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# Spectrum Sensing in Cognitive Radio by using Bayesian Approach

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**Abstract:** ***Empty portions of assigned fixed spectrum treated as spectrum holes or white spaces. These white spaces spectrum holes are used by cognitive radio technology in an opportunistic manner. It will solve the problem of spectrum scarcity in global. Cognitive radio assigns radio resources or spectrum in a manner to keep interference between licensed users and CR devices within limit. The scope of the given paper is to get higher spectrum utilization in cognitive radio networks, by using an optimal Bayesian Detector. If the primary signals are digitally modulated and primary user is highly inactive, we will derive optimal detector structure. And further suboptimal detectors in high and low SNR scenario. Bayesian Detector has same performance as ED in low SNR for spectrum utilization and better performance than the Energy Detector in high signal to noise ratio. In Paper we provide false alarm probability and Detection probability analysis.***

**-Keywords:-** Spectrum sensing, Cognitive radio, spectrum utilization, Energy Detector, Bayesian Detector

## 1. Introduction

The deficiency of spectrum is often a spectrum access problem. That means a spectrum is available, but its use is limited by traditional technologies. Now new technologies may allow sharing of spectrum resources which will increase available spectrum utilization. So Federal communications commission could form policies to permit access of presently underutilized. It may fulfill requirement of overall nation's growing spectrum needs for a long time [1]. Current spectrum use indicates that often the spectrum is not being fully utilized, even though spectrum in a general area may be licensed. However by permitting spectrum access for different uses will add to capacity and hence increase spectrum efficiency. The new operations may be permitted

When the current user is not using the spectrum. The frequency sensitive operations can be moved to less crowded spectrum bands. Existing primary users studies business potential in various service areas and accordingly mounts only enough radio transmitters. Here, the remote areas don't get the radio services. Hence lack of service in those areas called white spaces, which may be made available to other licensees who want to provide service in that particular area. Overall Spectrum utilization survey in Europe [2] suggests that the usage of spectrum 6.5% to 10.7% for frequency band of 400MHz to 3 GHz. However results measured in Singapore [3] show that most of the frequencies ranging from 80MHz to 5.85GHz of allocated spectrum are under-utilized. Only the cell phone and broadcasting frequencies are an exception to it. The average occupancy was noted only 4.5%. So we can say that there is high probability that the primary users are likely idle for most of the time. In order to increase the spectrum efficiency, we have to improve access to spectrum. FCC promotes below mentioned steps in this regard

a) Development and deployment of advanced technologies and

b) Secondary markets for spectrum and

c) Flexible use of spectrum.

By using cognitive radios, the secondary users can allowed to use the spectrum originally allocated for PU's as long as PU's are not using it temporarily. This is called opportunistic spectrum access (OSA). In order to avoid interference to the primary users, SUs have to perform spectrum sensing before their attempts to transmit over the spectrum [4]. Secondary unlicensed users keep sensing the spectrum to determine the PU is transmitting or not. Upon detecting Primary User idle, the Secondary Users can use those frequencies for transmission. This can cause rise in spectrum utilization and in turn increase the spectrum efficiency. There for it



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becomes robust techniques to sense the spectrum which are reliable and extremely important to employ efficient. Detection of a signal in noise needs processing which depends upon what is known of the signal characteristics and noise characteristics. Energy detection is easy to implement since it doesn't require the knowledge about the structure of the primary signal. Here Urkowitz [5] discussed the detection of unknown structured signal in the presence of flat, band limited Gaussian noise of power density which is known. The decision statistic chi-square distribution which is not central. Here the received signal has amplitude in random form due to atmospheric troubles, multichannel wave propagation and other. Further in [6] used sampling approach for doing an energy detector under both fading channels and AWGN. Matched filter detection is not feasible practical applications as it needs complete knowledge of PS's. Properties of Cyclostationarity primary signal are needed in Cyclostationarity detection which is not used fully. In given paper, we propose Bayesian Detector for digitally modulated primary signals for to maximize spectrum utilization. We do not need prior information on the transmitted sequence of the PS's. It used the prior statics information of primary user and signaling information such as modulation and symbol rate in order to improve the SU's throughput and overall spectrum utilization. The Neyman-Pearson is having the same structure as Bayesian detector. The design principle of given Neyman-Pearson method is to maximize detection probability for the given maximal false alarm probability, which results in the difference in detection threshold selection for them. So here we consider primary signals over additive white Gaussian noise channels. These signals are modulated in MPSK modulation. In low SNR region, The Bayesian detector is same to energy detector of BPSK modulated signal and MPSK for M>2. In high signal to noise ratio for BPSK signals Bayesian detector is approximated to detector which employee's sum of the received signal amplitudes for to detect the primary signals. The maximum likelihood ratio test detector may be approximated by corresponding suboptimal structure in high and low SNR regimes. We will analyze the false alarm and detection probabilities. In section II we will discuss some conventional detection methods. Section III will give system model along with assumptions and Bayesian detector for MPSK modulated primary signal. Suboptimal detector structure is derived in section IV. We also analyze the probabilities of detection and false alarm in section V. Finally, we conclude it in section VI by studies.

## 2. Conventional Detectors

Energy Detector: Energy detection method is the simplest of all, so widely used and hence easy to implement. This method will calculate the energy of input signal and compares it with some threshold energy values. The signal is considered to be present at a particular frequency if the energy of the signal exceeds the energy level for the threshold. In noise presence and interference power uncertainty, the performance of energy detection severely degrades so the detector fails to differentiate primary signal from interference [6]. So Matched filter: Matched filter correlates or matches a known signal or template with unknown signal to detect presence of template in unknown signal. Matched filter is the optimal linear filter for maximizing SNR in the presence of additive noise. These types of filters are mostly used in radar, but it needs prior knowledge of primary signal, such as signal shape, modulation type, and then matched filter can be used. We don't have any prior knowledge here about the primary signal. Therefor we cannot use matched filter detection.

Waveform based sensing: - In given wireless systems, the known patterns are usually used to assist synchronization. Whereas regularly transmitted pilot patterns, midamble, preamble are such known patterns as mentioned. Sensing's are performed by correlating received signal with its known copy of signal. So In terms of convergence and reliability time these detectors have better performance than energy detectors. The performance of it increases with the length of the known signal pattern. Presence of primary signal is detected by comparing the decision metric against a fixed threshold values. Disadvantages of this method are as follows short measurement time and the susceptibility to synchronization errors. Cyclostationarity feature detector:- Spectral correlation function is one of the special characteristics of modulated signal. And it is used for various signal processing tasks like synchronization and detection. Analysis of random signals is done using the autocorrelation function. Cyclostationary signals reflect the correlation between the distinct spectral components because of periodicity. The Spectral correlation function will



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separate noise included in the signal. Therefore it is easy to detect primary signal which use the longer transmission length, but mentioned detection method involves high computational complexity and the long observation time [7, 8, and 9]. `

### 3. Bayesian Detector for the MPSK Modulated Primary Signal

Here we have two hypotheses for spectrum sensing: - H0 denotes that primary user is absent and H1 denotes primary user is present, so we have now two important design parameters for spectrum sensing: probability of detection (Pd) and probability of false alarm (Pf). Here notation Pd is probability that SU accurately detects presence of active primary signals and Pf is the probability that SU falsely detects primary signals when PU is in fact absent. So we define spectrum utilization as

$$P(\mathcal{H}_0)(1-P_F)+P(\mathcal{H}_1)P_D \qquad \textbf{(1)}$$

And normalized SU throughput as

$$P(\mathcal{H}_0)(1-P_F) \qquad \textbf{(2)}$$

The signals and the Secondary Users detect the presence of the primary signal. Let us consider Td, as the detection statistic to determine whether the spectrum is being used by the primary user. Td is compared with a predetermined threshold ϵ. Pf the probability of false alarm that the hypothesis test chooses H1 while it is in fact H0:

$$P_f = P(T_D > \epsilon|\mathcal{H}_0) \qquad \textbf{(3)}$$

Probability of detection Pd is the probability that the test correctly decides H1 when it is H1:

$$P_f = P(T_D > \epsilon|\mathcal{H}_0) \qquad \textbf{(4)}$$

### 3.1 Detection Statistics

As per the signal model in [6], we consider time-slotted primary signals where N primary signal samples are used to detect the existence of primary signals. The PU symbol duration is T which is known to the SU and the received signal r(t) is sampled at 1/T at the secondary receiver. For MPSK modulated primary signals, the received signal of k-th symbol at the CR detector, r(k) is

For MPSK modulated primary signals, the received signal of *k*-th symbol at the CR detector, *r*(*k*)

$$r(k)=\begin{cases} n(k) & \mathcal{H}_0 \\ he^{j\varphi_n(k)}+n(k) & \mathcal{H}_1 \end{cases} \qquad \textbf{(5)}$$

Where $n(k) = n_c(k) + jn_s(k)$ is a complex AWGN signal with variance *N*0, *nc*(*k*) and *ns*(*k*) are respectively the real and imaginary part of n(k), φn(k) = 2nπ/M , *n* = 0, 1,.....,*M* – 1 with equi-probability, *h* is the propagation channel that is assumed to be constant within the sensing period. Denote **r** = [*r*(0) *r*(1)….. *r*(*N* − 1)]. Assume that the SU receiver has no information with regards to the transmitted signals by the PU and *φn*(*k*), *k* = 0, 1, ……,*N* − 1 are independent and identically distributed (i.i.d.) and independent of the Gaussian noise.

The detection statistics of energy detector (ED) can be defined as the average energy of observed samples as

$$T_{ED} = \frac{1}{N}\sum_{k=1}^{N}|r(k)|^2 \qquad \textbf{(6)}$$

Although energy detector does not require the knowledge of the symbol rate, we assume that the sample rate is identical to the symbol rate. It is well-known that the optimal detector for binary hypothesis testing based on Bayesian rule or Neyman-Pearson theorem is to compute the likelihood ratio and then make its decision by comparing the ratio with the threshold. The likelihood ratio test (LRT) of the hypotheses $\mathcal{H}_0$ and $\mathcal{H}_1$ can be defined as

$$T_{LRT}(r) = \frac{p(r|\mathcal{H}_1)}{p(r|\mathcal{H}_0)} \qquad \textbf{(7)}$$

### 3.2 Optimal Detector Structure

We can find the PDF(Probability Density Function) of received signal, r when PU is absent over N symbol duration as below

$$p(r|\mathcal{H}0) = \prod_{k=0}^{N-1}\frac{e^{-|r(k)|^2/N_0}}{\pi N_0} \qquad \textbf{(8)}$$

Since the noise signals n(k), k=0,….,N-1 are independent.

The PDF of received signals over *N* symbol duration under hypothesis *H*1 is denoted as *p* (**r**|*H*1). With equiprobability of *φn*(*k*) = 2*nπ*/*M* , *n* = 0, 1, . . .,*M* − 1, and the independence of *φn*(*k*), we can obtain

$$p(r|\mathcal{H}1) = \prod_{k=0}^{N-1}\sum_{\varphi_n(k)} p(r(k)|\mathcal{H}1,\varphi_n(k)) \;\; p\,\varphi_n(k)$$

**(9)**

Hence, the log-likelihood ratio (LLR),

$$T_{LRT}(r) = \sum_{k=0}^{N-1}\left(ln\left(\sum_{n=0}^{M-1} e^{\frac{2}{N_0}\Re[r(k)h^{*}e^{-j\varphi n(k)}]}\right) - \gamma - \ln M\right)$$

**(10)**

where γ is the SNR of the received signal sample,i.e $\gamma = \frac{|h|^2}{N_0}$.

Let

$$v_n(k) = \frac{2}{N_0}\Re[r(k)h^{*}e^{-j\varphi n(k)} \qquad \textbf{(11)}$$

It is easy to derive the structure of the optimal detector (BD) for MPSK signals as:

$$T_{BD} = \frac{1}{N}\sum_{k=0}^{N-1} ln\left(\sum_{n=0}^{M/2-1} cosh(v_n(k))\right)$$


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$$\gtrless \gamma + ln\frac{M}{2} + \frac{\ln \epsilon}{N} \quad (12)$$

Although the detector is optimal, it is too complicated to use in practice. In the following, we will simplify the detector when the SNR is very low or very high.

## 4 BAYESIAN DETECTOR STRUCTURE THROUGH THE APPROXIMATIONS IN THE LOW AND HIGH SNR REGIMES

We give the theoretical analysis (detection performance and threshold) for the suboptimal detector to detect complex MPSK ($M$ = 2 and $M$ > 2) in low SNR regime and compare with the results for real BPSK primary signals.

### 4.1APPROXIMATION IN THE LOW SNR REGIME

We study the approximation of our proposed detector for MPSK modulated primary signals in the low SNR regime. When $x \to 0, \cosh(x) \approx 1 + \frac{x^2}{2}$ *and* $\ln(1+x) \approx x$ we can obtain:

$$\sum_{k=0}^{N-1} ln\left(\sum_{n=0}^{\frac{M}{2}-1} \cosh(v_n(k))\right) \quad (9)$$

Through approximation, the detector structure becomes:

$$T_{L-ABD-1} = \frac{1}{N}\sum_{k=0}^{N-1}|r(k)|^2 \gtrless \frac{N_0}{\gamma}\left(\gamma + \frac{\ln\epsilon}{N}\right) \quad (10)$$

To achieve a better approximation, we can use higher order approximation for the suboptimal detector structure. Since x→ 0, cosh(x)≈ $1 + \frac{x^2}{2!} + \frac{x^4}{4!}$ and ln (1+x) ≈ $x - \frac{x^2}{2} + \frac{x^3}{3}$, letting

$$u_n(k) = \frac{1}{M}\sum_{n=0}^{\frac{M}{2}-1}\left[v_n^2(k) + \frac{1}{12}v_n^4(k)\right] \quad (11)$$

$$T_{L-ABD-2} = \frac{1}{N}\sum_{k=0}^{N-1}\left[u_n(k) - \frac{u_n^2(k)}{2} + \frac{u_n^3(k)}{3}\right]$$

$$\gtrless \left(\gamma + \frac{\ln\epsilon}{N}\right) \quad (12)$$

### 4.2APPROXIMATION IN THE HIGH SNR REGIME

We consider the high SNR regime in this section. When $x \gg 0, cosh(x) \approx \frac{e^x}{2}$ or when $x \ll 0, cosh(x) \approx \frac{e^{-x}}{2}$

The detector structure becomes

$$T_{H-ABD} = \sum_{k=0}^{N-1}\left(ln\left(\sum_{n=0}^{M/2-1} e^{\frac{2}{N_0}\Re[r(k)h^* e^{-j\varphi n(k)}]}\right)\right)$$

$$\gtrless \gamma + lnM \quad (13)$$

A special case of MPSK signals, we assume a real signal model for BPSK modulated primary signals. The suboptimal BD detector employs the sum of received signal magnitudes to detect the presence of primary signals in the high SNR regime, which indicates that energy detector is not optimal in this regime.

### 4.3 FALSE ALARM PROBABILITY

The false alarm probability, is

$$P_F = P(T_{L-ABD-1} > \frac{N_0}{2}(\gamma + \frac{\ln\epsilon}{N})|\mathcal{H}0)$$
$$= Q\left(\frac{\frac{N_0}{\gamma}\left(\gamma + \frac{\ln\epsilon}{N}\right) - \mu}{\sigma}\right)$$
$$= Q\left(\frac{\ln\epsilon}{r\sqrt{N}}\right) \quad (14)$$

### 4.4 DETECTION PROBABILITY

The detection probability is

$$P_D = P(T_{L-ABD-1} > \frac{N_0}{2}(\gamma + \frac{\ln\epsilon}{N})|\mathcal{H}1)$$
$$= Q\left(\frac{\frac{N_0}{\gamma}\left(\gamma + \frac{\ln\epsilon}{N}\right) - \mu}{\sigma}\right)$$
$$= Q\left(\frac{\ln\epsilon - N\gamma^2}{r\sqrt{N(1+2\gamma)}}\right) \quad (15)$$

## 5. Analysis of Detector Performance and False Alarm Probability using simulation results

We assume that the primary network operates on an AWGN channel for BPSK modulated primary signals. The signal to noise ratio is varied to evaluate the performance of the energy detectors and Bayesian detectors. The detection threshold for BD is determined by the ratio of P(H0)=0.85 and P(H1)=0.15The detection performance is given in terms of Pf and Pd.The detector for complex MPSK signals is energy detector, while the detector for BPSK signals is the real part of the ED[11]. We study the performance of approximate BD for 8PSK and BPSK channels at low and high SNR regime.

### 5.1 At Low SNR

We have plotted Pd and Pf versus SNR for ABD for 8PSK signals in Figs. 1 to 2 respectively, with number of samples N is set to 5000. It shows that when SNR is larger than -13 dB , ABD has a high detection probability larger than 0.9,and Pf of much less than 0.3.It shows that PUs are most likely idle than busy indicating highest spectrum utilization. We observe that the performance difference between ED and BD is insignificant due to their detector structures are quite similar. Surprisingly, false alarm probability of L-ABD in low SNR regime first becomes worse and gradually becomes


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better due to the threshold defined to maximize spectrum utilization given by (12).

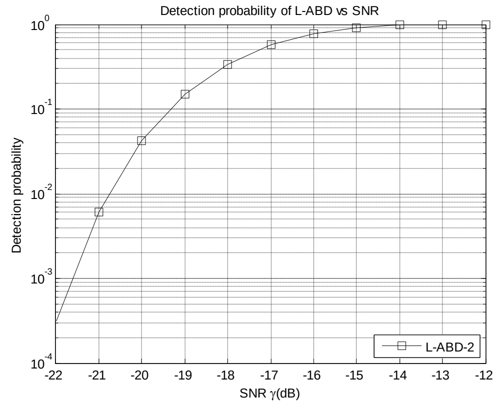


Figure.1 Detection probabilities of ED, BD and L-ABD-2 vs SNR(dB) for 8PSK modulated primary signals

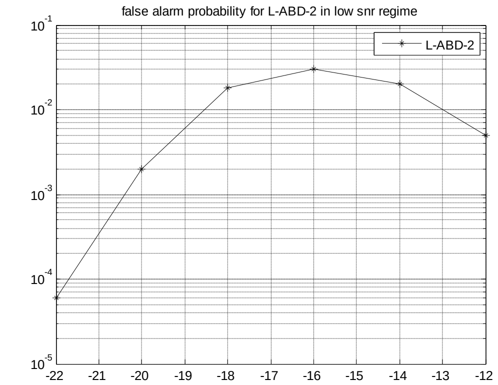


Figure.2 false alarm probabilities of ED, BD and L-ABD-2 vs SNR(dB) for 8PSK modulated primary signals

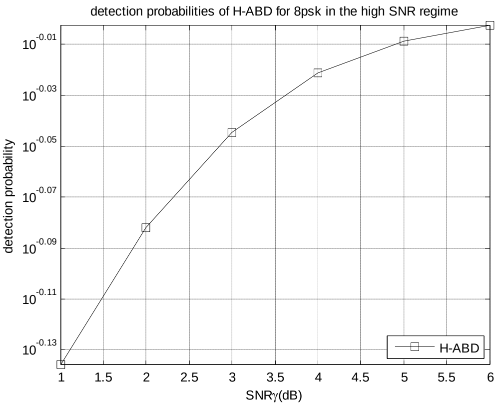


Figure.3 Detection probabilities of ED, BD and H-ABD vs. SNR (dB) for 8PSK modulated primary signals.

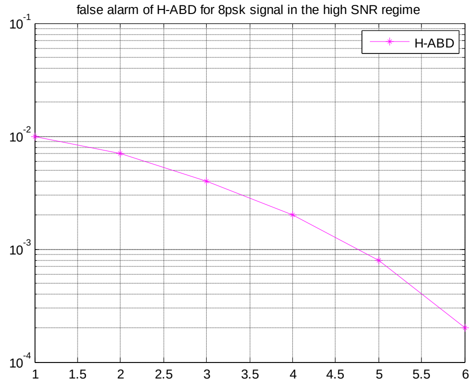


Figure.4 False alarm probabilities of ED, BD and H-ABD vs. SNR (dB) for 8PSK modulated primary signals over AWGN channels

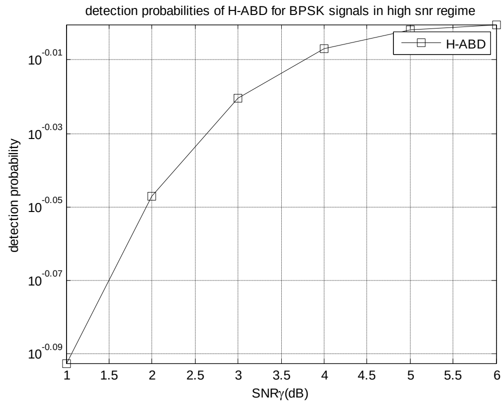


Figure.5 Detection probabilities of ED, BD and H-ABD vs. SNR (dB) for BPSK modulated primary signals over AWGN channels in the high SNR regime.

## 6. Conclusion

Based on Bayesian rule, detector structure is presented here to detect known order MPSK modulated primary signals over AWGN channels. We have found that at low SNR regime energy detector is the same as Bayesian detector. But at high SNR energy is the sum of signal magnitudes. Bayesian detector has advantages over ED and NP detector due to the difference in detection threshold. It also maximizes the detection probability for a given false alarm probability.

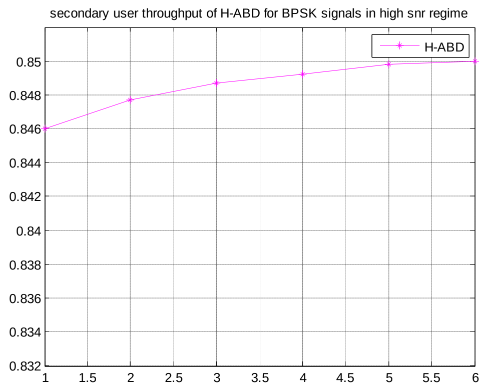


Figure.7 Secondary users throughput of H-ABD vs.SNR(dB) for BPSK signal at high SNR


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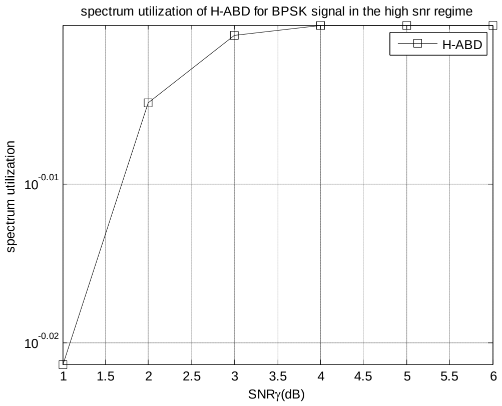


Figure.8 Spectrum utilization of ed, bd and h-abd vs. Snr (db) for bpsk modulated primary signals over awgn channels.

**References**

[1] FCC, "Spectrum Policy Task Force Report," FCC ETDocket No. 2-135, Washington DC. No.2009.

[2] V. Valenta, R. Marsalek, G. Baudoin, M Villegas, M Suarez, and F. Robert "Survey on Spectrum Utilization in Europe: Measurements, Analyses and Observations" in Proc 2010 int. Conf on Cognitive Radio Oriented Wireless Networks and Communication CrownCom. pp. 1-6.

[3] "Spectrum Survey in Singapore: OccupancyMeasurements and Analyses", in Proc 2006 int. Conf. On Cognitive Radio Oriented Wireless Networks and Communication CrownCom. pp 1-.7

[4] J. Mitola III, and G.Q. Maguire "Cognitive Radio:Making Software Radios More Personal," IEEE Personal Communications. IEEE, 6:13-18

[5] H. Urkowitz, "Energy detection of unknown deterministic signals," Proc. IEEE, vol.55 no.4, pp.523- 531, 1967.

[6] F. Digham, M-S Alouini and M. K. Simon, "On the energy detection of unknown signals over fading channels," IEEE Trans. Commun. Vol. 55, No.-1, PP 21-24,2007

[7] Asif Mirza and Faigue Bin Arshad,"PerformanceAnalysis of Cyclostationary sensing in cognitive radio networks", Technical report IDE-1127, May 2011.



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