Interference Management in Cognitive Radio Satellite Networks based on Time and Spectrum Sensing

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Abstract— **In this paper, an interference management for multi-beam satellite network to enhance spectral efficiency is studied. First, a two-satellite for future generation satellite network using cognitive radio technology is provided. This network is composed of a secondary satellite and a primary satellite where the primary satellite system does not suffer from severe destructive interferences coming from the secondary satellite system. Upward/downward link power is assumed to be fixed and no power control is used. Therefore, the received data from each beam has a specific level. Also, a novel bandwidth sharing algorithm is provided for the first time. Next, total rate for both primary and secondary satellite systems are computed. Furthermore, Receiver Operating Characteristic (ROC) curve and numerical results based on the number of antennas and threshold levels are given.**

Index Terms— **Satellite communication, cognitive radio, likelihood ratio detector, time sensing, spectrum sensing.**

I. INTRODUCTION

DURING the recent years, resource management was a challenge in next generation satellite networks to share available bandwidth between two or more satellites. Under these circumstances, suitable bandwidth sharing between ground stations and satellite network plays an important role in space communications without any harmful interference [1]- [2]. The goal of next generation wireless communication network such as fifth generation is to integrate the satellite communication network to provide global coverage, multimedia and internet connectivity service and so on [3]- [4]. For this reason, multi-beam satellite system has been proposed to increase spectral efficiency with suitable Quality of Service (QoS) and suitable resource management. This new solution has led to the cognition concept for satellite systems which allocate resources such as spectrum between satellites or satellites and ground stations in the hybrid structure based on satellites and ground stations. One of the major challenges of implementing this technology is that each satellite must accurately monitor and be aware of the presence of the other satellites over a particular bandwidth based on interference threshold level. To address this challenge, there is many solutions for terrestrial networks [5]- [6]. In this paper, an interference threshold level to verify the presence or absent primary satellite system for data transmitting was investigated by the received power of satellites. This threshold level is a common technique to manage interference between satellites. Also, traffic demand based on ultra-wide bandwidth for satellite networks is increasing, to provide some new satellite services, while the space spectrum is becoming scarce in space regulation [7]. Therefore, a novel bandwidth sharing algorithm between primary and secondary satellite systems was provided. In this algorithm, it was assumed that the interference caused by the secondary satellite system did not degrade the performance of the primary satellite system. According to results obtained, space spectrum measurement at different coverage shows that the average used space spectrum rate is very low [8]. Therefore, the space spectrum is time dependent. In this regard [2], cognitive radio technique is a suitable method to improve the satellite spectrum access between two or more satellites [9]- [10]. There are many types of cognitive techniques in the literature, which include underlay/overlay, Spectrum Sensing (SS) and Database (DB) related techniques [7]. In this paper, a new algorithm based on cognitive radio specification is proposed. This algorithm is beam sharing between primary and secondary satellites based on spectrum coexistence. This algorithm is mostly used in the terrestrial architecture but the satellite systems are rarely applied [9]- [11]. The rest of this paper is organized as follows. In Section II, we introduce the role of Cognitive Radio (CR) which it is a kind of technology to identify communication channels are in use or not in use, and instantly move into vacant channels while avoiding occupied ones [12]. In Section III, we explain our satellite system model. In Section IV, we provide a novel bandwidth sharing algorithm for our system model. In Section V, we calculate the total achievable rate for both the primary and the secondary satellite systems based on the total transmission region. Section VI provides simulation results and discussions about the performance of the system model. Finally, Section VII draws our conclusions.

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II. THE COGNITIVE RADIO ROLE IN SATELLITE SYSTEMS

Notably, the CR has more applications in the ground system than the satellite networks which have two or more satellite in space industry [11]. Overall, space cognitive radio techniques allow the coexistence of primary and secondary systems and the same spectrum have no effect on the normal function of the primary licensed systems. In satellite networks scope, the main research related to sharing satellite beams, was considered for the end users [2]- [13]. The available cognitive radio technology related to satellite systems can be classified as that in [9], [14] and [15]. In [16], [17] and [18], a cognitive beam sharing satellite system in which many beams within a large proposed coverage area share available spectrum in the time domain was used. Assuming in this model, only a single beam of proposed coverage area is active during a specific time duration, there are chances to use the other beams which have unused spectrum by another secondary satellite system in the same time duration. In this proposed coverage area, a satellite network including two satellites in different orbits with a primary satellite system with a unique and large beam, and secondary satellite with smaller spot beam, were considered. In the new generation satellite networks, the satellites should be updated based on new technologies to permit more flexibility for new structures and theories by increasing new satellite services demand and users [2]. Thus, the use of cognition solution allows more flexibility for new standards [13]. In [14], the cognitive radio and specific time duration information is taken as a managed interference link to guarantee the proper spectral performance coexistence between primary and secondary satellite systems. Also, the proposed method to interference management adjust transmit power of secondary satellite system to ensure suitable operation of the primary satellite. In recently years, multiple antennas solution in cognitive communication networks were used for one possible techniques in enhancing total rate and resource allocation [18]. It should be noted that, to provide any suitable solution for resource management in satellite communications systems, Fixed Satellite Services (FSS) commonly use C and K band frequencies, but for wide band services and limited C and K bands, Ku and Ka bands are used for mobility satellite services [9] and [15].

III. A TWO-SATELLITE NETWORK MODEL

The cognitive radio satellite communication networks can be classified as providing satellite services in different orbital altitudes including Geostationary Earth Orbit (GEO) or Medium Earth Orbit (MEO) for wireless communication such as satellite mobile or internet as shown in Fig.1, the considered bandwidth for this satellite network is applied in Ka-band. Based on cognitive radio concept and assumption in this system model, the primary satellite system is the GEO satellite and the secondary can be other types such as GEO or LEO satellites. As shown in Fig.1, a two-satellite network composed of one primary satellite and one secondary satellite is assumed. The primary satellite system has K transmitting antennas and each antenna transmits s symbols. Also, the secondary satellite system has L transmitting antennas and each antenna transmits u symbols s $>$ u. Furthermore, the coverage area includes a number of large primary beams, each of which is divided into many small spot-beams [18]- [19]. For managing interference, the duration of each transmitting frame includes many symbols normalized to unity for primary and secondary satellite systems. It is obvious that long time intervals improve the protection of the primary satellite system against interference from the secondary satellite system otherwise it allows the secondary satellite system to transmit more symbol. Now, we suppose that there is two different situations as follows:

- If the primary satellite system is absent based on threshold level η which will be explained in the next section, the secondary satellite system will send frame over the first time interval T-μ. In the receiver side, the secondary satellite system will receive frame during the remaining μ time interval.
- But, the secondary satellite system will cause interference to the primary satellite system if the primary satellite system transmits symbols while the secondary satellite system is active which is determined based on threshold level η again. In this situation, this problem can be resolved by sending a timing pilot frame (time sensing) which it includes information about data transmission by primary satellite system. Therefore, data transmission is stopped by secondary satellite system and the following frames are used for sensing only until the primary satellite system is sensed absent again [20]. Since the primary satellite system only uses a small portion of the primary beams, the rest of the primary beams are unusable when symbol is to be sent. In this scenario, a secondary satellite system within the same spectrum without destructive interference was proposed for primary satellite system. Also, the cognition is achieved by sharing the timing information of the primary satellite system to the secondary satellite system using a signaling link between them. The timing information is exchanged to guarantee the proper synchronization of the primary and secondary transmit

symbols. For this reason, the secondary satellite system dynamically adapts its bandwidth pattern ensuring the proper operation of the primary satellite system. In this paper, the signaling method is Orthogonal Frequency Division Multiple Access (OFDMA) which can be used to send data by primary satellite system for small part of beam region while beam is used and in active mode. Each receiver antenna for primary satellite system has the additive Gaussian noise with zero-mean. Let $\mathbf{Y}$ be the received signal in each ground cell from primary satellite and $\mathbf{Y}'$ is received symbol in each ground cell from secondary satellite transmitter (1).

$$\begin{aligned} &\mathbf{Y}_{primary.satellite.system} = \\ &[y_{1\times1}, y_{1\times2}, y_{1\times3}, \ldots\ldots, y_{1\times K}] \in \mathbf{C}^{K\times s} \\ &\acute{\mathbf{Y}}_{secondary.satellite.system} = \\ &[y'_{1\times1}, y'_{1\times2}, y'_{1\times3}, \ldots\ldots, y'_{1\times L}] \in \mathbf{C}^{L\times u} \end{aligned} \tag{1}$$

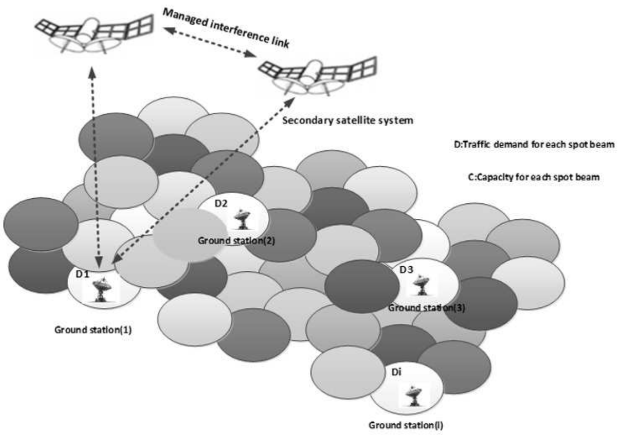

Fig. 1. A two-satellite network model using CR technology.

Now, it is assumed that two multi-beam satellite systems have common beams that overlap with each other based on a specific region. But the primary satellite system has a larger beam than the secondary satellite system. Since the primary satellite only illuminates a small fraction of a specification beam in active mode and the large remaining part of the beams remain idle, therefore, the primary satellite system can be permitted by sharing the space spectrum or bandwidth coexistence with the secondary satellite system. This is suitable to improve total rate to provide satellite services. Space frequency evaluation is usually evaluated based on the ROC curves. These ROC curves show the probability of miss detection (P_m) which is the probability that the cognitive radio fails to detect the presence of the primary satellite system versus the probability of false alarm (P_f) which is the probability that the cognition technology puts the primary satellite system in active mode, but secondary in inactive mode. In [21], the space interference caused by primary satellite symbols on the secondary satellite symbols was considered. This type of problem which is related to spectrum management techniques and formulations is not taken into account. But in this paper, spectrum management is shown as a binary testing problem with hypothesis $\mathbf{H}_0$ and $\mathbf{H}_1$ defined as the following equations [18]:

- If primary user is not in operation:

$$\mathbf{H}_0 : \mathbf{Y} \in \mathrm{C}^{K\times s} \sim \ CN(0, {\sigma_n}^2 \mathbf{I}_K), \tag{2}$$

- If primary user in operation:

$$\mathbf{H}_1 : \mathbf{Y} \in \mathrm{C}^{K\times s} \sim \ \mathrm{C}N(0, {\sigma_s}^2 \mathbf{h}\mathbf{h}^H + {\sigma_n}^2 \mathbf{I}_K), \tag{3}$$

where $\mathbf{h} \in C^{K\times1}$ denotes the space channel gain vector between satellite system and K antennas, σ_s^2 is the power of fading component and σ_n^2 is additive Gaussian noise, the secondary satellite system recognizes the space channel gain vectors and noises. Therefore, under $\mathbf{H}_0$ the Probability Density Function (PDF) of observation $\mathbf{Y}$ is as follows:

$$f(\mathbf{Y}; \mathbf{H}_0, {\sigma_n}^2) = \prod_{l=1}^{L} \frac{\exp\left(-\frac{1}{{\sigma_n}^2} \times {y_l}^H \times y_l\right)}{(\pi \times {\sigma_n}^2)^M}. \tag{4}$$

Similarly, from (4) under the hypothesis $\mathbf{H}_1$, the PDF can be written as:

$$f(\mathbf{Y}; \mathbf{H}_1, \mathbf{h}, {\sigma_n}^2, {\sigma_s}^2) = \prod_{l=1}^{L} \frac{\exp(-{y_l}^H \times \mathbf{R}^{-1} \times y_l)}{\pi^M \times \det(\mathbf{R})}, \tag{5}$$

where $\mathbf{R} = E\left[\mathbf{Y}\mathbf{Y}^H | \mathbf{H}1\right] = {\sigma_s}^2 \times \mathbf{h} \times \mathbf{h}^H + {\sigma_n}^2 \times \mathbf{I}$, $\det(\mathbf{R}) = ({\sigma_s}^2 \times ||\mathbf{h}||^2 + {\sigma_n}^2) \times \left({\sigma_n}^2\right)^{(M-1)}$.
Also by applying the matrix inversion lemma [22]:

$$\mathbf{R}^{-1} = {\sigma_n}^{-2} \times \mathbf{I} - {\sigma_n}^{-2} \times \frac{\mathbf{h} \times \mathbf{h}^H}{\frac{{\sigma_n}^2}{{\sigma_s}^2} + ||\mathbf{h}||^2}. \tag{6}$$

For having an optimal detector based on absent or present primary satellite system in Neyman-Pearson sense, we need to compare the Likelihood Ratio (LR) function with a threshold η is shown as:

$$LR = \ln \frac{f(\mathbf{Y}; H_1, \mathbf{h}, {\sigma_n}^2, {\sigma_s}^2)}{f(\mathbf{Y}; \mathbf{H}_0, {\sigma_n}^2)} > \eta \rightarrow H_1, \tag{7}$$

$$LR = \ln \frac{f(\mathbf{Y}; H_1, \mathbf{h}, {\sigma_n}^2, {\sigma_s}^2)}{f(\mathbf{Y}; \mathbf{H}_0, {\sigma_n}^2)} < \eta \rightarrow H_0.$$

Considering that in the optimal detector, the channel gains, noise and primary satellite system variance are known. By applying straightforward simplifications, the optimal detector can be obtained as follows:

$$\eta \approx \frac{L \times \ln(\frac{{\sigma_n}^2}{{\sigma_s}^2} \times ||\mathbf{h}||^2 + 1)}{(\frac{{\sigma_n}^2}{{\sigma_s}^2} + ||\mathbf{h}||^2) \times {\sigma_n}^2}. \tag{8}$$

Obviously, in the above definition, one has to differentiate between the active (and the inactive) of the primary satellite system and the secondary satellite system i.e., the decision made by spectrum management. Finally, P_m and P_f were formulated as [23]- [24]:

$$P_m = P(\mathbf{H}_0|\mathbf{H}_1), \tag{9}$$

$$P_f = P(\mathbf{H}_1|\mathbf{H}_0). \tag{10}$$

The conditional probability in (9), denotes the probability that the secondary satellite system fails to detect the absence of the primary transmission. Also, equation (10) determines the probability that the secondary fails to detect the presence of the primary satellite transmission. In a non-fading environment where **h** is deterministic variable, the detection probability (P_d) is obtained according to the equation [18].

$$P_d = \frac{\Gamma\left(L, \frac{\eta}{||\mathbf{h}||^2 \times {\sigma_n}^2 \times (1+\gamma)}\right)}{\Gamma(L)}, \tag{11}$$
$$\gamma = \frac{{\sigma_s}^2 \times ||\mathbf{h}||^2}{{\sigma_n}^2},$$

where $P_d = 1 - P_m$, $\Gamma(a, x)$ is the upper incomplete and $\Gamma(a)$ is the complete gamma function, respectively [24], [25] and [26].

$$\Gamma(a, x) = \int_x^\infty t^{a-1} \times e^{-t} dt, \tag{12}$$
$$\Gamma(a) = \int_0^\infty t^{a-1} \times e^{-t} dt.$$

Also, $G(\eta) = 1 - P_f$ and $G(.)$ is the function of the decision statistic.

IV. A NOVEL BANDWIDTH SHARING ALGORITHM

In our system model, we assume that satellites have a bandwidth sharing algorithm. Each beam in this model has a specific value between B_{max} and B_{min} based on Space Service Level Agreements (SSLAs). Also, the spectrum sensing in our assumption is ideal and data transmission between primary and secondary satellite systems will not interfere with each other. As illustrated in Fig.2, in this step, secondary satellite system connects to a ground station and the primary satellite system connection. If the bandwidth is unused, the primary and secondary satellite systems synchronous transmissions will not interfere with each other.

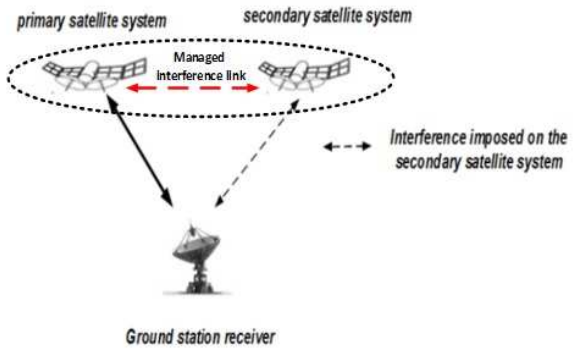

Fig. 2. Transmission symbols between the primary and the secondary satellite systems.

As the first step, the following assumptions are provided for bandwidth sharing algorithm:

1) The minimum required bandwidth of the i^{th} beam of the primary satellite system is $B1_{min}$.
2) The minimum required bandwidth of the i^{th} beam of the secondary satellite system is $B2_{min}$ which $B1_{min} \geq B2_{min}$.
3) The maximum bandwidth of the i^{th} beam of the primary satellite system is $B1_{max}$.
4) The maximum bandwidth of the i^{th} beam of the secondary satellite system is $B2_{max}$ which $B1_{max} \geq B2_{max}$.
In the second step, bandwidth sharing between two satellite systems is very important to enhance spectral efficiency. In this section, we show an algorithm to share additional bandwidth of the primary satellite system with the secondary satellite system which needs more bandwidth based on the SSLAs. In the proposed algorithm, $B1_{init}$ and $B2_{init}$ are the first bandwidth for each beam in primary and secondary satellite systems, respectively.

First step, compare $B1_{min}$ and $B1_{init}$:
If $B1_{min} < B1_{init}$, the additional bandwidth for primary satellite system $(B1_{PSS})$ is:

$$B_{additional} = B1_{init} - B1_{min}, \tag{13}$$
$$B1_{PSS} = B1_{min}.$$

Second step, based on priority beams which was specified in SSLAs:
If $B2_{min} > B2_{init}$, the additional required bandwidth for secondary satellite system $(B2_{SSS})$ is:

$$B2_{required} = B2_{min} - B2_{init}. \tag{14}$$

If $B_{additional} > B2_{required}$, the bandwidth for secondary satellite system $B2_{SSS}$ can be obtained according to the following equation:

$$B'_{additional} = B_{additional} - B2_{required}, \qquad (15)$$
$$B2_{SSS} = B2_{init} + B2_{required}.$$

Third step, based on the following constraints in SSLAs, the primary satellite system performance is not degraded:

$$B2_{min} \leq B2_{SSS} \leq B2_{max}, \qquad (16)$$
$$B2_{SSS} \leq B1_{min}.$$

V. ACHIEVABLE RATE OF THE COGNITIVE SATELLITE NETWORK

First, the attainable rate of the primary link was formulated by assuming the secondary satellite system transmission as a source of interference. Therefore, the attainable rate was based on operating point (P_m, P_f) over the ROC curve. Based on the above assumptions, the total rate achieved by the primary and secondary satellite systems was formulated.

A. Achievable rate for primary satellite system

First, it is assumed that the primary satellite system uses a fraction α of the Total Transmission Region (TTR) in our system model. Fig.3 shows the TTR that the fraction α used in the primary satellite system. In the current study model, the secondary satellite system tries to detect the presence of the data from primary satellite system in a fraction $\alpha \times P_m$ when spectrum sensing is imperfect. Consequently, total transmission region for satellite systems is divided as:

- α×(1-P_m) region: only primary satellite system transmission,
- α×P_m region: common primary and secondary satellite system transmission leading to interference,
- (1-α)×(1-P_f) region: only secondary satellite system transmission,
- (1-α)×P_f region:not used for transmission.

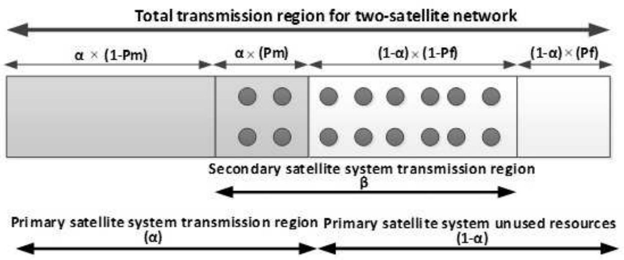

Fig. 3. Total transmission region for satellite.

The attainable rate for the primary satellite system using a fraction α of TTR can be written as [27]:

$$R_{PSS} = \alpha \times \log(1 + \frac{S^{PSS} \times |\mathbf{h}|^2}{\alpha \times N_0^{PSS}}), \qquad (17)$$

where S^{PSS} is the received power of primary satellite system over the primary satellite system transmission region and (${N_0}^{PSS}$) is the variance of the additive white Gaussian noise at the primary satellite system. Note that the the attainable rate is obtained when the spectrum sensing is ideal. However, in practice, spectrum sensing is imperfect. In $\alpha \times P_m$ region, the transmission region of the primary satellite system interferes with the secondary satellite system. Therefore, the achievable rate of the primary satellite is written as:

$$R'_{PSS} = R^{PSS}_{common} + R^{PSS}_{independent}, \qquad (18)$$

where ($R^{PSS}_{independent}$) is the achieved rate in fraction $\alpha \times (1 - P_m)$ region of TTR and R^{PSS}_{common} is the achieved rate in $\alpha \times P_m$ region when the secondary satellite system interferes with the primary satellite system $(\beta = ((1 - \alpha) \times (1 - P_f)) + \alpha \times P_m)$. Consequently, we have:

$$R^{PSS}_{independent} = \alpha \times (1 - P_m) \times \qquad (19)$$
$$\log(1 + \frac{S^{PSS} \times |\mathbf{h}|^2}{\alpha \times N_0^{PSS}}),$$
$$R^{PSS}_{common} = \alpha \times P_m \times$$
$$\log(1 + \frac{S^{PSS} \times |\mathbf{h}|^2}{\alpha \times (I^{SSS} + N_0^{PSS})}),$$
$$I^{SSS} = \frac{S^{SSS} \times |\mathbf{h}|^2}{((1 - \alpha) \times (1 - P_f)) + \alpha \times P_m},$$

where (S^{SSS}) is the received power of secondary satellite system over the primary satellite system and I^{SSS} is the power of the interference due to imperfect spectrum management from the secondary satellite system on the primary satellite system (I^{SSS} is equal to total interferences in secondary satellite system transmission region from primary satellite system). Moreover in (19), we considered an AWGN model for the I^{SSS}.

B. Achievable rate for secondary satellite system

Second, the achievable rate for the secondary satellite system can be written as:

$$R_{SSS} = (1 - \alpha) \times \log(1 + \frac{S^{SSS} \times |\mathbf{h}|^2}{(1 - \alpha) \times N_0^{SSS}}). \qquad (20)$$

Note that the achievable rate is obtained when the spectrum sensing is ideal. Now, under imperfect spectrum sensing, the total rate in fraction β of the TTR in our system model is given by:

$$R'_{SSS} = R^{SSS}_{common} + R^{SSS}_{independent}, \tag{21}$$

where (R^{SSS}_{common}) is the rate obtained by the secondary satellite system when the primary satellite system is considered as interference (i.e., $\alpha \times P_m$ region in Fig.3) and $R^{SSS}_{independend}$ is the achievable rate of the secondary satellite system in a fraction of TTR without any interference from the primary satellite system (i.e., 3 $(1-\alpha) \times (1-P_f)$ region in Fig. 3). Therefore, the rate of each part can be obtained as:

$$\begin{aligned} R^{SSS}_{common} &= \alpha \times P_m \times \\ \log(1 &+ \frac{S^{SSS} \times |\mathbf{h}|^2}{\beta \times (I^{PSS} + N_0^{PSS})}), \\ I^{PSS} &= \frac{S^{PSS} \times |\mathbf{h}|^2}{\alpha \times (1-P_m) + \alpha \times (P_m)}, \end{aligned} \tag{22}$$

$$\begin{aligned} R^{SSS}_{independent} &= (1-\alpha) \times (1-P_f) \times \\ \log(1 &+ \frac{S^{SSS} \times |\mathbf{h}|^2}{\beta \times N_0^{SSS}}), \end{aligned} \tag{23}$$

where I^{PSS} is the power of the interference imposed by the primary satellite system transmission when the secondary satellite system use the same transmission region (I^{PSS} is equal to interference in primary satellite system transmission region from secondary satellite system). Again, an AWGN model assumed for the interference I^{PSS} in (22). Therefore, the maximum rate which is formulated as:

$$\begin{aligned} R_{sum} &= R'_{SSS} + R'_{PSS} = \\ \alpha \times (1-P_m) &\times \log(1 + \frac{S^{PSS} \times |\mathbf{h}|^2}{\alpha \times N_0^{PSS}}) + \\ \alpha \times P_m &\times \log(1 + \frac{S^{PSS} \times |\mathbf{h}|^2}{\alpha \times (I^{SSS} + N_0^{PSS})}) + \\ \alpha \times P_m &\times \log(1 + \frac{S^{SSS} \times |\mathbf{h}|^2}{\beta \times (I^{PSS} + N_0^{SSS})}) + \\ (1-\alpha) \times (1-P_f) &\times \log(1 + \frac{S^{SSS} \times |\mathbf{h}|^2}{\beta \times N_0^{SSS}}). \end{aligned} \tag{24}$$

Finally, we notice that under an ideal spectrum sensing without destructive interference characterized by $\beta' = ((1-\alpha) \times (1-P_f))$ and $P_f = 0$, therefore the best value for α and β' is given by:

$$\beta' = 1 - \alpha. \tag{25}$$

VI. SIMULATION RESULTS

In this section, the performance of the proposed algorithm is investigated through extensive simulations under different system parameters [28]. In the present study simulation, the priori probability of the presence of a primary satellite system is $P(\mathbf{H}_1)$ = 0.2 for spectrum management. Fig.4 shows the total (provided by both the primary and the secondary satellite system) achievable rate (in bits/s/Hz) versus the SNR (in dB). It can be seen when the sum rate are about 4 (bits/s/Hz) for with/without interference between primary and secondary satellite systems, the SNR gap from primary satellite system to secondary system is enhanced by only 1.5 dB. As can be seen in Fig.5 and Fig.6, SNR is unchanged but the numbers of the antennas and the transmitter symbols of the primary satellite varies from 2 to 8, respectively. Also, the simulation results show that increasing the number of antennas K, compared to increasing the number of symbol s, has more substantial effect on the system performance.

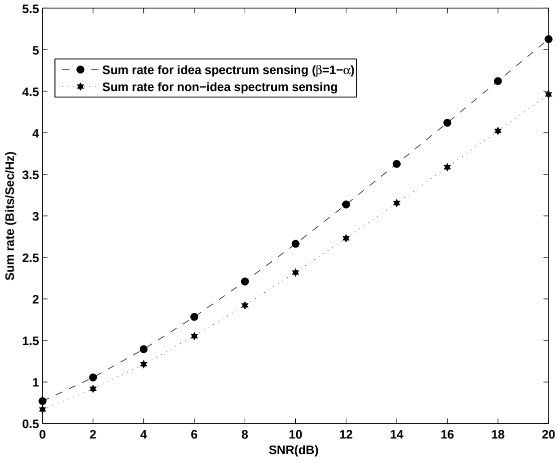

Fig. 4. Sum rate for primary and secondary satellite systems based on ideal and non-ideal spectrum sensing.

Finally, as shown in Fig.7, it can be concluded that false alarm probability decreases while miss detection probability is increased by increasing SNR and the transmission symbols of the primary satellite system.

As discussed in section IV, P_f represents the percentage of the transmission region which is not used. Therefore, the secondary satellite system must reduce the P_f as much as possible. Also, P_m shows the probability that a used transmission region is mistakenly detected.

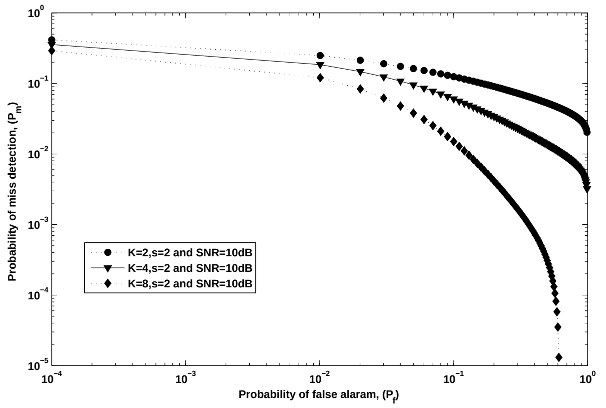

Fig. 5. Probability of miss detection simulation versus probability of false alarm, K= [2,4,8], s= 2 and SNR=10 dB .

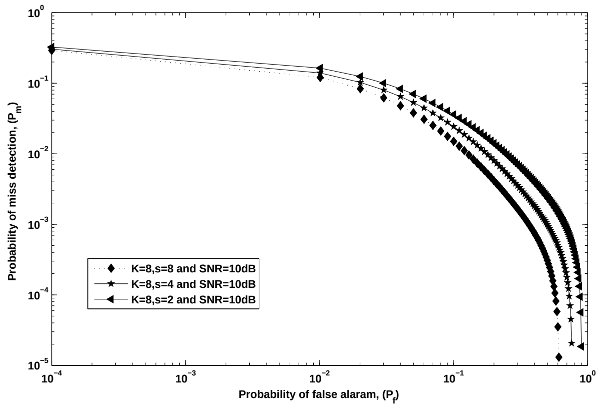

Fig. 6. Simulation of optimal LR detector, K =8, s= [2,4,8] and SNR=10 dB.

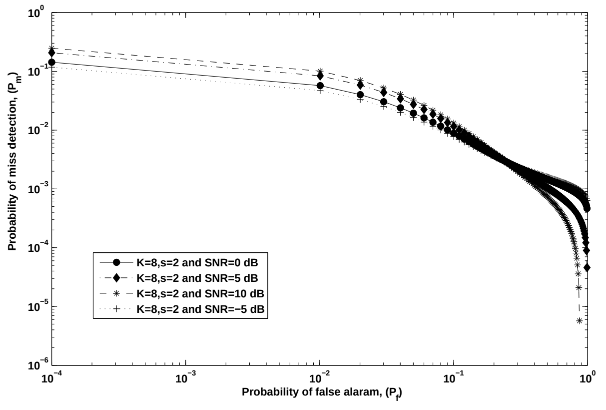

Fig. 7. Simulation of optimal LR detector, K=8, s=2 and SNR= [-5,0.5,10] dB.

VII. CONCLUSION

In this paper, a satellite network based on radio cognitive technique between primary and secondary satellite systems based on an interference management link was proposed. With the modelling of the primary satellite system, portion beams of a common region can be applied to share capacity for secondary satellites. This structure can be concluded that cognitive radio technique improves the total performance for a typical hybrid satellite network mode in different orbits. Moreover, based on the comparison between different scenarios, it can be concluded that the ROC curve has better situation for probability miss detection by increasing the number of antennas. Also, the ROC curve has the worst situation, by increasing the data stream for primary satellite system.

REFERENCES

[1] K. Patil, R. Prasad, and K. Skouby, “A survey of worldwide spectrum occupancy measurement campaigns for cognitive radio,” *In proc. IEEE International Conference Devices and Communications (ICDeCom)*, pp. 1–5, Feburary 2013.

[2] D.S.Ahn, H.W.Kim, J.Ahn, and D.C.Park, “Integrated/hybrid satellite and terrestrial networks for satellite imt-advanced services,” *International journal Satellite Communications Networking*, vol. 29, no. 3, pp. 269–282, April 2011.

[3] B. Evans, O. Onireti, T. Spathopoulos, and M. A. Imran, “The role of satellites in 5g,” *In proc. 23th European Signal Processing Conference (EUSIPCO)*, pp. 2756–2760, August 2015.

[4] A. Guidotti, D. Tarchi, V. Icolari, A. Vanelli-Coralli, and G. E. Corazza, “Spectrum awareness techniques for 5g satellite communications,” *In proc. 23th European Signal Processing Conference (EUSIPCO)*, pp. 2761–2765, August 2015.

[5] G. Ganesan and Y. Li, “Cooperative spectrum sensing in cognitive radio,part i: two user networks,” *IEEE Transactions on Wireless Communication*, pp. 2204–2213, June 2007.

[6] S. C. C. Hwang and T. Hsinchu, “Spectrum sensing in wideband ofdm cognitive radios,” *IEEE Transactions on Signal Processing*, pp. 709–719, Feburary 2010.

[7] S. K. Sharma, S. Chatzinotas, and B. Ottersten, “Satellite cognitive communications interference modelling and techniques selection,” *In proc. 6th Advanced Satellite Multimedia Systems Conference (ASMS) and 12th Signal Processing for Space Communications Workshop (SPSC)*, pp. 111–118, September 2012.

[8] I. F. Akyildiz, W. y. Lee, M. C. Vuran, and S. Mohanty, “A survey on spectrum management in cognitive radio networks,” *In proc. IEEE Communications Magazine*, vol. 46, no. 4, pp. 40–48, April 2008.

[9] S. K. Sharma, E. Lagunas, S. Maleki, S. Chatzinotas, J. Grotz, J. Krause, and B. Ottersten, “Resource allocation for cognitive satellite communications in ka-band (17.7–19.7 ghz),” *In proc. IEEE International Conference on Communication Workshop (ICCW)*, pp. 1646–1651, June 2015.

[10] M. Naeem, A. Anpalagan, M. Jaseemuddin, and D. C. Lee, “Resource allocation techniques in cooperative cognitive radio networks,” *IEEE Communications Surveys Tutorials*, vol. 16, no. 2, pp. 729–744, Feburary 2014.

[11] E. Lagunas, S. K. Sharma, S. Maleki, S. Chatzinotas, and B. Ottersten, “Resource allocation for cognitive satellite communications with incumbent terrestrial networks,” *IEEE Transactions on Cognitive Communications and Networking*, vol. 1, no. 3, pp. 305–317, September 2015.

[12] P. V. R. Ferreira, R. Metha, and A. M. Wyglinski, “Cognitive radio-based geostationary satellite communications for ka-band transmissions,” *In proc.Global Conference on Signal and Information Processing (GlobalSIP)*, vol. 1, no. 1, pp. 1093–1097, December 2014.

[13] S. L. Kota, “Hybrid/integrated networking for ngn services,” *In proc. 2nd IEEE International Conference on Wireless Communication, Vehicular Technology, Information Theory and Aerospace Electronic Systems Technology (Wireless VITAE)*, pp. 1–6, Feburary 2011.

[14] S. Kandeepan, L. D. Nardis, M. G. D. Benedetto, A. Guidotti, and G. E. Corazza, “Cognitive satellite terrestrial radios,” *In proc. IEEE Global Telecommunications Conference (GLOBECOM)*, pp. 1–6, December 2010.

[15] J. Anzalchi, A. Couchman, P. Gabellini, G. Gallinaro, L. D’Agristina, N. Alagha, and P. Angeletti, “Beam hopping in multi-beam broadband satellite systems: System simulation and performance comparison with non-hopped systems,” *In proc. IEEE 5th Advanced Satellite Multimedia Systems Conference and the 11th Signal Processing for Space Communications Workshop*, pp. 248–255, September 2010.

[16] A. Mokhtar and M. Azizoglu, “On the downlink throughput of a broadband leo satellite network with hopping beams,” *IEEE Communications Letters*, vol. 4, no. 12, pp. 390–393, December 2000.

[17] N. J. G. Fonseca and J. Sombrin, “Multi-beam reflector antenna system combining beam hopping and size reduction of effectively used spots,” *IEEE Antennas and Propagation Magazine*, vol. 54, no. 2, pp. 88–99, April 2012.

[18] A. Taherpour, M. Nasiri-Kenari, and S. Gazor, “Multiple antenna spectrum sensing in cognitive radios,” *IEEE Transactions on Wireless Communications*, vol. 9, no. 2, pp. 814–823, February 2010.

[19] O.Kilic, “Interference analysis for spot beam partitioning in cellular satellite communication systems,” *In proc. IEEE Antennas and Propagation Society International Symposium*, pp. 1–4, July 2008.

[20] T. E. Bogale, L. Vandendorpe, and L. B. Le, “Sensing throughput tradeoff for cognitive radio networks with noise variance uncertainty,” *In proc.9th IEEE International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM)*, pp. 435–441, June 2014.

[21] M. Naeem, U. Pareek, and D. C. Lee, “Interference aware relay assignment schemes for multiuser cognitive radio systems,” *In proc. 72nd IEEE Vehicular Technology Conference (VTC)*, pp. 1–5, September 2010.

[22] G.Strang, “Introduction to linear algebra,” *Wellesley Cambridge Press*, pp. 1–574, 4th edition (2011).

[23] W.Zhang and K.B.Letaief, “Cooperative spectrum sensing with transmit and relay diversity in cognitive radio networks,” *IEEE Transactions on Wireless Communications*, vol. 7, no. 12, pp. 4761–4766, December 2008.

[24] A.Ghasemi and E.S.Sousa, “Collaborative spectrum sensing for opportunistic access in fading environments,” *In proc. 1st IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN)*, pp. 131–136, Novomber 2005.

[25] M.A.Beigi and S.M.Razavizadeh, “Cooperative beamforming in cognitive radio networks,” *In proc. 2nd IEEE IFIP Wireless Days (WD)*, pp. 1–5, December 2009.

[26] A.H.Nuttall, “Some integrals involving the q-function,” 1972.

[27] N. T. Khajavi and S. M. S. Sadough, “Improved spectrum sensing and achieved throughputs in cognitive radio networks,” *6th Conference on Wireless Advanced*, pp. 1–6, 2010.

[28] F. F. Digham, M. S. Alouini, and M. K. Simon, “On the energy detection of unknown signals over fading channels,” *IEEE Transactions on Communications*, vol. 55, no. 1, pp. 21–24, May 2007.