Proc. of the 9th International Wireless Communications and Mobile Computing Conference (IWCMC)

Optimized Cross-Layer Protocol Choices for LTE in High-Speed Vehicular Environments

Bjoern Dusza, Christoph Ide, Patrick-Benjamin Bök and Christian Wietfeld
Communication Networks Institute
TU Dortmund University
44227 Dortmund, Germany
e-mail: {Bjoern.Dusza, Christoph.Ide, Patrick-Benjamin.Boek, Christian.Wietfeld}@tu-dortmund.de

***Abstract*— One important advantage of the Orthogonal Frequency Division Multiple Access (OFDMA) based cellular communication system Long Term Evolution (LTE) is its robustness against different kinds of impairments as they may occur on the mobile radio communication channel. This includes an increased toughness not only in harsh multi path scenarios, but also for the case of extremely high user velocities. In this paper, the applicability of the LTE system for two example applications (LTE based backhaul for high speed trains and live transmission of flight recorder data) is investigated by means of extensive throughput measurements (TCP and UDP) incorporating a radio channel emulator. The measurement results show that LTE in general is capable to provide reliable communication links for both considered scenarios. However, extreme velocities as they occur in a "flight data transmission at cruising speed" scenario rely on a specialized cross-layer parameterization.**

***Keywords*—LTE, Performance Evaluation, Cross-Layer Parameterization, UDP, TCP**

I. Introduction

The increased robustness of LTE compared to its predecessor technologies allows for a variety of novel applications. In this paper, the focus lies on two particular scenarios which are characterized by extremely high user velocities. The aim here is to determine whether and, if so, under which conditions extremely high user speeds can be handled by the LTE system. The example use cases are described in the following.

Connecting the people on board of high speed trains to the Internet has been an ongoing research topic in the past [1], [2], [3]. In this context one could imagine either a direct link from the user to the Evolved Node B (eNodeB) or a heterogeneous network consisting of WiFi inside the train and an LTE backhaul. While the direct link poses no additional costs to the railway operators, the data aggregation approach comes along with an increased Signal to Noise Ratio (SNR) which is due to the usage of exterior antennas with high antenna gain. Fig. 1 illustrates such scenario.

An even more challenging possible application of LTE is the live transmission of civil aircrafts flight recorder data. While the usefulness of such proceeding has already been recognized in the past, the only suitable solution for such data transmission have been satellite links with very limited bandwidth [5]. Although satellite links will never be completely substituted by LTE due to

978-1-4673-2480-9/13/$31.00 © 2013 IEEE

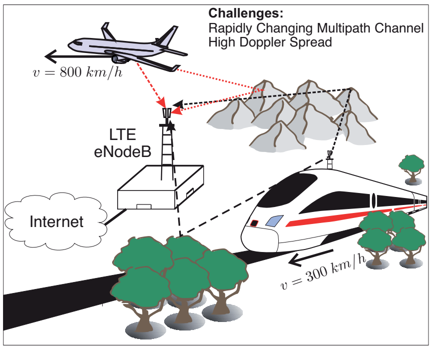

Fig. 1. Multipath Propagation in High Speed Scenarios.

their worldwide availability (especially over water), the cellular system can be a valuable supplement in urban areas which are characterized by over proportionally crowded airspace. First ideas on this LTE based Direct Air to Ground Communication (DA2GC) are presented in [6].

The aim of this paper is to provide a well-founded estimation of the applicability of LTE for the two different scenarios. For this purpose, sophisticated laboratory throughput measurements (Transmission Control Protocol (TCP) and User Datagram Protocol (UDP)) based on an LTE base station emulator and a mobile radio channel emulator have been performed. This includes the variation of the signal to noise ratio as well as the emulated user velocity, the applied Modulation and Coding Scheme (MCS) and the Automatic Repeat Request (ARQ) mode of operation. Table I illustrates the relevant degrees of freedom on the different layers of

TABLE I
PROTOCOL STACK WITH STATE-OF-THE-ART SYSTEM PARAMETERIZATION FOR DIFFERENT APPLICATIONS.

	Real-time PER < 1 % All Velocities	**Non-real-time PER = 0 % v ≤ 200 km/h**	**Non-real-time PER = 0 % v > 200 km/h**
Transport Layer	UDP	TCP	TCP
Network Layer	IP	IP	IP
Data Link Layer RLC Mode	UM [4]	AM [4]	AM [4]
Data Link Layer MAC	HARQ	HARQ	HARQ
Physical Layer MCS	?	?	?

the protocol stack and pinpoints the usually proposed cross-layer parameterization.

The rest of this paper is organized as follows. In Section II, an overview of the related work is given before the measurement setup and the measurement campaign are described in Section III. The results of the data rate measurements for pure Additive White Gaussian Noise (AWGN) channels as best case reference are given in Section IV before the measured data rates for the actual vehicular multipath fading channels are presented in Section V. In Section IV, the achievable throughput as a function of the user velocity is shown including the case of extremely high speed. Section VII concludes the work and gives a short outlook.

II. Related Work

In [7] performance issues if using TCP over LTE are investigated. The results show that Radio Link Control (RLC) Acknowledged Mode (AM) outperforms the Unacknowledged Mode (UM) in terms of the achievable throughput. To reduce the deriving overhead from multi-layer ARQ, in [8] a cross-layer error control optimization for LTE networks which reduces the number of TCP acknowledgment packets (ACK) that come with short Medium Access Control (MAC) layer frames is proposed. Simulation results show that this approach may be able to improve the performance of TCP over LTE. Also in [9] the influence of ARQ on the performance of TCP in LTE is analyzed, but with focus on hybrid ARQ on the MAC layer which has a higher impact on the performance of TCP than the RLC ARQ. Similar results are shown for other environments in [10], [11].

In [12] different variants of TCP are analyzed for LTE. All variants differ regarding their influence on the performance and, thereby, user satisfaction. [13] and [14] illustrate how to improve end user satisfaction in LTE networks for mixed traffic scenarios by improving the Quality of Service (QoS) support and, thus, flow control mechanisms (also see [15]). [16] proposes to use additional hardware for on-the-fly protocol improvement of TCP which is however not practicable in real environments. The performance of TCP during intra LTE handover is studied using simulations in [17] and [18], and using a test-bed in [19]. All three papers present different approaches to improve the performance of TCP in handover scenarios, but all neglect the impact of mobility on the radio channel characteristics. Although the analysis of TCP has not been a hot topic for LTE networks by now, it has been a topic for different variants of IEEE 802.11 networks (cf. [20], [21], [22]). All of these papers show solutions that are in parts comparable to the previously described approaches for LTE environments.

All of the work mentioned before tries to improve the performance of TCP in LTE networks, but most of the current research neglects the mobility of nodes, especially with high cruising speeds that occur if a node moves by high-speed train or plane.

III. Measurement Setup and Campaign

For performing the radio channel aware throughput measurements, the setup illustrated in Fig. 2 is used. It consists of an Rohde & Schwarz CMW 500 LTE Base Station Emulator (BSE) as well as an Elektrobit Propsim C8 radio channel emulator. Using these devices in the laboratory comes along with the important advantage of full system control compared to field test approaches. Beside this, real world field tests for the special high user speed investigations would pose major challenges and are significantly lacking controllability. Thus, the laboratory test-bed, although not completely realistic, is the best available choice. The setup is completed by a Universal Serial Bus (USB) enabled Samsung GT-B3740 LTE User Equipment (UE) and two Personal Computer (PC) with iPerf [24] and D-ITG [25]. For coupling the radio signal from the UE to the Radio Frequency (RF) cables used in the setup, a shielding box with integrated antenna is used.

TABLE II
LTE System Parameterization.

BSE Parameter	Value
Carrier Frequency (Uplink)	847 MHz (LTE Band 20)
Channel Bandwidth	10 MHz
Duplexing Scheme	FDD
Uplink Tx-Power	5 dBm
Allocated PRB	50
MAC Scheduling	constant (single user scenario)
Modulation and Coding Scheme	TBS-IDs 1 to 19
RLC mode	AM & UM
Antenna Scheme	1x1 (SISO)
Channel Emulator Parameter	**Value**
SNR	5 to 30 dB
Fading Channel Model	Extended Vehicular A [23]

The most important system parameters that are set at the LTE BSE are the MCS as well as the RLC mode of operation [4]. While AM makes use of a highly reliable window-based selective repeat ARQ, this feature is disabled in the so called RLC UM. However, it is worth noting that the Hybrid ARQ (HARQ) on the MAC layer is not effected by the RLC mode of operation. The most important parameters that are set at the radio channel emulator are the signal to noise ratio and the user velocity that relates to the relevant Doppler spectrum as well as the dynamic of the channel tap amplitudes. For the measurements presented in this paper, the tap delay line model Extended Vehicular A (EVA) [23] is applied as well as a pure AWGN channel. A comprehensive list of the parameters used for the measurements is given in Table II. More details on the radio channel emulator mode of operation are available in [26], [27]. For the throughput analysis, iPerf [24] is chosen for both, TCP and UDP measurements with a TCP window size of 50 kByte and a UDP packet size of 1460 Byte respectively. The Round Trip Time (RTT) for each measurement campaign has been determined using D-ITG [25] with default configuration.

IV. Reference Measurements for Pure AWGN Channel

For the determination of the available SNR dependent TCP throughput over the LTE uplink, reference measurements have been performed for a Line of Sight (LOS) channel with no multipath propagation and a variable

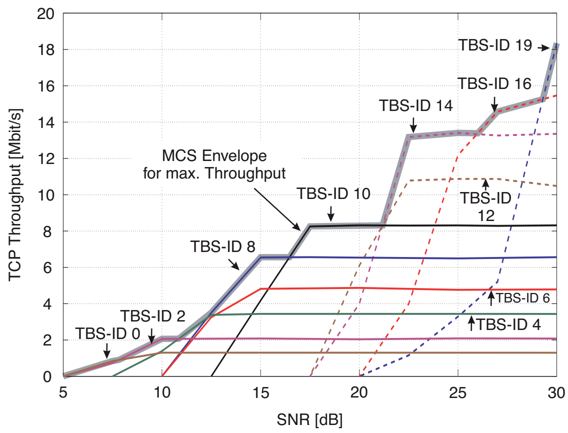

Fig. 3. MCS and SNR Dependent TCP Throughput for Pure AWGN Channel (**RLC Acknowledged Mode**).

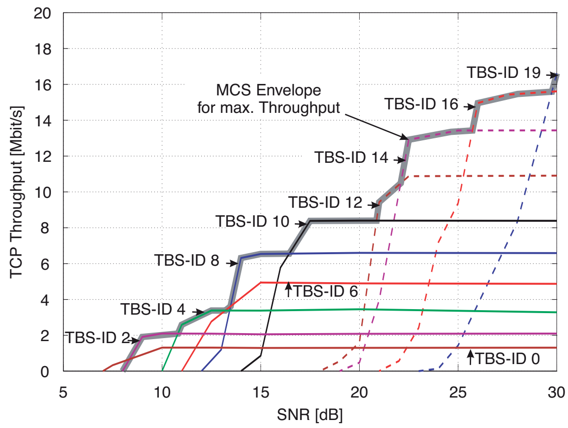

Fig. 4. MCS and SNR Dependent TCP Throughput for Pure AWGN Channel (**RLC Unacknowledged Mode**).

SNR. For varying the SNR, the signal power at the input of the radio channel emulator is measured and AWGN is created to match the predefined SNR (cf. [26]). Fig. 3 shows the so derived results for TCP with an additional ARQ on the LTE RLC layer (acknowledged mode).

One can see from the plot that for high SNR values, very high order MCS can be applied which allow for data rates of up to 18 Mbit/s. Together with the MCS dependent achievable throughput, Fig. 3 shows the optimum MCS envelope. For achieving the optimum SNR dependent data rate, the MCS have to be switched referring to this curve. Although TCP traffic is usually combined with the RLC acknowledged mode [4], one aim of this paper is to investigate the cross layer interdependencies and therefore the specific impact of the different RLC modes of operation. For this purpose, the measurement has been repeated for the RLC UM. Fig. 4 illustrates the corresponding results.

V. TCP Throughput for Vehicular Multipath Environments

In how far the achievable TCP throughput is effected by degradation due to multi-path propagation is investigated by additional measurement campaigns for which an EVA radio channel at a fixed user velocity of 60 km/h is enabled. Fig. 5 illustrates the corresponding results for the case of an enabled RLC acknowledged mode. Beside the fact that the maximum achievable data rate decreases to only 3.9 Mbit/s at 30 dB SNR, one can observe an increased minimum SNR that is required for achieving an example data rate of 500 kbit/s has increased from 7 dB for the AWGN case to now 14 dB. Furthermore, the determination of the optimum MCS switching points is not as clear and simple as for the AWGN case. This is due to the complex cross layer interdependencies between the MCS, the MAC HARQ, the RLC ARQ and the TCP ARQ. Simplifying these cross layer issues by disabling the RLC ARQ leads to the result plot in Fig. 6. Although for this system parameterization the minimum SNR requirement increases further to 17 dB for a data rate of 500 kbit/s, the overall shape of the data rate result plot becomes much clearer and the optimum MCS switching points therefore easier to determine. Fig. 7 summarizes the results obtained so far. It shows the optimum throughput envelopes for the pure AWGN channel as well as the EVA60 channel for both the RLC acknowledged and unacknowledged mode. On top of this, the UDP data rates for the respective radio channels from [26] are shown in the figure. The most important observation here is that although the acknowledged mode has its advantages for very low SNR, i.e. very bad radio channel conditions, the performance for a wide range of SNR values is equal for both RLC modes. Therefore, the optimal solution would be to apply the RLC acknowledged mode, that comes along with an increasing system complexity and overhead, only for SNR below 10 dB in case of LOS conditions and below 18 dB in Non-Line-of-Sight (NLOS) vehicular scenarios.

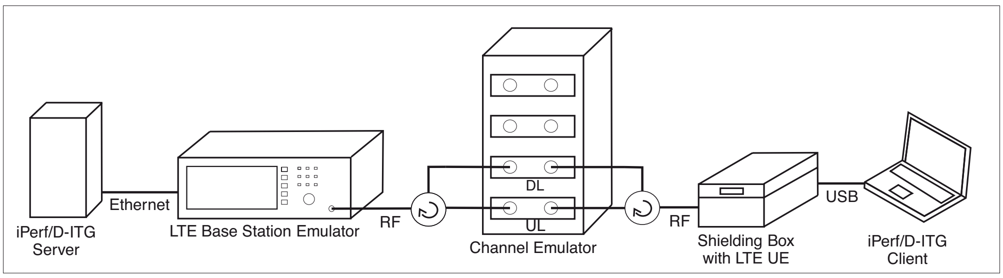

Fig. 2. Measurement Setup for Bi-Directional LTE Performance Testing.

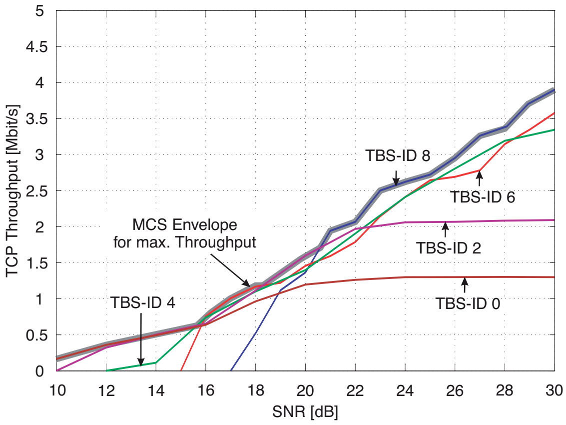

Fig. 5. MCS and SNR Dependent TCP Throughput for Extended Vehicular A Channel (**RLC Acknowledged Mode**).

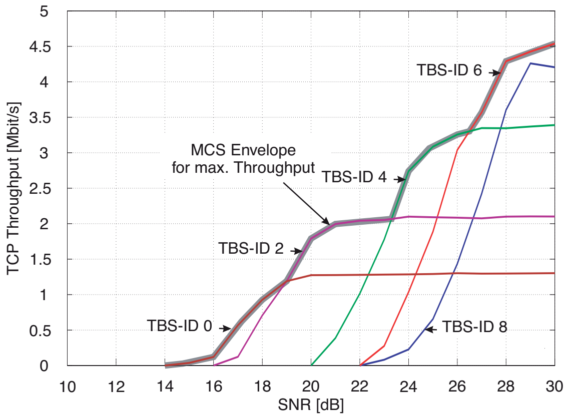

Fig. 6. MCS and SNR Dependent TCP Throughput for Extended Vehicular A Channel (**RLC Unacknowledged Mode**).

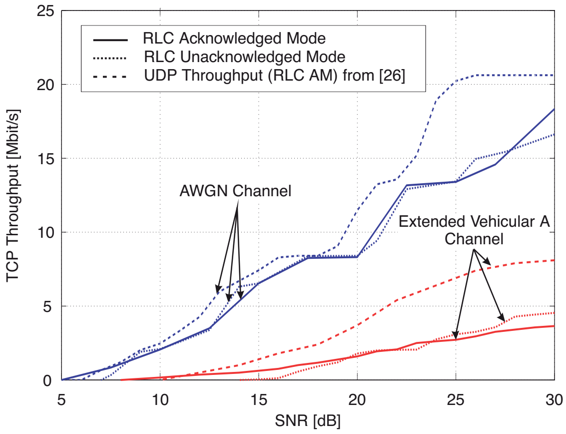

Fig. 7. Radio Channel Dependent TCP Throughput Assuming an Optimum MCS Choice.

VI. User Velocity Dependent Throughput

Although a velocity of 60 km/h as assumed in the previous section is very common for vehicular scenarios in urban and suburban environments, the specific applications of LTE addressed in Section I are requiring for much higher user velocities. For this reason, additional measurement campaigns are performed for which the SNR is kept constantly at 30 dB while the emulated user velocity is varied. Fig. 8 shows the respective results for the RLC acknowledged mode and TCP traffic. Again it can be observed that the acknowledged mode is characterized by a unclear determination of the channel dependent optimum MCS (cf. Fig. 5). Quite in contrary, the achievable throughput for the higher order MCS is almost independent of the actually applied scheme for the velocity range of 60 km/h to 200 km/h which is a typical cruising speed of high speed trains in urban areas. Nevertheless, a data transmission remains possible for user velocities of up to 750 km/h applying the optional RLC AM. Beside the achievable throughput, the average RTT is an important Key Performance Indicator (KPI) for some applications (e.g. web surfing). For this reason, the results of the additionally performed RTT measurements are also given in Fig. 8. Here, one can observe a significant impact of the user velocity on the delay reaching up to 3.3 s. If this high delay is not acceptable for a specific application, switching off the RLC AM might be a suitable solution. The achievable results without this additional error correction scheme

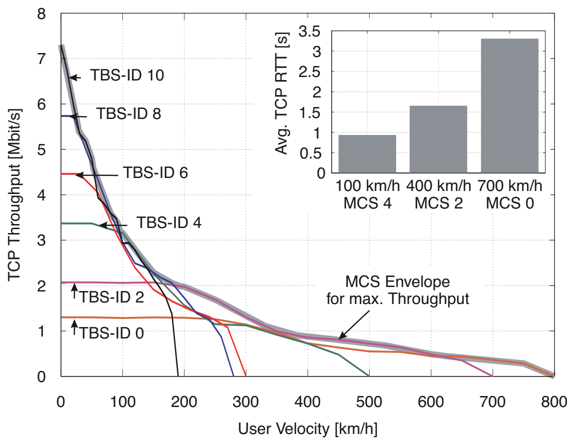

Fig. 8. MCS and User Velocity Dependent TCP Throughput for Extended Vehicular A Channel (**RLC Acknowledged Mode**).

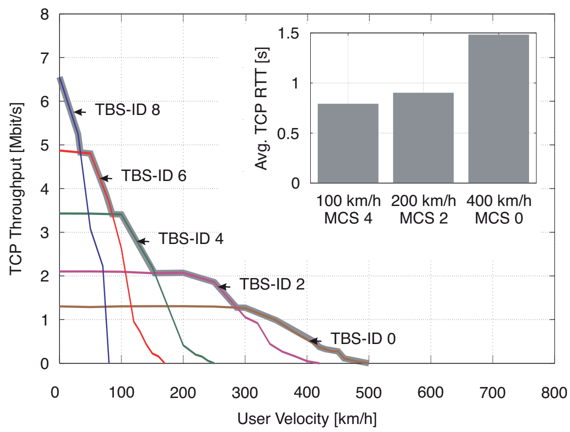

Fig. 9. MCS and User Velocity Dependent TCP Throughput for Extended Vehicular A Channel (**RLC Unacknowledged Mode**).

are illustrated in Fig. 9. For this case, one can observe that the determination of the velocity dependent MCS is much simpler. However, the maximum achievable user velocity is restricted to only 450 km/h which is still sufficient for high speed train scenarios. For the velocities that are possible using the unacknowledged mode, the RTT is slightly reducing from 0.93 s to 0.79 s for a velocity of 100 km/h and from 1.65 s to 1.48 s for a velocity of 400 km/h. However, for the real time flight recorder data transmission the RTT is not crucial. Therefore, the AM should be applied all the time to ensure reliable communication even for extremely high velocities (cf. Fig. 8).

While until now the RLC mode of operation was the only variable parameter for the investigation of the cross-layer interdependencies, in the following the transport layer protocol is switched from TCP to UDP. The additional requirement for the UDP throughput measurement is that the Packet Error Rate (PER) has to be below 1 %. This is a realistic assumption for many real time applications such as Voice over IP (VoIP) or video streaming [28]. If the PER target can not be fulfilled for any source data rate, the radio channel is considered as unsuitable for the given MCS and the achievable throughput is set to zero. Fig. 10 shows the results for UDP and the RLC unacknowledged mode which is a common combination for real-time applications [4]. Beside the fact that the maximum tolerable velocity is only 250 km/h, the throughput curves are characterized by immediate throughput drops. These are due to the fact that if the PER can not be fulfilled for a given velocity, reducing the source data rate does not have any effect. This is different for the combination of UDP and the RLC acknowledged mode as it can be seen in Fig. 11. Here, reducing the source data rate frees resources that can be used for ARQ retransmissions. This leads to the fact that if the PER target cannot be fulfilled for a given source data rate, lowering this rate leads to an error free transmission from a transport layer point of view. For the RTT one can observe that for UDP with no RLC ARQ, the measured values are independent of the user velocity. This is due to the fact that only those MCS/velocity combinations with almost no packet loss (< 1 %) after the MAC ARQ are considered. For this case, no additional delay is introduced by higher layer retransmissions. For the combination of UDP on the transport layer and the acknowledged mode on the RLC layer one can again observe an impact of the user velocity on the RTT. However, the RTT is still far below the corresponding value for the TCP case (e.g. 0.28 s vs. 3.3 s at 700 km/h user velocity).

Finally, Fig. 12 compares the achievable data rates and RTTs for all possible permutations of RLC mode of operation and transport layer protocol. The most interesting outcome of this study is that the very unusual combination of UDP and the RLC acknowledged mode allows for the highest throughput for the whole velocity range while allowing for very low delays. This means that if an application can cope with an residual error of up to 1 %, this combination can be considered as the most suitable cross layer parameterization for extreme channel conditions in terms of high user mobility. If an error free transmission is mandatory (e.g. for file transfer application) the TCP protocol has to be used on the transport layer. However, for user velocities below 300 km/h (e.g. high speed train) using the RLC AM

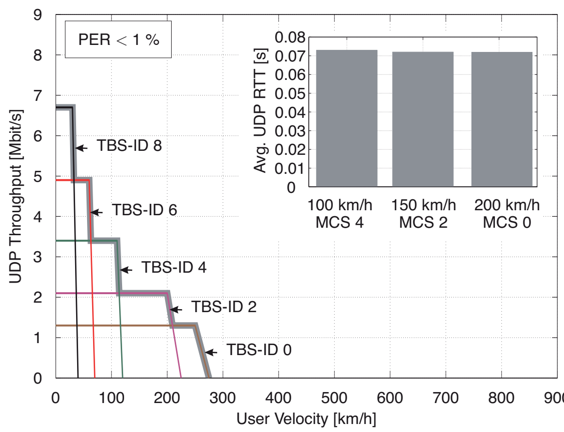

Fig. 10. MCS and User Velocity Dependent UDP Throughput for Extended Vehicular A Channel (**RLC Unacknowledged Mode**).

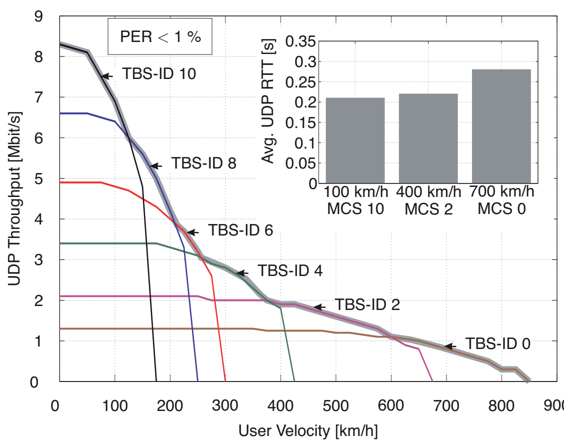

Fig. 11. MCS and User Velocity Dependent UDP Throughput for Extended Vehicular A Channel (**RLC Acknowledged Mode**).

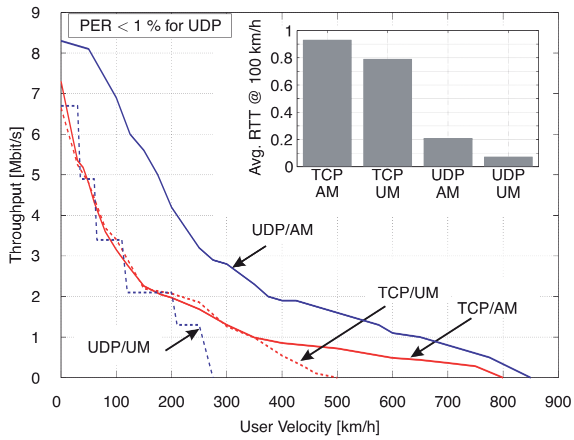

Fig. 12. User Velocity Dependent Throughput for Optimum MCS Choice.

has no impact on the achievable throughput and should therefore be disabled to reduce the RTT.

VII. Conclusion

In this paper, we have presented the results of an extensive measurement campaign on the impact of extreme channel conditions on the achievable throughput over the LTE uplink as well as the impact of these conditions on the signal round trip time. The results show that applying a suitable cross layer system parameterization incorporating physical, MAC, RLC and transport layer protocols, LTE enabled high speed train applications are possible as well as flight recorder data transmission. In particular we suggest the cross layer parameterizations given in Table III for achieving optimal results in the given extreme communication scenarios. This includes a concrete proposition of user velocity dependent MCS. Unlike it is generally expected, the results show that for UDP applications the RLC AM mode causes a better performance than UDP with RLC UM mode.

TABLE III
Protocol Stack with Recommended System Parameterization for Different Application.

	Real-time PER < 1 % All Velocities	**Non-real-time PER = 0 % v $\leq$ 200 km/h**	**Non-real-time PER = 0 % v $>$ 200 km/h**
Transport Layer	UDP	TCP	TCP
Network Layer	IP	IP	IP
Data Link Layer RLC Mode	**AM**	**UM**	AM
Data Link Layer MAC	HARQ	HARQ	HARQ
Physical Layer MCS	**cf. Fig. 11**	**cf. Fig. 9**	**cf. Fig. 8**

In the future we are going to extend our work by testing realistic application mixes over the high velocity radio link.

Acknowledgment

Part of the work on this paper has been supported by Deutsche Forschungsgemeinschaft (DFG) within the Collaborative Research Center SFB 876 Providing Information by Resource-Constrained Analysis, projects A4 and B4.

References

[1] Y. Zhou, Z. Pan, J. Hu, J. Shi, and X. Mo, "Broadband wireless communications on high speed trains," in *20th Annual Wireless and Optical Communications Conference (WOCC)*, apr. 2011, pp. 1 –6.

[2] K.-D. Lin and J.-F. Chang, "Communications and entertainment onboard a high-speed public transport system," *IEEE Wireless Communications*, vol. 9, no. 1, pp. 84 – 89, feb. 2002.

[3] G. Tingting and S. Bin, "A high-speed railway mobile communication system based on LTE," in *International Conference On Electronics and Information Engineering (ICEIE)*, aug. 2010, pp. V1–414 –V1–417.

[4] A. Larmo, M. Lindstrom, M. Meyer, G. Pelletier, J. Torsner, and H. Wiemann, "The LTE link-layer design," *IEEE Communications Magazine*, vol. 47, no. 4, pp. 52 –59, apr. 2009.

[5] M. Werner and M. Holzbock, "System design for aeronautical broadband satellite communications," in *IEEE International Conference on Communications (ICC)*, may 2002, pp. 2994 – 2998 vol.5.

[6] E. C. Committee, "Surfing the clouds: ECC works on Broadband Direct-Air-to-Ground Communications," jun. 2012. [Online]. Available: http://apps.ero.dk/eccnews/june-2012/surfing-the-clouds.html

[7] H.-S. Park, J.-Y. Lee, and B.-C. Kim, "TCP performance issues in LTE networks," in *International Conference on ICT Convergence (ICTC)*, sep. 2011, pp. 493 –496.

[8] D. Kliazovich, F. Granelli, S. Redana, and N. Riato, "Cross-Layer Error Control Optimization in 3G LTE," in *IEEE Global Telecommunications Conference (GLOBECOM)*, dec. 2007, pp. 2525 –2529.

[9] K. Sandrasegaran, S. Reeves, H. Ramli, and R. Basukala, "Analysis of Hybrid ARQ in 3GPP LTE systems," in *16th Asia-Pacific Conference on Communications (APCC)*, nov. 2011, pp. 418 – 423.

[10] V. Subramanian, K. Ramakrishnan, and S. Kalyanaraman, "Experimental study of link and transport protocols in interference-prone wireless LAN environments," in *1st International Communication Systems and Networks and Workshops (COMSNETS)*, jan. 2009, pp. 1 –10.

[11] M. Heusse, G. Urvoy-Keller, and A. Duda, "Layer 2 vs. layer 3 mechanisms for improving TCP performance in 802.11 wireless LANs," in *21st International Teletraffic Congress (ITC)*, sep. 2009, pp. 1 –8.

[12] G. Abed, M. Ismail, and K. Jumari, "Appraisal of Long Term Evolution System with Diversified TCP's," in *5th Asia Modelling Symposium (AMS)*, may 2011, pp. 236 –239.

[13] Q. Qiu, C. Jian, P. Lingdi, and P. Xue-zeng, "Hierarchy Virtual Queue Based Flow Control in LTE/SAE," in *2nd International Conference on Future Networks (ICFN)*, jan. 2010, pp. 78 –82.

[14] I. Siomina and S. Wanstedt, "The impact of QoS support on the end user satisfaction in LTE networks with mixed traffic," in *19th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, sep. 2008, pp. 1 –5.

[15] A. Yamaguchi, T. Fujimoto, Y. Imagaki, and T. Fukuhara, "Downlink Link Aggregation Performance with Delay Adjustment Capability in Multi-Radio Access System," in *73rd IEEE Vehicular Technology Conference (VTC Spring)*, may 2011, pp. 1 –5.

[16] K. Liu and J. Lee, "Mobile accelerator: A new approach to improve TCP performance in mobile data networks," in *7th International Wireless Communications and Mobile Computing Conference (IWCMC)*, jul. 2011, pp. 2174 –2180.

[17] D. Pacifico, M. Pacifico, C. Fischione, H. Hjalrmasson, and K. Johansson, "Improving TCP Performance During the Intra LTE Handover," in *IEEE Global Telecommunications Conference (GLOBECOM)*, dec. 2009, pp. 1 –8.

[18] W. Ahn, Y. Gwak, and Y. Y. Kim, "A low-complexity delay injection algorithm for improving TCP performance during LTE intra handover," in *International Conference on Information Networking (ICOIN)*, feb. 2012, pp. 177 –181.

[19] L. Zhang, T. Okamawari, and T. Fujii, "Performance evaluation of TCP and UDP during LTE handover," in *IEEE Wireless Communications and Networking Conference (WCNC)*, apr. 2012, pp. 1993 –1997.

[20] C. P. Fu and S. Liew, "TCP Veno: TCP enhancement for transmission over wireless access networks," *IEEE Journal on Selected Areas in Communications*, vol. 21, no. 2, pp. 216 – 228, feb. 2003.

[21] E. Yanmaz, S.-C. Wei, and O. Tonguz, "Performance enhancement techniques for TCP over wireless links," in *61st IEEE Vehicular Technology Conference (VTC Spring)*, jun. 2005, pp. 2245 – 2249 Vol. 4.

[22] J.-Y. Yoo and J. Kim, "Impact of TCP ACK Losses on TCP Fairness in Wireless Mesh Networks," in *IEEE Global Telecommunications Conference (GLOBECOM)*, dec. 2009, pp. 1 –6.

[23] ETSI, "Base Station (BS) Radio Transmission and Reception," 2008.

[24] (Accessed 2007) NLANR/DAST : Iperf - The TCP/UDP Bandwidth Measurement Tool. http://dast.nlanr.net/Projects/Iperf/. [Online]. Available: http://dast.nlanr.net/Projects/Iperf/

[25] A. P. A. Dainotti, A. Botta, "A tool for the generation of realistic network workload for emerging networking scenarios," *Computer Networks (Elsevier)*, vol. 56, no. 15, pp. 3531–3547, oct. 2012.

[26] B. Dusza, C. Ide, and C. Wietfeld, "Measuring the Impact of the Mobile Radio Channel on the Energy Efficiency of LTE User Equipment," in *21st International Conference on Computer Communications and Networks (ICCCN)*, aug. 2012, pp. 1 –5.

[27] C. Ide, B. Dusza, and C. Wietfeld, "Mobile WiMAX Performance Measurements with Focus on Different QoS Targets," in *18th IEEE Workshop on Local and Metropolitan Area Networks (LANMAN)*, Chapel Hill, North Carolina, USA, oct. 2011.

[28] C. Lewis and S. Pickavance, *Selecting MPLS VPN Services*, 1st ed., ser. Networking Technology. Cisco Press, pp. 167- 169, feb. 2006.