Energy Efficiency in Cognitive Radio with Cooperative MME (Maximum to Minimum Eigenvalue) Spectrum Sensing Method

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***Abstract*—Cognitive radio is one way to overcome the limitations of the frequency spectrum. Cognitive radio users can utilize the frequency spectrum that is not being used (white space) by detect the frequency spectrum. Spectrum sensing is done periodically to ensure there is no interference, in that sense spectrum sensing activity in cognitive radio will increase energy consumption. Therefore, energy efficiency is very important to consider in cognitive radio technology. This research is study on energy efficiency in cognitive radio with cooperative MME (Maximum to Minimum Eigenvalue) spectrum sensing method. Energy efficiency is implemented by finding the optimal values of probability of a user wait or switch/handoff to another channel while the primary user is using the current channel. Cooperative MME spectrum sensing detection process which is not depend on the uncertainty of noise shows better performance than the energy detection method.**

Keywords—cognitive radio; spectrum sensing; cooperative; MME; energy efficiency

I. INTRODUCTION

Nowadays, the increasing requirement of frequency spectrum for wireless communications is a thing that must be fulfill. Cognitive radio technology promises an optimum utilization of the frequency spectrum. IEEE (Institute of Electrical and Electronics Engineers) 802.22 is a standard for WRAN (Wireless Regional Area Network) which includes physical layer and media access with the aim of using the TV channel broadcast (white space) at a bandwidth of 6 MHz, 7 MHz, and 8 MHz [1].

Cognitive radio has ability to detect frequency spectrum that is not being used by spectrum sensing. Therefore, spectrum sensing is an important component in cognitive radio. There are several methods of spectrum sensing which are matched filter detection, cyclostationary detection, energy detection, and eigenvalue detection [2].

Each of these methods has advantages and disadvantages. Matched filter detection requires information about the channel and the waveform of PU (Primary User), cyclostationary detection requires information about the cyclic frequency of PU, while energy detection does not require signal and channel information from the PU but it is highly dependent on the uncertainty of noise channel. Eigenvalue method detect the signal based on the eigenvalues of the covariance matrix received signal power at the SU (Secondary User). So, eigenvalue detection can overcome the problem of the uncertainty of noise channel [2].

Spectrum sensing is done periodically will lead to increased energy use. Therefore, using energy efficiently is very important in cognitive radio technology.

II. SYSTEM MODEL

In cognitive radio access, there are K primary users (PU) available and one secondary user (SU) which will perform sensing and data transmission. In the early step of secondary user (SU) using a PU channel, but when PU is present so that the SU should hand over the channel to PU. Furthermore, SU will make a decision whether to wait until the PU left that channel so there is a time delay in data transmission SU or SU will handoff to another channel that idle [3].

At the time of SU decide to wait PU on the channel is assumed that there is no energy consumption but SU will lose throughput. Conversely when the SU decide to handoff to another PU channel, it will make energy consumption to perform handoff, but also will increase the throughput [3].

Therefore, it is necessary tradeoff to determine whether the SU should wait or handoff to obtain optimal energy efficiency. On the energy efficiency of this scheme is to find the optimal value of the probability of the SU to wait on the channel called P_s or SU probability for handoff to another channel called $1-P_s$ [3].

III. DESIGN AND CALCULATION

This research designed a scheme and calculate the energy efficiency of cognitive radio technology that uses cooperative MME (Maximum to Minimum Eigenvalue) spectrum frequency detection method.

A. Primary User (PU)

In this research, using the DVB-T signal data as PU (Primary User) wirh the following specifications:

- Frequency : 545 MHz
- Bandwidth : 6 MHz
- Over sampling : 8/7 x Bandwidth

B. Determination of Parameters

PU signal detection is done by using cooperative MME (Maximum to Minimum Eigenvalue) spectrum sensing method with the parameters in Table 1 as follows:

TABLE I. PARAMETER OF PU SIGNAL DETECTION

Parameter	Description	Value
M	Number of SU (Secondary Users)	2-10
N_s	Number of sampling	297,1000
L	Smoothing factor	8
P_{fa}	Probability of false alarm	0.1

C. Calculation of MME Threshold

Based on the above parameters, can be calculated threshold value (γ) with the following equation [2]:

$$\gamma = \frac{\left(\sqrt{N_s}+\sqrt{M.L}\right)^2}{\left(\sqrt{N_s}-\sqrt{M.L}\right)^2}.\left(1+\frac{\left(\sqrt{N_s}+\sqrt{M.L}\right)^{-\frac{2}{3}}}{(N_s M.L)^{\frac{1}{6}}}{F_1}^{-1}\left(1-P_{fa}\right)\right)$$

[2] (1)

Where F_1 is the CDF (Cumulative Distribution Function) of the Tracy-Widom order 1 distribution and ${F_1}^{-1}$ is Tracy-Widom order 1 distribution invers.

D. Covariance Matrix

Covariance matrix is obtained from the PU data signal which is received by the SU. In this research, the signal received is DVB-T signal, it is assumed that the propagation and the distance between the PU with all the SU is same so that the signal received by each SU is same.

For cases where the propagation and the distance between each PU and SU is not same so that the signal received at each SU is not same, the matrix covariance still can be calculated since covariance matrix only depends on the received signal and does not depend on the distance.

Covariance matrix calculated by the following equation:

$$R_x(N_s) \stackrel{\text{def}}{=} \frac{1}{N_s}\sum_{n=L-1}^{L-2+N_s} \hat{x}(n)\hat{x}^{\dagger}(n) \qquad [2] \qquad (2)$$

where :

$\dagger$: hermitian

$$x(n) \stackrel{\text{def}}{=} [x_1(n), x_2(n), \dots, x_M(n)\,]^T \qquad [2] \qquad (3)$$

Where :

$x(n)$: data received at all SU

$x_1(n)$: data in first SU

$x_2(n)$: data in second SU

$x_M(n)$: data in M-th SU

$$\hat{x}(n) \stackrel{\text{def}}{=} [x^T(n), x^T(n-1), \dots, x^T(n-L+1)\,]^T \qquad [2] \ (4)$$

Where :

$\hat{x}(n)$: data received in all SU at observation time

Based on the obtained covariance matrix then we can calculated the maximum eigenvalue and the minimum eigenvalue.

E. Probability of Detection

In this research uses signal detection with cooperative MME method. The probability of detection is obtained by comparing the maximum eigenvalue to the minimum eigenvalue.

The maximum and minimum eigenvalue can be estimated by the following equation [2]:

$$\lambda_{max}\left(R_x(N_s)\right) \approx \rho_1 + \lambda_{max}\left(R_\eta(N_s)\right) \qquad [2] \ (5)$$

where :

$\lambda_{max}\left(R_x(N_s)\right)$: the maximum eigenvalue+noise

ρ_1 : the maximum eigenvalue of signal

$R_\eta(N_s)$: the covariance matrix of noise

$\lambda_{max}\left(R_\eta(N_s)\right)$: the maximum eigenvalue of noise

$$\lambda_{min}\left(R_x(N_s)\right) \approx \rho_{ML} + \frac{\sigma_\eta^2}{N_s}\left(\sqrt{N_s}-\sqrt{M.L}\right)^2 \qquad [2] \ (6)$$

where :

$\lambda_{min}\left(R_x(N_s)\right)$: the minimum eigenvalue+noise

ρ_{ML} : the minimum eigenvalue of signal

σ_η^2 : power noise of WGN

So that the value of the probability of detection for the method MME is obtain by the following equation :

$$P_d = 1 - F_1\left(\frac{\frac{N_s}{2}(\gamma\rho_{ML}-\rho_1)+\gamma\left(\sqrt{N_s}-\sqrt{M.L}\right)^2-\mu}{\frac{\sigma_\eta^2}{v}}\right) \qquad (7)$$

where :

$$\mu = \left(\sqrt{N_s-1}+\sqrt{M.L}\right)^2 \qquad [2] \ (8)$$

$$v = \left(\sqrt{N_s-1}+\sqrt{M.L}\right)\left(\frac{1}{\sqrt{N_s-1}}+\frac{1}{\sqrt{M.L}}\right)^{1/3} \qquad [2] \ (9)$$

μ : *centering* of Tracy-Widom Order-1 distribution

v : *scalling* of Tracy-Widom Orde-1 distribution

F. Energy-Efficient

Optimization of energy-efficient is formulated by this equation [3]:

$$\min_{\tau_s, P_s} \mathcal{J}(\tau_s, P_s)$$

With
$$P_d(\tau_s) \geq P_{d_t}$$
$$P_f(\tau_s) \leq P_{f_t}$$
$$R(\tau_s, P_s) \geq \mathcal{R}$$
$$D(\tau_s, P_s) \leq \mathcal{D} \qquad [3]\ (10)$$

where :

$\mathcal{J}$: total of energy that consumed by SU in one data packet transmission

P_d : probability of detection

P_{d_t} : probability of detection target

P_f : probability of false alarm

P_{f_t} : probability of false alarm target

R : total of data throughput

$\mathcal{R}$: trade of the total of throughput

D : total of delay time at SU

$\mathcal{D}$: trade of the total of delay time at SU

G. Provide Input $\boldsymbol{P_d}$ *and* $\boldsymbol{P_f}$

Scheme of energy efficiency in cognitive radio in this research uses the signal detection MME method. So the value of $\boldsymbol{P_d}$ and $\boldsymbol{P_f}$ obtained from signal detection with MME method that has been done before.

H. Determine Parameters on Energy Efficiency Scheme

Table 2 below is the assumption of the parameters in cognitive radio scheme :

TABLE II. PARAMETER AT COGNITIVE RADIO SCHEME

Parameter	Value	Description
K	3	Number of PU channel which available
S	6 second	Time duration for one data packet transmission
T	0.5 second	Time duration for each frame transmission
ρ	0.35	Probability of busy channel
SNR_{SU}	10 dB	Signal to noise ratio at SU
β_0	2 second	Average PU off duration at given channel
E_s	40 mW	Detection power
E_t	69.5 mW	Transmission power
J_{sw}	40 mJ	Switching energy (handoff)
P_{dt}	0.9	Target of probability of detection
P_{ft}	0.1	Target of probability of false alarm

I. Sensing Duration

Sensing Duration (τ_s) is determined by collection of samples (τ_{Ns}) and a sensing decision making (τ_d).

$$\tau_s = \tau_{Ns} + \tau_d \qquad (11)$$

$$\tau_{Ns} = \frac{N_s}{f_{sampling}} \qquad (12)$$

where :

$f_{sampling}$: sampling frequency

τ_d assumed in this research is 1 ms.

J. Probability of Detection Idle Channel and Busy Channel [3]

Status of the i-th channel idle is $X_i = 0$ and the status of the i-th channel busy is $X_i = 1$. While $\tilde{X}_i = 0$ is the status of the i-th channel is detected as idle and $\tilde{X}_i = 1$ is the status of i-th channel is detected as busy. Of these events can be lowered some probability as follow [3]:

- $P_{c1} = P(\tilde{X}_i = 0 | X_i = 0) P(X_i = 0) = (1 - P_f)(1 - \rho)$ is probability of the channel detected rightly as idle
- $P_{c2} = P(\tilde{X}_i = 0 | X_i = 1) P(X_i = 1) = (1 - P_f)\rho$ is probability of the channel detected wrongly as idle
- $P_{c3} = P(\tilde{X}_i = 1 | X_i = 1) P(X_i = 1) = P_d \rho$ is probability of the channel detected rightly as busy
- $P_{c4} = P(\tilde{X}_i = 1 | X_i = 0) P(X_i = 0) = P_f(1 - \rho)$ is the probability of the channel detected wrongly as busy

K. Probability of SU Activities

- **Probability of Channel is Detected as Idle** $\boldsymbol{(P_1(\tau_s))}$ **[3]**

The probability of channel is detected as idle is the sum of the probability of channel is correctly detected as idle (P_{c1}) and the probability of channel is wrongly detected as idle (P_{c2}).

$$P_1(\tau_s) = P_{c1} + P_{c2} = (1 - \rho)(1 - P_f) + \rho(1 - P_d) \qquad (13)$$

- **Probability of Other Channel (K-1) is Detected as Busy** $\boldsymbol{(P_b(\tau_s))}$ **[3]**

$$P_b(\tau_s) = (P_{c3} + P_{c4})^{K-1} = (P_d \rho + P_f(1 - \rho))^{K-1} \qquad (14)$$

- **Probability of SU is Handoff to Idle Channel** $\boldsymbol{P_3(\tau_s, P_s)}$ **[3]**

$$P_3(\tau_s, P_s) = (1 - P_1)(1 - P_b)(1 - P_s) \qquad (15)$$

Where P_s is the probability of SU waiting on PU channel and $(1 - P_s)$ is the probability of SU handoff to other PU channel. P_s will be obtained in next section.

- **Probability of SU Handoff to Busy Channel $(\boldsymbol{P_e(\tau_s)})$ [3]**

$$P_e(\tau_s) = P(S_b = 1)$$

$$P_e(\tau_s) = \sum_{\omega=1}^{K-1} \sum_{j=1}^{\omega} P(S_b = 1, |\mathcal{I}| + |\mathcal{J}| = \omega, |\mathcal{J}| = j) \quad (16)$$

where :

$S_b = 1$: the state that SU handoff to busy channel

ω: the number of channel is detected as idle

$\mathcal{I}$: the number of channel is correctly detected as idle

$\mathcal{J}$: the number of channels is wrongly detected as idle

L. Optimization Probability of SU is Waiting $(\boldsymbol{P_s})$ [3]

P_s optimization can be determined by the following equation :

$$P_s^{opt}(\tau_s) = \min\{\alpha(\tau_s), \beta(\tau_s)\} \in [0,1] \quad (17)$$

Where $\alpha(\tau_s)$, $\beta(\tau_s)$ is obtained by assuming $R(\tau_s, P_s) = \mathcal{R}$ and $D(\tau_s, P_s) = \mathcal{D}$. These are the equation of $\alpha(\tau_s)$ and $\beta(\tau_s)$:

$$\alpha(\tau_s) = 1 - \frac{(\tau_s + T)\mathcal{R} - P_{c1} B_T}{B_T (1-P_1)(1-P_e)(1-P_b)} \quad (18)$$

$$\beta(\tau_s) = \frac{\eta T - (1-\eta)\tau_s}{T(1-P_1)(1-P_b)} - \frac{P_b}{1-P_b} \quad (19)$$

where :

$$\eta = \frac{\mathcal{D}}{(\mathcal{D}+S)} \quad (20)$$

$$\mathcal{R} = \mu \mathcal{R}_0 \qquad \mu \in [0,1] \quad (21)$$

$$\mathcal{R}_0 = (1-\rho) C_0 \quad (22)$$

$$\mathcal{D} = \lambda S \qquad \lambda \in [0,1] \quad (23)$$

M. Throughput (R) [3]

Data throughput on cognitive radio is the number of bits data that can be transmitted by the SU in one data packet duration. Throughput can be calculated based on the following parameters:

$$\bar{t} = T - \beta_0 \left(1 - e^{-(T/\beta_0)}\right) \quad (24)$$

where :

$\bar{t}$: the average of time duration for the PU to be present in an channel in slot transmission (T)

β_0: the average of duration that PU off at that channel

$$B_T = \left(1 - (\bar{t}/T)\right) C_0 T \quad (25)$$

$$C_0 = \log_2(1 + SNR_{SU})\ bits/s/Hz \quad (26)$$

where:

B_T : number of bits is transmitted in one slot transmission T

C_0 : SU capacity

SNR_{SU} : signal to noise ratio of SU

$$B_1 = P_{c1} B_T \quad (27)$$

$$B_2 = P_3 (1 - P_e) B_T \quad (28)$$

where:

B_1 : number of bits is transmitted in event 1 in Fig. 2 at [3]

B_2 : number of bits is transmitted in event 3 in Fig. 2 at [3]

So that from the equation, we can determine the throughput:

$$R(\tau_s, P_s) = \frac{B_1 + B_2}{\tau_s + T} = \frac{P_{c1} + P_3(1-P_e)}{\tau_s + T} B_T \quad (29)$$

N. Total of Energy Consumption [3]

The total of energy consumption in cognitive radio scheme in this research is:

$$\mathcal{J}(\tau_s, P_s) = N \tau_s E_s + N P_3 J_{sw} + S E_t \quad (30)$$

where:

$$N(\tau_s, P_s) = \left\lceil \frac{S}{P_t T} \right\rceil \quad (31)$$

N : total of frames are required to transmit one data packet

P_t : Probability of SU transmit data

$$P_t(\tau_s, P_s) = P_1 + P_3 = P_1 + (1 - P_1)(1 - P_b)(1 - P_s) \quad (32)$$

O. Energy Efficiency [7]

Energy efficiency is obtained by using the following equation :

$$\text{energy efficient} = \frac{\text{total of } throug\ hput\ in\ cognitive\ \ radio}{\text{total of energy consumption in } cognitive\ \ radio} \quad (33)$$

IV. SIMULATION AND ANALYSIS

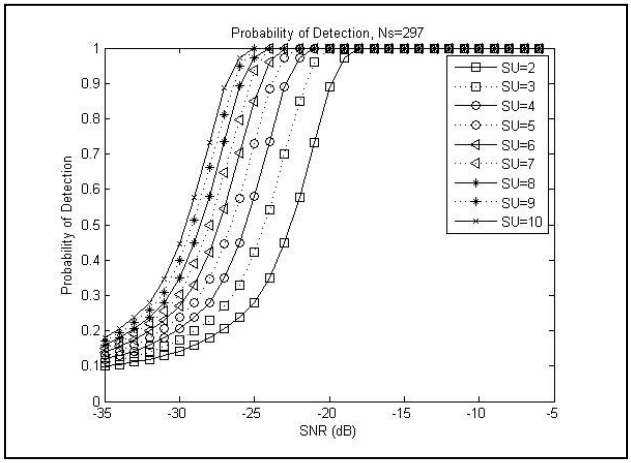

Fig. 1. Probability of Detection, Ns=297

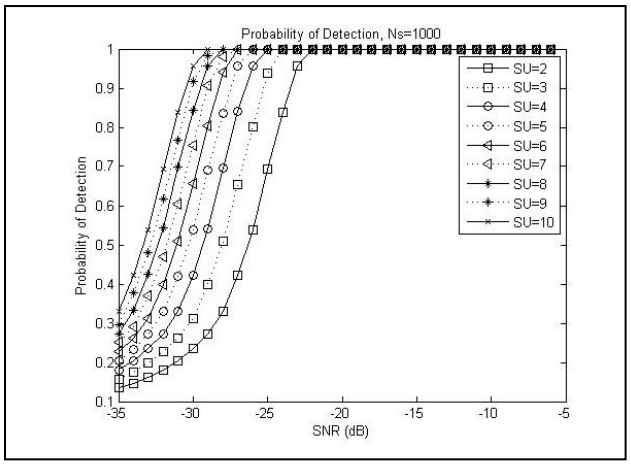

Fig. 2. Probability of Detection, Ns=1000

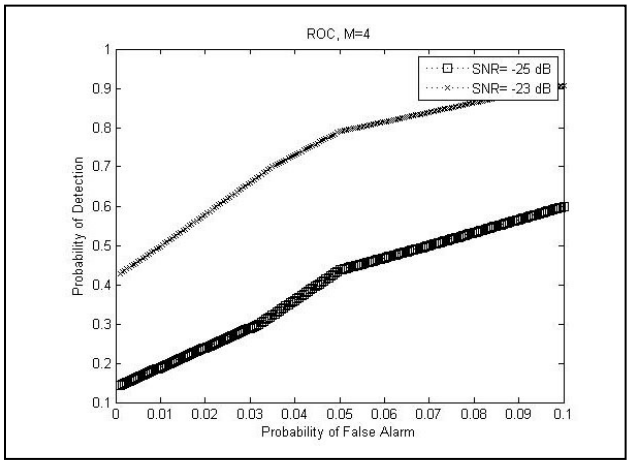

Fig. 3. ROC,Ns=297

In fig. 1 and 2 above, it can be seen that the cooperative SU to detect frequency spectrum with MME shows better performance. The more number of SU, the greater probability of detection, and the more number of SU then the detection can perform at lower SNR. Further, number of samples (N_s) can increase the probability of detection performance at lower SNR.

Fig. 3 above is the ROC (Receiver Operating Characteristics) which shows the relatioship between the probability of detection and probability of false alarm at a certain SNR. Increasingly probability of false alarm causes the miss detection probability decreases thus increasing the probability of detection.

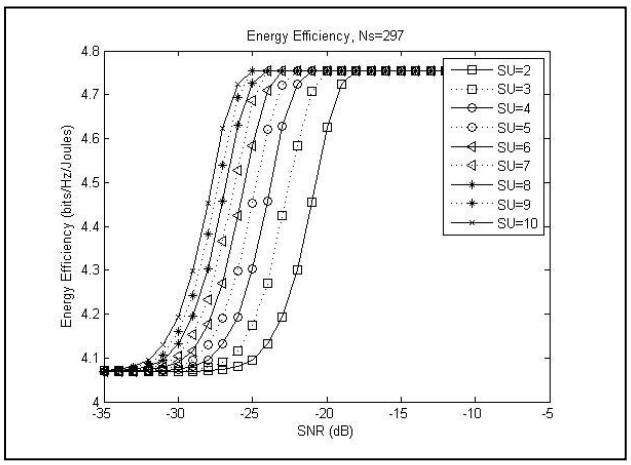

Fig. 4. Energy Efficiency, Ns=297

Based on fig. 4 above, it is known that the cooperative spectrum sensing MME can increase the probability of detection.

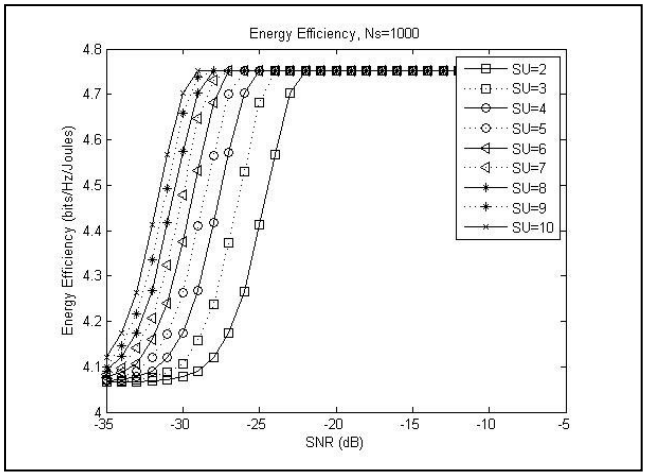

Fig. 5. Energy Efficiency, Ns=1000

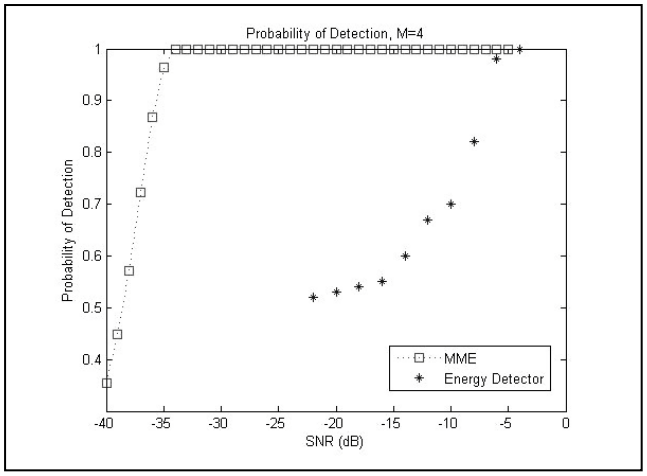

Fig. 6. Comparison of MME and Energy Detection Method [20] Ns=50000

Based on fig. 6, it shows that probability of detection MME method is better than energy detection method. MME

result is get from this research and energy detection result is get from reference [20] with Ns=50000.

V. CONCLUSION

This research replacing energy detector spectrum that used in previous studies using MME (Maximum to Minimum Eigenvalue) which does not depend on uncertainty noise and it shows better performance. Then, energy efficiency is implemented by finding the optimal values of probability of a user wait or switch/handoff to another channel while the primary user is using the current channel. Simulation based on DVB-T signal at frequency 545 MHz.

VI. OPEN ISSUES

One of open issues for further research is to combine optimal value sensing time (τ_s) and optimal value of P_s on cooperative spectrum sensing MME scenario in cognitive radio to get efficiency energy. In this research, sensing duration (τ_s) is sum of a collection of samples time (τ_{Ns}) and a sensing decision time (τ_d), where a collection of samples are influenced by the number of samples and sampling frequency while sensing decision time is fix variable are assumed to be 1 ms.

The difficulty in determining the optimum value of the sensing duration is the formula to determine the probability of detection and probability of false alarm of MME method is not affected by sensing duration. So, it is not known clearly about sensing time required. Therefore, further research is needed to find the actual value of sensing duration.

APPENDIX A

$$P_d = P\left(\lambda_{maks}\left(R_x(N_s)\right) > \gamma\lambda_{min}\left(R_x(N_s)\right)\right)$$

$$P_d = P\left(\rho_1 + \lambda_{maks}\left(R_\eta(N_s)\right) > \gamma\lambda_{min}\left(R_x(N_s)\right)\right)$$

$$P_d = P\left(\lambda_{maks}\left(R_\eta(N_s)\right) > \gamma\lambda_{min}\left(R_x(N_s)\right) - \rho_1\right)$$

$$P_d = P\left(\begin{array}{c}\lambda_{maks}\left(R_\eta(N_s)\right) > \\ \gamma\rho_{ML} + \gamma\dfrac{\sigma_\eta^2}{N_s}\left(\sqrt{N_s} - \sqrt{M.L}\right)^2 - \rho_1\end{array}\right)$$

$$P_d = P\left(\begin{array}{c}\dfrac{\lambda_{maks}\left(A(N_s)\right) - \mu}{v} > \\ \dfrac{\frac{N_s}{2}\gamma\rho_{ML} - \frac{N_s}{2}\rho_1 + \gamma\left(\sqrt{N_s} - \sqrt{M.L}\right)^2 - \mu}{v}\end{array}\right)$$

$$P_d = 1 - F_1\left(\frac{\frac{\frac{N_s}{2}(\gamma\rho_{ML} - \rho_1) + \gamma\left(\sqrt{N_s} - \sqrt{M.L}\right)^2 - \mu}{\sigma_\eta^2}}{v}\right) \quad (34)$$

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