Identifying LTE Connectivity Hot Spots in Vehicular Environments: A Learning Approach

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***Abstract*—Due to the increasing demand of mobile Machine-Type Communications (MTC), the interaction between MTC and human services is a recent problem for cellular communication systems like Long Term Evolution (LTE). In order to reduce the negative impact of MTC on human communication, a Learning-based Channel-Aware Transmission (L-CAT) scheme will be introduced in this paper. The algorithm bases on a learning process of cellular connectivity hot spots and is designed for non-time-critical vehicular data applications like extended Floating Car Data (xFCD) transmissions for traffic forecast systems. The results based on real-world measurements show that L-CAT leads to a much faster data transmission that correlates with a more resource efficient MTC.**

I. INTRODUCTION AND RELATED WORK

Many mobile devices follow the routes of driving vehicles. This routes are not randomly, but follow special patterns. For example the same routes are taken by a vehicle many times: the way to work or to good friends. This fact can be used in order to predict mobility of a cellular communication device that is mounted on a car. The mobility prediction is a feasible input for traffic management systems. It can be predicted how many vehicles will pass a certain highway and if this would cause a traffic jam, some of them could be rerouted. But the mobility estimation can also be useful for communication issues. In [1] a method to improve handover quality of cellular communication systems by means of a mobility forecast algorithm is shown. However, the same routes correspond also to a similar communication connectivity. This fact will be used in this paper to improve non-real-time vehicular data applications. We present Learning-based Channel-Aware Transmission (L-CAT), a decentralized communication approach that uses a learning process of cellular connectivity in vehicular environments. L-CAT detects good communication locations, stores them, provides them to others users and uses them for the next drive at the same route to improve the communication efficiency.

The transmission scheme can be used to provide vehicular sensor data (so called extended Floating Car Data (xFCD) [2]) very efficiently to a traffic management server. This Machine-Type Communication (MTC), which can be carried e.g. by a Long Term Evolution (LTE) network, should interfere as less as possible with other human users in the communication network. LTE MTC is a recent topic in the evolution of the standardization of LTE technology follower [3] [4]. An overview about vehicular LTE data communication can be found in [5].

The usage of the channel quality for efficient cellular communication is a common approach on different layers of the communication system. Channel-dependent scheduling [6] (also for the uplink [7]) is one famous example for using the channel quality, aggregated at the base station of many active LTE users, to schedule the users to the best resources in time and frequency domain. In contrast to channel-dependent scheduling, L-CAT works on the application layer and decentralized without the need of an active communication link. In [8] a channel-aware transmission scheme is presented for random access networks. This scheme works without learning process and uses a threshold function for the transmission decision. A forecast algorithm for mobile connectivity in the area of wireless and cellular communication systems is presented in [9]. The scheme takes active performance indicators (e.g. data rate) into account for the prediction of good communication locations for WiFi and cellular communication networks.

The key contributions of this paper are:

- The L-CAT scheme that uses a learning process of the cellular connectivity (cf. Sec. II).
- L-CAT implementation for the performance evaluation by real world measurements (cf. Sec. III).
- L-CAT leads to a much faster data transmission due to a local transmission decision that is based on the LTE connectivity (cf. Sec. IV).
- The faster data transmission is correlated with a more resource efficient communication, so that L-CAT needs less physical resources for the same MTC payload size.

II. L-CAT CONCEPT

In [10], a channel-aware transmission scheme is proposed for xFCD transmissions. The transmission policy is extended by a learning component of the cellular connectivity in this paper. Fig. 1 illustrates the L-CAT concept. The transmission decision is done locally in the LTE device mounted on a vehicle. It depends on the data priority and cellular connectivity. The LTE connectivity estimation is based on two components, historical data and live measurements of passive indicators like Reference Signal Receive Power (RSRP) and Reference Signal Received Quality (RSRQ). The historical data contains passive as well as active connectivity indicators (e.g. local dependent data rate) and the historical mobility. The live measurements are only focused on passive performance indicators so that no active connection to the cellular communication system is needed before the transmission decision is done locally in the LTE device.

The cellular communication carries the xFCD in the uplink as well as the traffic state and forecast from the traffic server in the downlink. Connectivity maps that are generated by the devices are also stored in the server. We suggest a bidirectional update of the map in the vehicular and server via WiFi (e.g. ones in a week).

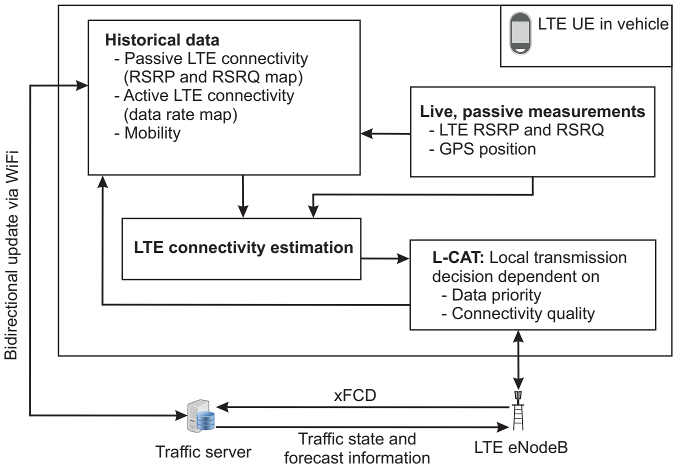

Fig. 1: Illustration of the L-CAT Concept.

III. IMPLEMENTATION OF L-CAT FOR LTE FIELD TESTS

This section summarizes the so far implemented functionalities of L-CAT. According to Fig. 1, we implemented a first version in an Android app. The app contains four basic components that are needed for L-CAT in the device:

- A look up map, where the historical connectivity map is stored. In the app, local dependent connectivity is simplified by good connectivity hot spots. These are Global Positioning System (GPS) locations with a radius that describes regions with a very good connectivity (we use RSRP $>$ -90 dBm).
- A measurement function that monitors passively the current LTE parameters.
- The LTE connectivity estimation is simplified in a function that calculates the time until the next connectivity hot spot is reached by the current GPS position and velocity.
- The transmission decision in our app depends on good connectivity hot spots. We transmit a User Datagram Protocol (UDP) packet of 100 kByte if we are in such a hot spot or if we predict that the next hot spot is more than five minutes away.

The measurements are performed in the public LTE network of Deutsche Telekom. As performance indicator we measure the transmission time. We will show in the result section that this indicator is strongly correlated with the number of LTE Resource Blocks (RBs).

IV. RESULTS

For the performance analysis of L-CAT, we performed field tests in Dortmund, Germany. A map with measured LTE RSRP values of one example test drive is illustrated in Fig. 2. The RSRP over time is shown in Fig. 3. On the one hand, the driving route includes regions where no LTE coverage is given: e.g. at location B, a tunnel shadows the LTE signal. On the other hand, there are locations where the LTE signal quality is very good. Nearby to position D, an LTE base station is located. This results in RSRP values to up to -75 dBm.

The average RSRP is -99 dBm. This is also the average value if no CAT is applied, which means that the data is transmitted periodically. By applying L-CAT, the average RSRP

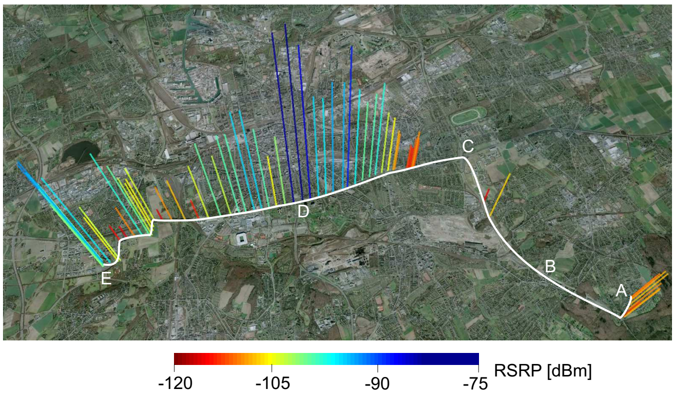

Fig. 2: Map of Example Measurement with RSRP Measurements. © Google.

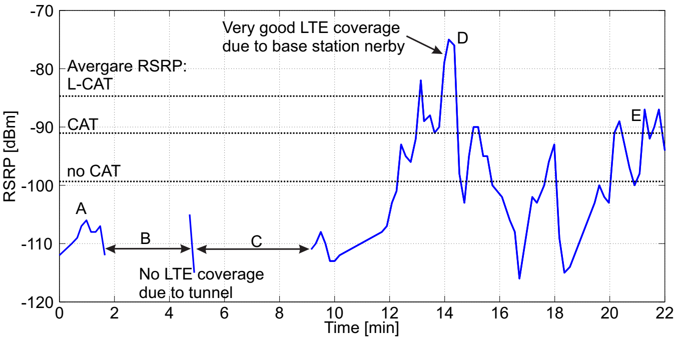

Fig. 3: RSRP over Time for one Example Measurement incl. RSRP Improvement due to CAT and L-CAT.

for triggering an LTE communication, increases to -85 dBm. This is due to the fact that locations D and E are identified as hot spots. For CAT, an average RSRP of -89 dBm can be achieved. The communication under better channel conditions leads to a much faster data transmission. Fig. 4 illustrates the transmission time of 100 kByte uplink data as box plots. These results are gained from a measurement campaign of 2 h duration. It can be seen from the figure that a very wide range of transmission times is given for a transmission without CAT. The very high values result from LTE communications at location A or between D and E, where the connectivity is very bad. For CAT, the average transmission time decreases to 540 ms in contrast to 720 ms for a periodical transmission. The fact that many transmissions are also very fast (< 1 s) without CAT is caused by the good LTE coverage in the surroundings of location D. By applying L-CAT, the average transmission time can be deceased to 430 ms. Furthermore, peaks with a very high transmission time can be avoided by the usage of these hot spots. In our measurement campaign, the maximum transmission time with L-CAT is 730 ms. These results show that the LTE connectivity based on a passive indicator (we use the RSRP) recorded in previous measurements can be used in order to optimize an active LTE communication in the presence.

We have shown in [11] that the same LTE deployment provides a scheduler that is similar to a max rate scheduling for small packets. This means that users with a very low RSRP value are assigned less RBs in the frequency domain than users with good channel conditions. This leads to the fact that for a low RSRP, the duration of the transmission is not only longer because more total resource are necessary (due to a more robust modulation and coding and retransmissions), but also because the resources in the frequency domain are restricted. However, there is still a strong correlation between transmission time and total number of RBs given. This relationship is shown in Fig. 4. These LTE field measurements are gained with the same setup used in [11]. By means of a real-time spectrum analyzer, the RBs in time and frequency domain are captured at seven different locations with various channel conditions. The correlation coefficient between transmission time and total number of RBs is 0.82.

V. CONCLUSION AND FUTURE WORK

In this paper, we have presented L-CAT, a decentralized transmission protocol for vehicular data applications. The transmission decision is based on a learning process of the cellular communication connectivity. The performance of L-CAT is analyzed by real-world measurements. It is shown that the communication policy leads to a much faster vehicular data transmission that is correlated with a much higher LTE resource efficiency. In the future, we will validate the L-CAT scheme by protocol simulations and extent the transmission decision by taken application characteristics into account. In addition, we will develop more complex forecasting algorithms in order to predict the mobility in challenging scenarios.

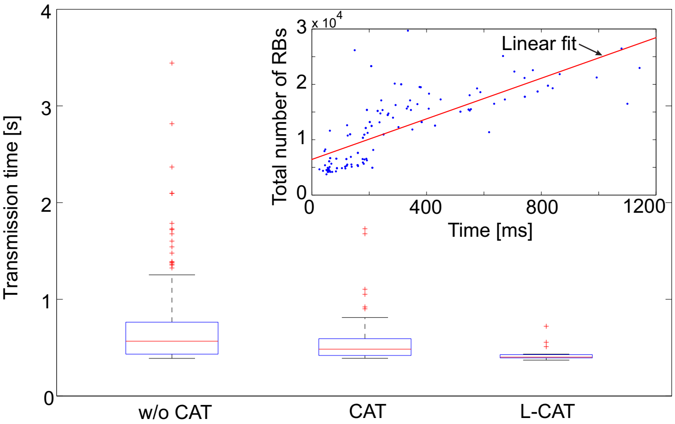

Fig. 4: Comparison of the Transmission Time for without CAT, CAT and L-CAT as well as Correlation between Transmission Time and Total Resource Allocation (100 kByte).

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