



Thota, J., Bulut, B., Doufexi, A., Armour, S., & Nix, A. (2017). Performance Evaluation of Multicast Video Distribution using LTE-A in Vehicular Environments. In 2016 IEEE 84th Vehicular Technology Conference (VTC2016-Fall). Institute of Electrical and Electronics Engineers (IEEE). DOI: 10.1109/VTCFall.2016.7881159

Peer reviewed version

Link to published version (if available):
[10.1109/VTCFall.2016.7881159](https://doi.org/10.1109/VTCFall.2016.7881159)

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Performance Evaluation of Multicast Video Distribution using LTE-A in Vehicular Environments

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Abstract— Application Layer Forward Error Correction (AL-FEC) based on Raptor codes has been employed in Multimedia Broadcast/Multicast Services (MBMS) to improve reliability. This paper considers a cross-layer system based on the latest Raptor Q codes for transmitting high data rate video. Multiple Input Multiple Output (MIMO) channels in a realistic outdoor environment for a user moving at 50kmph in an LTE-A system is considered. A link adaptation model with optimized cross-layer parameters is proposed under different channel conditions and quality of service requirements. The system investigates throughput performance for Spatial Time Block Coding (STBC) and Spatial Multiplexing (SM) MIMO with and without raptor codes. Improvements of up to 4dB SNR are seen by using raptor codes with SM depending upon the channel conditions and chosen Modulation and Coding Scheme (MCS). Results also show that at low SNR and low spatial correlation, the performance of AL-FEC with SM is better than STBC even when the user is moving at high speeds.

Keywords—Raptor codes; MIMO; spatial multiplexing; vehicular; space-time block coding; reliable multicast; LTE-A.

I. INTRODUCTION

In the future, vehicular communications will provide services such as infotainment, e-commerce, safety and location-aware services. 3GPP LTE-A system is emerging as a dominant radio access technology for vehicular communication due to faster deployment and reduced costs. The main challenges of vehicular communications are high doppler spread and low latency requirements. One way to provide end-to-end reliability in such a challenging environment is to use systematic raptor codes to decode the missing packets.

Application Layer Forward Error Correction (AL-FEC) based on systematic raptor codes has been proposed in 3GPP MBMS (Multimedia Broadcast/Multicast Service) and DVB-H (Digital Video Broadcasting for Handheld) applications [1]. These codes are optimized for shorter and longer packet lengths to provide reliable multicast or broadcast services. AL-FEC is flexible with reconfigurable number of repair symbols that can be generated on-the-fly depending upon the channel conditions. These systematic raptor codes are specifically useful as they have direct access to the original packets and are beneficial for users with good channel conditions. Users with bad channel conditions can use the subsequent repair symbols to decode. However, the reliability comes at the expense of additional bandwidth requirements. The raptor

overhead should be chosen depending on the channel conditions and Modulation and Coding (MCS) schemes in order to utilize the bandwidth more efficiently.

In vehicular environments, the promised theoretical gains are not realized due to the significant spatial correlation present in the channel [2]. A range of MIMO modes such as Space Time Block Coding (STBC) and Spatial Multiplexing (SM) can be used depending upon the type of quality of service (QoS) requirements. STBC is a highly reliable scheme but does not provide higher data rates. However, SM provides high data rates but depends on the spatial correlation of the channel. To address this issue, we explore the combination of SM multicast transmissions with raptor codes. Furthermore, we compare the performances of SM combined with raptor codes and STBC MIMO technique.

One of the major contributions of this work is the use of a 3D channel model and a detailed cross-layer simulator that can link adapt to any realistic outdoor environment to predict the performance. In this study, we consider the latest Raptor Q codes (based on IETF RFC 6330 standard) [3], since they provide improved performance, coding efficiency, and flexibility when compared to the legacy Raptor 10 approach. To the best of the author's knowledge, there are no existing studies in the literature that predict the LTE-A MIMO performance in a 3D channel model for a user moving at high speed using the latest Raptor Q codes. There have been similar studies by the authors in an IEEE 802.11 system but these did not consider speed or an LTE-A network [4].

The remainder of this paper is organized as follows: The modeling of the wireless channel, LTE PHY bit level simulator, and the cross-layer system model is presented in Section II. Section III presents the results and analysis followed by conclusions.

II. CROSS-LAYER SIMULATION

A cross-layer simulator has been developed by the authors to evaluate the end-to-end performance. The overall system is divided into modules such as video simulator, raptor system, LTE PHY bit level simulator, and a channel simulator.

- At the transmitter, the video simulator models the transmission of an H.264 video sequence. The video encoder translates video frames into fixed size Network Abstraction Layer Units (NALUs). It is assumed that one NALU is placed into one RTP/UDP/IP packet and also no fragmentation or

retransmissions at MAC are performed. Hence there is a 1:1 mapping between NAL Units and PHY layer Protocol Data Units (PPDU).

- The Raptor encoder (IETF RFC 6330 [3] standard) collects the incoming RTP/UDP packets (i.e. source symbols) from video simulator to construct source blocks each comprising K packets of size T bytes. It also generates a number of repair symbols R defined by the CR [5] [6] and is given by (1). Since we consider systematic raptor codes in our approach, the first K encoded symbols are the original symbols. Note that $CR=1$ represents no raptor in our simulations and a $CR=0.5$ represents an additional 50% overhead.

$$CR = \frac{K}{K + R} = \frac{K}{N} \quad (1)$$

- These N encoded symbols are sent to the LTE-A PHY bit level simulator which models the packet error trace for a sequence of NALUs based on a time varying 3D ITU channel model. This process is performed for various MCS and MIMO modes over a range of SNRs.

- At the receiver, the raptor decoder collects all the UDP packets that belong to a given source block. If the total number of received symbols for a given block of data, $K' \geq (\mathcal{E} + 1) * K$, where $\mathcal{E} > 0$ then, the raptor decoder successfully decodes all the source packets and delivers to the application layer. However, if the decoder fails, only the correctly received source UDP packets are passed up to the application layer. Note that Raptor codes (RQ) have been implemented for only SM MIMO modes.

A. 3D ITU Channel Model

To accurately assess the performance of the MIMO techniques in LTE-A, a 3D ITU channel model developed and published as an open source code (website: <http://enhanced-3d-itu-channel-model.sourceforge.net>) by the university of Bristol has been used. It considers propagations in the azimuth and elevation plane based on point-to-point predictions from each Access Point to every user location for each site-specific urban database. This results in a more accurate estimation of channel capacity, spatial correlation and system level performance [7] [8]. This 3D ITU channel model was developed by extending the existing two-dimensional (2D) 3GPP/ITU channel model's [9] Large Scale parameters (LSPs), which only focus on the propagation in the azimuth plane. The extended LSPs include RMS delay spread and RMS angular spread of the departure azimuth angles, arrival azimuth angles, departure elevation angles and arrival elevation angles. They were obtained by averaging all the channel predictions generated from using a university of Bristol 3-dimensional (3D) ray tracer engine for Bristol macro and micro cellular environments. These generated 3D statistics for an urban macro environment in the city of Bristol have been imported directly into the 3GPP/ITU process for generating 3D channel realizations. An isotropic antenna was deployed when generating the 3D channel statistics. Antennas described in section B have been applied as a spatial-phase-polarization convolution process at a later stage.

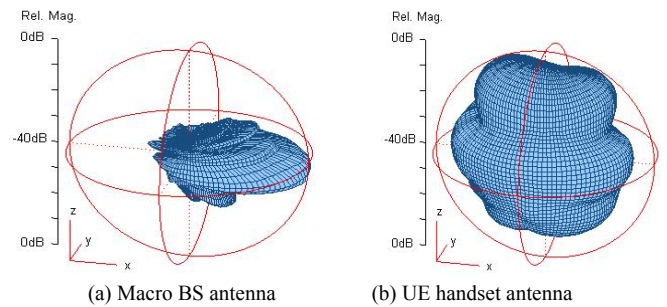


Figure 1: Total measured radiation power.

Parameter		Value
BS Antenna Type		Uniform linear array with 6 dual polarized patches
UE Antenna Type		mobile phone antenna (omnidirectional)
Antenna 3dB Azimuth/Elevation Beamwidth	BS	65°/15°
	UE	360°/36°
BS antenna down tilt		10°

TABLE I: 3D Antenna Pattern Parameters

B. Antenna pattern

For the transmitter, a realistic 10° down-tilted directional base station antenna (directivity 13 dBi) was considered, while at the receiver, an omnidirectional antenna was deployed. This receiver antenna emulates the case of a receiving antenna mounted on the rooftop of a vehicle. These radiation patterns were measured in an anechoic chamber at the university of Bristol. All patterns are 3D and include full phase and polarization information. The total power radiation patterns are shown in Fig.1 and the antenna parameters in Table I.

C. LTE PHY bit level simulator

A detailed LTE PDSCH simulator is used depending on the transport and physical channel processing described in [10]. This is used to evaluate the performance of a user moving at 50kmph in an urban environment assuming a macro cell of 1km radius in the city of Bristol, United Kingdom. The 3D statistics in section A are imported directly into the ITU channel model for generating a set of channel realizations, which are used in the LTE bit level simulator. The channel realizations are normalized and Additive White Gaussian Noise (AWGN) noise is then added to the channel. Table II lists the system parameters, where the NLOS condition is assumed when generating the channel matrix. For each Signal to Noise Ratio (SNR) value, 2000 channel realizations are considered. Channel estimations are carried out on a per sub-frame basis across all subcarriers. A fast fading channel is used to investigate the system's performance using the 2-D interpolation techniques both in frequency and time. A 2D Minimum Mean Square Error (MMSE) channel estimator is used in this study to estimate the channel response from the pilot structure of the LTE resource grid.

TABLE II
LTE SYSTEM PARAMETERS

Parameter	Values
Bandwidth	10MHz
BS Transmission Power	43dBm
Number of Antenna elements	2X2 SM, 2x2 STBC
MIMO antenna spacing	BS (10λ), UE (0.5λ)
Antenna type	Measured Pattern
Carrier Frequencies	2.6 GHz
Wireless Channel Model	Extended 3D 3GPP/ITU channel model
Mobility speeds	50 km/h
Channel Estimation	2D MMSE
Number of OFDM symbols	7
Channel Sampling frequency	15.36 M samples/s
Packet Size	1400 Bytes
LOS condition	NLOS

D. Performance Evaluation

A constant bit rate video sequence is transmitted at 4Mbps. The LTE PHY bit level simulator as discussed in section C is used to model the Packet Error Rate (PER) for different MCS modes, MIMO schemes and raptor code rates. 3GPP LTE-Advanced specification [11] [12] defines the downlink spatial correlation matrix in terms of α (BS spatial correlation) and β (UE spatial correlation) using equations (2) and (3), where \mathbf{h}_{ij} represents the channel matrix for the Rx antenna ($i=1, 2$) and the Tx antenna ($j=1, 2$) for a 2x2 MIMO. The MIMO channel can also be characterized by H matrix determinant given by $Hdet = det [(\mathbf{h}_{ij})(\mathbf{h}_{ij})^H]$, where $(\cdot)^H$ denotes the Hermitian function. 3GPP defines $\alpha=0.9$ and $\beta=0.9$ (or $Hdet<0.1$) as high correlation, $\alpha=0.3$ and $\beta=0.9$ ($Hdet >1$) as medium correlation and $\alpha=0$ and $\beta=0$ ($Hdet >2$) as low correlation.

$$\alpha \text{ (BS correlation)} = \langle \mathbf{h}_{11}(\tau; t), \mathbf{h}_{21}(\tau; t) \rangle \quad (2)$$

$$\beta \text{ (UE correlation)} = \langle \mathbf{h}_{12}(\tau; t), \mathbf{h}_{22}(\tau; t) \rangle \quad (3)$$

$$R_{opt} = (1 - PER) * Bitrate * \min(n_T, n_R) \quad (4)$$

SNR and Hdet can be used to accurately select the required MCS mode in a MIMO system for a defined quality of service [13]. Thus, different types of channels with varying spatial correlation are considered to present the effect on choice of system parameters such as raptor Code Rate (CR) and selected MCS mode. The achievable optimum PHY Peak Rate (R_{opt}) for SM MIMO is given by (4), where PER is the Packet Error Rate, Bitrate is the number of data bits depending on MCS, and n_T, n_R are the number of transmitting and receiving antennas.

III. RESULTS AND ANALYSIS

In this section, the performance of MIMO transmission is presented in terms of target UDP PER ≤ 0.01 as error-free. First, combining the 3D ITU channels with the LTE PHY bit level simulator, the UDP PER for SM MIMO and STBC MIMO without any raptor codes is calculated. Simulations using application layer raptor codes for an SM MIMO system for the same channel conditions as above are then performed to compare the performance with and without raptor codes. Note that for all simulations a packet size of 1400B and a Raptor source block length $K=200$ is used. A number of (1500) raptor encoded UDP packets with different code rates, $0.5 \leq CR \leq 0.95$ are transmitted from the video simulator.

An example of the system performance without raptor codes can be seen in Fig 2 and Fig 3. It can be seen that when the spatial correlation is high ($\alpha > 0.9$ and $\beta > 0.9$ or $Hdet=0.1$), the performance of SM seriously degrades compared to STBC, i.e. SM requires an additional 16dB SNR to achieve a PER=0.01. However, when the channel changes to low correlation values as shown in Fig 3 ($\alpha < 0.1$ and $\beta < 0.1$ or $Hdet > 2$), the SM requires an additional 5dB SNR to achieve the same PER.

An example of the system performance using raptor codes for SM MIMO can be seen in Fig 4 and Fig 5. It can be seen that depending on the MCS, correlation values, and CR, there can be as much as 4dB SNR improvement after using application layer raptor codes. For example in Figure 4, 64QAM3/4 requires SNR > 37 dB in order to provide error-free transmission (PER ≤ 0.01), however, when raptor codes are used with a CR= 0.5, the required SNR is > 33 dB. This is a good improvement considering LTE-A is robust because of its 2D channel estimation technique in frequency and time. This enables either using higher MCS modes for the transmission of data when channel conditions are good and/or extending the coverage area when channel conditions are bad.

It is also observed that, when correlation is high, even very low CRs fail to deliver error-free data to application. For example, when the mean SNR of the channel is 22dB, high correlation ($Hdet=0.1$, Fig 4), QPSK $\frac{3}{4}$ CR=0.5 gives PER=0.75 and fails to deliver error-free transmission (PER < 0.01). With low correlation ($Hdet > 2$, Fig 5), a CR of 0.5 can provide error free transmission for QPSK $\frac{3}{4}$ at SNR=6dB. This is because, the decoding success of raptor codes depends on the symbol block error rate in a source block and even if a single block is not decoded successfully, it results in a very high UDP PER. In general, when correlation is high, the probability of observing longer bursts of errors in a source block is increased.

Simulations for different correlation values ($0.01 < Hdet < 4$) with a range of SNR values and MCS modes have been performed for SM MIMO using raptor codes. A link adaptation system is proposed to analyze the PER performance (outputs best CR and MCS with a target UDP PER ≤ 0.01 for inputs SNR and Hdet). Finally, this system is used in a realistic channel model to evaluate the peak data rate performance for SM MIMO with and without raptor codes.

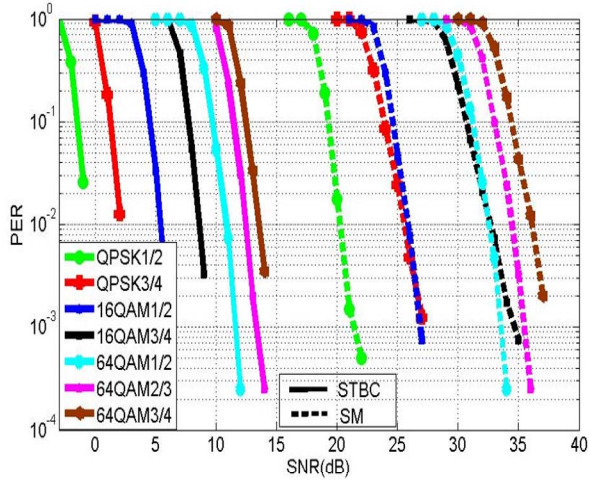


Figure 2: UDP PER performance comparison SM and STBC ($H_{det}=0.1$)

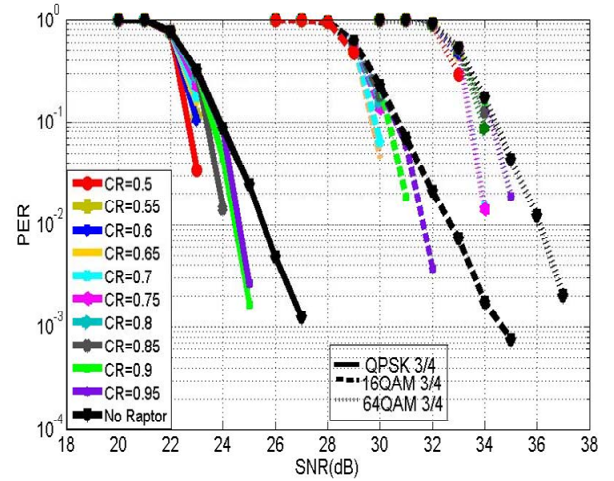


Figure 4: UDP PER performance of SM using Raptor code rates ($H_{det}=0.1$)

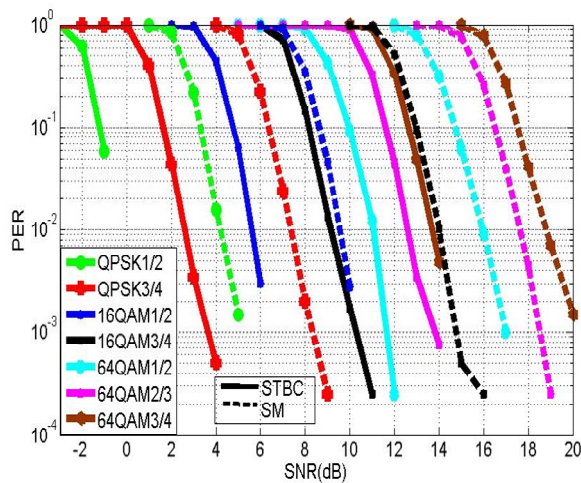


Figure 3: UDP PER performance comparison SM and STBC ($H_{det}>2$)

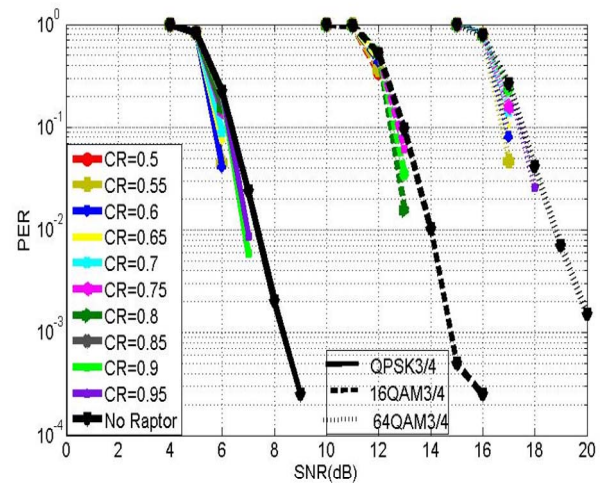


Figure 5: UDP PER performance of SM using Raptor code rates ($H_{det}>2$)

IV. CASE STUDY

The above-proposed system is evaluated in a realistic environment for a route in the city center of Bristol, UK as shown in Fig. 6. A state of the art 3D ray tracer [14] was used to generate the time-varying MIMO channel matrix between the Access Point and the user moving at 50kmph to replicate the time and space correlated nature of the received signal along a route. Since the channel changes over time the link adaptation parameters (best CR, MCS for a given SNR and H_{det}) are evaluated every half second (time slots) using our proposed system and the PHY peak data rate is calculated using equation (4). In this study, the most appropriate MCS mode and CR for the given channel conditions are selected based a target UDP PER ≤ 0.01 . Fig 7 and 8 show received mean SNR and H matrix determinant for the route.

In Fig 9, the achievable PHY peak rate for SM with and without Raptor codes and STBC is compared. It can be seen that with low correlation (time slots 85-280 sec), SM with raptor codes performs better than STBC. However, when the spatial correlation is high (timeslots 20-85 sec), STBC performs better than SM. This is because STBC performance

strongly depends on SNR whereas, SM performance depends on both SNR and correlation. However, with the use of raptor codes, SM performance can be significantly improved in some of these locations as shown in the Fig 9.



Figure 6: Route of Bristol city Centre for case study

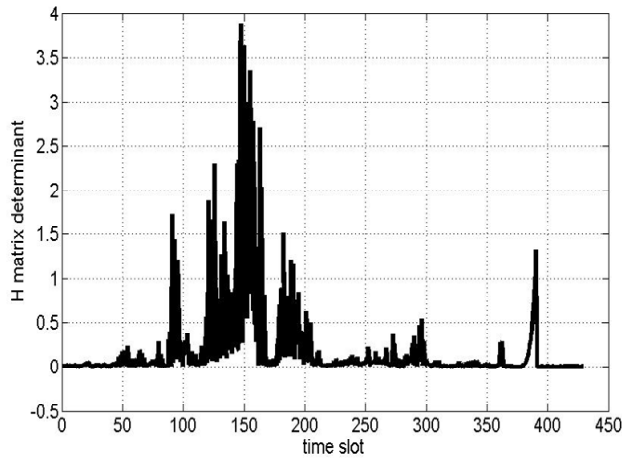


Figure 7: Received H matrix determinant through the route

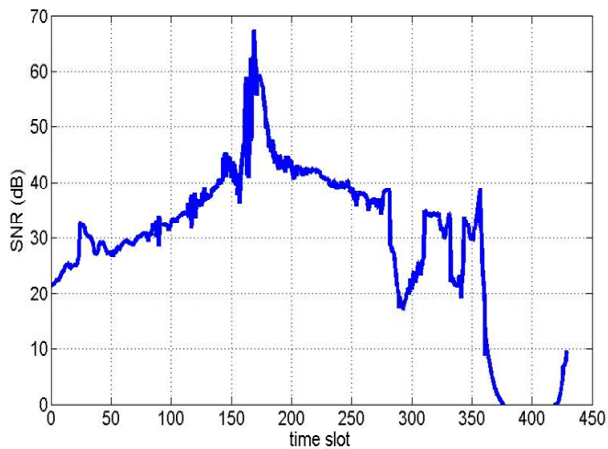


Figure 8: Received SNR through the route.

V. CONCLUSIONS

In this paper, a cross-layer system based on latest Raptor Q codes to enhance reliability and transmission efficiency for a given target UDP PER have been examined. Simulations have been performed for different channel conditions for a user moving at 50kmph in LTE cell. Results indicate that SM MIMO with raptor codes can provide up to 4dB SNR improvement to achieve $PER \leq 0.01$ in a highly correlated channels (bad channel conditions). However, this requires a high number of repair packets to provide reliability and results in reduced transmission efficiency. Therefore, STBC shows better peak data rate in some scenarios. When the channel has a lower correlation (good channel conditions), SM with Raptor codes outperforms STBC and can be used to increase the reliability and transmission efficiency of the system.

ACKNOWLEDGMENTS

Jayashree Thota would like to acknowledge the technical contribution of Andrew Lavey of Jaguar Land Rover and expresses her gratitude for their financial support.

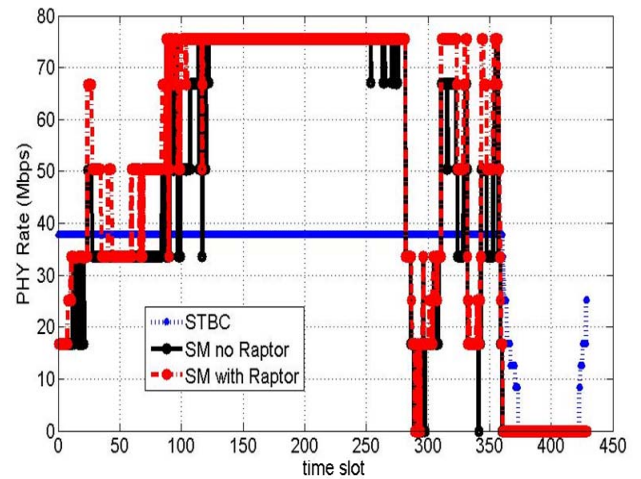


Figure 9: Comparison of achievable PHY peak rate, UDP PER $\leq 1\%$, $K=200$

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