Game Theoretic Wireless Resource Allocation for H.264 MGS Video Transmission over Cognitive Radio Networks

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ABSTRACT

We propose a method for the fair and efficient allocation of wireless resources over a cognitive radio system network to transmit multiple scalable video streams to multiple users. The method exploits the dynamic architecture of the Scalable Video Coding extension of the H.264 standard, along with the diversity that OFDMA networks provide. We use a game-theoretic Nash Bargaining Solution (NBS) framework to ensure that each user receives the minimum video quality requirements, while maintaining fairness over the cognitive radio system. An optimization problem is formulated, where the objective is the maximization of the Nash product while minimizing the waste of resources. The problem is solved by using a Swarm Intelligence optimizer, namely Particle Swarm Optimization. Due to the high dimensionality of the problem, we also introduce a dimension-reduction technique. Our experimental results demonstrate the fairness imposed by the employed NBS framework.

Keywords: Cognitive radio, resource allocation, scalable video coding, Nash Bargaining Solution, Game Theory, fairness, Particle Swarm Optimization, OFDMA.

1. INTRODUCTION

Over the recent years, the number of applications related to wireless multimedia communications has been increasing at a remarkable pace. However, the limited spectrum availability has become a barrier for high rate services. Cognitive Radio (CR) systems manage to overcome this problem. CR systems are intelligent wireless communication systems which are aware of their environment and support reliable communication by efficiently utilizing the available electromagnetic spectrum. The spectrum holes that are unoccupied by a primary user are exploited and the available bands of frequencies are assigned to secondary communications to be used without interfering to the primary communications.[1] To satisfy this requirement, we employ a Multiple-Input-Multiple-Output (MIMO) antenna system at the CR network. MIMO antenna systems perform much better than Single-Input-Single-Output systems in multimedia transmission. They achieve beamforming and, as a result, the secondary users' received signal gain is increased and the interference to primary users is significantly reduced.[2] In such channel conditions, Orthogonal Frequency Division Multiple Access (OFDMA) is proposed, as it can deal with multipath interference with more robustness and can achieve a higher MIMO spectral efficiency.[3]

Scalable Video Coding has been considered in recent works as a highly attractive solution to the challenges posed by the requirements of CR systems. Due to the changing channel conditions and the varying bandwidth availability of our system model, the dynamic nature of the SVC extension of the H.264 standard provides the system with the ability to adjust to the fluctuations and enhance the Quality of Service (QoS) for each user. SVC provides temporal, spatial and quality scalability. Quality scalability empowers transporting complementary data in different layers in order to produce videos with distinct quality levels. In this work, we exploit the quality scalability modality and Medium Grain Scalability (MGS) coding mode.

In recent years, CR systems have been widely used as system models in related works.[4–6] In Ref. 6, a *Nash Bargaining Solution* (NBS) is employed for fair power allocation among the users of a CR OFDMA system. In Ref. 4, Coarse Grain Scalability (CGS) and MGS modes are considered for allocating resources among secondary users, defining optimality in terms of the aggregate visual quality of the received video sequences. The problem is solved using discrete programming methods. In the present work, we consider the transmission of MGS video streams over a downlink cognitive radio system. We propose Orthogonal Frequency Division Multiple Access (OFDMA) as modulation scheme and multiple transmit antennas are used at the cognitive base station to reduce the outage probability of secondary users.[4] We formulate the problem of optimally allocating the system

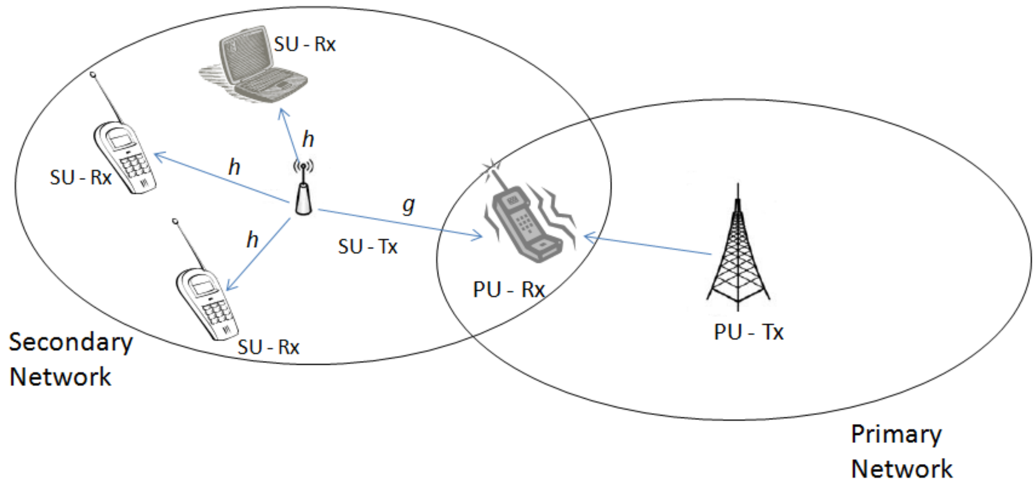

Fig.1: The considered system model.

resources, specifically the subcarriers and the antennas, among the secondary users with respect to fairness objectives. Fairness is defined as the minimization of video quality deviation among users who subscribe to the same Quality of Service.[7] To this end, an NBS framework is presented. We formulate an optimization problem with the purpose of achieving this NBS, while minimizing the unnecessary resources utilization. We use a Swarm Intelligence optimization method to solve the problem, namely Particle Swarm Optimization (PSO).[8] Because of the high complexity of the formulated objective function, we reduce its dimension by introducing appropriate techniques based on the system's structure.

The paper is organized as follows: Section 2 presents the considered CR system and video coding scheme. In Section 3, we formulate the proposed allocation framework along with the definition of the objective functions to be optimized. In Section 4, we present the experimental settings and simulation results along with discussion. The paper concludes in Section 5.

2. SYSTEM MODEL

We consider an OFDMA multiple-input-single-output Cognitive Radio system which co-exists with a Primary User Network. The two networks share the same spectrum. It is assumed that the interference power from the primary transmitter to the secondary users is negligible compared to the power from the secondary transmitter to secondary users. The bandwidth is divided into N subcarriers, which are shared by the two networks. The number of antennas at the cognitive base station is M. We denote with $h^k_{n,m}$ the frequency response of the kth SU from the mth transmit antenna of the cognitive base station through the nth subcarrier and with $g_{n,m}$ the frequency response of the primary receiver from the mth transmit antenna of the cognitive base station through the nth subcarrier. We also define in matrix form,

$$\mathbf{H}_k = \begin{bmatrix} h^k_{1,1} & h^k_{1,2} & \cdots & h^k_{1,M} \\ h^k_{2,1} & h^k_{2,2} & \cdots & h^k_{2,M} \\ \vdots & \vdots & \ddots & \vdots \\ h^k_{N,1} & h^k_{N,2} & \cdots & h^k_{N,M} \end{bmatrix}, \tag{1}$$

and,

$$\mathbf{G} = \begin{bmatrix} g_{1,1} & g_{1,2} & \cdots & g_{1,M} \\ g_{2,1} & g_{2,2} & \cdots & g_{2,M} \\ \vdots & \vdots & \ddots & \vdots \\ g_{N,1} & g_{N,2} & \cdots & g_{N,M} \end{bmatrix}. \tag{2}$$

Table 1: Required SNR to attain $P_e = 10^{-6}$ for different modulation schemes and the corresponding number of bits/symbol.

Case	Modulation	$\gamma_{case}(dB)$	Bits per symbol
1	BPSK	10.53	1
2	4-QAM	14.03	2
3	16-QAM	21.01	4
4	64-QAM	27.25	6

In order to ensure the protection of the primary network communications, an interference power limit $I_{\max}$ is imposed on every subcarrier.[4] Then, the maximum power that can be loaded on the nth subcarrier by the mth antenna of the cognitive transmitter is given by

$$\bar{p}_{n,m} = \min\left(\frac{I_{\max}}{|g_{n,m}|^2}, p_{\max}\right), \tag{3}$$

where $p_{\max}$ is the maximum power that the transmitter can load on any subcarrier. The maximum number of bits that can be loaded on each subcarrier can be computed given a target bit error rate (BER). The SNR required to achieve a target BER, P_e, for 2^c-ary QAM, is calculated using

$$\gamma = \frac{1}{3}\left[Q^{-1}\left(\frac{P_e}{4}\right)\right]^2 (2^c - 1) \tag{4}$$

and for BPSK modulation using

$$\gamma = \frac{1}{2}\left[Q^{-1}\left(P_e\right)^2\right], \tag{5}$$

where Q is the Q-function.[9] To have a BER $P_e = 10^{-6}$, as proposed in Ref. 4, the calculated SNR values for different modulation schemes are depicted in Table 1. The fourth column presents the number of bits per symbol that each modulation scheme supports. To find the maximum number of bits that can be loaded on the nth subcarrier of kth SU by the mth antenna $c_{k,n,m}$, we compute,

$$\gamma_{k,n,m} = \bar{p}_{n,m}\frac{|h^k_{n,m}|^2}{\sigma_v^2}, \tag{6}$$

where σ_v^2 is the noise variance, which is assumed to have the same value for all subcarriers. The modulation scheme, thus the maximum number of bits supported by the subcarrier, is then determined by Table 1, according to the following rules,

$$\begin{array}{llll} \text{if} & \gamma_1 \leq \gamma_{k,n,m} < \gamma_2 & \text{then} & c_{k,n,m} = c_1 = 1, \\ \text{if} & \gamma_2 \leq \gamma_{k,n,m} < \gamma_3 & \text{then} & c_{k,n,m} = c_2 = 2, \\ \text{if} & \gamma_3 \leq \gamma_{k,n,m} < \gamma_4 & \text{then} & c_{k,n,m} = c_3 = 4, \\ \text{if} & \gamma_{k,n,m} \geq \gamma_4 & \text{then} & c_{k,n,m} = c_4 = 6. \end{array}$$

2.1 H.264/SVC Extension - Medium Grain Scalability (MGS)

As mentioned above, the Scalable Video Coding extension of the H.264 standard has been chosen for the sequences' coding, because it provides QoS enhancement for each user and adapts to the CR system fluctuations. Each cognitive secondary user transmits an encoded video sequence. The SVC quality scalability mode enables the generation of substreams having different quality levels (layers). Depending on the bit loading method that we described, each user receives data at a specific bit rate, which determines the substreams that will be transmitted. In Fig. 2 we demonstrate a graph that shows the relationship between the Peak-Signal-to-Noise Ratio (PSNR) and bit-rate for an MGS encoded sequence.

PSNR suggests a quality measure and we can identify 13 levels of quality (layers) for different rate values. An important observation is that an increase in rate does not lead to an increase in quality between extractable points but results in utilizing unnecessary resources for the same outcome. This is taken into consideration in our problem's formulation.

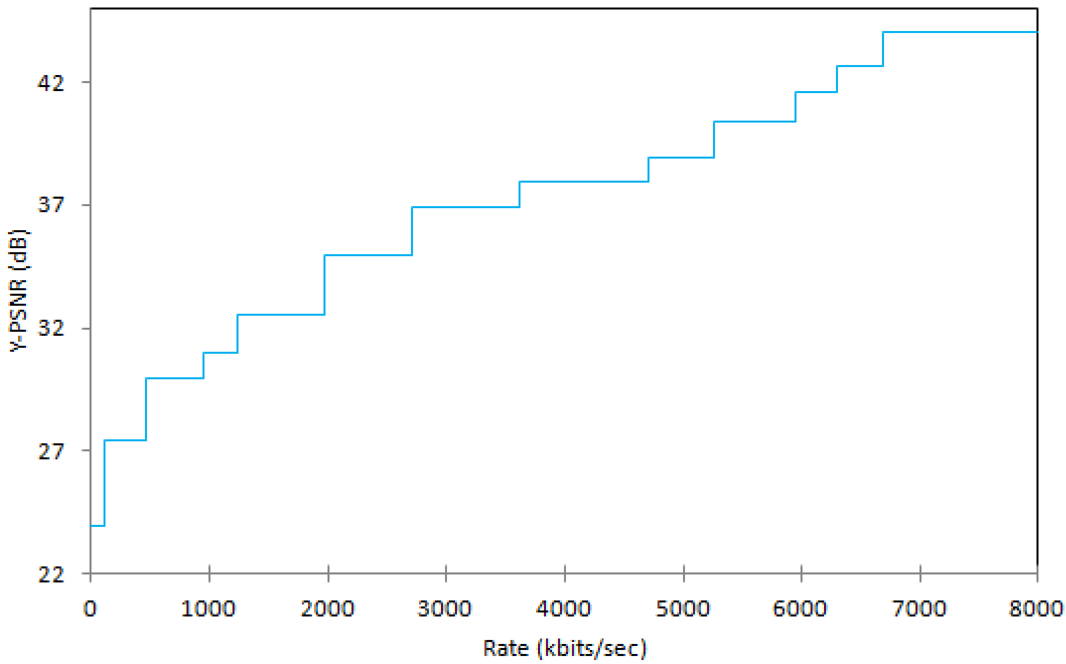

Fig.2: Quality-rate plot with MGS encoding for "Bus" sequence.

3. RESOURCE ALLOCATION METHODOLOGY

In this section, we describe the proposed methodology of allocating resources (subcarriers and antennas) in a multiuser cognitive environment.

3.1 Problem Formulation

3.1.1 Nash Bargaining Solution Method (NBSm)

This formulation is based on a Game Theory framework, performing a Bargaining Game where the secondary users of the cognitive radio systems are considered as the players. The Bargaining Game is one kind of cooperative game where the players, who have conflicts of interest, have the opportunity to reach a mutually beneficial agreement. A Bargaining Solution produces the pay-off where all the users agree on. We are especially interested in the Nash Bargaining Solution (NBS), which is the solution set that maximizes the *Nash product*, i.e.,

$$(\tilde{d}_1, \tilde{d}_2, .., \tilde{d}_k) = \arg\max \prod_{k=1}^{K} (d_k - d_k^0)^{bp_k}, \text{ with } d_k \geq d_k^0, \ \forall k, \tag{7}$$

where d_k is the received PSNR for user k, and d_k^0 is the *disagreement point*, which is the value the players can expect to receive if negotiations break down. Any generalized NBS satisfies four axioms: The first one is that the bargaining solution lies in the bargaining set. The second one is that the final outcome should not depend on how the users calibrate their utility scales. The third axiom is the *Independence of Irrelevant Alternatives*.[10] The fourth axioms is that, in symmetric situations, both users get the same quality.[10] An NBS is a *Pareto efficient* solution to a Nash Bargaining Game. This means that a state where it is impossible to improve any player's gain without reducing another's, is reached.

We start by introducing an indicator variable $\alpha_{k,n,m}$, which is defined as:

$$\alpha_{k,n,m} = \begin{cases} 1, & \text{if user } k \text{ receives from the } m\text{th} \\ & \text{antenna through the } n\text{th subcarrier,} \\ 0, & \text{otherwise,} \end{cases} \tag{8}$$

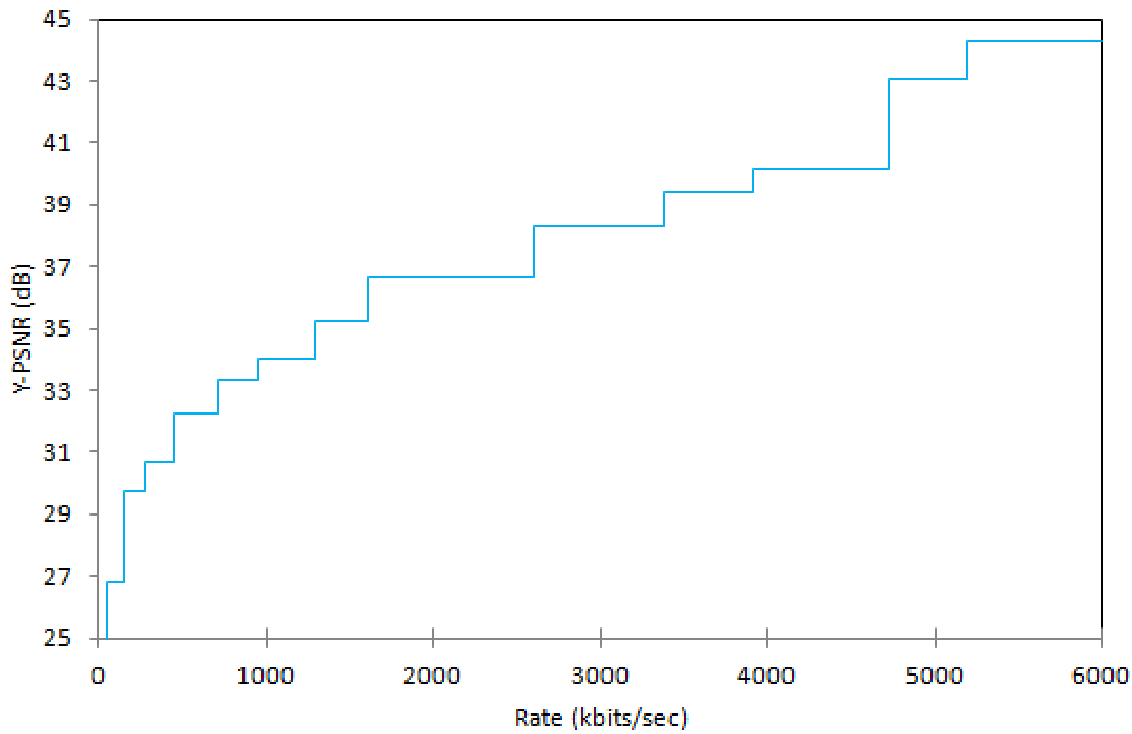

Fig.3: Quality-rate plot with MGS encoding for "Foreman" sequence.

as in Ref. 4. The rate at which kth user receives can be expressed as,

$$r_k = \sum_{m=1}^{M} \sum_{n=1}^{N} c_{k,n,m} a_{k,n,m}. \tag{9}$$

If r_k is determined, the visual quality of the sequence of kth user, $d_k(r_k)$, can be defined by using the quality-rate plot.

One of our major concerns is the maximization of the Nash product, thus the allocation of the available resources in such a way that provides mutual agreement of the users (fairness). Another major concern is the minimization of waste of resources. As mentioned above, given the staircase quality-rate form of the MGS sequence, a higher bit-rate does not always lead to PSNR improvement. For instance, in Fig. 2 at a rate of 3000 kbits/sec a user receives PSNR = 36.88 dB and, at a rate of 3500 kbits/sec, receives the same quality leading to a waste in resources. Moreover, due to the fact that many possible solutions were produced by considering only the maximization of the Nash product, a restriction should be imposed to limit those results. With respect to this, we introduce a penalty term that expresses the difference between the rate at which each user receives the substream and the actual rate for achieving the same quality level. Under the constraint that any subcarrier can be assigned to at most one secondary user and one antenna, the resource allocation solution can now be formulated as,

$$\alpha = \arg\max \left[W_1 \prod_{k=1}^{K} (d_k - d^0) - \sum_{k=1}^{K} (r_k - r_{k,l}) \right], \tag{10}$$

where α is the allocation matrix consisting of the elements $\alpha_{k,n,m}$; d^0 is the disagreement point of the Nash bargaining solution, which we consider to be the PSNR of the base layer of the video sequence to ensure that each user will receive the minimum QoS; and $r_{k,l}$ is the minimum rate to achieve the distortion level that the kth user achieves. The first term of the objective function concerns the maximization of Nash product and the second part is the penalty term mentioned above. The constant W_1 is a weight factor (generally a large number),

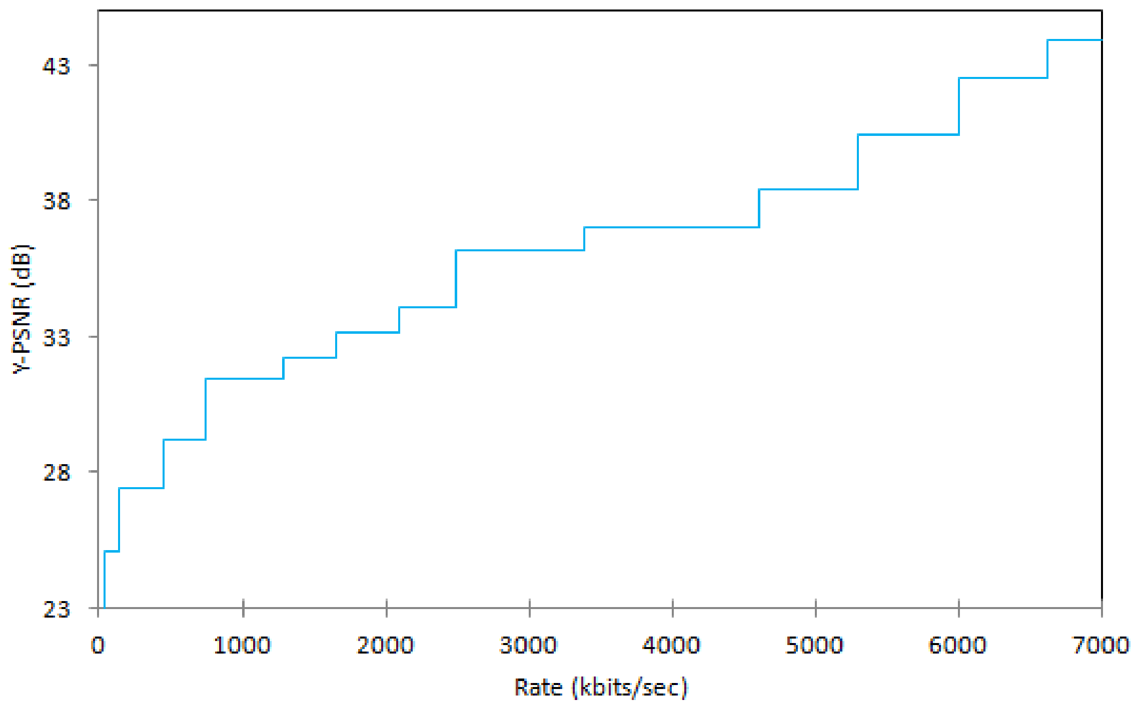

Fig.4: Quality-rate plot with MGS encoding for "Coastguard" sequence.

which implies that the maximization of the Nash product is more important than the minimization of the waste of resources.[4]

3.1.2 Aggregate Visual Quality Method (AVQm)

The second formulation of the objective function focuses on the maximization of the aggregate visual quality as described in Ref. 4. The resource allocation problem solution for this formulation is,

$$\alpha = \arg\max \left[W_2 \sum_{k=1}^{K} d_{k,l} - \sum_{k=1}^{K} (r_k - r_{k,l}) \right], \tag{11}$$

where $d_{k,l}$ is the PSNR value obtained if user k receives all layers up to the lth layer; $r_{k,l}$ is the minimum rate to achieve the distortion level that the kth user achieves; and W_2 is the corresponding weight factor mentioned above. The constraint of assigning any subcarrier to at most one SU and one antenna applies to this objective function as well, in addition to each cognitive user's receiving at least the base layer.

3.2 Particle Swarm Optimization

The employed optimizer is the *Particle Swarm Optimization* (PSO) algorithm due to its efficiency in similar problems.[11,12] PSO utilizes a *swarm* of search points, called *particles*, which iteratively move in the search space with an adaptable velocity. Each particle has a memory where it retains the best position it has ever visited in the search space, which can be communicated also to (some of) the rest. Let the swarm $S = \{X_1, X_2, X_3, ..., X_N\}$ consist of N particles. Each particle is a n-dimensional vector $X_i \in \mathcal{S}$, $i = 1, 2, \ldots, N$, where $\mathcal{S}$ is the search space. Let V_i and P_i denote the velocity and the best position, respectively, of the ith particle. If t denotes the current iteration, the velocity and position of X_i are updated according to the following equations:

$$V_i(t+1) = \chi[V_i(t) + C_1 R_1 (P_i(t) - X_i(t)) + C_2 R_2 (P_{g_i}(t) - X_i(t))], \tag{12}$$

$$X_i(t+1) = X_i(t) + V_i(t+1), \tag{13}$$

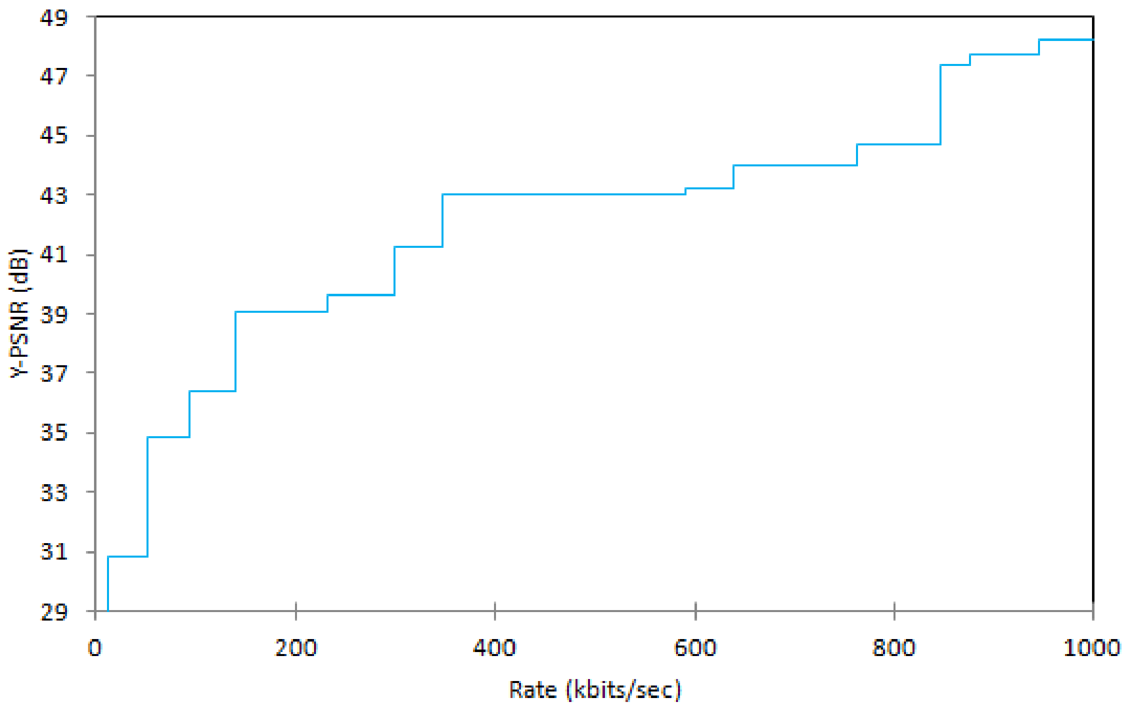

Fig.5: Quality-rate plot with MGS encoding for "Akiyo" sequence.

where χ is the *constriction coefficient*; C_1 and C_2 are positive constants, also known as *cognitive* and *social* parameter, respectively; and R_1 and R_2 are random vectors with components uniformly distributed within the range $[0, 1]$. All vector operations in Eqs. (12) and (13) are performed componentwise.[8] We used the standard parameter values, namely $\chi = 0.729$, $C_1 = C_2 = 2.05$.[13]

The resource allocation variable $\alpha_{k,n,m}$ indicates the CS transmission antenna and the user each subcarrier is assigned to. If N is the number of subcarriers, K the number of secondary users, and M the number of transmit antennas, then $\alpha_{k,n,m}$ could be represented as a set of $M \times N$ vectors of K elements, where each element k belongs in $\{0, 1\}$ and each array can contain at most one element valued 1, because (as mentioned in Section 3.1) each subcarrier can be assigned to only one user and one transmit antenna. Additionally, with respect to this restriction, exactly one non-zero single vector and $M - 1$ zero-valued vectors can be assigned to each subcarrier. There are $K + 1$ possible single vector representations. This formulation sets the dimension of the problem to $(K + 1)^{M \times N}$. We adopted a formulation that leads to dimensionality reduction. Specifically, since only one antenna transmits to one user through a subcarrier, we can employ N integers (expressing each subcarrier) to indicate to which antenna the non-zero vector is assigned (expressing which antenna is being used by this subcarrier), and N integers expressing which non-zero vector this is. This leads to a $(2N)$-dimensional vector. With this formulation, the dimension is reduced to $(M \times K)^N$.

4. EXPERIMENTAL RESULTS

This section presents the results and the simulation settings of the experiments that were conducted to evaluate the proposed scheme. Two experiment series were performed: One for single video transmission, where each secondary user was receiving the "Bus" sequence and another for multiple video transmission, where we used three video sequences, the "Foreman","Coastguard" and "Akiyo" sequences. Moreover, regarding multiple video transmission, each user was receiving one predefined video sequence and the assignment was defined serially, i.e. the first user received "Foreman", the second "Coastguard", the third "Akiyo", the fourth "Foreman", the fifth "Coastguard", and so on. The first two sequences ("Foreman" and "Coastguard") are high-motion while "Akiyo" is a low-motion sequence. This means that the PSNR values for low rate values are higher in "Akiyo", compared

Table 2: PSNR for each user and JI values for four experiment instances (K=3, M=4, Single Video Transmission)

	Instance 1		Instance 2		Instance 3		Instance 4	
	NBSm	AVQm	NBSm	AVQm	NBSm	AVQm	NBSm	AVQm
SU1 (dB)	32.56 (5)	31.01 (4)	32.56 (5)	31.01 (4)	31.01 (4)	31.01 (4)	32.56 (5)	32.56 (5)
SU2 (dB)	32.56 (5)	34.92 (6)	32.56 (5)	34.92 (6)	34.92 (6)	34.92 (6)	34.92 (6)	36.88 (7)
SU3 (dB)	31.01 (4)	31.01 (4)	34.92 (6)	34.92 (6)	34.92 (6)	36.88 (7)	31.01 (4)	31.01 (4)
JI	**0.9899**	**0.9607**	**0.9922**	**0.9697**	**0.9697**	**0.9538**	**0.9740**	**0.9481**

to the other two sequences. As a result, for the same rate, different video quality layer will be transmitted to each user, depending on the video sequence that it has been assigned to him/her. This explains the differences in PSNR values and corresponding layers in the result tables.

All sequences were in Common Intermediate Format (CIF, 352 × 288 resolution), obtained in 4:2:0 YUV format and encoded using the MGS technique. For the encoding process, the JSVM 9.19.14 software was used. Each bitstream was encoded in five video layers, one base layer with quantization parameter $QP_b = 48$, and four enhancement layers with quantization parameters $QP_l = (16, 24, 32, 40)$. Every enhancement layer was split further into three MGS enhancement layers and the MGS vectors chosen in the encoding process were $[4, 4, 8]$. The resulting 13 layers of the video sequences are illustrated in Figs. 2,3,4 and 5.

The system consisted of $N = 128$ subcarriers. We considered $M = 4$ antennas at the cognitive base station, contributing to interference reduction to multiple users and rate performance enhancement. The frequency selective fading channel consisted of eight Rayleigh fading paths. The channel fading between users and channels was modeled as an independent and identically distributed complex Gaussian. An interference power limit $I_{\max} = 0.2$ units of power was imposed on every subcarrier and the maximum transmit power on any subcarrier was $p_{\max} = 1$ unit of power. We set the Carrier-to-Noise Ratio (CNR) to 25 dB. The rate at which the symbols were transmitted was set to $R_s = 9600$ symbols/sec (48 OFDM symbols in 5 msec transmission frame period).

Regarding PSO, the swarm size and the number of iterations were estimated after preliminary experimentation for each simulation case, recording the best detected solution. The discrete parameters were allowed to take continuous values for the position and velocity update, although they were rounded to the nearest integer for the evaluation of the particle. Since PSO is a stochastic algorithm, for each problem instance we conducted 30 independent experiments.

The metric that we used to evaluate our results is the *Jain's Index* (JI), which assesses the fairness of the resource allocation, defined as the minimization of video quality deviation among users who subscribe to the same Quality of Service. The JI metric expresses how close to a state of equality is a resource allocation scheme, and it is defined as,

$$JI = \frac{\left(\sum_{k=1}^{K} L_k\right)^2}{K \sum_{k=1}^{K} (L_k)^2}, \tag{14}$$

where L_k is the number of video layers that user k receives. JI takes values between 0 and 1. The closer its value is to 1, the more equal is the resource allocation scheme.[12]

We performed a multitude of experiments for different channel settings and system configurations. Tables 2,3,4 report for illustration purposes, the video PSNR value and the corresponding number of layers (in parenthesis) each user receives, for a portion of experiment instances, and $K = 3, 6, 9$ cognitive users, respectively, for single video transmission. Accordingly, tables 5,6,7 report the video PSNR value and the corresponding number of layers (in parenthesis) each user receives, for a portion of experiment instances, and $K = 3, 6, 9$ cognitive users, respectively, for multiple video transmission. In the vast majority of all the experimental results, there was a distinct superiority of the NBS method over the AVQ method in terms of fairness, as dictated by the significantly greater values of the JI metric in most problem instances. Moreover, the average JI values for different numbers of secondary users are depicted in Figs. 6,7 for single and multiple video transmission respectively, for both methods. This outcome verifies that the considered NBS framework tackles the issue of fairness with success.

Table 3: PSNR for each user and JI values for four experiment instances (K=6, M=4, Single Video Transmission)

	Instance 1		Instance 2		Instance 3		Instance 4	
	NBSm	AVQm	NBSm	AVQm	NBSm	AVQm	NBSm	AVQm
SU1 (dB)	29.93 (3)	31.01 (4)	31.01 (4)	32.56 (5)	29.93 (3)	31.01 (4)	31.01 (4)	31.01 (4)
SU2 (dB)	29.93 (3)	27.40 (2)	31.01 (4)	29.93 (3)	31.01 (4)	29.93 (3)	31.01 (4)	31.01 (4)
SU3 (dB)	29.93 (3)	32.56 (5)	29.93 (3)	31.01 (4)	31.01 (4)	31.01 (4)	31.01 (4)	31.01 (4)
SU4 (dB)	31.01 (4)	32.56 (5)	31.01 (4)	29.93 (3)	31.01 (4)	31.01 (4)	31.01 (4)	32.56 (5)
SU5 (dB)	31.01 (4)	29.93 (3)	31.01 (4)	31.01 (4)	29.93 (3)	31.01 (4)	29.93 (3)	29.93 (3)
SU6 (dB)	31.01 (4)	31.01 (4)	29.93 (3)	29.93 (3)	31.01 (4)	31.01 (4)	31.01 (4)	29.93 (3)
JI	**0.9800**	**0.9280**	**0.9837**	**0.9603**	**0.9906**	**0.9795**	**0.9906**	**0.9688**

Table 4: PSNR for each user and JI values for four experiment instances (K=9, M=4, Single Video Transmission)

	Instance 1		Instance 2		Instance 3		Instance 4	
	NBSm	AVQm	NBSm	AVQm	NBSm	AVQm	NBSm	AVQm
SU1 (dB)	27.40 (2)	27.40 (2)	31.01 (4)	31.01 (4)	29.93 (3)	31.01 (4)	27.40 (2)	27.40 (2)
SU2 (dB)	27.40 (2)	31.01 (4)	29.93 (3)	29.93 (3)	27.40 (2)	27.40 (2)	27.40 (2)	27.40 (2)
SU3 (dB)	27.40 (2)	29.93 (3)	29.93 (3)	27.40 (2)	27.40 (2)	27.40 (2)	27.40 (2)	27.40 (2)
SU4 (dB)	29.93 (3)	31.01 (4)	27.40 (2)	27.40 (2)	27.40 (2)	27.40 (2)	27.40 (2)	27.40 (2)
SU5 (dB)	31.01 (4)	27.40 (2)	29.93 (3)	29.93 (3)	29.93 (3)	27.40 (2)	31.01 (4)	31.01 (4)
SU6 (dB)	29.93 (3)	27.40 (2)	27.40 (2)	27.40 (2)	29.93 (3)	27.40 (2)	27.40 (2)	27.40 (2)
SU7 (dB)	27.40 (2)	27.40 (2)	29.93 (3)	29.93 (3)	29.93 (3)	29.93 (3)	27.40 (2)	27.40 (2)
SU8 (dB)	27.40 (2)	27.40 (2)	27.40 (2)	27.40 (2)	27.40 (2)	29.93 (3)	27.40 (2)	27.40 (2)
SU9 (dB)	27.40 (2)	27.40 (2)	27.40 (2)	31.01 (4)	27.40 (2)	31.01 (4)	29.93 (3)	31.01 (4)
JI	**0.9272**	**0.9043**	**0.9412**	**0.9259**	**0.9603**	**0.9160**	**0.9245**	**0.8962**

5. CONCLUSION

We proposed a resource allocation method for transmitting video sequences encoded using the H.264 SVC extension, among multiple cognitive users. A game-theoretic Nash Bargaining Solution framework was introduced to explore fairness attribution to subscribed secondary users. Moreover, a method based on maximizing the aggregate visual quality of secondary users was implemented to compare and evaluate the results. We formulated an optimization problem and employed the PSO algorithm to solve it. Finally, we used a metric to evaluate fairness, so as to assess our approach. The experiments showed that the NBS method provided much fairer allocation solutions against the AVQ method, over all systems settings and scenarios.

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Table 5: PSNR for each user and JI values for four experiment instances (K=3, M=4, Multiple Video Transmission)

	Instance 1		Instance 2		Instance 3		Instance 4	
	NBSm	AVQm	NBSm	AVQm	NBSm	AVQm	NBSm	AVQm
SU1 (dB)	32.28 (4)	32.28 (4)	32.28 (4)	30.70 (3)	30.70 (3)	32.28 (4)	33.31 (5)	32.28 (4)
SU2 (dB)	31.43 (4)	27.45 (2)	29.23 (3)	27.45 (2)	31.43 (4)	27.45 (2)	29.23 (3)	27.45 (2)
SU3 (dB)	43.05 (7)	48.22 (13)	43.05 (7)	48.22 (13)	43.05 (7)	47.70 (12)	43.05 (7)	48.22 (13)
JI	**0.9259**	**0.6367**	**0.8829**	**0.5934**	**0.8829**	**0.6585**	**0.9036**	**0.6367**

Table 6: PSNR for each user and JI values for four experiment instances (K=6, M=4, Multiple Video Transmission)

	Instance 1		Instance 2		Instance 3		Instance 4	
	NBSm	AVQm	NBSm	AVQm	NBSm	AVQm	NBSm	AVQm
SU1 (dB)	30.70 (3)	29.74 (2)	30.70 (3)	30.70 (3)	32.28 (4)	32.28 (4)	30.70 (3)	30.70 (3)
SU2 (dB)	27.45 (2)	27.45 (2)	27.45 (2)	27.45 (2)	27.45 (2)	27.45 (2)	27.45 (2)	27.45 (2)
SU3 (dB)	43.05 (7)	43.05 (7)	39.07 (4)	43.05 (7)	39.07 (4)	43.05 (7)	39.07 (4)	43.05 (7)
SU4 (dB)	30.70 (3)	30.70 (3)	30.70 (3)	29.74 (2)	32.28 (4)	29.74 (2)	30.70 (3)	30.70 (3)
SU5 (dB)	27.45 (2)	27.45 (2)	29.23 (3)	27.45 (2)	27.45 (2)	27.45 (2)	29.23 (3)	27.45 (2)
SU6 (dB)	39.07 (4)	43.05 (7)	43.05 (7)	43.05 (7)	43.05 (7)	43.05 (7)	43.05 (7)	43.05 (7)
JI	**0.8077**	**0.7409**	**0.8403**	**0.7409**	**0.8397**	**0.7619**	**0.8403**	**0.7742**

Table 7: PSNR for each user and JI values for four experiment instances (K=9, M=4, Multiple Video Transmission)

	Instance 1		Instance 2		Instance 3		Instance 4	
	NBSm	AVQm	NBSm	AVQm	NBSm	AVQm	NBSm	AVQm
SU1 (dB)	30.70 (3)	29.74 (2)	29.74 (2)	29.74 (2)	29.74 (2)	29.74 (2)	30.70 (3)	29.74 (2)
SU2 (dB)	27.45 (2)	27.45 (2)	27.45 (2)	27.45 (2)	27.45 (2)	27.45 (2)	27.45 (2)	27.45 (2)
SU3 (dB)	39.07 (4)	43.05 (7)	43.05 (7)	43.05 (7)	39.07 (4)	43.05 (7)	39.07 (4)	41.27 (6)
SU4 (dB)	29.74 (2)	29.74 (2)	29.74 (2)	29.74 (2)	29.74 (2)	29.74 (2)	29.74 (2)	29.74 (2)
SU5 (dB)	27.45 (2)	27.45 (2)	27.45 (2)	25.11 (1)	27.45 (2)	27.45 (2)	27.45 (2)	25.11 (1)
SU6 (dB)	39.07 (4)	39.07 (4)	39.07 (4)	43.05 (7)	43.05 (7)	43.05 (7)	39.07 (4)	43.05 (7)
SU7 (dB)	30.70 (3)	29.74 (2)	30.70 (3)	29.74 (2)	29.74 (2)	29.74 (2)	30.70 (3)	29.74 (2)
SU8 (dB)	27.45 (2)	25.11 (1)	27.45 (2)	27.45 (2)	27.45 (2)	25.11 (1)	27.45 (2)	25.11 (1)
SU9 (dB)	39.07 (4)	43.05 (7)	39.07 (4)	39.07 (4)	39.07 (4)	39.07 (4)	39.07 (4)	43.05 (7)
JI	**0.9160**	**0.6922**	**0.7919**	**0.6922**	**0.771429**	**0.692181**	**0.9160**	**0.6579**

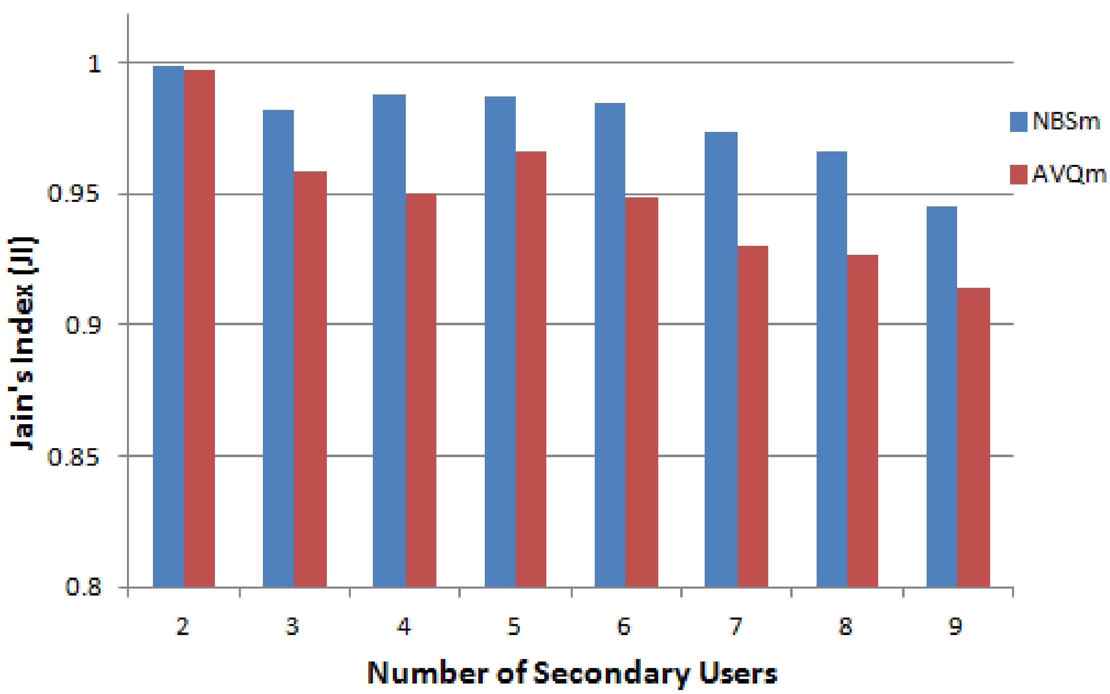

Fig.6: Average JI for different number of SU (M=4, CNR=25 dB, Single Video Transmission).

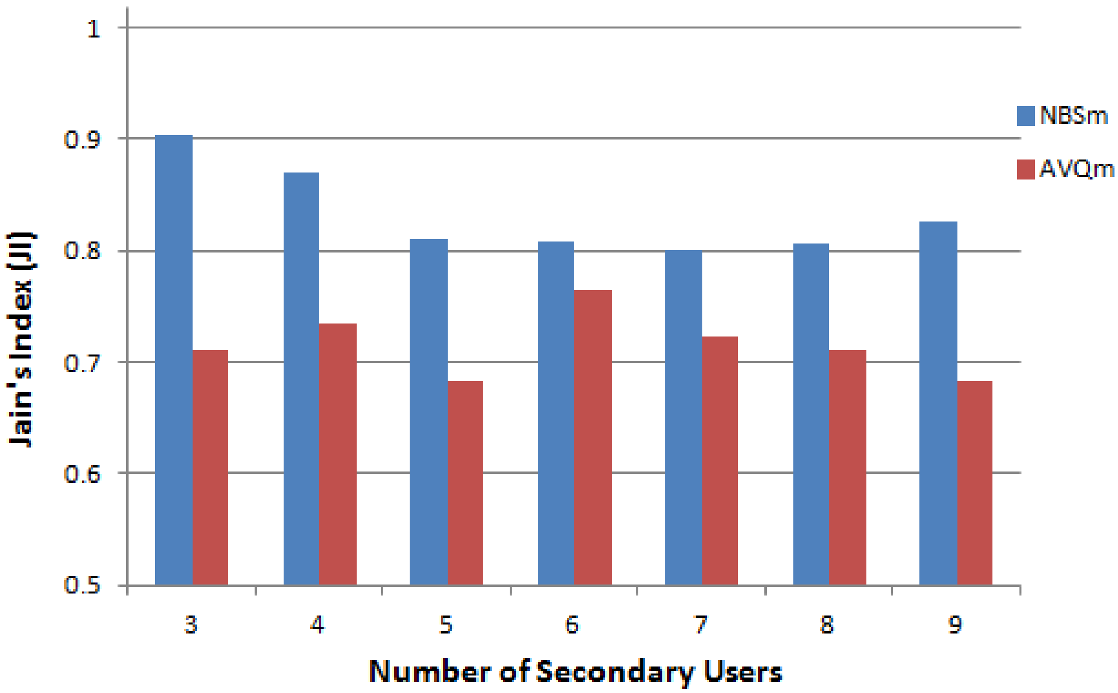

Fig.7: Average JI for different number of SU (M=4, CNR=25 dB, Multiple Video Transmission).

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