Algorithm for Sensor Exclusion and Dynamic Cluster Head Selection in Cognitive Radio Networks

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Brief introduction

Alcides Tomás, graduated in Telecommunications and Electronics from the José Antonio Echeverría Technological University of La Habana (Cujae) in 2020. Currently, I'm completing my master's degree at Inatel, focusing on energy efficiency in Cognitive Radio Networks (CRN).

I'm interested in researching renewable energy sources and Artificial Intelligence (AI) models capable of monitoring energy consumption, aiming for a more efficient allocation of resources.

Aims and contributions of our paper

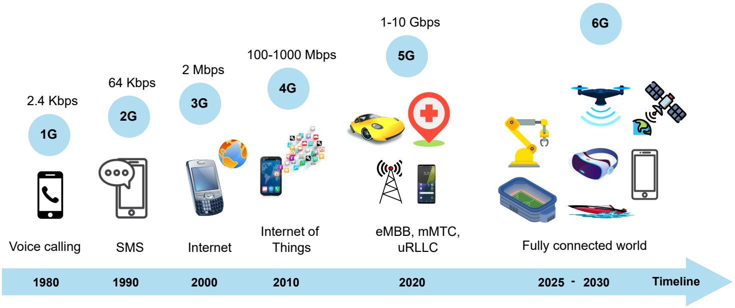
In our paper, we aimed at:

1. Reduce energy consumption without compromising the system's detection capability;
2. Develop an algorithm to improve the lifespan of the secondary network;
3. Compare the performance, in terms of detection probability and lifespan, of the proposed algorithm with that of the classical system and the system with clustering.

Contributions of our study are threefold:

1. We developed an algorithm based on the detection performance of the sensors, where sensors with poor performance remain inactive for a period, without participating in the sensing process.
2. The proposed algorithm also includes the rotation of Cluster Heads (CH), based on the calculation of the center of mass (CM) weighted by the residual energy of the cluster's sensors.
3. The sensors are distributed within the coverage area of the primary signal, where shadow zones were previously defined to assess the impact of the signal received by the sensors located in these regions.

- **Cellular Technology Evolution**

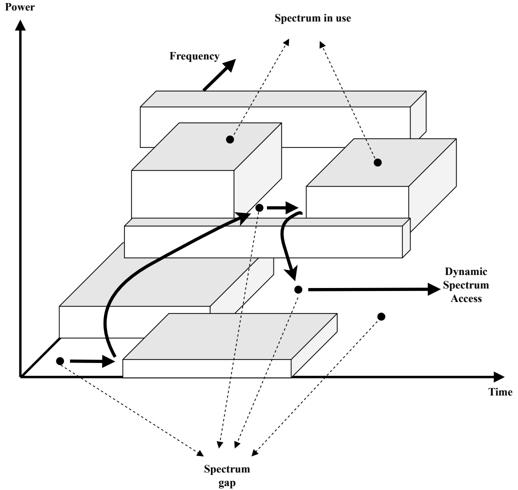


The evolution of cellular technologies, especially with the advent of 5G and 6G, has enabled broader connectivity between devices, expanding the network's capacity to support an increasing number of simultaneous connections, particularly in large-scale Internet of Things (IoT) environments [1].

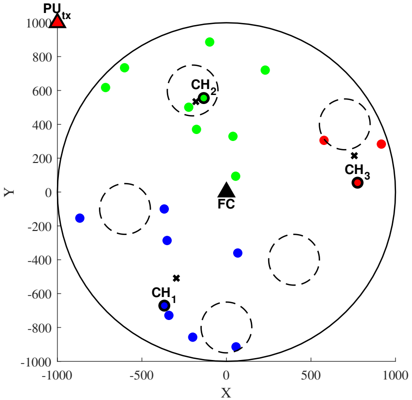
Motivation

- **Cognitive Radio Network (CRN)**

This technology consists of intelligent transceivers integrated into a secondary network, which, among other functions, perform Spectrum Sensing to opportunistically transmit in the gaps left by the primary network [2].



Cooperative Spectrum Sensing and System Model



- **PU$_{tx}$**: Primary network transmitter
- **FC**: Fusion Center
- **CH**: Cluster Head
- **Dashed circle**: Shadow areas
- **Cross**: Centroids
- **Circle**: Primary network coverage area
- The colored points represent the secundary users (SUs), with each sensor belonging to a group, and the color differentiating the clusters.

Energy Consumption Modeling

$$E_r^{(j)} = E^{(j)} - \left(P_s \cdot \tau_s + P_{\text{txSU}}^{(i,j)} \cdot \tau_r^{\text{SU}} + P_{\text{txCH}}^{(j)} \cdot \tau_r^{\text{CH}} \right) \tag{1}$$

$$P_{\text{txSU}}^{(i,j)} = P_{\text{rxCH}} \cdot d_{\text{CH}}^{(i,j)\alpha} \tag{2}$$

$$P_{\text{txCH}}^{(j)} = P_{\text{rxFC}} \cdot d_{\text{FC}}^{(j)\alpha} \tag{3}$$

Proposed Algorithm

1. **Temporary and Permanent Exclusion of Underperforming SUs**

Table: Sensor Penalty Based on the Type of Failure

GD	TX	LD	Type of Failures	Penalty (f_i)
0	0	1	GSLF-P	2
0	1	0	GLF-P	2
1	1	0	GSLF-U	1

$$\mathrm{backoff}_j = \left(\mathrm{start}_{\mathrm{time}} \cdot 2^{f_j}\right) - 1 \tag{4}$$

Proposed Algorithm

2. **Dynamic CH Selection**

$$X_{\text{cm}} = \frac{\sum_{j=1}^{m} E_r^{(j)} \cdot x_j}{\sum_{j=1}^{m} E_r^{(j)}} \tag{5}$$

$$Y_{\text{cm}} = \frac{\sum_{j=1}^{m} E_r^{(j)} \cdot y_j}{\sum_{j=1}^{m} E_r^{(j)}} \tag{6}$$

Proposed Algorithm

2. Dynamic CH Selection

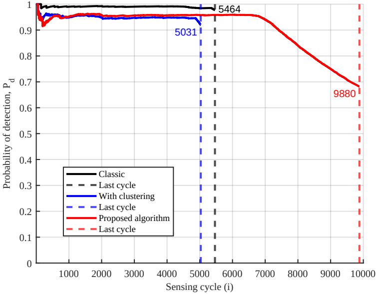
Pseudocode: Dynamic CH Selection Algorithm

If cycle = = $cycle_{CH}$
- **For** the $i - th$ cluster in the set, up to $i = c_{max}$, **do**:
  - Obtain the m SUs of cluster i
  - Identify the live SUs among the m SUs in cluster i
  - Obtain the coordinates of the live SUs
  - Obtain the residual energy of the live SUs
  - Compute the CM weighted, based on (5) and (6) (new centroid)
  - Select the new CH as the SU closest to the new centroid with the highest residual energy available in the cluster.
  - **If** the CH has changed
    - Update the CH coordinates and distances (d_{CH}, d_{FC})
  - **End If**
- **End For**
- $cycle_{CH} = cycle_{CH} + 1000$

End If

Results

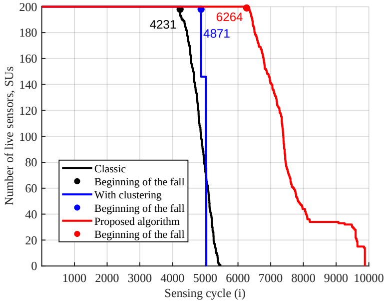
- P_d for the different systems, for $m_T = 200$, $n = 60$ samples per SU, and $c_{\max} = 3$.



In the classical system, P_d stays close to 1 for most cycles due to decision fusion at the FC, with higher detection accuracy as more SUs report. The proposed system, however, shows more consistent performance, with P_d remaining above 0.9 for more cycles.

Results

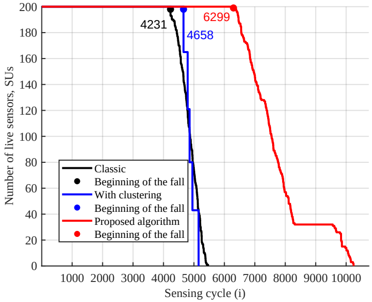
- Network life cycle of the systems analyzed with $c_{\max} = 3$.



The proposed system demonstrates the best performance in terms of lifespan, showing a significantly slower reduction in the number of live sensors compared to the other systems. The introduction of the backoff mechanism and the dynamic CH rotation promotes a more balanced distribution of the energy load among the sensors.

Results

- Network life cycle of the systems analyzed with $c_{\max} = 5$.



With $c_{\max} = 5$, the increased number of clusters reduces sensor-CH distance, improving decision transmission and lowering energy consumption. Consequently, the proposed system's lifespan exceeds twice the defined cycles, while other systems show minimal improvement or no significant change.

Conclusion and future work

Conclusion:

- The proposed algorithm enhances the lifespan of secondary networks by combining sensor exclusion and dynamic CH selection in CRNs.
- These strategies extend the network's operation without compromising performance (P_d), maintaining approximately 90% P_d over multiple sensing cycles.
- The algorithm also balances the sensor load, contributing to an increase in the overall network lifespan.
- Increasing c_{max} improves the network's lifespan by reducing the distance between sensors and their CHs, optimizing energy consumption and extending the sensor's life cycle.

Future work:

- Explore other fusion rules, such as the hybrid one.
- Implement the mobility of the SUs to analyze different scenarios.

References

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Tanks