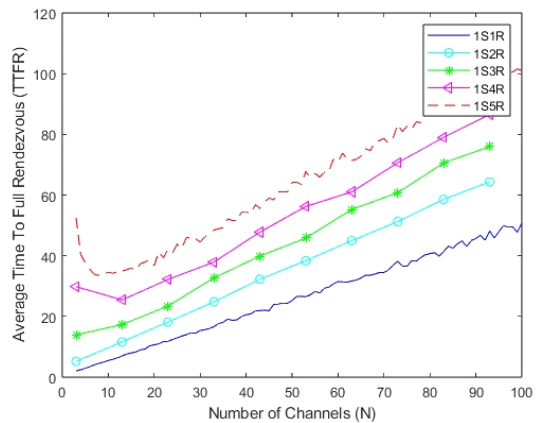

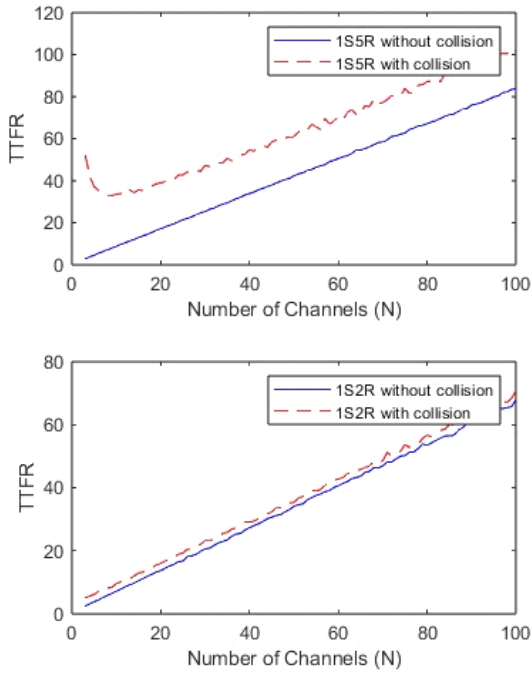Fig. 9. Average TTFR in synchronous case with collisions.

Fig. 10. TTFR for different cases, 2 and 5 receivers.

increases, the likelihood of collisions rises substantially, leading to an increase in the TTFR.

In a synchronous situation, it is assumed that all users start the rendezvous process at the same time, but in an asynchronous situation, users start the process at different times. Hence, we performed the simulation considering that it started at different times within the same period. Figure 11 shows the average TTFR as a function of number of available channels in an asynchronous scenarios without considering
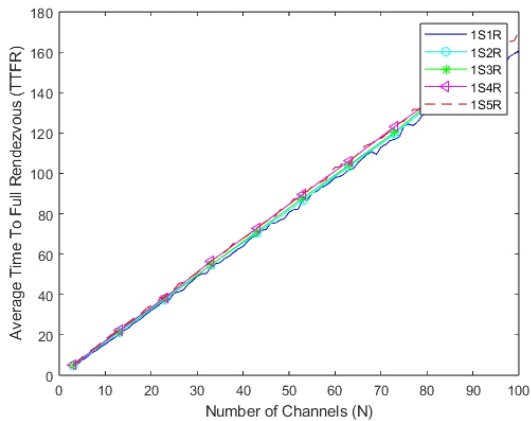
collisions. This is a similar result to the synchronous case seen earlier, but in the asynchronous case, the slope of the line is steeper and the rendezvous time takes longer as the number of channels increases. Moreover, it can be seen that even if the number of users increases, the gap in TTFR is very small. This means that the number of users does not have a significant impact when collisions are not considered in an asynchronous situation.

Regarding the phenomenon of TTFR converging rapidly to a fixed number of channels irrespective of the number of users, it is observed that although it does not exactly match the synchronous case, it is similar. As the number of users increases, the TTFR convergence behavior for a fixed number of channels is comparable to that in the synchronous scenario. To
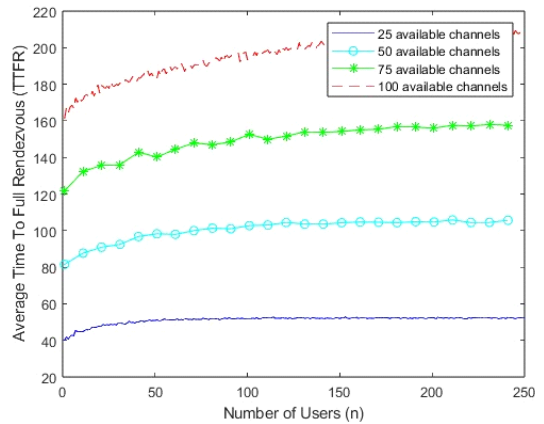

Fig. 12. TTFR as a function of the number of receivers with N fixed.

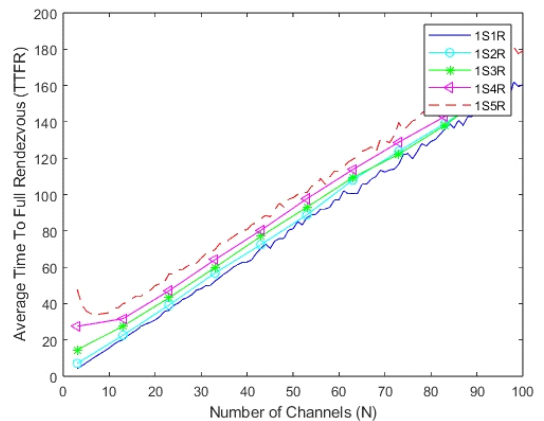Fig. 11. TTFR for asynchronous without collisions.

Fig. 13. TTFR for asynchronous with collisions.

confirm this phenomenon more clearly, the results of measuring TTFR while fixing the number of available channels and increasing the number of users are shown in Figure 12. The same principle as in the synchronous case applies, only the difference between the various scenarios is much smaller like we can see in Figure 13 bellow. This indicates that the number of receivers is less significant in the asynchronous case compared to the synchronous case.

V. Discussion

In this section, we discuss the limitations of the FRARS algorithm analyzed in this paper and identify areas for further performance analysis. First, to achieve a more accurate performance analysis, it is necessary to increase the number of senders in addition to the number of receivers in our simulations. In real-world scenarios, users perform both sending and receiving functions, resulting in a network with multiple users simultaneously acting as both senders and receivers. While this will result in a more complex simulation compared to considering only multiple receivers, it may be necessary for accurate performance evaluation in future research. Second, future studies could select several representative rendezvous algorithms in addition to the FRARS algorithm to analyze how performance varies due to collision phenomena in a network with multiple senders and receivers. Such research could compare the differences in performance across various algorithms, providing valuable insights into their relative effectiveness under these conditions.

VI. Conclusion

This study has provided a deeper understanding of the changes in TTFR when the network consists of one sender and multiple receivers. Simulations were conducted considering both synchronous and asynchronous scenarios, and it was observed that the TTFR value is higher in asynchronous scenarios compared to synchronous ones. In both scenarios, with a fixed number of available channels, the TTFR converges to a certain value as the number of users

increases, with the convergence occurring more rapidly in the synchronous case. When comparing scenarios with and without collision phenomena, it was observed that TTFR increases in the presence of collisions. Additionally, an inverse relationship between the number of users and TTFR was observed in certain intervals when collisions were considered. Regardless of the presence of collisions, the increase in TTFR value due to the increase in the number of users was less pronounced in asynchronous scenarios compared to synchronous scenarios. In conclusion, this study presents a detailed analysis of the performance of the FRARS algorithm in scenarios with multiple users.

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