QUALITY–DRIVEN POWER CONTROL AND RESOURCE ALLOCATION IN WIRELESS MULTI–RATE VISUAL SENSOR NETWORKS

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ABSTRACT

In the present paper, we deal with the problem of allocating the network resources in multi–rate *Direct Sequence Code Division Multiple Access* (DS–CDMA) *Visual Sensor Networks* (VSNs). We consider a single–cell system where each node uses the same chip rate, but can transmit at a different bit rate. In wireless VSNs, we face the constraints of limited power lifetime and of an error–prone environment, mainly due to attenuation and interference. The proposed cross–layer scheme enables the *Centralized Control Unit* (CCU) to jointly allocate the transmission power, the transmission bit rate and the source–channel coding rates for each VSN node in order to optimize the delivered video quality. The transmission power of each visual sensor assumes values from a continuous range, while the rest of the resources take values chosen from an available discrete set. The numerical results demonstrate the performance of the proposed multi–rate scheme vs a single–rate system.

***Index Terms*—** Multi–rate DS–CDMA, Power Control, Resource Allocation, Visual Sensor Networks.

1. INTRODUCTION

An important requirement for the rapidly evolving wireless systems is to support the plethora of the services that use mobile devices able to transmit heterogeneous types of data (e.g. voice, audio, video) at different data rates. Due to the wide use of *Code Division Multiple Access* (CDMA) for wireless communications, we consider a multi–rate *Direct Sequence* CDMA (DS–CDMA) system where each network node may transmit its data at a rate that is chosen from a set of available rates. In order to support heterogeneous multi–rate devices, various ways of designing a CDMA system have been exploited so far, such as using multi–modulation systems, systems with variable chip rate, multi–code systems and variable sequence length systems. Variable sequence length systems (or often called multi–processing gain spread spectrum systems) allocate different processing gain for different transmission rates, while maintaining a constant chip rate.

The present work focuses on wireless DS–CDMA *Visual Sensor Networks* (VSNs) that provide a plethora of multimedia services for the military, health, home and environmental sector including monitoring, surveillance, tracking applications and more. We implement a single cell DS–CDMA system that uses the same chip rate for all transmitting nodes, yet allocates different processing gain per node in order to support multiple transmission bit rates. Much research has focused on systems that alter the processing gain [1, 2, 3].

Besides the attenuation, interference and background noise that constitute wireless VSNs as error–prone environments, we also face the issue of limited power. Furthermore, using the VSNs to monitor a real environment of different scenes, it is evident that each visual sensor has different network resource requirements in order to transmit the different video streams and achieve better video quality. Most of the literature about multirate DS–CDMA systems focuses on the important issue of controlling the power consumption [1]. In [2, 3] this approach is extended. Particularly, in [2] the transmission power and the processing gain are adapted aiming at maximizing the total achievable rate per node, while satisfying minimum rate requirements. In [3] the transmission power and the transmission bit rate are jointly adapted with the aim of satisfying a constraint on the signal to noise ratio. In our work we move beyond this baseline by optimizing a different objective function that reflects the received end–to–end video quality and takes into account the nature of the videos captured by the sensors.

Moreover, each visual sensor transmission causes interference to the other sensors' video transmissions resulting in video quality degradation at the receiver. In order to reduce the effects of the interference caused by the simultaneous video transmission of the neighboring visual sensors, we need to establish a joint network resource allocation aimed at enhancing global video quality. The interference moderation problem has been tackled before in single–rate DS–CDMA systems using joint allocation of the source and channel coding rates and the transmission power. Specifically, several cross–layer optimization schemes have been employed aiming at the reduction of the intra–cell interference and, as a result, enhancing the end–to–end video quality [4, 5]. While in our previous work [5] the CCU jointly allocated the transmission power and source and channel coding rate under the constraint of a constant transmission bit rate, the present paper extends this research problem by allowing the visual sensors to transmit at more than one available bit rates.

The rest of the paper is organized as follows. In Section 2, the background information for the considered VSN is provided. The problem formulation and the proposed approach are detailed in Section 3. The experimental results are presented in Section 4, and conclusions are drawn in Section 5.

2. SYSTEM MODEL

Centralized wireless DS–CDMA VSNs are composed of two basic parts: low–weight spatially distributed video cameras and a *Centralized Control Unit* (CCU). The nodes communicate with the CCU unit over the network layer. The CCU applies channel and source decoding to obtain the received video from each node. The CCU has

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This research was supported by a Marie Curie International Reintegration Grant within the 7–th European Community Framework Programme.

to tackle the important issue of the resource allocation among the VSN nodes in order to maintain good end–to–end video quality.

In the physical layer, single–cell multi–rate DS–CDMA is used, where each node k transmits L_k "chips" for each transmitted bit. L_k is the *spreading sequence length* or *processing gain*. The chip rate R_{chip} depends on the transmission bandwidth W and on the type of pulse shaping that is used. Using for example Nyquist pulse shaping, the relationship between bandwidth and chip rate is:

$$W = \frac{R_{\text{chip}}}{2}. \tag{1}$$

Assuming that the bandwidth W is constant for all nodes, the chip rate R_{chip} is constant, as well. In the present work, we assume that the spreading sequence length L_k is variable (multi–processing gain DS-CDMA). The transmission bit rate R_k is

$$R_k = \frac{R_{\text{chip}}}{L_k}. \tag{2}$$

So, R_k is also variable. By combining the Eq. (1) and (2), we get for the spreading sequence length that

$$L_k = \frac{2W}{R_k}. \tag{3}$$

Equation (3) demonstrates how the bandwidth W and transmission bit rate R_k implicitly determine the spreading sequence length. Thus, by keeping the bandwidth constant while increasing R_k, we are implicitly decreasing the spreading sequence length L_k. A smaller spreading sequence length will mean fewer transmitted chips per bit, thus it will also mean a smaller transmitted energy per bit. Moreover, from Eq. (3) it results that L_k is not necessarily an integer. This is due to the fact that we do not assume specific spreading codes. In the equations used in the experiments, the spreading code length does not appear directly as a parameter.

Background and thermal noise are ignored because intra–cell interference is assumed to be the major limitation. As in [6], we assume that the interference received from all other nodes at the node of interest can be modeled as *Additive White Gaussian Noise* (AWGN). Assuming that the VSN comprises K nodes, the received power per node k is $S_{\text{r},k} = E_k R_k$ in Watts, where E_k is the received energy per bit. The total transmission bit rate for each node k is defined as the fraction of the source coding rate $R_{\text{s},k}$ to the channel coding rate $R_{\text{c},k}$, namely $R_k = R_{\text{s},k}/R_{\text{c},k}$ with $k = 1, 2, \ldots, K$.

On the assumption that the spreading code sequences used are random and do not have any special properties (such as orthogonality) [6], which would limit the interference caused by other nodes, the energy per bit to *Multiple Access Interference* (MAI) ratio becomes

$$\frac{E_k}{I_0} = \frac{S_{\text{r},k}/R_k}{\sum\limits_{j=1, j\neq k}^{K} S_{\text{r},j}/W} \tag{4}$$

where $I_0/2$ is the two sided noise power spectral density due to MAI in Watts/Hertz, $S_{\text{r},j}$ is the power of the node–of–interest in Watts, and W is the total bandwidth in Hertz. From this equation, it is evident that any variation of the transmission bit rate of the node–of–interest (and thus of its spreading code length) has an imminent effect on the energy per bit to MAI ratio. For example, if the received powers at the receiver node are the same for all source nodes, then an increase of the transmission bit rate results in a decrease of the energy per bit to MAI ratio and in an increase of the bit error rate. Thus, we have a bit rate vs bit error rate trade–off.

For the estimation of the received power at the node–of–interest from the neighboring nodes, we use the Two–Ray Ground Reflection model. The received power $S_{\text{r},k}$ at distance d from the transmitting node k can be expressed as

$$S_{\text{r},k} = \frac{S_k G_{\text{t}} G_{\text{r}} h_{\text{t}}^2 h_{\text{r}}^2}{d^4}, \tag{5}$$

where S_k is the transmission power of node k in Watts, G_{t}, G_{r} are the antenna gains and h_{t}, h_{r} the antenna heights of the transmitter and the receiver, respectively [7].

In order to encode the captured videos at the source nodes, we use the H.264/AVC video coding standard. For channel coding, *Rate Compatible Punctured Convolutional* (RCPC) codes are deployed [8]. For bit error probability estimation the Viterbi's upper bounds are used, namely

$$P_{\text{b},k} \leq \frac{1}{P} \sum_{d=d_{\text{dfree}}}^{\infty} c_d P_{d,k}, \tag{6}$$

where P is the code period, d_{free} is the code free distance, c_d is the information error weight, and P_d is the probability that the wrong path at distance d is selected. For an AWGN channel with BPSK modulation, $P_{d,k}$ is given by: $P_{d,k} = Q(\sqrt{2dR_{\text{c},k}E_k/I_0})$ with $Q(x) = (\int_x^\infty \exp(-u^2/2)du)/\sqrt{2\pi}$.

The network resources are allocated to the nodes by the CCU at the network layer. The CCU manages the nodes and may request changes in the network resources (transmission power, transmission bit rate, source coding and channel coding rate) with the aim to achieve optimal end–to–end video quality under the constraint that the chip rate R_{chip} is the same for all nodes. Therefore, the CCU needs to estimate the expected video quality at the receiver prior to the resource allocation. In order to estimate the expected distortion at the receiver for each node k, we assume the *Universal Rate Distortion Characteristics* (URDC):

$$E\{D_{\text{s+c},k}\} = \alpha_k \left[\log_{10}\left(\frac{1}{P_{\text{b},k}}\right)\right]^{-\beta_k}, \tag{7}$$

where $P_{\text{b},k}$ is the bit error probability (after channel decoding) for node k, and parameters $\alpha_k > 0$ and $\beta_k > 0$ depend on both the motion level of the video sequence and the source coding rate of each node k [9]. To determine the values of parameters α_k and β_k for each user at the encoder, we use mean square optimization from a fiew $(E\{D_{\text{s+c},k}\}, P_{\text{b},k})$ pairs which are obtained experimentally. For the accurate estimation of the expected end–to–end distortion $E\{D_{\text{s+c},k}\}$ at the encoder, the *Recursive Optimal Per–pixel Estimate* (ROPE) proposed in [10] is used.

3. PROBLEM FORMULATION AND OPTIMIZATION

Combining all previous equations, the expected distortion $E\{D_{\text{s+c},k}\}$ for node k can be written as a function of the transmission bit rate R_k, the source coding rate $R_{\text{s},k}$, the channel coding rate $R_{\text{c},k}$, and the transmitted power of all nodes, $S = (S_1, S_2, \ldots, S_K)^\top$. So, $E\{D_{\text{s+c},k}\}$ can be written as $E\{D_{\text{s+c},k}\}(R_k, R_{\text{s},k}, R_{\text{c},k}, S)$. The present paper tackles the problem of enabling the CCU to optimally allocate the vectors of the transmission bit rate, the source coding rate, the channel coding rate and the transmission power level, so that a function of the end–to–end expected distortions of all nodes is minimized. Mathematically, the power control and resource allocation problem is formulated as follows:

Determine the vectors $R = (R_1, R_2, \ldots, R_K)^\top$;
$R_{\text{s}} = (R_{\text{s},1}, R_{\text{s},2}, \ldots, R_{\text{s},K})^\top$;
$R_{\text{c}} = (R_{\text{c},1}, R_{\text{c},2}, \ldots, R_{\text{c},K})^\top$;
$S = (S_1, S_2, \ldots, S_K)^\top$
in order to minimize $f(E\{D_{\text{s+c},1}\}, \ldots, E\{D_{\text{s+c},K}\})$
subject to $R_{\text{chip}} = R_{\text{budget}}$ and $S_{\text{min}} \leq S \leq S_{\text{max}}$.

In order to define the function $f(.)$ that will enable the CCU to effectively perform the power control and resource allocation in the considered VSN, we employed quality–driven (distortion–related) optimization criteria. The first criterion is the *Minimization of the Average Distortion* (MAD), which results in the minimization of the average end–to–end distortion among all transmitting nodes [4]. The second criterion is the *Minimization of the Maximum Distortion* (MMD), which focuses on the minimization of the maximum distortion of the VSN [4]. The last criterion, the *Nash Bargaining Solution* (NBS) [5] comes from Game Theory and performs a bargaining game among the nodes. All these criteria result in global optimization problems that are tackled with the Particle Swarm Optimization (PSO) algorithm. We employed PSO due to its ease of implementation, the provision of optimal global solution (escape from sub-optimal solutions) and its quick convergence. Those characteristics satisfy the requirements for optimality in many VSNs applications. Regarding the algorithm's complexity, it is linear to the number N of the particles used in PSO, as well as to the maximum number $I_{\max}$ of iterations for the detection of the global solution, i.e., $O(N \times I_{\max})$.

3.1. Minimization of the Average Distortion (MAD)

This criterion helps us determine the vectors of the optimal transmission bit rates R^*, the source coding rates R^*_{s}, the channel coding rates R^*_{c}, and the transmission powers S^*, such that the overall end–to–end average distortion over all nodes $E\{D^{\text{ave}}_{\text{s+c}}\}(R, R_{\text{s}}, R_{\text{c}}, S)$ is minimized:

$$(R^*, R^*_{\text{s}}, R^*_{\text{c}}, S^*) = \arg \min_{R, R_{\text{s}}, R_{\text{c}}, S} E\{D^{\text{ave}}_{\text{s+c}}\}(R, R_{\text{s}}, R_{\text{c}}, S), \quad (8)$$

subject to $R_{\text{chip}} = R_{\text{budget}}$ and $S_{\text{max}} \leq S \leq S_{\text{max}}$.

3.2. Minimization of the Maximum Distortion (MMD)

According to this criterion, we determine the vectors of the optimal transmission bit rates R^*, the source coding rates R^*_{s}, the channel coding rates R^*_{c}, and the transmission powers S^*, such that the end–to–end maximum distortion over all nodes is minimized:

$$(R^*, R^*_{\text{s}}, R^*_{\text{c}}, S^*) = \arg \min_{R, R_{\text{s}}, R_{\text{c}}, S} \max_k E\{D_{\text{s+c},k}\}(R_k, R_{\text{s},k}, R_{\text{c},k}, S), \quad (9)$$

subject to $R_{\text{chip}} = R_{\text{budget}}$ and $S_{\text{max}} \leq S \leq S_{\text{max}}$.

3.3. Nash Bargaining Solution (NBS)

The last criterion is based on organizing a bargaining game where the source nodes agree to jointly determine their transmission powers and the network resources, nevertheless with the restriction of not degrading the video quality below the least acceptable level (the quality it could achieve without cooperation). This is called the disagreement point dp. To reflect the quality profit of each node we define the *utility function* U_k as the PSNR of the received video of each node k:

$$U_k = 10 \log_{10} \frac{255^2}{E\{D_{\text{s+c},k}\}}, \quad (10)$$

where $E\{D_{\text{s+c},k}\}$ is the expected video distortion for node k. Since the defined utility function of Eq. (10) depends on the expected end-to-end distortion $E\{D_{\text{s+c},k}\}$, it also depends on transmission bit rate R_k the, source coding rate $R_{\text{s},k}$, the channel coding rate $R_{\text{c},k}$ and the vector of transmission power S.

We define $\mathbf{U}$ as the feasible set of all possible utility allocations $U = (U_1, U_2, \ldots, U_K)^\top$. Each member of $\mathbf{U}$ results from a different combination of transmission bit rates, source coding rates, channel coding rates, and transmission powers for all nodes. The NBS $F(\mathbf{U}, dp)$ is a member of the feasible set that satisfies the axioms of *Feasibility*, *Pareto Efficiency*, *Invariance to Equivalent Utility Representations* and *Independence of Irrelevant Alternatives* [11]. In order to find the NBS, $F(\mathbf{U}, dp)$, we have to maximize the Nash Product (NP). Particularly, given that all source nodes use the same chip rate R_{chip}, we determine the utilities vector U such that the NP is maximized:

$$F(\mathbf{U}, dp) = (R^*, R^*_s, R^*_c, S^*) = \arg \max_{R, R_s, R_c, S} NP, \quad (11)$$

$$NP = (U_1 - dp_1)^{bp_1} (U_2 - dp_2)^{bp_2} \ldots (U_K - dp_K)^{bp_K}, \quad (12)$$

subject to $U_k > dp_k$, $R_{\text{chip}} = R_{\text{budget}}$ and $S_{\text{max}} \leq S \leq S_{\text{max}}$.

In the present work, we assume that $dp = (dp_1, dp_2, \ldots, dp_K)^\top$, $dp \in \mathbf{U}$ is the minimum acceptable PSNR and is determined by the CCU operator. The bargaining powers $bp = (bp_1, bp_2, \ldots, bp_K)^\top$ that express which node is more advantaged by the bargaining game [11] are considered equal to $1/K$, due to the fact that there is no intention of giving the advantage to any node against the others.

4. NUMERICAL RESULTS AND DISCUSSION

In order to evaluate the proposed approach, we considered a VSN with six nodes that are all equidistant from the CCU. Consequently, the attenuation is the same for all nodes. The nodes view scenes with different amount of motion. Specifically, nodes 1 and 5 record high motion scenes, node 3 views medium motion scenes, and nodes 2, 4 and 6 transmit low motion scenes. The used video sequence format is QCIF. We have conducted a series of experiments in a Matlab–based simulator in order to assess the considered system. We present here the experimental results after comparing a multi–rate system with available transmission bit rates $\{48, 72, 96, 120\}$kbps, and a single–rate system with the same transmission bit rate for all nodes, i.e. 48kbps. The available source and coding rates $(R_{\text{s}}, R_{\text{c}})$ for the different transmission bit rates are the following:

$R_k = 48\text{kbps}:$ $\{(16\text{kbps}, 1/3), (24\text{kbps}, 1/2), (32\text{kbps}, 2/3)\}$
$R_k = 72\text{kbps}:$ $\{(24\text{kbps}, 1/3), (36\text{kbps}, 1/2), (48\text{kbps}, 2/3)\}$
$R_k = 96\text{kbps}:$ $\{(32\text{kbps}, 1/3), (48\text{kbps}, 1/2), (64\text{kbps}, 2/3)\}$
$R_k = 120\text{kbps}:$ $\{(40\text{kbps}, 1/3), (60\text{kbps}, 1/2), (80\text{kbps}, 2/3)\}$

The transmission power assumes continuous values from the range $[50, 500]$mW and the bandwidth for all nodes is $W = 1$MHz. Considering the stochastic nature of the PSO algorithm, 30 independent experiments were executed for each problem instance to ensure the results' validity.

Table 1 shows the obtained results for the transmission power and the network resources allocation using the proposed method for the considered multi–rate system and single–rate system. An inspection of the results indicates that for the high motion nodes 1 and 5, the highest source coding rates are assigned in all cases in the multi–rate set up. This is because the quality increase is higher when increasing the source coding rate than using a stronger channel coding rate. On the other hand, high quality can be achieved for nodes of low motion even with a low source coding rate and weaker

Table 1. Experimental Results for Multi–rate vs Single–rate VSN.

Multi–rate												
	MAD				**MMD**				**NBS**			
Nodes	PSNR(dB)	R(kbps)	S(mW)	(R_s(kbps),R_c)	PSNR(dB)	R(kbps)	S(mW)	(R_s(kbps),R_c)	PSNR(dB)	R(kbps)	S(mW)	(R_s(kbps),R_c)
1	34.1552	96	134.8927	(64,2/3)	35.4533	96	190.0836	(64,2/3)	31.8034	72	77.1826	(48,2/3)
2	38.6846	48	50.0000	(32,2/3)	35.4533	48	50.0000	(32,2/3)	42.3207	48	52.8633	(32,2/3)
3	36.4662	48	63.9178	(32,2/3)	35.4533	48	72.6669	(32,2/3)	37.9507	48	56.7801	(32,2/3)
4	39.0880	48	50.5261	(32,2/3)	35.4533	48	50.3637	(32,2/3)	43.4456	48	55.1537	(32,2/3)
5	34.0974	96	136.0598	(64,2/3)	35.4533	96	192.7755	(64,2/3)	31.6071	72	77.6880	(48,2/3)
6	36.4910	48	56.3341	(32,2/3)	35.4533	48	63.1084	(32,2/3)	37.7933	48	50.0000	(32,2/3)
Single–rate												
	MAD				**MMD**				**NBS**			
Nodes	PSNR(dB)	R(kbps)	S(mW)	(R_s(kbps),R_c)	PSNR(dB)	R(kbps)	S(mW)	(R_s(kbps),R_c)	PSNR(dB)	R(kbps)	S(mW)	(R_s(kbps),R_c)
1	31.4185	48	112.8069	(32,2/3)	32.6565	48	238.8260	(32,2/3)	29.6642	48	50.0000	(32,2/3)
2	39.5817	48	50.0000	(32,2/3)	32.6565	48	50.0000	(32,2/3)	43.6966	48	53.3157	(32,2/3)
3	37.2869	48	64.8575	(32,2/3)	32.6565	48	63.9856	(24,1/2)	39.3132	48	58.0118	(32,2/3)
4	40.0249	48	50.2982	(32,2/3)	32.6565	48	51.0466	(32,2/3)	45.0085	48	56.0053	(32,2/3)
5	31.2514	48	120.8360	(32,2/3)	32.6565	48	262.1782	(32,2/3)	29.2814	48	50.7670	(32,2/3)
6	37.2516	48	57.4203	(32,2/3)	32.6565	48	56.9231	(32,2/3)	38.8429	48	50.1370	(32,2/3)

channel coding. Regarding the assigned transmission bit rate in the multi–rate VSN, we observe that NBS uses the lowest transmission bit rates than the other two criteria. This is because of the fact that lower transmission bit rate implies lower source coding rate, which is usually more effective than using stronger channel coding, especially for channels with high bit error rate. As highlighted from the results, in the multi–rate set up the higher transmission bit rates are assigned to the high motion nodes.

On the whole, as far as the received end–to–end quality per node is concerned, using multiple transmission rates enhanced the delivered video quality of the high motion source nodes (the increase ranges from 2.1393dB to 2.8461dB), while in the case of MAD and NBS, it caused a quality drop for the low and medium motion nodes (the decrease ranges from 0.7606dB to 1.5630dB). However, in most applications the requirement for high quality regards videos with high amount of motion. From the results, we also notice that using the NBS criterion allows us to achieve the highest PSNR for the low motion nodes, whereas the lowest for the high motion nodes in all cases. As anticipated from our previous work [5], the MMD criterion results in the same quality levels for all nodes for both setups.

It is also evident that in either in the multi–rate or in the single–rate set–up, using the NBS criterion results in the lowest transmission power consumption. On the other hand, using the MMD criterion leads to the highest transmission power requirement, especially for the high motion nodes. The MAD criterion results in intermediate power levels, compared with the other two criteria.

5. CONCLUSIONS

In summary, we considered the problem of allocating the network resources in multi–rate DS–CDMA VSNs. We modeled the VSN as a single cell variable sequence length system, where each node uses the same chip rate, but can transmit at a different bit rate. Allowing the nodes to transmit at different bit rates is of great importance, since they can support a wide range of heterogeneous devices and accommodate a wide range of channel conditions. The experiments showed that for the nodes recording scenes of high motion, higher source coding and transmission rates were assigned, instead of adopting stronger channel coding. Moreover, using multiple transmission rates enhanced the delivered video quality of the high motion source nodes, which is a fundamental requirement in most applications.

6. REFERENCES

[1] L. D. H. Sampaio, M. F. Lima, B. B. Zarpelo, M. L. Proena Jr., and T. Abro, "Power allocation in multirate DS/CDMA systems based on Verhulst equilibrium," in *Proc. IEEE Intern. Conf. on Communications*, Cape Town, 2010.

[2] I. Koutsopoulos, U. C. Kozat, and L. Tassiulas, "Dynamic resource allocation in CDMA systems with deterministic codes and multirate provisioning," *IEEE Transactions on Mobile Computing*, vol. 5, no. 12, pp. 1780–1792, 2006.

[3] Y. H. Lee and S. W. Kim, "Generalized joint power and rate adaptation in DS–CDMA communications over fading channels," *IEEE Trans. on Vehicular Technology*, vol. 57, no. 1, pp. 603–608, 2008.

[4] E. S. Bentley, L. P. Kondi, J. D. Matyjas, M. J. Medley, and B. W. Suter, "Spread spectrum visual sensor networks resource management using an end-to-end cross layer design," *IEEE Trans. on Multimedia*, vol. 13, no. 1, pp. 125–131, 2011.

[5] A. V. Katsenou, L. P. Kondi, and K. E. Parsopoulos, "Resource Management for Wireless Visual Sensor Networks Based on Individual Video Characteristics," in *Proc. IEEE Intern. Conf. on Image Processing*, Brussels, 2011, pp. 149–152.

[6] Y. S. Chan and J. W. Modestino, "A joint source coding–power control approach for video transmission over CDMA networks," *IEEE Journ. on Selected Areas in Communications*, vol. 21, no. 10, pp. 1516–1525, Dec. 2003.

[7] T. Rapaport, *Wireless Communications Principles and Practise*, Prentice Hall Communications Engineering and Emerging Technologies Series. Prentice Hall, 2nd edition, 2001.

[8] J. Hagenauer, "Rate–compatible punctured convolutional codes (RCPC codes) and their applications," *IEEE Trans. on Communications*, vol. 36, no. 4, pp. 389–400, April 1988.

[9] L. P. Kondi and A. K. Katsaggelos, "Joint source–channel coding for scalable video using models of rate distortion functions," in *Proc. IEEE Intern. Conf. on Acoustics, Speech and Signal Processing*, Salt Lake City, 2001, pp. 1377–1380.

[10] R. Zhang, S.L. Regunathan, and K. Rose, "Video coding with optimal inter/intra–mode switching for packet loss resilience," *IEEE Journ. Select. Areas in Communications*, vol. 18, no. 6, pp. 966–976, 2000.

[11] K. Binmore, *Playing for Real: A Text on Game Theory*, Oxford University Press, 2007.