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Performance Analysis of WLAN based Cognitive Radio Networks using Matlab

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***Abstract*— Cognitive Radio (CR) is a new technology that paves way for better spectrum efficiency. It adapts itself to the dynamically varying environment enabling Dynamic Spectrum Access (DSA). Wireless Local Area Networks (WLANs) is an alternative to the high cost implementation and maintenance of wired technology. Analysis of WLAN-CR model brings out the combined utilization of spectrum where the Primary Users (PUs) is being sensed and their responses are inferred with varying frequencies. The 802.11 based CRN is made where a Distributed Opportunistic Spectrum Access (D-OSA) scenario is considered.. Sensing is being carried out to know the idle period of the primary network. CR users employ 802.11 Distributed Coordination Function (DCF) protocol. In this paper, the probability of false alarm, throughput, user transmission in each slot are carried to bring out the essence of taking a cross layer approach and joint design of PHY layer spectrum sensing and MAC layer channel access.**

Index terms - Cognitive Radio (CR), Dynamic Spectrum Access (DSA), Wireless Local Area Networks (WLANs), Primary Users (PUs), Distributed Opportunistic Spectrum Access (D-OSA), Distributed Coordination Function (DCF), contention-based channel access.

I. INTRODUCTION

Cognitive Radio (CR) is a system for wireless communication. It is built on Software Defined Radio (SDR) which is an emerging technology that provides a platform for flexible radio systems, versatile service, multi-standard, multiband, reconfigurable and reprogrammable by software for Personal Communication Services (PCS). CR extends the software radio with radio-domain enhancing the flexibility of personal services through a Radio Knowledge Representation Language (RKRL). RKRL represents knowledge of radio etiquette, devices, software modules, propagation, networks, user needs, and application scenarios to support needs of the user. Some portions of the spectrum, such as the 2.4GHz ISM band becomes congested due to the widely used Wi-Fi and Bluetooth devices. Thus spectrum scarcity problem is due to the uneven spectrum utilization.

CR sorts out this problem by accessing the white space without interfering with PUs. It uses the methodology of sensing and learning through which the spectrum is being sensed without creating any interference to the PUs. Spectrum sensing is a primary function of CR networks. It is the ability to measure, sense and be aware of the parameters related to the radio channel characteristics. It is done across Frequency, Time, Geographical Space, Code and Phase.

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IEEE 802.11 is the standard for Wireless Local Area Networks (WLANs) promoted by the Institute of Electrical and Electronics Engineers. Wireless technologies in the LAN environment are becoming increasingly important and the IEEE 802.11 is the most mature technology to date. 802.11 is an IEEE standard for MAC and Physical Layer for WLAN. The standards become important due to Multi Vender inter operability, Protection of customer investment and Economies of scale. WLANs are being developed to provide high bandwidth to users in a limited geographical area [6]. The IEEE 802.11 layers are as shown in figure 1. The importance of this WLAN standard can be stated as:

1. To provide wireless connection to automated stations or machineries that requires rapid development.
2. To provide standards to bodies for standardizing their local area communication.

<table>
<tr><td colspan="3">IEEE 802.2
LOGIC LINK CONTROL (LLC)</td></tr>
<tr><td colspan="3">IEEE 802.11
MEDIA ACCESS CONTROL (MAC)</td></tr>
<tr><td>FREQUENCY
HOPPING
SPREAD
SPECTRUM
PHY</td><td>DIRECT
SEQUENCE
SPREAD
SPECTRUM
PHY</td><td>INFRA RED
PHY</td></tr>
</table>

Figure 1 IEEE 802.11 Layers

As seen in the figure 1, the IEEE WLAN defines both PHY and MAC layer specifications. The WLAN implementation can be followed as two different approaches. The first is the Infrastructure based 802.11 WLAN which is widely used. And the other approach is the Adhoc approach. The Congestion problems that occur inside the network are managed by the WLAN MAC. Several versions of IEEE are framed such as IEEE 802.11, IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, and IEEE 802.11n which provides service in different frequency bands, data rate with different specifications and Quality of Service (QOS) [4].

II. WLAN-CR MODEL

The implementation of this WLAN-CR model is done using the 802.11a standard and the CR radio environment comprising of the primary users. The IEEE 802.11a standard specifies an OFDM physical layer (PHY) that splits an information signal to provide transmission of data at a rate of 6, 9, 12, 18, 24, 36, 48, or 54 Mbps. The primary purpose of the OFDM PHY in the 802.11a standard is to transmit Media Access Control (MAC) Protocol Data Units (MPDUs) as directed by the 802.11 MAC layer [7].

The WLAN-CR model is implemented using Simulink which is an extension of MATLAB. The block diagram of WLAN-CR is shown in Figure 2. The 802.11a is primarily made using blocks that constitute the OFDM PHY and the output is sorted out by embedding this model to the CR environment which consists of primary users [8]. These primary users said to act and be in frequency that depends on primary sensing. The PUs are modeled and analyzed with respect to the WLAN such as when all the PUs act under the same frequency upon sensing and the second case as when all the PUs are under different frequency range resulted due to sensing. The input is fed from a Bernoulli generator that creates random binary sequence number. It is a random data source. All the inputs are fed to the product multiplier where it gets mixed up with the frequency that is being set for a particular PU.

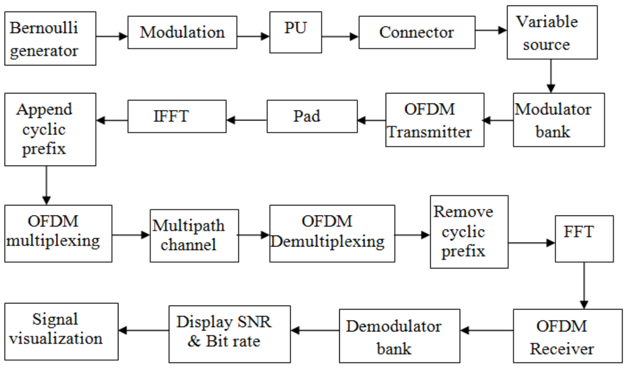


Figure 2 WLAN-CR Model (Block Diagram)

The modulation technique used here is the Double Side Band Suppressed Carrier (DSBSC). The modulation is made through the analog pass band modulator. A scope is used to view the graphical view of each carrier signal upon which the frequency is being set. The frequency is set on the PU block. Finally this constitutes the CR portion which is connected through a common line to the variable data source of the WLAN model.

WLAN portion starts with the random data generator and finally ends in the packet error correction. Some simulation parameters can be changed in the model in order to view different results; the number of OFDM symbols and the SNR as well can be set in the model. These parameters can be set by clicking in the simulation parameters block. The assemble OFDM block is the one that combines all the OFDM symbols, training, pilot signals together. All these together are called as OFDM transmitter. It performs the functions of pilot, preamble insertion, IFFT and cyclic prefix addition.

Padding is an operation that is performed before IFFT (Inverse Fast Fourier Transform). Zero pads append zeros to the input signal and the selector block reorders the subcarriers. It appends or prepends a constant value to input and truncation takes place here. After performing an IFFT, the output is cyclically extended to the desired length. An inverse Fourier transform converts the frequency domain data set into samples of the corresponding time domain representation of this data.

Specifically, the IFFT is useful for OFDM because it generates samples of a waveform with frequency components satisfying orthogonality conditions. The receiver performs the inverse of the transmitter. The Fast Fourier Transform (FFT) converts the time domain samples back into a frequency domain representation.

The multiplex block is used to convert the signal from parallel to serial and to transmit time-domain samples of one symbol. The multipath channel parameter is the one that sets the fading mode, maximum Doppler shift, Signal-to-noise ratio value in dB and the channel sample period is given. The fading mode can be of flat fading or dispersive fading; here it is set as flat fading and the maximum Doppler shift is set as 200 Hz with an SNR of 30 dB. At the receiver side inverse function of all the blocks at the transmitter side are carried out. The adaptive modulation control controls over the threshold given in dB, the hysteresis factor and the bit rates. The Error Rate Calculation block compares input data from a transmitter with input data from a receiver. Thus the above all forms the WLAN-CR model. The analysis is made such that all the PUs is whether under same frequency or under different frequency statistics that depends on primary sensing.

III. ANALYSIS OF 802.11 CRN

802.11 based CRN is a scenario where several metrics are analyzed over a Distributed Opportunistic Spectrum Access (D-OSA). Spectrum sensing is carried out at beginning of each frame to know whether the primary network is idle or not where the CR users operate on frame-basis. When the primary network is found idle, CR users employ modified Distributed Control Function (DCF) Protocol [1]. Probability of false alarm and mis detection gets introduced if spectrum sensing is imperfect.

The D-OSA adapts an effective protocol design that involves the standard 802.11 DCF. The throughput for the D-OSA taking into account the frame-boundary effects and sensing accuracy is analyzed [2]. This analysis brings out the importance of taking cross-layer view in controlling PHY-layer spectrum sensing and MAC-layer random access. System throughput can be increased when the probability of mis-detection and false alarm are chosen appropriately. The throughput is analyzed for Carrier Sense Multiple Access (CSMA) schemes when carrier sensing at PHY layer introduces mis-detections and false alarms.

The first analysis starts with throughput vs. number of users. The next analysis is made for the number of users transmitting in each slot. The probability that each user transmits in each slot is given as p. And the probability of having atleast one CR node transmitting on each slot is given as P_{tr}. The comparison of user transmitting on each slot is made with respect to number of users [1], [5]. The collision probability is given as ρ. The equation corresponding to this is as shown in Equation (1) and (2) respectively.

$$P_{tr}=1-(1-p)^{N} \quad (1)$$
$$P= 2(1-2\rho) / ((1-2\rho)(w+1)) + ((pw(1-2\rho)^{m})) \quad (2)$$

Statistical results are obtained while computing the throughput which involves the probability of false alarm as given in Equation (3), the blocking probability, probability of user transmitting in each slot as in Equation (2), probability of successful transmission (P_s) which is given in Equation (4), probability of non-transmitting user and throughput for which the equation is as shown in Equation (5).

$$P_{fa}(\tau) = Q(\sqrt{2}^{\gamma} + 1\ Q^{-1}(1-P_{md}) + \sqrt{\tau} f_s \quad (3)$$
$$P_s = N*p(1-p)^{N-1} / P_{tr} \quad (4)$$
$$T= P_s * P_{tr} * T_p / (1- P_{tr})*\Delta + P_{tr} T'_b \quad (5)$$

Where,
W - Contention window
P_{md} – probability of mis-detection
T_p – time to transmit the packet payload
Δ - duration of an 802.11 CSMA/CA slot
T'_b – average duration of effective busy periods

The next analysis is carried for false alarm and throughput. The plot is made for throughput and probability of false alarm P_{fa} with respect to number of users. P_{fa} is a decreasing function in the sensing time τ. In a random access scenario, there is a tradeoff between the numbers of competing users and the system throughput. If the number of users is too small, the channel is not fully utilized. But if the number of users increases this leads to high collision that reduces the system throughput. If probability of false alarm P_{fa} is set too low, there lie too many CR users in each frame. The other case is that if the probability of false alarm P_{fa} is set too high then CR users may not successfully transmit within the available time.

There is also a tradeoff between the sensing time and throughput. If the sensing time is decreased, this gives an option for all the CR users to transmit within the rest of the frame. But this increases the false alarm rate. Therefore an optimal sensing time is the one that balances both the sensing time and the transmission duration that improves the system performance. This analysis highlights the importance of taking a cross-layer approach and choosing the operating parameters of the system. Thus increasing the probability of false alarm P_{fa} increases the throughput. But it also must be noted that increasing probability of false alarm P_{fa} also affects the delay performance. Thus minimum transmission delay and throughput are achieved at an optimal value of probability of false alarm P_{fa}.

IV. RESULTS AND SIMULATION

A. WLAN-CR MODEL

The WLAN standard used here is the IEEE 802.11a which employs the orthogonal frequency division multiplexing. Analysis is done for two cases here which includes when all the PUs are acting under the same frequency of the radio environment and when the PUs of the radio environment are under different frequency.

a) When all the PU carrier frequency is same:

This is the case made when all the users after sensing if they belong to a particular radio scenario, their response is different with the transmitted signal where they show a higher signal to noise ratio. The transmitted signal time is of 5 micro second. The PU modulator pass band frequency here is 300Hz. This frequency is dynamic and may alter with respect to the sensing statistics. But the bit rate in Mbps seems to be higher as of SNR. The strength of the bits per packet is high. The RF power spectrum is the projection of the scatter plot of the equalized and unequalized signal. It is nothing but the transmitted signal is being into two portions based on the signal strength which are in dB. The SNR is the signal to noise ratio of the transmitted signal. The SNR and the bit rate (Mbps) are shown in Figure 3. The SNR obtained here is of 25.19db and the bit rate is 24 Mbps.

b) PUs with different Carrier frequency:

This is the case when the PUs of the radio environment is seemed to be in a different frequency after the primary sensing. Unlike the above case, in this we can see degradation in the signal to noise ratio level and also a small decrease in the bit rate (Mbps). The transmitted signal gets split based on the signal strength and is seen here that there is minimal distribution due to the different frequency accessing the PU. The transmitted signal time is of 5 micro second. The PU modulator pass band frequency here is 300Hz, 200 Hz, 400 Hz, 100 Hz, and 300 Hz. This frequency is dynamic and may alter with respect to the sensing statistics. The strength of the bits per packet is less compared to the above. The SNR and the bit rate (Mbps) is shown in Figure 4. The SNR obtained here is of 21.98db and the bit rate is 18 Mbps.

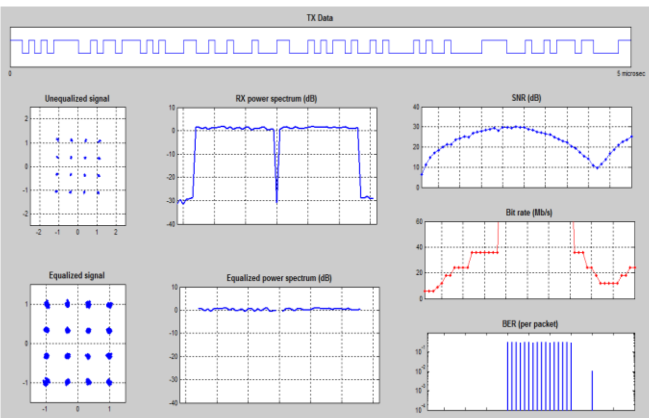


Figure 3 PUs with same carrier frequency

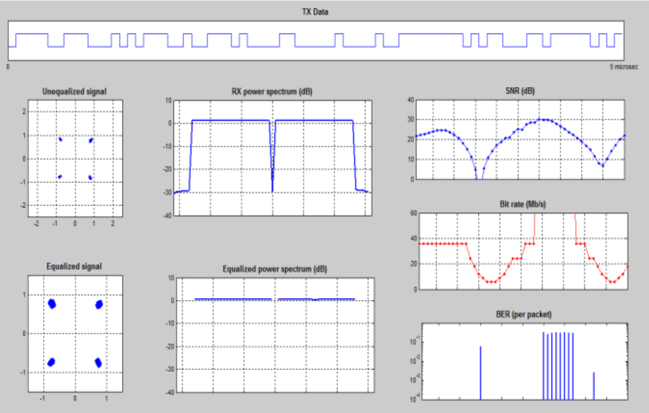


Figure 4 PUs with different carrier frequency

B. ANALYSIS FOR AN 802.11 BASED CRN

The parameters taken for analysis here includes sensing duration τ, the probabilities of false alarms P_{fa} (τ), effective frame duration, and probability of mis detection (P_{md}).

a) THROUGHPUT OF 802.11

The analysis first starts with the modified-802.11/frame based system without considering spectrum sensing. Here the frame duration is set as 100 msecs. If the frame duration is increased to 1,000,000 msecs to meet the standard 802.11 DCF operation, it has no frame limitation. The packet payload here is 8184 bits, probability of mis-detection is 0.5 and the contention window size is 32 with m=3. It can be inferred from the following figure 5 that, as the number of users' increases, there is seen an exponential decrease in the throughput corresponding to the frame based operation.

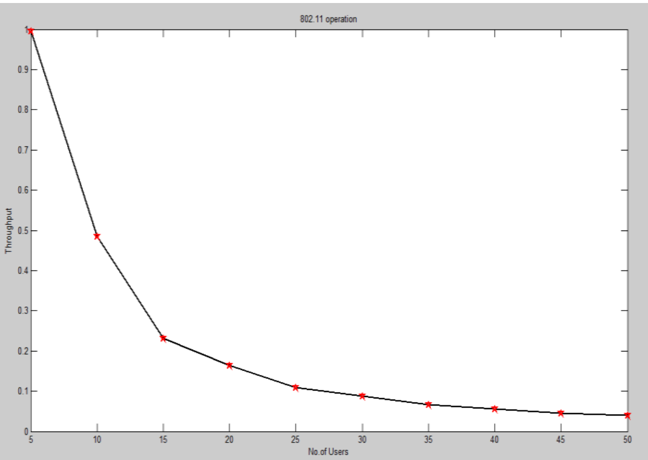


Figure 5 Throughput of 802.11 DCF

b) USERS TRANSMITTING IN EACH SLOT

It becomes essential to analyze the number of users transmitting in each stage. Each stage here refers to each time slot. The plot is made between the number of users and the probability of users transmitting in each stage. It is made with inputs having a contention window size 32, SNR of primary signal detector as 10 dB, the probability of mis detection 0.5, sensing time 100 ms, channel sampling rate 600 Hz. The probability of user transmitting at each stage is given as P_{tr} in the following figure 6, which shows a gradual increase in probability that user, tends to transmit.

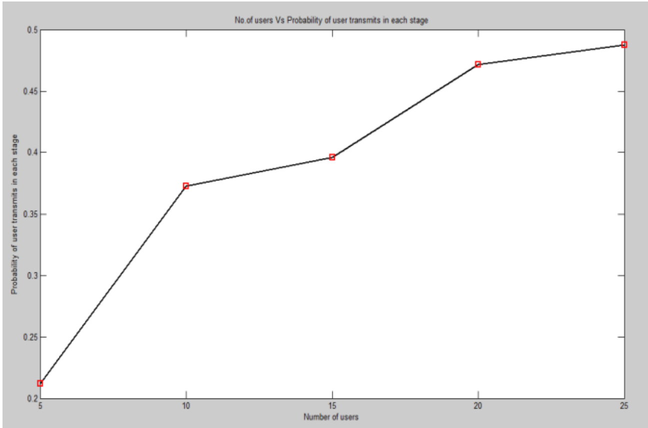
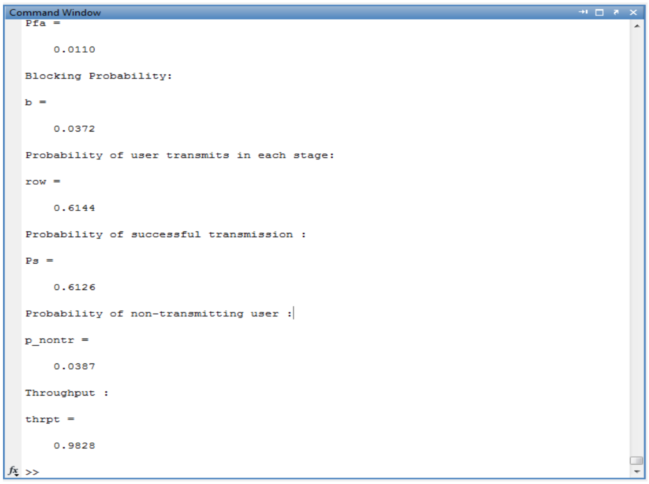


Figure 6 Probability of user transmission

c) STATISTICAL RESULTS

Based on the execution of mathematical experiments, the numerical values are obtained. All these are carried out with the contention window size 32, SNR of primary signal detector as 10 dB, the probability of mis detection 0.5, sensing time 100 ms, channel sampling rate 600 Hz. The following figure 7 shows the values obtained.



```
Command Window
Pfa =
    0.0110
Blocking Probability:
b =
    0.0372
Probability of user transmits in each stage:
row =
    0.6144
Probability of successful transmission :
Ps =
    0.6126
Probability of non-transmitting user :
p_nontr =
    0.0387
Throughput :
thrpt =
    0.9828
fx >>
```

Figure 7 Numerical values

d) FALSE ALARM ANALYSIS

The next analysis is carried out for false alarm and throughput. The number of users and throughput showed that as the number of users' increases, there is seen an exponential decrease in the throughput corresponding to the frame based operation. As like that this analysis shows the relation and contribution of false alarm that result due to improper spectrum sensing and the throughput. The analysis is being carried out for 10, 50 and 100 users. The drastic increase in users is made to show the throughput impact for the given number of users. For a stipulated increase in users the throughput is seen with a gradual slope varying in the order of 0.5 and tends to increase in false alarm rate that directly impacts over the throughput. The following figures 8, 9 and 10 show them respectively.

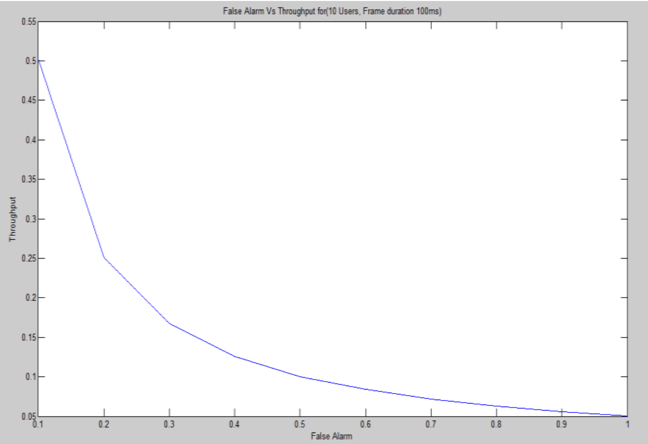


Figure 8 False alarm vs. Throughput (N=10)

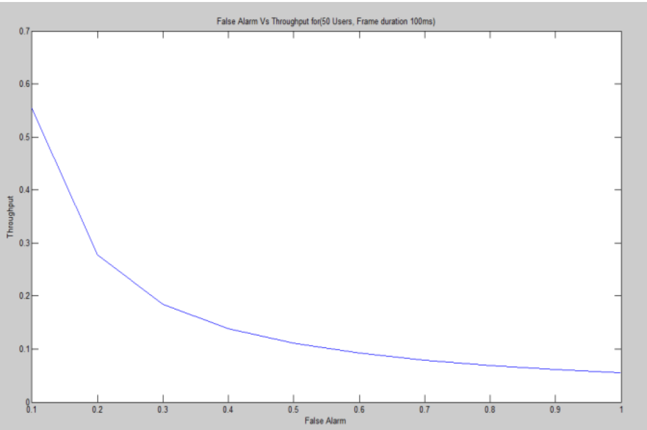


Figure 9 False alarm vs. Throughput (N=50)

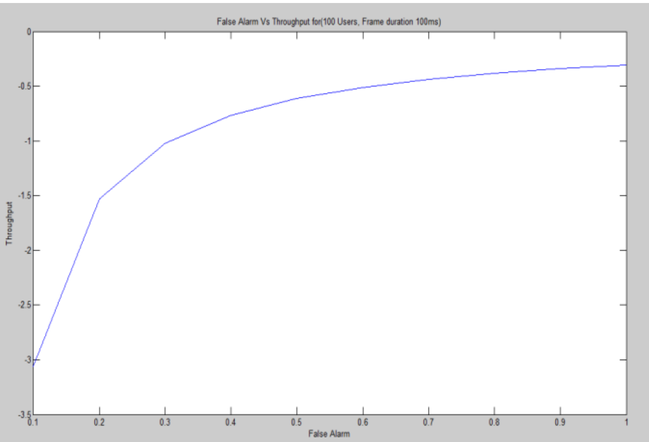


Figure 10 False alarm vs. Throughput (N=100)

e) PROBABILITY OF SUCCESSFUL TRANSMISSION

The next execution is carried on 802.11 based CRN to know the probability of successful transmission corresponding to number of users. The inference made from here is that as the number of users increases the probability of successful transmission slides down. It is because of the high mis-detection rate as user's increases. When the users rate rolls down, the transmission probability rate changes. Figure 11 shows the relation between number of users and probability of successful transmission.

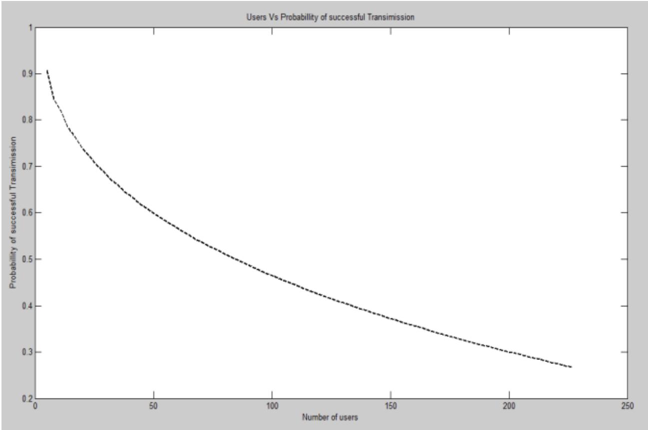


Figure 11 Probability of successful transmission

V. CONCLUSION

The analysis and simulations made demonstrates the importance of each metrics that accounts for the effective performance of both the CR and WLAN elements. The impact of probabilities of false alarm and mis-detections brings awareness about the other parameters that are involved. The WLAN-CR model explains the analogy of the SNR and Bit Error Rate which changes in accordance with the PU frequency upon sensing. The two categories of sensing: sensing for CR and the sensing in CSMA/CA for frame based operation in 802.11 DCF supports the sensing and the protection of primary network. The throughput of the system is analyzed with respect to the sensing time, the contention window size, and frame duration. The analysis of probability of user transmission in each slot and probability of successful transmissions helps to know about the response with respect to the number of users involved in the transmission. The D-OSA design draws the importance of taking a cross layer approach of PHY layer spectrum sensing and MAC layer random access under WLAN based CRN.

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