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An Accurate Measurement-Based Power Consumption Model for LTE Uplink Transmissions

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***Abstract*—In this poster the results of an accurate, measurement-based power consumption profiling of Long Term Evolution (LTE) User Equipment (UE) are presented together with concrete model parameter sets for four different most recent LTE data sticks and one LTE smart phone. In contrast to existing power consumption models for cellular devices, the model presented in this poster allows for a precise quantification of energy supply requirements depending on the LTE uplink data transmission power, the device type and the carrier frequency. This knowledge can be for example applied for the suitable dimensioning of batteries and energy harvesting devices in the context of LTE-based wireless sensor networks.**

I. MOTIVATION

The battery lifetime is one of the most important performance parameters for customers. Also in the context of LTE-enabled remote sensing, energy consumption is a topic of major importance. The communication activities -in particular the uplink transmissions- are one of the major drivers of the overall power consumption. The important relationship between the uplink transmission power P_{Tx} [dBm] and the overall power consumption of the UE $\bar{P}$ [W] has however not been sufficiently addressed for LTE so far. Especially for high transmission powers, the LTE UE platform consumes a disproportional amount of power leading to increased heat loss. This effect is illustrated by an experiment shown in Fig. 1. The picture (left bottom) shows chocolate which was melted after 45 min of continuous operation of an LTE stick at the maximum allowed transmission power of 23 dBm.

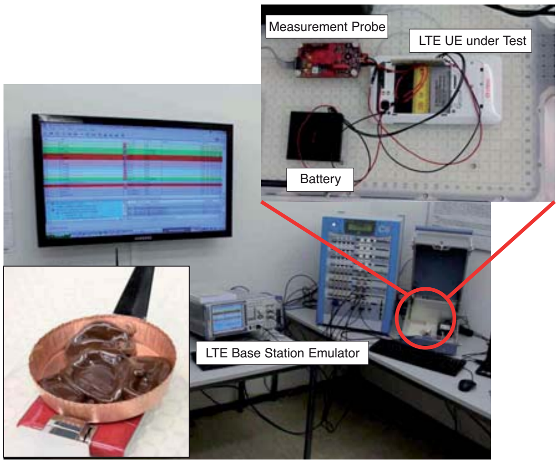

Fig. 1. Lab Facilities for Power Consumption Measurements.

II. EMPIRICAL POWER CONSUMPTION MODELING

To derive an accurate power consumption model, extensive measurements for different commercially available LTE UEs have been performed in our mobile communications lab. Fig. 1 illustrates the measurement setup, which includes an LTE base station emulator to allow for an accurate control of the uplink transmission power of the LTE UE (cf. [1] for more details). The measured correlation between the uplink transmission power and the power consumption of the UE is illustrated in Fig. 2 for different devices operating in LTE band 7 (2.6 GHz).

One can see from the plot that the power consumption curve can be divided into two parts: For a low transmission power, below a device specific threshold γ, the graph is characterized by a small, almost horizontal slope. For higher transmission power values, the power amplifier switches the mode and the slope becomes significantly steeper. This specific characteristic can be observed for all UEs under test. The empirically derived power consumption curve $\bar{P}$ can be approximated by two

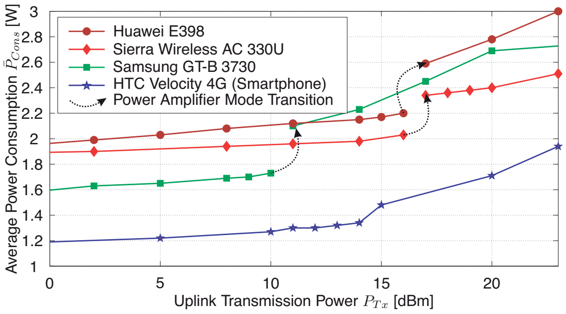

Fig. 2. Device-specific Power Consumptions for Different Uplink Transmission Power Values (all in 2.6 GHz). The results will be updated continuously as new LTE devices become available and are publicly accessible at *www.cni.tu-dortmund.de/LTEpowermodel*.

TABLE I
EMPIRICAL MODEL PARAMETERS FOR DIFFERENT LTE UES.

Model Parameter	**HTC** Velocity 4G		**Samsung** GT-B 3740	**Samsung** GT-B 3730	**Huawei** E 398	**Sierra Wireless** AC 330U	
Frequency [MHz]	800	2600	800	2600	1800	2100	2600
α_L [mW/dBm]	4.8	4	7.7	7.2	10	5.6	5.4
β_L [W]	1.6	1.2	1.6	1.6	1.7	1.6	1.9
α_H [mW/dBm]	68	61	13	54	24	27	28
β_H [W]	0.79	0.52	0.4	1.5	1.9	1.5	1.8
γ [dBm]	12	12	11	10	16	16	16
$\bar{P}_{IDLE}$ [mW]	40	40	175	44	236	63	63
Maximum Error [%]	5.1	3.5	1.7	3.9	4.7	3.6	1.5

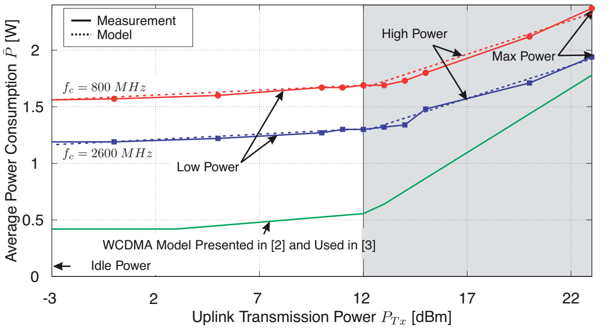

Fig. 3. Tx-Power Dependent Average Power Consumption vs. Empirical Model (HTC Velocity 4G, cf. Table I).

linear functions:

$$\bar{P}(P_{Tx}) = \begin{cases} \alpha_L \cdot P_{Tx} + \beta_L & \text{for } P_{Tx} \leq \gamma \\ \alpha_H \cdot P_{Tx} + \beta_H & \text{for } P_{Tx} > \gamma \end{cases} \qquad (1)$$

with the device specific parameters α, β and γ as given in Table I and the uplink transmission power P_{Tx}. For the downlink reception our measurements have shown that the consumed power is practically independent of downlink system parameters and can be approximated by the β_L value.

Table I provides the approximation error for all devices. As an example, Fig. 3 illustrates in detail the good match between the proposed model and the actual measurements for the HTC velocity 4G smartphone and both frequency bands supported by this device. Additionally, the power consumption model for the WCDMA UE presented in [2] and used in [3] for LTE devices is shown. Comparing the curves one can clearly observe that the previous work significantly underestimates the power consumption of the UE (by 0.75 W in case of 12 dBm uplink transmit power).

III. EXAMPLE APPLICATION: DIMENSIONING OF ENERGY STORAGE FOR WIRELESS SENSOR NODES

One application of the proposed LTE power consumption model is the suitable dimensioning of batteries and energy harvesting devices for wireless sensor networks (e.g. for video surveillance in emergency situations when the grid or the power connection to grid is destroyed). Assuming that a certain amount of data must be transferred before the battery runs out, the energy E_{Bit} that needs to be spent for the transmission of one bit is used to determine the suitable size of the energy storage. This figure of merit can be calculated by dividing the power consumption $\bar{P}(P_{Tx})$ by the throughput T (cf. formula in Fig. 4). Both parameters depend on the distance d between UE and eNodeB. We assume that a target Signal to Noise Ratio (SNR) of 30 dB is required at the base station for achieving the maximum throughput. An increase of the distance d therefore leads to an increased path loss and a respectively higher transmission power P_{Tx} that is required for compensating it. While $\bar{P}$ depends on P_{Tx} (cf. Equation (1)) the throughput T is a function of the SNR as shown in [4]. For high distances the path loss can no longer be compensated by adjusting P_{Tx} (due to the limitation of the transmission power to 23 dBm) which leads to a lower T and therefore a higher E_{Bit}. Fig. 4 illustrates E_{Bit} vs. the distance d for two frequently used LTE frequency bands. Beyond that, the energy per bit is translated to a distance dependent battery capacity that is as least required for transmitting 100 Gbit of data. One can observe that for the case of 2.6 GHz increasing the communication distance from 50 m to 500 m requires a 59% larger energy storage (cf. ① and ② in Fig. 4). For a distance of 1250 m, using LTE at 800 MHz instead of 2.6 GHz allows for battery capacity savings of 20% (cf. ③ and ④ in Fig. 4). This is because the lower path loss at 800 MHz overcompensates the lower efficiency. For higher communication distances, the achievable gain by using an 800 MHz system is further increasing.

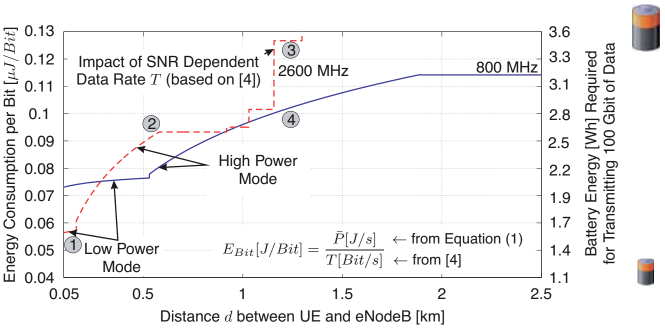

Fig. 4. Energy Consumption per Bit E_{Bit} and Battery Energy Requirement vs. Communication Distance d for Wide Area Wireless Sensing Applications (assuming free space propagations losses).

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