An Efficient Resource Allocation Scheme for Scalable Video Multicast in LTE-Advanced Networks

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ABSTRACT

We address the challenge of optimizing the radio resource allocation for scalable video multicast over LTE-Advanced. The advantage of multicast service is to utilize the available bandwidth efficiently in delivering the same content to multiple receivers. However, the instantaneous channel condition of each receiver in the multicast group varies independently. To guarantee all receivers experiencing similar performance becomes more challenging. Hence, we need an advanced radio resource management to guarantee the least quality of service levels. In this paper, we propose a novel heuristic strategy which aims to jointly optimize the frequency selectivity, adaptive modulation and coding, and random linear network coding scheme performed at Medium Access Layer. The key aspect is that our proposal enhances the reliability of video services by exploiting random linear network coding in LTE-Advanced. Moreover, the available bandwidth is utilized efficiently by taking the advantage from the frequency selectivity in subgroup formation. We do various simulations for performance evaluation. The results show that our proposed resource allocation outperforms the existing studies regarding resource load, spectral efficiency, recovery probability and the attainable video quality (i.e., peak signal-to-noise ratio).

CCS Concepts

•**Communications → Networking/Telecommunications** ; *Mobile multimedia QoS;*

Keywords

Scalable Video Multicast; Resource Allocation; Network Coding

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1. INTRODUCTION

Scalable video coding (SVC) is an extension of the H.264 (MPEG-4 AVC) video compression standard [1]. The SVC is capable of generating multiple video bitstreams that consist of a base layer (BL) and several enhancement layers (ELs). The BL contains the information of the typical video quality, and the ELs carry refinement information. Receivers can achieve the video quality corresponding to the number of decoded video layers (i.e., associated with the experiencing channel condition). Since the SVC can provide the scalability, numerous research studies select the SVC as a solution for many transmission scenarios such as multicast services [2], heterogeneous networks [3], and unreliable networks with bandwidth fluctuation [4].

Cisco VNI Forecast reported that the video traffic would be 82 percent of all consumer traffic by 2020 [5]. Multicast service has been considered as a promising solution for the explosion of the video data traffic. The Third Generation Partnership Project (3GPP) has standardized the Multimedia Broadcast/Multicast Service (MBMS) and Evolved MBMS (eMBMS) through an LTE (Long Term Evolution) network since 3GPP releases 6 [6] and 9 [7]. As multiple users request the same video content, the base station, or eNB, only uses one available channel for transmission instead of multiple point-to-point communications. However, since the instantaneous channel state of each user varies independently, the guarantee of quality of service (QoS) for all users becomes more challenging. The multicast applications are typically resource-hungry [3]. Hence, an advanced radio resource management (RRM) needs to be utilized for multicast services.

An advanced RRM can increase the system performance up to the Shannon limit [8]. The numerous studies exploited the RRM in Orthogonal Frequency-Division Multiple Access (OFDMA)-based systems for scalable video multicast [2, 3, 9]. We can classify into three categories: conservative [2], opportunistic [4, 9], and subgrouping [3, 10, 11]. The conservative strategies select a single modulation and coding scheme (MCS) aiming to the worst channel state for broadcasting [2]. Hence the performance of the multicast group is bounded by the cell-edge users (i.e., the worst channel quality). The opportunistic strategies dynamically select the MSCs within each scheduling frame [4, 9]. The method of selecting the MCS is based on the objective cost function such as spectral efficiency or throughput [4] or the threshold-based solutions [9]. Lastly, the subgrouping strategies are based on multi-rate approaches [10, 11]. To solve the bottleneck issue from cell-edge users, the multicast group is divided into multiple subgroups in which each member experiences similar channel condition. The scheduling strategy applies to each subgroup individually. The subgrouping strategy can adopt the advantage of the SVC. The subgroup with bad channel condition can decode the BL, on the other hand, the subgroup with good channel condition can decode more ELs [10]. However, Deb *et al.* [11] proved that finding the optimal subgroup configuration with the maximization/minimization of a given objective function is an NP-hard problem.

On the other hand, the random linear network coding (RLNC) provides the advantage of removing the effect of loss order in multicast services [12]. The UE can decode the transmitted stream as receiving a sufficient number of coded symbols (i.e., the full rank of the coefficient matrix is satisfied) [13]. For instance, assume that each UE loses a symbol, and the loss position differs between UEs. We need two different original symbols for error-resiliency while the use of only one network-coded symbol is enough. The network-coded symbol is the combination of two loss original symbols. The UE can efficiently perform Gaussian Elimination for decoding with low complexity [14]. Since the RLNC enables the reliability with fewer resources, the bandwidth efficiency increases. The RLNC has attracted many studies on jointly the RLNC and resource allocation for improving the performance of the multicast services [15–18]. Zhang *et al.* [16] proved that the joint of RLNC and resource allocation (RA) in OFDMA network could achieve the robust performance with different throughput requirements. Khirallah *et al.* [17] proposed the Random Network Coding (RNC)-based Medium Access Control (MAC) protocol. The authors showed that the RNC-MAC protocol introduces simplicity and flexibility required for future LTE-A while improving the performance for single-hop macro-cellular scenarios. Recently, the joint of RLNC and RA for scalable video multicast has been investigated in [18]. The authors addressed the subgrouping strategy, in which the multicast group is split into multiple subgroups by the multicast area. The heterogeneous groups of users can receive the layered video streams at the predefined quality and progressively decreasing service levels according to their locations with the base station.

In this paper, we also address the challenge of optimizing the radio resource allocation for scalable video multicast over LTE-Advanced using RLNC-MAC protocol. Differ to [18]; we perform the subgrouping strategy based on the channel quality indicator (CQI) indexes, which are feedbacks from users [3]. Furthermore, the proposed scheme guarantees all members in the multicast group can achieve the typical video quality. Also, the number of users experiencing better attainable video quality is maximized by receiving the enhancement layers as many as possible. Specifically, our contributions are as follows:

- We design a resource allocation strategy that not only minimizes the resource load but also improve the video quality under strict time and resource constraints.
- The proposed scheme addresses well the characteristic of the inter-dependent SVC layers. When the important BL is corrupted, the less important ELs must be dropped whether they are decoded successfully. We treat the SVC layers with different protection in descending order starting from the BL.
- We do various simulations for performance evaluation with four metrics: resource load, spectral efficiency, recovery probability and video quality measurement (i.e., peak signal-to-noise ratio). The simulation results show that our resource allocation outperforms the recent studies.

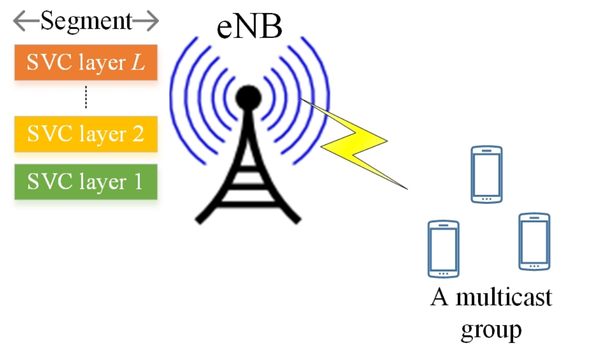

Figure 1: System model.

The remainder of this paper is organized as follows. We describe system model and a short background on LTE-A resource allocation handled by the packet scheduler in Section 2. The description of the RLNC-MAC protocol is presented in Section 3. In Section 4, we present our proposed resource allocation strategy. Furthermore, we evaluate the system performance regarding the resource load, spectral efficiency, recovery probability, and video quality measurements compared to other schemes in Section 5. Finally, we conclude this paper in Section 6.

2. SYSTEM MODEL AND PRELIMINARY

Figure 1 depicts a single-cell LTE/LTE-A video multicast, in which an eNB broadcasts the scalable video network-coded packets to a group of User Equipments (UEs). Each UE experiences independent and identically distributed channel state. We assume that UE distribution follows a uniform distribution of cell radius r. Let d be the distance between the eNB and UE. The signal-to-interference-plus-noise ratio (SINR) at the UE is calculated as follows [17]:

$$\begin{aligned} SINR(d) = P_{TX} + G_{TX} + G_{RX} - N_{RX} - I \\ -PNL - S(d) - PL(d), \end{aligned} \quad (1)$$

where P_{TX} is the eNB transmission power; G_{TX} and G_{RX} are the eNB and UE antenna gains, respectively; N_{RX} and I are noise figure and interference from other transmissions, respectively; PNL is the wall penetration loss for indoor UEs; $S(d)$ and $PL(d)$ are the shadowing loss and the pathloss at the distance d.

2.1 Scalable Video Coding

Layered video compression encodes a video sequence into L multiple SVC layers which consist of a base layer (i.e., SVC layer 1) and $L-1$ enhancement layers [1]. The BL is the

Table 1: CQI values versus the number of coded symbols per an RB (symbol size of 4 bytes) [18]

CQI Index	MCS	Code Rate	$f(\cdot)$	SINR (dB)
1-3	No Tx	-	-	< -1.25
4	QPSK	0.3	2	-0.94
5	QPSK	0.44	3	1.09
6	QPSK	0.59	4	2.97
7	16QAM	0.37	5	5.31
8	16QAM	0.48	6	6.72
9	16QAM	0.6	8	8.75
10	64QAM	0.45	10	10.47
11	64QAM	0.55	12	12.34
12	64QAM	0.65	14	14.37
13	64QAM	0.75	16	15.94
14	64QAM	0.85	18	17.81
15	64QAM	0.93	20	20.31

most important layer; the enhancement layers are multiple inter-dependent layers with less importance. Let g_{GOP} and f_{GOP} be the number of pictures within a group of pictures (GOP) and the video frame rate, respectively. The time duration of a GOP is as follows:

$$t_{GOP} = \frac{g_{GOP}}{f_{GOP}}. \tag{2}$$

Since the time duration of a GOP is typically greater than the transmission time interval (i.e., TTI of 1 ms). For instance, we encode the video content with $g_{GOP} = 16$ frames and $f_{GOP} = 30$ frames per second (fps), the time duration of a GOP is 0.53 s. Obviously, we can not use a TTI to deliver the video data of a GOP. The packet scheduler needs to divide the GOP stream into multiple segments for transmission (i.e., depicted in Fig. 1). Let $\mathcal{V}_l$ be a set of original video symbols for transmission associated to the l^{th} SVC layer of a TTI of 1 ms. The number of original symbols in the l^{th} SVC layer is as follows:

$$\big|\mathcal{V}_l\big| = \left\lceil \frac{R_l \times TTI}{SS} \right\rceil, \tag{3}$$

where $\big|\cdot\big|$ denotes the number of elements of the set; R_l is the video bitrate of the l^{th} SVC layer; and SS is symbol size. All symbols are fixed size.

2.2 LTE/LTE-A Resource Allocation

The LTE/LTE-A resource allocation is handled by packet scheduler [8], which composes of a time domain and a frequency domain schedulers. The time domain packet scheduler selects the transmission flows at each scheduling frame. On the other hand, the frequency domain packet scheduler allocates each scheduled flow to the sufficient number of resource blocks (RBs) at each transmission time interval of 1 ms (TTI). Each RB contains 12 consecutive sub-carriers with an equal bandwidth of 15 kHz in the frequency domain and lasts 0.5 ms in the time domain [3]. In our paper, we exploit the frequency selectivity to address the challenge of minimizing the number of allocated RBs for transmission (i.e., bandwidth efficiency).

Let $\mathcal{N}$ be a set of available resources in a subframe of 1 ms. Depending on the channel bandwidth configuration, $\big|\mathcal{N}\big|$ can vary from 12 (i.e., the bandwidth of 1.4 MHz) to 200 (i.e., the bandwidth of 20 MHz). Note that; a subframe of 1 ms conveys two RBs. We consider the case of fixed length symbols. Since the symbol lengths are fixed but the RB capacities are variable depending on the modulation and coding scheme (MCSs) assigned. Hence, the number of symbols in each RB is variable. As we assign higher MCS for an RB, the number of carried symbols increases, but the loss rate also increases. Let $f(\cdot)$ be a function of channel quality indicator (CQI) index which returns the number of carried symbols per an RB corresponding to the CQI index. The UEs update their CQI indexes every scheduling subframe. Table 1 denotes the list of all possible cases of the CQI index, MCSs, code rate, and the number of carried symbols (i.e., $f(\cdot)$) corresponding to channel state allocated for an RB at the physical layer (PHY) in the LTE/LTE-A.

Table 2: Commonly used notation.

Notation	Definition
$\mathcal{K}$	Set of users in multicast group
$\mathcal{C}$	Set of admissible CQI levels
$c_{k,n} \in \mathcal{C}$	CQI index of user k on the n^{th} resource block (RB)
m_n	The index of the modulation and coding scheme assigned for the transmission over the n^{th} RB
L	The number of scalable video layers
$\mathcal{V}_l$	Set of information symbols associated to the l^{th} SVC layer of a TTI of 1 ms
$v_{i,l}$	The i^{th} original symbols associated to the l^{th} SVC layer, with $i = 1, ..., \|\mathcal{V}_l\|$
$\hat{\mathcal{V}}_l$	Set of encoded symbols for transmission associated to the l^{th} SVC layer of a TTI of 1 ms
$\hat{v}_{j,l}$	The j^{th} coded symbols associated to the l^{th} SVC layer, with $j = 1, ..., \|\hat{\mathcal{V}}_l\|$
R_l	Bitrate of the l^{th} SVC layer
$\mathcal{N}$	Set of available resources in a subframe of 1 ms
$\mathcal{N}_l$	Set of allocated resources associated to the l^{th} SVC layer
$\widetilde{\mathcal{N}}_l$	Set of candidates for resource allocation strategy associated to the l^{th} SVC layer
$\big\|\cdot\big\|$	The number of elements of the set
$f(\cdot)$	A function of CQI index which returns the number of coded symbols per an RB corresponding to the CQI index
$p_{k,n}$	The PHY block loss rate of a user k associated to the n^{th} RB
$P_{k,l}$	The successful probability that a user k decodes successfully the first l SVC layers

Let $\mathcal{K}$ be a set of users in a multicast group; $\mathcal{C}$ be a set of admissible CQI levels; $c_{k,n}$ be the CQI index of user k on the n^{th} resource block (i.e., $k \in \mathcal{K}$ and $n \in \mathcal{N}$) reported in the CQI feedback from UE; m_n be the index of MCS assigned for the transmission over the n^{th} RB; finally, let $p_{k,n}$ be the PHY block loss rate of user k associated to the index of assigned MCS m_n. Since eNB can not be aware of the exact value of $p_{k,n}$. To address this issue, we set $p_{k,n}$ as folows:

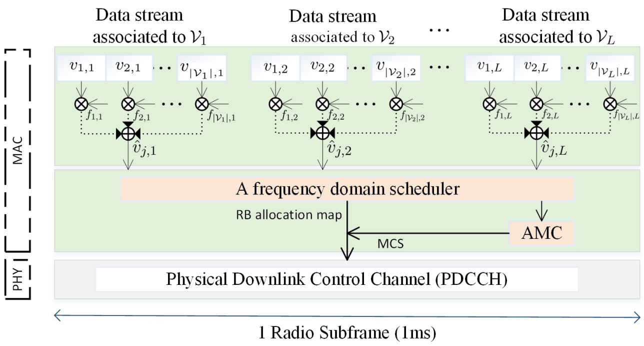

Figure 2: A part of the LTE/LTE-A protocol stack with RLNC embedded at the MAC layer.

$$p_{k,n} = \begin{cases} p_e & \text{if } m_n \leq c_{k,n},\ m_n,\ c_{k,n} \in \mathcal{C} \\ 1 & \text{otherwise,} \end{cases} \tag{4}$$

where p_e is the target block error probability (BLER) (i.e., commonly $p_e = 0.1$ [18]). As we assign the MCS for the n^{th} RB with index smaller than the CQI index $c_{k,n}$ of user, the error probability will be treated as the target BLER. For clarity, we list the commonly used notations in Table 2.

3. RLNC-MAC PROTOCOL

Figure 2 presents a part of the LTE/LTE-A protocol stack with RLNC embedded at the MAC layer. Note that; $\mathcal{V}_l$ is a set of original video symbols associated to the l^{th} SVC layer of a TTI of 1 ms, and $|\mathcal{V}_l|$ is determined by (3).

$$\mathcal{V}_l = \{v_{i,l} : v_{i,l} \in \mathcal{V} \big| 1 \leq i \leq |\mathcal{V}_l|, l = 1, ..., L\}, \tag{5}$$

where $v_{i,l}$ is the i^{th} original symbols associated to the l^{th} SVC layer. The Packet Data Conversion Protocol (PDCP) and Radio Link Control (RLC) layers forward the data stream of each SVC layer to the MAC layer. We modify the MAC layer with the RLNC operation. The original video symbols of each layer is encoded individually. The network-coded symbols of the l^{th} SVC layer is a linear combination of all original video symbols in the l^{th} SVC layer presented as follows:

$$\hat{v}_{j,l} = \sum_{i=1}^{|\mathcal{V}_l|} f_{i,l} \times v_{i,l}, \tag{6}$$

where $f_{i,l}$ is a coding coefficient generated uniformly at random over a finite field GF(q) of size q using Random Number Generator (RNG). We assume that the RNG seed is synchronized at receivers[18]. There is no standard method for selecting field size, but there are majority of works that consider a Galois field size of 8 to guarantee linear independence with very high probability [12]. Without loss of generality, we assume the RNG can perfectly generate the linearly independent coding coefficients. Let $\hat{\mathcal{V}}$ be a set of coded symbols used for transmission, hence a set of coded symbols associated to the l^{th} SVC layer is written as follows:

$$\hat{\mathcal{V}}_l = \{\hat{v}_{j,l} : \hat{v}_{j,l} \in \hat{\mathcal{V}} \big| 1 \leq j \leq |\hat{\mathcal{V}}_l|, l = 1, ..., L\}. \tag{7}$$

Typically, the RLNC multicast scheme generates a stream of coded symbols greater than the stream of original symbols [18] (i.e., $|\hat{\mathcal{V}}_l| \geq |\mathcal{V}_l|$). Since the receiver only decodes the coded stream as the coefficient matrix is satisfied, otherwise the receiver decodes nothing. We present the method to select the number of coded symbols that satisfies the QoS constraint in Section 4. The eNB uses the CQI information for making a decision of resource allocation. The AMC module assigns the best MCS used for transmission of network-coded symbols. The MAC layer sends the information about allocated RBs and the assigned MCSs to UEs on the Physical Downlink Control Channel (PDCCH). Each UE reads the payload of PDCCH and accesses to the payload of the proper Physical Downlink Shared Channel (PDSCH).

4. PROPOSED RESOURCE ALLOCATION

The objective design of the resource allocation that minimizes the number of allocated RBs for transmission (i.e., spectral efficiency), subject to constraints on a lower bound on the quality of service levels can be written as follows:

$$\min_{\{\mathcal{N}_l \subseteq \mathcal{N},\ m_l \in \mathcal{C}\}} \sum_{l=1}^{L} |\mathcal{N}_l| \tag{8}$$

subject to:

$$\textstyle\sum_{l=1}^{L} |\mathcal{N}_l| \leq |\mathcal{N}|, \tag{9}$$

$$U_{TH,l} \leq {}^{|\mathcal{U}_l|}/_{|\mathcal{K}|},\ l = 1, ..., L, \tag{10}$$

$$U_{TH,l+1} \leq U_{TH,l},\ l = 1, ..., L-1, \tag{11}$$

$$P_{TH,l+1} \leq P_{TH,l},\ l = 1, ..., L-1, \tag{12}$$

where $\mathcal{N}_l$ is a set of resources allocated for the l^{th} SVC layer; $\mathcal{U}_l$ is a set of satisfied UEs that can decode the first l SVC layers. $U_{TH,l}$ is the threshold ratio of the number of satisfied UEs associated with the l^{th} SVC layer to the total number of UEs (i.e., $0 \leq U_{TH,l} \leq 1$). The $\mathcal{U}_l$ can be defined as follows:

$$\mathcal{U}_l = \{k : k \in \mathcal{K}_{l-1} \big| P_{k,l} \geq P_{TH,l}\}. \tag{13}$$

where $P_{TH,l}$ is the given threshold probability that guarantees the UE achieves the attainable video quality of the first l SVC layers. Since each RB experiences the target error probability of p_e and each SVC layer uses the same MCS m_l for transmission. The probability that a UE achieves the attainable video quality of the first l SVC layers using the MCS m_l is as follows:

$$P_{k,l} = \prod_{i=1}^{l} \sum_{j=|\mathcal{V}_l|/f(m_l)}^{|\mathcal{N}_l|} \binom{|\mathcal{N}_l|}{j} p_e^{(|\mathcal{N}_l|-j)} \times (1-p_e)^j, \tag{14}$$

to guarantee each SVC layer meets the target QoS levels, the eNB needs to send the $|\mathcal{N}_l|$ RBs to satisfy the condition $P_{k,l} \geq P_{TH,l}$.

The objective (8) is to minimize the number of transmitted RBs. Constraint (9) ensures that the number of allocated resource should not exceed the available bandwidth resources. Constraint (10) guarantees the receivers achieve the predefined video quality (i.e., the lower bound on the QoS levels). An average number of satisfied UEs associated to the first l SVC layers is not smaller than a threshold value. Since the SVC layers are inter-dependent, when the important BL is corrupted, the less important ELs must be dropped whether they are decoded successfully. Hence, constraints (11) and (12) ensure that the SVC layers are treated with different protection in descending order starting from the BL (i.e., $l = 1$).

We propose a novel heuristic resource allocation which aims to jointly optimize the frequency selectivity, AMC, and RLNC scheme performed at the MAC layer (HRA-NC). The outputs are sets of allocated resources corresponding to each SVC layer and the assigned MCSs for each SVC layer m_l. The proposed heuristic strategy consists of two phases: 1) the algorithm finds the maximum MCS indexes over all available resources, this meets the constraints (10) and (11); 2) resource allocation assigns the optimal MCS for each SVC layer to increase the perceived video quality as much as possible depending on the available resources and channel condition, this meets the constraints (9) and (12).

Algorithm 1 FindMaxMCS

Input: $\mathcal{K}$, $\mathcal{N}$, $\mathcal{C}$ and $c_{k,n}$
Output: m_n

1: **procedure**
2:     **for** all $n \in \mathcal{N}$ **do**
3:         **for** $t \leftarrow |\mathcal{C}|$ to 4 **do**
4:             $U_t = \sum_{k=1}^{|\mathcal{K}|} I(c_{k,n} \geq t)$
5:             **if** $^{U_t}/_{|\mathcal{K}|} \geq U_{TH,l}$ **then**
6:                 $m_n \leftarrow t$
7:                 **break**;
8:     **return** m_n

Algorithm 1 summarizes the procedure for finding the maximum MCS indexes over all available resources named FindMaxMCS, where $I(\cdot)$ is the indicator function, i.e., $I(\cdot) = 1$ if the statement is true, otherwise $I(\cdot) = 0$. At each RB, the FindMaxMCS finds the maximum MCS index that satisfies the constraints (10) and (11) (lines 3–7). The algorithm is run in linear time with the complexity of $\mathcal{O}(|\mathcal{N}||\mathcal{C}|)$.

Algorithm 2 summarizes the procedure for the SVC allocation which guarantees all UEs achieving the predefined video quality and also improves the spectral efficiency. Based on the collected CQI indexes from UEs, the algorithm computes the maximum MCS index of each available RB (i.e., m_n) using the Algorithm 1 (line 3). Let m_l be the MCS index assigned for delivering the l^{th} SVC layer. The iteration for the assignment of each SVC layer starts from lines 5 through 17. Since the HRA-NC returns the minimum number of RBs, the iteration starts from the largest MCS index in line 4 (i.e., $|\mathcal{C}|$). At each iteration, the HRA-NC determines the candidate sets of resources that satisfy the condition $m_n \geq m_l$, where $\widetilde{\mathcal{N}}_{t,l}$ is set of candidates for resource allocation strategy associated to the l^{th} SVC layer. Then the HRA-NC finds the minimum number of RBs that satisfies the constraint (12) using the expression (14) in line 9. The iteration stops when the minimum number of RBs is found (line 17). If almost UEs experience the bad channel condition, we can not find the solution because all resources with the predefined maximum MCSs can not carry enough number of coded symbols for the SVC layer (line 10). In this case, the HRA-NC assigns the smallest MCS in line 11 (i.e., $m_l = 4$) and increases the m_n index by 1. If the MCS index reaches the maximum CQI index, the MCS index will be

Algorithm 2 Scalable Video Layer Allocation

Input: $\mathcal{K}$, $\mathcal{V}_l$, $\mathcal{N}$, $\mathcal{C}$ and $c_{k,n}$
Output: m_l and $\mathcal{N}_l$

1: **procedure**
2:     **for** $l = 1 \rightarrow L$ **do**
3:         Compute m_n using the Algorithm 1
4:         $t \leftarrow |\mathcal{C}|$
5:         **repeat**
6:             $m_l \leftarrow t$
7:             $t \leftarrow t - 1$
8:             $\widetilde{\mathcal{N}}_{t,l} = \{n : n \in \mathcal{N} | m_n \geq m_l\}$
9:             Find $|\mathcal{N}_l|$ that satisfies $P_{k,l} \geq P_{TH,l}$
10:             **if** $|\widetilde{\mathcal{N}}_{t,l}| < |\mathcal{N}_l|$ and $t = 3$ **then**
11:                 $m_l \leftarrow 4$
12:                 **repeat**
13:                     $m_n \leftarrow m_n + 1$, $m_n \leq |\mathcal{C}|$
14:                     $\widetilde{\mathcal{N}}_{t,l} = \{n : n \in \mathcal{N} | m_n \geq m_l\}$
15:                     Find $|\mathcal{N}_l|$ that satisfies $P_{k,l} \geq P_{TH,l}$
16:                 **until** $|\widetilde{\mathcal{N}}_{t,l}| \geq |\mathcal{N}_l|$
17:         **until** $|\widetilde{\mathcal{N}}_{t,l}| \geq |\mathcal{N}_l|$
18:         Update $\mathcal{N}_l = \min_{\widetilde{\mathcal{N}}_{t,l} \subseteq \mathcal{N}} \widetilde{\mathcal{N}}_{t,l}$
19:         Update $\mathcal{N} = \mathcal{N} \setminus \mathcal{N}_l$
20:     **return** m_l and $\mathcal{N}_l$

assigned to the maximum CQI index (line 13). This process in lines 12–16 repeats until the solution is found. Finally, the HRA-NC selects the candidate with the minimum RBs and updates the available resources $\mathcal{N}$ in lines 18–19. As seen, the algorithm is run in linear time with the number of finite steps. The complexity of the code in line 3 and lines 5–17 are $\mathcal{O}(|\mathcal{N}||\mathcal{C}|)$ and $\mathcal{O}(|\mathcal{C}|^2)$, respectively, where $|\mathcal{N}|$ is the number of available resources; $|\mathcal{C}|$ is the total number of MCS indexes. Since $|\mathcal{N}|$ is typically greater than $|\mathcal{C}|$). Hence the overall complexity of the whole algorithm is equal to $\mathcal{O}(L|\mathcal{N}||\mathcal{C}|)$.

5. PERFORMANCE EVALUATION

We investigate the performance evaluation of the HRA-NC in this section. We consider a single-hop cellular network. The eNB broadcasts the coded video streams scheduled by the proposed resource allocation to UEs. To evaluate the effectiveness of the proposed HRA-NC, we compare it against the resource allocation idea proposed in [18] (HMr-NC) and the multi-rate transmission-based strategy (MrT) [2] with four performance metrics: 1) resource load; 2) spectral efficiency; 3) recovery probability; 4) average maximum PSNR.

Since we exploit the frequency selectivity within a subframe of 1 ms. The HMr-NC problem can be restated as follows:

$$\min_{\{\mathcal{N}_l \subseteq \mathcal{N}, m_l \in \mathcal{C}\}} \left\{ \sum_{l=1}^{L} |\mathcal{N}_l| \middle| m_{l+1} < m_l, P_{TH,l} \leq P_{MA,l} \right\}, \tag{15}$$

where $P_{MA,l}$ is the probability that a user can decode the first l SVC layers in the multicast area of the l^{th} layer. The HMr-NC provides the capability of unequal error protection by assigning the lower MCS to the higher important layer (i.e., constraint $m_{l+1} < m_l$). The multicast area is defined based on the assumption that UE distribution follows a Poisson point process.

Table 3: **Simulation parameters.**

Parameter	Value
System bandwidth	5 MHz
Carrier frequency	2.0 GHz
Transmission power	46 dBm
Antenna gains	eNB: 14 dBi, UE: 0 dBi
Antenna Height	eNB: 30 m, UE: 1.5 m
Penetration loss	20 dB
Radio frequency propagation model	Okumura-Hata model
Shadowing	Standard deviation: 7 dB
Noise figure	7 dB
$U_{TH,l}$	$U_{TH,1}$: 0.9; $U_{TH,2}$: 0.7; $U_{TH,3}$: 0.5
$P_{TH,l}$	$P_{TH,1}$: 0.99; $P_{TH,2}$: 0.95; $P_{TH,3}$: 0.9
$\mathcal{N}$	50 RBs
H.264/SVC video stream	News CIF with $L = 3$
Video bitrate (Mbps)	R_1: 2.45; R_2: 2.45; R_3: 7.35
The highest PSNR (dB)	ρ_1: 31.6; ρ_2: 37.4; ρ_3: 43.7
GOP	16 frames
Frame rate	30 fps

The MrT optimization problem can be restated as follows:

$$\arg\max_{\{m_l \in \mathcal{C}\}} \{m_l \big| U_{TH,l} \leq {}^{|\mathcal{U}_l|}/_{|\mathcal{K}|}\}. \quad (16)$$

The MrT splits the multicast group into multiple subgroups. The transmission rate of each subgroup is constrained to the user experiencing the worse channel state in the subgroup. To increase the QoS, the MrT uses 50% redundancy (i.e., the MrT selects each symbols for retransmission with the probability of 50%) to reduce the target BLER from 0.1 to 0.055 (i.e., the target successful probability of each RB increases from 0.9 to 0.945).

We run the simulation with the transmission range of 300 m. At each step, the user distribution follows the uniform distribution with the distance d and 100 UEs. The distance represents the channel condition. UEs are closed to the eNB experiencing the good channel condition, otherwise for UEs far from the eNB. Note that; the SINR at the UE is defined as (1). Table 3 describes the main simulation parameters.

First, we define the resource load index as follows:

$$\eta = \frac{\sum_{l=1}^{L} |\mathcal{N}_l|}{|\mathcal{N}|}, \quad (17)$$

where $\sum_{l=1}^{L} |\mathcal{N}_l|$ is the radio resource footprint of the allocation strategy. Figure 3 shows the performance of the resource load versus distance. The proposed HRA-NC outperforms the other schemes followed by HMr-NC and MrT. The number of allocated resources almost keeps the same within the range of 220 m since the UEs experience the good channel condition. There are not much variation of the channel states among UEs. On the other hand, when the channel condition is getting worse (i.e., UEs are far from the eNB). The allocated resources increase since the eNB needs to send more data for UEs to guarantee the lower bound on QoS levels. Overall, the HRA-NC shows better performance compared to others regarding the minimum number of RBs (i.e., the design objective of the resource allocation is achieved).

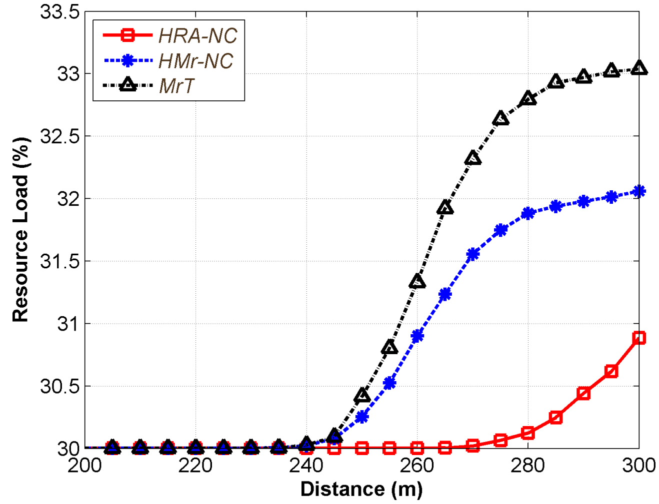

Figure 3: Resource load versus distance.

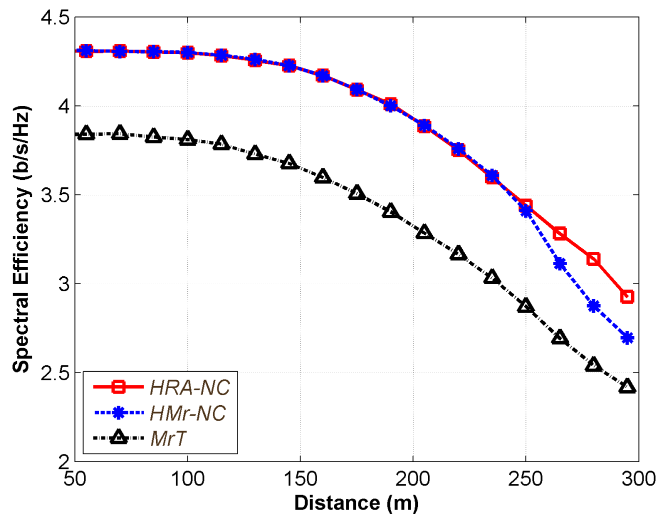

Figure 4: Spectral efficiency versus distance.

Second, though the proposed scheme achieves the best performance regarding the resource load, it is important to evaluate the effectiveness of the HRA-NC regarding the corresponding QoS levels of the SVC layers, we do the performance evaluation with the index of spectral efficiency as follows:

$$\eta_E = \frac{TTI \times \sum_{l=1}^{L} R_l \times P_l}{B \times \sum_{l=1}^{L} |\mathcal{N}_l|}, \quad (18)$$

where B is bandwidth of each RB; $P_l = \frac{\sum_{k=1}^{|\mathcal{K}|} P_{k,l}}{|\mathcal{K}|}$ is the average probability that a user decodes the first l SVC layers. Figure 4 shows that the HRA-NC achieves the best spectral efficiency followed by HMr-NC and MrT schemes. The better performance indicates that the resource allocation utilizes the bandwidth efficiently. The proposed scheme not only achieves the minimum number of allocated resources but also satisfies the lower bound on QoS levels. The HRA-NC can provide the significant improvement when there are many UE devices experience the bad channel condition.

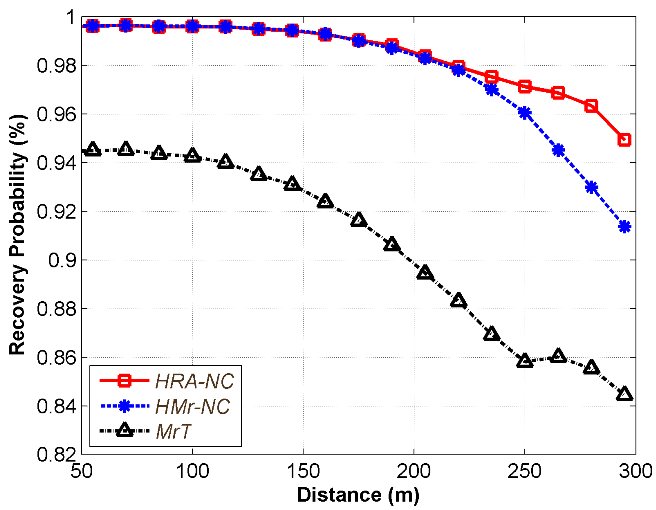

Figure 5: Recovery probability of the base layer versus distance.

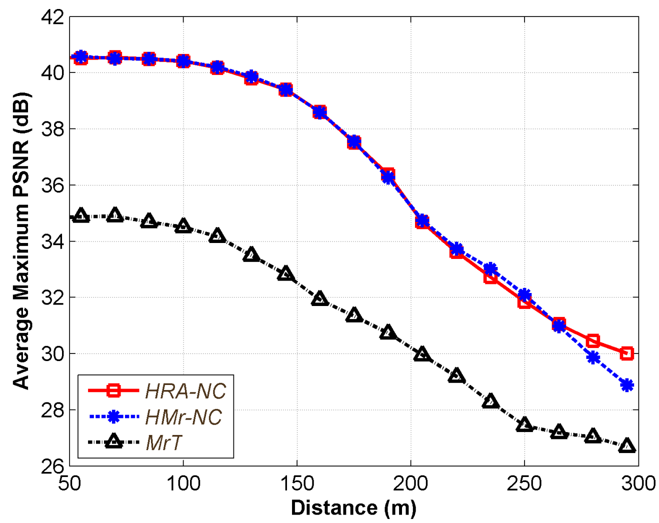

Figure 6: Average maximum PSNR versus distance.

Third, we evaluate the recovery probability that a UE decodes the BL. The better recovery probability denotes the higher number of UEs experiencing the typical video quality. Figure 5 shows that the HRA-NC is also better performance than the other schemes followed by HMr-NC and MrT, respectively. The HRA-NC and HMr-NC outperform the MrT because of the RLNC-MAC protocol. The RLNC enables the reliability of transmission when many UEs are especially experiencing the bad channel condition. The RLNC can remove the effect of loss order in the multicast scenario since each UE only needs to receive a sufficient number of coded symbols.

Last, we measure the video quality in terms of PSNR, widely used for video quality measurement [18], with the sequence video titled News (i.e., more setting parameters is presented in 3). Let ρ_l be the highest PSNR achieved by a user after recovering the first l SVC layers. The maximum achievable PSNR is defined as follows:

$$\hat{\rho}_k = \max_{l=1,\ldots,L} \{\rho_l \times P_{k,l}\}. \quad (19)$$

Note that; $P_{k,l}$ is the recovery probability that a UE k decodes successfully the first l SVC layers. As shown in Fig. 6, HRA-NC achieves the best performance, followed by HMr-NC and MrT. Also, the results also indicate that the HRA-NC can provide full high-resolution video quality with the bandwidth efficiency (i.e., the minimum number of UEs) to all UEs in the multicast group. Overall, the HRA-NC and HMr-NC can provide quite a similar video quality. Nonetheless, the proposed scheme achieves better performance of the resource load, spectral efficiency as many UEs experiencing the bad channel condition (i.e., Figures 3 and 4). Furthermore, the HRA-NC increases the number of UEs that experience the typical video quality as shown in Fig. 5.

6. CONCLUSIONS

In this study, we proposed a novel heuristic resource allocation which aims to jointly optimize the frequency selectivity, AMC, and RLNC scheme performed at the MAC layer. The objective design of the resource allocation that minimizes the number of transmitted RBs (i.e., spectral efficiency), subject to constraints on a lower bound on the quality of service levels. The simulation results showed that our proposed resource allocation achieves the design objective since almost all of the UEs satisfy the video quality with high-resolution and smooth playback with the bandwidth efficiency (i.e., the minimum number of RBs). The performance outperformed the recent studies in terms of resource load, spectral efficiency, recovery probability and average maximum peak signal-to-noise ratio of the video. In future work, we plan to extend our scheme to the case of multiple video streams.

7. ACKNOWLEDGMENTS

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