Cooperative Spectrum Occupancy Measurements and Analysis in 2.4 GHz ISM band

A. Cheema[(1)], S. Salous* [(1)]
[(1)] Centre for Communications Systems, Durham University, Durham, UK, DH1 3LE. (*sana.salous@durham.ac.uk)

Abstract

Cooperative spectrum sensing measurements were performed in the 2.4 GHz industrial, scientific and medical band to quantify the occupancy events which are beneficial for users' cooperation in a cognitive radio network. Parameters are formulated to quantify the amount of occupancy events which are beneficial for cooperation between users using hard combining techniques. It is found that the user's location strongly influences the amount of distinct occupancy events, which are essential to improve cooperation between or among users.

1. Introduction

The vision of 5G network (5GN) encapsulates many application areas, e.g. mobile broadband, connected health, intelligent transportation and industry automation [1]. To entertain such a wide variety of applications, the 5GN is required to support high date rates, few Gbps, and latency to a fraction of a millisecond as expected by the research communities, telecom manufacturer and standardization bodies. However, the bottleneck to achieve such requirements will depend on better understanding of the radio propagation channel in the mmWave band to meet such critical constraints. Another aspect of the 5GN is to provide coexistence and also to improve the spectrum utilization in below the 6 GHz band by using concepts of the cognitive radio network (CRN).

One of the key challenges in the deployment of the CRN is to avoid the hidden node problem (HNP). Multiple cognitive radio users can cooperate by sharing their local spectrum occupancy events to each other (i.e. decentralized cooperation) or to a central fusion station (i.e. centralized cooperation) in order to reliably detect the spectrum opportunities to minimize the HNP. Theoretically, many schemes have been proposed to minimize the HNP [2] however very few experimental studies have been performed [3][4].

Particularly in the 2.4 GHz industrial, scientific and medical (ISM) band, an experiment was conducted to investigate the benefit of cooperation between two users in a CRN [3]. In this work, we have conducted an extended measurement campaign where three users were considered in an indoor environment. In addition, three parameters are formulated to quantify the amount of occupancy events beneficial for cooperation between user(s). These experimental results help to provide a better understanding to improve cooperation in order to minimize the HNP in 5GN. In this paper, sections 2 and 3 give an overview of the experimental setup and data analysis methodology, respectively. The results are discussed in section 4 and conclusions are in section 5.

2. Experimental Setup

The experiment which was conducted in the School of Engineering and Computing Sciences at Durham University, UK was composed of three homogeneous sensors (Nodes 1 to 3), to represent three users in a CRN. Details of the sensor can be found in [5]. Nodes 1 and 2 were placed inside an office and in a corridor, respectively, while Node 3 was moved in steps of 4.5–5 m on a pre-defined route as shown in Figure 1. A total of 26 measurement locations were traversed and monitored.

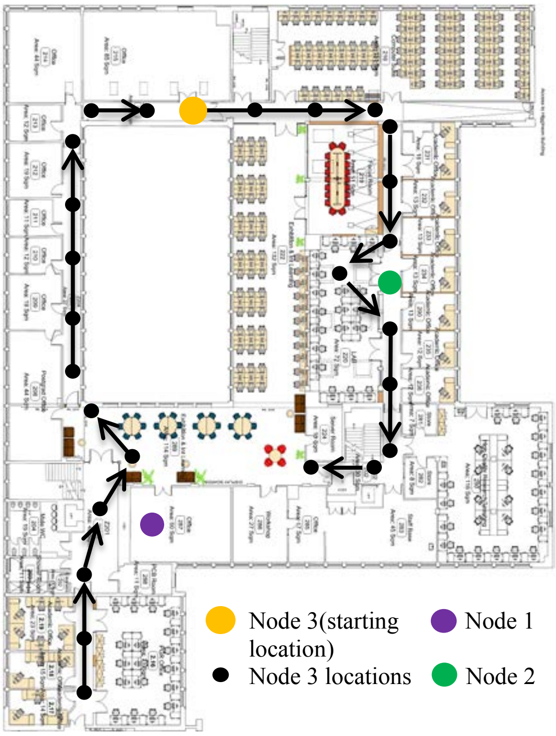

Figure 1. Layout of measurement environment

Each node was configured to sense 100 MHz swept bandwidth from 2.4 to 2.5 GHz with a sweep duration of 204.8 μsec and baseband data were sampled at 80 MHz. Each node was equipped with a discone antenna and placed at 1.5 m above the floor level. Moreover, 500 sweeps were recorded at every location for each node.

Table 1 lists the key parameters of the conducted measurements campaign and it also makes a comparison with the experiment conducted in [3].

Table 1. Comparison of parameters

Experiment	[3]	This Work
Antenna	Discone	Discone
Number of Nodes	2	3
Sensing Node	Spectrum analyzer	Chirp Channel Sounder Receiver
Time Resolution	250 ms	204.8 µs
Number of Sweeps	200	500
Step size of Grid	12.5-15 m	5 m

In order to time-synchronize the sensing nodes for cooperation using a centralized cooperation scheme, the reference clock in each node was phase aligned with respect to each other. The relative time drift between the nodes over one hour was on the order of 12 – 24 ns, which was sufficiently low compared to the configured sweep time to cause any misalignment in the baseband data.

3. Data Analysis Methodology

The raw data were calibrated for all the gains and losses (sensors, cables and antennas) to get the received power over the sensing bandwidth with a frequency resolution of 400 kHz by performing offline processing in MATLAB. More details on the data processing methodology is given in [5]. To find the decision threshold for an energy detection algorithm, the thermal noise floor of the sensor was measured using a continuous wave (CW) signal as an input into the sensor which was gradually attenuated until it could not be distinguished from the noise floor. For this, each node was configured according to the parameters listed in section 2 and the noise floor of -107 dBm was measured. So, the decision threshold was chosen 10 dB above the measured noise floor for all the three sensors.

The amount of distinct occupancy events (DOE), detected only by a user or users, which a node can provide to other user or users for cooperation is calculated using the following four parameters.

Parameter 1[1]:

$$\boldsymbol{P^l}_{\boldsymbol{i\to j}} = \frac{\mathbf{1}}{\boldsymbol{N_f}}\sum_{\boldsymbol{f=1}}^{\boldsymbol{N_f}} \frac{\sum_{\boldsymbol{n=1}}^{\boldsymbol{N_s}} \boldsymbol{\beta^l}_{\boldsymbol{i}}(\boldsymbol{t,f})\ \&\ !\,\boldsymbol{\beta^l}_{\boldsymbol{j}}(\boldsymbol{t,f})}{\sum_{\boldsymbol{n=1}}^{\boldsymbol{N_s}} \boldsymbol{\beta^l}_{\boldsymbol{i}}(\boldsymbol{t,f})\ |\ \boldsymbol{\beta^l}_{\boldsymbol{j}}(\boldsymbol{t,f})} \qquad 1$$

where i, j, k represent the indices of nodes, N_f defines the number of frequency points, N_s defines the number of sweeps recorded per measurement location, $\beta^l{}_i(t,f)$ and $\beta^l{}_j(t,f)$ define the binary time-frequency map of the i^{th} and j^{th} nodes, respectively which are computed using an energy detection technique at measurement location l, where $l = 1,2,..,26$. The symbol '&' denotes logical AND operator, '!' denotes logical NOT operator, '|' denotes logical OR operator. The $P^l{}_{i\to j}$ defines the amount of probability that the i^{th} node has detected the DOE in comparison to the j^{th} node in the binary time-frequency map at measurement location, l. The higher value of parameter 1 shows that cooperation between the i^{th} and j^{th} nodes is beneficial as the i^{th} node can provide new information to the j^{th} nodes for cooperation.

Parameter 2:

$$\boldsymbol{P^l}_{\boldsymbol{i\to jk}} = \frac{\mathbf{1}}{\boldsymbol{N_f}}\sum_{\boldsymbol{f=1}}^{\boldsymbol{N_f}} \frac{\sum_{\boldsymbol{n=1}}^{\boldsymbol{N_s}} \boldsymbol{\beta^l}_{\boldsymbol{i}}(\boldsymbol{t,f})\ \&\ !\,\boldsymbol{\beta^l}_{\boldsymbol{j}}(\boldsymbol{t,f})\ \&\ !\,\boldsymbol{\beta^l}_{\boldsymbol{k}}(\boldsymbol{t,f})}{\sum_{\boldsymbol{n=1}}^{\boldsymbol{N_s}} \boldsymbol{\beta^l}_{\boldsymbol{i}}(\boldsymbol{t,f})\ |\ \boldsymbol{\beta^l}_{\boldsymbol{j}}(\boldsymbol{t,f})\ |\ \boldsymbol{\beta^l}_{\boldsymbol{k}}(\boldsymbol{t,f})} \qquad 2$$

The parameter $P^l{}_{i\to jk}$ denotes the amount of DOE which the i^{th} node can provide collectively to both the j^{th} and k^{th} nodes at measurement location l. This parameter provides the overall contribution of the i^{th} node for other users. The higher value of the parameter means that it can help other members of the network to reduce the HNP at their respective locations. Two important issues associated with cooperative spectrum sensing are the optimum node position and the node selection criteria to improve cooperation. Parameter 2 can be beneficial to solve the aforementioned issues by selecting locations (equivalently nodes) which yield higher values.

Parameter 3:

$$\boldsymbol{P^l}_{\boldsymbol{ij\to k\,(AND)}} = \frac{\mathbf{1}}{\boldsymbol{N_f}}\sum_{\boldsymbol{f=1}}^{\boldsymbol{N_f}} \frac{\sum_{\boldsymbol{n=1}}^{\boldsymbol{N_s}} \boldsymbol{\beta^l}_{\boldsymbol{i}}(\boldsymbol{t,f})\ \&\ \boldsymbol{\beta^l}_{\boldsymbol{j}}(\boldsymbol{t,f})\ \&\ !\,\boldsymbol{\beta^l}_{\boldsymbol{k}}(\boldsymbol{t,f})}{\sum_{\boldsymbol{n=1}}^{\boldsymbol{N_s}} \boldsymbol{\beta^l}_{\boldsymbol{i}}(\boldsymbol{t,f})\ |\ \boldsymbol{\beta^l}_{\boldsymbol{j}}(\boldsymbol{t,f})\ |\ \boldsymbol{\beta^l}_{\boldsymbol{k}}(\boldsymbol{t,f})} \qquad 3$$

Parameters 1 and 2 are essential to study the contribution of an individual node in a CRN. However, binary occupancy decisions of two or more nodes can be combined to find the cumulative amount of DOE for cooperation. Parameter 3, $P^l{}_{ij\to k\,(AND)}$, represents the probability of the DOE for the k^{th} node which is obtained by combining binary occupancy decisions of the i^{th} node and j^{th} node using the AND hard combining technique[2].

Parameter 4:

$$\boldsymbol{P^l}_{\boldsymbol{ij\to k(OR)}} = \frac{\mathbf{1}}{\boldsymbol{N_f}}\sum_{\boldsymbol{f=1}}^{\boldsymbol{N_f}} \frac{\sum_{\boldsymbol{n=1}}^{\boldsymbol{N_s}} \boldsymbol{\beta_i}(\boldsymbol{t,f})\ |\ \boldsymbol{\beta_j}(\boldsymbol{t,f})\ \&\ !\,\boldsymbol{\beta_k}(\boldsymbol{t,f})}{\sum_{\boldsymbol{n=1}}^{\boldsymbol{N_s}} \boldsymbol{\beta_i}(\boldsymbol{t,f})\ |\ \boldsymbol{\beta_j}(\boldsymbol{t,f})\ |\ \boldsymbol{\beta_k}(\boldsymbol{t,f})} \qquad 4$$

Parameter 4, $P^l{}_{ij\to k(OR)}$, represents the amount of DOE for cooperation which the i^{th} node and the j^{th} node can provide to the k^{th} node using the OR hard combining technique[3].

[1]This parameter was used in [3] while this work modifies parameter 1 to three new parameters.

[2]Under AND hard combining technique, a signal is considered present if it is detected at both nodes.

[3]Under OR hard combining technique, a signal is considered present if it is detected at any one of the nodes.

4. Analysis

Figure 2 shows the percentage of the spectrum utilization for each node. Since Nodes 1 and 2 were fixed, the figure shows the time variations in the spectrum utilization at these two nodes. Node 1 has higher spectrum utilization values compared to Nodes 2 and 3. In order to find that cooperation is beneficial at a particular location, the spectrum utilization of the mutual occupancy events (detected by all the nodes) and the DOE (detected by only one of the nodes) at a given time-frequency map index were computed. The mutual occupancy events, which are not beneficial for cooperation, were found to be less than 2 %. In comparison, the DOE have higher utilization between 19 – 34 %, which means that cooperation is possible and beneficial. Here, it is also important to note that cooperation can be useful if spectrum utilization of the DOE is higher than the mutual occupancy events.

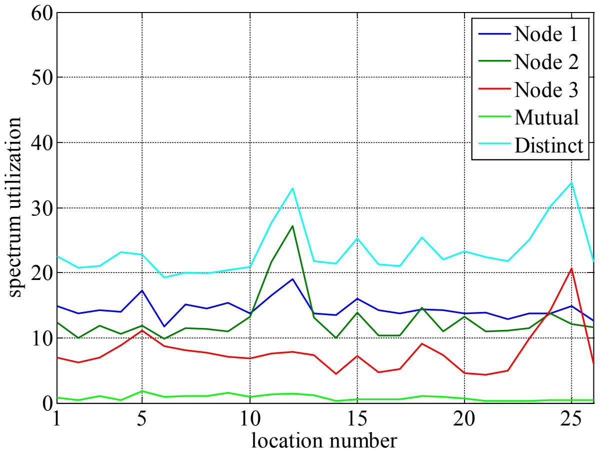

Figure 2. Spectrum utilization for each node along with spectrum utilization for mutual and DOE

In order to find which node is more suitable for cooperation, parameters 1 and 2 are calculated. Figure 3 shows the amount of DOE which Node 1 can provide to Nodes 2 and 3 and collectively to Nodes 2 and 3. First observation is that higher probability values are observed for Node 3 due to a change in location in comparison to the fixed position of Node 2. Moreover, it can also be observed that when Node 1 has mutual events with the other nodes the probability values tend to drop while the increase in values represents those locations where distinct events have been observed and are more useful for cooperation. Parameter 2 has smaller values for the DOE which is only present at Node 1 and also not being detected by Nodes 2 and 3.

Figure 4 shows the contribution of Node 2 which other nodes can benefit from. It can be observed that Node 3 can benefit more due to variations in the location which produces more distinct events with a high probability compared to the fixed position of Node 1. Figure 5 shows the contribution of Node 3 to the two fixed nodes: nodes 1 and 2. Compared to Node 1 and Node 2 contributions, Node 3 has lower values of probabilities due to having lower spectrum utilization and fixed locations.

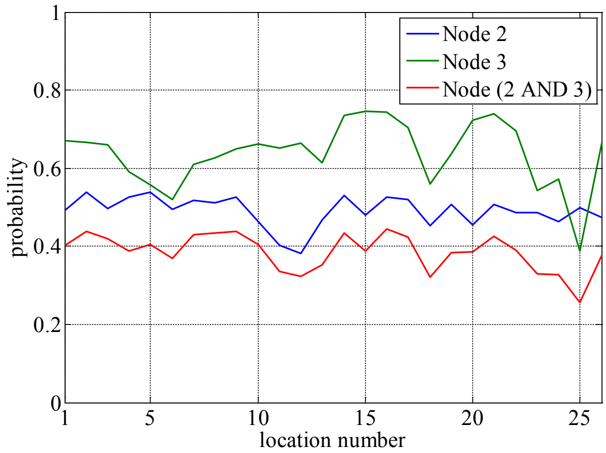

Figure 3. Probability of DOE events from Node 1 to the other two nodes

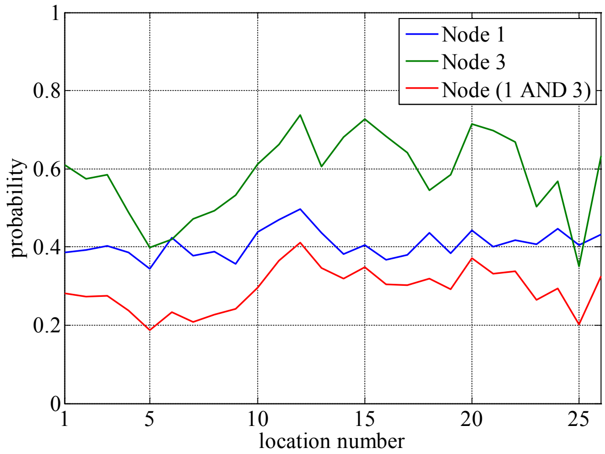

Figure 4. Probability of DOE from Node 2 to others

The occupancy decisions of the nodes are also combined with respect to time and frequency indices, to analyze the changes in the amount of DOE. The occupancy decisions of the two nodes are combined using OR or AND techniques and compared with occupancy decisions of another node to compute the amount of DOE. Figures 6-8 show the amount of distinct events using hard combining techniques where the OR combining technique yield the highest values. As the OR technique allows all occupancy events during the combining process it has a higher chance to find the DOE in comparison to the AND technique which is based on mutual information of the DOE among the nodes.

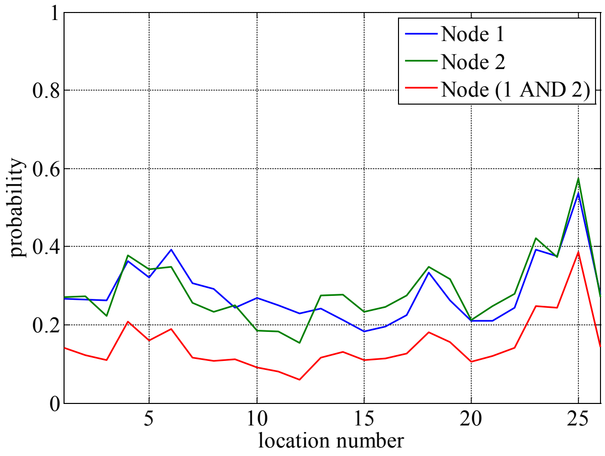

Figure 5. Probability of DOE from Node 3 to others

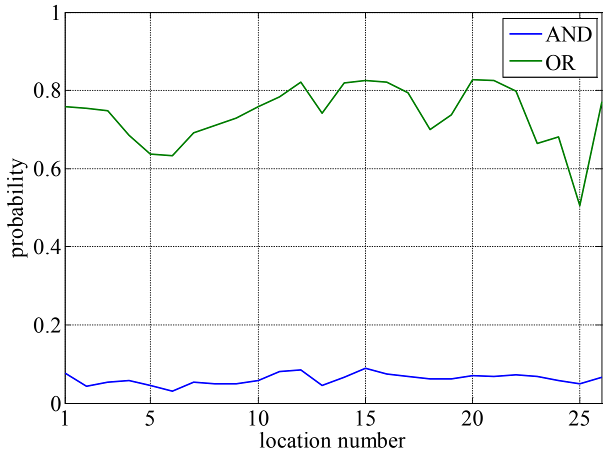

Figure 6. Probability of DOE by combining occupancy events of Nodes 1 and 2 for Node 3

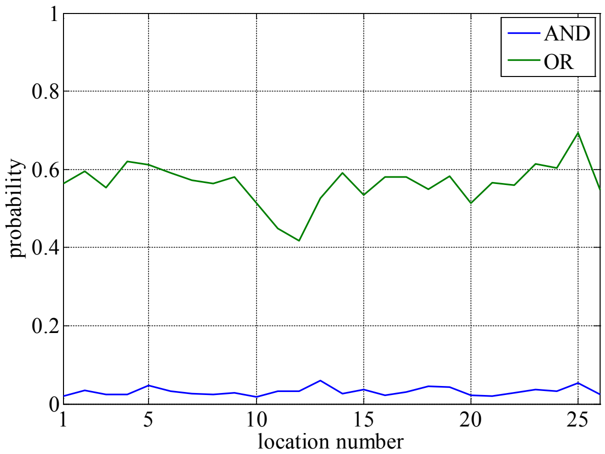

Figure 7. Probability of DOE by combining occupancy events of Nodes 1 and 3 for Node 2

5. Conclusion

Cooperative spectrum occupancy measurements have been performed using three nodes in an indoor environment. The spectrum utilization of the DOE has

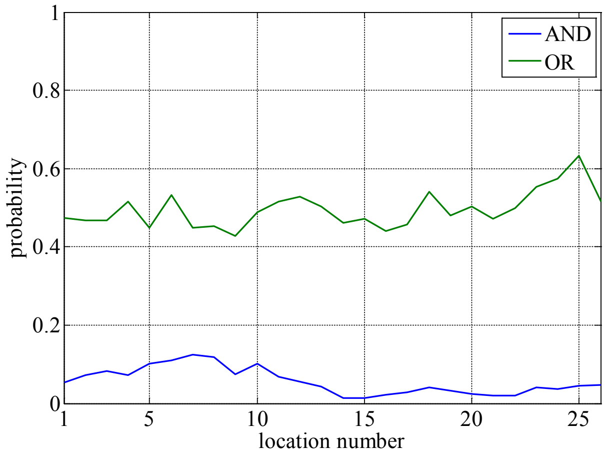

Figure 8. Probability of DOE by combining occupancy events of Nodes 2 and 3 for Node 1

been found in the range of 19 – 34 %, which indicates that the nodes can cooperate to reduce the HNP.

The amount of cooperation given by a node or nodes is computed, where it has been found that the location of the sensor influences the amount of DOE significantly. Moreover, the local binary decision for each node has been combined to improve cooperation using hard combining techniques, where the OR technique outperforms the AND technique.

6. Acknowledgements

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7. References

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