Threshold Based Censoring of Cognitive Radios in Rician Fading Channel with Perfect Channel Estimation

M. Ranjeeth and S. Anuradha(✉)

National Institute of Technology, Warangal 506004, Telangana, India
ranjithamamidi2001@gmail.com, anuradha@nitw.ac.in

Abstract. In this paper, we have discussed about the performance analysis and comparison between hard decision (majority rule) logic and soft decision (maximal ratio combining) logic on cooperative spectrum sensing network using censoring scheme. We are assuming that both sensing channel and reporting channel are affected by Rician fading. Due to presence of fading in the channels, the information received at the fusion center is erroneous. Threshold based censoring scheme is used to eliminate the heavily faded cognitive radios in reporting channel. Majority logic and maximal ratio combining (MRC) schemes are applied individually at fusion center to make final decision about primary user. Finally, the performance is evaluated in terms of missed detection probability (Q_m) &total error probability $\left(Q_m + Q_f\right)$ using majority logic and MRC rule at fusion center. Simulations are performed with perfect channel estimation by varying the network parameters like probability of false alarm $\left(P_f\right)$, S-channel SNR, R-channel SNR, Rician fading parameter (K) and number of CR users (N). Comparison table between majority logic and MRC rule is provided to know which fusion rule performs better under Rician fading.

Keywords: Co-operative spectrum sensing · Censoring · Energy detection · Majority logic · Maximal ratio combining · Rician fading

1 Introduction

The emerging new technologies and applications of wireless communication increase the uses of radio spectrum. To make good usage of spectrum, unused spectrum band also should be used in proper manner. Various reports on spectrum utilization have shown that the spectrum is inefficiently utilized. This means that there is ample opportunity to find many vacant spaces in the radio spectrum. In [1], to tackle the problem of spectrum underutilization they proposed a flexible spectrum models rather than fixed spectrum models. The main aim of the spectrum sensing (SS) is to detect the spectrum holes when the information about primary signal is unknown. Energy detection (ED) is relevant detection scheme that is used when the primary signal is unknown, because of most simple and non-coherent detector [2]. In spectrum sensing, detection performance is limited due to single cognitive radio (CR) user is present in the network, moreover due to fading and shadowing present in the environment. To overcome these drawbacks

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co-operative spectrum sensing (CSS) [3] concept is introduced, where primary user (PU) is detected by multiple numbers of CRs, hence, detection probability of PU increases. These multiple number of CRs senses the PU individually and stores the information with them using sensing channel (S-channel). Fusion center (FC) collects the sensing information stored by individual CRs through reporting channel (R-channel). FC makes final decision about PU using hard decision (majority logic) rule and soft decision (MRC rule) rule individually [4].

However, most of the literature work exist on CSS is done by assuming noiseless R-channels [5]. But, in practical situations R-channels may not be noiseless (ideal) channels. There may be a chance to occur fading effect in R-channel due to this information passed through the R-channel gets affected and information received at FC also erroneous. Due to fading effect, the R-channel links gets heavily faded; this type of radio links has to be eliminated to improve the detection probability and to decrease system complexity. So, Threshold based censoring scheme is used to eliminate heavily faded R-channel radio links. The idea of censoring scheme is initiated and implemented on CSS in cognitive radio network in 2007 [6]. In [7] sensor network with impact of channel estimation error is described. Threshold-based censoring scheme is applied on CR users, whose R-channel fading coefficients exceed a pre-determined threshold. In [8], censoring scheme is used to overcome the drawback of overhead traffic at FC. By

Table 1. Comparison between majority logic and MRC fusion rules with perfect channel estimation using various network parameters at threshold value C_{th} = 1.0.

		Perfect channel		
Parameters		Q_m	Q_f	Total Error
1.	R-SNR = −9 dB (Majority)	0.0512	0.0395	0.0907
	R-SNR = − 9 dB (MRC)	0.0288	0.0233	0.0521
	R-SNR = −7 dB (Majority)	0.0264	0.0217	0.0481
	R-SNR = −7 dB (MRC)	0.0178	0.0127	0.0305
2.	S-SNR = 20 dB (Majority)	0.0264	0.0217	0.0481
	S-SNR = 20 dB (MRC)	0.0178	0.0127	0.0305
	S-SNR = 15 dB (Majority)	0.0753	0.0677	0.1430
	S-SNR = 15 dB (MRC)	0.0651	0.0615	0.1266
3.	P_f = 0.05 (Majority)	0.0264	0.0217	0.0481
	P_f = 0.05 (MRC)	0.0178	0.0127	0.0305
	P_f = 0.0005 (Majority)	0.0472	0.0397	0.0869
	P_f = 0.0005 (MRC)	0.0395	0.0386	0.0781
4.	N = 30 (Majority)	0.0512	0.0395	0.0907
	N = 30 (MRC)	0.0288	0.0233	0.0521
	N = 15 (Majority)	0.1340	0.0839	0.2179
	N = 15 (MRC)	0.0739	0.0743	0.1482
5.	K = 6 (Majority)	0.0393	0.0307	0.0700
	K = 6 (MRC)	0.0241	0.0127	0.0368
	K = 3 (Majority)	0.0512	0.0395	0.0907
	K = 3 (MRC)	0.0288	0.0233	0.0521

using this paper our contribution to the existing literature is that both S-channel and R-channel are affected by Rician fading and Threshold based censoring scheme is applied in R-channel to eliminate the heavily faded radio links. Performance comparison between majority logic and MRC rule is provided by varying several network parameters using perfect channel estimation in Table 1. Finally, we have investigated the performance using Q_m and $Q_m + Q_f$ with perfect channel estimation by varying the network parameters: S-channel SNR, R-channel SNR, false alarm probability (P_f), Rician fading parameter (K) and number of available CR users (N).

The rest of the paper is arranged as follows. The energy detection (ED) system model, CSS network, majority rule and MRC logic are discussed in Sect. 2. The discussion about simulation results are presented in Sect. 3, conclusions are provided in Sect. 4.

2 System Model

The below Fig. 1 represent the energy detection (ED) block diagram. The signal from the transmitter is first received i.e. x(t), it passed through the band pass filter (BPF) to limit the noise variance of the signal, then filtered signal is given to non–linear device called square law device. Due to filter action the filtered signal is band-limited and signal has a flat spectral density. The output of the square law device is given to the integrator block; it measures the energy of the received signal for a particular duration of time interval (T). Integrator output (Y), is compared with a pre-defined fixed threshold (λ) to make final decision about the PU [3]. The output of the threshold block produces two hypothesis H_0 & H_1 represent the absence and presence of PU. The test statistics can be given as:

$$T(y) = \frac{1}{N}\sum_{n=1}^{N}\{y(n)\}^2 \tag{1}$$

The received signal $y(n)$ can be shown as below:

$$y(n) = \begin{cases} w(n) & H_0 \\ h * s(n) + w(n) & H_1 \end{cases} \tag{2}$$

Where $s(n)$ is transmitted signal, $w(n)$ is the normal distributed Additive White Gaussian Noise (AWGN) and 'h' is fading coefficient of Rician channel.

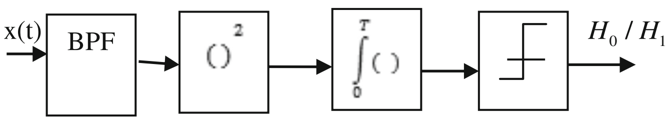

Fig. 1. Energy Detection block diagram

The expressions for probability of false alarm P_f and detection probability P_d over AWGN channels are given respectively [3],

$$P_d = pr(y > \lambda \mid H_1) = Q_m\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \tag{3}$$

$$P_d = pr(y > \lambda \mid H_0) = \frac{\Gamma\left(u, \frac{\lambda}{2}\right)}{\Gamma(u)} \tag{4}$$

where $\Gamma(a,b)$ is the incomplete gamma function [9] and $Q_m(a,b)$ is the generalized Marcum Q-function [10].

The ED compares the output of integrator Y_k with pre-defined detection threshold (λ) then decides the presence of PU. The sensing information about the PU is sent to the FC through R-channel using BPSK signal modulation under Rician faded environment. The signal from k-th CR user received at the FC is:

$$y_k = m_k h_k + n_k \tag{5}$$

where m_k represent the bit energy of the each CR, in case of BPSK signal that bit energy values indicated as ($\sqrt{E_b}$ and $-\sqrt{E_b}$), corresponding H_1 & H_0, respectively. We are considering that R-channel is Rician faded and that fading coefficient h_k is modeled as a zero-mean complex Gaussian random variable with variance, σ^2, i.e., $h_k \sim CN(0, \sigma^2)$ and noise present in the channel is considered as zero-mean complex Gaussian noise with variance, σ_n^2, $n_k \sim CN\left(0, \sigma_n^2\right)$. Let us consider that $n_k \,\&\, h_k$ are mutually independent. Fading coefficients h_k present in the R-channel are estimated by minimum mean square estimation (MMSE) strategy, then as follows [11]:

$$\hat{h}_{\mathrm{k}} = E[h_k \,/\, y_k] = y_k \frac{\sqrt{E_b}}{E_b + \sigma_n^2} \tag{6}$$

$$\hat{h}_{\mathrm{k}} = E[h_k \,/\, y_k] = h_k \frac{E_b}{E_b + \sigma_n^2} + n_k \frac{\sqrt{E_b}}{E_b + \sigma_n^2} \tag{7}$$

In the above equations, $\hat{h}_{\mathrm{k}}$ represents the estimated value of fading coefficient (h_k) after using MMSE estimation and E_b represents the bit energy of R-channel radio link.

Finally, the channel estimation error $\tilde{h}_k$ can be calculated by taking the difference between the actual fading coefficient and the estimated channel coefficient i.e.$\tilde{h}_k = h_k - \hat{h}_{\mathrm{k}}$. In case of perfect channel, both actual fading coefficient & estimated fading coefficient are equal, hence estimation error is zero. So, estimation error does not show any effect on missed detection probability. Censoring scheme is applied on the estimated channel coefficients. CRs which are greater than predefined threshold, those estimated channel coefficients are selected to transmit through the R-channel to the FC. All these estimated channel coefficients are gathered at FC, it uses majority logic, MRC rule to know the activity of primary user.

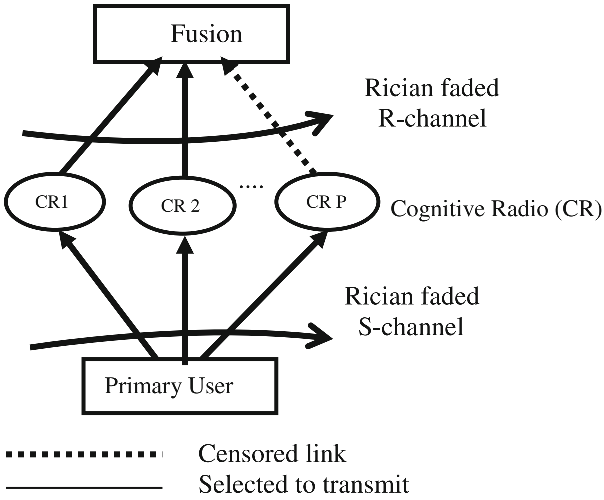

Fig. 2. Cooperative spectrum sensing network with censoring

2.1 Rician Fading

In Fig. 2, we are considering both S-channel and R-channel are affected by Rician fading. Due to Rician fading effect all the radio links present in the network are follows Rician distribution. Then fading coefficients can be generated as [3];

$$|h_k| = |X_1 + jX_2| = \sqrt{X_1^2 + X_2^2} \tag{8}$$

$$X_1 \sim (\mathrm{v}, sigma) \qquad X_2 \sim (0, sigma)$$

$$v = \sqrt{\frac{K}{1+K}} \qquad \text{sigma} = \sqrt{\frac{1}{2(1+K)}} \tag{9}$$

Where ‘K’ is the Rician fading parameter.

Rician distribution PDF given [3],

$$f_y(x) = \frac{K+1}{\overline{\gamma}} \exp\left(-K - \frac{(K+1)\gamma}{\overline{\gamma}}\right) * I_0\left(2\sqrt{\frac{K(1+K)}{\overline{\gamma}}}\right) \tag{10}$$

Where $\overline{\gamma}$ is the average SNR. The average detection probability for Rician channel ($P_{d,Ric}$), can be obtained as:

$$\overline{P}_{dRic}|_{u=1} = Q\left(\sqrt{\frac{2K\overline{\gamma}}{k+1+\overline{\gamma}}}, \sqrt{\frac{\lambda(K+1)}{k+1+\overline{\gamma}}}\right) \tag{11}$$

2.2 Majority Logic Fusion Rule

In hard decision fusion rule, FC receives the one bit information (either '0' or '1') from all CRs. With the aid of censoring scheme in the R-channel, out of '*P*' number of CR users only '*k'* numbers of CRs are received at FC. These '*k'* numbers of CRs send their information to the FC through the R-channel. The receive decision denoted by

$$u_k = \begin{cases} 1 & \textit{if the received decision is} \quad H_1 \\ 0 & \textit{if the received decision is} \quad H_0 \end{cases} \tag{12}$$

where $k \in \{1, 2, \ldots\ldots P\}$. Finally, all the information is collected at FC and majority logic rule can be applied at the fusion center by using below expressions [7];

$$u_0 = \Gamma(u_1 \ldots\ldots u_p) = \begin{cases} H_1 \text{ if } \sum_{k=1}^{\mathrm{p}} u_k \geq \frac{\mathrm{P}}{2} + 1 \\ H_0 \text{ if } \sum_{k=1}^{\mathrm{p}} u_k < \frac{\mathrm{P}}{2} + 1 \end{cases} \tag{13}$$

2.3 Maximal Ratio Combining

In case of soft decision fusion rule all the CRs send their sensing information in the form of energy values to the FC without performing any local decision. MRC logic can be obtained by simplifying LRT fusion rule [9]:

$$\wedge = \prod_{k=1}^{P} \frac{f\left(y_{k,d} \,|\, H_1\right)}{f\left(y_{k,d} \,|\, H_0\right)} \tag{14}$$

$$= \prod_{k=1}^{p} \frac{P_{d_k} + (1 - P_{d_k}) e^{\frac{-4\sqrt{E_b}}{\sigma_w^2} \mathrm{Re}(\mathrm{y_{k,d}} \mathrm{h_k^*})}}{P_{d_k} + (1 - P_{f_k}) e^{\frac{-4\sqrt{E_b}}{\sigma_w^2} \mathrm{Re}(\mathrm{y_{k,d}} \mathrm{h_k^*})}} \tag{15}$$

$$\sigma_w^2 = E_b \sigma_h^2 + \sigma_n^2 = \frac{E_b \sigma_n^2}{E_b + \sigma_n^2} + \sigma_n^2 \tag{16}$$

If the channel is error free i.e. perfect channel then, $\sigma_{\tilde{h}}^2 = 0$ then above Eq. (16) reduces to $\sigma_w^2 = \sigma_n^2$

taking logarithm on both sides to (15) and after simplification, it reduces to

$$\wedge_1 = \log(\wedge) = \frac{2\sqrt{E_b}}{\sigma_w^2} \sum_{k=1}^{K} (P_{d_k} - P_{f_k}) \, \mathrm{Re}(y_{k,d} \, h_k^*) \tag{17}$$

If the selected CRs have identical local performances, $\wedge_1$ can be simplified further as follows:

$$\wedge_{MRC} = \sum_{k=1}^{K} \mathrm{Re}\left(y_{k,d} h_k^*\right) \tag{18}$$

Where h_k^* is the complex conjugate of $\hat{h}_k$. At FC decision can be taken in favor of H_0 or H_1 by comparing $\wedge_{MRC}$ with the threshold zero.

3 Threshold Based Censoring

In case of threshold based censoring scheme, a particular CR can be transmitted if the amplitude of estimated R-channel coefficient is greater than censoring threshold (C_{th}). The cumulative distribution function (CDF) of Rician distributed random variable in terms of C_{th} can be derived as

$$F_{Ric}(C_{th}) \; = \; 1 - Q_1\left(\frac{v}{\sigma}, \frac{C_{th}}{\sigma}\right); \; C_{th} \geq 0 \tag{19}$$

where Q_1 is the Marcum-Q function, $v = \sqrt{\frac{K}{1+K}}, \sigma = \sqrt{\frac{\Omega}{2(1+K)}}$ and 'K' is the Rician fading parameter. Now the probability of selecting a CR in Rician faded R-channel can be derived as

$$p_{ric} = \Pr\left(\left|\hat{h}_k\right| > C_{th}\right) \tag{20}$$

$$1 - F_{ric}(C_{th}) \; = \; Q_1\left(\frac{v}{\sigma}, \frac{C_{th}}{\sigma}\right) \tag{21}$$

Now by using binomial distribution, the probability of selecting '*k'* CRs from '*P'* CRs can be calculated as follows:

$$P(k) = \binom{P}{k} p^k (1-p)^{(P-k)} \tag{22}$$

In above Eq. (22), *P(k)* represents the probability of selecting *k* CRs, *P* is the total number of CR users and *k* is the CRs which are gathered at FC.

4 Results and Discussion

Figure 3 is drawn between the missed detection probability Q_m Vs censoring threshold value C_{th} with perfect channel estimation using threshold based censoring scheme. Following network parameters are considered to simulate this graph: number of CR users N = 30, probability of false alarm P_f = 0.05, S-channel SNR = 20 dB, Rician

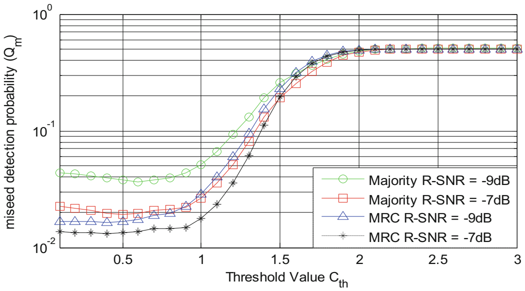

Fig. 3. Missed detection probability versus censoring threshold for various values of R-channel SNR with perfect channel estimation using majority and MRC logic rules at fusion center.

fading parameter (K) = 3 and R-channel SNR = −9 dB & −7 dB in the presence of Rician fading. As C_{th} value increases, Q_m obtain an optimum value, after that it increases with C_{th}, later it attains constant value after reaching a certain value of C_{th}, this is due to changing the value of probability mass function with the threshold value for each CR. We have considered two various values of R-channel SNR (−9 dB & −7 dB), as the R-channel SNR increases, Q_m value decreases in both MRC and majority logic rules because of fading effect present in the R-channel decreases, so that more number of CR users get selected and all these selected CRs passes their sensing information to the FC. After certain value of threshold, Q_m became constant in perfect channel because FC select best R-channel links which are having lowest probability of getting rejected. For a particular value of C_{th} = 0.8, R-channel SNR = −7 dB and MRC logic rule is used at FC instead of majority logic, the Q_m value reduced by 31.42 %.

From above lines we can conclude that MRC achieves lower value of Q_m than majority logic. If R-channel SNR increases from −9 dB to −7 dB, Q_m value decreases by 46.7 % with majority logic and it decreases by 25.1 % with MRC rule at C_{th} = 0.8.

In Fig. 4, comparison between MRC and majority logic with perfect channel estimation is provided for various values of S-channel SNR. Network parameters: N = 30, P_f = 0.05, R-channel SNR = −7 dB, K = 3 and S-channel SNR = 15 dB & 20 dB are used to simulate this graph under Rician fading. As the S-channel SNR increases, Q_m value decreases in both majority and MRC logic fusion rule because of fading effect and noise value in S-channel is decreases. As the fading effect decreases in the S-channel, CRs sense the PU activity more effectively hence, Q_m value decreases. For a particular value of C_{th} = 0.8 and S-channel SNR = 20 dB, Q_m values with majority logic and MRC fusion rules are 0.0215 and 0.0144 respectively. MRC logic achieves least value of Q_m compared to the majority logic. When S-channel SNR value is varying from 15 dB to 20 dB,Q_m value decreases by 68.2 % with majority logic and it decreases by 76.1 % with MRC rule at C_{th} = 0.8. For a particular value of S-SNR = 20 dB and C_{th} = 0.8, the Q_m value reduced by 31.4 % with MRC rule compared to the majority logic rule.

Figure 5 shows that graph between Q_m versus C_{th} value for various values of probability of false alarm P_f with perfect channel estimation under Rician fading. N = 30, R-channel SNR = −7 dB, P_f = 0.05 & 0.0005, (K) = 3 and S-channel

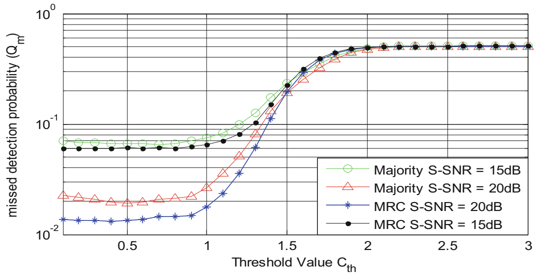

Fig. 4. Missed detection probability versus censoring threshold for various values of S-channel SNR with perfect channel estimation using majority and MRC logic rules at fusion center.

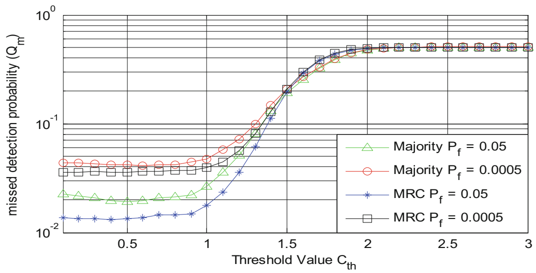

Fig. 5. Missed detection probability versus censoring threshold for various values of probability of false alarm with perfect channel estimation using majority and MRC logic rules at FC.

SNR = 20 dB are considered as network parameters to get Fig. 5. In this case, Q_m achieves constant value of 0.5056 for both majority logic and MRC fusion rule after it reaches C_{th} = 2.0. As P_f value increases from 0.0005 to 0.05,Q_m value decreases in both majority and MRC logic rule. If P_f value increases (from Eq. (4)), the detection threshold value (λ) is decreases for each CR, it improves the detection probability value. As P_f increases, there is a possibility of spectrum utilization becomes low and number of missing opportunities decreases this leads to increases in detection probability. As P_f value varying from 0.0005 to 0.05, Q_m value decreases by 61 % with MRC fusion rule and it decreases by 49.6 % with majority rule at C_{th} = 0.8. For a particular value of P_f = 0.05 and C_{th} = 0.8, the missed detection probability value is reduced by 31.4 % with MRC rule compared to the majority logic rule.

In Fig. 6, the performance comparison between majority logic and MRC fusion strategies are evaluated with perfect channel estimation by varying number of CR users (N). The performance is evaluated for P_f = 0.05, different values of number of CRs N = 15 & 30, K = 3, R-channel SNR = −7 dB and S-channel SNR = 20 dB. As the number of CR users increases, cooperation among the users increases, hence, (Q_m) value decreases in both MRC and majority logic rule. As the number of CR users are increases, the sensing information received from each CR at FC about PU increases, hence, detection performance is increases. For a particular value of C_{th} = 0.8 and N = 15, missed detection probability is more with majority logic (0.1102) compared to

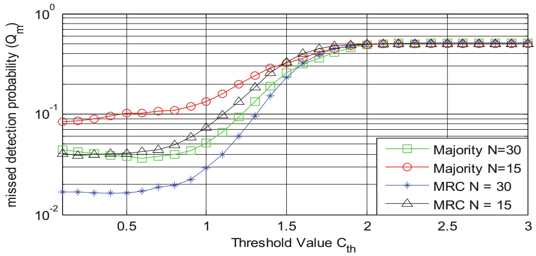

Fig. 6. Missed detection probability versus censoring threshold for various number of CRs with perfect channel estimation using majority and MRC logic rules at fusion center.

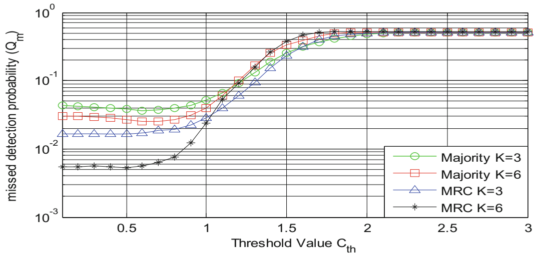

Fig. 7. Missed detection probability versus censoring threshold for various values of Rician fading parameter with perfect channel estimation using majority and MRC logic rules at FC.

MRC logic rule (0.0496), (Q_m) value reduced by 54.9 % with MRC rule compared to the majority logic rule.

Next, we have considered the effect of Rician fading parameter (K) on missed detection probability (Q_m) in Fig. 7. The following factors are used to simulate this graph: N = 30, P_f = 0.05, (K) = 3 & 6, R-channel SNR = −9 dB and S-channel SNR = 20 dB. As the fading parameter (K) increases, Q_m value decreases in both MRC logic rule and majority logic fusion rule because of fading effect and noise value decreases in S-channel and R-channel. As the fading parameter increases, the dominant multipath component power (means line of sight (LOS) wave power) increases, hence, information received at FC will be more perfect; this will increase the detection probability. For a particular value of C_{th} = 0.8 and fading parameter increases from K = 3 to K = 6, Q_m value decreases by 61.5 % with MRC logic rule and it decreases by 32.4 % with majority logic rule. Here also MRC logic has less value of Q_m compared to majority logic. At certain instant, if K = 6 and C_{th} = 0.8, (Q_m) value reduced by 71.8 % with MRC rule compared to the majority logic.

In Fig. 8, Rician fading parameter (K) and number of CRs (N) are considered as variable parameters to evaluate the performance of total error probability $(Q_m + Q_f)$. As 'K' value is increases from 3 to 6 & 'N' value is decreases from 30 to 15, $(Q_m + Q_f)$ decreases by 61.2 % with majority logic and it decreases by 62.2 % with MRC rule with perfect channel estimation at (C_{th}) = 1.0. Though 'K' value increases

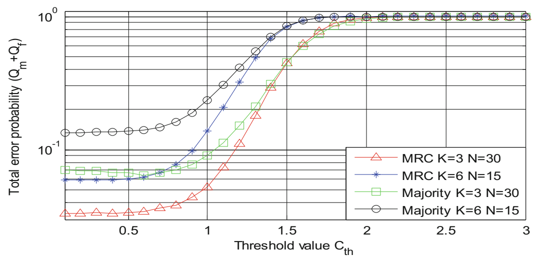

Fig. 8. Total error probability versus censoring threshold for various values of fading parameter (K) and number of CR users (N) with perfect channel estimation using majority and MRC logic rules at fusion center.

and 'N' value decreases, $(Q_m + Q_f)$ value increases because of cooperation among the users are decreases. MRC achieves lower value of total error compared to majority logic. For a particular case, for K = 3, N = 30 and MRC rule is used at FC instead of majority rule, $(Q_m + Q_f)$ value reduced by 42.5 % at C_{th} = 1.0.

The above Table 1 shows that missed detection probability (Q_m),false alarm probability (Q_f) and total error probabilities values and comparison between majority and MRC logic by varying different network parameters like: R-channel SNR, S-channel SNR, probability of false alarm, CR users (N) and Rician fading value (K) with perfect channel estimation. All the above tabulated values are considered at C_{th} = 1.0 under Rician fading channel. The performance of MRC logic is better in terms of missed detection and total error probabilities than majority logic fusion rule. MRC logic achieves lower error values compared to majority logic with perfect channel estimation.

5 Conclusion

In this paper, censoring of cognitive radios (CRs) under Rician fading using energy detection has been investigated in CSS. MRC rule and majority logic fusion rules are applied at FC to decide about primary user activity with perfect channel estimation. The performance is evaluated using missed detection probability (Q_m) & total error probability $(Q_m + Q_f)$. We also observed the effect on (Q_m) & $(Q_m + Q_f)$ by varying the network parameters like: S-channel SNR, R-channel SNR, probability of false alarm (P_f) and Rician fading parameter (K) with perfect channel estimation. Comparison between majority logic and MRC rule is provided and also observed that majority logic is having higher missed detection probability than MRC rule. Finally, we can conclude that the detection performance is increases by using censoring of CRs. This work is useful to reduce the complexity of CSS network, useful to eliminate the unwanted CRs which having lowest threshold value and traffic overhead problem can be avoided.

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