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CONMIQ Multicast: A Scalable Multicast Video Streaming in LTE Networks

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***Abstract*— Multicast transmission is a recurrent problem in wireless networking as the system has to cater to multiple numbers of users at the same time. Furthermore, video payload adds more complexity to the problem, i.e., video needs to be delivered in a timely and orderly manner. Using H.264/SVC standard for scalable video, scaling could be used to compromise the quality and the size of the video, yet it poses a complex dependency problem. We propose a multicast scheme named CONMIQ (Constrained Non-linear Model of Incremental Quality) that provides suboptimal video quality to all users and still fulfill resource requirement. The solution will be applied to LTE-A (Long-Term Evolution-Advanced) network, which provides robust user channel quality assessment and a better OFDMA channel. To find the maximum video quality, we model the video quality of each video block in a GOP (Group of Pictures) as a second-degree polynomial function, then solve the maximization problem on that function, along with the considerations of resource constraints, video block dependency, and the varying channel condition of subscribed users. The experimental results verify that our suboptimal solution outperforms naive approaches while still performing comparably well than the much slower optimal solution.**

Keywords*— *LTE Networks, multicast, video streaming

I. INTRODUCTION

In recent years, online video streaming has been one of the most frequently consumed media on the internet, with 64% accounted for all of consumer internet traffic in 2014, according to a recent study conducted by Cisco [1]. Global mobile traffic will increase by 11-fold between 2014 and 2019. Furthermore, video streaming traffic from mobile devices is projected to grow at a 67% rate annually until 2019. Following this trend, bandwidth-extensive videos such as high-definition (HD) video, ultra-high-definition (UHD/4K) video, and 3D video are also becoming widely adopted standards.

Fourth-generation (4G) standards are created with the forethought to overcome the problem of bandwidth and network speed and improve various aspects that previous generation standards (e.g., WiFi and 3G mobile networks) are lacking. One of the latest 4G standards for the cellular network, namely Long-Term Evolution Advanced (LTE-A), provides more robust wireless connections to mobile users, higher and scalable system bandwidth, extended coverage, and better multicast schemes. More specifically, LTE-A with aggregated bandwidth of 100 MHz can provide an average data rate of 300 Mbps for high-mobility users [2].

On the other hand, multicast and broadcast transmission have been proven to be the fundamental solutions to point-to-multipoint (PtM) communications. Its popular use cases include audiovisual streaming of programs which are immediate in nature, such as live sports events and breaking news. The ability to transmit data over multiple users at the same time has been shown to be adequate and efficient.Yet maintaining the Quality of Service (QoS) requirement is still a challenging problem due to the varying channel conditions of subscribed users.

To support video multicasting and broadcasting, LTE-A introduces the evolved Multimedia Broadcast and Multicast Service (eMBMS), which is capable of managing PtM communications [3]. It proposes improvements such as higher and more flexible LTE bit rates, Single Frequency Network (SFN) operations, and carrier configuration flexibility. While LTE-A provides a robust framework for measuring the channel quality of each user, its packet scheduling strategy is still open for research and discussion [4].

We also observe the usage of Scalable Video Coding (SVC), an extension to the widely adopted H.264/MPEG-4 video compression standard, for reliable and scalable video delivery. SVC provides temporal, spatial, and quality scalability by supplying high-quality video streams that contain one or more subset bit streams that can be decoded independently. A smaller subset of bit stream provides a smaller size than the original stream (i.e., less transmission resource), with the drawback of worse video quality but still better than none.

Recent work on scalable video multicast in OFDMA-based wireless networks has been presented [5–9]. An optimal solution [5] employs a recursive method for finding the maximum of assigned utility. However, the pseudo-polynomial complexity of its recursive method is arguably impractical to be applied to systems with a large number of search spaces (i.e., time and frequency resources) such as LTE. Furthermore, scheduling strategies that make use of the LTE specification have been extensively discussed [6–8].These two works focus on the importance of QoS requirements while maintaining fairness between users in the LTE system. While a higher bit rate may result in better-perceived video quality, none of these strategies straightforwardly set its maximization as a target.

As such, we provide an alternative solution by directly maximizing users' perceived video quality. We develop a novel method of scheduling scalable video for multicast transmission in SFN eMBMS systems, using a non-linear model of incremental quality. With the user's perceived video quality measured as Peak Signal to Noise Ratio (PSNR) of a received video to its original source, we then define

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incremental quality to quantify the quality of each video block. Afterward, video blocks on each GOP are scheduled by modeling its incremental quality as a second-degree polynomial function. With the considerations of video block dependency, the channel condition of each user, and the resource constraints, we maximize overall perceived video quality by finding the best modulation coding scheme (MCS) to be assigned to each video block.

II. RELATED WORKS

A. QoS optimization

Most of the related work in recent years has focused on achieving QoS through minimizing packet delay and loss [5–7], minimizing resource load [7–10], or achieving the best throughput [5–7,11,12]. J. Yoon et al. [5] propose a sub-optimal scheduling scheme for scalable video multicast in OFDMA networks using a recursive method. Yet, the increase in complexity in real LTE deployment (i.e., the high number of multicast subscribers and modulation options) will render it infeasible as its running time becomes longer. C. Lou et al. [6] propose two-level scheduling, with the first level occurring during each scheduling period and the second level occurring during each TTI.A strategy named Least Channel Gain (LCG) aims to minimize resource loads by delivering services such that they can be recovered by UEs experiencing the worst propagation conditions in the network [10].

Carrier aggregation has also been utilized to take advantage of its diverse channel conditions [7,11,12]. R. Sivaraj et al. [7] utilized carrier aggregation and also addressed the problem of varying channel conditions on each carrier. They choose the appropriate set of carriers for the multicast transmission by taking the spectral efficiency of that channel and the user's probability of successful transmission into consideration. While most of the related work measures the resulting video quality of each user in their performance evaluation, none of it attempts to directly maximize the perceived video quality of each user.

B. SVC video

SVC which is an extension to H.264 video, provides scalability by supplying multiple bitstreams. These bitstreams serve different video quality levels and can be decoded independently. The problem of multicast transmission of scalable video has been extensively researched in recent years [6–9,13–16]. H. Zhou et al. [13] address the resource allocation problem of SVC video in wireless relay networks. They simplify the problem by assuming that the MCS assigned to lower video layers have equal or better coverage area than the MCS assigned to higher video layers, and then solve the problem using tabu search.In another work, H. Zhou et al. [14] investigated the resource allocation problem of SVC multicast over a heterogeneous cellular network. In WiMAX, intra-frame scheduling has been utilized to schedule an SVC video in a WiMAX relay network [15]. The resource allocation problem for the SVC multicast has also been presented in Vehicular Ad Hoc Networks (VANETs) [16]. The Basic-full-coverage, profit-oriented resource allocation is presented and solved using a heuristic algorithm.

The majority of works that use SVC video [6–9,16] take advantage of SVC video's scalability with a two-step approach for the different bitstreams.First, they schedule the mandatory base layer (i.e. set of bitstreams) with the possible minimum resource and then schedule the rest of the resources to the better enhancement layers to maximize video quality. This two-step approach is simple in design, but difficult to be maximally fine-tuned. Most of the quality gain depends on the remaining resources that will be assigned to the enhancement layers. Furthermore, the problem of layer dependency could complicate the scheduling problem. We address this problem by giving a higher priority to assigning the lower MCS index to the base layer.

C. Network coding

Network coding has been presented as one of the solutions to the scalable video multicast problem. C. Huang et al. [9] approach the problem of multicast transmission to minimize the required resource. They use the two-step approach of scheduling the base layer first, then enhancement layers. Similarly, A. Tassi et al. [8] developed a resource load minimization approach using network coding, but applied the problem to the LTE network, which directly utilizes the Application Level-Forward Error Correction (AL-FEC) schemes in the LTE specification. Link-level Random Network Coding (RNC)-based strategies have also been proposed as an alternative to fountain code-based AL-FEC schemes [17,18]. Several papers [19-24] have been proposed that deal with the optimization of Network Coding (NC) for data broadcasting over a multi-hop network.Both of the papers propose a utility-based optimization model where the multicast scheme is used to optimize the overall delivery utility function and minimize the network cost. Additionally, D. Zhang et al. [20] propose a multicast scheme which aims to minimize the total transmission power associated with the multicast data delivery over a multi-hop relay network. Our work provides a simpler solution by defining the individual quality of each video block as a value to be maximized.

III. METHODOLOGY

A. Incremental PSNR

To quantify the value of a video, we use the luma PSNR (Peak Signal-to-Noise Ratio).We then define the incremental PSNR to measure the value of each video block. The incremental PSNR of a video block is the extra PSNR received after it is successfully decoded. For clarity, we use the term incremental PSNR and incremental quality interchangeably in this work.

JSVM (Joint Scalable Video Model) is a H.264 software suite that supports SVC operations such as encoding, decoding, bit stream extraction, trace file generation, and PSNR measurement [27]. In our research, we use JSVM for most of the SVC operations. However, there is a limitation to measuring PSNR using JSVM. That is, the PSNR of a video is measured on a frame-by-frame basis, regardless of how many layers are in the frame. Therefore, we use two different methods to calculate the incremental PSNR of a video block, for the base layer and for the enhancement layers, respectively.

B. Problem Formulation

First, we define B as the total number of video block in a GOP and that$B = FL$. We omit the usage of $b_{f,l}$ to present a video block. Rather, β is used as a single index with no relation to frame and layer index, which means that the video blocks are presented in a linear manner. We then formulate the maximization problem of total video quality perceived by UEs on each GOP.

There are M number of MCS indexes, and U number of UEs. The available MCS indexes will correspond the CQI indexes, therefore, there are maximum of 15 MCS indexes. It maximizes the incremental PSNR $\Delta q(\beta)$ of block β with the variable of success transmission probability of UE u, $p_{i,u}$, and binary variable $\omega_{i,\beta}$ as the indication if block β is assigned to MCS i. The restriction of $\omega_{i,\beta}$ is to binary values. The constraint limits assignment to only one MCS index for each video block. The second constraint restricts the assignment to the maximum available transport block T, with S_β as the size of video block β, and δ_i as size of transport block while using MCS index i. Finally, to further improve the perceived quality, a video block dependency constraint is introduced. It addresses it in which thedependency block β must be assigned an MCS index lower or equal to the dependent block β^{J}. If the dependency video block assigned to a higher MCS index than the dependent block, there possibly be a case when the dependency block is not received but the dependent block is received. In this case, the dependent block cannot be decoded and wastefully discarded.

Utilizing LTE framework, we are taking advantage of the CQI reporting to determine if an MCS index is appropriate for a UE [4].

C. *Constrained Non-linear Model of Incremental Quality*

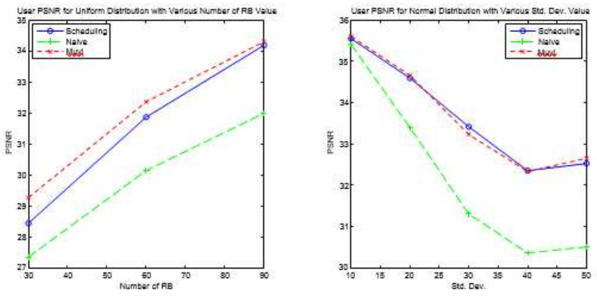
We introduce a multicast scheduling scheme named CONMIQ (Constrained Non-linear Model of Incremental Quality), which utilizes a non-linear model of incremental video quality. We perform a preliminary simulation using an HD YUV video dataset "spark joy". First, we extract the incremental PSNR of each video block. Next, the video blocks in each GOP are sorted on a layer basis. We observe a pattern in the incremental PSNR of the sorted video block and use a second-degree polynomial function to model its incremental PSNR.

Note that since the video block in the first frame and base layer of GOP 1 has no reference to any block, its incremental PSNR is very high compared to other blocks. The figures show that video blocks' incremental PSNR is decreasing in a non-linear manner, which fits well into the two-degree polynomial function model.

To model the total PSNR, we divide the curve-fitted function into a set of partitioned areas as illustrated by figure 4.3, with x_i, $\forall 1 \le i \le M$ as the divider.This partitioned areas model total perceived PSNR of the video blocks when they are sent using MCS index i. Finally, the problem formulation takes a form as the maximization of the constrained non-linear function, with the constraint of resource and video dependency.We are able to eliminate the dependency constraint by sending the video blocks sorted on a layer basis, and assigning an MCS index in an increasing manner.

IV. SIMULATIONS AND EVALUATIONS

To evaluate the efficacy of our scheduling scheme, we compare it to the naive approach and the existing wireless multicast scheduling schemes in a simulation. We use PSNR as the evaluation metric. To implement the simulation, we use Matlab and its optimization toolbox. UEs are deployed randomly to simulate the channel conditions. We assume that the video payload is already encoded and ready to be sent by eNB. We simulate transmission by taking simulation parameters into consideration and calculate the probability of successful transmission of each UE. Subscribed UEs will then decode the received video blocks and calculate their PSNR. If a video frame is dropped or received past its deadline, it is considered lost and concealed by copying the last received frame.



(a) (b)

Fig. 1. Average user-perceived PSNR for (a) the uniform distribution test, and (b) the normal distribution test.

We consider a single cell LTE network with one eNB and multiple subscribed UEs. In each simulation, UEs are randomly deployed around the eNB using a uniform and normal random distribution. The UE's distance is randomly generated using the chosen distribution type, while its angle is randomly generated using uniform distribution. Figure 5.1 illustrates an example of random user distribution for 100 users in a radius of 250 m. In figure 5.1b, users are generated using a normal distribution with a mean value of 150 m and a standard deviation of 10 m. We assume that UEs are static, and there is no retransmission if a UE fails to receive data. Using a bandwidth of 20 MHz, we are able to utilize a maximum NPRB of 110. We use 15 MCS indexes, each directly correlated to a CQI index with the calculation to find the MCS index is described in Appendix A.

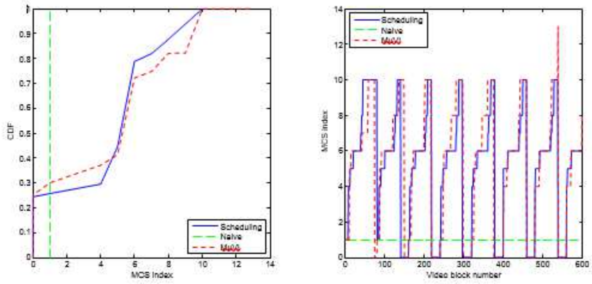
Table 5.2 shows the TB sizes for the 15 MCS indexes and the various NPRB values. To simulate the sending and receiving of multicast transmission, first we allocate video blocks to the transport blocks according to the MCS index assigned by the scheduling scheme. The RB resources inside a transport block are allocated using LTE Resource Allocation Type 2 [4]. We simulate the probability of successful transmission on each UE according to the simulation parameters, the path loss model and the macrocell propagation model. The path loss model which is taken from the LTE technical report is defined as: PL = 128.1 + 37.6 log10 (d), where d is the distance of a UE to the eNB in kilometers. Each UE then calculates its successfully received video blocks and reproduces the received video. We substitute video frames that are dropped or received past their deadline by copying the last received frame. Finally, we calculate the PSNR of the received video for each UE. Unless mentioned, we are using the default simulation parameter. We schedule the videos on a GOP basis. Since the test video is encoded at 30 frames per second, it needs 533.33 ms to send a GOP. The length of 1 TB is exactly 1 ms, therefore we set total TB T as 533. We repeat each set of tests more than 30 times and present the averaged results to present convincing results.

We used the Park Joy HD YUV sequence with a spatial resolution of 1280 by 720 pixels. Prior to the simulation, we encoded it as an SVC video that contains 31 GOPs with 16 frames per GOP. We use medium-grain SNR scalability for the quality scaling with quantization parameters of 38, 32, 28, 26, and 25, each for a base layer and 4 enhancement layers, respectively. The incremental quality of each video block is then obtained by analyzing the video. Afterwards, we model the incremental quality of each GOP as a non-linear function. The incremental quality models and the block size models for all 31 GOPs are listed on Appendices B and C.

We benchmark the CONMIQ scheme against a naive and a sub-optimal scheme. The Naive approach uses the highest MCS which can be supported by all users. The other scheme used for comparison is a sub-optimal scheme that utilizes recursive search called MuVi [5]. It uses recursive search to maximize its utility function, which consists mainly of two components. The first component, which is the number of users that could decode an MCS, is used similarly to our scheme for representation of users' channel condition. The second component is the number of video blocks that are dependent on that block, and it is used to represent the value of a video block. While MuVi is designed for scheduling non-scalable H.264 AVC video in a multicast transmission, we could easily adapt it for scalable video since the original approach uses H.264 temporal scalability. We can also change it to conform to the LTE standard with ease, since it is broadly designed for OFDMA.

We observe the performance of the schemes on the varying allocation of the number of PRB for each slot. We deploy users in a uniform distribution and adjust the number of PRB used in the test NPRB to 30, 60, and 90. The data throughput is defined by NPRB and the chosen MCS index. For example, the bit rate of the lowest MCS when using 60 NPRB is 1.595 mbit/s. On the other hand, the test video has the bit rate requirement of 1.9 mbit/s at its highest enhancement layer. Therefore, it is insufficient to allocate 60 NPRB with the lowest MCS index for transmitting the test video. We present 30 and 60 NPRB as representations of tight resource constraints, while 90 NPRB is a representation of abundant resources. Although in practice, it may be forbidden in the eMBMS specification to allocate more than 50% of the maximum PRB in a slot for multicast transmission.

We compare the performance of the schemes when users are randomly deployed on a normal distribution. We set the distribution's mean value to 150 and vary the standard deviation to a set of values = [10, 20, 30, 40, 50].For this test, we only used 60 NPRB. The result shows the average user-perceived PSNR. We identified that in this set of tests, the CONMIQ scheme also outperforms the Naive scheme in average PSNR, and also performs closer to the MuVi scheme. On standard deviation values between 30 and 40, CONMIQ even slightly outperforms the MuVi scheme, but the difference of only 0.1 dB may be insignificant.The utility function of MuVi does not focus on serving the best total video quality for all users. Rather, it gives priority to assigning a lower MCS index to the block with higher utility (i.e., the block with the higher dependent block count, which is mostly the base layer blocks). On the other hand, while CONMIQ resulted in a sub-optimal result, it directly aims to maximize the total perceived video quality for all users. Therefore, CONMIQ could achieve a similar performance to MuVi in this test. We also observe that all of the schemes perform best with a standard deviation value of 10 m. The Naive scheme works better in this case because the users are grouped closely and the MCS scheduled by the scheme is the best for most users. As the standard deviation value gets higher (i.e., users are more spread out), both the CONMIQ and MuVi schemes work a lot better than the Naive scheme. This shows that both of the schemes could adapt to changes in the position and the channel condition of users.



(a) (b)

Fig. 2. Microscopic observation of the uniform distribution test. (a) CDF of MCS index assignment per video block, and (b) the assigned MCS index for the first 600 video blocks.

We are also observing the average time needed to schedule each GOP for the CON-MIQ and MuVi schemes, shown in table 5.3. We observe that the schedule time for the CONMIQ scheme is exceedingly better than the MuVi scheme. This is due to the complexity of the MuVi scheme, which utilizes recursive search. We are aware that in the original publication, the authors of the MuVi scheme evaluated their scheme on each slot to minimize the complexity of the search space. However, we are confident that the CONMIQ scheme will produce the same result in a test environment similar to that of the MuVi publication. While the CONMIQ scheme has the same polynomial complexity as the MuVi scheme, we use a gradient-based method to solve the constrained non-linear problem, which minimizes the search space according to stopping and convergence criterion. Therefore, we can tune this criterion to approximate the best result with the smallest amount of computation time.

V. CONCLUSION

We present a packet scheduling scheme for the multicast transmission of a scalable video in the LTE network called CONMIQ. CONMIQ is designed to achieve the best total perceived video quality for all subscribed users, along with consideration of resource constraints. We incorporate the LTE channel feedback mechanism and the CQI index to adapt the MCS index assignment for each video block. The SVC video standard also provides a scale in video quality but poses a video block dependency problem. The incremental quality is introduced to measure the value of a video block by calculating the addition of PSNR value when it is successfully decoded. We model the incremental video quality of each block as a second-degree polynomial function and use the constrained non-linear optimization method to solve the scheduling problem. The video block dependency problem is also solved by sending the video blocks sorted on a layer basis and assigning MCS indexes in an increasing order. We benchmark our scheme with a naive approach and a sub-optimal solution which employs recursive search. Our performance evaluation shows that CONMIQ could perform as well as the sub-optimal solution while performing exceedingly faster than the sub-optimal solution.

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