Autonomous Sensing Order Selection Strategies for Cognitive Radios: Benefit of Adaptive Strategies

Zaheer Khan, Marcos Katz, Zhu Han
and Luiz A. DaSilva

Outline

- Background and motivation.
- Outline of the system setup.
- Autonomous OSA strategy.
- Performance analysis of the presented strategy.
- Adaptive OSA strategies.
- Questions/Comments.

Background: Definition of cognitive radio used in this work

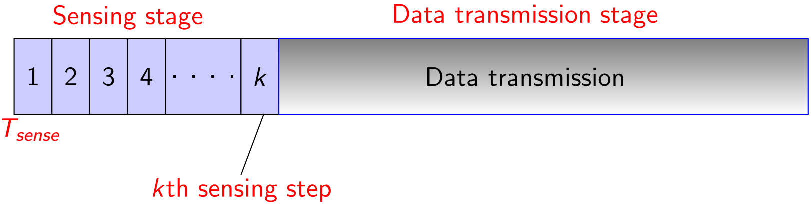
- **Cognitive Radio:**
  a) An intelligent terminal device who can learn about available frequency spectrum by employing sensing-based opportunistic spectrum access (OSA).
  b) The device is able to self-organize and adapt appropriate communication and networking functions through re-configurable communication/network processor(s).

Background: Sensing-based OSA

- In sensing-based OSA:
  Cognitive radios (CRs) monitor the environment to reliably detect the licensed (primary) user signals and operate whenever the primary band is empty.

Background: Multichannel OSA

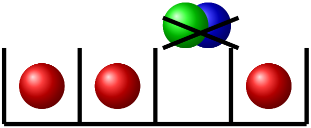
- Availability of multiple potential frequency bands (channels).
- Need for periodic sensing of the potential channels.
- In general a time slotted CR network is widely considered.



- The first portion of each time slot is used for sensing.
- The second portion is used to access the free channel, if one is found.
- Sensing strategies:
  1) The CRs may sense only a single channel in any given time slot.
  2) They may sense the potential channels sequentially in some order until they find a free to transmit, if one exists.

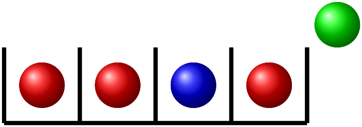
Motivation

- **Example 1**: If two or more uncoordinated CRs simultaneously decide to sense the same channel, find it free from primary user activity, and decide to transmit in the channel, this will lead to frame collisions.



Red= Channel is occupied by primary user, Blue= CR 1, Green=CR 2

- **Example 2**: In a given sensing step a CR selects a channel that is free from primary user activity, but it was found empty by the other CR in one of the previous sensing steps. In this case the CR will not be able to utilize this channel.



Red= Channel is occupied by primary user, Blue= CR 1, Green=CR 2

Outline

- We consider a distributive cognitive radio (CR) network of:
  M cognitive radios (trasnmitter/receiver pairs)
  $\mathbf{N} = \{1, 2, ..., N\}$ potential primary user channels with equal bandwidth W.
- The primary users and CRs are both assumed to use a time slotted system.
- One transmission by primary user corresponds to one time slot.
- The probability of primary user present, and the probability of primary user absent, in a given slot are assumed to be unknown to the CRs.
- We assume that N CRs employ energy detection to make primary user observations in the frequency band they are monitoring.

Outline (contd)

- At the end of each slot, each CR gets the value $C_i(k)$, which is given by

$$C_i(k) = \begin{cases} (1 - \frac{kT_{sense}}{T})R_i & \text{If a CR picks an empty channel in } k\text{th step} \\ & \text{and no other CR picks the same channel as that} \\ & \text{CR in all 1 to } k \text{ steps.} \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where R_i represents the transmission rate of the CR i to its receiver when the channel is empty.

- The average value (throughput) of each CR i is given by

$$\bar{C}_i = \sum_{k=1}^{N} [(1 - \frac{kT_{sense}}{T})P_{success}(k)R_i], \quad (2)$$

where $P_{success}(k)$ represents the probability that a given CR finds a channel free (free from both primary and other CR transmissions) in the kth step.

Can we improve in terms of system throughput? Adaptive Strategies (rand-AP and rand-LS adaptive strategies) (rand-AP when all permutations are used)

- To minimize this probability of collisions we propose the following multi-channel sensing strategies.
- CRs adaptively change the sequence selection based on collisions experienced in the previous time slot.
- For the *Random Permutation Sensing*, where the indices of N potential channels, i.e., $\{1, 2, ..., N\}$, are randomly permuted by each CR independently and then channels are sensed by each CR according to its own random permutation:
- **If a CR experiences a collision in the previous slot then randomly permute in the next slot, otherwise use the same permuted sequence as in the previous slot.**

1	2	3	4		3	1	2	4
1	2	4	3		3	1	4	2
1	3	2	4		3	2	1	4
1	3	4	2		3	2	4	1
1	4	2	3		3	4	1	2
1	4	3	2		3	4	2	1
2	1	3	4		4	1	2	3
2	1	4	3		4	1	3	2
2	3	1	4		4	2	1	3
2	3	4	1		4	2	3	1
2	4	1	3		4	3	1	2
2	4	3	1		4	3	2	1

a)

1	2	3	4
2	1	4	3
3	4	1	2
4	3	2	1

b)

Fig. 7. Examples of sensing orders for $N = 4$ potential channels. In alternative a), the space of all permutations of $N = 4$ channels is illustrated, while in alternative b), a subset of that space (a Latin Square) is illustrated.

Further improvement? (Using a Latin Square for sensing orders)
Adaptive Strategies (contd)

- In the sensing period each CR senses the primary user channels sequentially in a sensing order $(c_1, c_2, ..., c_N)$ which is a row of the orthogonal matrix.
- **Example:** $\mathbf{P} = \text{circ}\{1, 2, ..., N\}$, where matrix $\mathbf{P}$ represents the circulant matrix associated to $\mathbf{N}$.
- For $\mid \mathbf{N} \mid = 5$, the matrix $\mathbf{P}$ is given as:

$$\mathbf{P} = \begin{array}{c} \begin{matrix} c_1 & c_2 & c_3 & c_4 & c_5 \end{matrix} \\ \begin{pmatrix} 1 & 2 & 3 & 4 & 5 \\ 5 & 1 & 2 & 3 & 4 \\ 4 & 5 & 1 & 2 & 3 \\ 3 & 4 & 5 & 1 & 2 \\ 2 & 3 & 4 & 5 & 1 \end{pmatrix} \end{array}$$

Each cognitive radio randomly chooses one of the rows of the matrix **P** and the channels are sensed sequentially according to the sensing order in the selected row.

- Using this strategy two or more or CRs will only collide if they choose the same row of the matrix **P**.
- **If a CR experiences a collision in the previous slot then randomly choose one of the sequence in the next slot, otherwise use the same sequence as in the previous slot.**

Gamma Persistent Strategy:

In this strategy,a CR uses two binary flags d and c that track its success and failures of accessing the channel in prior steps.

The basic difference between the randomize after every collision strategy (rand-AP and LS) and the gamma-persistent strategy is that:

a) In the randomize after every collision strategy a sensing order is randomly selected by a CR whenever it experiences a collision in the previous time slot.

b) In contrast, in the gamma-persistent strategy, using the binary flags c and d a CR takes into account whether it was successful, experienced a collision or it found all channels busy after the previous collision, and in case of a successful transmission or collision it persists with that sensing order even after a small number of consecutive collisions.

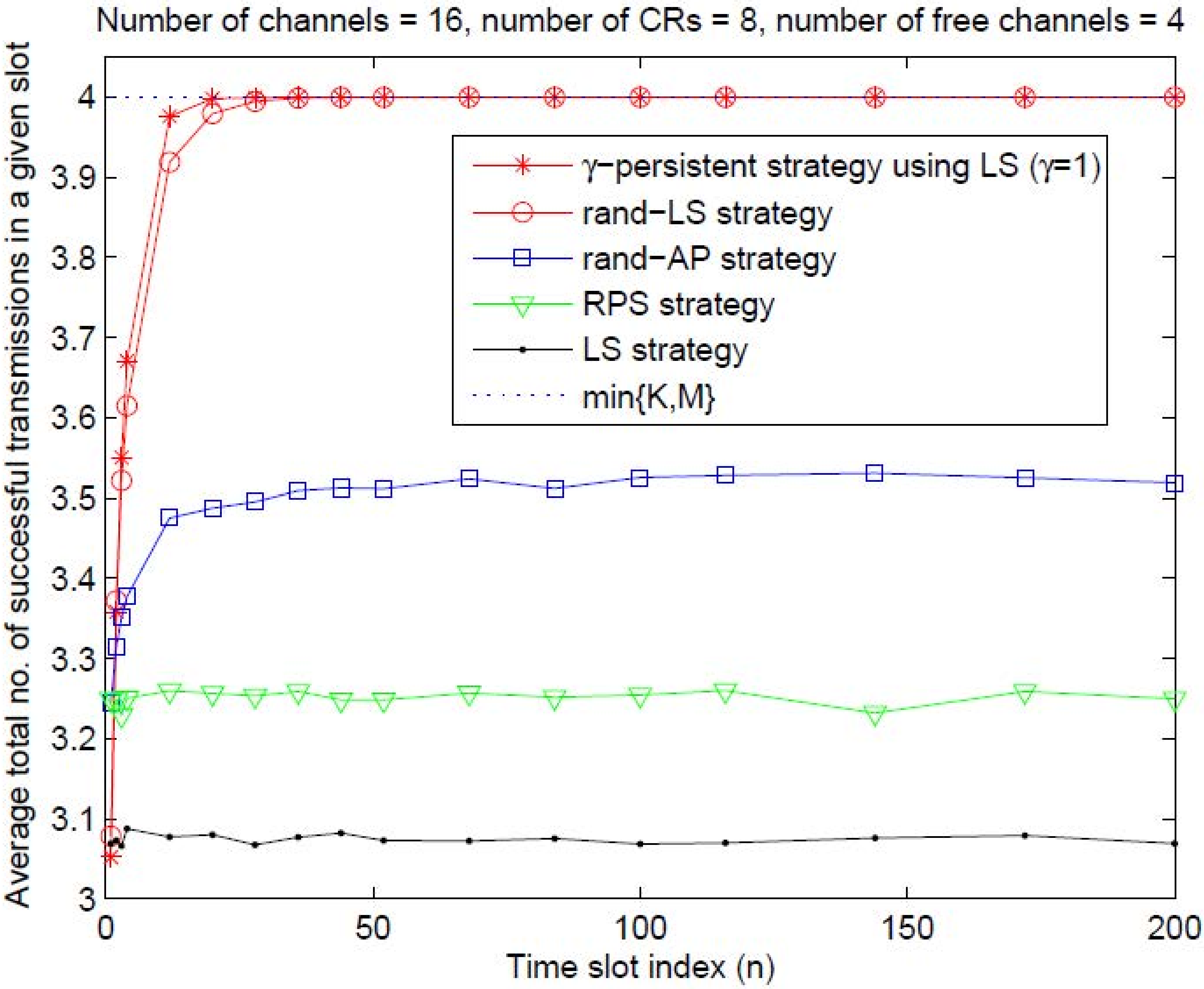
Analysis under different primary user occupancy models and also

For detailed theoretical analysis of the presented strategies please see

Zaheer Khan, Janne Lehtomäki, Luiz A. DaSilva, Markku Juntti. Analysis of Autonomous Opportunistic Spectrum Access Strategies for Cognitive Radios: Benefits of Adaptive Strategies. University of Oulu, Technical Report, 2012.

Zaheer Khan, Janne J. Lehtomäki, Luiz A. DaSilva, Matti Latva-aho. Autonomous Sensing Order Selection Strategies Exploiting Channel Access Information. IEEE Transactions on Mobile Computing, published 2013

Next we present some simulation results:


Number of channels = 16, number of CRs = 8, number of free channels = 4
γ−persistent strategy using LS (γ=1)
rand−LS strategy
rand−AP strategy
RPS strategy
LS strategy
min{K,M}
Average total no. of successful transmissions in a given slot
Time slot index (n)
3
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4
0
50
100
150
200

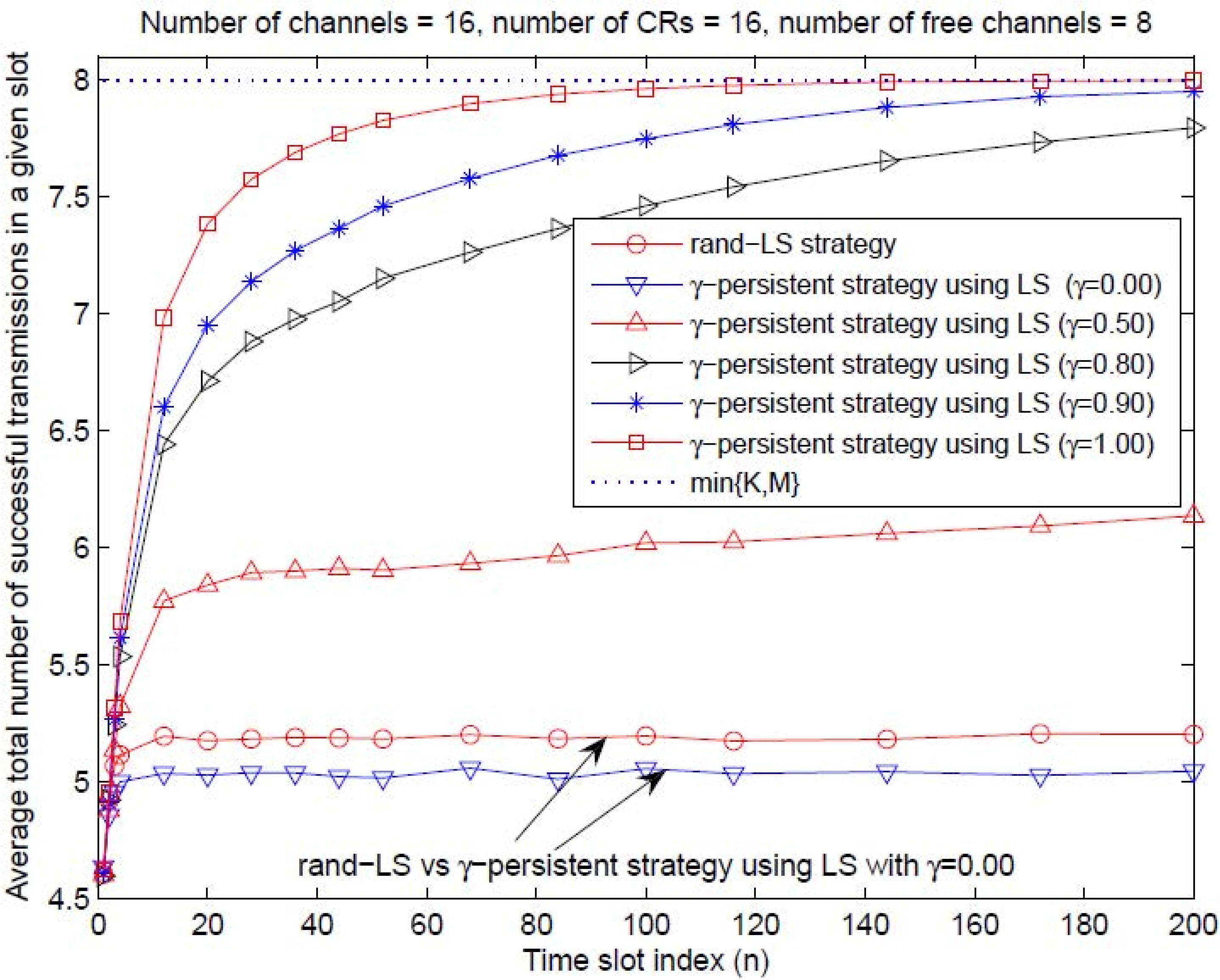


Fig. 10. Performance comparison of γ-*persistent* strategy with randomize after every collision strategy when values of γ are varied between 0 to 1. In all scenarios CRs select a sensing order from a predefined Latin Square.

Questions and comments

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