# A Packet Prioritization Scheme for 3D-HEVC Content Transmission over LTE Networks

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***Abstract*—Long Term Evolution (LTE) has been standardized at the 3GPP since 2008 and targets the delivery of high data rate services with strict quality-of-service (QoS) requirements. It is now the fastest ever growing mobile technology and is gradually becoming the mainstream radio access technology used in cellular networks. The latest video coding standard, High Efficiency Video Coding (HEVC), achieves higher compression rate than its predecessor Advanced Video Coding (AVC) and for the same level of quality uses almost 50% less bandwidth. HEVC is the leading video compression technology that will be used to deliver high-definition (HD) and ultra-high-definition (UHD) video content to users. Extensions of HEVC, such as 3D-HEVC, are now being developed and standardized by MPEG to deliver 3D video content. The current issues with LTE include its lack of awareness regarding the type of packets being transmitted, and their importance to the end user. The aim of this paper is to investigate the performance of 3D-HEVC over LTE networks using metrics such as packet loss ratio and average user throughput. We also propose a cross-layer solution in the form of a packet prioritization scheme to help provide better quality-of-experience (QoE) to users and demonstrate its advantages over a baseline scheme that is not QoE-aware.**

***Keywords—LTE; 3D-HEVC; Cross-Layer Design; Video Streaming.***

## I. Introduction

Ever since Long Term Evolution (LTE) has been deployed as the state-of-the-art radio access technology for cellular networks, mobile traffic has been growing at an unprecedented rate. Recent studies indicate that the biggest portion of the IP traffic will be comprised of video data, and consumer video-on-demand (VoD) traffic will be doubled by 2018 [1]. This poses challenges to both the wireless telecommunication industry and encoder vendors, as radio spectrum is a scarce and expensive resource. Therefore, there is a need for further advancements in radio access technologies to enable high data rate delivery for next generation services. In parallel to these advancements, efficient video compression technologies will be sought after to restrain the ever-growing need for high data rate and to reduce the load on cellular networks.

LTE and its successor LTE-Advanced raised the theoretical peak downlink data rate to 1 Gbps through use of various features such as carrier aggregation and enhanced multiple-input and multiple-output (MIMO). However, this rate might not always be achievable due to imperfect wireless medium conditions. Moreover, the content format has been evolving parallel to the compression technology to provide consumers with a profound experience and stronger immersiveness. These advancements, in turn, typically imply a larger data volume. For example, a multiview plus depth (MVD) video sequence requires a higher data rate than a single view (2D) video.

The High Efficiency Video Coding (HEVC) [8] standard achieves much higher compression rates than H.264/AVC [13] by using advanced and very elaborate predictive techniques, which helps reduce the volume of encoded data. However, such levels of compression also make packet loss more detrimental, as losing encoded data may affect larger areas of a frame or multiple frames, leading to increased error propagation in the decoding process of a video sequence. Especially when the content is in MVD format, the state-of-the-art 3D-HEVC standard supports further prediction between different views, creating highly dependent and layered coding structures. Beyond this vulnerability to potential packet losses, the lack of redundancy also hampers the error concealment attempts. It is, therefore, critical that the radio access technology accounts for these drawbacks when transmitting encoded video data.

A media aware node can help fulfill the application level requirements under adverse network conditions by allowing interactions between application layer and lower layers. There have been several studies on cross-layer techniques for video content in the literature. However, to the best of our knowledge, there is no prior work exploiting the interactions between LTE and 3D-HEVC for improving the performance of MVD video streaming. In this paper, we propose a content-aware packet prioritization scheme that can utilize the readily available information in the application layer. We devise a media aware eNodeB, which can analyze a 3D-HEVC encoded bitstream, and adapt the modulation and coding scheme (MCS) according to the type of the network abstraction layer (NAL) units. We evaluate the proposed method using packet loss ratio and average user throughput.

The rest of the paper is organized as follows: we outline our system model and provide background information on LTE and 3D-HEVC in Section II. Section III elaborates on the details of the proposed packet prioritization scheme. In Section IV, the simulation results that demonstrate the efficacy of the proposed prioritization scheme are presented. Concluding

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remarks and possible future research directions are presented in Section V.

## II. Overview of LTE and HEVC

This section provides background on LTE technology, the HEVC standard and its 3D extension.

### A. *Long Term Evolution*

LTE is the fastest growing cellular telecommunication technology worldwide. Its successor LTE-Advanced is presently being rolled out by carriers around the world. LTE's radio access technology is based on OFDMA for the downlink and SC-FDMA for the uplink. It offers high data rates, low latency, and packet-optimized architecture in order to support flexible bandwidth deployments ranging from 1.4 MHz to 20 MHz. LTE also supports innovative transmission schemes using MIMO systems and employs both frequency division duplex (FDD) and time division duplex (TDD). LTE offers link adaptation based on channel state information (CSI) feedback and uses hybrid-ARQ to transmit the transport blocks [2]. The 3GPP (Third Generation Partnership Project) standard has adopted an implicit feedback framework for CSI reporting in LTE since Release 8, in which the user equipment (UE) sends CSI reports comprised of rank indication (RI), precoding matrix indicator (PMI) and channel quality indicator (CQI). RI is reported by analyzing the characteristics of the wireless channel [3], PMI report is conditioned on the selected RI, and the CQI report is conditioned on the selected RI and PMI [6]. The content of a CSI report depends on the transmission mode being used and the CSI reporting parameters set by the serving cell. For more details, we refer the readers to [6].

The MAC layer scheduler manages the allocation of radio resources to UEs for data transmission. One of the most common scheduling policies used in wireless systems is the proportional fair scheduling policy [2]. The proportional fair scheduling metric for $m^{th}$ user in $n^{th}$ subframe can be expressed as follows:

$$m(n) = \arg\max_{m=1\ldots M} \frac{[R_m(n)]^{\alpha}}{[T_m(n)]^{\beta}} \tag{1}$$

where $m$ is the user index, $n$ is the subframe index, $R_m(n)$ is the data rate for the $m^{th}$ user in the $n^{th}$ subframe, $T_m(n)$ is the average data rate for the $m^{th}$ user in a past window of a given length, $\alpha$ and $\beta$ parameters are used to tune the fairness of the scheduling metric. Typically, $\alpha$ and $\beta$ are both one. MAC layer scheduler is also responsible for receiving packets from the higher layers and passing them to the physical layer by reorganizing the data into transport blocks.

### B. *High Efficiency Video Coding*

HEVC is the latest video compression technology that was jointly standardized by MPEG (Moving Picture Experts Group) and ITU-T (Telecommunication Standardization Sector of International Telecommunication Union). It can achieve bit rate reductions of up to 50% over its predecessor H.264/AVC. It benefits from a combination of new modes and tools such as adaptive block sizes, and filters. HEVC partitions pictures into coding tree blocks (CTBs) of size $2^N \times 2^N$ with $N \in \{4,5,6\}$ for luma component. These blocks can further be split into coding blocks (CBs), which are in turn split into transform blocks (TBs) and prediction blocks (PBs). Two types of predictions are used depending on the type of the picture; intrapicture prediction and interpicture prediction; and along with these, advanced motion vector prediction and merge mode are introduced for further efficiency. In interpicture prediction, the motion vectors are used to predict and compensate for the motion between pictures. In intrapicture prediction, the spatial information of an area is used to predict the pixels values of a different region within the same frame. Frames are split into slices that are independently encoded from each other. Slices consists of sequences of CTUs. All NAL units carrying slices of the same picture collectively constitute an access unit and all the access units corresponding to a video sequence form a bitstream [4]. The output of an HEVC encoder is a bitstream that contains the compressed data of the video sequence in decoding order, which can be different from the output order in most cases.

MPEG is currently working towards the standardization of 3D-HEVC, which is an extension of the HEVC standard for 3D applications. With the use of sophisticated depth coding tools, 3D-HEVC separates itself from MV-HEVC (Multiview-HEVC), which is another extension of the HEVC standard for multiview applications. 3D-HEVC is designed for efficient compression of MVD content. In MVD format, one or multiple texture videos are compressed along with their associated depth maps. There are several techniques to create such content, but the most commonly used ones are 1) capturing with multiple cameras at different viewpoints, and generating depth maps by using advanced depth estimation algorithms, 2) using special cameras that can capture the depth information of a scene. By using one or multiple videos and their depth maps, it is possible to generate additional views using depth-image-based rendering (DIBR) techniques [9]. In the context of 3D-HEVC, each texture and depth video is carried in so-called layers. The combination of a texture video and its associated depth map is referred to as a view. Access units from each layer are multiplexed such that all corresponding NAL units of each time instance are sent in decoding order. Important information about a NAL unit can be obtained by parsing its header. As shown in Fig. 1, the NAL unit header is two bytes long, where the first bit is always equal to "0", the next six bits specify the NAL unit type whose values can be found in the HEVC specification [4,8], and the following six bits represent NAL unit layer id that indicates which layer the NAL unit belongs to. The last three bits of the header carry the temporal id and specify the temporal layer the video sequence belongs to.

```
+---------------+---------------+
|0|1|2|3|4|5|6|7|0|1|2|3|4|5|6|7|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|F|   NALType   |  LayerId  | TID |
+-------------+-----------------+
```

Fig. 1. NAL unit header structure

## III. Proposed Method

Content-awareness is certainly one of the most essential enablers of high QoE delivery. Yet, most commercially deployed cellular systems lack content-aware technologies and network elements. The 3GPP standard supports a very limited form of QoS management for video streaming which only considers timing requirements, irrespective of the nature, size and content of the packets being transmitted [7]. As mentioned in Section II, a 3D-HEVC bitstream consists of multiple layers carrying NAL units of various types and different importance levels. In this section, we briefly describe the high level syntax of 3D-HEVC compression standard and detail our packet prioritization scheme that is designed to unevenly reduce the packet loss depending on the perceptual importance of packets of a 3D-HEVC bitstream.

### *A. NAL units in 3D-HEVC*

A syntax structure is the logical entity of the information that is being coded in the bitstream in the form of NAL units. This information can be parameter sets, supplemental information or slices. NAL units are split into two classes: Video Coding Layer (VCL) NAL units and non-Video Coding Layer (non-VCL) NAL units. Parameter sets are carried inside non-VCL NAL units whereas slices and CTUs are carried inside VCL NAL units. Examples of non-VCL NAL units are Video Parameter Set (VPS) NAL units, Sequence Parameter Set (SPS) NAL units and Picture Parameter Set (PPS) NAL units. Non-VCL NAL units carry basic parameters which are used by the HEVC decoder to perform its decoding task. Some of the basic parameters that can be found in an SPS are the CTB size, the CB size, the TB size, reference picture sets, which the HEVC decoder must have in order to perform decoding correctly. VCL NAL units typically carry Coded Slice Segment (CSS) information for intra-coded pictures (I-frames), for uni-predicted pictures (P-frames) or bi-predicted pictures (B-frames). Depending on the nature of the picture, VCL NAL units have different headers: for instance there are Random Access Point pictures, Leading pictures and Trailing pictures. By only analyzing the NAL unit header, the information inside a NAL unit can be known prior to its transmission. In our packet prioritization scheme for 3D-HEVC over LTE, this information is used to provide an efficient yet computationally attractive solution.

Several types of NAL units are defined in [8]. I-frames are typically carried inside so-called Instantaneous Decoding Refresh Random Access Decodable Leading (IDR_W_RADL) NAL units or Clean Random Access (CRA) NAL units. Leading Pictures preceding an I-frame are carried inside so-called Random Access Skipped Leading (RASL) NAL units. There are RASL_R or RASL_N NAL units, depending on whether the encoded frame is referenced by another frame in the video sequence or not. Trailing Pictures are carried inside TRAIL NAL units. There are TRAIL_R and TRAIL_N NAL units depending on whether the encoded frame is referenced by some other frame within the video sequence or not.

### *B. Proposed Prioritization Scheme*

The baseline scheme simply packs NAL units inside transport blocks on a first-come-first-served basis. MAC layer scheduler is not aware about the types of the NAL units being sent, so it just sends whichever NAL units are available at the time of scheduling. The problem with this approach is that, for instance, there may be NAL units belonging to I-frames that need to be sent, but are left to wait because other NAL units were ahead of them in the queue. In order for dependent frames to be decoded, the 3D-HEVC decoder needs to have all the referenced pictures.

In our proposed prioritization scheme, the LTE system is aware of the structure of the bitstream generated by the 3D-HEVC encoder, therefore in our system model the MAC layer scheduler has the ability to send NAL units based on the layer it belongs to and the information it carries as indicated by its header. Our system model also allows the LTE system to select the MCS depending on the type of the NAL unit that is being transmitted. As per the 3GPP standard, UEs send CSI reports with CQI values tuned to a target block error rate of 10%. However, the CSI reports sent by UEs are merely recommendations for the LTE network and the MAC layer scheduler has the final say on what kind of transmission scheme, what kind of MCS and consequently what transport block size will be used for transmission for a given UE. I-frames only use intrapicture prediction and any P-frames or B-frames that follow may use I-frames as reference for motion prediction and derive motion vectors. Losing NAL units that carry encoded data from I-frames would, therefore, have a very detrimental impact on the decoding process, as all pictures that reference the I-frame whose NAL units were lost will not be decoded correctly; therefore such NAL units must be treated with great care. Conversely, NAL units carrying information from pictures that are not referenced by any other will not result in any error propagation in the decoding process, and thus it is reasonable to classify such NAL units as less important.

In our proposed prioritization scheme, non-VCL NAL units are sent using QPSK modulation. This is a very conservative choice and reflects the fact that control parameters for the 3D-HEVC decoder are transmitted with very high protection against errors. For such NAL units, we use any MCS that uses QPSK up to $I_{MCS} = 9$. For all the bitstreams we generated, we used periodic CRA NAL units to send I-frames, thus transmitting them with a lower MCS than the one reported by the UE in order to lower its retransmission probability and offer a stronger protection against possible channel fluctuations. For all other NAL units, we use the MCS recommended by the UE and NAL units from lower layers are sent before proceeding to NAL units from higher layers. For a given layer, we first send NAL units belonging to I-frames, followed by Leading pictures and Trailing pictures. The proposed prioritization scheme is described by the pseudo-code algorithm shown in Fig. 2.

## IV. Experimental Results

In order to evaluate the performance of our proposed prioritization scheme, four MVD video sequences from the 3DV Call for Proposals by MPEG were used: Lovebirds, Balloons, Kendo and Newspaper [14,15]. For encoding these test videos, we used the 3D-HEVC encoder reference software, *HTM 12.0* [11]. For our simulation purposes, the 3D-HEVC encoder was configured in such a way that it used only one slice per frame, thus resulting in a bitstream that contains exactly one NAL unit per frame per layer. The resulting bitstream is then used as input into our LTE simulator that is derived from the open-source system level simulator *IMTAphy* [12], which then proceeds to transmit the whole bitstream to the UEs in the network. Our implementation uses the 3GPP Spatial Channel Model [16] and models a typical hexagonal grid layout assuming 19 cell sites and three sectors per site, thus resulting in a total of 57 sectors [2,5]. The 3D video sequences used in our experiments are eight seconds long and in order to be consistent with that assumption, our LTE simulation lengths were also eight seconds long. The simulation results we present in this section are given in terms

```
for all Users do
  while User m Transport Block not full do
    if non-VCL NAL unit then
      if I_MCS > 9 then
        use I_MCS = 9
      end
      update Transport Block size
      for all non-VCL NAL units do
        put NAL unit in Transport Block
      end
    end
    else if CRA NAL unit then
      use I_MCS = I_MCS - 1
      update Transport Block size
      for all CRA NAL units do
        put NAL unit in Transport Block
      end
    end
    else
      for all remaining NAL units do
        find NAL unit with lowest Layer Id
        if IDR_W_RADL NAL unit found then
          put NAL unit in Transport Block
        end
        if RASL_R NAL unit found then
          put NAL unit in Transport Block
        end
        if RASL_N NAL unit found then
          put NAL unit in Transport Block
        end
        if TRAIL_R NAL unit found then
          put NAL unit in Transport Block
        end
        if TRAIL_N NAL unit found then
          put NAL unit in Transport Block
        end
      end
    end
  end
end
```

Fig. 2. Pseudo-code algorithm of the proposed prioritization scheme

TABLE I. TABLE OF ENCODER AND LTE SIMULATION PARAMETERS

| **3D-HEVC Parameters** | |
|---|---|
| Frame size | 1024 x 768 |
| Frame rate | 30 fps |
| Number of Frames | 240 |
| Number of Slices per Frame | 1 |
| GOP size | 8 |
| I-frame Period | 24 |
| Frame Structure | IBB…BIBB…B |
| Decoding Refresh Type | Clean Random Access |
| Quantization Parameter | 25 (Texture) ; 34 (Depth) |
| **LTE Parameters** | |
| System Bandwidth | 10 MHz |
| Channel Model | SCM |
| Scenario | Macro-cell Case 1 |
| Carrier Frequency | 2 GHz |
| Link-to-System Interface | Exponential ESM |
| Receiver Type | Linear MMSE |
| Transmission Mode | TM 4 |
| Scheduling | Proportional Fair |
| Feedback | Rel-8 based {RI,PMI,CQI} |

of packet loss ratio and user throughput averaged across four video sequences we have encoded using *HTM 12.0*. The guidelines and set of assumptions that we used are similar to those used in [10]. The list of simulation parameters for both 3D-HEVC encoder and LTE simulator are listed in Table I.

### *A. Numerical Results*

In Fig. 3, the average packet loss ratio for all test sequences is shown across all simulated traffic load levels. As can be seen, the average packet loss ratio increases as the traffic load level increases. The baseline system suffers from a higher level of packet loss compared to the system with the proposed prioritization scheme. This is especially evident at heavier traffic load levels. With 20 UEs per cell on average, the average packet loss ratio is at 27.6% in the baseline system as opposed to 16.6% in the prioritized system. This metric alone is not sufficient since it does not convey information about the layers from which NAL units are lost. It is critical to investigate the distribution of the lost NAL units to layers which inherently affects the quality of the delivered video. Fig. 4 provides a breakdown of the packet loss results.

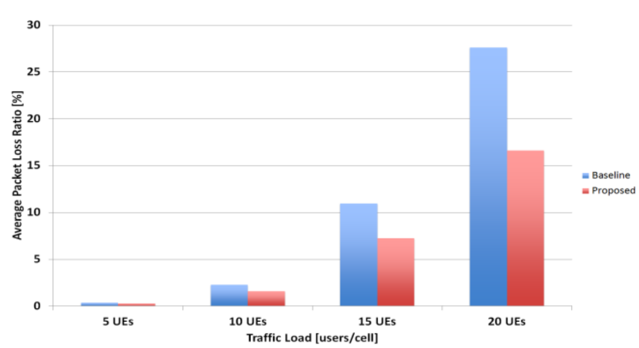


Fig. 3. Comparison of the average packet loss ratio between the baseline and the proposed approach for different traffic load levels

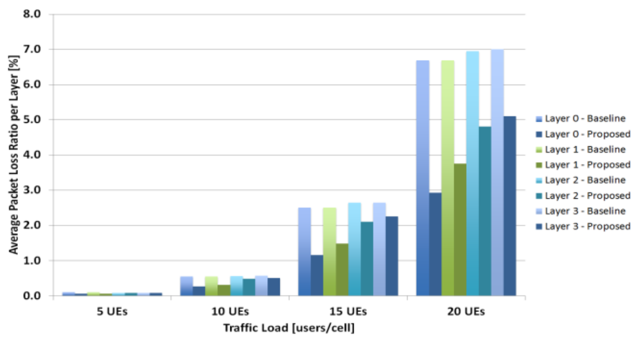


Fig. 4. Comparison of the layer-wise average packet loss ratio between the baseline and the proposed approach for different traffic load levels

In Fig. 4, the layer-wise average packet loss ratio is shown across all simulated traffic load levels. For lower traffic loads, the difference between the baseline and the prioritized system is minimal. For higher load levels, the number of lost NAL units from the first two layers is significantly reduced. The average packet loss ratio per layer is reduced by up to 50% on the first two layers and by about 20% on the last two layers using our proposed prioritization scheme. Another aspect that can be noted is that for the baseline system, the loss of packets is fairly uniform across all layers whereas for the proposed system, packet loss varies across layers, with layer 0 showing the lowest amount of packet loss and layer 3 showing the highest amount of packet loss.

In Fig. 5, the average packet loss ratio for different NAL unit types is shown across all simulated traffic load levels. For clarity, we opt to present the results of CRA, RASL_R and TRAIL_R. It can be observed that the baseline system shows higher packet loss across all NAL unit types compared to the proposed system. We note that this trend persists for the other NAL unit types. The packet loss ratio for CRA NAL units is reduced by up to 33% (for the highest traffic load level), and RASL and TRAIL NAL units also exhibit significantly reduced packet loss ratio.

In Fig. 6, the average user throughput is shown across traffic load levels. We can see that the user throughput, averaged across all four video sequences for a given traffic load, is slightly higher for the baseline system compared to the proposed system, with the exception of the simulation with 10

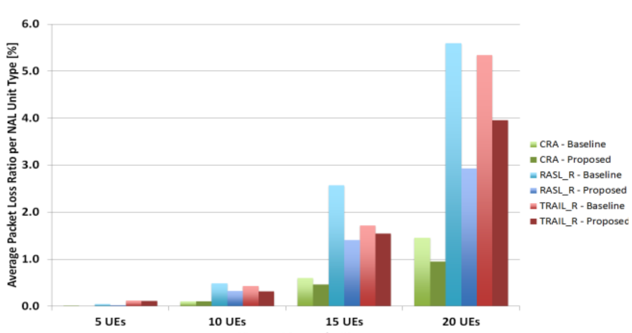


Fig. 5. Comparison of the packet loss ratio with respect to NAL unit type for different traffic load levels

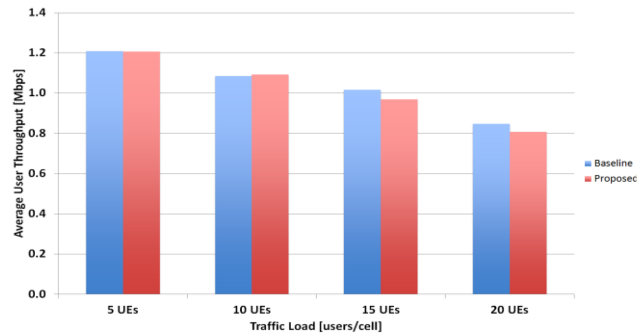


Fig. 6. Comparison of the average user throughput between the baseline and the proposed approach for diferent traffic load levels

UEs per cell. Such trend is expected because all UEs have the same traffic volume to stream, although the proposed system reduces the transport block size when sending CRA NAL units. This may result in an overall throughput reduction since reducing the transport block size means the UE needs more time to download a CRA NAL unit. More discussions on our experimental results are provided in the following sections.

### *B. Analysis*

The bitstreams generated by the 3D-HEVC encoder carry different types of NAL units with varying amount of data. NAL units carrying data from I-frames are typically much larger than other NAL units, because I-frames are intrapicture predicted. This observation implies that NAL units carrying I-frames will have a much larger footprint on the bitstream than other NAL units carrying data from P-frames or B-frames for instance. In the bitstreams we generated, CRA NAL units carry the encoded data from I-frames and they are typically very large so they have to be segmented before being packed into transport blocks. Also, in our simulation setup, there is always one NAL unit per frame and there are 240 frames in total per video sequence. Therefore the bitstream contains 968 NAL units, 240 NAL units per layer and the remaining 8 NAL units are non-VCL NAL units. Although there are only 10 CRA NAL units per layer, they represent a very large portion of the bitstream in terms of encoded data bits. Moreover, all the other frames in the video sequence depend on I-frames for motion prediction, therefore losing even one CRA NAL unit can hamper the ability to decode the subsequent NAL units correctly. Losing NAL units from frames that are not referenced is much less consequential, because the loss of such NAL units does not lead to error propagation during the video decoding process.

The other key point to take from the simulation results is that high achievable throughput does not ultimately guarantee a high decoding performance. Our proposed prioritization scheme results in a slightly lower overall throughput than the baseline scheme, and yet the packet loss ratio is considerably reduced compared to the baseline scheme. This was achieved by making the MAC layer scheduler aware of the bitstream structure, i.e. which NAL units are in the bitstream, what kind of information they are carrying and which layer they belong to. By giving higher priority to CRA NAL units, the 3D-HEVC decoder at the receiver side has a much better chance of decoding the video sequences, as it has access to the frames that are used as reference during the motion prediction phase. A system that accounts only for QoS by enforcing timing constraints on packets that are being sent does not necessarily ensure that the important encoded data is delivered first. HEVC and its extensions rely highly on motion prediction from reference frames to achieve higher compression rates. Thus, it is necessary that the transmitting system is aware of the characteristics and features of compressed video stream in order to provide the best QoE to the end user.

## V. Conclusion

In this paper, we presented a content-aware packet prioritization scheme for transmission of 3D-HEVC encoded video over LTE networks. Performance evaluations shows that the proposed cross-layer scheme achieves a lower average packet loss ratio despite offering slightly reduced average user throughput compared to a baseline system that is not QoE-aware. Importantly, we showed that a cross-layer scheme is a better design choice to deliver higher QoE to the end users, because QoS metrics are not sufficient to allow transmission systems identify which packets carry the most important information, which in the case of 3D-HEVC are the NAL units that carry encoded data from reference pictures and lower layers of an encoded bitstream. Further research is warranted in order to get a better idea of how packet loss and QoE are related and to evaluate through objective or subjective tests the impact of our proposed content-aware packet prioritization scheme. As part of our future work, we plan to develop error concealment methods at the receiver side and perform further subjective tests to evaluate the overall performance of the system.

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