Indonesian Journal of Electrical Engineering and Informatics (IJEEI)
Vol. 13, No. 2, June 2025, pp. 410~423
ISSN: 2089-3272, DOI: 10.52549/ijeei.v13i2.4094

Benchmarking of OFDM Spectrum Exchange for Mobile Cognitive Radio Networks

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Article Info

Article history:

Received Dec 15, 2024
Revised Mar 24, 2025
Accepted Jun 1, 2025

Keyword:

Spectrum Sensing
Cooperative Sensing
Mobility Node
Spatial Diversity
Spectrum Exchange

ABSTRACT

The local spectrum sensing objective in spectrum sensing is to detect the PU's signal. The sensing node's (SN) capacity to detect the PU's signal is of paramount importance. However, it is presumed to be stationary in the majority of SN in cognitive radio networks. The detection performance on local observation is significantly influenced by the mobility of the PUs and SNs. The SNs' movement generates spatial diversity in the PU's signal observation. The signal's condition would fluctuate during the sensing process as a result of Doppler effect, spatial distance, velocity, movement, and geolocation information. Therefore, a benchmark is required to compare the primary user signal detection level of stationary and moving SNs from each sensing node. The performance results have demonstrated that static nodes with SCM are superior to conventional subcarrier mapping (SCM) methods in the case of a subcarrier mapping width of $\alpha = 2$. Additionally, the quantization width is uniform. It has been determined that the performance disparity is substantial, ranging from 2 dB to 4 dB. The results indicate that the static nodes SCM have achieved acceptable performance detection at a low subcarrier detection threshold (SDT) value of 0 dB up to 5 dB. Conversely, the probability of conventional SCM detection is less than 1 of probability detection (PD) value at the same low SDT value. The detection probability (PD) of static nodes with SCM is satisfactory at an SDT value of 15 dB. Moreover, the probability begins to decline until 20 dB at an SDT value of 11.5 dB, a substantial decrease that is rendered negligible. In contrast to the new subcarrier mapping (N-SCM) method, which has a false alarm probability (PFA) of approximately 0 dB to 9.5 dB, conventional subcarrier mapping (SCM) has a high false alarm probability in mobility networks. Furthermore, it is evident that the PFA curves for the conventional SCM method are lower than those of other methods at low speeds, as they approach the null value at SDT 7.5 dB. The PFA curve for both methods is higher than other velocities by attaining a null value at 10 dB, in contrast to high velocity. In general, the mobility parameter has the potential to meet the detection performance and perform well in the false alarm probability of mobile spectrum exchange. Consequently, it could be employed to provide information on spectrum exchange in the future.

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1. INTRODUCTION

Recently mobile wireless sensing node information has become an interesting study in cognitive radio. Geo-location-based information includes location-based messaging, personal and package tracking, tracking position, route guidance and traffic information. The frequency and accuracy of location requests vary with the required application. It has potential to be the future generation of mobile system which provides location-based services information. Usually, wireless system requires base station for distributed and reception communication from wireless stations in the networks. A mobile wireless node could provide the location information based on ***time-of arrival*** (ToA), ***time-difference-of arrival*** (TDoA), ***angle-of-arrival*** (AoA), ***received signal strength*** (RSS) and identification of wireless station (Cell ID). The signals detected is measured and determined by ***sensing nodes*** (SN's)[1], [2], [3], [4], [5].

2. CHARACTERISTICS OF SPECTRUM EXCHANGE INFORMATION FOR COOPERATIVE SENSING

In micro cells are those that are normally found in densely populated areas which may have a diameter of around 1 km. Assuming that each sensing nodes (SN) in micro-cellular systems is located at the urban area which the majority are static nodes. However, for the most part of research in cooperative spectrum sensing often stated that the sensing nodes are absolutely stationary. This has an impact on the process of sending and receiving in secondary ***master node*** (MN). Especially in [6] [7]there are some drawbacks that occur in the process of receiving and sending information or data if done by a stationary SN. First, the probability of occurrence of interference and quantisation power are mapping in the same subcarrier number enormous happen if the scenario of the distance between the PU and SN is the same, as illustrated in Figure 1. It is hard to synchronize the incoming tone signal from surround local sensing nodes. MN should identify whether the signal leading or lagging during one cycle sensing time. The MN should mitigate the scheduling reception for this condition, however increasing sensing time and wasted the resources.

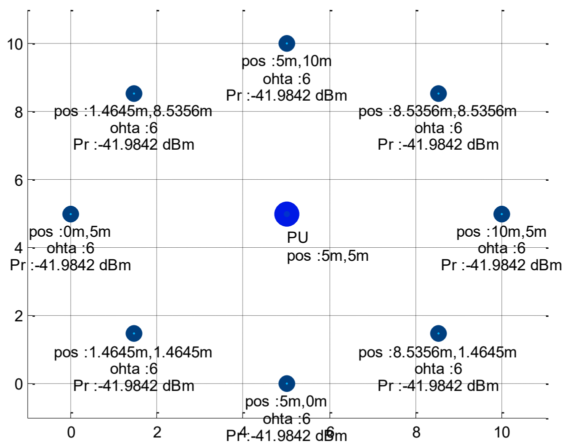

Figure 1. Scenario when SN is mapped to the same subcarrier number

In Figure 1, SN's has resulted to the same distance from the PU. Therefore, every SN receives the same power detected. The processing conversion of receives power as well as known as quantisation of the detected power into subcarrier mapping. Thus, the detected power is quantized at the same subcarrier number. This situation could emerge overlap (intercarrier interference (ICI) or inter symbol interference (ISI)) among SN in common control channel. This is become limitation in spectrum exchange information. However, the using of common control channel is limited as well as 8 bits' guard interval in OFDM systems. However, OFDM systems restrict the use of a common control channel and an 8-bit guard interval. Consequently, in a practical setting, it is challenging to parse the 512 subcarriers of FFT bins one by one onto the 8-bit control channel, particularly in 802.11g. Therefore, each bit symbol of FTT into a symbol that the subcarrier width parameter alpha (α) encapsulates should transformed. [8].

In the case of mobility environment, increasing and decreasing the distance between TX and RX during the duration T is strongly influenced by the distance and frequency receives as known as Doppler Effect. This is because the movement of SN (beginning and end of the symbol that associated with the difference distances in mileage), causing changes in the duration of the reception symbol (frequencies)[9], [10].

The previous [8] work is not considering the Doppler Effect in subcarrier mapping. Whenever MN request for available spectrum hole from primary user (PU), supposing at the f_1. The SN starts to sense and exchange their results into OFDM symbols. While mobile, the SN has resulted in difference angle of detected PU power and causes frequency shifted. In reception of PU spectrum channel, SN has received in difference phase (θ) and frequency, Δ_f the offset known as Doppler shifting. For the performance of spectrum sensing, this is a drawback due to SN has sense in false detection. The effect of Doppler shifting will impact on the loss of orthogonality and resulting signal to noise ratio (SNR) loss due to the presence of frequency offset [11].

Second, since SN assumed to be identical and independent in Figure 1, there's no communication among SN inside common control channel (CCC). For addressing this limitation, cross layer platform should apply for full duplex communication. However, cross layer platform needs new protocol for routing and transfer data information among the layers. Thus, these conditions are increasing complexity and hard to deploy in real world (application). Third, whenever SN transmits quantisation results, overhead process in MN when parsing subcarrier number one by one. Fourth, if there is a data inside the quantisation of subcarrier mapping, the measurement should translate into higher layer whenever transmitted the quantisation results into MN. This is become limitations. Fifth, in real wireless world, mobile users could have given a frequency shifted due to mobility, therefore could present the ICI and the orthogonality is losses [12].

Generally, in cognitive radio spectrum exchange information process is providing at the data link layer. Severally is also providing in MAC and data link layer that exchange over common control channel (CCC)[6], [8], [13], [14]. In this process, the CCC could provide channel access and contention, neighbour discovery and spectrum management. However, lacks the methods provide inefficiency of measurement complexity and overhead. In [15] they provide spectrum exchange measurement through data link layer and MAC, however sensing time and its complexity computation due to spectrum exchange information into one single tone of OFDM subcarrier does not consider.

Furthermore, the benchmarking [1] in mobility environment is important to compete the performance of spectrum exchange information in cognitive radio networks. Probability detection (PD) and false alarm probability (PFA) are the factors that could evaluate the performance of SN within [8], [16], [17], [18] method.

It might be stressed that the conversion process of detected power level into a subcarrier signal of the OFDM signal structure is called a spectrum exchange of information. The subcarriers have an energy signal which could represent SN nodes. Therefore, it is just a sensing process which is enough to proceed with the quantisation power into subcarrier number in PHY layer. Regardless of the data; as long as the SNR inside, then the subcarrier is higher rather than noise, the MN will detect from the SN because they will not involve upper layer, there's no modulation of the k into the data, only power[19], [20].

Regarding to [12], only the power concept, if the SN get k; and there is 512; calculated inside the SN; it's from 0 to 512, the possibility of the subcarrier that needed to sense from the SN will be different from another SN to other. There's inefficiency from that one, need to translate this k to 512 and then the MN needs to hear those 512 channels. That means there are cycles for 512 inside one second array antenna in the implementation. It will be inefficiency for the N subcarrier number; need to translate literally into subcarrier; there is way the spectrum exchange information.

According to the method presented in [6] and [14], if the value of subcarrier width, α (alpha), is small, then the selected subcarrier that is chosen is small, but the probability of each SN having the same subcarrier number is large because the value of k depends on the received signal power Xi. If the SN is within the boundary area, it has been closed to the PU transmission, and the noise (AWGN) does not affect the power received by the SN. If the distance between the SN and PU is about the same, and they experience the same noise (AWGN) and detection power level, then the chance of subcarrier (SC) mapping of k at each SN will also be the same.

Consequently, the performance of cooperative decision will be decreased when MN receives subcarrier information

1. The Detection of the received power is relatively the same for each k^{th} that representing SN's. Therefore, sensing nodes could probably have the same subcarrier number (k^{th}).
2. With $\alpha = 2$, then only 50% instead of 512 which can be mapped; the calculation will be more than 512; means huge percentage in the beginning and last of the SC number ≤ 256.

3. SPECTRUM INFORMATION EXCHANGE SYSTEM MODEL IN MOBILE CRN

To evaluate the system performance, the statistical analysis of the relation among random SN position and velocity of the sensing nodes is evaluated. The evaluation of Doppler Effect on accuracy of the mobile spectrum exchange transmission is less attention in cognitive radio networks research [9], [21], [22], [23], [24]. Some previous research assuming the spectrum exchange information transmission is perfectly done in the networks. However, lack of the results shows that the Doppler frequency shifted in time difference of arrival (TDoA) is not consider. In mobility nodes, uncertainty path loss model is considerable to give an important problem in mobile spectrum exchange information[9], [10], [25]

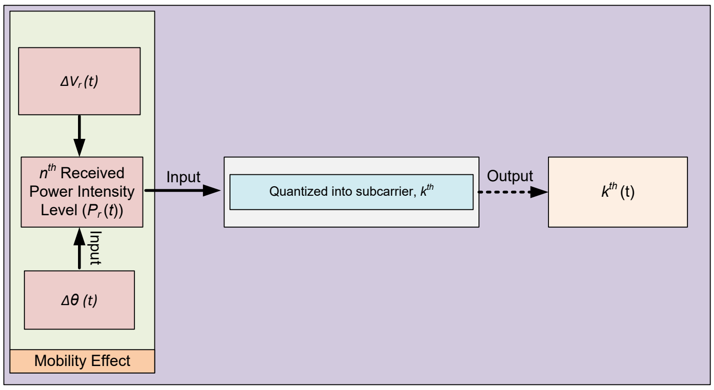

Figure 2. Simulation Processes for Subcarrier Mapping when SN is Mobile.

As illustrated in Figure 2, the process is declared to give the clear path of the research objectives. Generally, there are three inputs that should precede for each sensing node, such as the detected power intensity level (Pr), velocity (v_r) and phase angle (Δθ). Those input parameters are sampled over time during movement and sensing. Therefore, the output is changing based on the distance (time difference of arrival (TDoA)), velocity, phase angle (angle of arrival (AoA)) and detected power level each sample per period.

4. MOBILE SYSTEM MODEL

As illustrated in Figure 4, a mobile SN is shown as mobile sensors entities in cognitive radio networks (CRN). This nodes are moving with different speed of *v* and distance of *d* (meters) among them in cooperative spectrum sensing CRN. Assuming, the entities of n^{th} SN are moving in the same geo-location areas arround 0.1 km. If SN considered as d_0 position and moving forward into distance, d_1, while it is still moving and running, SN continuosly perform sensing during the processing of local quantisation and sending the results over channel, and re-do for detected power again, and repeateadly. In order to perform sensing nodes in mobility environments, it is assumed that SN have a characterization of continuous wave radar. The SN's characters will be based on the Doppler shift of detected signals [26].

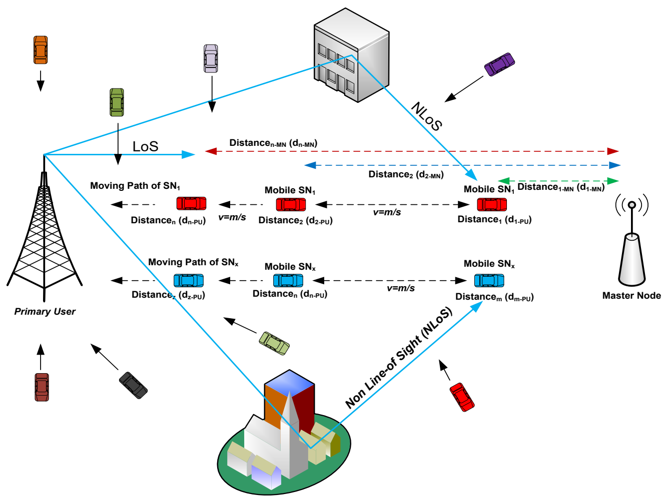

Figure 4. Scenario of Spectrum Sensing Information Exchange Method with SN mobility.

In order to investigate the offset frequency during sensing process, the target angle should be known first. The position of the SN node with velocity *v*, moving in certain time, *t*. Whenever SN start moving, the velocity is given by

$$v_r(i) = \left(\frac{\Delta d_{SN}}{\Delta t_{SN}}\right)\cos\theta \quad (1)$$

$V_r(i)$ is velocity speed of SN in meter per seconds (m/s) and Δt is time travel which is needed to move from source place to current position, d'_{SN} in second, and $\cos\theta$ is the angle of arrival position. When the SN is moving in high speed, causes a shift frequency of the signal transmitted through the length of signals path. The different path of the movement impact to the differ angle of arrival of the SN position therefore the received frequency can be different. This condition known as Doppler frequency shifted. In this term, the detected signals have different path which correspond to difference ***angle of arrival*** (AoA). The SN is moving forward towards closer to the PU by moving forward in left side position. Therefore, according to the trigonometric law, the distance that measured is the hypotenuse of a right-angle triangle with angle θ so it has side's $sin^{-1}\theta$. To estimate Doppler frequency shifted *theta* or angle of the SN is considered measured. Supposing that SN have an antenna beams to estimate the target's angle, the distinction of the frequency received (AoA) each movement of SN node is given by

$$\theta\ (i) = arccos\left(\frac{\left(d_{x-SN}(i) - d_{x-PU}(i)\right)}{\Delta d_{SN}(i)}\right) \tag{2}$$

Suppose that the frequency and power of the transmitted signal is f_T and P_T, respectively; the detected signal with a frequency f_R and the Doppler shift is given

$$f_R(i) = f_T\left(1 + \frac{2V_r \cos\theta}{c}\right) \tag{3}$$

where V_r is the velocity of the SN, $\cos\theta$ is the SN's target angle, c is the speed of light, f_T is the frequency transmission (carrier frequency).

5. THE WAVELENGTH AND SPATIAL SAMPLING

After process finding AoA completes, it is necessary that the detected signal power is sampled spatially during the sensing process. The objective is to sense the environment changes such as displacement, random paths on movements, and other varied variables. Moreover, to found the Doppler Effect it's required to knowing that the velocity from the distance travelled and time travel for each SN's.

In perform subcarrier exchange, each SN need to sample the detected of the radio wavelength energy into a discrete-time signal. A sequence of sampling could utilize to sample the electromagnetic waves. The main function of sequence sample is reduced of continuous signal which value is set at a point in time and/or space involves time periodically sensing within it sampler. An extraction of continuous signal is providing a quantisation level and quantisation interval in sensing process. Therefore, in one particular sensing process, the sampling is depending on the sample rate of the signal. Moreover, the sampling rate is averaged number of samples obtained in one second (samples per second). Then, the wavelength of the random signal expressed by

$$\lambda = \frac{c}{f_R} \tag{4}$$

λ is the wavelength; f_R is the Doppler Frequency c is light speed, $3*10^8$ m/s

Whenever the wavelength travelled through the air, it's necessary to utilizing path loss model which given based on the mobile distance travelled over the air expressed as

$$M = \left(\frac{\lambda}{4 * \pi * d_{SN}(i)}\right)^2 \tag{5}$$

where M is the signal sampled. It is necessary also that the detected signal power during mobile need translated into some information signal. Therefore, the signal should be extracted into small pieces based on geo-location travelled. It is sampled the signal over the time travel. The sampling signal length is depend on the duration of the times whenever SN has travelled through the distance. By using Friis free space propagation equation, the spatial sampling during movement is given by

$$f_s = \left(\frac{1}{M}\right) = 20log_{10}\left(\frac{4 * \pi * d_{SN}(i)\Delta f_R}{c}\right) \tag{6}$$

f_s is the spatial sampling frequency of the wavelength, d_{SN} (m) is SN distance in meter and Δf_R is the Doppler frequency.

6. MULTIPATH FADING MODEL

The SN node channel defines fundamental limitations on the performance of spectrum exchange information. This feature has played an important role to obtain the detected signal strength in SN. The detected signal strength could provide varying SN location information (Δd), based on the movement of node stations (ΔV_r). It also provides the path loss model with distance that composed in detected signal strength. In general, the detected signal strength as well as known detected power. However, it is difficult to predict signal behaviour in mobile environment. The spatial propagation effect is modelled including the total distance travelled, velocity of the nodes, elevation angle and detected power level, using perpendicular micro-cellular system environment. Those parameters are used widely in path loss model for free space propagation. In this case, Friis free space propagation model is chosen. The receiver power is obtained by the following equation

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 = P_r(dB) = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} = P_t + G_t + G_r + 20\ log\left(\frac{\lambda}{4\pi d}\right) \tag{7}$$

$P_r(d)$ is the detected signal power in Watts expressed as a function of separation $-d$ meters between the transmitter & receiver. P_t is the power at which the signal was transmitted in Watts; $G_t G_r$ is the gains of transmitter and receiver antennas when compared to an isotropic radiator with unit gain; λ is wavelength of carrier in meters.

In radio frequency (RF) signal transmitted over wireless a mobile channel which suffers from several effects like small-scale fading, signal dispersion and distortion. The multiple paths fading in receives signal due to the obstacles and reflectors existing in the wireless channel. Reflection mechanism, diffraction, scattering from buildings, structure and obstacle are main causes multiple fading occurs in propagation channel. ***Line-of-sight*** (LoS) and ***non-line-of-sight*** (NLoS) usually experiences in multipath propagation. Whenever SN's are farther from PU transmitter, the LoS signal path does not exist and the reception mainly from NLoS signal path. Typically, the aggregate of the power received from interfering transmitter signal paths at least 10 dB lower than that received from the desired transmitter. Differences propagation lengths have been receipted where phase, time and amplitude are fluctuated in the detected signals as well as known as multipath fading or small-scale fading, known as Rayleigh fading. In this work, after propagation over N reflected and scattered paths, the received signal maybe considered as the sum of N components with random amplitude and phase.

The received signal $r(t)$ is Rayleigh fading based on summing sinusoids with Jakes model [27] can be written as

$$r_I(t) = \frac{1}{\sqrt{N}} \sum_{m=1}^{N} \cos(2\pi f_d cos\alpha_m t + a_m) \tag{8}$$

And

$$r_Q(t) = \frac{1}{\sqrt{N}} \sum_{m=1}^{N} \sin(2\pi f_d cos\alpha_m t + b_m) \tag{9}$$

$$r(t)(i) = r_I(t) + jr_Q(t) \tag{10}$$

f_d is the Doppler shift, a_m and b_m is the amplitude of the signal and N is multipath components with angle of arrival α_m of the nodes.

7. POWER DETECTION SENSING AND SPECTRUM INFORMATION EXCHANGE MODEL

All the components parameter has been modeled as stated in previous sub-section. In this part, every mobile SN node will receive some distributed power from primary users (PU), which is given by

$$P_{R-Mobile}(i) = P_{Tx} dBm + P_{Txgain} + SN_{gain}(i) - 20log_{10}\left(\frac{4 * \pi * d_{SN}(i)\Delta f_R}{c}\right) + r(t)(i) \tag{11}$$

Where $P_{Tx} dBm$ is the PU power transmit power, P_{Txgain} is the PU power transmit gain at the i^{th} nodes, $SN_{gain}(i)$ is the SN node gain, $r(t)$ is Rayleigh fading based on summing sinusoids.

The detected primary signal power then exchanged into subcarrier number of OFDM known as quantisation power process. ***The conventional quantisation subcarrier mapping*** (SCM) of the spectrum exchange information at i^{th} SN given by [6], [13] without Doppler Effect is given by

$$k_{conv}(i) = \left\lfloor P_{R-conv}(i) * \frac{N_c}{\alpha} \right\rfloor \tag{12}$$

Where $P_{R-conv}(i)$ is the received detection power at i^{th} conventional SN's.

$$P_{R-conv}(i) = P_{Tx}dBm + P_{Txgain} + SN_{gain}(i) - 20log_{10}(4 * \pi * d_{SN}(i)) + r(t)(i) \tag{13}$$

And k is assumed is the function of power quantisation at the frequency carrier, f_c. If assuming that the $f_c = f_R$; f_R is the function of frequency in Doppler Effect which is given by

$$\Delta f_R = f_c - f_k \tag{14}$$

If detected power is a function of frequency, then the k is a function of frequency. However, a movement and impairment of the propagation channel could rise during the sensing process, therefore, the received frequency of new subcarrier fk_1' is shifted during mobility in ΔV_r speed, which resulted into Δf_R area. Therefore, k' is given by

$$k'_{Mobile} = \frac{(f_k + \Delta f_R) - f_c}{f_i} = 1 \pm \left[\frac{\Delta f_R}{f_i}\right] \tag{15}$$

Where f_i is subcarrier width (***mobile* subcarrier mapping/SCM**) frequency in Hertz; However, due to signal is non-linear therefore f_i is distinction in varies, hence

$$k'_{Mobile} = \left[1 \pm \frac{\Delta f_R}{f_i}\right] * \left\lfloor P_{R-Mobile}(i) * \frac{N_c}{\alpha} \right\rfloor \tag{16}$$

Where f_R the maximum received frequency Doppler shifted at the n^{th} sensing nodes, [28].

$$\text{if } f_i \gg \Delta f_R \text{ then } k' = k \tag{17}$$

8. COOPERATIVE DECISION AT MASTER NODE

In the cooperative sensing, master node gathers surrounding sensing information. This method known as soft information based cooperative sensing. The decision from this method is done by master node with the primary user signal information received from sensing nodes. In this works, a new evaluation formula for master node decision is proposed. The proposed evaluation formula is shown in equation 4.2 and 4.3. These formulas is an improved formula of statistical decision by [29] with combination of k-th subcarrier power as soft information.

$$\mathrm{H_0}: \mathrm{x}\ (\mathrm{k}) = \frac{1}{M_s \mathrm{I}} \sum_{\mathrm{i}=0}^{\mathrm{I}-1} \chi_{\mathrm{i}} = \frac{1}{M_s \mathrm{I}} \sum_{\mathrm{i}=0}^{\mathrm{I}-1} \sum_{\mathrm{m}=0}^{\mathrm{M_i}-1} |\, N_o[\mathrm{k}]|^2 \tag{18}$$

$$\mathrm{H_1}: \mathrm{x}(\mathrm{k}) = \frac{1}{M_s \mathrm{I}} \sum_{\mathrm{i}=0}^{\mathrm{I}-1} \chi_{\mathrm{i}} = \frac{1}{M_s \mathrm{I}} \sum_{\mathrm{i}=0}^{\mathrm{I}-1} \sum_{\mathrm{m}=0}^{\mathrm{M_i}-1} |\, \mathrm{B_i C_i} + N_o[\mathrm{k}]|^2 \tag{19}$$

Let $x\ (k)$ denotes an energy signal of subcarrier k-th received at master node. It is a result of sensing M times at a discrete time interval. The statistical decisions are dividing into two hypotheses, H_0 and H_1 where I is the node index number; I is the number of all sensing nodes and χ_i is the test statistic of the cooperative sensing. $N_o[k]$ denotes the noise of the n^{th} sample, M_s is the number of all signal samples during the sensing periods T_s (e.g., 1 ms). B_iC_i is the amplitude of the detected signal when the signal $C_i[k]$ transmitted. At the secondary master node (MN) the presence of the primary user is decide based on the energy detector which given by

$$x > \gamma \tag{20}$$

When the equation is true, the primary user is judge to be present. This threshold γ is decide to satisfy the probability of false alarm, P_{fa}, if assumed the summed signal is regarded as Gaussian as shown in [30]. Then the threshold γ is given by:

$$\mathrm{P_{FA}} = \int \mathrm{P}(x > \gamma|\mathrm{H_0})\mathrm{dx} \tag{21}$$

Where

$$\gamma = \sqrt{\frac{2}{N}}\sigma^2 erfc^{-1}(2P_{fa}) + \sigma^2 \tag{22}$$

The performance of the proposed mobile subcarrier exchange method is evaluated using computer simulation to confirm the performance of the proposed method. Collected subcarrier number k is converted into the soft sensing information, S_m for the [14] method that utilized new subcarrier mapping is given by

$$\widehat{S_m}(dB) = log_{10}(\frac{(k_{conv} * \alpha)}{N_c})) * 20 \tag{23}$$

Where $\widehat{S_m}(dB)$ denotes the value of the soft information converted from the detected subcarrier number of OFDM signal, m is the detected sensing node index.

9. ANALYSIS ON THE EFFECT OF MOBILITY IN COOPERATIVE DECISION WITH DIFFERENT SUBCARRIER MAPPING

In this scheme, the quantisation results of local observation from surrounding SN's are transmitted to make cooperative decision on master node. Since the sensing nodes are closed to the master node and distributed surround master node, the SNR is set to 30 dB for gathering signal at the master node [8]. It assumed that by SNR is 30 dB at master node; it is sufficient performance for gathering sensing information from surround mobile sensing nodes. The analysis performances that are presented in this works are gathering subcarrier information process between mobile (or static) SN transmitted onto master node (MN). The AWGN channel is experienced between mobile SN nodes and master node. The performance of spectrum sensing depends on two key parameters known as probability of detection (PD) and probability of false alarm (PFA). In general, a higher probability of detection (PD) gives a better performance in which case PD equal to 1 denotes absolute detectability. Moreover, in probability of false alarm (PFA) gives better performance in case PFA equal to zero (null).

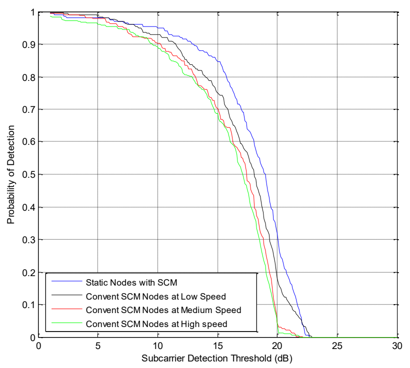

Figure 5. Probability of detection using ***conventional Subcarrier Mapping*** (SCM)

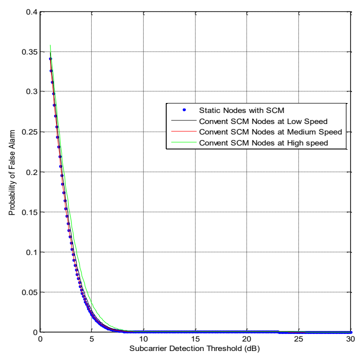

Figure 6. Probability of false alarm using conventional subcarrier mapping

As illustrated on Figure 5, the performance analysis of probability detection between static nodes with SCM and conventional SCM nodes are presented. Figure 5 illustrated comparison of detection probability (PD) between conventional static nodes with SCM method and conventional mobile SN nodes in CRN environment. A static node with SCM method has performed better detection performance; due to theirs is less signal fluctuation and attenuation in the nodes. In a case of subcarrier mapping width, α = 2, the quantisation width is uniform, for static nodes with SCM is better than conventional SCM method. It's found that the difference performance is significant around 2 dB to 4 dB. According to the Figure 5, the static nodes SCM at low ***subcarrier detection threshold*** (SDT) value is 0 dB up to 5 dB have obtained good performance detection, whereas at the same low SDT value, the probability of detection conventional SCM is less than 1 of PD value. At the SDT value is 15 dB, static nodes with SCM have obtained good performance in detection probability. However, at SDT value is 11.5 dB, the probability starts to decrease until 20 dB which is decrease significantly becomes null.

Figure 6 depicts the false detection of the subcarrier information gathering within MN. It can be confirming that the performance of conventional static nodes with SCM method have a good false alarm probability which is lowest than mobile nodes. The mobile nodes show the performance in false alarm probability is moderate. Even though is not slightly different, the static node is performing better in false subcarrier estimation. If the false alarm has a larger value, the subcarrier detection threshold has large value. On other hand if false alarm has smaller value, the subcarrier detection threshold has smaller value. According to the Figure 6, a low ***subcarrier detection threshold*** (SDT) at 7 dB is impacted onto false alarm probability due to MN cannot sense the incoming signal. The MN cannot estimate whether the received signal is comprising of signal and noise or only noise. It's beginning at SDT 7.5 dB, the PFA becomes large, and this is consistent with the proposed theory for the selection of subcarrier signal in MN. This is can be limitation for both of the methods.

The following is comparative study on detection performance on gathering subcarrier information on master node is presented. It is compared between a **conventional subcarrier mapping** (SCM) and ***the new subcarrier mapping*** (N-SCM) method in various speeds.

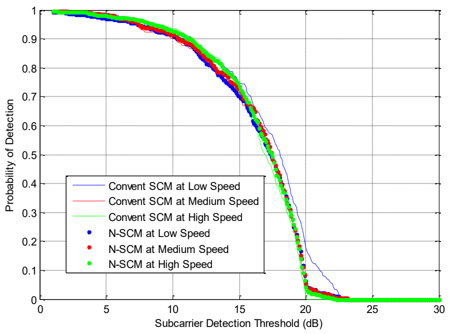

Figure 7. Probability of detection performance using different subcarrier mapping techniques at various SN velocities.

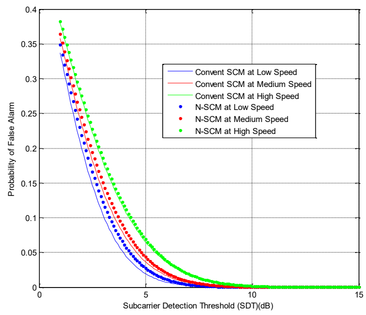

Figure 8. Probability of false alarm performance using different subcarrier mapping techniques at various SN velocities.

Conventional SCM method curves are superior to N-SCM curves in terms of detection probability, as illustrated in Figure 7. The conventional SCM technique demonstrates that it can outperform the N-SCM method at the greatest SDT value. The following false detection probability charts are displayed on Figure 8, with varying velocities. These charts illustrate two methodologies: SN nodes with and without mobility. PFA equal to null indicates an excellent false alarm probability, as the evaluation performance is predicated on the performance key of false alarm probability. In contrast to the high speed, both methodologies have achieved identical false detection performances. In contrast to the new subcarrier mapping (N-SCM) method, conventional subcarrier mapping (SCM) has a low false alarm probability. Nevertheless, both approaches have yielded approximately 0 dB to 9.5 dB for false alarms that become excessive. MN is unable to evaluate the subcarrier signal at a low subcarrier detection threshold. In addition to noise and uniform quantization, mobility is one of the factors that contribute to a high false alarm probability in the decision-making process. The mobility aspect is becoming increasingly restricted, and it is imperative that it be addressed. In Figure 8, it is evident that the PFA curves for the conventional SCM method are lower than those of the other methods at low speeds, as they approach the null value at SDT of 7.5 dB. In addition, the PFA curve for both methods is higher than that of the others, as it approaches the null value at 10 dB, in contrast to the high velocity.

In this work, illustrates that static-node SCM surpasses recent mobility-aware spectrum sensing methods, including AI-based Doppler compensation[31], [32], [33], hybrid deep learning [20], [34], [35], [36], [37], [38], [39], and Kalman filtering [40], [41], by achieving a 2–4 dB improvement in detection accuracy at low SNR (0–5 dB SDT) with near-zero PFA (at 7.5 dB) while avoiding computational overhead. Unlike cluster-based CSS [40], [41] or federated learning [42], [43], [44], our SCM-based approach improves cooperative sensing without necessitating complex training or PU coordination. This work bridges a critical gap in benchmarking static versus mobile node performance under mobility-induced fading by providing a simpler, real-time solution for OFDM spectrum exchange in mobile CRNs, in contrast to NOMA-OFDM [45], [46] and RL-based subcarrier allocation [17]. In general, the mobility parameter could meet the detection performance and perform well in false alarm probability in mobile spectrum exchange and hence could be used for spectrum exchange information in future.

Benchmark evaluation between static and mobile SCMs as shows in Figure 10 and Figure 11 has been presented that the static SCM approach based on deterministic channels (AWGN) is unable to reflect dynamic real-world conditions such as fading, Doppler, and SNR fluctuations. Static SCMs excel in detection under ideal conditions but are less adaptive than mobile SCMs which are more capable of adjusting sensing to channel changes in real-time.

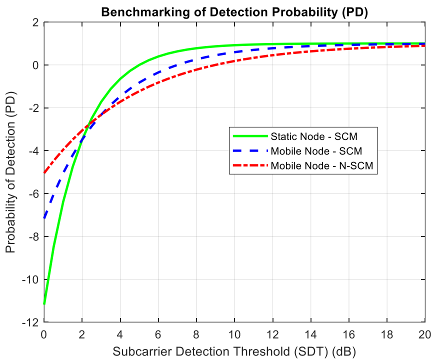

Figure 10. Benchmarking of Probability of Detection (PD) performance between static node SCM and mobile node SCM.

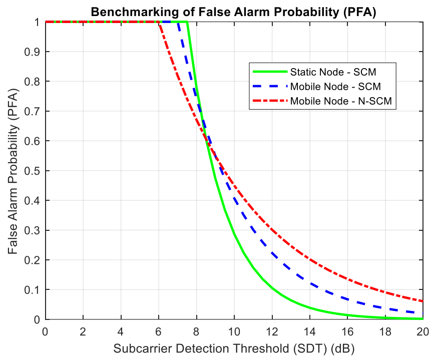

Figure 11. Benchmarking of False Alarm Probability (PFA) performance between static node SCM and mobile node SCM.

The benchmarking results demonstrate that SCM enhances the sensitivity of spectrum detection, particularly under low SNR circumstances, with static nodes exhibiting a detection probability (PD) of around -2.5 at SDT = 0 dB, outperforming mobile nodes with SCM (PD ≈ -4) and mobile N-SCM (PD ≈ -6.5). At SDT = 6 dB, static nodes attain PD ≈ -0.5, but mobile SCM achieves ≈ -1.5 and mobile N-SCM ≈ -2.5, demonstrating the advantage of SCM in enhancing detection performance. The graph indicates that SCM enhances PD by 2–4 dB under low SDT circumstances, with static nodes exhibiting the highest sensitivity, followed by mobile nodes using SCM, and lastly mobile nodes without SCM. This distinction is vital in networks with variable SNR. This graph illustrates the significance of supply chain management flexibility, particularly under fluctuating channel circumstances like mobility nodes as shown in Figure 10.

Figure 11 illustrates the benchmarking of false alarm probability (PFA), demonstrating that the SCM approach significantly decreases the false alarm probability, particularly at elevated detection thresholds (≥10 dB). Static nodes with SCM exhibit optimal performance, characterized by expedited PFA reduction and the minimal final value (about 0.03). Mobile nodes using SCM have significantly greater efficiency compared to those without SCM, demonstrating that SCM allows a PFA reduction of 0.03–0.05 at elevated thresholds. This demonstrates the significance of SCM in stabilizing spectrum detection inside dynamic networks like CRN.

Table 1. A Comparison of PD and PFA Benchmarks for Static SCM Nodes and Mobile CRN Nodes

SDT (dB)	PD - Static SCM	PD - Mobile SCM	PD - Mobile N-SCM	PFA - Static SCM	PFA - Mobile SCM	PFA - Mobile N-SCM
2	~ -6	~ -4.5	~ -5.2	~1.0	~1.0	~1.0
4	~ -2.8	~ -2	~ -3.2	~0.98	~0.99	~0.995
6	~ -1.2	~ -0.7	~ -1.4	~0.9	~0.95	~0.98
10	~ -0.2	~ -0.3	~ -0.6	~0.2	~0.35	~0.45
14	~0	~0.05	~0.1	~0.05	~0.1	~0.15
18	~0	~0.01	~0.02	~0.03	~0.05	~0.08

Table 1 and Figure 12 had presents the results demonstrating that SCM on static nodes demonstrates the highest sensitivity in detection, with PD values approximately –0.2 at SDT 10 dB and false alarms around 0.2. In contrast, mobile-SCM exhibits PD values of approximately –0.3 and PFA values of about 0.35, while mobile N-SCM shows PD values near –0.6 and PFA values around 0.45.

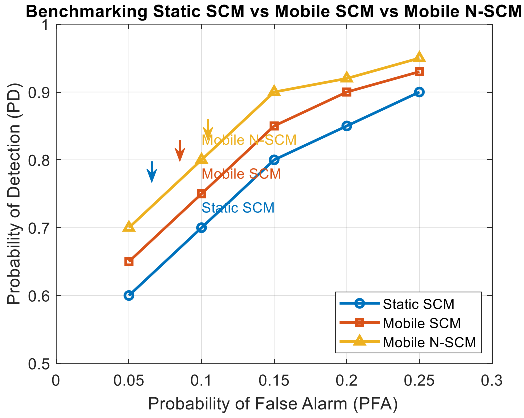

Figure 12. Receiver Operating Characteristic graph illustrating benchmarking results from Static SCM, Mobile SCM, and Mobile N-SCM, utilizing Probability of Detection (PD) and Probability of False Alarm (PFA) data.

Static nodes demonstrate a performance advantage of 0.3–0.6 dB in PD and a reduction in false alarms by 0.1–0.15 relative to mobile nodes, highlighting the efficacy of SCM in non-dynamic channels and the critical role of adaptability in mobile nodes. Enhance the SDT selection within the 10–14 dB range, since this interval offers the optimal equilibrium between a high detection probability (PD near 0) and a low false alarm probability (PFA < 0.1) across all SCM-based models.

10. SUMMARY

Based on the performance analysis both methods have been examined under wireless mobility environment. In medium and high velocity, the conventional SCM have different results with the N-SCM due to mobility. In mobility, the movement of the nodes and displacement spatially will impact to the detection power level. Whenever SN node moving, there are phase angle and distances are changes. From the performance analysis, mobility effect has influenced the performance of cooperative subcarrier decision in master node. For both methods, the result a show that at 7.5 dB of SDT value, false alarm performance is huge, which impact to the decision in the MN. The un-selected subcarrier number is considered as noise and counts as false detection by MN. Therefore, higher false alarm is achieved at MN. Respectively, if higher PFA occurred, thus detection probability is decreased. This becomes limitation to the system that should be addressed to alleviate this constraint. Moreover, the flexibility of frequency mapping parameter becomes a challenge in order to make SN nodes adaptively adjusted which can follow the detection power level changes. Even though conventional SCM has perform better performance in compared with N-SCM method.

In this study, it is shown that static sensing nodes (SNs) with subcarrier mapping (SCM) outperform mobile SNs in terms of detection accuracy by 2–4 dB. Additionally, they maintain a reliable detection probability (PD > 1) at low thresholds (SDT: 0–5 dB), where conventional SCM fails. In contrast to conventional methods, the static-node SCM that has been proposed substantially reduces the false alarm probability (PFA) in mobile networks, attaining a near-zero PFA at SDT 7.5 dB. Static nodes with SCM achieve reliable detection probability (PD > 1) even at low subcarrier detection thresholds (SDT: 0–5 dB), whereas conventional SCM fails under the same conditions. The proposed static-node SCM significantly reduces false alarm probability (PFA) compared to conventional SCM in mobile networks, particularly at low speeds (null PFA at SDT 7.5 dB). The findings suggest that integrating mobility parameters improves spectrum exchange reliability, making it viable for future dynamic spectrum sharing in cognitive radio networks. Enhance the SDT selection within the 10–14 dB range, since this interval offers the optimal equilibrium between a high detection probability (PD near 0) and a low false alarm probability (PFA < 0.1) across all SCM-based models.

ACKNOWLEDGEMENTS

This research was supported by Ministry of Higher Education of Indonesia, University Islam Sultan Agung (UNISSULA), University Teknologi Malaysia (UTM). We are thankful to our colleagues Prof. Dr. Sharifah Kamilah Syed Yusof and Dr. Muhammad Haikal Satria who provided expertise that greatly assisted the research.

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