Optimal Power Allocation Auction for H.264/SVC Coded Wireless Video Transmission

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***Abstract*—In this paper, we propose optimal power allocation schemes for quality maximization of the transmitted video streams in wireless multicast communication scenarios. For this purpose we employ parametric scalable video models, which model the rate and quality of the scalable streams as a function of the quantization parameter and frame rate. These are derived from the standard JSVM reference codec for the H.264 SVC/ AVC and are hence readily applicable in practical scenarios. These models are subsequently employed to present a novel revenue maximization scheme in Orthogonal Frequency Division for Multiple Access (OFDMA) based wireless broadband 4G systems employing transmitted video steam quality based auction bidding models. The framework for optimal power allocation is formulated as a constrained convex optimization problem towards sum video utility maximization. We observe that as the demand for a video stream increases in broadcast/ multicast scenarios, higher power is allocated to the corresponding video stream leading to a gain in the overall revenue/ utility. Simulations illustrate that the proposed optimal power allocation schemes result in a significant performance improvement over the suboptimal equal power allocation schemes for scalable video transmission.**

I. INTRODUCTION

The widespread adoption of wireless communication systems in recent times has greatly accelerated the development of the fourth generation (4G) standards towards broadband wireless access. Further, the demand for multimedia/ video based applications is increasing rapidly and is expected to consume a dominant fraction of the available bandwidth in the near future. Applications such as real-time surveillance, video conferencing, multimedia streaming, mobile gaming etc. as shown in Fig. 1 require high data rate transmission over erratic wireless links, which are beset with the problem of inter symbol interference (ISI) resulting from multipath propagation. Hence, orthogonal frequency division for multiple access (OFDMA) based on the revolutionary Orthogonal Frequency Division Multiplexing (OFDM) physical layer technology, which eliminates ISI arising in wideband wireless channels, forms the bedrock of most of the 4G wireless standards such as WiMAX, LTE and many others. OFDMA is based on the principle of partitioning the wideband frequency selective channel into number of parallel narrowband flat fading fading subcarrier channels as shown schematically in Fig. 2. In such scenarios, optimal distribution of power across the subcarriers allocated to the users and groups in unicast and multicast scenarios respectively is essential towards video quality maximization for wireless transmission in an OFDMA system. Typical power allocation schemes existing in literature such as those based on the water filling algorithm [1] and allied iterative power allocation [2] methods are optimal power allocation schemes based on sum capacity maximization for generic data transmission and not tailored towards video quality maximization. Hence, there is a need to develop optimal power allocation schemes that are suited to the scenarios of high quality video transmission.

Fig. 1. Wireless Video Communication System with different device capabilities

Towards this purpose we propose a power optimization framework which maximizes the quality of the transmitted video streams. The presented framework is based on parametric scalable video quality and bit-rate models derived from the JSVM reference codec. The quality and bit-rate of the

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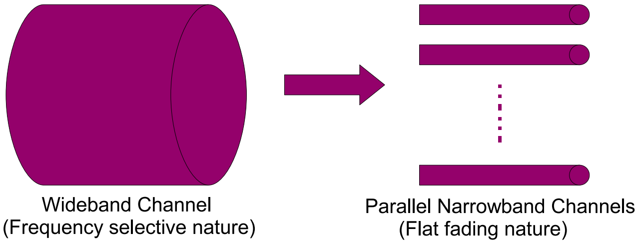

Fig. 2. OFDMA System

video sequence are expressed as functions of the frame rate and quantization parameters. The scalable video coding (SVC) profile of the H.264/AVC [3] is a special coding technique in which a combination of base and enhancement layers are employed to store an embedded master bit-stream of a coded video stream at its highest fidelity level [4]. Such a scalable video stream has been shown to be ideally suited to ensure reliable video delivery while meeting the video quality guarantees over the erratic fading wideband wireless channels coupled with the disparate capabilities of the end user devices. Subsequently, we also propose an optimization framework for power auction based revenue maximization [5] for optimal H.264 coded video transmission in 4G OFDMA systems. Employing the parametric video models derived from the JSVM reference codec, we formulate the power constrained auction based video transmission scenario as an appropriate convex optimization problem. This leads to a revenue/ utility based end-user video quality maximization. Simulation results for video transmission in 4G OFDMA systems employing several video sequences illustrate that the proposed optimal power allocation scheme significant enhances the quality of video transmission compared to video agnostic suboptimal power allocation schemes.

The subsequent sections of this paper are organized as follows. In section II we explain briefly the scalable video rate and quality models. In section II-A we describe the different auction price bidding models. The optimization framework for optimal power allocation in OFDMA systems is presented in section III. Section IV demonstrates the simulation results and conclusions are given in V.

II. SCALABLE VIDEO RATE AND QUALITY MODEL

The rate quality models of the transmitted scalable video streams relate the rate R and the video quality Q to the quantization parameter q and the frame rate t employed in the encoding process. The scalable video joint quality function $Q(q,t)$ is given as,

$$Q(q,t) = Q_{\max}\underbrace{\left(\frac{1-e^{-at/t_{\max}}}{1-e^{-a}}\right)}_{Q_t(t)}\underbrace{(\beta q+\gamma)}_{Q_q(q)},$$

where $Q_{\max} = Q(q_{\min}, t_{\max})$ is the maximum quality of the video sequence corresponding to the maximum frame rate $t_{\max}$ and minimum quantization parameter $q_{\min}$ with the normalized maximum quality $Q_{\max} = 100$. It can be seen that the normalized quality $Q(q,t)$ can be expressed as the separable product of the quality functions $Q_t(t)$, $Q_q(q)$ with respect to the frame rate t and quantization parameter q respectively [6]. Similarly, the scalable video joint rate function $R(q,t)$ in terms of quantization parameter q and frame rate t is given as,

$$R(q,t) = R_{\max}\underbrace{\left(\frac{1-e^{-ct/t_{\max}}}{1-e^{-c}}\right)}_{R_t(t)}\underbrace{e^{d(1-q/q_{\min})}}_{R_q(q)}, \tag{1}$$

where $R_{\max} = R(q_{\min}, t_{\max})$ is the maximum bit rate of the highest quality video sequence corresponding to the maximum frame rate $t_{\max}$ and minimum quantization parameter $q_{\min}$, and $R_q(q)$, $R_t(t)$ are the normalized marginal rate functions of the quantization parameter and frame rate respectively. The quantities $R_{\max}$, a, c, d, β, γ are the video characteristic parameters and are obtained from the standard JSVM reference codec [7] for the SVC developed jointly Joint Video Team (JVT) of the ISO/IEC Moving Pictures Experts Group (MPEG) and the ITU-T Video Coding Experts Group (VCEG). The characteristic video parameter values for the standard video sequences are given in [8].

A. Power Auction Bidding Models

Dynamic auctioning of the limited power resources leads to pricing based incentives to stimulate the users to compete for allocation, thereby improving the overall efficiency. Various video price versus quality based auction bidding models are presented this section. These models can then be conveniently employed to construct the power constrained optimization problem for revenue/ utility maximization of the transmitted video sequences. Naturally, as users are expected to pay higher prices for for progressively increasing video quality, the utility function for rational user are constrained to belong to a parametric class of monotonically increasing price with respect to video quality [5]. The users submit their bids for video resource allocation either individually (unicast scenarios) or through content providers (multicast scenarios) which are employed by the QoS enforcer for optimal power allocation. The optimal power allocation solution of the optimization problem thus considered leads to efficient wireless power allocation for video transmission. Below we present the linear, logarithmic and square root based video bidding models. A linear utility price bid is given by the canonical expression, 2 ,

$$B_i\left(Q_i\right) = e_i Q_i + f_i, \tag{2}$$

where f_i is the minimum admission price for the linear price bidding model and e_i is the linear price control factor. A more practical logarithmic bid model which considers the concave nature of the video utility as a function of quality is described as,

$$B_i\left(Q_i\right) = \delta_i \log_{10}\left(Q_i\right) + l_i, \tag{3}$$

where l_i is the minimum admission price for the logarithmic price bidding model and δ_i is the logarithmic price control

Sequence	a_i	c_i	d_i	β_i	γ_i	$n_i(multicast)$	$R^i{}_{\max}$	e_i	f_i	δ_i, θ_i	l_i, b_i
Foreman CIF	7.7000	2.0570	2.2070	-0.0298	1.4475	79	3046.30	6	209	209	410
Akiyo CIF	8.0300	3.4910	2.2520	-0.0316	1.4737	72	612.85	10	185	253	529
Football CIF	5.3800	1.3950	1.4900	-0.0258	1.3872	101	5248.90	6	229	253	488
Crew CIF	7.3400	1.6270	1.8540	-0.0393	1.5898	110	4358.20	9	230	286	532
City CIF	7.3500	2.0440	2.3260	-0.0346	1.5196	116	2775.50	6	236	248	580
Akiyo QCIF	5.5600	4.0190	1.8320	-0.0316	1.4737	48	139.63	6	227	239	592
Foreman QCIF	7.1000	2.5900	1.7850	-0.0298	1.4475	105	641.73	5	289	267	357
City 4CIF	8.4000	1.0960	2.3670	-0.0346	1.5196	102	20899.00	8	141	274	341
Crew 4CIF	7.3400	1.1530	2.4050	-0.0393	1.5898	32	18021.00	9	242	252	509

TABLE I

CHARACTERISTIC VIDEO PARAMETERS OF THE RATE AND QUALITY MODELS FOR THE H.264 SVC STANDARD VIDEO SEQUENCES

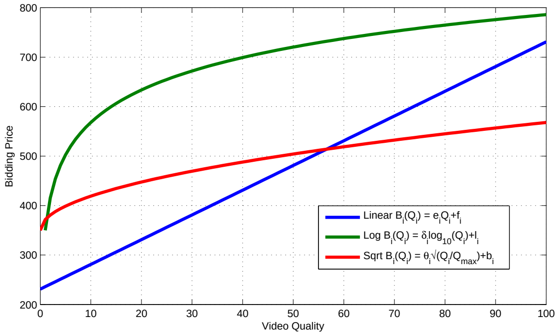

Fig. 3. Comparison of price functions considered in the simulation

factor. Another related simplistic bidding model is the square-root bid function given as,

$$B_i\left(Q_i\right) = \theta_i\sqrt{\frac{Q_i}{Q_{\max}}} + b_i, \tag{4}$$

where b_i is the minimum admission price for the square root price bidding model and θ_i is the square root price control factor. In all the above models i denote the i^{th} user/ user group in unicast/ multicast scenarios. In the practical parametric scenario described above, the users simply submit the parameter values characterizing their bids based on their requirements and the demand for the video sequences. The price variation for each of the above auction bidding models is shown in Fig.3. Next we describe the framework for optimal OFDMA power allocation.

III. OPTIMIZATION FRAMEWORK

In this section, we begin by proposing an optimization frame work for maximizing the quality of the transmitted video sequence with optimal allocation of power in 4G OFDMA systems. This optimization problem is based on the scalable video rate and quality parametric models as discussed in section II for the video transmission in both unicast and multicast 4G wireless broadband scenarios. The standard Shannon channel capacity C of a communication channel for a total transmitted power P and noise level σ_n^2 is given as,

$$C = B\log_2\left(1 + \frac{P}{\sigma_n^2}\right), \tag{5}$$

where B is the channel bandwidth. Considering transmission of video sequences at the maximum framerate $t_{\max}$, the bit-rate of the video stream can be related to the quantization parameter as,

$$R_{\max}e^{d(1-q/q_{\min})} = B\log_2\left(1+\frac{P}{\sigma_n^2}\right)$$
$$q = q_{\min}\left[1 - \frac{1}{d}\ln\left(\frac{B}{R_{\max}}\log_2\left(1+\frac{P}{\sigma_n^2}\right)\right)\right]$$

Therefore, the normalized quality of the video sequences in terms of transmitted video power can be expressed as,

$$Q = \beta q_{\min}\left[1 - \frac{1}{d}\ln\left(\frac{B}{R_{\max}}\log_2\left(1+\frac{P}{\sigma_n^2}\right)\right)\right] + \gamma.$$

Hence, the power constrained convex optimization problem for optimal power allocation towards quality maximization for video transmission in both unicast and multicast wireless broadband 4G OFDMA systems can be formulated as,

$$\begin{aligned}
&\max. \sum_{i=1}^{N} n_iQ_i \\
&\text{s.t.} \\
&Q_i = \beta_i q_{\min}\left[1 - \frac{1}{d_i}\ln\left(\frac{B}{R^i_{\max}}\log_2\left(1+\frac{P_i}{\sigma_n^2}\right)\right)\right] + \gamma_i \\
&\sum_{i=1}^{N} P_i \leq P_t \\
&P_i \geq 0,\ 1 \leq i \leq N,
\end{aligned} \tag{6}$$

where P_t denotes the total available power in OFDMA system and n_i, $1 \leq i \leq N$ denotes the number of users corresponding to the i^{th} multicast group and N denotes the total number of such groups. It can be readily observed that the above problem is convex in nature and can be solved using CVX solver [9] to obtain the optimal power and the quality of the video sequence by maximizing the sum quality under the power constraints. Fig. 4 shows that the sum quality of the video sequences increases with the increase of total transmitted power. Further, the above optimization framework can be readily extended to the auction bidding models presented in section II-A corresponding to the different video utility function based parametric bidding models. The proposed auction based optimization framework for optimal power allocation towards

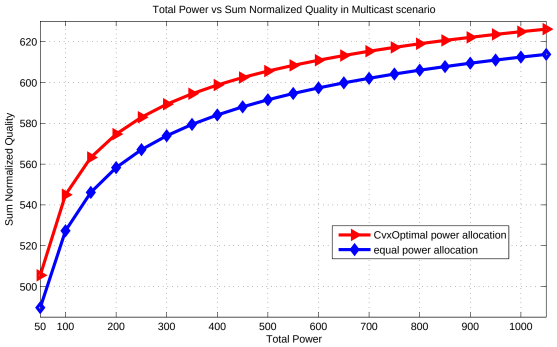

Fig. 4. Total power vs. Sum normalized quality for multicast scenario at $t = 30$ fps

auction based revenue maximization in the 4G network can be formulated as,

$$\begin{aligned}
&\max. \sum_{i=1}^{N} n_i U_i(Q_i)\\
&\text{subject to}\\
&U_i = \theta_i \sqrt{\frac{Q_i}{Q_{\max}}} + b_i\\
&Q_i \leq \beta_i q_{\min}\left[1 - \frac{1}{d_i}\ln\left(\frac{B}{R^i_{\max}}\log_2\left(1 + \frac{P_i}{\sigma_n^2}\right)\right)\right] + \gamma_i\\
&\sum_{i=1}^{N} P_i \leq P_t\\
&P_i \geq 0; 1 \leq i \leq N
\end{aligned} \tag{7}$$

where U_i can be chosen in general as any one of the utility functions of video quality presented in section II-A. We illustrate the performance of the proposed optimization framework for optimal video power allocation through simulation results in the next section.

IV. SIMULATION RESULTS

We consider $N = 9$ standard test video sequences to simulate the proposed optimization framework. We employ standard JSVM software to derive the parametric models for scalable rate and quality of the standard test video sequences. The bandwidth B corresponding to a WiMAX scenario is set equal to $B = 24 \times 10.94 = 262.56$ KHz, where each subchannel consists of 24 subcarriers with a spacing of 10.94 KHz. The normalized noise power σ_n^2 is set equal to 0 dB. The characteristic parameters of the video sequences $R_{\max}$, a, c, d, β, γ obtained from the JSVM software are listed in the table I. The parameters e_i, f_i, δ_i, l_i, θ_i and b_i of the auction bidding models listed in the table I are obtained from the bids submitted by the users based on their requirements and the demand for the video sequences in practical scenarios. In our simulations, the minimum admission prices f_i and the linear price control factors e_i for the linear price bidding models are chosen randomly in the range 100 to 300 and 5 to 10 respectively. The parameters δ and θ_i, l_i and b_i for the non-linear bidding models are chosen randomly in the range 200 to 300 and 300 to 600. In multicast scenarios, the number of subscribers in each multicast group are chosen randomly in the range 10 to 150. In the simulations, we first solve the direct power constrained quality optimization problem proposed in (6) to maximize the sum quality of the video sequences for optimal power allocation employing the parametric video models in 4G OFDMA unicast/ multicast scenarios using the CVX solver [9]. From the Fig. 4 we can observe that the sum quality of the video sequences increases with the total power and we can also observe that the sum quality with optimal power allocation is significantly higher than the sum quality with equal power allocation.

Next we solve the revenue maximization problem in (7) under the power constraints of the video transmission for optimal power allocation employing the auction bidding models in both unicast and multicast scenarios using the CVX solver. The results obtained from the revenue maximization scheme for optimal power allocation and sub-optimal equal power allocation scheme are listed in the table II for the square root bidding model for both unicast and multicast scenarios in 4G OFDMA systems. The associated net revenue comparison for the optimal power allocation and equal power allocation for a unicast scenario and multicast scenario at various values of total power P_t is given in Fig.5 and 6 respectively for the square root bidding function auction. Also, we compare equal power allocation and optimal power allocation for both unicast/ multicast scenarios in the Fig. 7 for the said bidding model. One can observe that as the number of users in a group increases, the power allocated to the video stream increases progressively increases, leading to optimization of the precious power resources. This implies that as the demand for a video stream increases, the potential revenue produced by the video increases, thus requiring a high level of power to be allocated to the corresponding video for overall video utility maximization. From the simulation results we can observe that the proposed optimal power allocation scheme presents a significant improvement in the net video revenue and the quality of the video sequences over the equal power allocation scheme.

V. CONCLUSION

We proposed and presented a quality maximization technique based on optimal power allocation for transmission of video streams with respect to the power constraints in unicast and multicast 4G wireless scenarios. The Scalable video parametric models derived from the standard JSVM codec are employed in this novel scheme. Further, with the aid of these models we proposed and presented a revenue maximization scheme based on the auction bidding models towards optimal power allocation based video utility/ revenue maximization in 4G OFDMA systems. In this auction bidding mechanism the users of unicast video streams and the service providers in multicast scenarios submit their bids to the resource scheduler at the base station. Simulation results were

Sequence	Equal Power Allocation		Optimal Power Allocation					
			Unicast Scenario			Multicast Scenario		
	p^i_{equal}	Q^i_{equal}	p^i_{opt}	Q^*_i	$n_iB_i(Q_i)$	p^i_{opt}	Q^*_i	$n_iB_i(Q_i)$
Foreman CIF	22.22	0.9403	16.186	0.9198	610.45	15.315	0.9256	482.75
Akiyo CIF	22.22	1.0000	17.118	1.0000	782.00	15.076	1.0000	563.04
Football CIF	22.22	0.7819	24.334	0.7890	712.73	27.786	0.7991	721.30
Crew CIF	22.22	0.7923	31.003	0.8232	791.50	37.830	0.8405	873.62
City CIF	22.22	0.9549	19.764	0.9468	821.32	25.130	0.9631	955.13
Akiyo QCIF	22.22	1.0000	17.104	1.0000	831.00	11.043	1.0000	398.88
Foreman QCIF	22.22	1.0000	20.191	1.0000	624.00	23.791	1.0000	655.20
City 4CIF	22.22	0.5125	26.679	0.5244	1169.40	30.648	0.6531	573.68
Crew 4CIF	22.22	0.4918	27.620	0.5076	688.54	13.382	0.4903	219.34

TABLE II

SIMULATION RESULTS FOR EQUAL AND OPTIMAL POWER ALLOCATION USING SQUARE ROOT AS BIDDING PRICE AND UTILITY FUNCTION OF QUALITY $B_i(Q_i) = \theta_i\sqrt{\frac{Q_i}{Q_{\max}}} + b_i$, IN UNICAST AND MULTICAST SCENARIOS. THE BIDDING PRICE VALUES FOR MULTICAST ARE NORMALIZED BY 100.

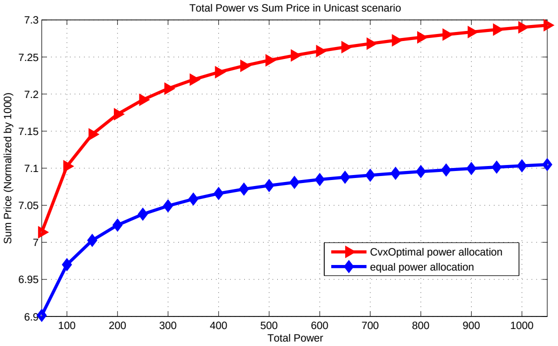

Fig. 5. Total power vs. sum price for unicast scenario at $t = 30$ fps and price as a square root function of quality $(P_i(Q_i) = \theta_i\sqrt{\frac{Q_i}{Q_{\max}}} + b_i)$.

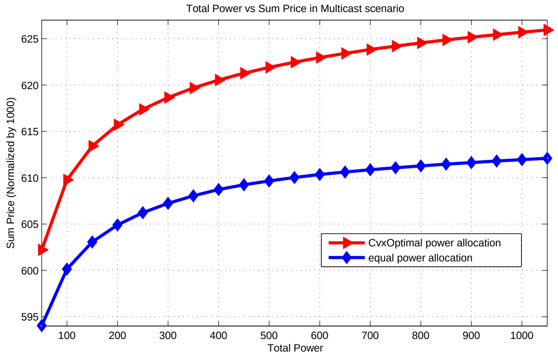

Fig. 6. Total power vs. sum price for multicast scenario at $t = 30$ fps and price as a square root function of quality $(P_i(Q_i) = \theta_i\sqrt{\frac{Q_i}{Q_{\max}}} + b_i)$.

presented to demonstrate that the proposed optimal power allocation schemes result in significantly higher video quality/utility compared to suboptimal power allocation schemes.

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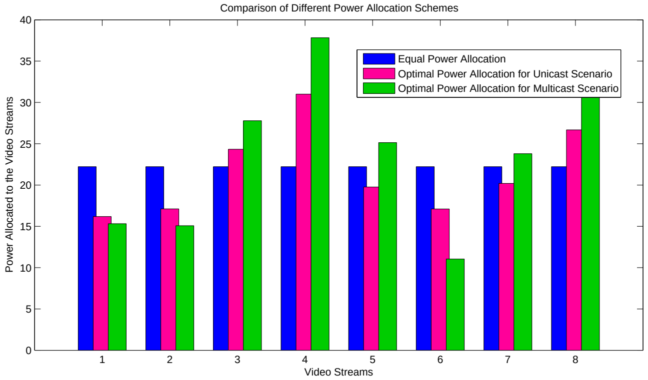

Fig. 7. Comparison of different power allocation schemes at $t = 30$ fps and bidding price as a square root function of quality $(P_i(Q_i) = \theta_i\sqrt{\frac{Q_i}{Q_{\max}}} + b_i)$.

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