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Scalable Video Broadcasting Trials in 4G Cellular Deployments

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Abstract: Future LTE mobile communication systems provide for the first time low delay and high data rate and access over wireless. This enables transmission of new multimedia applications with high quality. H.264/Scalable Video Coding delivers high-quality video content with a scalable data rate, which perfectly matches with the LTE technology. The combination of H.264/SVC and LTE enables in a cross-layer approach with unequal error protection a robust transmission of HDTV multimedia content over the air. First field trial results in the cellular downlink of a LTE system show that scalable video broadcasting is a promising approach with a robust performance delivering high quality video transmission to mobile users.

Keywords: Long Term Evolution (LTE), H.264/Scalable Video Coding (SVC), Cross-Layer Design, LTE Field Trials

1. Introduction

Multimedia transmission over wireless communication systems is difficult to realize especially under adverse network conditions. The air interface provides a highly variable data pipe to the Internet user. Previous mobile networks like UMTS and GPRS suffer from high delay and allow only best-effort Internet traffic.

The drawback of current video streaming is that the video is transmitted in a single bit stream. Besides many packets have to be buffered, the receiver has to decode all data packets in order to show a continuous video, and usually the video is played for a few seconds until the stream is interrupted and the play-out buffer is empty. Hence, transmission fails if a user is moving or the multimedia content requires a high data rate. Existing solutions are especially optimized for fixed networks. A solution to this problem for cellular mobile networks is the cross-layer approach H.264/SVC over LTE.

In H.264/SVC over LTE, the Scalable Video Coding (SVC) extension of H.264 demultiplexes a video stream into several data streams with different data rates. Each SVC data stream represents a different quality aspect of the video. Partial decoding of these data streams allows a graceful degradation when parts of the video cannot be decoded. If the base layer of the SVC video stream can be received, a basic version of the video can be decoded. If a user experiences a good channel, several video layers can be decoded. Thus, a video stream with a high quality can always be transmitted. This provides for the first time robust multimedia transmission in cellular mobile communication systems. A joint application and medium access control layer (MAC layer) design with unequal error protection (UEP) can save resources and map SVC resources to the LTE system. In [1], the authors showed the idea of combining cooperative diversity gain with UEP in a progressive image bit stream. The authors from [2] propose policies for unequal error protection (UEP) for scalable video transmission by choosing between different forward error correction (FEC) and MIMO modes. In our paper, we show the first results from a measurement field trial with H.264/SVC over LTE broadcasting in the cellular downlink of an LTE system.

2. LTE Testbed - MAC and PHY Layer

The LTE testbed [3] incorporates LTE key features such as OFDMA resource block assignment over 1200 sub-carriers in 20 MHz bandwidth. The adaptive modulation and coding (AMC) supports QPSK, 16-QAM, and 64-QAM modulation with code rate 0.5. In addition, the LTE system implements channel adaptive spatial mode switching with different MIMO modes for 2x2 MIMO, e.g. SDMA, spatial multiplexing or transmit diversity, see [4]. For spatial equalization, the system considers linear MRC and MMSE filters [5]. Resource blocks selected for single-stream mode are transmitted using cyclic delay diversity (CDD) for additional robustness. The maximum supported data rate on the physical layer (PHY layer) is approximately 160 Mbps. On the MAC layer a multi-queuing system is implemented to realize different radio bearers, see Figure 2. QoS can be configured on a radio bearer basis. 4 transmit queues, or so-called connection identifiers (CIDs), are reserved for multi-cast and broadcast services, 4 CIDs are reserved for unicast services. This allows simultaneous transmission of multi-cast, broadcast and unicast services. The MAC layer radio resource management (RRM) assigns data from the queuing system according to the OFDMA structure of the LTE radioframe. The system provides a very low delay between base station (BS) and user equipment (UE) for real-time data transmission. The minimum round-trip-time delay on the IP layer is 10-20 ms.

Transport Layer	H.264/SVC Layer	Description	Bitrate[1] [kbps]
1	0	12.5 Hz Low Quality	300
2	1	25 Hz Low Quality	600
3	2,3	25 Hz Medium Quality	1300
4	4,5	25 Hz High Quality	3600

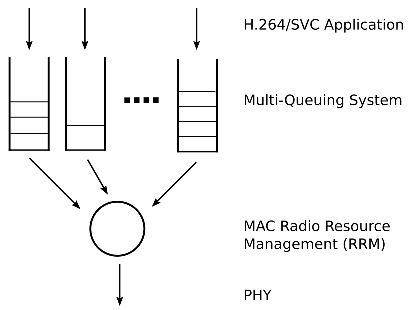

Table 1: H.264/SVC Video Configuration (left), Queuing System (right).

3. H.264/Scalable Video Coding

The SVC extension of H.264/Advanced Video Coding (AVC) is a promising approach to deliver scalable content for future mobile applications, refer to [6] and [7]. Scalability is achieved by placing several enhancement layers in the SVC bit stream next to a base layer being backwards compatible to H.264/AVC and representing the lowest quality

[1]Mean bitrate of H.264/SVC encoded transport layer including IP and UDP headers.

gradation. Partial decoding of the scalable bit stream allows graceful degradation when parts of the bit stream go missing and allows adaptation of bit rate, format and power. The enhancement layers improve the perceived video quality through higher fidelity, a higher spatial resolution, a higher frame rate or any combination of these three scalable modes. Partial transport and decoding of this scalable bit stream allows a hierarchical adaptation to the transport layer in terms of bit-rate and format of the video stream as well as of the processing power of the mobile device.

For the test trials in the LTE testbed, the SVC video is encoded with 3 different quality layers and 2 different temporal layers. The resulting 6 different SVC video layers are mapped onto 4 different transport layers ranging from low quality at 12.5 Hz with a mean bitrate of 300 kbps, up to high quality at 25 Hz with a mean data rate of 3.6 Mbps, see Table 2. The video is encoded with a variable bit rate (VBR). The resolution for the chosen video was set to 720p (1280x720 pixels). The streaming protocol used for the SVC video stream is UDP/IP via real-time protocol (RTP) [8], where the RTP protocol adds an additional overhead of 12 Bytes to each data packet.

4. Cross-layer Design

The scalable content adaptation of H.264/SVC and the scheduling flexibilities of the MAC layer of MIMO-OFDMA systems make both technologies a perfect match to provide mobile video broadcasting in cellular systems. H.264/SVC over LTE is a unique cross-layer design and provides higher layers with a scalable access to the LTE air interface. The LTE scheduler is free to assign resources in time, frequency and spatial domain. Multi-layered transmission is established by mapping the SVC encoded base and enhancement layers in a hierarchical manner onto several LTE transport channels. For the mapping of SVC transport layers to PHY resource blocks, unequal error protection (UEP) is applied such that more important SVC transport layers are mapped onto more robust transmission modes. This reduces the outage probability for the lower and more important layers, e.g. base layer, and ensures video broadcasting with low outage probability since mobile terminals can always receive the base layer. In order to reduce the total number of assigned resources, enhancement layers are mapped to resource blocks allowing higher AMC or utilizing spatial multiplexing. Users experiencing better channel conditions can benefit from capabilities of successfully decoding higher layers and therefore increased video quality perception. This mapping scheme can also be adopted to different scenarios like user mobility, processing power of the terminal equipment or service pricing policies.

The mapping table used in the measurements is depicted in Table 4. 10 MHz of the bandwidth was reserved for the broadcast service. The other 10 MHz were scheduled for additional unicast traffic. Since every UE can decode the downlink radio resource map, the BS could also adapt the mapping table which is transmitted in advance to the UEs using the signaling control channel.

5. Outdoor Measurement Scenario

For the experiments we used the Berlin LTE-Advanced Testbed, which was installed in the center of Berlin throughout 2008. This 3G-LTE testbed consists of three base station (BS) sites and nine sectors, see [9]. For the measurement discussed in this paper, the 30° north-east sector of the BS on top of the Telefunken building at the

Transport Layer	H.264/SVC Layer	PHY Mode	Bandwidth [MHz]
1	0	QPSK SIMO, code rate 0.5	3.75
2	1	16-QAM SIMO, code rate 0.5	2.5
3	2,3	64-QAM SIMO, code rate 0.5	1.25
4	4,5	16-QAM MIMO, code rate 0.5	2.5

Table 2: Cross-Layer Design: H.264/SVC Layer to LTE PHY Mode Mapping.

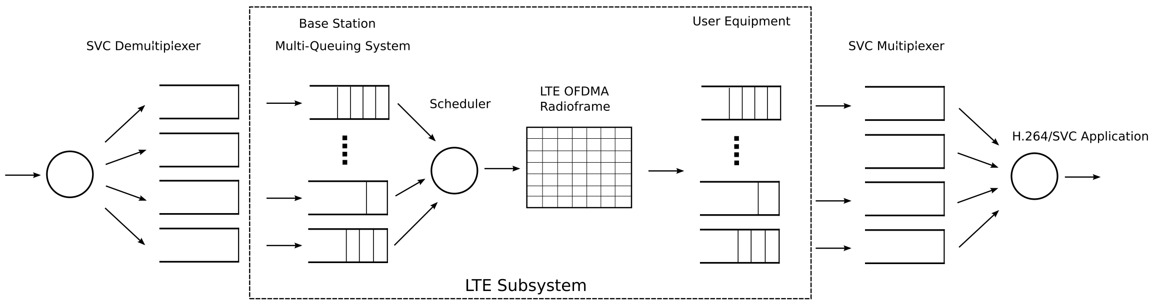

Figure 1: H.264/SVC over LTE transmission chain.

Ernst-Reuter-Platz was used. The measurements are limited to a single-sector scenario without multi-cell interference from other BSs. The BS transmission power was set to 10 Watts per transmit branch. The antennas are mounted on an antenna pole on top of the building, 85 m above ground. The carrier frequency was 2.6 GHz which is within the UMTS extension band. The BS antenna is a cross-polarized panel with 2 antenna elements and 18 dBi antenna gain. This highly directive antenna is a standard antenna used for future sectorized cellular urban deployments. The mobile terminal is installed inside a measurement van and utilizes cross-polarized antennas which are mounted on the roof of the van. Several measurement runs were taken at a velocity ranging from 5 to 50 km/h through the testbed. The route consists of LOS and NLOS components to the BS covering a dynamic range of received powers between -50 dBm and -92 dBm.

The H.264/SVC over LTE transmission chain is shown in Figure 1. A video server multiplexes the video stream into 4 data stream. The stream is SVC encoded and put into the queuing system of the BS. The BS transmits the 4 data streams to the UE via LTE. At the UE, the received data streams are SVC decoded into a single RTP data stream. The RTP data stream is then send to the video application. Statistics are captured on the PHY layer and MAC layer of the LTE system as well as at the client and server of the SVC video application.

6. Results

Figure 2 depicts the highest decodeable H.264/SVC transport layer along the measurement track. We observed that the base layer, transport layer 1, can be received with a probability of 97 % along all points on the measurement track, also compare Figure 3. The mobile terminal experienced 3 % outage at a distance of 2 km to the serving BS. Here, the received prower dropped below -92 dBm, which was below receiver sensitivity of the test mobile, and the mobile terminal lost synchronization to the BS. In general, Figure 2 shows that H.264/SVC over LTE supports mostly 2 or 3 SVC transport layers

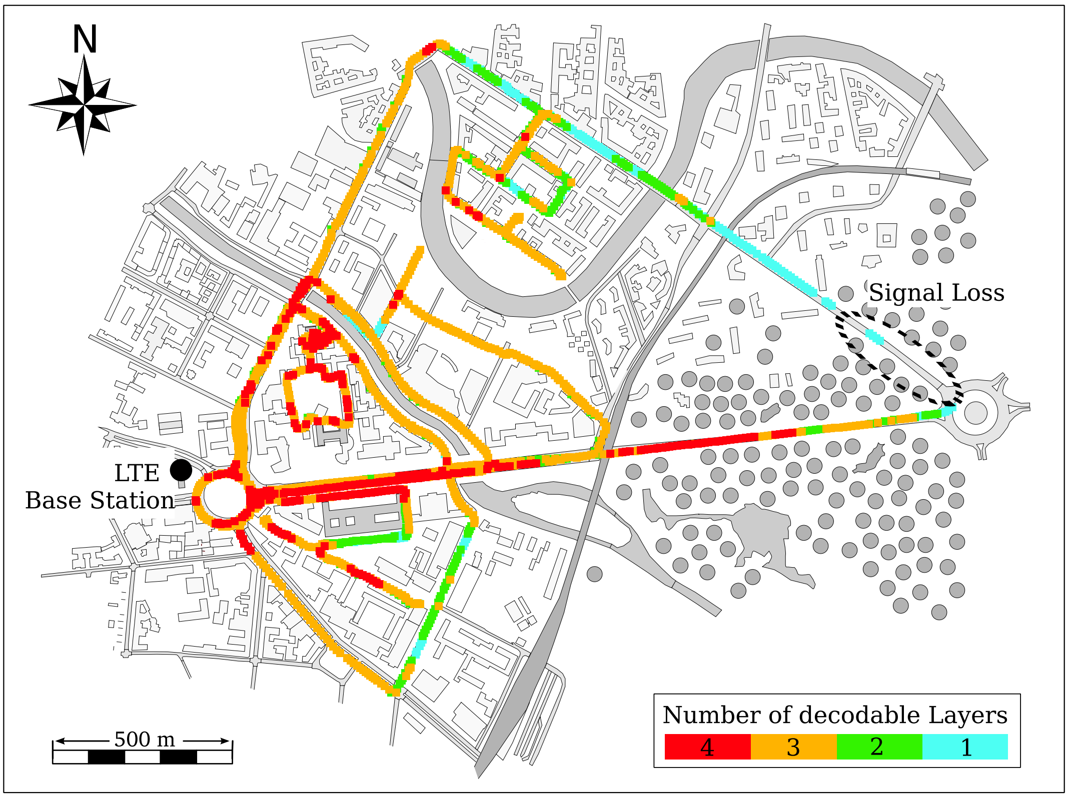

Figure 2: The coverage map shows the highest decodeable H.264/SVC transport layer along the measurement track.

under mobility throughout the serving sector. In the area close to the base station, the system utilizes most of the time the highest SVC transport layer providing the best video quality. In case of temporary bad channel quality, which can easily be caused by mobility effects or temporary shadowing caused by other vehicles, the SVC decoder might only be able to successfully decode 2 layers, also if the terminal is close to the base station. In a mobile environment, a situation like this might only last for a couple of milliseconds to seconds. Consequently, a sudden drop to 2 layers and then back to 3 or 4 SVC layers might even be unnoticeable for a particular user.

Figure 3 shows the throughput CDFs for different transport layers on the application layer. The figure depicts the IP throughput without overhead, and the IP throughput with RTP overhead as seen at the MAC layer queuing system. The gray dotted curve shows that IP and UDP layers add approximately 30 % overhead to the median throughput. Finally, this figure shows the required throughput on the PHY layer under the assumption of code rate 0.5. The CDFs show especially for the higher transport layers a higher variance resulting from the VBR video stream. As a consequence, the resource assignment has to consider a large amount of resources for over-provisioning which favors constant bit-rate (CBR) encoders. Nevertheless, already the implemented algorithms give a good performance and show that especially mobile terminals benefit from cross-layer design. In particular, the nature of the fading channel matches well with the mechanism of H.264/SVC.

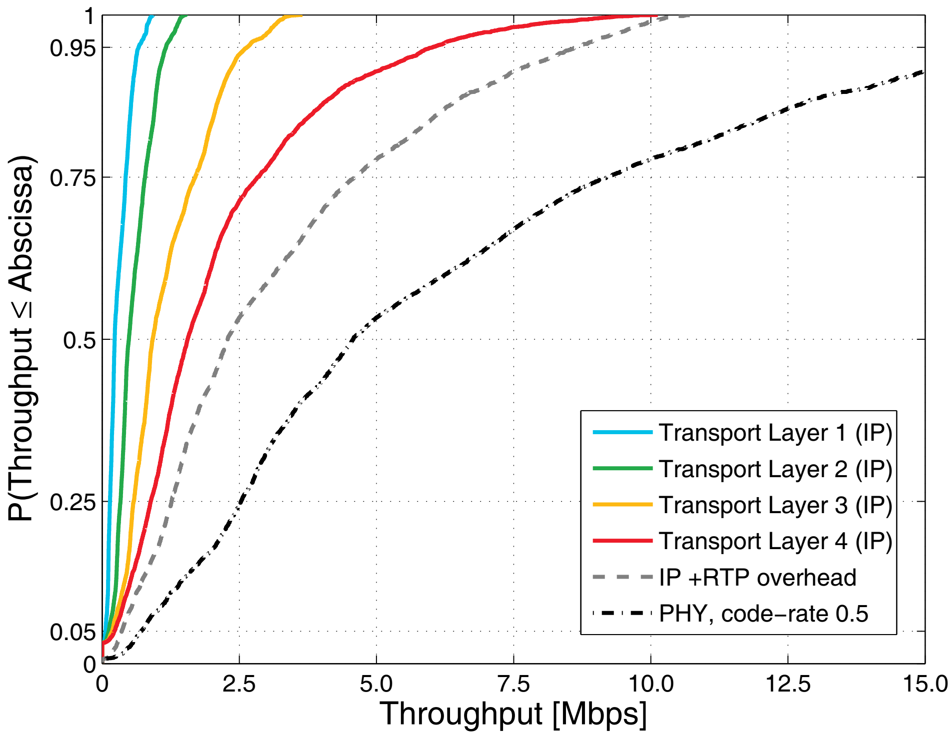

Figure 3: Comparing throughput CDFs with regard to Application-, MAC- (IP+RTP) and PHY-layer with code rate 0.5.

7. Conclusion and Outlook

We presented the first field trial results on broadcasting H.264/Scalable Video Coding in the LTE downlink. Here, a H.264/SVC encoded video stream with 720p was transmitted with unequal error protection using a hierarchical resource mapping on the LTE MAC layer. The field trials were performed in a real urban macro scenario within the Berlin LTE-Advanced Testbed. Measurements show, that fast adaption in a mobile environments is crucial especially for real-time content but can be realized with SVC over LTE cross-layer design. The implemented cross-layer approach shows respectable performance. In 97 % of the cases, the SVC base layer can be received by the mobile terminal, even if the terminal is moving with up to 50 km/h. If the terminal is within 500 m of the serving base station, 3 or 4 SVC layers can always be decoded. This shows that SVC over LTE allows a very robust video transmission. Future work will include investigations in LTE systems operating as a single frequency network (SFN) to enhance coverage.

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References

[1] A. Kwasinski and K. Liu, "Optimal unequal error protection with user cooperation for transmission of embedded source-coded images," in *Image Processing, 2006 IEEE International Conference on*, pp. 717–720, Oct. 2006.

[2] H. Kim, S. Y. Kim, P. C. Cosman, and L. B. Milstein, "Motion-compensated scalable video transmission over MIMO wireless channles under imperfect channel estimation," *IEEE Globecom 2009*, December 2009.

[3] T. Wirth, V. Jungnickel, A. Forck, S. Wahls, H. Gaebler, T. Haustein, J. Eichinger, D. Monge, E. Schulz, C. Juchems, F. Luhn, and R. Zavrtak, "Realtime multi-user multi-antenna downlink measurements," *Proc. IEEE Wireless Communications and Networking Conference (WCNC)*, Mar. 2008.

[4] L. Zheng and D. Tse, "Diversity and multiplexing: A fundamental tradeoff between multiple antenna channels," *IEEE Transactions on Information Theory*, vol. 49, pp. 1073–1096, May 2003.

[5] L. Thiele, M. Schellmann, T. Wirth, and V. Jungnickel, "Interference-aware scheduling in the synchronous cellular multi-antenna downlink," *IEEE 69th Vehicular Technology Conference VTC2009-Spring, Barcelona, Spain*, Apr. 2009. invited.

[6] H. Schwarz, D. Marpe, and T. Wiegand, "Overview of the scalable video coding extension of the H.264/AVC standard," *Circuits and Systems for Video Technology, IEEE Transactions on*, vol. 17, pp. 1103–1120, Sept. 2007.

[7] ITU-T and ISO/IEC JTC 1, *Advanced Video coding for generic audiovisual services*, November 2007. Version 8.

[8] H. Schulzrinne, S. Casner, R. Frederick, and V. Jacobson, "RTP: A transport protocol for real-time applications," 2003.

[9] Nokia Siemens Networks, "LTE performance for initial deployments."