Whether and When to Share: Spectrum Sensing as An Evolutionary Game

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- The fundamental task of spectrum sensing contains two aspects:
  - Protect the active primary users.
  - Detect the available channels.
- The objectives of secondary users are to maximize the utilization of the available spectrum and to prevent interference with primary users.

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- To ensure the spectrum sensing quality, adequate sample collection is required over a period of time for analysis by secondary users.

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- For each secondary user, there is a tradeoff between the time used for spectrum sensing and the time used for data transmission.
- One effective approach to solve this is cooperative sensing.

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  - The strategy set is usually {contribute, not contribute}.
- We consider an extended strategy set, including "when to share".

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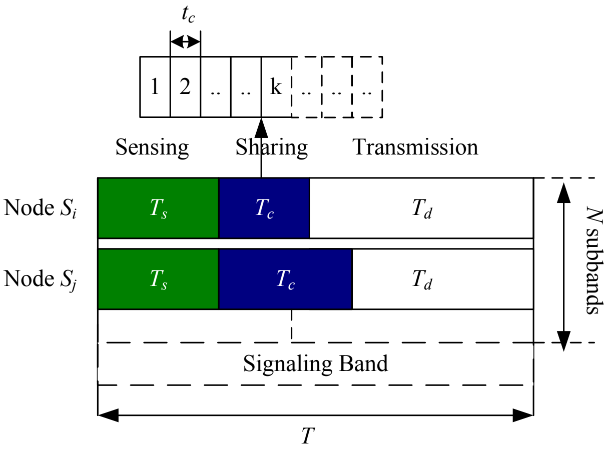
System Model

Each time slot is divided into three parts.



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- Suppose the minimal time required for sending the sensing results when there is no conflict is t_c. Then T_c is divided into $\lceil \frac{T_c}{t_c} \rceil$ sub slots.

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- Suppose the minimal time required for sending the sensing results when there is no conflict is t_c. Then T_c is divided into $\lceil \frac{T_c}{t_c} \rceil$ sub slots.
- For a certain SU, it can choose whether to share its sensing results or not. If a node decides not to share its sensing results, its sharing time length would be 0.
- If it chooses to cooperate with others, it needs to choose one sub slot of T_c to send the sensing results.
  - The sensing results are confirmed to be received successfully through the ACKs. The sharing phase of a node ends as long as one ACK is received.
  - Before that, the current secondary user keeps listening to the signaling channel for others' sensing results.

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Objective & Constraints

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  - Both the probability of detection and probability of false alarm have to meet the required threshold.
- The objective is defined based on each secondary user's view, which is to maximize its own utility.
  - The utility is related to the throughput of the secondary user considering both active and inactive status of primary users.

Evolutionary Game

- We build the evolutionary game for our model.
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  - The key insight is that many behaviors involve the interactions of multiple strategies of different players, and the success of any strategy depends on how it interacts with others.
- The objective is to find the evolutionarily stable strategy (ESS), which tends to persist once it is adopted by most players.
  - Due to dynamics in the spectrum availability in CRNs, there is not a static stable strategy for each user conducting spectrum sensing.

Game Model

- The secondary users in our model consider both whether and when to share their sensing results.

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- Based on this intuition, we have the definition of the strategy set for our model.
  - The strategy set of an SU is $\{(C, j)\}$, where $j \in \{0, 1, ..., \lceil \frac{T_c}{t_c} \rceil\}$. $j = 0$ means the SU denies to share its sensing results. Otherwise, the SU sends its sensing results at the jth sub slot of T_c.

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- The payoff of each secondary user is defined based on the throughput after it adopts one strategy.

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- We prove the existence of ESS in our game model and give the replicator dynamics that can have a secondary user converge to the ESS.

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- The algorithm for each secondary user is basically to adjust its strategy based on its payoff and the replicator dynamics.

Algorithm 1 Evolutionary algorithm for S_i

$t_0 = 0$, $\forall (C, j)$, $p_{(C,j)}(S_i) = p_0$
$temp = 0$
while NOT an ESS **do**
  $\tilde{t} = t_0$
  while $\tilde{t} < t_0 + \tilde{T}$ **do**
    Choose (C, j) with probability $p_{(C,j)}$
    Calculate $U_{(C,j)}(S_i)$ using Eq. 8
    $\tilde{t} = \tilde{t} + T$
  $t_0 = t_0 + 1$
  Calculate $\bar{U}_{(C,j)}(S_i)$ and $\bar{U}(S_i)$
  $\forall (C, j)$, update $p_{(C,j),S_i}$ using Eq. 13
  if $temp * (\bar{U}_{(C,j)}(S_i) - \bar{U}(S_i)) < 0$ **then**
    $\mu = \mu/2$
  $temp = \bar{U}_{(C,j)}(S_i) - \bar{U}(S_i)$

Experiment Settings

- We use four USRPs to evaluate our model.
- Three USRPs simulate three secondary users. One USRP simulates the primary user.
- The three secondary users work on three subbands with different central frequencies: 1.3GHz, 1.30025GHz and 1.3005GHz.
- The primary user works on all three subbands at the same time.

Experiment Settings

Some other settings:

- The time slot length to 20s here (for better synchronization).
- The static sensing time is set to 5s, which is divided into 5 sub slots.
- The window size for each secondary to calculate the average throughput is 4 slots.
- The bandwidth of each secondary is 50k bps and the gain at each receiver is set to 20.

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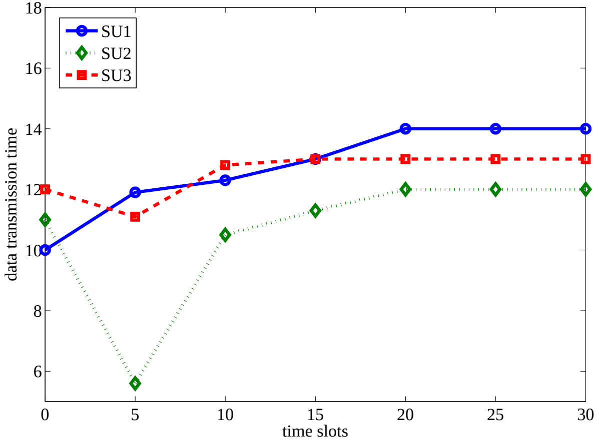
Experiment Results

The experimental results of three secondary users:



Conclusion

- We consider both whether-to-share and when-to-share for the cooperative spectrum sensing in CRNs.
- We apply an evolutionary game model and define a novel strategy set for each player.
- We prove the existence of the evolutionary stable strategy (ESS) and provide a practical algorithm.
- We evaluate our model and the parameter influences through experiments.

Thank you!