Video Streaming Over Wireless LAN With Network Coding

Mo'taz Al-Hami, Abdallah Khreishah, and Jie Wu

***Abstract*—Client diversity is one of the main characteristics of wireless networks. Due to channel diversity, multicasting a video stream in a wireless LAN to multiple clients with different channel conditions is a challenging task. A promising approach for such a problem is to use multiresolution video coding (i.e scalable video coding) with network coding. In this paper, we study a triangular approach for network coding in a one-hop wireless LAN network. Previous work searches for all possible coding opportunities, which is computationally expensive. In this work, we use regression to derive efficient transmission protocols that take into account the delivery rate, as well as the variance of the channels. We show that the regression approach is more practical than the previous method. Also, the achievable rate using the regression approach can produce competitive results.**

***Keywords*-Multiresolution video streaming, network coding, inter-layer, intra-layer, video coding, regression.**

I. Introduction

Delivering media streams (i.e. YouTube video stream) over the Internet is becoming increasingly popular. Therefore, many approaches discuss the efficiency of delivering video over the Internet, how to generate video streams with different resolutions, and how to send these streams over the Internet. The use of different resolutions can efficiently satisfy different client characteristics, where clients with low channel conditions will receive low resolution streams, and clients with high channel conditions will receive high resolution streams.

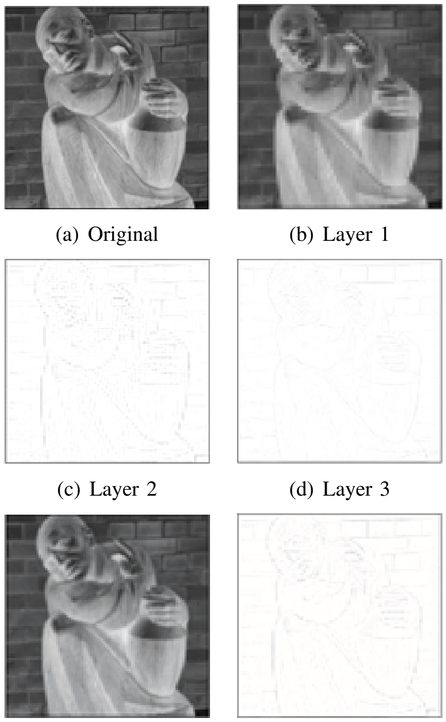
In general, end points of the Internet are wireless terminals, which adds more flexibility to the Internet. Many of these end points, like WiFi, connect different numbers of users, and support them with a shared medium to access the Internet.

In a wireless environment, where the client diversity property and shared medium exist due to the channel loss and broadcast nature, there are many approaches used to deliver the video stream to multiple clients. These approaches include unirate multicast, where only one rate stream is generated for multiple receivers. Using unirate multicast, some of the receivers with weaker channel conditions than the generated rate will starve, while other receivers with strong channel conditions are restricted to receive streams according to the generated rate [1]. Another approach is to share the transmissions among different resolutions (i.e. Multirate Multicast) which is suitable for wireline networks; in this approach the video stream is delivered to receivers using different rates [1]. However, this approach does not work well in wireless networks, due to the broadcast nature of the wireless links. The promising approach for delivering a video stream to multiple receivers in a wireless environment is to use multiresolution broadcast video stream or layered multicast, where the transmitted video stream is converted into multiple streams or layers with different resolutions [14].

Since the video stream consists of a sequence of video frames, each frame can be decomposed into multiple layers having different resolutions. According to this decomposition, the client diversity can be handled through decoding streams with different resolutions. In Multi-Resolution Coding (MRC) [3] the frame is decomposed into layered resolutions as shown in Fig. 1, where there is a basic layer and many refinement layers. The benefit of MRC is its ability to satisfy receivers with different channel conditions. In Fig. 1 Matlab wavelet toolbox is used to generate different layers with different resolutions. In MRC, the frequency of generated streams differs according to the layer level, which means substreams generated by the first layer have lower frequencies than substreams generated by the second layer, and substreams generated by the second layer have lower frequencies that substreams generated by the third layer.

(Fig. 1(a)) shows an original image, the constructed layers from this image (Fig. 1(b)-1(d)), and the effect of combining some of the layers together (Fig. 1(e)-1(f)). Layer 1 (i.e. basic layer) is the most important layer, and is necessary for any client to decode this layer. Layers 2 and 3 are considered to be refinement layers that increase the quality of the constructed image. On the other hand, adding layer 1 and layer 2 will increase the quality of the constructed image, while adding layer 2 and layer 3 alone, without layer 1, will drastically degrade the constructed image quality.

Another approach for multirate video streaming is Multiple-Description Coding (MDC) [7]. In this approach, the original video stream is encoded into independent substreams. If the receiver receives any of these substreams, then it will be able to reconstruct the video at a specific quality level; if the receiver receives more than one substream, the quality of the reconstructed video will increase. In general, in MDC, receiving any k layers is better than receiving any $(k-1)$ layers. The Peak Signal to Noise Ratio (PSNR) metric measures the quality of the reconstructed video stream. As the PSNR value increases, the quality of the video will increase. In general, if we use the same number of bytes to represent the layer in both MDC and MRC, the PSNR value for MRC will be higher than the PSNR value for MDC [2]. The work in [2] shows that with



(a) Original (b) Layer 1 (c) Layer 2 (d) Layer 3 (e) Layers 1+2 (f) Layers 2+3

Figure 1. Multiresolution Coding Using 3 Layers.

network coding in wireless LAN, MDC provides no benefit over MRC. Therefore, in this paper, we focus on MRC. Network coding is used to maximize network throughput by utilizing network capacity. One of the main benefits of network coding is its performance, especially in packet loss environment by increasing network throughput, and its flexibility to the losses [8]. Network coding supports the ability to share the bandwidth between nodes in a way that maximizes throughput [8], [4].

In random-linear network coding (RLNC), the source node forms linearly independent combinations of the packets [8]. The coding coefficients are selected randomly from a finite field of large size [5]. The following represents a motivating example, showing the effect of network coding on network throughput. If we assume a given wireless LAN network with lossy channel having throughput equal to Packet Delivery Rate (PDR) from the base station to the receiver equal to 0.5, this means half of the sent packets can be received by the receiver. we will assume the frame deadline is 6 time slots (i.e. after 6 time slots the frame is meaningless), and the number of packets per layer is equal to 1. In this example, we use MRC. Without network coding and using the round robin manner, the packets will be sent according the following order: $L_1, L_2, L_3, L_1, L_2, L_3$. If the channel is active through slots 3, 5, and 6, then the receiver will receive L_3, L_2, L_3; this makes the receiver unable to decode any layer, because layer 1 is not received. Let us compare the round robin approach with the following triangular network coding approach: instead of sending L_i in the round robin approach, we send a random linear combination of all the layers below, including L_i. In this case, if the channel is active in slots 3, 5, and 6, then the receiver is able to receive a linear combination of the coded packets, according to triangular scheme $\alpha_1 L_1 + \beta_1 L_2 + \gamma_1 L_3$, $\alpha_2 L_1 + \beta_2 L_2$, and $\alpha_3 L_1 + \beta_3 L_2 + \gamma_3 L_3$. From this, the receiver will have received 3 linearly independent combinations with 3 variables, and it becomes able to decode the original 3 layers. Network coding can be classified into two categories, inter-layer coding, and intra-layer coding.

Intra-Layer Network Coding: In this scheme, coding occurs on packets from the same layer. So, if we assume that k packets are coded together, then by receiving any k linearly independent combined packets, the receiver will be able to decode this layer. The power of Intra-layer network coding is its ability to maximize the throughput where the channels are lossy, because we do not need to receive any specific set of packets [12].

Inter-Layer Network Coding: In this scheme, packets from different layers can be combined together, and each layer is dependent on all lower layers [9]. The power of inter-layer network coding is its ability to deal with clients' diversity, and its ability to allow them to decode different number of layers, according to their channel conditions. In this paper, we combine inter and intra-layer coding to utilize their benefits jointly. The rest of this paper is organized as follows. The related works are discussed in Section II. Problem formulation is introduced in Section III. The triangular coding schemes are described in Section IV. Our approach is discussed in Section V. Section VI introduces performance analysis. Finally the conclusion is in Section VII.

II. Related Work

There are many previous studies related to video streaming. Video streaming with MRC has been studied in [3], [10]. The work in [3] includes a study that uses realistic feedback on the same unreliable channel. The idea behind this work is that when the server sends a generation of coded packets (i.e. coded packets related to a GOP), then it starts loss recovery process, in order to recover lost packets. Realistic feedback is sent back from receiver nodes to the server in order to minimize the amount of unnecessary transmissions for recovering lost packets.

Other studies use video streaming with MDC [7], [6]. For example, the work in [7] employs MDC using optimized rate allocation algorithm to minimize overall distortion. The work uses set partitioning in hierarchical trees (SPIHT) algorithm to generate a convenient video stream that uses adaptive bit-rate according to the network conditions. Any rate changes in the network can be accommodated by dropping unnecessary packets from the generated stream.

Many other studies, like [14], [13] study video streaming in wireless environments. The approach proposed in [13] focuses on minimizing the congestion experienced by video stream by jointly allocating link capacity and traffic flow. The work uses cross layer design framework that aims to support maximum data rates and yields minimum end to end delay.

There are many other studies that focus on using network coding with video streaming [12]. In [12], the approach focuses on multicasting video stream using network coding in a polynomial time. The proposed scheme uses layered coding for multirate multicasting using network coding. At the same time, some approaches like [14], use video streaming without using network coding. The paper reviews cross layer design approaches like transmission rate adaptation, and channel time assignment among different streams. The approach used in [9] uses triangular schemes to code video stream with multiresolution coding.

III. Problem Formulation

In this paper, we consider a video stream as a sequence of packets such that they have a deadline of X transmissions (i.e. the number of transmissions that Access Point can send within a deadline) in one-hop wireless LAN. Also, we assume the existence of loss on channel, and we assume a bernoulli channel. In this case, our problem is finding the best way (i.e. strategy) of distributing these X transmissions among L layers that enable heterogeneous receivers with different channel conditions to decode as many layers as possible in a one-hop, wireless LAN environment. Throughout this work, we will show the effect of channel variance on the decoding process, and we will try to figure out how to maximize the throughput under these environment conditions. In addition to that, we will discuss many scenarios of receivers.

IV. Triangular Coding Schemes

In video coding, a video stream is partitioned into a sequence of pictures referred to as Group of Pictures (GOP) [11]. The typical duration of GOP is 1 to 2 seconds. Each GOP consists of pictures or frames, and this GOP is divided into a sequence of segments, Q. If we assume video stream to have a constant bit rate, then the number of packets per GOP is constant throughout the stream [2]. The value of Q (i.e. the number of packets per segment) depends on video streaming rate [9]; and in general it is a large value. Therefore, the segment Q is further partitioned into N partitions, where N represents the number of packets per segments per layer. Under these schemes, GOP is encoded into L layers, as shown in Fig. 2, where each layer has a substream with different resolution for the same GOP; each layer consists of a fixed number of packets [2]. Triangular network coding makes the decoding process more flexible than RLNC, and instead of having full cardinality coded

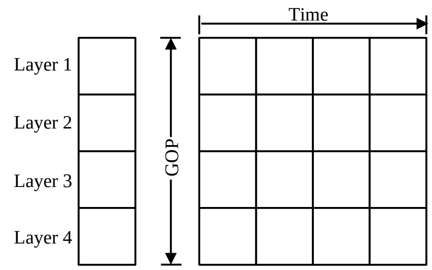


Figure 2. Encoding Group of Pictures on Layers.

X	Strategy	N	PDR	Received Packets	Decoded Layers
64	[32,32,0,0]	8	0.25	[8,8,0,0]	2
64	[32,32,0,0]	8	0.25	[7,9,0,0]	2
64	[32,32,0,0]	8	0.25	[9,7,0,0]	1
64	[32,32,0,0]	8	0.25	[7,7,0,0]	0
64	[32,32,0,0]	8	0.25	[9,9,0,0]	2

Table I
ABILITY TO DECODE LAYERS BASED ON RECEIVED TRANSMISSIONS ON EACH LAYER.

packets (i.e. full square matrix) to decode the whole layers, it allows the coded packets to deal with partial layers from 1 to L to decode layers from 1 to L only. The structure of triangular network coding supports common prioritization, where the basic layer has more priority than the upper layers.

In inter-layer network coding, any layer i depends on all previous layers (i.e. layers $1, .., (i-1)$) to decode this layer [3]. Triangular schemes consider only L ways of coding packets from L layers, where the k^{th} way is coding packets from the first k layers, for $k \in 1..L$. The Access Point (AP) can send as many transmissions as X within the frame of a deadline corresponding to NL packets for L layers. In this work, to solve our problem, we consider all possible triangular schemes which are denoted as $(x_1, .., x_l)$, where $\sum_{i=1}^{L} x_i = X$, and x_i denotes the number of packets that are used to code the first i layers [18]. The unique possible ways of assigning X transmissions into L ways of generating the coded packets are equal to $\binom{X-1+L}{L-1}$ [9].

V. Our Approach

A. *Effect of Choosing Value N*

Throughout this work, we study the effect of choosing different values of N on the decoding process, and the effect of any value of N on the achievable rate, at which packets are received on each receiver. We define the achievable rate at which packets are received on any receiver, as:

$$R = \frac{L \cdot N}{X} \qquad (1)$$

Different values of N can result in different achievable rates, so we focus on finding the value of N that maximizes the achievable rate.

B. Variance Problem

Calculating the received packets out of each strategy by using $PDR{\cdot}x_i$ for all layers, where x_i represents the number of packets transmitted on layer i, is a roughly inaccurate process, because it does not reflect the actual case. Fig. 3 shows the actual throughput and the ideal throughput, so any analysis should consider the actual throughput rather than the ideal one. Fig. 3 was obtained by comparing the ideal case (i.e. the case where there is no variance property, and at the same time all received packets participated in the decoding process) and the actual case where we used triangular optimal algorithm [9].

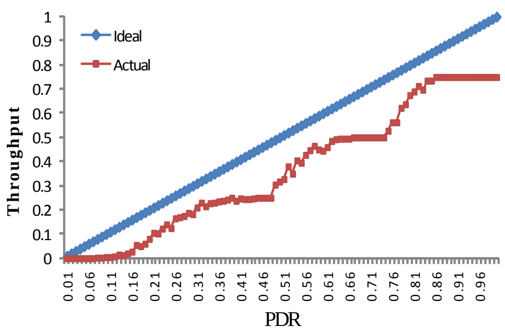


Figure 3. Comparison Between Actual Throughput and Ideal One for One Receiver.

Channel variance has a major effect on the ability to decode layers, and can affect the achievable rate at which a receiver can decode layers. For example, in Table I, we notice that there is a probability to receive different numbers of packets on each layer. For strategy $[32, 32, 0, 0]$, 64 transmissions are distributed equally among the first two layers only. In the case of no-variance property, if the receiver PDR is 0.25 then this receiver will receive $[8, 8, 0, 0]$ where 8 packets are received on the first two layers; if $N = 8$, then this receiver is able to decode the first two layers. The problem occurs under the channel-variance environment, where the receiver has different probabilities of receiving different numbers of transmission on each layer. This affects the decoding process, based on how much is received on each layer. For example, there is a chance to receive packets $[9, 7, 0, 0]$; in this case, the receiver is able to decode the first layer only. The variance problem makes the process of calculating the number of decoded layers not trivial.

C. Expected Throughput

To alleviate the variance problem effect, we should find the characteristics of the strategy, and the choice of N that generates the maximum throughput. This can be done when the X transmissions are distributed among many layers, or uses only one layer.

For one-layer case: Our task is to find the best N value for given PDR, which means that we want to find the value of N where a given receiver can get higher throughput as often as possible. Since receiving N transmissions out of the original X transmissions happens with probability:

$$P[N] = \sum_{i=N}^{X} \binom{X}{i} \cdot PDR^i \cdot (1 - PDR)^{X-i} \qquad (2)$$

Then, we can find the expected throughput for each value of N ranging from $[1..X]$ given PDR and the original X transmissions value such that:

$$E[N] = \sum_{i=N}^{X} \binom{X}{i} \cdot PDR^i \cdot (1 - PDR)^{X-i} \cdot N \qquad (3)$$

For multiple-layers case: In this case, the original X transmissions are distributed among several layers, so our task is to find the strategy and N value for a given PDR value that generates the maximum expected throughput. At the same time, we should consider the decoding criteria for any reception outcome. For any reception outcome $(y_1, ..., y_L)$, the receiver can decode first i layers if:

$$\sum_{j=i}^{i-k} y_j \geq (k + 1) \cdot N, \quad \forall \ k \in [0, i - 1] \qquad (4)$$

Based on this decoding criteria, we want to find the value of N, and the strategy, that satisfies the decoding criteria. We also aim to generate the maximum expected throughput. For this, we extended eq. 3 for the multiple-layers case; for any given strategy $[x_1, .., x_L]$, the expected throughput $E[N]$ is such that:

$$\sum_{y_i \leq x_i} \prod_{i=1}^{L} \binom{x_i}{y_i} \cdot PDR^{y_i} (1 - PDR)^{x_i - y_i} \cdot B \cdot N$$
$$s.t. \sum_{j=B}^{B-k} y_j \geq (k + 1) \cdot N, \quad \forall \ k \in [0, B - 1] \qquad (5)$$

In eq. 5, B represents the number of decoded layers. The eq. 5 is calculated for all strategies, and the strategy with maximum expected throughput is chosen as the best strategy. Using eq. 5, we can find the expected throughput for each value of N given the equation parameters like PDR, original X transmissions value, and the original number of layers L, which is equal to 4 layers. Based on the generated results, we can determine the best choice of the value N, and the actual number of layers used in distributing the X transmissions. One more thing we have to mention here is how to distribute the X transmission among these actual layers. In this approach, we used majority voting, based on generated results, to decide how to distribute X transmissions among actual L layers.

D. Applying Regression

Until this point, we constructed the expected throughput table, which contains the value of N that maximizes the

No of Receivers	N and L Regression Equations
1	$N = \lfloor(-0.199999999999999 + 9.09090909090909 * PDR)\rfloor$ $L = \lfloor(2.46666666666667 - 0.121212121212122 * PDR)\rfloor$
2	$N = \lfloor(-0.66 - 5.333 * PDR1 + 9.2727 * PDR2)\rfloor$ $L = \lfloor(3.2 + 0.242 * PDR1 - 0.36363 * PDR2)\rfloor$
3	$N = \lfloor(-1.052380 - 0.90 * PDR1 - 1.83982 * PDR2 + 7.229437 * PDR3)\rfloor$ $L = \lfloor(3.63809 + 0.2813 * PDR1 - 0.84415 * PDR2 - 0.02164 * PDR3)\rfloor$
4	$N = \lfloor(-1.42857 - 3.67965 * PDR1 + 1.55844 * PDR2 + 2.66233 * PDR3 + 3.57142 * PDR4)\rfloor$ $L = \lfloor(3.7619 + 0.90 * PDR1 - 0.974 * PDR2 - 0.99567 * PDR3 + 0.47619 * PDR4)\rfloor$
5	$N = \lfloor(-1.10476 - 2.36363 * PDR1 - 3.24242 * PDR2 + 3.757 * PDR3 + 4.212 * PDR4 + 0.757 * PDR5)\rfloor$ $L = \lfloor(3.85714 + 1.36363 * PDR1 + 0.2121 * PDR2 - 1.969 * PDR3 - 0.03 * PDR4 + 0.333 * PDR5)\rfloor$

Table II
REGRESSION EQUATIONS EXTRACTED THROUGH EXPECTED THROUGHPUT ANALYSIS.

expected throughput for given PDR value, as well as the strategies used to produce the maximum expected throughput. We apply a regression technique in an attempt to extract equations that approximate the relationship between PDR, N, and L for given X transmissions. Since the running time is a critical issue for finding the optimal strategy, as in the case of optimal method used in [9], the running time increases drastically as the number of transmissions increase. Simultaneously, a strategy table is used to calculate the decoded layers for each strategy. In the regression approach there is no need to keep any table; all that we need is to use regression equations directly to calculate the required N and L. Based on these values, we adopt a given strategy. The main influence in regression approach regarding running time makes it more practical to implement and adopt. Table II shows the extracted equations through the regression approach. These generated values of N can be assigned as decoding criteria N(packets/layer) for their associated PDR values. Therefore, any receiver that has a given PDR value can use the related N as a required number of receptions on that layer. To detect the performance of regression technique, we applied the regression equations directly to the simulator, which is prepared using Matlab, we then compared our results with optimal technique, which is used in [9].

VI. PERFORMANCE ANALYSIS

In this section we show the performance analysis of our proposed approach, using regression technique. The performance analysis focuses on the achievable rate. Achievable rate is defined as the number of decoded packets per time unit. The performance of the achievable rate varies according to the number of receivers. Since the regression technique constructs a linear function that fits the dependent variables with a minimum sum of squared errors, the constructed linear function will not achieve results like optimal approach. Regardless, it will still achieve very good rates when compared with the optimal approach. We use PDR values ranging from 0.1 to 1.0, with increments of 0.1.

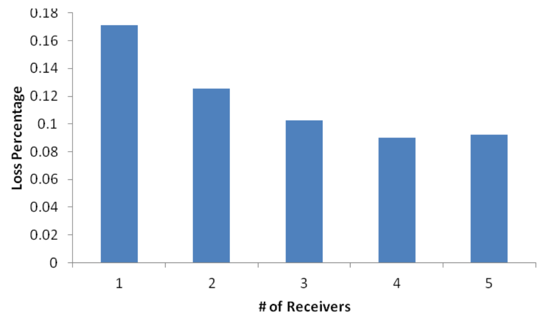


Figure 4. Comparing Loss Percentage for Different Receivers to Optimal Approach.

The results in Fig. 4 show the average loss percentage in the regression approach, compared to the optimal approach for $X = 16$ transmissions. The objective function here is to maximize the total achievable rate at all receivers. The results show that the loss percentage does not exceed 0.18 for one receiver, and does not exceed 0.1 for 5 receivers. According to this graph, as the number of receivers increases, the average percentage of loss rate decreases. This is due to the diversity of PDR values in the optimal approach. Fig. 5 compares the achievable rate ratio between regression approach and optimal approach for different numbers of receivers, using the empirical CDF function for each case. In general, the graph is biased toward the right, which means the ratio is approaching 1.0 for a majority of PDR values. For example, the median of the PDR values achieves a rate with more than a 0.9 ratio between the regression approach and the optimal approach for 2 or more receivers.

In Fig. 6, we changed the objective function from maximizing the total throughput to a different objective, achieving proportional fairness among the receivers. The weight of the proportional fairness given to each receiver is proportional to the PDR value for that receiver. The results show degradation in the regression approach, where the loss amount is 0.18 for one receiver, and its maximum value occurred for 4 receivers. It reached to nearly 0.50 and 0.43 for five receivers. This means the proportional fairness objective is difficult to approximate using linear equations.

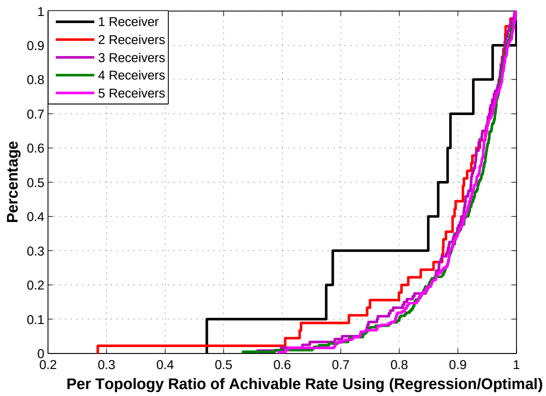


Figure 5. Empirical CDF for the Different Topologies and Different Numbers of Receivers.

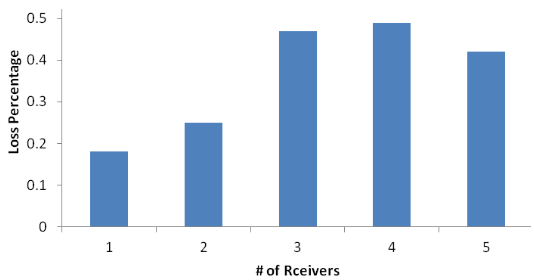


Figure 6. Comparing Loss Percentage for Different Receivers to Optimal Approach Using Proportional Fairness.

VII. CONCLUSION

In this paper, we present video streaming over wireless LAN, and we describe the problem for many receivers with different channel conditions. Previous work in [9] showed many triangular coding schemes, including the optimal scheme, that requires constructing a table to calculate the number of decoded layers for each strategy; this is found to be time-consuming. We study the effect of choosing the number of frames per layer on the total achievable rate, and we analyze this relationship. Using regression technique, we try to find an equation that controls the relationship between PDR value, the most appropriate number of frames per layer, and the number of used layers. The results show that the regression technique is a practical approach of distributing X transmissions over L layers when the objective is to maximize the total rate, because there is no need to construct any table like previous optimal approach [9]. This does not work directly when the objective is proportional fairness. The work in this paper opens the door for different future research problems (1) studying the effect of choosing different values of frames per layer on different layers, (2) trying different approximation techniques to solve this problem; this includes relaxation and integer programming.

REFERENCES

[1] S. Dumitrescue, M. shao, and X. Wu. Layered multicast with inter-layer network coding. In *28th IEEE Conference on Computer Communications (INFOCOM)*, Apr 2009.

[2] R. Gandhi, M. Yang, D. Koutsonikolas, Y. Hu, M. Comer, and A. Mohammad. The impact of inter-layer network coding on the relative performance of MRC/MDC WiFi media delivery. In *21st International Workshop on Network and Wperating Systems Support for Digital Audio and Video (NOSSDAV)*, Jun 2011.

[3] S. Gheorghiu, L. Lima, J. Barros, and A. Toledo. On the performance of network coding in multi-resolution wireless video streaming. In *IEEE International Symposium on Network Coding (NetCod), CA, USA*, Jun 2010.

[4] M. Halloush and H. Radha. Network coding with multi-generation mixing: analysis and applications for video communication. *IEEE/ACM Transactions on Wireless Communication*, 10(2):466 – 473, 2011.

[5] T. Ho, M. Medard, R. Koetter, D. Karger, M. Effros, J. Shi, and B. Leong. A random linear network coding approach to multicast. *IEEE/ACM Transactions on Information Theory*, 52(10):4413–4430, 2006.

[6] J. Kim. Layered multiple description coding for robust video transmission over wireless ad-hoc networks. In *Proceedings of World Academy of Science, Engineering, and Technology (PWASET)*, 2006.

[7] J. Kim, R. Mersereau, and Y. Altunbasak. Network-adaptive video streaming using multiple description coding and path diversity. In *International Conference on Multimedia and Expo (ICME)*, Jul 2003.

[8] R. Koetter and M. Medard. An algebraic approach to network coding. *IEEE/ACM Transactions on Networking*, 11(5):782–795, 2003.

[9] D. Koutsconikolas, Y. Hu, C. Wang, M. Comer, and A. Mohammad. Efficient online WiFi delivery of layered-coding media using inter-layer network coding. In *International Conference on Distributed Computing System (ICDCS), USA*, Jun 2011.

[10] L. Lima, J. Barros, M. Medard, and A. Toledo. Secure network codig for multi-resolution wireless video streaming. *IEEE Journal on Selected Areas in Communications*, 28(3):377–388, 2010.

[11] Z. Liu, Y. Shen, S. Panwar, K. Ross, and Y. Wang. Using layered video to provide incentives in P2P live streaming. In *ACM Workshop on Peer to Peer Streaming and IP-TV, NewYork, NY, USA*, Aug 2007.

[12] N. Sundaram, P. Param, and S. Banerjee. Multirate media streaming using network coding. In *43 Annual Allerton Conference on Communication, Control, and Computing, Monticello, Il, USA*, Sep 2005.

[13] T. Yoo, E. Sehon, X. Zhu, A. Goldsmith, and B. Giord. Cross-layer design for video streaming over wireless ad hoc networks. In *IEEE 6th workshop on Multimedia Signal Processing*, Sep 2004.

[14] X. Zhu and B. Jiord. Video streaming over wireless networks. In *European Signal Processing Conference (EUSIPCO)*, Sep 2007.