Optimal 4G OFDMA Dynamic Subcarrier and Power Auction-based Allocation towards H.264 Scalable Video Transmission

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ABSTRACT

In this paper, authors presented a price maximization scheme for optimal orthogonal frequency division for multiple access (OFDMA) subcarrier allocation for wireless video unicast/multicast scenarios. They formulate a pricing based video utility function for H.264 based wireless scalable video streaming, thereby achieving a trade-off between price and QoS fairness. These parametric models for scalable video rate and quality characterization are derived from the standard JSVM reference codec for the SVC extension of the H.264/AVC, and hence are directly applicable in practical wireless scenarios. With the aid of these models, they proposed auction based framework for revenue maximization of the transmitted video streams in the unicast and multicast 4G scenario. A closed form expression is derived for the optimal scalable video quantization step-size subject to the constraints of the unicast/multicast users in 4G wireless systems. This yields the optimal OFDMA subcarrier allocation for multi-user scalable video multiplexing. The proposed scheme is cognizant of the user modulation and code rate, and is hence amenable to adaptive modulation and coding (AMC) feature of 4G wireless networks. Further, they also consider a framework for optimal power allocation based on a novel revenue maximization scheme in OFDMA based wireless broadband 4G systems employing auction bidding models. This 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. We simulate a standard WiMAX based 4G video transmission scenario to validate the performance of the proposed optimal 4G scalable video resource allocation schemes. Simulations illustrate that the proposed optimal bandwidth and power allocation schemes result in a significant performance improvement over the suboptimal equal resource allocation schemes for scalable video transmission.

Keywords: Orthogonal frequency division for multiple access, subcarrier, wireless video, scalable video coding

I. INTRODUCTION

Orthogonal frequency division for multiple access (OFDMA) is rapidly emerging as the PHY layer scheme of choice in modern wireless communications and is employed by the dominating 4G wireless standards such as WiMAX and LTE for broadband wireless access. OFDMA enables the transmission of high data rate symbol streams over wideband wireless channels, which would otherwise succumb to the distortion arising out of inter-symbol interference due to the frequency selective nature of such broadband wireless channels. OFDMA is based on orthogonal frequency division multiplexing (OFDM) which can be implemented by employing low complexity IFFT/FFT operations. OFDM converts a frequency selective wideband channel into multiple parallel narrowband frequency flat sub-carriers, thereby drastically reducing the complexity of receive processing. These sub-carriers are allocated to the users and groups in unicast and multicast scenarios respectively for appropriate periods of time. This process is referred to as time-frequency resource allocation in OFDMA systems and holds key to 4G wireless network performance optimization.

Video based applications such as video conferencing, multimedia streaming, mobile TV and real-time surveillance are emerging as popular 4G applications. Hence, a significant component of the 4G Wireless traffic is expected to comprise of video and multimedia based rich applications. Such video applications require the development of sophisticated multimedia codecs for video transmission in the mobile wireless environment. To ensure video delivery while meeting the video quality guarantees is challenging due to the erratic fading nature of the wideband wireless channel coupled with the disparate device capabilities of the cellular users and quality of service (QoS) requirements. This challenge has led to the development of the scalable video coding (SVC) profile of the H.264/AVC which is attractive especially for video transmission in unicast and multicast wireless scenarios.

Scalable Video Coding is a unique paradigm wherein a video is coded as a series of embedded bit streams and is stored at its highest fidelity levels as a combination of several base and enhancement layers. However, a novel feature of such a stream is that partial bit streams can be extracted to fulfill the requirements of the wireless video users depending on the nature of their individual link qualities and device capabilities. SVC enables the filtering and extraction of partial bit streams...
of diverse spatial, quality and temporal resolutions. The bit rate and quality of the coded video streams depend intrinsically on the frame rate, spatial resolution and quantization parameters. Hence, these parameters have to be chosen appropriately so as to maximize the net video quality while meeting the end user QoS aspects for video delivery.

Hence, efficient allocation of subcarriers is essential in 4G OFDMA towards meeting the above objective in wireless scalable video transmission. Further, generic subcarrier allocation schemes which are not tailored to the nature of the scalable video streams are not amenable to practical wireless scenarios. Hence, one needs to develop schemes for the scalable video streams are not amenable to practical allocation schemes which are not tailored to the nature of scalable video transmission. Further, generic subcarrier allocation schemes which are employed by the QoS enforcer for optimal time/frequency resource allocation at the 4G wireless QoS enforcement points such as base stations (BS) and access service network gateways (ASN-GW) in a 4G wireless network. The proposed scheme is based on dynamic subcarrier auctioning which supports pricing based incentives to stimulate users to sell and lease under-utilized sub carriers, thereby improving the overall efficiency. 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 time/frequency resource allocation. Since rational users are expected to pay appropriate prices as per allocation of the 4G wireless resources, this naturally leads to revenue maximization towards scalable video transmission in 4G wireless networks. Conventional approaches related to scheduling and resource allocation in 4G wireless systems are not specialized to the context of video and do not consider the scalable nature of video transmission, thereby resulting in suboptimal resource allocation and end user video quality reduction. The proposed scheme avoids this by direct video codec adaptation, thereby enhancing its appeal for use in practical wireless scenarios.

Towards this end we consider parametric scalable video quality and bit-rate models as functions of the scalable video frame rate and quantization parameter for optimal OFDMA subcarrier allocation. These robust models for H.264 SVC coded streams are computed using the JSVM reference codec and hence are readily applicable in practice. We formulate a constrained convex optimization problem based on the above models for auction based optimal OFDMA resource allocation. We use the robust framework of convex optimization to obtain the closed form expression for computation of the optimal coded video parameters, thus leading to codec adaptation. This results in revenue based end-user video quality maximization and efficient bandwidth utilization in 4G wireless networks. Subsequently we also propose an optimization framework for power auction based revenue maximization 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 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 subcarrier and power allocation schemes significantly enhance the quality of video transmission compared to video agnostic suboptimal power allocation schemes.

2. SCALABLE VIDEO AUCTION MODEL

The rate and quality of the transmitted scalable video streams are intrinsically related to the quantization parameter and frame rate of the scalable codec and have been derived.

The scalable video rate function $R(q, t)$ in terms of quantization parameter $q$ and frame rate $t$ is given as,

$$R(q, t) = R_{\text{max}} \left( \frac{1 - e^{-ct/t_{\text{max}}}}{1 - e^{-c}} \right) \frac{R_1(t)}{R_q(q)}$$

where $R_{\text{max}} = R(q_{\text{max}}, t_{\text{max}})$ is the highest bit rate of the highest quality video sequence corresponding to the maximum frame rate $t_{\text{max}}$ and minimum quantization parameter $q_{\text{min}}$, and $R_q(q)$, $R_1(t)$ are the normalized rate function vs quantization parameter and frame rate respectively. Similarly, the scalable video joint rate function is given as,
where \( Q_{\text{max}} = Q(q_{\text{min}}, t_{\text{max}}) \) is the highest quality of the video sequence corresponding to the maximum frame rate \( t_{\text{max}} \) and minimum quantization parameter \( q_{\text{min}} \) and is normalized to 100 i.e. \( Q_{\text{max}} = 100 \). The normalized quality functions \( Q_i(t), Q_q(q) \) with respect to the frame rate \( t \) and quantization parameter \( q \) are respectively defined as,

\[
Q_i(t) = \frac{Q(q, t)}{Q(q_{\text{min}}, t_{\text{max}})},
\]

\[
Q_q(q) = \frac{Q(q, t_{\text{max}})}{Q(q_{\text{min}}, t_{\text{max}})}.
\]

The quantities \( R_{\text{max}}, a, c, d, \beta, \gamma \) are the video characteristic parameters and are obtained from the standard JSVM reference codec\(^4\) for the SVC developed jointly by the 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 standard video sequences are available in literature\(^5\).

### 2.1 Auction Bidding Model

In this section, we present the video auction bidding models employed to derive the optimization framework for revenue maximization subject to the bandwidth constraints and quantization parameter bounds of the video sequence. This is employed to propose a revenue objective function as a function of video quality with the bit-rate constraints for video transmission imposed by the communication system. Naturally, the proposed bid function must be increasing with respect to quality of the video as users are expected to pay higher prices for increased video quality. Several parametric utility functions\(^2\) can be employed as valid bid functions towards revenue maximization. In this context a linear price quality bid function can be presented as,

\[
P = eQ + f;
\]

where \( f \) is the minimum admission price and \( e \) is the linear price control factor. Then we consider price as a utility function which is derived from the user requirements. Further, the proposed framework for auction based revenue maximization is general and other allied bid functions such as the logarithmic and square root functions shown in Fig. 3 can be readily incorporated.

### 3. OFDMA BASED WIMAX WIRELESS NETWORKS

Orthogonal frequency division for multiple access (OFDMA) is based on the multi-carrier orthogonal frequency division multiplexing (OFDM) modulation scheme. In OFDM systems the given high bit-rate data stream is divided into lower bit-rate parallel streams, each of which is modulated and transmitted individually over separate orthogonal subcarriers as shown in Fig. 4. Hence, in OFDMA systems the available broadband channel is subdivided into different frequency subcarriers which convert the wideband frequency selective channel into parallel narrowband flat fading channels resulting in significantly lower processing complexity. The primary advantage of OFDM is its resilience to delay spread, which arises due to the increased per symbol duration. The presence of the cyclic prefix (CP) greater than the worst-case channel delay spread ensures that the effect of ISI is restricted to the duration of the CP, which can be discarded. The presence of

### Table 1. Characteristic video parameters of the rate and quality models for the H.264 SVC standard video sequences

<table>
<thead>
<tr>
<th>Sequence</th>
<th>( a_i )</th>
<th>( c_i )</th>
<th>( d_i )</th>
<th>( \beta_i )</th>
<th>( \gamma_i )</th>
<th>( m_i )</th>
<th>( r_i )</th>
<th>( n_i )</th>
<th>( R_{i_{\text{max}}} )</th>
<th>( e_i )</th>
<th>( f_i )</th>
<th>( \theta_i )</th>
<th>( h_i )</th>
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</thead>
<tbody>
<tr>
<td>Foreman CIF</td>
<td>7.7000</td>
<td>2.0570</td>
<td>2.2070</td>
<td>-0.0298</td>
<td>1.4475</td>
<td>1</td>
<td>5/6</td>
<td>79</td>
<td>3046.30</td>
<td>6</td>
<td>209</td>
<td>209</td>
<td>410</td>
</tr>
<tr>
<td>Akiyo CIF</td>
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<td>3.4910</td>
<td>2.2520</td>
<td>-0.0316</td>
<td>1.4737</td>
<td>2</td>
<td>2/3</td>
<td>72</td>
<td>612.85</td>
<td>10</td>
<td>185</td>
<td>253</td>
<td>529</td>
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<tr>
<td>Fotball CIF</td>
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<td>1.3950</td>
<td>1.4900</td>
<td>-0.0258</td>
<td>1.3872</td>
<td>1</td>
<td>2/3</td>
<td>101</td>
<td>5248.90</td>
<td>6</td>
<td>229</td>
<td>253</td>
<td>488</td>
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<td>Crew CIF</td>
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<td>1.6270</td>
<td>1.8540</td>
<td>-0.0393</td>
<td>1.5898</td>
<td>1</td>
<td>5/6</td>
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<td>4358.20</td>
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<td>-0.0346</td>
<td>1.5196</td>
<td>1</td>
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<td>236</td>
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<td>580</td>
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<td>1.8320</td>
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<td>1.4737</td>
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<td>1/2</td>
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<td>139.63</td>
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<td>592</td>
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<td>Foreman QCIF</td>
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<td>1.4475</td>
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<td>-0.0346</td>
<td>1.5196</td>
<td>4</td>
<td>2/3</td>
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<td>1</td>
<td>1/2</td>
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transmission of very high data rates through the use of different modulation rates and error correcting coding schemes. WiMAX based on OFDMA PHY supports scalable bandwidth, data-rates and also flexible, dynamic per user resource allocation. WiMAX MAC is designed to support a large number of users, with multiple connections per terminal, each with its own QoS requirement. WiMAX supports strong encryption using advance encryption standard (AES), and has a robust privacy and key management protocol. All end-to-end services are delivered over an IP architecture relying on IP-based protocols for end-to-end transport, QoS, session management, security and mobility.

4. OPTIMAL SUBCARRIER AUCTION

The QoS enforcer initially solicits the quality based pricing bids $P_i(Q_i)$ from the users/ content providers in the 4G wireless network. The adaptive modulation coding (AMC) rate aware constrained optimization framework for symbol rate allocation towards auction based revenue maximization in the 4G network can be formulated as,

$$\max \sum_{i=1}^{N} n_i P_i(Q_i)$$

s.t

$$P_i(Q_i) = c_i Q_i + f_i, 1 \leq i \leq N$$

$$\sum_{i=1}^{N} \frac{1}{m_i} R_i(q_i, t_f) \leq R_s$$

$$q_{\min} \leq q_i \leq q_{\max}$$

where $R_i$ denotes the aggregate symbol rate of the OFDMA system and $n_i; 1 \leq i \leq N$ denotes the number of users corresponding to the $i^{th}$ multicast group, where $N$ denotes the total number of groups. The quantities $Q_i = Q(q_i, t_f)$ and $R(q_i, t_f)$ represent the quality and rate of the $i^{th}$ video sequence corresponding to the quantization parameter $q_i$ and fixed frame rate $t_f$. The adaptive modulation order $m_i$ corresponding to the number of bits per symbol and $r_i$ as code rate of the $i^{th}$ scalable video stream, which is allocated dynamically by the scheduler as per the user DL channel conditions. It can be readily seen that the above problem is convex in nature and the optimization framework can be naturally converted to a standard form convex optimization problem Eqn (9) by modifying the optimization objective as,
min. \( -\sum_{i=1}^{N} n_i P_i(Q_i) \)

The above standard form convex optimization problem can be conveniently solved employing standard convex optimization techniques which employ the Karush-Kuhn-Tucker (KKT) framework. The Lagrangian function \( L(\bar{q}, \lambda, \bar{\mu}, \bar{\delta}) \) for the above revenue maximization problem is given as,

\[
L(\bar{q}, \lambda, \bar{\mu}, \bar{\delta}) = -\sum_{i=1}^{N} n_i (\tilde{\beta}_i q_i + \bar{\gamma}_i) + \lambda \left( \sum_{i=1}^{N} k_i e^{d_i (1-q_i/q_{min})} - R_S \right) + \sum_{i=1}^{N} \mu_i (q_i - q_{max}) + \sum_{i=1}^{N} \delta_i (q_{min} - q_i)
\]

where \( \lambda, \mu_i, \delta_i, 1 \leq i \leq N \) are Lagrange multipliers, \( \tilde{\beta}_i = \epsilon Q_{max} Q_i(t_f) \beta_i, \) \( \bar{\gamma}_i = \epsilon Q_{max} Q_i(t_f) \gamma_i, \) and \( R_{max}^i \) is the maximum bitrate corresponding to the \( i^{th} \) video stream. The quantity \( k_i \) is defined as,

\[
k_i = \frac{R_{max}^i}{m_i r_i} \left( 1 - e^{-c_{ij}/t_{max}} \right) \frac{1}{1 - e^{-c_{ij}}}
\]

Applying the KKT conditions for the above Lagrangian optimization criterion and setting \( i.e. \nabla L(\bar{q}, \lambda, \bar{\mu}, \bar{\delta}) = 0 \) with \( \lambda \geq 0, \mu_i \geq 0, \delta_i \geq 0 \), we obtain

\[
-n_i \tilde{\beta}_i - \lambda k_i \left( \frac{d_i}{q_{min}} \right) e^{d_i (1-q_i/q_{min})} + \mu_i - \delta_i = 0
\]

From (2), the KKT complementary slackness condition corresponding to the rate inequality constraint is given as,

\[
\lambda \left( \sum_{i=1}^{N} k_i e^{d_i (1-q_i/q_{min})} - R_S \right) = 0,
\]

Therefore, the Lagrangian multiplier \( \lambda^* \) corresponding to the optimal scalable video quantization parameter adaptation obtained by setting \( \mu_i = 0 \) and \( \delta_i = 0 \) (corresponding to slack quantization parameter constraints) can be derived as,

\[
\lambda^* = \frac{q_{min}}{R_S} \sum_{j=1}^{N} \frac{\tilde{\beta}_j m_j}{d_j}.
\]

We substitute the above expression for \( \lambda^* \) in Eqn (4) to derive the closed form expression for the optimal quantization parameter \( q_i^* \) as,

\[
q_i = q_{min} \left( 1 - \frac{1}{d_i} \ln \left( \frac{q_{min} \tilde{\beta}_j m_j}{\lambda^* k_i d_i} \right) \right)
\]

\[
-q_{min} \left( 1 - \frac{1}{d_i} \ln \left( \frac{R_S n_i \tilde{\beta}_j (d_j)^{-1}}{k_i \sum_{j=1}^{N} n_j \tilde{\beta}_j (d_j)^{-1}} \right) \right)
\]

The above expression yields the optimal quantization parameter \( q_i^* \) for the scalable video codec adaptation and time-frequency resource allocation towards video revenue maximization. Thus the above closed form solution provides a fast and low computational complexity scheme for optimal scalable video adaptation compared to employing convex solvers such as CVX and is applicable for both unicast and multicast scenarios.

Further, as described in the earlier section, the proposed optimal framework for the rate constrained time-frequency allocation towards revenue maximization is not restricted to linear bidding models and can be readily employed for a large class of utility functions. For instance, consider the general parametric bidding model \( P_i(Q_i) = \theta_i \log\delta_{10} (Q_i) \). The corresponding framework for auction based revenue maximization can be formulated as,

\[
\max. \sum_{i=1}^{N} n_i P_i(Q_i)
\]

s.t. \( \sum_{i=1}^{N} \frac{1}{m_i r_i} R_i(q_i, t_f) \leq R_S \)

\[
q_{min} \leq q_i \leq q_{max}
\]

Further, another such utility function that can be considered is \( P_i(Q_i) = \delta_i \frac{Q_i}{Q_{max}} \). Simulation results in the later section demonstrate the performance of the proposed algorithms for scalable video rate adaptation.

5. 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 in 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 progressively increasing video quality, the utility functions for rational users are constrained to belong to a parametric class of monotonically increasing price with respect to video quality\(^2\). 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,

\[ B_i(Q_i) = e_i Q_i + f_i, \quad (8) \]

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,

\[ B_i(Q_i) = \delta_i \log_{10}(Q_i) + l_i, \quad (9) \]

where \( l_i \) is the minimum admission price for the logarithmic price bidding model and \( \delta_i \) is the logarithmic price control factor. Another related simplistic bidding model is the square-root bid function given as,

\[ B_i(Q_i) = \theta_i \sqrt{Q_i/Q_{\text{max}}} + b_i, \quad (10) \]

where \( b_i \) is the minimum admission price for the square root price bidding model and \( \theta_i \) is the square root price control factor. In all the above models \( i \) denotes 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.

6. OPTIMAL POWER AUCTION

In this section, we begin by proposing an optimization framework 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 discussed earlier 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 \( \sigma_n^2 \) is given as,

\[ C = B \log_2 \left( 1 + \frac{P}{\sigma_n^2} \right), \quad (11) \]

where \( B \) is the channel bandwidth. Considering transmission of video sequences at the maximum frame rate \( f_{\text{max}} \), the bit-rate of the video stream can be related to the quantization parameter as,

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

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

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

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

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,

\[ \max \sum_{i=1}^{N} n_i Q_i \]

subject to

\[ Q_i = \beta_i \frac{Q_{\text{min}}}{d} \left[ 1 - \frac{1}{d} \ln \left( \frac{B}{R_{\text{max}} \log_2 \left( 1 + \frac{P_i}{\sigma_n^2} \right)} \right) \right] + \gamma_i \]

\[ \sum_{i=1}^{N} P_i \leq P_t \]

\[ P_i \geq 0, 1 \leq i \leq N, \]

where \( P_t \) denotes the total available power in OFDMA system and \( n_i \) 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 to obtain the optimal power and the quality of the video sequence by maximizing the sum quality under the power constraints. Fig. 5 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 the earlier section corresponding to the different video utility function based parametric bidding models.

The proposed auction based optimization framework for optimal power allocation towards auction based revenue maximization in the 4G network can be formulated as,

\[ \max \sum_{i=1}^{N} n_i U_i(Q_i) \]

subject to

\[ U_i = \theta_i \left[ \frac{Q_i}{Q_{\text{max}}} + b_i \right] \]

\[ Q_i \leq \beta_i \frac{Q_{\text{min}}}{d} \left[ 1 - \frac{1}{d} \ln \left( \frac{B}{R_{\text{max}} \log_2 \left( 1 + \frac{P_i}{\sigma_n^2} \right)} \right) \right] + \gamma_i \]

\[ \sum_{i=1}^{N} P_i \leq P_t \]

\[ P_i \geq 0, 1 \leq i \leq N, \]

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

7. SIMULATION RESULTS

In our simulations we consider the streaming of \( N = 9 \) standard test video sequences and we employ a standard WiMAX profile to illustrate the performance of the proposed optimal OFDMA time-frequency resource allocation schemes. The parameters \( e_i, f_i, \theta_i \) and \( b_i \) corresponding to the bids of the different users are listed in Table 1. 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
The parameters \( q_s \) and \( b_i \) for the nonlinear bidding models are chosen randomly in the range 200 to 300 and 300 to 600. The optimal price maximizing bit-rate allocation and the corresponding optimal quantization parameter \( q^*_i \) are evaluated by formulating the optimization problem and computing the optimal solution using the closed form expression in Eqn (6). We compare our allocation with the one obtained from the standard CVX based convex solver. The corresponding per video sequence optimal quantization parameter \( q^*_i \) optimal price maximizing bit-rate allocation are listed in Table 2 for the logarithmic bidding model using the WIMAX profile mentioned with the effective downlink symbol rate \( R_s = 6.336 \) Msym/s. Further, the corresponding values for the sub-optimal equal bit-rate allocation are also given therein. The associated net revenue comparison for the optimal bit-rate allocation and equal bit-rate allocation for a unicast scenario at various values of symbol rates \( R_s \) is given in Fig. 6 for the linear bidding function auction. Similarly, Fig. 7 demonstrates the comparison for a multicast scenario with the number of

Table 2. Symbol allocation for equal and optimal symbol rate using logarithmic bidding price \( P_i(Q_i) = \theta_i \log_{10}(Q_i) + b_i \), in unicast and multicast scenarios. The bidding price values for multicast are normalized by 100.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Equal symbol rate allocation</th>
<th>Optimal symbol rate allocation</th>
</tr>
</thead>
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multicast subscribers for each group chosen randomly in the range 10 to 150.

From Fig. 6 we can observe that the closed form solution allocation from Eqn (6) closely agrees with the CVX solver based allocation. We also present the OFDMA multi-user DL-MAP for subcarrier allocation in both equal and optimal bitrate allocation scenarios in Figs. 8 and 9 respectively, for the log pricing based video auction.

From the simulation results we can observe that the optimal symbol rate allocation framework yields significant improvement in the net video revenue and can be conveniently employed by the QoS points and Core Network in 4G wireless scenarios.

For the optimal power auction we again consider $N = 9$ standard test video sequences to simulate the proposed optimization framework. 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 $\sigma_n^2$ is set equal to 0 dB. The characteristic parameters of the video sequences $R_{max}$, $a$, $c$, $d$, $\gamma$, $\beta$ obtained from the JSVM software are listed in the Table 1. The parameters $e_i$, $f_i$, $\delta_i$, $l_i$, $\theta_i$ and $b_i$ of the auction bidding models listed in the Table 1 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 $\delta_i$ and $\theta_i$, $l_i$ 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 numbers 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\(^{12}\) 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\(^{10}\).

From the Fig. 5 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\(^{13}\) 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 3 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 Figs. 10 and 11 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. 12 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 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.

8. CONCLUSION

We proposed and presented auction based schemes for optimal sub carrier and power allocation towards revenue maximization in a 4G OFDMA system. The proposed schemes are based on the bidding mechanism, where users of unicast video streams and service providers in multicast scenarios submit their bids to the resource scheduler at the base station. An optimization framework has been proposed for optimal resource allocation with respect to the OFDMA aggregate rate constraints and adaptive modulation and coding paradigm in 4G systems. A closed form solution has been derived for the optimal quantization parameter based link-codec adaptation in OFDMA systems. Further, this framework has been shown to be general in nature and can be readily extended to a variety of suitable utility functions for optimal resource allocation. It has been shown through simulations that the presented optimal subcarrier and power allocation yield improved performance compared to the suboptimal equal subcarrier and power allocation respectively for the case of DL/UL PUSC WiMAX.

<table>
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Table 3. Simulation results for equal and optimal power allocation using square root as bidding price and utility function of quality $B(Q) = \sqrt{\frac{Q}{Q_{\text{max}}}} + b$, in unicast and multicast scenarios. The bidding price values for multicast are normalized by 100.
REFERENCES


Contributors

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