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4 authors:

C. S. Pattichis
University of Cyprus

Andreas S. Panayides
University of Cyprus

Zinonas C. Antoniou
University of Cyprus

Marios S Pattichis
University of New Mexico

The Use of H.264/AVC and the Emerging High Efficiency Video Coding (HEVC) Standard for Developing Wireless Ultrasound Video Telemedicine Systems

A. Panayides[1,2], Z. Antoniou[1], M.S. Pattichis[3] , and C. S. Pattichis[1]

[1]Department of Computer Science, University of Cyprus, Nicosia, Cyprus
[2]Department of Electrical and Electronic Engineering, Imperial College, London, UK
[3]Department of Electrical and Computer Engineering, University of New Mexico, Albuquerque, USA

Abstract—For wireless medical video communications, the emerging high-efficiency video coding (HEVC) standard and network standards support low-delay and high-resolution video transmission, at the clinically acquired resolution and frame rates. Ultimately, the goal is to support remote diagnosis for emergency incidents in standard clinical practice. Clinical video quality assessment needs to be clearly defined in terms of clinical criteria.

This paper investigates the advantages of the HEVC standard over the H.264/AVC standard and the wireless transmission of high-resolution stroke ultrasound videos over mobile WiMAX networks. We test different HEVC modes that include high-efficiency and low-complexity configurations combined with low-delay and random access. The results are compared against similar H.264/AVC configurations. The experimental evaluation demonstrates significant reductions in bitrate requirements for equivalent clinical quality of approximately 37%. Moreover, careful selection of network parameters based on objective and subjective clinical criteria demonstrates that mobile WiMAX can be used to communicate low-delay H.264/AVC ultrasound video at the clinically acquired resolution.

I. Introduction

The use of H.264/AVC video compression standard over 3G and beyond cellular networks has driven research in mobile-health (m-health) medical video communication systems over the past decade [1]-[3]. Continuously increasing data transfer rates and coverage linked with compression efficiency, enabled shifting from medical image transmission to low and then moderate bitrate medical video communications.

Despite significant research in this area, there has been very limited adoption of clinical ultrasound video transmission telemedicine systems in clinical practice [4]. A possible reason for the failure to adopt such telemedicine systems may be due to the inability to communicate video that would rival in-hospital examination screen resolutions and frame rates, in addition to the lack of standardized clinical video quality assessment methods [5]-[6]. A decade later, the emerging HEVC standard, together with already deployed 3.5G and fast-emerging 4G wireless networks [7], promise for responsive systems that will communicate high-resolution and high frame rate video that can rival in-hospital exams [3].

In this study, our aim is to investigate the coding efficiency gains introduced by the new HEVC standard for ultrasound video communications, by performing an initial comparison to the H.264/AVC predecessor. The high efficiency video coding (HEVC) standardization initiative begun in 2010 when a joint call for proposals was issued by the ITU-T VCEG and the ISO/IEC MPEG groups, who formed the Joint Collaborative Team on Video Coding (JCT-VC). The 1st HEVC's reference software, HM test model, was later released in October 2010, formed by the best performing proposals, and is the standard software used for testing new coding elements and refinements of existing features for enhanced performance. HEVC is expected to be finalized in 2013. Thorough overview and performance evaluation appears in [7], [9].

HEVC for ultrasound video communication has been briefly highlighted in previous work in [10]. Here, we adopt the common test conditions used for comparing HEVC vs H.264/AVC over a larger ultrasound video data composed of twenty ultrasound videos of the common carotid artery (CCA). A primary focus of this paper is to investigate the communication of H.264/AVC-encoded stroke-ultrasound videos over mobile WiMAX 3.5G wireless networks, for low-delay high-resolution ultrasound video streaming.

Medical video transmission at the acquired resolution using new wireless infrastructure will enable the communication of higher diagnostic quality content that is comparable to in-hospital examination standards. The benefit of transmitting higher resolution video has been briefly described in [11]-[12]. In this study we showcase how optimum network parameter selection can be used to maximize the communicated video's clinical capacity. In addition to the objective Quality of Service (QoS) measurements, we employ clinical evaluation ratings based on the protocol described in [5] for different network parameter settings.

The rest of the paper is organized as follows: Section II provides a brief overview of the emerging HEVC video coding standard that is of interest to our clinical application. In Section III, we provide the methodology, while Section IV discusses the experimental evaluation. Finally, we give some concluding remarks and highlight the future work in Section V.

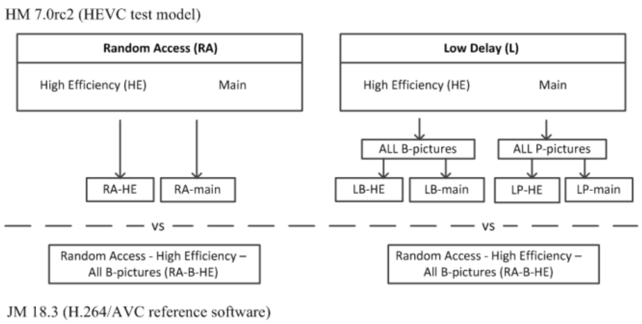

Fig.1. Summary of emerging HEVC test model (HM 7.0rc2) encoding schemes and corresponding H.264/AVC reference software (JM 18.3) for comparison evaluation.

II. High Efficiency Video Coding Standard (HEVC) For Telemedicine Applications

The emerging HEVC standard continues the block-based structure found in all video coding standards since H.261. A picture is partitioned into a number of blocks before it is intra or inter coded using enhanced motion vector and motion compensation prediction, followed by residual linear transform, quantization and entropy coding. In order to increase coding efficiency, reduce computational complexity, and maintain lower memory requirements, all features borrowed from H.264/AVC have endured significant refinement.

A new block structure, namely the coding tree unit (CTU), replaces the macroblock (MB) structure found in previous standards. A CTU allows partitioning of a picture to larger sub-blocks of variable luma size, up to 64x64 luma samples, compared to standard 16x16 luma samples of a MB. Luma and chroma coding tree blocks (CTBs) form a CTU. CTBs can be further split into smaller coding blocks (CBs). One luma CB and two chroma CBs compose a coding unit (CU). A CU also defines the prediction units (PU), for intra or inter picture prediction decision, and transform units (TUs), describing the block transform coding of the prediction residual. The CBs can then have identical or smaller in size prediction blocks (PBs) and transform blocks (TBs). A detailed overview and performance evaluation of the emerging HEVC standard can be found in [7], [9].

A substantial design element found in the new standard is the inclusion of new features which enhance the parallel processing capacity of HEVC. More specifically, in the new standard, new tiles tool allows the partitioning of a picture into independently decoded rectangular regions of approximately equal CTUs. While tiles share a similar concept with flexible macroblock ordering (FMO) error resilient tool found in H.264/AVC, tiles have been defined to support parallel processing rather than error resilience. Currently, this is a limiting factor in adopting HEVC for wireless communications.

Wavefront parallel processing (WPP) enables within slice parallel processing. Slices are split into rows of CTUs which can be processed in parallel, after allowing some time in the preceding row to produce some decisions related to entropy coding. Dependent slices on the other hand is a new structure which mainly targets low-delay applications, as it allows packet fragmenting of slices using tiles or WPP coding tools by enabling association with different NAL packets. A detailed overview and performance evaluation of the emerging HEVC standard can be found in [9].

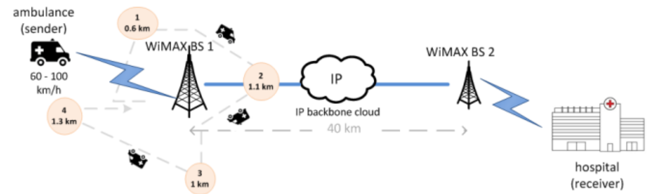

Fig. 2. A typical scenario of emergency ultrasound video communications over mobile WiMAX networks. The ambulance travels with speeds ranging from 60-100 km/h and traverses via vertices “1”-“4” situated close to the BSs effective coverage zone.

The deployment of HEVC in mobile devices requires significant computational resources. Low-delay and efficient encoding can support interactive telemedicine applications. However, wider adoption requires the emergence of efficient, error-resilient implementations that also support parallel processing features.

III. Methodology

A. *HEVC vs H.264/AVC coding efficiency comparison*

Throughout the HEVC development phase, the HEVC test model (HM) defined common test conditions (via configuration files) to be used both for testing the efficiency of new coding structures and tools, as well as serve as benchmark scenarios for comparisons to the H.264/AVC standard. These common test conditions could be further categorized as application oriented, *random access* and *low delay* schemes, and coding tools performance evaluation, *high efficiency* and *main* modes, respectively.

Random access setting allows for structural delay of processing units (i.e. coded frames order) and anchor frames insertion for synchronization at intervals of approximately one second (e.g. for use in broadcasting applications). For clinical applications, intra-updating can be synchronized with the beginning of a cardiac cycle for limiting error propagation, hence maximizing clinical quality. On the other hand low delay scheme does not allow any form of picture reordering or intra-updating. High efficiency configuration combines all coding tools for maximizing coding efficiency (some computationally intensive), while main mode uses the mainstream new features found in HEVC standard. In addition, in the HM test model, selection of all *P-pictures* or *B-pictures* (default), as well as *all-intra* modes, allows for the evaluation of tools related to the utilization of different picture coding modes.

JM H.264/AVC reference software defines two configuration schemes for HEVC comparison purposes. More specifically, random access mode using B-pictures coding and low delay mode using only P-pictures. Both settings employ the high profile, for maximizing H.264/AVC coding efficiency and hence providing for a more realistic evaluation of the new standard.

Here, we adopt the afore-described common test conditions to investigate coding efficiency comparisons between HEVC and H.264/AVC standards. The methodology appears in Fig. 1.

TABLE I
MOBILE WIMAX NETWORK CONFIGURATION PARAMETERS

Parameter	Value	Parameter	Value
Access Technology	OFDMA 20MHz	Total Capacity DL/UL	2.88 / 0.576 Msps (512 subcarriers)[1] 9.216 /2.6112 Msps (2048 subcarriers)[2]
Base Frequency	5.8 GHz	Duplexing Technique	TDD
Frame Duration/Symbol Duration	5ms/ 100.8	Multipath Channel Model/ Pathloss Model/ Shadow Fading Additive Correction in dBs	ITU Vehicular A/ Vehicular Environment/ 12 dB
Subcarrier Frequency Spacing	10.9375 KHz	MAC Layer QoS Class	Real time polling service (rtps)
Modulation and Coding	QPSK ½, 16-QAM 3/4, 64-QAM ¾	Minimum Sustained Data Rate[3]	768 - 1.5 Mbps
DISTANCE FROM BS	150 m-1.3 km	Mobility	60-100 Km/h

OFDMA: Orthogonal Frequency Division Multiple Access, TDD: Time Division Duplexing, DL: Downlink, UL: Uplink, Msps: Mega Symbols per Second, BS: Base Station, MS: Mobile Station.
[1]16-QAM ¾: 3/b/symbol/Hz * Msps (512 subcarriers) = 8.64/ 1.728 Mbps, 64-QAM 3/4: 4.5 b/symbol/Hz * Msps (512 subcarriers) = 12.96/ 2.592 Mbps, [2]QPSK ½: 1 b/symbol/Hz * Msps (2048 subcarriers) = 9.216 /2.6112 Mbps, [3]For the 5 atherosclerotic plaque ultrasound videos of the dataset.

TABLE II – AVERAGE BITRATE REQUIREMENTS REDUCTIONS (%) FOR EQUIVALENT PERCEPTUAL QUALITY OF EMERGING HEVC STANDARD WHEN COMPARED TO H.264/AVC STANDARD FOR LOW DELAY MODES

HEVC VS H.264/AVC	LP_HE vs JM_LP_HE	LB_HE vs JM_LP_HE	LP_MAIN vs JM_LP_HE	LB_MAIN Vs JM_LP_HE
BIT RATE SAVINGS	34.4%	37.3%	27.4%	34.8%

TABLE III – AVERAGE BITRATE REQUIREMENTS REDUCTIONS (%) FOR EQUIVALENT PERCEPTUAL QUALITY OF EMERGING HEVC STANDARD WHEN COMPARED TO H.264/AVC STANDARD FOR RANDOM ACCESS MODES

HEVC VS H.264/AVC	RA_HE vs JM_RA_B_HE	RA_main vs JM_RA_B_HE
BIT RATE SAVINGS	36.5%	33.8%

For this purpose, we compare the random access and low delay schemes encoded using the two standards and provide bitrate gains summary using the BD-PSNR algorithm [13]. For testing, we use an ultrasound video data set composed of 20 ultrasound videos of the common carotid artery (CCA) plaques, acquired at a video resolution of 560x448, at 50 frames per second (fps), and duration of ten seconds.

B. Ultrasound video transmission using Mobile WiMAX wireless networks

We investigate the network aspects associated with high-resolution ultrasound video telemedicine by modelling a typical emergency video transmission scenario using mobile WiMAX (IEEE 802.16e) networks. The scenario topology appears in Fig. 2 and describes an ambulance which wirelessly transmits ultrasound video on its route to the hospital premises. Our aim is to find an optimum network parameter's setup that maximizes the communicated video's diagnostic robustness. For this reason, we examine the primary network conditions that affect the quality of the communicated video. More specifically, we investigate different mobility patterns (60-100 km/h), distances to the serving WiMAX base station (BS) (150 m – 1.3 km), channel modulation and coding schemes (QPSK ½,16-QAM ¾, and 64-QAM ¾), signal attenuation due to different signal propagation models (vehicular OPNET model), and mobile WiMAX subcarriers scalability (512 and 2048). The experimental setup appears in Table I.

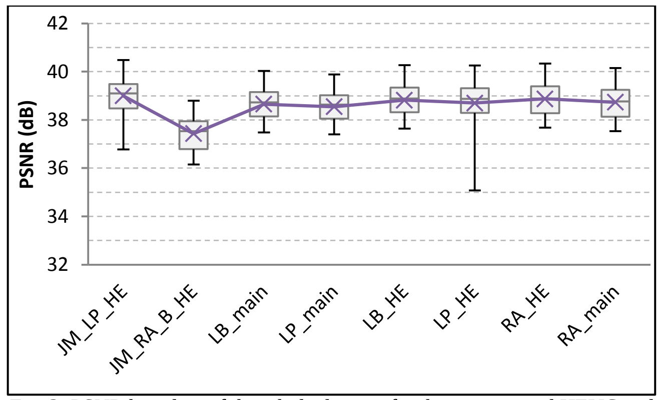

Fig. 3. PSNR boxplots of the whole data set for the investigated HEVC and H.264/AVC configuration settings, for a QP of 27.

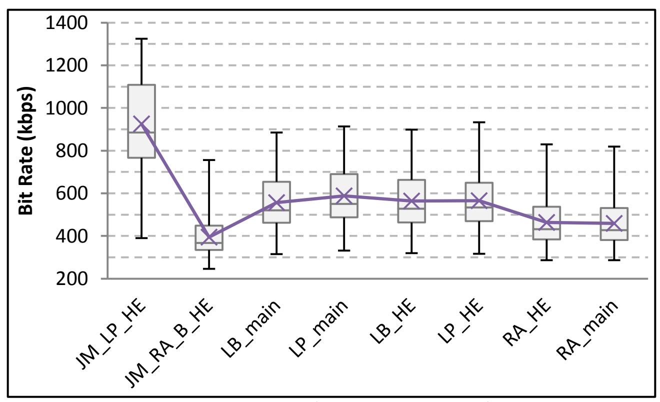

Fig. 4. Bitrate demands boxplots of the whole data set for the investigated HEVC and H.264/AVC configuration settings, for a QP of 27.

For a more realistic approach, we use trace files generated via real ultrasound video encodings, to model transmission over the mobile WiMAX wireless network using OPNET modeler [14]. Following transmission, the received trace files are mapped back to the original video, decoded, and then used for video quality assessment (VQA). For each case, Quality of Service (QoS) metrics including end-to-end delay, delay jitter and PSNR ratings are computed. Here, it is important to note that results for each video are averages of 10 simulation runs. Experimental evaluation is based on five atherosclerotic plaque ultrasound video (different than the ones used in HEVC performance evaluation) at 4CIF (704x576) resolution and

TABLE IV
QOS MEASUREMENTS FOR SCENARIO II

Channel Modulation & Coding Schemes	QPSK ½			16-QAM ¾			64-QAM ¾		
QoS Parameters	PLR % (σ)[1]	Delay (ms)	PSNR[2] (dB)	PLR % (σ)	Delay (ms)	PSNR (dB)	PLR % (σ)	Delay (ms)	PSNR (dB)
1 (0.6 km from BS)	1.40 (0.17)	21.03	38.76	1.74 (0.7)	20.17	38.58	1.68 (1.06)	20.37	38.73
2 (1 km from BS)	1.42 (0.71)	21.60	38.85	5.35 (5.71)	20.14	36.96	5.94 (7.70)	20.33	36.85
3 (1.1 km from BS)	1.98 (2.3)	23.06	38.76	5.82 (6.63)	20.17	36.97	7.50 (9.47)	20.36	36.29
4 (1.3 km from BS)	1.30 (0.64)	24.80	38.87	15.01 (16.52)	19.91	34.92	17.47(21.81)	20.18	33.52

[1]σ: standard deviation, [2]PSNR is given for the atherosclerotic plaque ROI extracted from the transmitted ultrasound video (see [5].

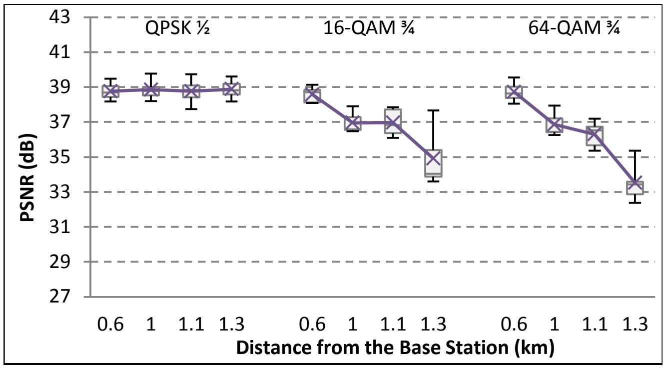

Fig. 5. Boxplots depicting the average PSNR ratings for the whole data set and for each channel modulation and coding scheme, as a function of the distance from the BS.

15fps. Videos are encoded using the H.264/AVC based diagnostically relevant encoding method described in [5].

1) Clinical Video Quality Assessment

In addition to the QoS measurements, VQA is also based on clinical ratings by a neurovascular specialist. For a representative number of cases, the medical expert evaluates the diagnostic capacity of the received ultrasound videos using the protocol described in [5]. Individual ratings are provided for each of the examined clinical criteria, namely a) Plaque presence, b) Artery degree of stenosis, and c) Plaque type. A five point rating scale is used with one being the lowest score, and five being the highest. A rating of five indicates that the evaluated video carries equivalent clinical information as the original video prior to transmission, while a rating of four is the diagnostically acceptable threshold.

IV. RESULTS AND DISCUSSION

In this section we present and discuss the objective results of HEVC and H.264/AVC video coding standards comparison, the ultrasound video transmission over mobile WiMAX networks evaluation, followed by the clinical evaluation.

A. HEVC vs H.264/AVC

Table II depicts the average bitrate gains of the whole ultrasound video data set for the low delay mode comparison. The highest gains, in the order of 37.3%, are attained using the high efficiency B-pictures mode, while the lowest, 27.4%, when employing the main P-pictures scheme. High efficiency scheme using P-pictures and main configuration using B-pictures achieve comparable savings at 34.4% and 34.8%, respectively. For the random access mode, summarized in Table III, HEVC reduces bitrate demands by as much as 36.5%, while the main configuration achieves 33.8% bitrate reductions. The demonstrated results are aligned with the results presented in [9], where 35.4% bitrate reductions have been recorded for entertainment application.

TABLE V
CLINICAL EVALUATION FOR THE INVESTIGATED CHANNEL MODULATION AND CODING SCHEMES AS A FUNCTION OF THE DISTANCE FROM THE BS

Resolution: **4CIF,** Frame Rate: **15fps,** BitRate: **1.5 Mbps**			
	QPSK ½	**16-QAM ¾**	**64-QAM ¾**
Location[a]	**1/ 2/ 3/ 4**	**1/ 2/ 3/ 4**	**1/ 2/ 3/ 4**
Plaque Detection	5/ 5/ 5/ 5	5/4.3/4.5/3.4	5/ 4.2/ 4.4/3.6
Artery Stenosis	5/ 5/ 5/ 5	5/4.1/4.2/3.4	5/ 4/ 4.3/3.6
Plaque Type	5/ 5/ 5/ 5	5/4.1/4.2/3.3	5/ 4/ 4.3/3.5

1: Lowest Score, **5:** Highest Score
[a]Distance from the BS: 1: 0.6 km, 2: 1.1 km, 3: 1 km, 4: 1.3 km.

Fig. 3 shows boxplots describing the PSNR ratings of individual configuration setting of the investigated HEVC and H.264/AVC video coding standards, for a QP of 27. Fig. 4 records the associated bitrate demands. It is clear that all HEVC coding modes require significantly lower bitrate demands to achieve comparable PSNR ratings to the H.264/AVC low delay mode. On the other hand, H.264/AVC random access scheme may involve lower bitrate demands, but at the same time it fails to rival the achieved PSNR ratings of the HEVC coding.

B. Mobile WiMAX for Ultrasound Video Communication Telemedicine System

Table IV depicts the average QoS measurements of the 5 examined ultrasound videos transmitted using the topology described in Fig. 2. Results are categorized according to the investigated channel modulation and coding schemes and distance from the serving BS. From the results, QPSK ½ is the most robust channel modulation and coding scheme, as it consistently achieves diagnostically acceptable QoS ratings irrespective of varying channel conditions. Packet loss rates (PLR) are less than 2% for all cases, while end-to-end delay does not exceed 25 ms, which is well within the acceptable threshold of 100 ms (300 ms for general purpose videos) [15]. Moreover, PSNR ratings are significantly higher than the clinically accepted threshold of 35 dBs set in [5].This is also evident by observing the leftmost boxplots of Fig. 5.

On the other hand, 16-QAM ¾ and 64-QAM ¾ show comparable performance (with 16-QAM ¾ being marginally better), but can rival QPSK ½ only for the 1st location situated closer to the BS. As the ambulance moves away from the BS, signal attenuation causes higher PLRs, and as a result PSNR measurements decrease proportionally. While at 1 km from the BS both schemes still attain diagnostically acceptable PSNR ratings, PLR standard deviation however suggest that quality can fall below of what is acceptable, as it signifies that PLR can climb at unacceptably high rates of over 10% (note that results for each video are averages of ten emulation runs, see section III). The latter, is even more intense at 1.1 km from the BS. At the furthest location, videos communicated using the 16-QAM ¾ and 64-QAM ¾ are of limited clinical interest. Clearly, a switch to a more robust scheme is required for preserving clinical quality at distances greater than 1 km, which constitutes the boundary distance for this scenario.

QPSK ½ channel modulation and coding scheme's robustness is attributed to the fact that it conveys information at 1 bit/symbol/Hz (mobile WiMAX capacity is estimated using mega symbols per second-Msps). As a result, in order to meet the bitrate demands for 4CIF medical video transmission (maximum video bitrate of 1.5 Mbps encoded using H.264/AVC in these series of experiments), it utilizes 2048 subcarriers at 20 MHz (see Table I). This is significantly more than the 512 subcarriers used by 16-QAM ¾ and 64-QAM ¾ which communicate information at 3 bits/symbol/Hz and 4.5 bits/symbol/Hz, respectively. Channels capacity is therefore compromised by the use of a more robust scheme. Clearly, the emergence of the new HEVC standard will enhance the ability of mobile networks' operators to satisfy the QoS demands of video streaming applications in general, by lowering the bitrate demands, and hence increasing the capacity of the wireless channels.

C. Clinical Evaluation

The results from the clinical evaluation appear in Table V. Clinical ratings are provided for a single ultrasound video (3 different channel modulation and coding schemes x 4 distances from the BS x 10 emulation runs, for a total of 120 instances), but the trend is the same for all investigated videos. Clinical ratings for videos communicated using the QPSK ½ scheme verify the results of the objective evaluation, as they attain the highest scores in all circumstances. This is also the case for rival 16-QAM ¾ and 64-QAM ¾ schemes at 600 meters from the BS. As the distance increases however, clinical capacity deteriorates. At 1.1 km from the BS, clinical ratings are marginal for both 16-QAM ¾ and 64-QAM ¾, as they are rated with scores of 4.1 and 4, respectively (clinically acceptable rating threshold is 4). As already discussed during the objective assessment, a switch to a more robust configuration will prevent clinical quality to fall below of what is acceptable. At 1.3 km form the BS, clinical quality is significantly inferior that what is required for use in standard clinical practice.

V. CONCLUDING REMARKS AND FUTURE WORK

This study demonstrates the coding efficiency gains of the emerging HEVC coding standard compared to its predecessor, the H.264/AVC standard. Bitrate demands reductions of approximately 37% are recorded for the investigated ultrasound video data set. The additional bitrate can be used for increasing the quality and error resilience capacity of the communicated ultrasound video. Moreover, the utilization of 3.5G mobile WiMAX networks for ultrasound video telemedicine systems showcased that low-delay high-resolution ultrasound video is possible using network parameters that maximize the clinical quality of the transmitted video. It is anticipated that HEVC utilization for medical video telemedicine systems over 3.5G and 4G wireless networks can effectively support applications in clinical practice.

On-going work includes exploiting HEVC new coding tools for diagnostically relevant and resilient encoding. In addition, HEVC-based telemedicine systems over High Speed Packet Access (HSPA(+)) and Long-term Evolution (LTE and LTE-Advanced) wireless networks using simulators and real-time setups is currently planned.

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