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POWER ALLOCATION POLICY FOR COGNITIVE RADIO NETWORKS WITH MULTIPLE RELAYS

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***Abstract*— This paper focuses on the study and analyzes of cooperative cognitive radio networks with arbitrary number of secondary users (SUs). Each SU is considered a prospective relay for the primary user (PU) besides having its own data transmission demand. It is considered a multi-packet transmission framework that allows multiple SUs to transmit simultaneously because of dirty-paper coding. It allows multiple power allocation and scheduling policies that optimize the throughput for both PU and SU with minimum energy expenditure is proposed. The performance of the system is evaluated in terms of throughput and delay under different opportunistic relay selection policies. Towards this objective, a mathematical framework for deriving stability conditions for all queues in the system is presented. Consequently, the throughput of both primary and secondary links is quantized. Furthermore, a moment generating function (MGF) approach is employed to derive a closed-form expression for the average delay encountered by the PU packets. Results reveal that better performance in terms of throughput and delay at lower energy cost as compared to equal power allocation schemes proposed earlier in literature is achieved. Extensive simulations are conducted to validate our theoretical finding.**

***Index Terms*— Cognitive relaying, opportunistic communication, throughput, delay, relay selection.**

I. INTRODUCTION

With the increasing demands for green communications , it has become an inconvertible trend that modern wireless systems are expected to achieve the same level of quality of service as the conventional systems, while consuming much less energy. Along this avenue, designers emphasize more and more on the energy efficiency (EE) of the considered systems, which is defined as the transmitted bits per unit energy, beyond the spectrum efficiency (SE), which is equal to the information transmission rate. It has been shown in the literature, and the references therein) that there exists an interesting EE-versus-SE trade-off for various wireless communication systems, i.e., increasing EE will decrease SE, and vice versa. The EE–SE region plays as a fundamental limitation for various wireless-communication systems and provides an important guideline for de-signing the physical-layer transmission schemes under different EE and SE requirements. For example, by assuming perfect channel state information (CSI) at the transmitter, Xiong et al. first characterized the EE–SE tradeoff for the downlink orthogonal frequency-division multiple

-access networks and some upper and lower bounds were obtained. A cognitive radio (CR) is a radio that can be programmed and configured dynamically to use the best wireless channels in its vicinity to avoid user interference and congestion. Such a radio automatically detects available channels in wireless spectrum, then accordingly changes its transmission or reception parameters to allow more concurrent wireless communications in a given spectrum band at one location. This process is a form of dynamic spectrum management. In response to the operator command the cognitive engine is capable of configuring radio system parameter. This parameter includes "waveforms, protocols, operating frequency and networking". This functions as an autonomous unit in the communication environment, exchanging information about the environment with the network which access and other cognitive radios (CRS). A CR

"monitor its own performance continuously", in addition to "reading the radios output", it then uses its information to "determine the RF environment, channel conditions, link performances, etc", and adjust the "radio settings to deliver the required quality of service subject to an appropriate combination of user

requirement, operation limitations and regulatory constraints". Cognitive radio is considered as a goal towards which a software-defined radio platform should evolve a fully reconfigurable wireless transreceiver. In this paper, block-fading channel, with zero CSI at the transmitter, and a delay-constrained traffic is considered, for which the transmission rate in each block should be no smaller than R. Under this scenario, it is easy to see that the receiver can only successfully decode the source messages with a probability<1. Instead of using the conventional Shannon capacity as the measure for SE, the effective throughput (ET), i.e. is adopted. The rate of the successfully decoded information at the receiver, as the design metric to evaluate the SE and aim to investigate the EE-versus-ET tradeoff for the considered channels. The main contributions of this correspondence are summarized as follows:

1) Under uniform power allocation, first show that each boundary point of thee–ET region is obtained by solving a transmission rate optimization problem, which is proved to be quasi-concave, and its optimal point is given by the root of an equation.

2) Next, that on the boundary of this region is proved, EE is a decreasing function of ET, and then compute the maximum EE, i.e., the maximum ET per unit energy, in closed form.

3) Finally, generalize our results to M-hop relay channels.

A. *Existing System*

It is assumed that the SUs perfectly sense the PU's activity, i.e., there is no chance of collision between the PU and any of the secondary users. A node that successfully receives a packet broadcasts an acknowledgment (ACK) declaring the successful reception of that packet. ACKs sent by the destinations are assumed instantaneous and heard by all nodes error-free. The channel between every transmitter-receiver pair exhibits frequency at Rayleigh block fading, i.e., the channel co-efficient remains constant for one time slot and changes independently from one slot to another. The scalars h RI [n] and h si [n] denote the absolute squared fading coefficient of the channels that connect the ith SU to DP and Ds, respectively, at the nth time slot. Similarly, the absolute squared fading coefficient of the channels that connect the PU to DP and si, at the nth time slot, are denoted by h p[n] and h psi [n], respectively. According to the Rayleigh fading assumption, h ri [n], h si [n], and h psi [n] are exponential random variables with means 2, for all i = 1: N. an exponential random variable with mean 2 by exp(2) is denoted. Then, h p[n] exp (2p) is got. All links are considered statistically equivalent except for the link p DP. It is assumed that2 p <2 to demonstrate the advantage of cooperation. For the ease of exposition, it is set 2 = 1 throughout the paper. All communications are subject to additive white Gaussian noise of variance N0. It is presented that the queuing model of the system followed by the description of the employed cooperation strategy. Cognitive network with arbitrary number of SUs co-existing with a PU is considered and sharing one common relay queue. Power allocation and scheduling policies that enhance the throughput of both primary and secondary links using the least possible energy expenditure is proposed.

1) *Disadvantages*

More difficult to solve than the problem with scalar variables.

Compared with existing works the transceiver optimization problem.

It's not to visualize the throughput, average energy values and increasing cost.

B. *Proposed System*

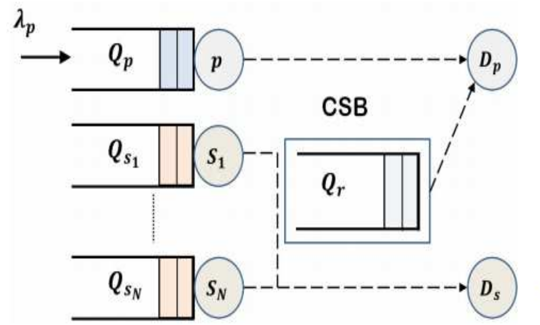


Fig -1.2: Proposed System

The system comprises a PU p that transmits its packets to a primary destination DP. A cognitive network consisting of an arbitrary number of SUs coexists with the primary network. Time is slotted, and the transmission of a packet takes exactly one time slot. The duration of a time slot is normalized to unity and hence, the terms power and energy are used interchangeably in the sequel. The burst nature of the source is taken into account through modeling the arrivals at the PU as a Bernoulli process with rate p (packets/slot).The channel between every transmitter-receiver pair exhibits frequency flat Rayleigh block fading, i.e., the channel coefficient remains constant for one time slot and changes independently from one slot to another. To address this complexity, Krikidis et al. introduced the idea of a common 'fictions' relay queue QR in, which is maintained by a so-called cluster supervision block (CSB) that controls and synchronizes all the activities of the cognitive cluster. Two SUs out of N transmit simultaneously by employing DPC. One SU relays a primary packet to Dp while the other transmits a secondary packet to Ds. Two different power allocation policies for the SUs are investigated, namely, equal power (EP) allocation and adaptive power (AP) allocation. Closed-form expression for this delay is obtained through deriving the moment generating function (MGF) of the joint lengths of QP and Qr. It is worth noting that the SUs' queues are assumed backlogged and hence, no queuing delay analysis is performed for the secondary packets. It is proceeded to highlight the role of the proposed power allocation and node selection policies.

1) *Advantages*

Better performance in terms of throughput and delay at lower energy cost as compared to equal power allocation is achieved.

II. Design and Algorithms

A. *Data Flow Diagram*

1. The flow chart is also called as bubble chart. It is a simple graphical formalism that can be used to represent a system in terms of input data to the system, various processing carried out on this data, and the output data is generated by this system.

2. The data flow diagram (DFD) is one of the most

important modeling tools. It is used to model the system components. These components are the system process, the data used by the process, an external entity that interacts with the system and the information flows in the system.

3. Flow diagram shows how the information moves through the system and how it is modified by a series of transformations. It is a graphical method that narrates information flow and the transformation that is applied as data moves from input to output.

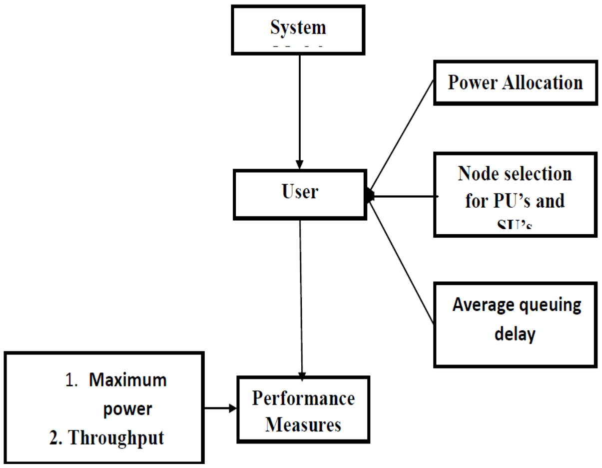


Fig -2.1: Data Flow Diagram

B. *Modules Description*

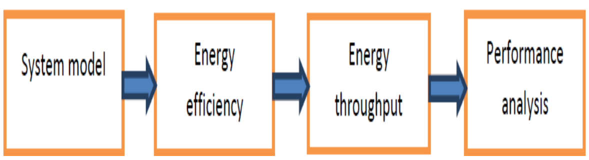


Fig -2.2: Power Allocation Design

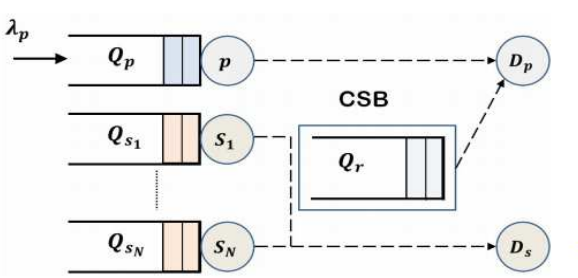


Fig -2.3: Cognitive Radio Network Model for Module Description

III. SYSTEM MODULE

We consider the cognitive radio system shown in fig. 2.1 flow diagram comprises a Pu that transmits its packets to a primary destination Dp. A cognitive network consisting of an arbitrary number of SUs coexists with the primary network. The number of SUs is denoted by N and we refer to the set of SUs by

S= {si} Ni=1. Each SU has its own data that requires to be delivered to a common secondary Destination Ds. All nodes are equipped with infinite capacity buffers. Time is slotted, and the transmission of a packet takes exactly one time slot. The duration of a time slot is normalized to unity and hence, the terms power and energy are used interchangeably in the sequel. We take into account the bursty nature of the source through modelling the arrivals at the PU as a Bernoulli process with rate λp (packets/slot).In other words, at any given time slot, a packet arrives at the PU with probability λp<1. The arrival process at the PU is independent and identically distributed (i.i.d.) across timeslots. On the other hand, the SUs are assumed backlogged, i.e., us always have packets awaiting transmission. We assume that the SUs perfectly sense the PU's activity, i.e., there is no chance of collision between the PU and any of the secondary users. A node that successfully receives a packet broadcasts an acknowledgment (ACK) declaring the successful reception of that packet. ACKs sent by the destinations are assumed instantaneous and heard by all nodes error-free. The channel between every transmitter-receiver pair exhibits frequency-flat Rayleigh block fading, i.e., the channel coefficient remains constant for one time slot and changes independently from one slot to another. The scalars hri[n] and hsi[n] denote the absolute squared fading coefficient of the channels that connect the ith SU to Dp and Ds, respectively, at the nth time slot. Similarly, the absolute squared fading coefficient of the channels that connect the PU to DP and si, at the nth time slot, are denoted by hp[n]and hpsi[n], respectively. According to the Rayleigh fading assumption, hri[n],hsi[n], and hpsi[n]are exponential random variables with meansσ2, for all i= 1,...,N. We denote an exponential random variable with mean σ2 by exp (σ2). Then, we have hp[n] ∼exp (σ2p). All links are considered statistically equivalent except for the linkp→Dp. We assume thatσ2p<σ2to demonstrate the benefits of cooperation [9]. For the ease of exposition, we set

σ2= 1throughout the paper. All communications are subject to additive white Gaussian noise of varianceN0. Next, we present the queuing model of the system followed by the description of the employed cooperation strategy.

A. *Power Allocation*

In this section, we introduce the adaptive power allocation and opportunistic relay selection strategies for an arbitrary number of SUs, N≥2. We propose a power allocation policy that minimizes energy consumption at each SU as compared to a fixed power allocation policy in [7]. In the sequel, node selection policy refers to the choice of the SU that relays a primary packet from QR to Dp, and the SU that transmits a packet from its own queue to Ds, i.e., the selection of r∗ and s∗. The availability of CSI for all the channels (and there by incurred interference) at the CSB is exploited to perform power allocation and node selection online, i.e., every time slot. Whenever Qp is non-empty, the PU transmits a packet with average powerP0. However, when the PU is idle and Qr is non-empty, two SUs out of N transmit simultaneously by employing DPC [10]. One SU relays a primary packet to Dp while the other transmits a secondary packet to Ds .Since all SUs can perfectly exchange information with the CSB, Qr is accessible by both SUs selected for transmission. Therefore, the transmission of r∗ is considered a priori known interference at s∗. Accordingly, s∗ adapts its signal to see an interference-free link to Ds using the result stated in

SectionII-A. On the other hand, s∗ transmits a packet from its own queue which is not accessible by r∗. Thus, the transmission of s∗ causes interference on the relay link, i.e., r→Dp. The achievable rate region on this Z-interference channel at the nth time slot is given by

Rs *[n] = log [1 +Ps*[n] hs* [n]/N0]

Rr * [n] = log [1 +Pr* [n] hr*[n]/N0+Ps* [n]hI[n]]

B. *Node Selection*

We consider a system that assigns full priority to the PU to transmit whenever it has packets. Therefore, the SUs continuously monitor the PU's activity seeking an idle timeslot. When the PU is sensed idle, the SUs are allowed to transmit their own and/or a packet from the common queue Qr. Note that it is possible to transmit only one packet by the SUs in the following scenarios:

1) If Qr is empty, i.e., no primary packet to be relayed. Then, we select the SU with the best channel to Ds.

2 Qr is non-empty, but r∗ or s∗ is set silent by the CSB to avoid a guaranteed outage event on the r∗→Dp or s∗→Ds link. Note that CSI for transmission is assumed to be known at CSB and outage event (due to power limitation) can be predicted before transmission as discussed in Section IV-A2.In this case, we choose the transmitting SU as the one with the best instantaneous link to the intended destination. For example, if r∗ is silent and s∗ is transmitting alone, the SU with the best link between S→Ds transmits.

The case for the simultaneous transmission of two SUs is the main topic for investigation in this project.

C. *Average Queuing Delay*

The queues involved in the system analysis, shown in Fig.2.1 are described as follows

•QP: a queue that stores the packets of the PU corresponding to the external Bernoulli arrival process with rate λp.

•Qsi: a queue that stores the packets at the ith SU, where i ∈ {1... N}.

•QR: a queue that stores PU packets to be relayed to Dp. Having independent relay queues for all SUs makes exact performance analysis intractable with the increasing number of users. To address this complexity, Krikidiset al. introduced the idea of a common 'fictitious' relay queue Qr in [7], which is maintained by a so-called cluster supervision block (CSB) that controls and synchronizes all the activities of the cognitive cluster. Along the lines of [7], we assume the existence of a common relay such that SUs can perfectly exchange information with the CSB with a negligible overhead. The Channels S→Dp, Ds are assumed known instantaneously at the CSB [7, 20]. The instantaneous evolution of queue lengths is captured as**: Qi [n+ 1] = (Qi[n] −Li[n]) ++Ai[n], i ∈ {p, r} ∪ S**

Where Qi[n]denotes the number of Packets in the Ith queue at the beginning of the nth time slot. The binary random variables taking values either 0 or 1, Li[n] and Ai[n], denote the departures and arrivals corresponding to the ith queue in the nth time slot, respectively.

D. *Throughput and Delay Analysis*

In this section, we conduct a detailed analysis for the system performance in terms of throughput and delay. Towards this objective, we derive the stability conditions on the queues with stochastic packet arrivals, namely, QP and Qr. The stability of a queue is loosely defined as having a bounded queue size, i.e., the number of packets in the queue does not grow to infinity [9]. Furthermore, we analyze the average queuing delay of the primary packets. We obtain a closed-form expression for this delay through deriving the moment generating function (MGF) of the joint lengths of Qp and Qr. It is worth noting that the SUs' queues are assumed backlogged and hence, no queuing delay analysis is performed for the secondary packets. In the following lines, we provide a general result for the throughput of the primary and secondary links as well as the delay of primary packets. Then, we proceed to highlight the role of the proposed power allocation and node selection policies. We first introduce some notation. The probabilities of successful transmissions on the relay and secondary links are denoted by fr∗ and fs∗, respectively. A transmission on the link p→Dp is successful with probability fp. In addition, the probability that at least one SU successfully decodes a transmitted primary packet is denoted by fps.

IV. SIMULATION RESULTS

In this section, we validate the closed-form expressions derived in this paper via comparing theoretical and numerical simulation results. We investigate the system performance in terms of the primary and secondary throughput as well as the average primary packets' delay. In addition, we quantify the average power consumption at the SUs. Furthermore, we conduct performance comparisons between the four strategies resulting from the proposed power allocation and SU selection policies. Accordingly, we draw insights about the benefit of employing the proposed power allocation schemes. We set P0=N0 = 10 dB. Results are averaged over 106 time slots. Generic expressions have been provided that work for any combination of power allocation and node selection policies. These expressions are functions of the probabilities of successful transmissions on relay and secondary links, i.e., fr_ and fs_.

This fact has been thoroughly addressed in the appendices, where the four different power allocation and node selection policies have been analyzed. We start by validating our theoretical findings through simulations.

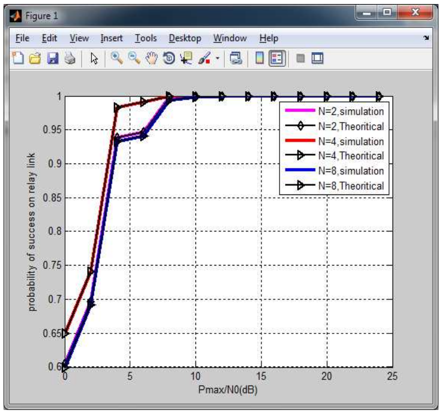


Fig -3.1: Relay link versus Pmax/N0 for AP-BSL

Towards this objective, the analytical expressions for fr_, derived are compared to their Corresponding simulation results for both AP-BSL and APBPL in Fig. 3.1 We set a target rate R0 = 1:5 (bits/channel use) and we choose _2p = 0:25. Fig 3.1 shows a perfect match of theoretical and simulation results for AP-BSL for any number of SUs, N. However, for AP-BPL, Fig shows a slight deviation between both results. This difference is attributed to the relaxation of the constraint that hI < hr_ in the derivation presented, where we treat hand hr_ as independent random variables. This constraint is an immediate consequence of the node selection policy presented. The relaxation has been done for the sake of mathematical tractability.

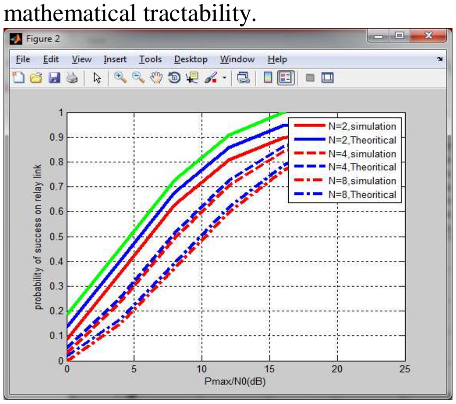


Fig -3.2: Relay link versus Pmax=N0 for AP-BPL.

Nevertheless, Fig 3.2 shows that the constraint relaxation has a minor effect on the obtained closed-form expression for fr. This validates our theoretical findings. Fig. 3.2 show that fr consistently increases as the number of SUs increases for both AP-based schemes. This behavior is also true for EP-based schemes and is attributed to multi-user diversity gains obtained through increasing N. We investigated the effect of varying N in Fig 3.2 Without loss of generality, the rest of the results is presented for N = 2, R0 = 2 (bits/channel use), and 2p = 0:25. We proceed with presenting the throughput of the PU and the SUs for all combinations of power allocation and node selection policies. Moreover, we validate the obtained closed-form expressions for average PU delay via simulations. Theoretical and simulation results for AP-BSL perfectly coincide. However, for AP-BPL, the slight deviation between theory and simulations is attributed to the relaxation of the constraint hI < hr.

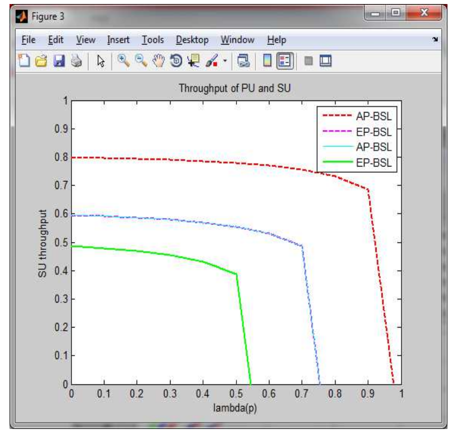
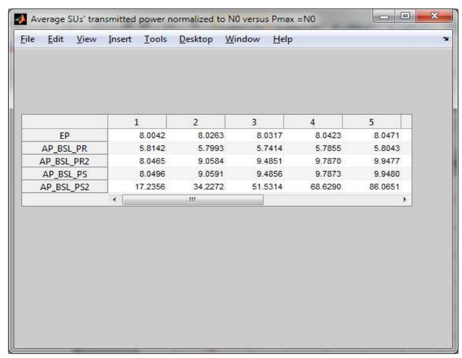


Fig -3.3: SU throughput versus λp.

In Fig 3.3, we plot the SU throughput versus λp at Pmax=N0 = 7dB. For the same node selection policy, the throughput region of the AP-based schemes is shown to strictly contain that of the EP based scheme. Furthermore, at every feasible _p for EP-BPL, higher SU throughput is attained by AP-BPL. Thus, power adaptation expands the stable throughput region. This shows the superiority of AP-based schemes in both PU and SU throughput over their EP-based counterparts.

Table -1: SU throughput versus λp(power)


Average SUs' transmitted power normalized to N0 versus Pmax =N0

	1	2	3	4	5
EP	8.0042	8.0263	8.0317	8.0423	8.0471
AP_BSL_PR	5.8142	5.7993	5.7414	5.7855	5.8043
AP_BSL_PR2	8.0465	9.0584	9.4851	9.7870	9.9477
AP_BSL_PS	8.0496	9.0591	9.4856	9.7873	9.9480
AP_BSL_PS2	17.2356	34.2272	51.5314	68.6290	86.0651

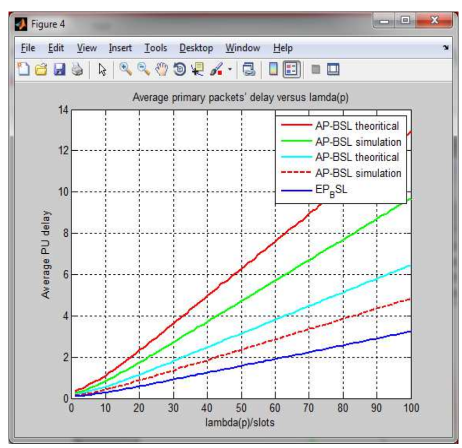
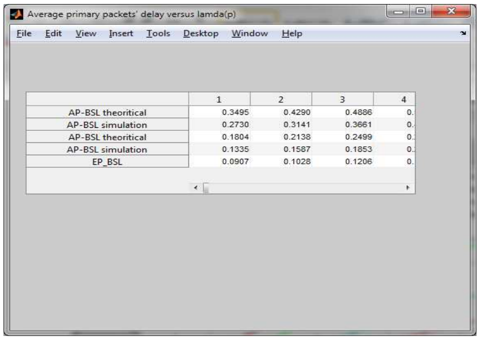


Fig -3.4: The average PU delay versus lambda (P).

Furthermore, we investigate the fundamental throughput-delay tradeoff in Fig 3.4. We plot the average packet delay for the PU versus its throughput at Pmax=N0 = 5 dB. Intuitively, when a node needs to maintain a higher throughput, it loses in terms of the average delay encountered by its packets. Given that the system is stable, the node's throughput equals its packet arrival rate. Thus, increased throughput means injecting more packets into the system resulting in a higher delay. Furthermore, Fig 3.4 shows that strictly lower average PU delay is attained via AP-based schemes compared to EP allocation in [7]. It can also be noticed that AP-BPL is still in the leading position among all schemes in terms of both throughput and delay. Fig 3.4 shows that at Pmax=N0 = 5 dB and _p = 0:1, AP-BPL reduces the PU's average delay by up to 27% compared to AP-BSL, and 40% compared to EP- BPL.

Table -2: The average PU delay versus lambda (P)



Average primary packets' delay versus lamda(p)

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	1	2	3	4
AP-BSL theoritical	0.3495	0.4290	0.4886	0.
AP-BSL simulation	0.2730	0.3141	0.3661	0.
AP-BSL theoritical	0.1804	0.2138	0.2499	0.
AP-BSL simulation	0.1335	0.1587	0.1853	0.
EP_BSL	0.0907	0.1028	0.1206	0.

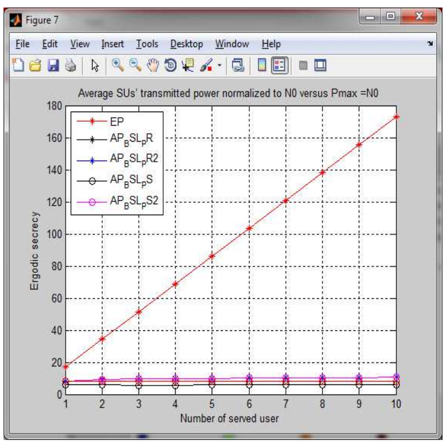

Fig -3.5: Ergodic secrecy versus number of served user

The average queuing delay of PU's packets for different combinations of power allocation and node selection policies is shown in fig 3.5.

V. CONCLUSIONS

Power allocation policy for cognitive radio networks with multiple relays and propose different relaying protocols depending on the network utility function is discussed. The effect of SU power adaptation on throughput and average delay is thoroughly investigated. The closed-form expressions for the achieved throughput and average delay and validate the results through numerical simulations derived. Dynamically adapting the transmission powers at the SUs according to the channel conditions results in substantial improvement in primary and secondary throughput. The SUs under EP-based schemes always transmit at maximum power. This results in excessive interference on the relay link which is not the case for the AP-based schemes. Power adaptation is performed at the SUs to transmit with the minimum power required for the successful transmission. To further benefit the system, the SUs back-off if their maximum permissible power is not sufficient to yield a successful transmission and avoid guaranteed outage events. The back-off benefits the other transmitting SU by reducing the incurred interference and thereby, causes throughput increase. The AP-based schemes are shown to reduce the average queuing delay encountered by the PU packets compared to their EP-based counterparts. Mathematical analysis of the proposed schemes and show numerically that the AP-based schemes save energy; and achieve higher throughput and lower delay simultaneously is performed.

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