A Comment on "Short Channel Hopping Sequence Approach to Rendezvous for Cognitive Networks"

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***Abstract*—Recently, Reguera *et al.* proposed a channel hopping scheme called short-sequence-based (SSB) rendezvous algorithm which works under symmetric and asymmetric channel models. After our revisit of the SSB implementation under the asymmetric model, we found that some cases will fail to have rendezvous in the asynchronous environment and the performance of SSB cannot be guaranteed as one would expect. In addition, we propose a conjecture for the failing cases.**

***Index Terms*—Cognitive radio networks, channel allocation, rendezvous algorithms.**

I. Introduction

COGNITIVE RADIO NETWORKs (CRNs) are proposed to solve the shortage problem of spectrum resources and improve the efficiency in spectrum usage. In CRNs, *primary users* (PUs) have the absolute priority to access the spectrum, while *secondary users* (SUs) can access the spectrum that is not currently used by PUs. Once any two SUs access a common channel, they can establish a link and start data delivery, which is called *rendezvous*. Since the channels that each SU can use may be different in different time or locations, the available channel set of each SU may also be time-varying. To solve this problem, *channel hopping* (CH) schemes are proposed.

In CH schemes, since each SU does not know available channel sets of other users, the process to make rendezvous is also called *blind rendezvous*. Many previous works have been proposed to make a guaranteed blind rendezvous as fast as possible. One term to evaluate the performance of CH methods is called the *maximum time to rendezvous* (MTTR), which is the maximum number of timeslots that any two CH sequences need to meet in a common channel. Moreover, since the available channel sets may be time-varying, there are two models of channel availability often considered in related works: i) *symmetric model*, in which all SUs share the same set of available channels; and ii) *asymmetric model*, in which different SUs perceive different available channels [1]. MTTR is often used to evaluate the performance of CH methods under the symmetric model, while the term *maximum conditional time to rendezvous* (MCTTR) in [2] is used under the asymmetric model.

Manuscript received May 10, 2014; revised June 14, 2014; accepted July 14, 2014. Date of publication July 31, 2014; date of current version September 8, 2014. This work was supported in part by the Ministry of Science and Technology of the Republic of China under Grant NSC 103-2221-E-007-067-MY3. The associate editor coordinating the review of this paper and approving it for publication was A. Rabbachin.

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Digital Object Identifier 10.1109/LCOMM.2014.2344035

Short-sequence-based (SSB) rendezvous algorithm [1] proposed a mathematical framework of blind rendezvous and a strategy to make rendezvous under both symmetric and asymmetric models. However, after a careful revisit on the implementation of SSB, we found that there are lots of cases failing to have rendezvous in the asynchronous environment, which will be described in Section III.

II. Brief Review of SSB

We first introduce the CH scheme of SSB briefly. Assume that there is a CH system with N channels, the SSB scheme generates a periodic CH sequence $S(t)$ with the following equation:

$$S(t)=\begin{cases}(t+k) \bmod N & \text{if } kT \leq t < kT+N\\ N-2-(t+k) \bmod N & \text{if } kT+N \leq t < (k+1)T,\end{cases} \tag{1}$$

for $k \in \mathbb{N}$, where $T = 2N - 1$ is the period of the sequence and $a \bmod b$ is the remainder of the division of a by b.

For example, if the available channel set is {0, 1, 2, 3, 4}, the CH sequence in a period generated with (1) will be {0, 1, 2, 3, 4, 3, 2, 1, 0}. As stated in [1], any two SSB periodic sequences $S(t)$ will have a guaranteed rendezvous in a period of time T, which implies that the MTTR of SSB is $2N - 1$.

After some available channels occupied by PUs, the available channel set may become different for different SUs, which causes the asymmetric model. Under the asymmetric model, SSB will replace the unavailable channels in the sequence with channel $m_{(k \bmod |M|)}$, where m_k is the kth channel in M (i.e., at the kth period the unavailable channels are replaced by the kth channel in M). Note that, M is the set of available channels detected by an SU given that not all the N channels are available to communicate.

For example, if the number of available channels N is 5 and the initial available channels set is {0, 1, 2, 3, 4}, the CH sequence in a period will be {0, 1, 2, 3, 4, 3, 2, 1, 0} with SSB algorithm. Now we assume that there are two SUs trying to make rendezvous and one of them has only three available channels {0, 2, 3} due to the PU's occupation. The CH sequences of the SU who has only three available channels will become {0, 0, 2, 3, 0, 3, 2, 0, 0}, {0, 2, 2, 3, 2, 3, 2, 2, 0}, and {0, 3, 2, 3, 3, 3, 2, 3, 0} in three contiguous periods since channels 1 and 4 are unavailable for the SU and replaced with channels 0, 2, and 3 in the three periods, respectively. After the replacement procedure, the authors in [1] claimed that any pair of SSB sequences will guarantee rendezvous in the time of $(N - 1)(2N - 1)$ under the asymmetric model, which is the MCTTR of SSB.

TABLE I
A LIST OF SOME FAILING CASES OF SSB

N	V_i	V_j	$Shift$
5	{0, 2, 3}	{0, 1, 2, 3, 4}	3, 6, 12, 15, 21, 24
5	{0, 2, 3, 4}	{0, 1, 2, 3}	6, 12, 15, 21
8	{0, 1, 2, 3, 4, 5, 6, 7}	{0, 2, 3, 5, 6}	3, 6, 9, 12, 18, 21, ...
8	{0, 1, 2, 3, 4, 5, 6, 7}	{1, 3, 6}	5, 10, 20, 25, 35, 40
11	{0, 1, 5, 6, 7, 8}	{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10}	7, 14, 28, 35, 49, 56, ...
11	{0, 1, 2, 3, 4, 5, 6, 7, 8, 9}	{0, 2, 4, 6, 7, 9}	14, 28, 140, 154
13	{0, 4, 5, 9, 10}	{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12}	5, 10, 15, 20, 30, 35, ...
14	{0, 6, 8, 9, 13}	{0, 7, 8, 9, 10}	36, 45, 63, 72, 90, 99, ...

III. FAILING CASES FOR SSB

After thousand times of simulations in the asynchronous model with SSB algorithm, we found that any two SUs may have no rendezvous if the number of channels $N = 5, 8, 11, 13, 14, 17, 18, 20, 23, 25, 26, 28, 29, 32$, etc. In the above example, we align the CH sequences of the two SUs with timeslot shifts from 0 to 35 under the asynchronous environment. We found that there are no rendezvous when the timeslot shifts are some multiples of 3 (3, 6, 12, 15, 21, 24). The result contradicts the proposition in [1] which claims that the MCTTR of SSB is $(N-1)(2N-1)$.

According to the statistics of the failing cases, we have a conjecture that the rendezvous cannot be guaranteed if $N = ((3+2\alpha)r+1)/2$ for all integer $\alpha \geq 0$ and odd integer $r \geq 3$ which is similar to the constraint of N mentioned in [2]. We can find lots of cases that match our conjecture. Some of them are listed in Table I, where V_i and V_j are the available channel sets for SUs i and j, respectively and *Shift* represents the timeslot shifts between the CH sequences of i and j.

In the failing cases, we found a commonality that the timeslot shifts are some multiples of $(3+2\alpha)$ or r. For example, if $\alpha = 0$ and $r = 3$, the timeslot shifts of the failing cases will be the multiples of 3 for $N = 5$, which meets the above asymmetrical example. If $N = 8$, (α, r) can be (0, 5) or (1, 3), the timeslot shifts of the failing cases will be the multiples of 3 or 5. For example, if the available channels set of one SU is {0, 1, 2, 3, 4, 5, 6, 7} while the other one has {0, 2, 3, 5, 6}, they will not meet when the timeslot shifts between them are 3, 6, 9, 12, 18, 21, etc. If one SU has available channels set {0, 1, 2, 3, 4, 5, 6, 7} and the other SU has {1, 3, 6}, the rendezvous for them will not happen when the timeslot shifts are 5, 10, 20, 25, 35, 40.

IV. CONCLUSION

In this comment, we revisited the SSB scheme proposed in [1]. Under the asymmetric model, we found that there are several cases failing to have rendezvous with various N in the asynchronous model, which contradicts the proposition that claims the MCTTR of SSB is $(N-1)(2N-1)$.

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