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NASH BARGAINING BASED BANDWIDTH ALLOCATION IN COGNITIVE RADIO FOR DELAY CRITICAL APPLICATIONS

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Abstract
In order to effectively regulate the existing resources, dynamic spectrum access in cognitive radio needs to adopt the effective resource allocation strategies. Multimedia applications require large bandwidth and have to meet the delay constraints while maintaining the data quality. Game theory is emerging as an effective analytical tool for the analysis of available resources and its allocation. This paper addresses resource allocation schemes employing bargaining game model for Multi-carrier CDMA based Cognitive Radio. Resource allocation scheme is designed for transmission of video over cognitive radio networks and aim to perform bandwidth allocation for different cognitive users. Utility function based on bargaining model is proposed. Primary user utility function includes the pricing factor and an upbeat factor that can be adjusted by observing the delay constraints of the video. Allocated bandwidth to the secondary user can be adjusted by changing the upbeat factor. Throughput in the proposed scheme is increased by 2% as compared to other reported pricing based resource allocation schemes. The edge PSNR of reconstructed video obtained as 32.6dB resulting to optimum decoding of the video at the receiver. The study also shows upbeat factor can be used to enhanced capacity of the network.

Keywords:
Resource Allocation, Cognitive Networks, Game Theory, Utility Function, Video

1. INTRODUCTION

Demand for wireless multimedia transmission has been constantly increasing because of the widespread deployment of high data rate wireless networks and the improvements in video compression technologies. Delay-sensitive multimedia communications services have brought profound changes to human society. More and more people have found their lives being enriched and facilitated by video applications such as video telephony, online video streaming, video conferencing, video gaming, and mobile TV broadcasting [1]. Digital video has already become the main traffic payload for Internet and major wireless networks.

Despite the increasing demand, wireless multimedia communications, especially real-time video applications, still suffer from number of problems. The wireless environment is much different from the Internet that it usually leads to performance degradation by directly applying video transmission techniques that are used in the current Internet environment. In wireless networks along with ad hoc networks, a wireless link usually has a high transmission error rate because of shadowing, fading, and interferences from other transmitting users. An end-to-end path in wireless networks has an even higher error rate since it is the concatenation of multiple wireless links. Moreover, user mobility makes the network topology causing frequent change. An end-to-end route may only exist for a short period of time. The frequent link failures and route changes cause packet losses, thus degrading the received video quality. Stringent bandwidth resource isunable to fulfill Quality of Service (QoS) requirements of video over wireless. Cognitive Radio (CR) is a promising technology which extends the software-defined radio concept to improve the spectrum utilization. Secondary user (SU) in a cognitive radio network (CRN) is able to operate in the licensed band by adjusting its transmission parameters. The Cognitive term was introduced in [2] with the new communication system that can observe and learn from the surrounding radio environment as well as can adapt its own transmission parameters by keeping user requirements in view. FCC Spectrum Policy Task Force reported that a large amount of spectrum is under-utilized [3]. In order to improve the utilization of the spectrum, a secondary system must coexist with the primary system (licensed network). This secondary system must bound the interference caused to the primary system. This implies that resource allocation (RA) is the key challenge in the successful implementation of cognitive radio technology. The introduction of CR technology poses new resource allocation (RA) problems that need to be solved. Compared to conventional wireless communication systems, two new issues arise, namely, the interference power to the primary user bands should be kept below a certain threshold and optimum Quality of Service (QoS) should be provided to CRs in spite of the time-varying nature of the available spectrum. To make unlicensed sharing of the licensed spectrum a reality, PU operation must not be compromised. Thus, CRs should monitor and keep the generated interference to PU bands to an acceptable level. The FCC Spectrum Policy Task Force has recommended the use of interference temperature for assessing the level of interference. Specification of an interference temperature limit for a PU corresponds to a maximum allowed level of interference power. CRs can use PU frequency bands as long as the total generated interference power to the PUs is kept below this limit. In a fading environment, a CR signal may undergo deep fading and received with very little power at the PU receiver. As a result, apart from the spectrum holes, CRs can opportunistically share PU active frequency bands, as long as the total generated interference power at the PU receiver is below the specified interference power threshold. Specifically CRs are required to find the spectrum holes in the spectral band and to decide if the spectrum allocation meets the QoS requirements of different users.

Game theory is a mathematical tool for analyzing the interaction between two or more decision makers [4]. It has been used in a variety of fields such as economics, political science, and biology. A strategic game consists of mainly three components: a set of players, a strategy set for each player and a utility (payoff) function for each player which measures the degree of “happiness” of the player. Game theory is proved to be very significant in the telecommunications, particularly wireless communication. User's interaction in a wireless network can be modeled as a game in which user's terminals are the players in the game competing for network resources (i.e. bandwidth and energy). Any action taken by a user affects the performance of other users in the network. Resource allocation can be modeled as a game that deals largely with how rational and intelligent individuals interact with each other in an effort to achieve their own goals. A wireless network can be analyzed with different types of games. This includes cooperative and non-cooperative games. The non-cooperative game theory focuses on the analysis of competitive decision-making involving several players. The players may have partially or totally conflicting interests over the outcome of the decision process which is affected by their actions. Furthermore, a game can be with complete information or incomplete information. In a game with complete information, each player is aware of the identities of all other players, their strategies, and pay-offs. In this work, game theory is used to solve problem of bandwidth allocation.

The remainder of this paper is organized as follows. Section 2 covers the related work whereas in section 3 we formulate the system model with single primary user. Section 4 and section 5 presents formulation of pricing-based utility function and utility function for the secondary users respectively. Existence of Nash Equilibrium is discussed in section 6. Simulation and discussion is presented in section 7 while paper is concluded in section 8.

2. RELATED WORK

CR technology can greatly improve spectrum efficiency by allowing unlicensed SUs to opportunistically obtain spectrum resources from licensed PUs, and thus can effectively alleviate the ever-increasing network pressure due to the rapid growth of wireless multimedia services [4]. Cao and Zheng [5] considered cooperative local bargaining to provide both spectrum utilization and fairness. Local bargaining is performed by constructing local groups according to a poverty line that ensures a minimum spectrum allocation to each user. Jiang et al. [6] proposed a reinforcement-learning-based spectrum-sharing scheme. CR users can learn from the interaction between themselves and the environment to assess the success level of a particular action. Zheng and Cao [7], unlike the aforementioned references, considered non cooperative intra-network spectrum sharing, in which an opportunistic spectrum management scheme was proposed. Users allocate channels based on their observations of interference patterns and neighbors.

In [8], the authors propose a dynamic game model between multiple primary users in cognitive radio networks. Primary users using Bertrand model game each other and then achieve the best price ultimately. In literature [9], authors present secondary users utility function and compete for bandwidth through non-cooperative game.Utility function [10] is defined in terms of system throughput and achieves the maximum system throughput ultimately through price and spectrum competition. Method of joint power and rate control mechanism is proposed in [11]. Based on the control of secondary users transmit rate, the method limits their power reasonable to reduce interference on the primary user. In [12], a power interference threshold of secondary users is set. Within allowable interference range, the secondary users game mutually, such that the final utility function is maximum. Authors in [13], propose method based on microeconomics. It introduces layering the users according to different service, and then allocates the spectrum dynamically on the basis of different hierarchy. Sub-layer users can perceive upper levels users spectrum, and sharing bandwidth with them. This method not only ensures the upper levels' traffic needs, but also improves the spectrum efficiency. Different methods and strategies discussed above do not explicitly consider the secondary user's traffic characteristics. Video services such as video conferencing, Internet TV, etc gradually increase. Compared to traditional data services, these video services are significantly different, such as that video service need consider the delay sensitive, user's subjective visual experience and so on. So the video traffic cannot simply use the conventional method of data service to allocate the bandwidth. Cross-layer optimization strategies have been proposed as a solution for improving the performance of video over wireless applications. These solutions include joint PHY-MAC, APP-PHY, MAC-APP layer optimizations for robust video over wireless transmission. Since video over cognitive networks require seamless communication in the dynamic spectrum access environment, game-theoretic techniques are more suitable for the spectrum allocation.

This paper proposes bargaining-based utility functions for primary and secondary users. Primary user's utility function introduces two factors termed as upbeat factor and penalty factor. These factors contribute for releasing more bandwidth by the PU and also applying penalty to SU in order to protect PU's QoS respectively. We propose a utility function for the SUs which incorporate the delay-sensitive characteristics of the multimedia transmissions.

3. SYSTEM MODEL WITH SINGLE PRIMARY USER

CRN under consideration comprises one PU and multiple SUs. Bandwidth allocated to PU is W Hz whereas the minimum bandwidth required to PU to carry his own traffic is considered as B_{req}. There are M secondary users and try to share bandwidth of PU. Primary user calculates the penalty factor information according to their utility maximization principle, and then, informs the secondary users about the value of penalty factor. Secondary users bargain mutually until they reach the satisfactory bargaining solution.

3.1 VIDEO RATE-DISTORTION MODEL

Video transmission is subjected to some degree of distortion due to the compression. This factor is considered in the Rate-distortion model. Video Rate-Distortion model describes the relationship between compression rate and distortion of the video. Distortion model is given by [10],

$$D(C) = \alpha e^{-\beta R} \tag{1}$$

where, D is video distortion and C is the video compression rate. α and β represent the specific parameters of video which are different from different video content. Peak Signal to Noise Ratio ($PSNR$) is used to describe the quality of the video as given by,

$$PSNR = 10\log_{10}\frac{255^2}{D}. \tag{2}$$

In video transmission, Edge Peak Signal to Noise Ratio (EPSNR) is significant in describing QoS parameters. It gives the average of the differences between the edge pixels of the source video sequence and the corresponding pixels of the processed video sequence. It can be considered as the edge mean squared error of the processed video sequence. *EPSNR* is for the peak value P of image and edge mean squared error MSE_{edge}, *EPSNR* is given by,

$$EPSNR = 10\log_{10}\frac{P^2}{MSE_{edge}}. \quad (3)$$

4. FORMULATION OF PRICING-BASED UTILITY FUNCTION (PRIMARY USER)

Utility function for the primary user in this spectrum sharing game model protects QoS parameters of primary user by introducing penalty factor for SUs. Thus utility function will be governed mainly by penalty to SUs, self enthusiasm factor which in the worst case will be the entire bandwidth of PU.

Considering above factors, we can define the primary user utility function as follows:

$$U_{pu} = gp\gamma\sum_{i=1}^{M} w_i - q\frac{\left(\sum_{i=1}^{M} w_i - B_{req}\right)^2}{B} \quad (4)$$

where, g is the rent per unit bandwidth when the primary user's bandwidth leases to secondary users; p is a upbeat factor of the primary user. Large value of p will facilitate secondary users to utilize increased amount bandwidth. Penalty factor γ is to punish the second users and increases with the occupied bandwidth of secondary users. Total number of the bandwidth of each secondary user occupies $\sum_{i=1}^{M} w_i$; Tradeoff parameter q controls the bandwidth allocation. PU guarantees his own QoS by keeping bandwidth B_{req} reserved. Primary user is allowed to release entire bandwidth B. Thus, utility function represents benefits obtained by leasing the bandwidth to secondary users and the interference from secondary users to primary user during bandwidth sharing process. Second term counts for the cost of primary users.

Maximum utility function is obtained by determining γ. Taking the partial derivatives of w_i over the utility function:

$$\frac{\partial U_{pu}}{\partial w_i} = gp\gamma - \frac{2\left(\sum_{i=1}^{M} w_i - B_{req}\right)^2}{B} = 0 \quad (5)$$

then,

$$\gamma = \frac{2\left(\sum_{i=1}^{M} w_i - B_{req}\right)^2}{gpB}. \quad (6)$$

The Eq.(6) presents that the penalty factor γ increase with the secondary users' bandwidth occupying factor $\sum_{i=1}^{M} w_i$.

5. FORMULATION OF UTILITY FUNCTION FOR THE SECONDARY USERS

As the video transmission is bandwidth-demand system, as the occupied bandwidth reaches towards the available bandwidth, there is congestion in the network. Eventually average delay in the network will be increased. Considering network congestion Z in the secondary user utility function,

$$Z(w_i) = \frac{\sum_{i=1}^{M} w_i}{B - B_{req} - \sum_{i=1}^{M} w_i} \quad (7)$$

where, w_i is the transmission rate of user i. Hence, $\sum_{i=1}^{M} w_i$ represents the total traffic in the network and denominator represents the current available network bandwidth.

Utility function for the secondary users is given by,

$$U_{SU} = \ln(PSNR_i) - k\frac{\sum_{i=1}^{M} w_i}{B - \sum_{i=1}^{M} w_i} - \gamma g w_i \quad (8)$$

Compression rate is given as [9],

$$R_i = w_i\rho_i \quad (9)$$

$$\rho_i = \log_2(1 + K\gamma_i) \quad (10)$$

$$K = \frac{1.5}{(\log_2 BER_T)} \quad (11)$$

where, γ_i is secondary user that receives signal to noise ratio.The target bit error rate is BER_T. If the secondary users signal to noise ratio and target bit error rate is known, ρ_i can be determined.

Simplifying,

$$U_{SU} = \ln(\varepsilon_i + \beta_i w_i \rho_i) - k\frac{\sum_{i=1}^{M} w_i}{B - \sum_{i=1}^{M} w_i}. \quad (12)$$

Video is encoded at different rates. The rate distortion curve is of significant importance in determining video-specific parameters α_i and β_i of the video transmission. In this function, ($\varepsilon_i = 2\ln 255 - \ln\alpha_i$) is a parameter related to the transmission of video content of the first i user. First term in Eq.(12) refers to revenue obtained from a secondary user for the transmission of video. As the secondary users occupy more bandwidth causing delay they are punished which is given by second term of Eq.(7). As the bandwidth occupied by the secondary users increases, network congestion is controlled by increasing the factor k which is the impact factor of network congestion. It indicates that traffic is very sensitive to network latency. Factor k can be adjusted to achieve the average network delay requirements. Primary user determines penalty factor γ which can reduce the interference to the primary user's own traffic.

The minimum transmission rate $R_{\min}$ signifies the minimum transmission rate that each video requires to be distinguished. In order to improve the utilization of resources, each video is assigned by a maximum transfer rate $R_{\max}$. The required minimum and the maximum transmission rate corresponding to the minimum and maximum required bandwidth ($w_{i(\min)}$ and $w_{i(\max)}$) can be decided in the case of certain spectral efficiency.

Game model of secondary user is given as,

$$\max U_{SU} = \ln(\varepsilon_i + \beta_i w_i \rho_i) - k\frac{\sum_{i=1}^{M} w_i}{B-\sum_{i=1}^{M} w_i} - \gamma gwi \quad (13)$$

$$s.t. w_{i(\min)} \le w_i \le w_{i(\max)} \quad (14)$$

$$\sum_{i=1}^{M} w_i \le B - B_{req}. \quad (15)$$

For a static game, it is assumed that each secondary user knows the current bandwidth allocation of other secondary users. In order to maximize the utility function, partial derivative of the utility function U_{SU} is taken over w_i and set the derivative to 0, that is,

$$\frac{\partial U_{SU}}{\partial w_i} = \frac{\beta_i}{\varepsilon_i + \beta_i w_i \rho_i} - \frac{kB}{\left(B-\sum_{i=1}^{M} w_i\right)^2} - \frac{2\left(B_{req} + \sum_{j=1, j\ne i}^{M} w_j - 2w_i\right)}{\alpha_i B} = 0. \quad (16)$$

6. EXISTENCE OF NASH EQUILIBRIUM

We consider there are M secondary users which bargain for the spectrum. Game Model can be expressed as,

$$G = \{M,\{u_i\},\{U_i\}\} \ (i \in N) \quad (17)$$

where, $\{u_i\}$ indicates strategy space of M SU's i.e. amount of bandwidth they got through competition and U_i represents their utility functions. Each user maximizes its utility function in the game of bandwidth allocation. Nash Equilibrium exists when the strategy space allocation policies are satisfied with $U\{u_i^*, u_{-i}\} \ge U\{u_i, u_{-i}\}$. The strategy combination $\{u_1, u_2, ..., u_N\}$ is called the Nash Equilibrium.

For M secondary users Nash Equilibrium exists if following conditions are met [10]:

Condition 1: With M person participant the Game, ever user i's all feasible strategy space u_i is non-empty and compact convex sets on the R^m.

Proof: In the proposed game model, each secondary user has bandwidth limits, $w_i \in (w_{i(\min)}, w_{i(\max)})$, and indicates a non-empty and convex set.

Condition 2: The user i's utility function is continuous quasi-concave functions.

Proof: Partial derivative of Eq.(12) over w_i, gives,

$$\frac{\partial U_{SU}}{\partial w_i} = \frac{\beta_i}{\varepsilon_i + \beta_i w_i \rho_i} - \frac{kB}{\left(B-\sum_{i=1}^{M} w_i\right)^2} - \frac{2\left(B_{req} + \sum_{j=1, j\ne i}^{M} w_j - 2w_i\right)}{\alpha_i W} \quad (18)$$

and partial derivative of Eq.(18) over w_i gives,

$$\frac{\partial^2 U_{SU}}{\partial w_i^2} = -\frac{\beta_i^2}{(\varepsilon_i + \beta_i w_i \rho_i)^2} - \frac{2kB}{\left(B-\sum_{i=1}^{M} w_i\right)^2} - \frac{4}{pB} < 0. \quad (19)$$

Therefore, user i's utility function U_{SU} is a concave function in terms of w_i that satisfies the condition 2. This indicates that there exists a Nash Equilibrium in this game.

7. SIMULATION RESULTS AND DISCUSSION

H.264/MPEG4-AVC video standard is considered for the simulation scenario, which is a widely used as an industrial standard that offers better compression efficiency and greater flexibility in compressing, transmitting and storing video. Compared with standards such as MPEG-2 and MPEG-4 Visual, H.264/MPEG4-AVC can deliver better image quality at the same compressed bit-rate and a lower compressed bit-rate for the same image quality.

The total bandwidth of primary user is considered as 3MHz. The SU transceiver uses 128 sub-carrier MC-CDMA for communication. The minimum required bandwidth for primary user to protect his own transmission, B_{req} is 1MHz. The dynamic learning factor used in two secondary user's game is $u_1 = u_2 = 0.12$. Received Signal to Noise Ratio (*SNR*) is considered asequal for two secondary users.Target bit error rate BER_T is taken as 10^{-3}. Parameters of two secondary user's video shown as Table.1.

Table.1. Parameters of Video for SUs

Secondary User	α_i	β_i	$R_{i(\min)}$ **(kbps)**	$R_{i(\max)}$ **(kbps)**
User 1	0.0026	5.2401	286	1200
User2	0.0027	5.4201	225	1000

The Fig.1 shows the effect of bandwidth released by PU on available bandwidth for SUs. Bandwidth released to SUs is a function of the factor k which is the impact factor of network congestion. In actual video transmission, average delay requirements of the network are achieved by adjusting value of impact factor. As k is increased, network congestion is increased and traffic has more strict requirements in the network delay. This requires to increase the punishment to the SUs by increasing the penalty factor. This increased value of penalty factor will reduce the bandwidth allocated to SUs. For $k = 1$, bandwidth accessed by SU1 is 1.4MHz whereas when k is increased, indicating congestion and network delay, and hence penalty factor reduces the bandwidth accessed by SU1. Thus, value of factor of network congestion and penalty factor achieves the delay requirements in the video transmission.

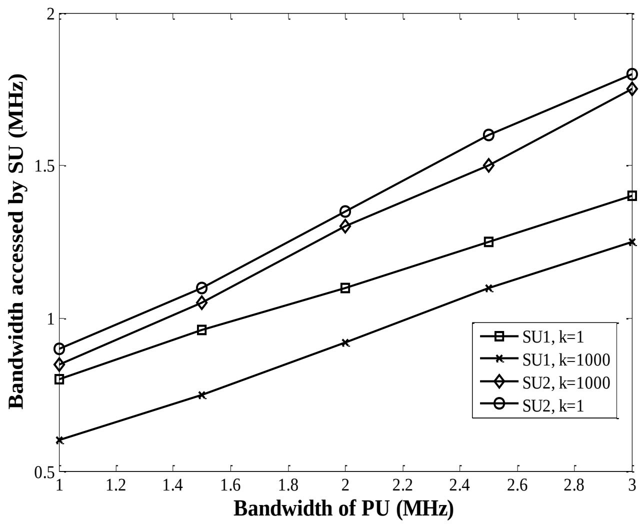

Fig.1. Effect of Penalty Factor on SU's Bandwidth Allocation

In Fig.2, we analyze the throughput of the network as a function of increase rate of SUs. Compared with [15], throughput in the proposed scheme for 5 SUs is increased by 2%. It is also observed that upto certain increase in call arrival rate, throughput increases but later on it gets saturated because of non availability of additional resources to SUs.

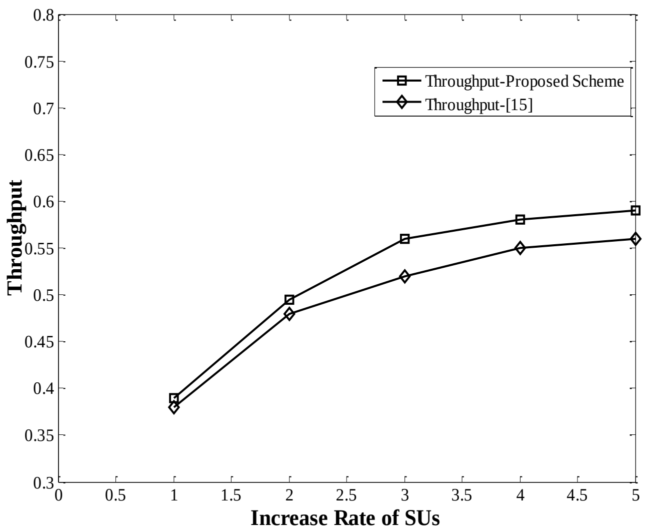

Fig.2. Performance of SUs at Different Arrival Rate

The blocking probability as a function of arrival rate of SUs is shown in Fig.3. It is observed that the blocking probability increases with the increase in arrival rates of SUs. In the proposed scheme, blocking probability can be reduced by increasing the upbeat factor which releases more bandwidth for SUs. As indicated in Fig.3, blocking probability for $p = 0.5$, is less as compared to its value for $p = 0.3$.

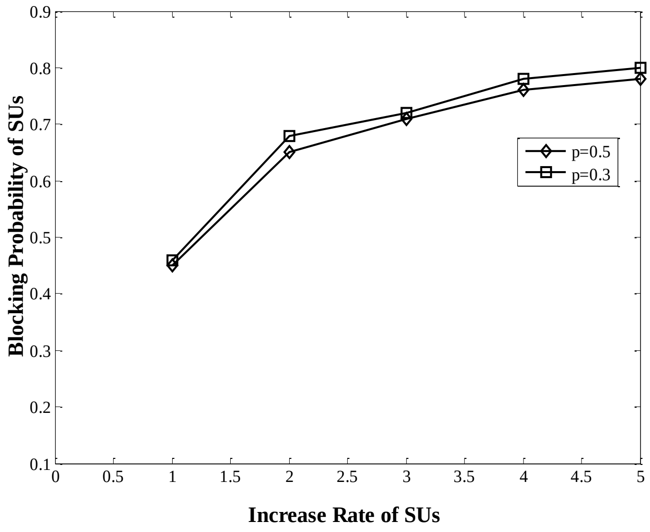

Fig.3. Blocking Probability of SUs for Different Arrival Rate

The Fig.4 shows the effect of increase rate of PUs on the mean PSNR. It depicts that with the increasing arrival rate of PUs, the transmission quality of SUs increases. However, the SU2 still achieves better quality than other SU1 due to its highest priority as implemented in bargaining game.

Introduction of upbeat factor in the utility function also improves the capacity of network. In Fig.5, we indicate this improvement in capacity as function of upbeat factor for a specified value of SNR. It is observed SNR of 10dB and upbeat factor equal to 0.3, capacity is 4 bits/s/Hz whereas it is improved to 8bits/s/Hz for upbeat factor of 0.8. The EPSNR of the proposed scheme is 32.6dB which indicates the optimum decoding of the video at the receiver.

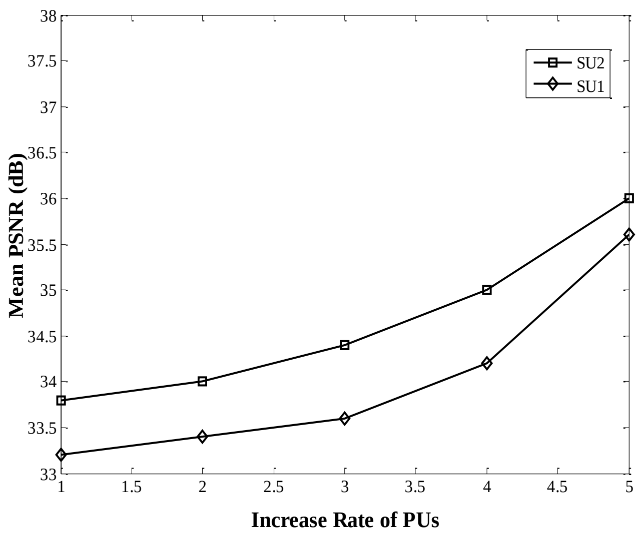

Fig.4. Mean PSNR of Video vs Increase Rate of PUs

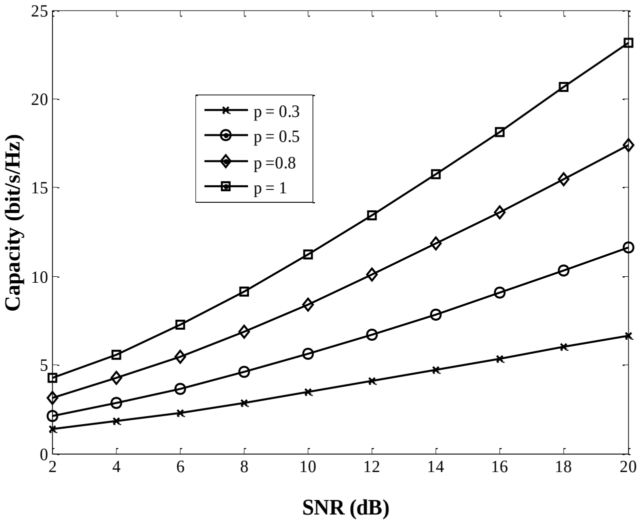

Fig.5. Capacity of Network as a Function of Up-beat Factor

The results discussed above reflect that the method proposed approaches to better fairness between different secondary users. In [14], the authors use the result of bandwidth multiplied by the unit bandwidth profit and bandwidth efficiency as the gain of secondary users without considering the video contents. Thus, as shown in Fig.1, according to the proposed method that take into account the different video content, the SU2 is allocated more bandwidth because of complex content whereas results in [15] shows that the two secondary users are allocated the same bandwidth. The innovative utility functions for primary and secondary users proposed in this paper consider different features of the videos and bandwidth is allocated after the fair bargaining of the users in order to maximize their own utility functions.

8. CONCLUSION

The major contribution of this paper is towards the bandwidth allocation for video transmission over MC-CDMA based cognitive radio networks by reducing the latency in network by considering the network traffic. Proposed utility functions are designed on bargaining-based non-cooperative game theory. The upbeat factor will release more bandwidth while the network delay is reduced by applying penalty factor to the secondary users. The scheme also improves PSNR and EPSNR during the video transmission. While the proposed algorithms are for static game model, bandwidth allocation can be further improved by introducing dynamic modeling. Our results demonstrate that the proposed game-theoretic bargaining model significantly improve the video transmission performance.

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