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# White Space Detection in a Multiple Antenna Spectrum Sharing System

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## ABSTRACT

Exact detection of White Space (WS) is one of the actions in a Spectrum Sharing System (SSS) to determine unused spectrum for proper utilization. However, exact detection of WS is being affected by channel impairments, resulting in harmful interference. The Existing Multiple Antenna Spectrum Sensing (EMASS) technique used in addressing this effect is characterized with noise uncertainty leading to low detection rate due to setting of thresholds that is based on noise variance. Hence, this paper proposes an Improved Multiple Antenna Spectrum Sensing (IMASS) for detecting the WS in a SSS. Various copies of licensed user's signals are received through the unlicensed user antennas over different antenna configurations. The received signals are combined using a modified equal gain combiner and energy of the combined signal is determined using Parseval's relation for a discrete time signal. The received signal is used to form a square matrix which is converted to covariance matrix. Characteristic equation is obtained from covariance matrix to determine the minimum eigenvalue. The ratio of energy to minimum eigenvalue of the received signal is obtained and used as test statistics. The IMASS technique is evaluated using Probability of Detection (PD) and Total Error Probability (TEP) by comparing with EMASS. The proposed IMASS technique gives better performance with higher PD and lower TEP values than EMASS at all different antenna configurations.

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## 1. INTRODUCTION

The substantial growth in wireless communication makes the demand for radio spectrum to rise exponentially. The daily increase in demand for radio spectrum has given rise to insufficient spectrum known as spectrum scarcity. The accessible frequency spectrum that has been licensed exclusively to only authorized user is getting crowded day by day. The unavailability of radio spectrum is not actually due to limited spectrum but majorly to the fixing of accessible spectrum to only the Licensed User (LU). The exploitation of the assigned spectrum is a function of time and several portions of the licensed spectrum are not utilized over a significant period [1, 2]. Therefore, efficient exploitation of available spectrum is of paramount importance since the process in regulating new frequency spectrum is time consuming. Spectrum Sharing System (SSS) is proposed to efficiently make use of the assigned spectrum by making Unlicensed User (ULU) to utilize the assigned spectrum when is not occupied. SSS scans the allocated spectrum within a certain frequency range to detect unused spectrum known as WS and resourcefully dispense communication links through the detected WS. The technique promotes dynamic spectrum access in contrary to the traditional fixed spectrum access. SSS enhances spectrum exploitation by making unlicensed users to utilize the assigned spectrum without causing interference to the licensed users [3, 4, 5].The performance of SSS is a function of ability of unlicensed user to detect unused spectrum known as WS and provide a communication link through the detected spectrum without causing interference to licensed user. The process of detecting WS is known as Spectrum Sensing (SS) and is one of the core operations in SSS [6, 7, 8, 9]. Single Antenna (SA) and Multiple Antenna (MA) are the two antenna configurations used in carrying out SS. In SA, only one antenna is used at both licensed and unlicensed users. On the other hand, MA involves single antenna at the LU and multiple antennas at ULU. Researches conducted on SS reveal that multiple antennas accurately detect WS more than single antenna, due to increase in LU signal strength that increases detection rate but requires diversity combiner that combines the multiple LU signals. The performance of Multiple Antenna Spectrum Sensing (MASS) depends on diversity combining technique and detector used to carry out sensing operation. The diversity combiner commonly used in MASS is Maximal Ratio Combiner (MRC) due to its combining nature that increases signal strength more than other combiners such as Equal Gain Combiner (EGC) and Selection Combiner (SC) [3, 10, 11, 12].

The detection technique commonly used in MASS is Energy Detector (ED) due to its simplicity and independent of LU signal [13, 14]. However, ED suffers from noise uncertainty which makes the detector to have a low performance under low signal strength. This is due to the noise variance which is not accurately known at low signal strength. Also, the selection of threshold in ED relies on the variance of noise which cannot be estimated accurately thereby resulting in unreliable detection. Furthermore, ED cannot sense a correlated signal due to difficulty in differentiating between signal and noise when it is correlated [15, 16, 17]. However, most of the signals in practice are correlated [1, 18 19, 20, 21).

Many researches have been carried out on MASS in a Cognitive Radio (CR) system. In [22], energy detection of unknown signal over fading channel was proposed to address LU interference in CR using square law combining technique. ED received signal from each antenna and the output signal of each ED was combined to make final decision on the availability of LU signal by comparing with set threshold. The technique gave low detection rate most especially at a very low signal strength due to noise uncertainty that affects ED. Energy detection-based SS in a two-wave with diffused fading channels power was proposed in [23] to address problem of LU interference in SSS using Selection Combiner (SC). The SC selected the best signal based on SNR from the multiple copies of the LU signal. The selected signal was used as input to ED to make final decision on availability of WS. The technique had a low sensing time but suffers from dependence on threshold of the noise variance leading to low detection rate. Furthermore, in [4], modification of square law combiner for LU detection in a SSS was proposed using ED. Threshold Combiner (TC) was used to select the PU branch that is higher than the threshold before applying ED to determine the energy of LU signal received. Though, the technique did not depend on PU but suffered from poor detection rate due to noise uncertainty that affected ED. Also, in [5], modification of MRC for detection of WS in a SSS was proposed to reduce the hardware complexity of the existing MRC spectrum sensing technique. The signal output of the modified MRC was used as input to ED to determine the energy of the combined signal. The energy obtained was compared with the threshold to determine the presence of WS. The technique was able to reduce the hardware complexity but suffered from poor detection rate and selection of threshold was based on noise variance which could not be estimated accurately. Therefore, the previous works on MASS suffered from noise uncertainty due to ED used resulting in poor detection rate. Also, the selection of threshold in ED was based on the variance of noise which couldn't be estimated accurately thereby resulting in unreliable detection. Therefore, this paper proposes an improved MASS to overcome the challenges of existing MASS using the ratio of energy to the minimum eigenvalue of the received LU signal thereby enhancing the detection rate. The contributions of this paper are:

1) a new MASS technique that is effective and more reliable in detecting WS even at a low signal strength has been proposed.
2) a technique that detects both correlated and uncorrelated signal has been established.

The remaining section of this paper is arranged as follows; the proposed improved multiple antenna WS detection technique is provided in section 2, where the mathematical expressions for PD and TEP are derived to appraise the performance of the proposed MASS technique. Section 3 depicts the results of the simulation with performance comparison and conclusion of the paper is depicted in section 4.

## 2. IMPROVED MULTIPLE ANTENNA SPECTRUM SENSING TECHNIQUE

Energy of the received signal is obtained using parseval's relation for a discrete time signal. The transmitted signal from LU is received by ULU multiple antenna. Equal gain combiner which has been adjusted to be using one match filter and RF chain denoted as "$EGC_{adj}$" is used to combine the signals at the RF stage to reduce the hardware complexity. Using parseval's relation for a discrete time signal, the energy 'R' of the combined received signal for the improved technique is given in equation (1)

$$R(i) = \sum_{i=0}^{T}[x(i)]^2 \quad (1)$$

where: $x(i)$ is the output signal of $EGC_{adj}$
$T$ is the symbol duration

The SNR output '$SNR_{EGC_{adj}}$'of $EGC_{adj}$ is given by [24, 27] as

$$x(i) = SNR_{EGC_{adj}} = \frac{1}{NL}\left(\sum_{n=1}^{L} S_n\right)^2 \quad (2)$$

where: $S(i)$ is the power of signal on individual branches
L is the branches received by the antenna
N is the noise power on individual branches

Therefore, by substituting Equation (2) into Equation (1), the energy 'R (p)' of the signal received for the improved technique is obtained as

$$R(i) = \sum_{i=0}^{T}\left[\frac{1}{NL}\left(\sum_{n=1}^{L} S_n\right)^2\right]^2 \quad (3)$$

$$R(i) = \frac{1}{NL}\sum_{i=0}^{T}\left[\left(\sum_{n=1}^{L} S_n\right)^2\right]^2 \quad (4)$$

Equation (4) is the energy of the signal received for the improved MASS technique.

The minimum eigenvalue of the signal received for the proposed technique is obtained as follows. The received signal '$Y$' from ULU antennas for the proposed technique is given as

$$Y = \sum_{i=1}^{Z}\sum_{j=1}^{Q} G_{i,j} + N_{i,j} \quad (5)$$

where:
Z is the number of antennas
Q is the number of branches received by individual antenna
$G_{i,j}$ is the LU signal
$N_{i,j}$ is the AWGN present on the LU link

To obtain covariance matrix, Equation (5) is converted to a square matrix and obtained as

$$\boldsymbol{Y} = \begin{bmatrix} G_{1,1} & G_{1,2\ldots} & G_{1,Q} \\ G_{2,1} & G_{2,2\ldots.} & G_{2,Q} \\ \vdots & & \vdots \\ G_{Z,1} & G_{Z,2} & G_{Z,Q} \end{bmatrix} + \begin{bmatrix} N_{1,1} & N_{1,2\ldots} & N_{1,Q} \\ N_{2,1} & N_{2,2\ldots.} & N_{2,Q} \\ \vdots & & \vdots \\ N_{Z,1} & N_{Z,2} & N_{Z,Q} \end{bmatrix} \quad (6)$$

According to [24, 25], covariance '$Y_C$' of the received signal is given as

$$\boldsymbol{Y_C} = \frac{1}{P}(\boldsymbol{Y})\boldsymbol{Y}^T \quad (7)$$

where:
P is the number of ULU antenna
$\boldsymbol{Y^T}$ is the transpose of the square matrix for the received signal

However, the characteristic equation of a square covariance matrix '**A**' is given by [25, 26] as

$$det(\boldsymbol{A} - \beta\boldsymbol{I}) = 0 \quad (8)$$

where: $\beta$ is the eigenvalue
$\boldsymbol{I}$ is the identity matrix.

Therefore, using Equation (8), the maximum eigenvalue ($\beta_{max}$) and minimum eigenvalues ($\beta_{min}$) are obtained from Equation (7) as

$$det(\boldsymbol{Y_C} - \beta \boldsymbol{I}) = 0 \tag{9}$$

Solving Equation (7) and substituting into Equation (9) gives

$$det \begin{bmatrix} Y_{C1,1} - \beta & Y_{C1,2\ldots} & Y_{C1,Q} \\ Y_{C2,1} & Y_{C2,2} - \beta \ldots & Y_{C2,Q} \\ \vdots & & \vdots \\ Y_{CP,1} & Y_{CP,2\ldots} & Y_{CP,Q} - \beta \end{bmatrix} = 0 \tag{10}$$

$\beta$ with highest value is the maximum eigenvalue and $\beta$ with lowest value is the minimum eigenvalue. Therefore, the test statistics 'Th' for the improved technique is given as

$$Th = \frac{R(i)}{\beta_{min}} \tag{11}$$

Substituting Equation (4) into (11) gives

$$Th = \frac{\frac{1}{wL}\sum_{i=0}^{T}\left[\left(\sum_{n=1}^{L} s_n(i)\right)^2\right]^2}{\beta_{min}} \tag{12}$$

In this paper, 2, 3 and 4 ULU antennas configurations are used.
With 2 ULU antennas, Equation (12) becomes

$$Th = \frac{\frac{1}{2w}\sum_{i=0}^{T}[(S_1)^2+(S_2)^2]^2}{\beta_{min}} \tag{13}$$

With 3 ULU antennas, Equation (12) becomes

$$Th = \frac{\frac{1}{3w}\sum_{i=0}^{T}\left[[(S_1)^2+(S_2)^2+(S_3)^2]^2\right]^2}{\beta_{min}} \tag{14}$$

With 4 ULU antennas, Equation (12) becomes

$$Th = \frac{\frac{1}{4w}\sum_{n=0}^{T}\left[[(S_1)^2+(S_2)^2+(S_3)^2+(S_4)^2]^2\right]^2}{\beta_{min}} \tag{15}$$

Therefore, if the test statistics 'Th' obtained in Equations (13), (14) and (15) are greater than one, then white space is absent, that is, the spectrum is occupied due to ongoing transmission of LU signal, otherwise white space is available.

## 2.1. Rate of Detecting WS in the IMASS

Rate of detecting WS which is proportional to the Probability of Detection (PD) shows the sensing reliability in SSS. The higher the PD, the better the LU protection. Therefore, it is most preferred to achieve high detection rate in order to avoid interference caused by ULU to LU. The PD for the IMASS technique is obtained as

$$PD = Pr\ (Th > 1) \tag{16}$$

where: $Th$ is the test statistic

The test statistics for the improved technique for 2 ULU antennas is given in Equation (13). Therefore, by substituting Equation (13) into (16) gives

$$PD = Pr\left(\frac{\frac{1}{wL}\sum_{i=0}^{T}\left[\left(\sum_{n=1}^{L} s_n(i)\right)^2\right]^2}{\beta_{min}} > 1\right) \tag{17}$$

## 2.2. Total Error Probability for IMASS

The Total Error Probability for the IMASS '$P_{TE}$' is given as

$$P_{TE} = P(V_0)PFA + P(V_1)(1 - PD) \tag{18}$$

But

$$P(V_0) = 1 - PFA \tag{19}$$

$$P(V_1) = PD \tag{20}$$

Therefore, by substituting Equations (19) and (20) into (18), TEP for the improved technique is obtained as

$$P_{TE} = (1 - PFA)PFA + PD(1 - PD) \tag{21}$$

The flowchart of the simulation process for the proposed technique is depicted in Fig. 1 and the simulation parameters are presented in Table 1. The received LU signal which has been modulated and filtered is used to form a $Z \times Q$ square matrix using Equation (5) and energy of the signal is determined using Equation (4). The minimum eigenvalue is obtained by using Equation (10), while the ratio of energy to minimum eigenvalue is obtained using Equation (11) and used as test statistics for the proposed technique. $D_1, D_2$ to $D_L$ in Fig. 1 represent distortions in the channel considered, while $N_1, N_2$ to $N_L$ represent AWGN present.

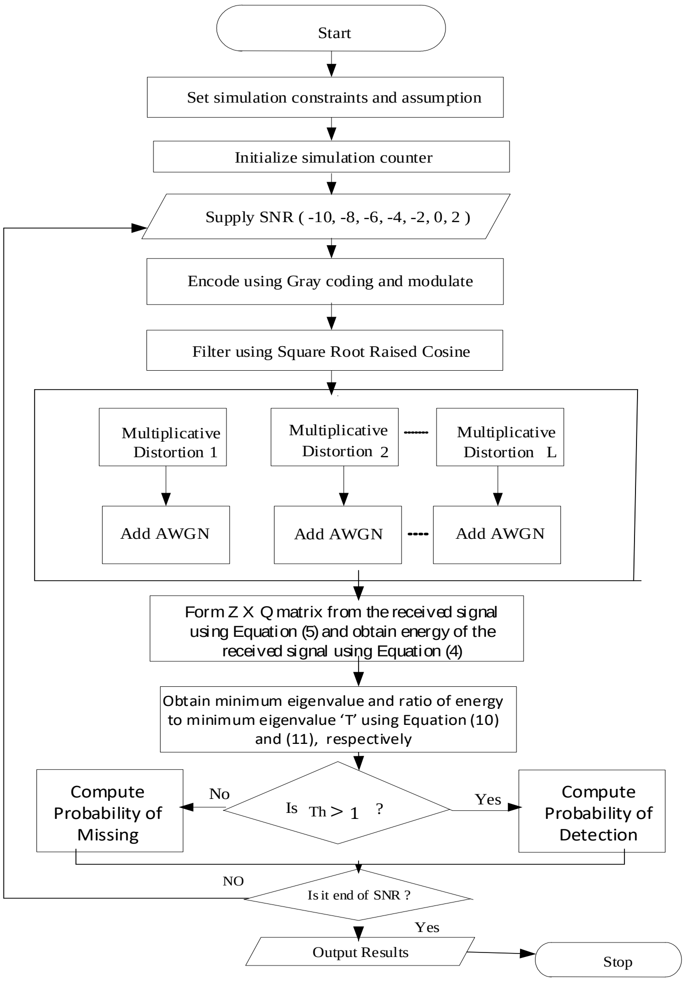

Figure 1. Flowchart of simulation process for the proposed technique

Table 1. Simulation parameters for the developed technique

| Parameters | Type |
|---|---|
| Modulation scheme at LU | Quadrature Amplitude Modulation |
| Channel | Nakagami-m |
| Noise | AWGN |
| Signal to Noise Ratio | (-10:2:2) |
| Number of LU antenna | 1 |
| Number of ULU antenna | 2, 3, 4 |
| Carrier frequency | 1800 MHz |
| Transmit filter | Square Root Raised Cosine |
| Receiver matched filter | Square Root Raised Cosine |

## 3. SIMULATION RESULTS

In this paper, the existing MASS represents the work of [10], while improved MASS represent the proposed technique. Figs. 2 to 4 present the PD against SNR for the improved MASS and existing MASS at varying number of branches (L). PD against SNR for the improved and existing MASS at L = 2 is presented in Fig. 2. The PD values at SNR of -10 dB are 0.5920 and 0.4896 for the improved MASS and existing MASS, respectively, while at SNR of -2 dB, 0.6725 and 0.5635 are the corresponding PD values obtained. PD against SNR for the improved and existing MASS technique at L = 3 is presented in Fig. 3. At SNR of -10 dB, 0.7074 and 0.5874 are the PD values obtained for the improved and existing MASS, respectively, while 0.8067 and 0.6763 are the corresponding values obtained at SNR of -2 dB. The results obtained reveal that, at all the SNRs considered, improved MASS gives the better performance with higher detection rate than the EMASS. The better performance of the improved technique is due to ratio of energy to minimum eigenvalue used in the proposed technique which avoids setting of thresholds based on noise variance. At a low signal strength, noise variance cannot be accurately estimated, thereby resulting in low detection rate. Also, for the two techniques, rate of detecting WS increases as SNR increases and this is as a result of increase in detection rate as strength of the signal increases. Fig. 4 presents PD against SNR for the improved and existing MASS at L = 4. The values of PD obtained at SNR of -10 dB are 0.8592 and 0.7128 for the improved MASS and existing MASS, respectively, while at SNR of -2 dB, 0.9783 and 0.8211 are the corresponding values obtained. The results obtained reveal that detection rate increases as the number of branches increase for the two techniques and this is as a result of increase in signal strength as the number of paths increases. However, at all the number of branches considered, improved MASS shows better performance with higher detection rate than the existing MASS and this is due to noise uncertainty affecting sensing accuracy when the setting of threshold is based on the noise variance.

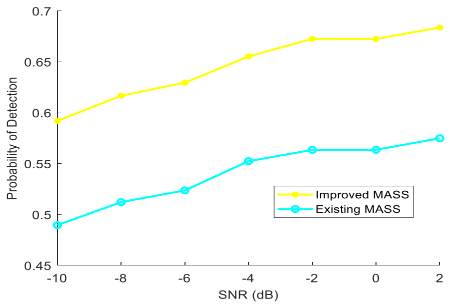

Figure 2. PD against SNR for Improved and Existing MASS at L = 2

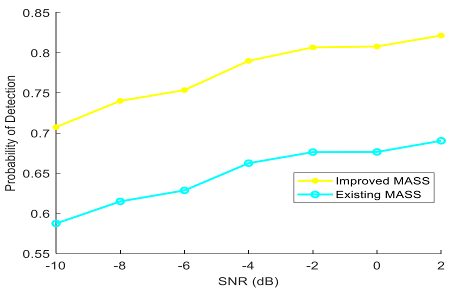

Figure 3. PD against SNR for the Improved and Existing MASS at L = 3

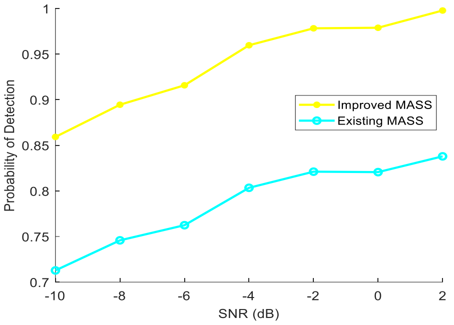

Figure 4. PD against SNR for the Improved and Existing MASS at L = 4

Figs. 5 to 6 depict the Total Error Probability (TEP) versus SNR for the improved MASS and existing MASS at varying number of paths (L). Fig. 5 presents TEP versus SNR for the improved and existing MASS at L = 2. At SNR of -10 dB, 0.5080 and 0.5204 are the TEP values obtained for the improved MASS and existing MASS, respectively, while the corresponding values obtained at SNR of -2 dB are 0.4275 and 0.4465. TEP versus SNR for the improved and existing MASS technique at L = 3 is presented in Fig. 6. At SNR of -10 dB, TEP values of 0.3926 and 0.4226 are obtained for the improved and existing MASS, respectively, while 0.2933 and 0.3337 are the corresponding TEP values obtained at SNR of -2 dB. The results obtained reveal that, at all the SNR considered, improved MASS gives better performance than the existing MASS with lower error rate. The better performance of the improved technique is due to ratio of energy to minimum eigenvalue used in the proposed technique without setting of the threshold based on noise variance. Also, for the two techniques, TEP reduces as SNR increases and this is due to reduction in error as the strength of signal increases. TEP versus SNR for the improved and existing MASS at L = 2 is depicted in Fig. 7. The TEP values obtained at SNR of -10 dB are 0.2408 and 0.2972 for the improved and existing MASS, respectively, while at SNR of -2 dB, 0.1217 and 0.1889 are the corresponding TEP values obtained for the improved and existing MASS, respectively. The results obtained reveal that error rate reduces as the number of paths increase for the two techniques and this is due to increase in strength of signal as the number of branches increases. However, at all the number of branches considered, improved MASS gives better performance with low error rate than the existing MASS and this is due to noise uncertainty that increases error rate. The results presented for all the paths and SNR considered are also contained in Tables 2 and 3.

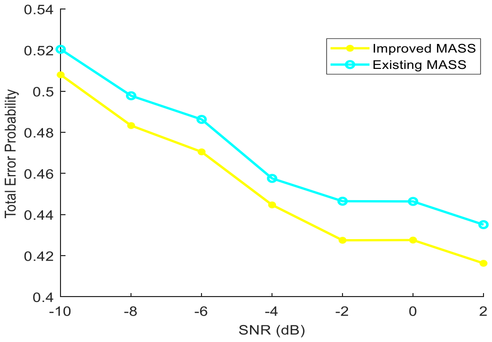

Figure 5. TEP against SNR for Improved and Existing MASS at L of 2.

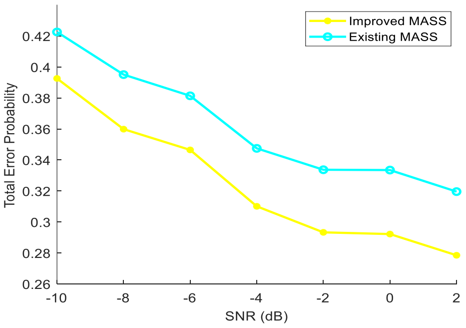

Figure 6. TEP against SNR for Improved and Existing MASS at L = 3.

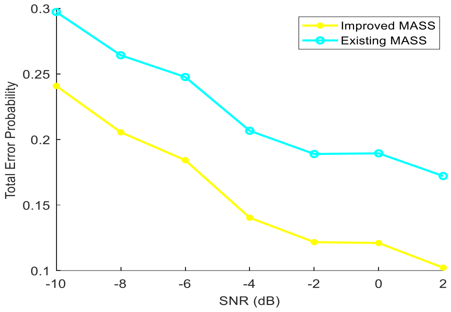

Figure 7. TEP against SNR for Improved and Existing MASS at L of 4

Table 2. Probability of Detection for the Improved and Existing MASS at L = 2, 3 and 4.

| SNR | L = 2 | | L = 3 | | L = 4 | |
|---|---|---|---|---|---|---|
| | Improved MASS | Existing MASS | Improved MASS | Existing MASS | Improved MASS | Existing MASS |
| -10 | 0.5920 | 0.4896 | 0.7074 | 0.5874 | 0.8592 | 0.7128 |
| -8 | 0.6167 | 0.5122 | 0.7401 | 0.6149 | 0.8945 | 0.7458 |
| -6 | 0.6295 | 0.5237 | 0.7535 | 0.6286 | 0.9158 | 0.7624 |
| -4 | 0.6553 | 0.5524 | 0.7899 | 0.6625 | 0.9597 | 0.8034 |
| -2 | 0.6725 | 0.5635 | 0.8067 | 0.6763 | 0.9783 | 0.8211 |
| 0 | 0.6724 | 0.5636 | 0.8078 | 0.6765 | 0.9789 | 0.8206 |
| 2 | 0.6837 | 0.5749 | 0.8215 | 0.6904 | 0.9978 | 0.8379 |

Table 3. Total Error Probability for Improved and Existing MASS at L of 2, 3 and 4.

| SNR | L = 2 | | L = 3 | | L = 4 | |
|---|---|---|---|---|---|---|
| | Improved MASS | Existing MASS | Improved MASS | Existing MASS | Improved MASS | Existing MASS |
| -10 | 0.5080 | 0.5204 | 0.3926 | 0.4226 | 0.2408 | 0.2972 |
| -8 | 0.4833 | 0.4978 | 0.3599 | 0.3951 | 0.2055 | 0.2642 |
| -6 | 0.4705 | 0.4863 | 0.3465 | 0.3814 | 0.1842 | 0.2476 |
| -4 | 0.4447 | 0.4576 | 0.3101 | 0.3475 | 0.1403 | 0.2066 |
| -2 | 0.4275 | 0.4465 | 0.2933 | 0.3337 | 0.1217 | 0.1889 |
| 0 | 0.4276 | 0.4464 | 0.2922 | 0.3335 | 0.1210 | 0.1894 |
| 2 | 0.4163 | 0.4351 | 0.2785 | 0.3196 | 0.1022 | 0.1721 |

## 4. CONCLUSION

In this paper, an improved MASS for detecting the WS in a SSS is proposed. Multiple ULU antennas are used to receive multiple copies of LU signals. The received signals are used to form covariance matrix to determine the minimum eigenvalue of the received signal. The ratio of energy to minimum eigenvalue of the signal received is obtained and used as test statistics to determine the availability of WS. The multiple LU signals are received at different number of antennas (L = 2, 3 and 4) to investigate effect of increasing the number of paths on the proposed IMASS technique. PD and TEP values for the improved and existing MASS are obtained at different SNRs with different number of paths. Performance of the improved and existing MASS have been evaluated at different number of paths with different SNRs using PD and TEP as performance metrics. The results obtained reveal that the proposed MASS shows better performance than existing MASS due to higher detection rate and lower error rate. The better performance of the proposed technique is due to ratio of energy to minimum eigenvalue used without setting the threshold on noise variance. Also, for the two techniques, PD increases as SNR increases, while TEP reduces as SNR increases. This is due to increase in LU signal strength as SNR increases. Consequently, the proposed technique will be effective in detecting LU signal with low sensing error.

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