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Energy Efficient LTE-Based Floating Car Data Collection for Dynamic Traffic Forecasts

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***Abstract*—In this paper, an energy efficient approach for the transmission of Floating Car Data (FCD) via Long Term Evolution (LTE) is presented. Applying channel sensitive transmission, FCD is collected by mobile devices in cars and transmitted preferably if the channel conditions are good. The results show that this approach reduces the negative impact on the utilization of the LTE air interface as well as on the energy consumption of the mobile devices. For the performance evaluation of the LTE system, a close to reality parametrized Markovian model is used. The parameters of the model are determined by laboratory measurements and ray tracing simulations. In the laboratory, also the energy consumption of the used LTE USB stick is measured. Hence, we evaluated that the channel sensitive transmission allows for an energy saving of up to 54 % for the transmission of the FCD.**

I. INTRODUCTION

The increasing availability of modern Orthogonal Frequency Division Multiple Access (OFDMA) based communication systems such as LTE comes along with a variety of innovative application fields beside the classical Human to Human (H2H) communication. Especially the communication between embedded sensor nodes and the corresponding infrastructure via cellular networks is rapidly gaining importance in the last few years. One example of this so called Machine to Machine (M2M) communication is the collection and distribution of Floating Car Data (FCD) for dynamic traffic forecasts. Therefore, sensors on board a vehicle are collecting information regarding for example position, velocity and acceleration (see Fig. 1). From a larger set of these information, belonging to different cars, reliable traffic jam prognosis can be derived. For the submission of the FCD to the infrastructure LTE is considered as promising candidate technology. A practical implementation of such a system could for example enhance navigation systems instead of being directly integrated to the car. As these devices are usually battery powered the submission of the FCD has to be performed as energy efficient as possible.

Therefore, in this paper we present an approach which allows for massive energy savings in the specific scenario by applying a channel sensitive transmission scheme. The basic idea is that preferably those devices encountering good channel conditions are allowed to transmit their data. As good channel conditions come along with a high spectral efficiency, the transmission time and therefore the energy needed for submission of a fixed sized datagram can be significantly reduced. For the performance analysis and quantification of the enhancements a sophisticated system model based on energy measurements in the laboratory and a close to reality parametrized Markovian model [1] are applied.

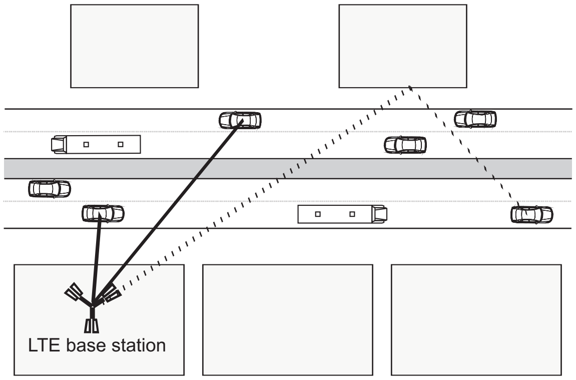

Fig. 1: Highway scenario with M2M communication via LTE for the transmission of Floating Car Data

II. RELATED WORK

Modeling the energy consumption of modern smart-phones is gaining importance during the last few years. This is due to the fact that cellular phones are no longer only phones but complete portable computer with lots of additional functions. This comes along with the fact that the power consumption is significantly increasing. In [2] an approach is presented which allows for the automated construction of energy models for Android based smart phones. Instead of measuring the actual current drain from the battery the method described here bases on the battery voltage sensor and knowledge about the battery discharge voltage curve. Although the model covers the power consumption of the overall device, the radio parts for WiFi and 3G are only modeled by means of three states each (Idle, Forward Access Channel (FACH) and Dedicated Transport Channel (DCH) for 3G). A comparable approach can also be found in [3] where only two states (Idle and active) for the energy consumption of the 3G radio interface are assumed.

A much more detailed investigation of the energy consumption of GSM, UMTS and WiFi has been performed in [4]. Here, the impact of different locations and different times are taken into consideration as well as user mobility. For the evaluation of the energy consumption the measured value is divided into a ramp-part, a data-part and a tail-part. The measurements show that for short data bursts the setup of the data channel as well as the termination causes significant costs in terms of energy consumption.

The inclusion of M2M communication into common traffic of cellular communication systems is one of the main goals in the standardization process of LTE-Advanced [5] [6]. In this context, the impact of hundreds of M2M devices on the QoS of normal H2H communication should be as small as possible. Strategies to keep the complexity of M2M application on different layers small are shown in [7].

For the performance evaluation of LTE, field trials are often used in order to analyze the impact of velocity on the performance of OFDMA-based links. For example, the performance of LTE is evaluated with a testbed in [8]. For throughput measurements, a monitoring car with an average speed of around 30 km/h is used. Hereby, it is very difficult to drive a car with a constant and preset speed to evaluate the influence of velocity.

To evaluate the channel conditions for cellular networks, ray tracing simulations are a well known method. In [9] coverage and achievable peak data rates for an urban area with three-dimensional building data and a ray tracing simulation are investigated for an LTE-Advanced relay scenario.

In [10], Markovian models are used to model LTE networks. Thereby, the different states in the model represent different channel characteristics. Markovian models for resource allocation, where one state represent a part of the shared resources, can be found in [11].

III. SYSTEM MODEL

In [1], a multi-class Erlang loss model is introduced for OFDM systems. Every state in the model represents one subcarrier. The same Markovian model is used in this paper, but we adapted the model to make it more practice-oriented for LTE systems by mapping the LTE Resource Blocks (RB) to the states. Furthermore, we make investigations of LTE in terms of data rate measurements in the laboratory and Signal to Interference plus Noise Ratio (SINR) calculations with ray tracing simulations to parameterize the Markovian model (see Fig. 2). By means of this Markovian model, a very effective investigation of LTE for different scenarios is possible.

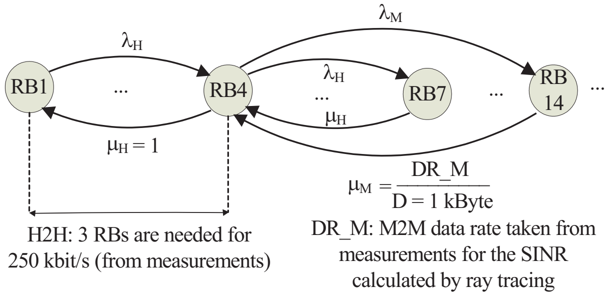

Fig. 2: Exemplary one-dimensional Markovian model with M2M and H2H traffic

A. Laboratory Measurement Setup

In the laboratory, we are able to perform close-to-reality investigations regarding an LTE cell with one user. For this purpose the LTE stick (Samsung GT B3730) as Device Under Test (DUT) is connected to an LTE base station emulator (10 MHz FDD LTE cell in band 7, acknowledged Radio Link Control Automatic Repeat Request (ARQ) mode). Between these devices, a channel emulator manipulates the LTE signal in the Radio Frequency (RF) domain. For fast fading the Vehicular A channel model defined by the ITU [12] and for the impact of interferences an OFDM interferer, with Quadrature Phase-Shift Keying (QPSK) and 1/8 guard interval, were used. By means of the setup, the influence of the radio channel and the number of RBs on the User Datagram Protocol (UDP) uplink data rate is observed. For the data rate measurements the LTE base station and the User Equipment (UE) are connected to two PCs with iPerf. More details about the measurement setup for a comparable scenario without OFDM interferences can be found in [13].

For the determination of the energy that is consumed by the USB enabled LTE device, a measurement probe is placed between the actual client PC and the DUT as it can be seen from Fig. 3. Therefore, the electrical energy powering the LTE stick has to pass the probe where it is sampled at a frequency of 100 kSamples/s. The so derived raw data is transferred to an evaluation PC via USB where the measurement can be analyzed in terms of for example minimum, maximum and average power consumption as well as the integration over individual time intervals for the determination of the consumed energy in this interval. The high resolution of the measurement does furthermore allow for a detailed examination of the power consumption in the different transmission states (e.g. Idle, not connected etc.).

B. SINR Estimation by Ray Tracing Simulations

The distribution of the SINR for an urban scenario is determined via intelligent ray tracing simulations [14]. We used a typical urban scenario with five Base Stations (BS) and three different frequencies from LTE band 7 (reuse 3) to minimize the interferences between the different sectors. Antennas (Ant.) 1 use 2.62 GHz, Ant. 2 use 2.63 GHz and Ant. 3 use 2.64 GHz center frequency.

The UE antennas have 1 dBi gain, a transmission power of 23 dBm is used and the UE noise figure is set to 6 dB.

C. Analytical Markovian Model

In order to model an LTE cell with many users and different QoS requirements, a Markovian model (multi-class Erlang loss model) is used. Our idea is that the states in the model represent the LTE Resource Blocks (RBs) which are shared between the H2H and M2M data links. The different user classes need a different number of RBs and each user class is represented by one dimension in this model. According to the reduction of dimensions [15] a one dimensional model with a different number of states per user can be developed. The blocking probability for this model can be calculated for

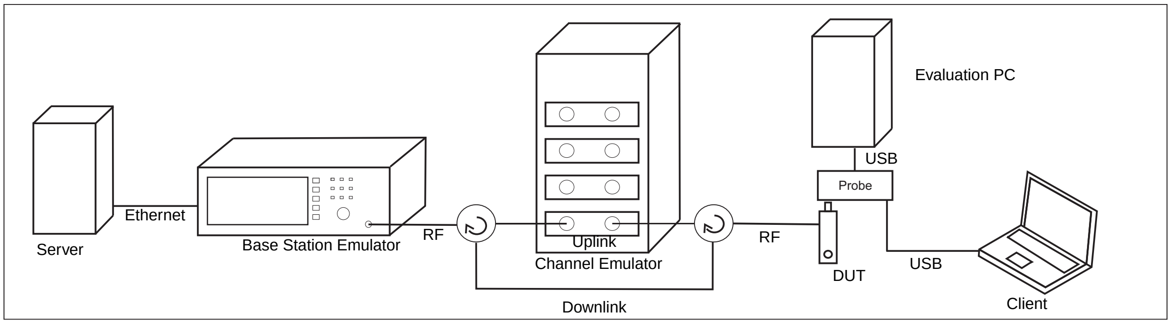

Fig. 3: Measurement setup for bidirectional LTE performance testing with power measurement for LTE USB Sticks

the assumption that the inter arrival time for the arrival rate λ_s and services rate μ_s for every class s follows a negative exponential distribution.

According to [15], the stationary distribution π_c, which characterizes in our case the probability that c RBs are allocated, can be determined in a recursive way

$$\pi_c = \frac{\widetilde{\pi}_c}{\sum\limits_{c=0}^{C} \widetilde{\pi}_c} \quad \text{with} \quad \widetilde{\pi}_c = \begin{cases} 1 & c = 0 \\ \sum\limits_{s=1}^{S} \frac{a_s c_s}{c} \widetilde{\pi}_{c-c_s} & c > 0\,, \end{cases}$$

where C is the maximum number of RBs used by an LTE base station, a_s the offered traffic of class s, c_s the resources of class s and S the number of service classes, i.e. dimension of the model. The blocking probability p_{b_s} of class s and the overall traffic load Y can now be calculated as

$$p_{b_s} = \sum_{c=C-c_s+1}^{C} \pi_c \quad \text{and} \quad Y = \sum_{c=1}^{C} c\pi_c\,.$$

By means of the Markovian model, the impact of the FCD transmission on the H2H communication is evaluated. For the H2H communication, users with a constant data rate of 250 kbit/s (e.g. video streaming) and for the M2M communication 1 kByte FCD per transmission are used. The number of FCD transmissions is specified by the arrival rate. The Markovian model incorporates the same priority for H2H traffic and FCD transmission. The service rate for the H2H users is set to $1/s$ and the offered traffic is adjusted by the arrival rate. For the M2M users, the service rate is calculated as data rate taken from the laboratory measurements divided by the transmitted data (1 kByte). The number of RBs for the M2M communication is set to 10 and for the H2H traffic we evaluated how many RBs are needed for 250 kbit/s by the measurements depending on the channel conditions.

D. Energy Aware Channel Sensitive Transmission Scheme

In order to save energy for the FCD transmission we propose a channel sensitive transmission. This guarantees that the FCD is transmitted very often if the channel conditions are good and the user velocities are low. We propose a transmit probability $p_{i,j}$ for class i, j of the Markovian model. The parameter i separates the different SINRs and j presents the classes with a different velocity.

$$p_{i,j} = \frac{\left(\frac{SINR_i}{SINR_{max}}\right)^{\alpha} \cdot \left(\frac{v_{max}}{v_j}\right)^{\beta}}{\sum\limits_{l=1}^{N} \sum\limits_{k=1}^{M} \left(\frac{SINR_l}{SINR_{max}}\right)^{\alpha} \cdot \left(\frac{v_{max}}{v_k}\right)^{\beta}}, i = 1...N, j = 1...M$$

$SINR_{max}$ is the SINR for which the highest data rate can be achieved and v_{max} is the highest velocity in the scenario. For the presented results, a $SINR_{max}$ of 30 dB and a v_{max} of 150 km/h is used. A method how to estimate the SINR in a real OFDM system in shown in [16]. The parameters α and β control the intensity of the channel sensitive transmission scheme. For the Markovian model, we divided the SINR in $N = 3$ parts and the velocity in $M = 2$ parts. This probabilities $p_{i,j}$ are included in the arrival rates of the different classes of the Markovian model. The arrival rate for each class is multiplied by $p_{i,j}$.

E. Energy Consumption for the FCD Transmission

The mean energy consumption for one FCD transmission can be calculated as weighted average of the transmitted data $D = 1\ kByte$, the data rate $DR_{i,j}$, the needed power $P_{i,j}$ and the transmit probability $p_{i,j}$ for the classes $i = 1...N$ and $j = 1...M$ of the Markovian model:

$$E_{FCD} = \sum_{i=1}^{N} \sum_{j=1}^{M} \left(\frac{D}{DR_{i,j}} \cdot P_{i,j} \cdot p_{i,j} \right)$$

$P_{i,j}$ is the power consumption of the LTE UE for different SINRs and velocities as measured in the laboratory.

IV. RESULTS

A. Laboratory Measurement of LTE Data Rates

In order to parameterize the Markovian model, we measured the LTE uplink data rate as a function of the SINR and the number of allocated Resource Blocks (RBs). The data rate for 50 RBs (max. for 10 MHz) is illustrated in Fig. 4. For the Modulation and Coding Scheme (MCS) 8 and 120 km/h no data transmission is possible. It can be seen that the influence of the SINR dominates the influence of the velocity. Hence, we divided the user classes for the Markovian model by 3 different SINRs and by 2 different velocities. As velocities 60 km/h and 120 km/h are used. The SINRs for the 3 classes are calculated by ray tracing simulations.

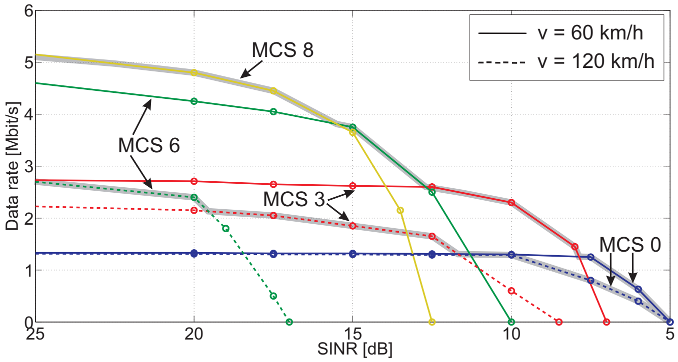

Fig. 4: Lab. measurements: Uplink data rate vs. SINR for 50 RBs per user and OFDM interferences

B. Ray Tracing Simulation to Calculate the SINR

The map for the SINR in the urban scenario is presented in Fig. 5. In Fig. 6 the Cumulative Distribution Function (CDF) of the SINR for different base station configurations is illustrated. We see that the base station height h and the tilt angle have a major influence on the SINR distribution. 20 m base station height and 5° tilt is a good compromise for low and high SINRs.

The distribution of the SINR in the used scenario is divided into 3 fractions with the same size to parameterize the Markovian model with 3 different SINRs:

- SINR $\leq$ 12.5 dB: represented by 8 dB SINR
- 12.5 dB $<$ SINR $\leq$ 21 dB: represented by 17 dB SINR
- 21 dB $<$ SINR: represented by 25 dB SINR

The represented values are the weighted averages of the intervals.

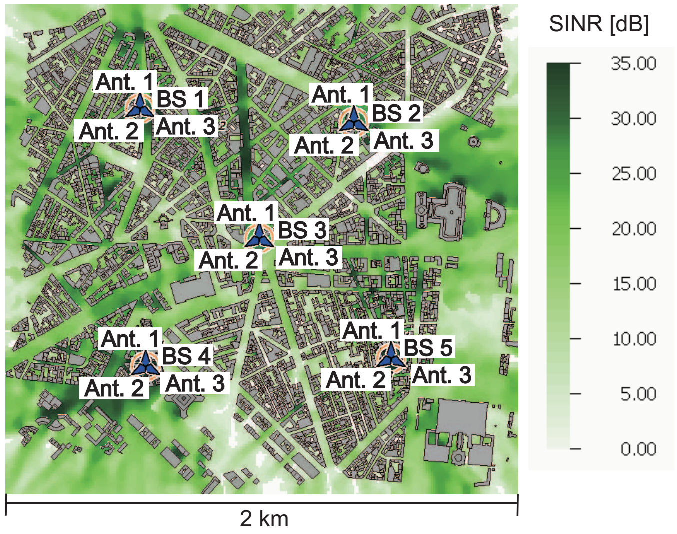

Fig. 5: Ray tracing: Map for the SINR in the urban environment with 20 m base station height and 5° tilt

C. Markovian Model

By means of the Markovian model the influence of the FCD transmission on the utilization of the LTE air interface of one cell is evaluated. Hereby, the negative impact is reduced by the channel sensitive transmission. The parameters of the model are presented in Tab. I. In Fig. 7 the blocking probability of H2H users as a function of the arrival rate of M2M communication for different weighted channel sensitive transmission schemes can be seen. For a QoS requirement of 10 % blocking probability for the H2H communication, the number of FCD transmissions can be increased from 65 per second without channel sensitive transmission to 173 per second with a very intensive channel sensitive transmission ($\alpha = 4$ and $\beta = 4$).

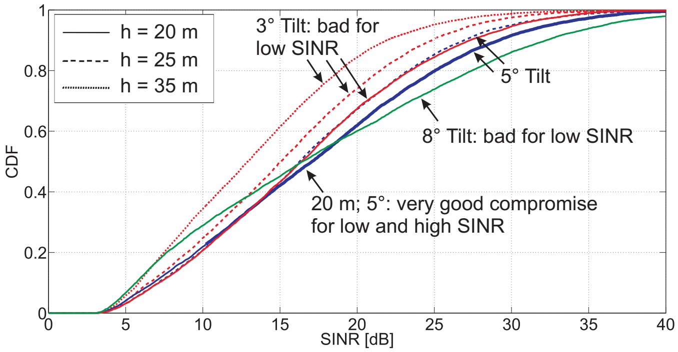

Fig. 6: Ray tracing: CDF of the SINR in the environment for different base station heights and tilt angles

For the range of these arrival rates the utilization of the RBs is the bottleneck of the LTE air interface. Although for each transmission a random access has to take place, a collision in the random access procedure is critical only for much more users in one cell [17].

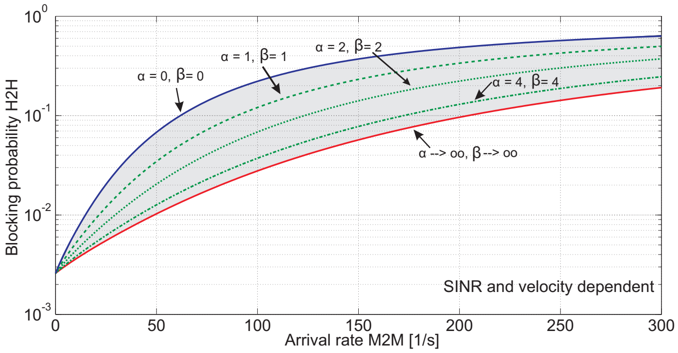

Fig. 7: Markovian model: Blocking probability of H2H users vs. arrival rate of M2M for differently weighted channel sensitive transmission schemes; 50 RBs shared by M2M and H2H

D. Energy Measurements for the LTE Stick

The main idea of the channel sensitive transmission is that the users wait for good channel conditions to transmit the FCD. This concept works, because the FCD is not time critical for the dynamic traffic forecast. Hence, the real FCD transmission is much faster due to the higher spectral efficiency. This has two positive effects: on the one hand side

TABLE I: Parameters of the Markovian model for $\alpha = 0$ and $\beta = 0$

	$M2M_1$	$M2M_2$	$M2M_3$	$M2M_4$	$M2M_5$	$M2M_6$	$H2H_1$	$H2H_2$	$H2H_3$	$H2H_4$	$H2H_5$	$H2H_6$
SINR [dB]	25	25	17	17	8	8	25	25	17	17	8	8
Velocity (v, [km/h])	60	120	60	120	60	120	60	120	60	120	60	120
Service rate (μ, [1/s])	110	52	75	38	22	15	1	1	1	1	1	1
Number of RBs (c)	10	10	10	10	10	10	3	7	4	8	16	22
Measured power [W]	1.50	1.50	1.51	1.51	1.52	1.52	-	-	-	-	-	-

the negative impact on the LTE air interface is smaller and on the other hand side energy can be saved. We measured the consumed power for the LTE USB stick in the laboratory for different channel conditions (see Tab. I). Here, no path loss compensation is assumed. The various channel conditions have only a minor influence on the consumed energy. Hence, the main part of the energy for the FCD transmission can be saved due to the better channel conditions and the resulting faster transmission. By applying the channel sensitive transmission with $\alpha = 4$ and $\beta = 4$ up to 54 % of the energy can be saved (see Fig. 8). Here, the SINR as well as the velocity depending transmission reduce the energy considerably.

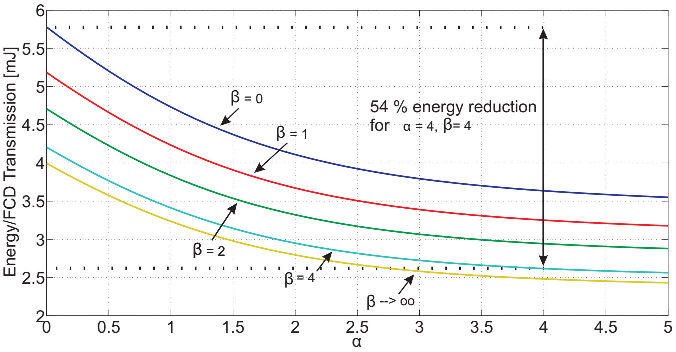

Fig. 8: Energy for one Transmission of FCD for differently weighted channel sensitive transmission schemes

V. CONCLUSION AND FUTURE WORK

In this paper, we have presented a channel sensitive transmission scheme for Floating Car Data which can be used for real time traffic jam prognosis. Therefore, the on board devices make use of generally available knowledge on the radio channel conditions and base their submission probability upon this. The presented complex investigations, which are based on Markovian models as well as ray tracing simulations and laboratory measurements show, that this approach does not only allow for a reduced blocking probability but additionally reduces the energy that is needed for one data submission by up to 54 %. The intensity of the channel sensitivity can be easily adopted by a suitable choice of only two parameters which allows for an easy deployment in different environments.

As next step, we will validate the results by a protocol simulation.

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