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Utilizing Unused Network Capacity for Battery Lifetime Extension of LTE Devices

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

Abstract—**The average operational time of today's smart phones with one filling of the accumulator is one of the most important performance parameters for the customers of new devices. Nevertheless, this value is remaining constant or even decreasing in the last few years due to the continuously increasing complexity. On the other hand, for ensuring the fulfillment of the high user-requirements even under worst case conditions, novel cellular systems such as Long Term Evolution (LTE) are usually over-dimensioned in terms of the maximum available capacity. In this paper, a novel approach is presented which allows for trading in unused cell capacity for battery lifetime extension of the mobile devices. The basic idea in this context is to increase the robustness of the submitted uplink (UL) signal by decreasing the order of the modulation and coding scheme used. If the provided data rate is kept constant, this comes along with an increasing number of allocated Resource Blocks (RB) and therefore a decreased overall cell capacity. Nevertheless, the more robust signal allows for reducing the uplink transmit power while the Quality of Service (QoS) parameters are still met. The results for exemplary Voice over IP (VoIP) traffic show that for users originally submitting at the maximum available transmit power, the consumed energy of the LTE chip-set can be reduced by up to 27.5 % applying this novel approach.**

I. Introduction

The operational time of modern smart phones with one filling of the accumulator is a major decision factor for the customers of new devices [1]. This is the reason why extensive research has been performed in the fields of battery design and system optimization with regard on energy consumption. Due to the fact that the radio part of a smart phone is one of the most important energy consumers, a special focus has to be set on different approaches and strategies how to reduce the energy that has to be spent for the transmission of a certain amount of data.

In this paper, we present an approach that is based on the reduction of the necessary uplink transmission power while simultaneously adapting the Modulation and Coding Scheme (MCS) as well as the number of allocated Resource Blocks (RB). Detailed measurement results show that especially those mobile stations which are submitting at a close to maximum transmit power can significantly reduce their averagely consumed power if they can avoid operating the Power Amplifier (PA) in its high power mode. In many cases this can be achieved by a minor reduction of the transmit power. The decreased signal quality, in terms of a smaller Signal to Noise Ratio (SNR) at the Base Station (BS), must simultaneously be compensated by choosing a more robust MCS and additional RBs. Actually one can say that the energy savings are paid by radio resources which is acceptable if the cell is not completely occupied.

II. Motivation and Related Studies

The transmission power that is used for LTE uplink signals has a major influence on the energy consumption of the radio part of a mobile device. Therefore, the aim of any system designer should be to reduce this figure as far as possible without decreasing the signal quality. The open and closed loop Transmit Power Control (TPC) algorithms, as standardized in [2], provide a suitable tool for the fast adaption of the tx-power in a context sensitive way for reducing the power that is consumed for radio transmission. Nevertheless, most studies dealing with TPC schemes are focusing on interference avoidance issues. Energy savings and the correspondingly increased battery lifetimes are mostly considered as a ”positive side-effect”. Exemplary studies dealing with closed loop power control and especially the so called ”Fractional Path Loss Compensation” (FPC) are [3] and [4]. FPC bases on the idea that those users which are close to the cell edge are transmitting at as low power as possible while those users which are close to the BS increase their transmit power for achieving higher data rates and therefore increase the cell capacity. From an energy efficiency perspective this behavior is not useful because those users which are close to the BS would even be able to decrease their transmit power and therefore save valuable energy. Especially in scenarios where the cell is not completely occupied, and therefore capacity is not a critical factor, increasing the transmission power would not be suitable for users with good channel conditions.

Another related field of research that is actually dealing with energy efficiency issues is the Downlink Discontinuous Reception (DRX) [5]. Here, the energy that is consumed by the receiving part of the radio is reduced by turning off the radio for a predefined period. The active time plus the power off time are referred as a DRX cycle. Especially for applications which periodically generate data (such as VoIP), this approach is quite promising as it is shown in [6] and [7]. Nevertheless, it is worth noting that in [5] it is said that the power consumption values for the different states are arbitrarily chosen. However, these values assuming a power consumption of $500\ mW$ in the "Active with RX data"-state where used for all subsequent studies.

III. Energy Consumption Measurements for LTE Devices

A detailed knowledge of the different factors that are influencing the energy consumption of an LTE User Equipment (UE) is mandatory for the development of efficient energy saving methods. Therefore, detailed measurements of the energy consumption of an exemplary USB enabled Samsung GT-B 3730 device have been performed in a laboratory environment. Fig. 1 illustrates the measurement setup. On the RF side, the UE is connected to an LTE Base Station Emulator (BSE) via RF cable. The BSE serves as counterpart for the LTE communication link and allows for a detailed parameterization of the connection parameters. The most important parameters in the context of this paper are the MCS, the number of allocated RBs and the Physical Uplink Shared Channel (PUSCH) Open Loop Nominal Power. The last mentioned parameter describes a cell specific nominal power value for full resource block allocation in the UL (entire channel bandwidth used). From this value the cell specific nominal power value related to one resource block P_0 is determined and sent to all UEs via broadcast [2]. The values of some important parameter for the measurements can be seen in Table I.

For the measurement of the actual power consumption of the LTE device the USB stick is not directly connected to the client PC but to a power probe that it placed between the UE and the PC. Therefore, the energy that is drawn from the device has to pass the measurement probe where it is sampled at a rate of $100\ kSamples/s$. This procedure allows for a precise capture of the currently consumed energy for the various investigated system states and resource allocations.

Fig. 2 shows the results of the average power consumption measurements for different uplink transmit power values and 50, 25 and 5 allocated RB. It is worth noting that the uplink

TABLE I
LTE System Parameterization

System Parameter	Value
Carrier Frequency (UL)	2.52 GHz (LTE Band 7)
Channel Bandwidth	10 MHz
FFT Size	1024
Duplexing Scheme	FDD
UE Category	3
RLC ARQ Mode	Acknowledged Mode
UL MCS	Variable
UL Tx-Power	Variable -10 to 24 dBm
Allocated Resource Blocks	Variable 1 to 50

power at the x-axis is the transmission power P_0 that is spent for one RB. The actually emitted submission power P_{Tx} is therefore given by $P_{Tx} = P_0 + 10log_{10}(M)$ with M being the number of allocated RB. As it can be seen from the figure, the averagely consumed power is slightly increasing for an increasing transmit power up to a value of $P_{Tx} = 10\ dBm$ ($P_0 = -7\ dBm$ for 50 RB). If the transmission power is increased beyond this point, the averagely consumed power is rapidly jumping from about $1.75\ W$ to $2.1\ W$. The same behavior can be observed for the other resource allocations as well. After the immediate jump the slope of the curve in significantly increasing for higher transmission power. The over proportionally increased power consumption for high transmission power is due to the transition from the low power mode to the high power mode of the SKY77709 power amplifier [8] that is installed in the LTE device. If the high power mode is needed, which is true for high transmission power close to the maximum, the consumed energy for data transmission is significantly increasing. Therefore, the aim of an efficient power saving scheme should be to avoid this transition to the high power mode of the amplifier. Comparable measurements with other commercially available LTE UE have shown, that this special characteristic is observable for all devices although the switching point between the modes is slightly diverging.

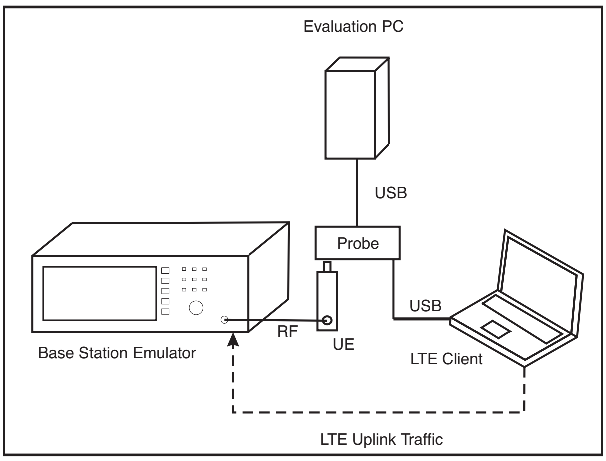

Fig. 1. Measurement Setup for Detailed Power Measurements

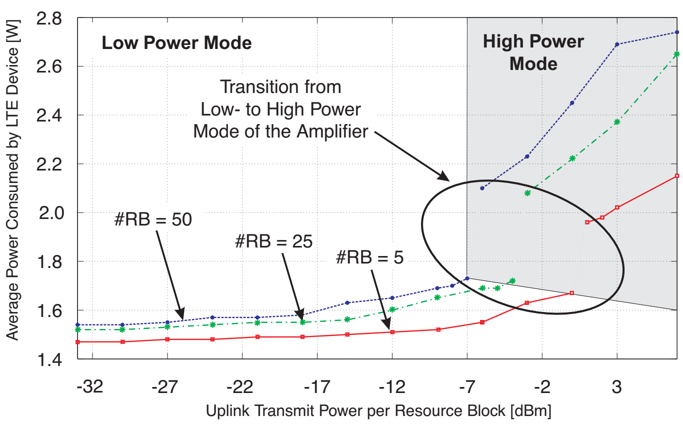

Fig. 2. Influence of the UL Transmit Power on the Energy Consumption

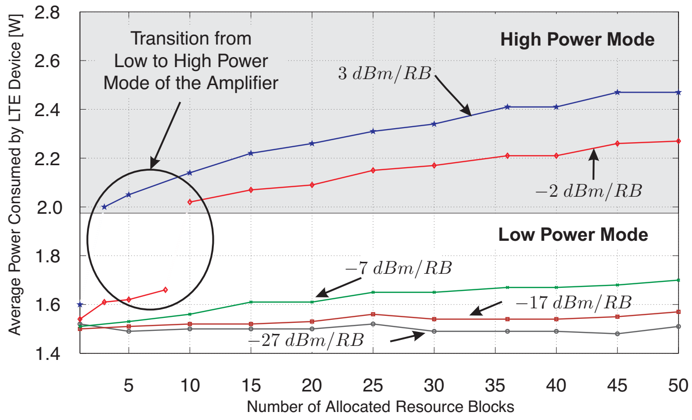

Fig. 3. Influence of the Number of Allocated RB on the Energy Consumption

Figure 3 illustrates the other dimension of the relationship between tx-power, number of resource blocks and consumed average power of the LTE device in more detail. Here, the averagely consumed power is plotted against the number of allocated RB for different transmission power per RB P_0 of $-27\ dBm$, $-17\ dBm$, $-7\ dBm$, $-2\ dBm$ and $3\ dBm$. One can see from the plot that for lower values of P_0, below $-2\ dBm$, the power amplifier is operated in the advantageous low power mode regardless the number of allocated RBs. For higher UL transmit power, the operational mode of the amplifier depends on the overall emitted power P_{Tx} and therefore the number of allocated RB. For a nominal transmission power of $-2\ dBm$ the transition to the high power mode occurs for RB allocations above $10\ RB$ while for a tx-power of $P_0 = 3\ dBm$ the amplifier can only be operated in the low power mode if only one RB is allocated.

IV. A Generic Approach for Trading Cell Capacity in for Battery Lifetime

As one can see from the previous section, a promising approach for the reduction of the consumed energy is to avoid the transition of the power amplifier to the high power mode. In most cases this target can be achieved by a reduction of the transmit power which comes along with a decreased SNR at the BS. To avoid signal degradation the MCS has to be adjusted to allow for a higher robustness of the signal. As the order of the MCS is reduced, the number of data bits that can be submitted at one RB is decreased correspondingly. Therefore, if the data rate shall remain constant the number of allocated RB has to be increased. A specific so called Transport Bock Size (TBS) is defined by an MCS together with the number of allocated RB. Therefore, the same TBS can be achieved by different combinations of MCS and RB allocations. Fig. 4 illustrates the generic approach for the reduction of the actual power consumption by means of a flow chart. From this one can see that the procedure can be divided into four steps:

1) Check if the device is currently operated in high power mode, e.g. the transmit power is close to the maximum.
2) If this is true, calculate the needed power savings. From this derive the MCS that is needed to work properly with the decreased SNR. Finally, calculate the number of additional RB needed to compensate for the reduced number of data bits per RB.
3) Check if the additional RB are available in the cell, e.g. the cell is not occupied completely or the user is considered as priority user.
4) If the additional RB are available, re-allocate the resources and reduce the tx-power for saving accumulator lifetime.

While the information that the LTE device is operated in the High Power Mode is only available at the devise itself, the resource allocation in LTE does usually take place in the eNodeB. Therefore, a protocol modification will be needed which allows the UE for asking for additional resources for power saving purposes. This could by done by slightly modifying the power headroom reports as specified in [2]. That the final decision about the power saving mode of a UE takes place at the BS comes along with the advantage that the additional RB can be retrieved immediately if new users enter the cell and there is no more capacity available for energy saving purposes.

Fig. 5 and Fig. 6 show the results of ray-tracing simulations for an exemplary urban LTE cell. The simulation calculates the SNR that can be achieved at the BS if the UE submits at the max. tx power of $23\ dBm$. One can see from Fig. 6 that the users can be divided into three groups: The first group is not able to establish an LTE connection with a BLER below 10^{-2} because the achievable SNR is below $2\ dB$. The second group can establish a connection but has to transmit in the high power mode because a power reduction of $14\ dB$, as needed for a fall back to low power mode, would cause a

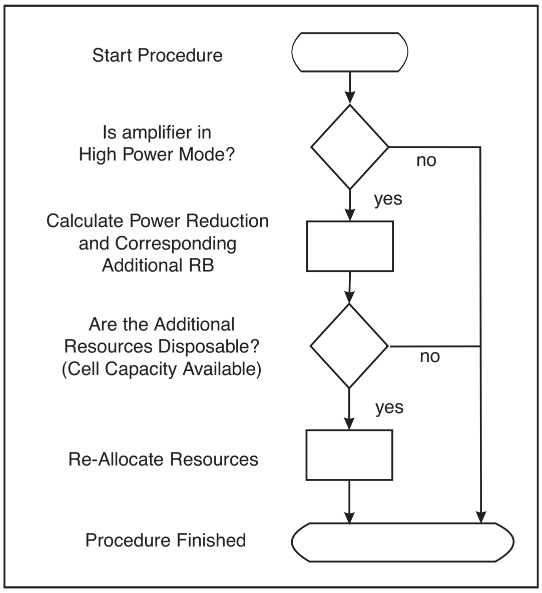

Fig. 4. Flow Chart Illustrating the Generic Power Reduction Scheme

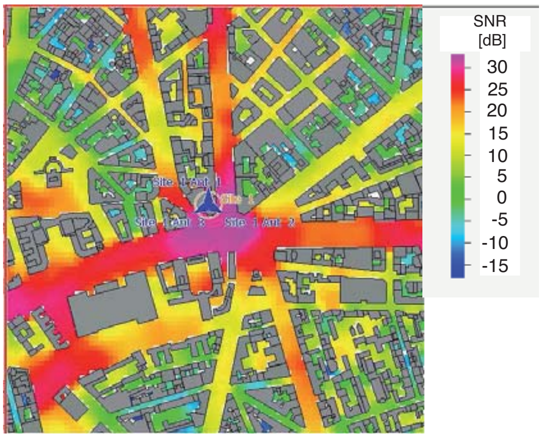

Fig. 5. Ray-Tracing Results for Exemplary Urban Environment (@24dBm tx-power)

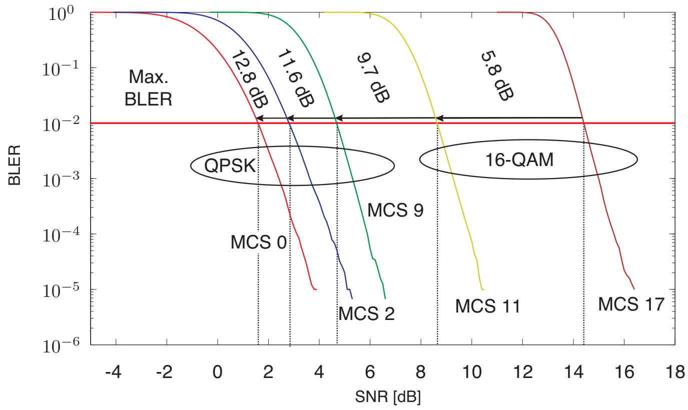

Fig. 7. SNR vs. BLER for different Modulation and Coding Schemes

connection loss. The third group finally, that is the biggest one with above 50 %, can fall back to the low power mode and therefore achieve significant power savings if additional resources are available in the cell. If the available recources are not sufficiant for applying the algorithm to all of the candidate UE, it is up to the operator to define priority rules. It is worth noting that the performance of this approach is yet only validated for applications with constant data-rate, e.g. real time applications such as streaming or interactive applications. If a file transfer has to be performed it might be suitable to minimize the transmission time no matter what the average power consumption is [9]. Nevertheless, telephone calls are still a mobile application of major importance and should not be neglected for system design considerations.

V. Reducing the Energy Consumption for Voice Over IP Traffic

For a concrete quantification of the energy savings that can be achieved by the novel approach a detailed measurement for Voice over IP (VoIP) traffic as an exemplary and prominent real time application has been performed. As the LTE system is an "all IP Network" also the voice submission is performed in the packet switched domain. The most widely used speech codec for 3GPP networks incl. LTE is the Adaptive Multirate Audio Codec (AMR). For this example a codec data rate of 12.2 $kbit/s$ is considered which is quite common for LTE. In LTE Rel. 8 a dedicated transport block size (TBS) equal to 328 is designated for VoIP [11]. For ensuring the submission of the 12.2 $kbit/s$ provided by the voice codec together with the overhead needed, the submission of one of these transport blocks comprising 328 Bit has to be performed every 20 ms, e.g. in every 20[th] Transmit Time Interval (TTI). For the configuration of TBS 328 several different possibilities are given for various combinations of MCS and number of RBs. Table II gives five examples ensuring this transport block size. The last column of the table gives the minimum SNR that it needed for achieving a Block Error Rate (BLER) below 1 %, which is needed for high quality VoIP communication [12]. The relationship between the SNR and the corresponding BLER were derived by means of simulations using OPNET Wireless Suite and the specialized LTE model herein. The resulting plot can be seen in Fig. 7. An important figure that can be derived from the plot is the amount of signal power that can be saved if the highest order MCS, which is a 16-QAM (ID 17) with a code rate $R = 0.569$ is replaced by a more robust MCS. If for example the more robust MCS 11 is used instead of MCS 17 the transmit power that has to be spent for achieving the target BLER of 1 % can be reduced by 5.8 dB.

For the final performance evaluation of the novel scheme the actual average power consumption was measured for the

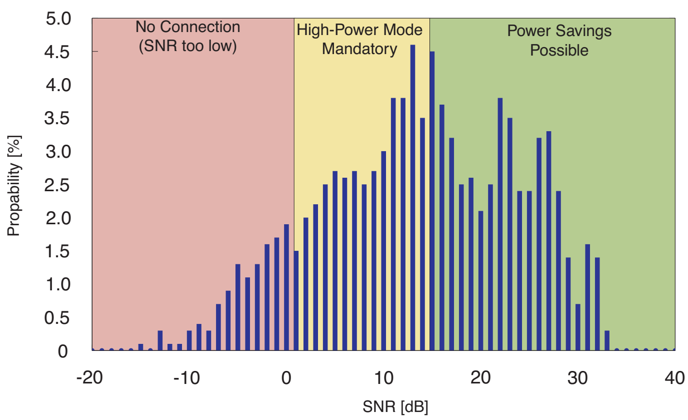

Fig. 6. Probability Density Function (PDF) of the SNR for Typical Urban Environment (@24dBm tx-power)

TABLE II
Different Resource Configurations for TBS 328 (VoIP)

# RB	MCS	R	SNR for BLER < 1% [dB]
1	16-QAM (ID 17)	0.569	14.4
2	16-QAM (ID 11)	0.285	8.6
4	QPSK (ID 5)	0.285	4.7
8	QPSK (ID 2)	0.142	2.8
12	QPSK (ID 0)	0.095	1.6

different resource allocations shown in Table II. Beside the parameterization of the MCS, the number of RB and uplink transmission power per RB P_0, the signal was parametrized that only the necessary fraction of TTI is occupied by a VoIP transport block. Fig. 8 shows the average results of the measurement together with the $95\ \%$ confidence intervals. As it can be seen from the plot, one second of VoIP communication is costing $2.14\ J$ from the accumulator of the LTE device if one RB with MCS 17 coded data is used for the submission of the data. For that, we assume that for using MCS 17 the transmission power of $7\ dBm/RB$ is needed for ensuring the required BLER. If the same user would switch to MCS 11 he needs one additional RB for ensuring a TBS of 328. On the other hand the user would be able to decrease the uplink power by about $6\ dBm/RB$ what makes the devices amplifier fall back from high power mode to low power mode. This transition leads to a decreased power consumption of the device to only $1.62\ J/s$ which makes a power saving of $23.8\ \%$. In terms of battery lifetime whis would mean that the average speaking time with one filling of the accumulator can be increased by almost $31\ \%$. If other ressource allocations are chosen further energy savings of up to overall $27.5\ \%$ are possible but the additional savings will not legitimate the increased demand of RB. This is due to the fact that major savings can only be achieved if a transition from the high power mode to low power can be performed. While for this example an user is assumed who has to submit at a quite high power for using MCS 17, the same results do also apply if a user has to transmit at a close to maximum power for any other MCS. Doubeling the number of allocated RB and reducing the MCS order will in most cases lead to a fall back to the low power mode and therefore significant energy savings.

VI. Conclusions

In this paper, we have shown a novel approach for saving energy during real-time data transmission in the LTE uplink. Detailed measurements of the energy consumption of an LTE USB device have shown that a major non-linearity in the relationship between transmit power and consumed power is caused by a mode transition from low power mode to high power mode of the installed power amplifier. Thus, we have shown that energy savings up to $27.5\ \%$ are possible, if the high power mode can be avoided. Therefore, we have proposed an energy aware scheduling scheme that allows for trading available resources in for a reduction of the transmit power. Finally, the approach was validated for a concrete Voice over IP parameterization. The results show that by spending only one additional RB in every 20th transmit time interval can reduce the power that is consumed by the LTE device by $23.8\ \%$. As a positive side-effect inter cell interference is reduced as the transmit power is decreased. Our next step will be extending the performance evaluation from link level to system level for judging the average savable power per user.

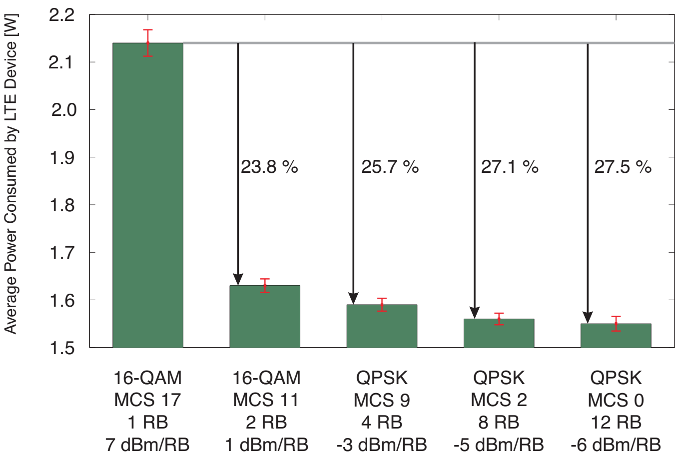

Fig. 8. Power Consumption of LTE Device for Different MCS/RB Constellations supporting TBS 328 (VoIP)

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References

[1] L. Bloom, R. Eardley, E. Geelhoed, M. Manahan and P. Ranganathan, *Investigating the Relationship Between Battery Life and User Acceptance of Dynamic, Energy-Aware Interfaces on Handhelds*, Mobile Human-Computer Interaction - MobileHCI, 2004.

[2] 3GPP, TS 36.213, "LTE Physical Layer Procedures", V 9.3.0, September 2009

[3] A. Simonsson and A. Furuskar, *Uplink Power Control in LTE - Overview and Performance, Subtitle: Principles and Benefits of Utilizing rather than Compensating for SINR Variations*, IEEE 68th Vehicular Technology Conference, pp.1-5, September 2008

[4] B. Muhammad, A. Mohammed, *Performance Evaluation of Uplink Closed Loop Power Control for LTE System*, IEEE 70th Vehicular Technology Conference Fall, pp.1-5, September 2009

[5] "DRX Parameters in LTE", 3GPP TSG RAN WG2 LTE contribution R2-071285, March 2007

[6] K. Aho, T. Henttonen, J. Puttonen and T. Ristaniemi, *Trade-Off between Increased Talk-Time and LTE Performance*, 9th International Conference on Networks (ICN), pp. 371-375, April 2010

[7] T. Kolding, J. Wigard and L. Dalsgaard, *Balancing power saving and single user experience with discontinuous reception in LTE*, IEEE International Symposium on Wireless Communication Systems (ISWCS '08), pp. 713-717, October 2008

[8] SKYWORKS, *SKY77709 Power Amplifier Module for LTE FDD Band VII(2300-2400 MHz)*, Product Summary, 2010

[9] M. Lauridsen, A. R. Jensen and P. Mogensen *Reducing LTE Uplink Transmission Energy by Allocating Ressources*, IEEE 74th Vehicular Technology Conference (VTC), September 2011

[10] J. Puttonen, T. Henttonen, N. Kolehmainen, K. Aschan, M. Moisio and P. Kela *Voice-over-IP Performance in UTRA Long Term Evolution Downlink*, IEEE 67th Vehicular Technology Conference (VTC), pp. 2502-2506, May 2008

[11] Y. Jou, R. Attar, J. Ma and X. Zhang *Performance Comparison of CDMA2000 1x and LTE for Voice Service*, IEEE Wireless Communications and Networking Conference (WCNC), April 2010

[12] M. Tran, D. Halls, A. Nix, A. Doufexi and M. Beach, *Mobile WiMAX: MIMO Performance Analysis from a Quality of Service (QoS) Viewpoint*, IEEE Wireless Communications and Networking Conference, Budapest, 2009.