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Published in:
I E E E V T S Vehicular Technology Conference. Proceedings

DOI (link to publication from Publisher):
10.1109/VETECF.2011.6092935

Publication date:
2011

Document Version
Accepted author manuscript, peer reviewed version

Reducing LTE Uplink Transmission Energy by Allocating Resources

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***Abstract*—The effect of physical resource block (PRB) allocation on an LTE modem's transmit power and total modem energy consumption is examined. In this paper the uplink resource blocks are scheduled in either a Frequency Division Multiple Access (FDMA) or Time Division Multiple Access (TDMA) manner, to determine if low transmission power & long transmission time or high transmission power & short transmission time is most energy efficient. It is important to minimize the LTE modem's energy consumption caused by uplink transmission because it affects phone battery time, and because researchers rarely focus on energy consumption when they optimize network controlled uplink transmission power parameters.**

Simulations based on a simple traffic model and a power consumption model show the TDMA scheme, where one user is allocated all 48 PRBs in a 10 MHz channel, is at least 24 % more energy efficient than the FDMA like approach with 8 PRBs per user. Furthermore the TDMA scheme decreases the average transmission time with minimum 24 %.

I. Introduction

The gap between mobile phone complexity and battery capacity is increasing year by year, leading to limited and continually decreasing battery lifetime. The problem is evident for smartphones, where power and data demanding applications, such as video streaming to and from YouTube, online gaming, and social applications like Facebook, have emerged.

To cope with the requirements for higher data rates, lower latency, and higher spectral efficiency, the Third Generation Partnership Project (3GPP) developed the Long Term Evolution (LTE) standard [1]. Unfortunately the new standard leads to more complex phones requiring more physical antennas and faster processors, [2]. Meanwhile less attention is paid to the amount of time the smartphone can run the aforementioned applications before the battery is discharged, leading to a problematic relationship between required and available energy.

Previous work on solving the battery gap problem has focused on maximizing the available energy and minimizing the energy consumption, [3]. The available energy can obviously be increased by improving the battery capacity, but this is not sufficient. A new potential solution is to utilize surrounding energy sources, such as kinetic, thermal, and solar energy, [4].

The smartphone's energy consumption can be minimized by optimizing the hardware (HW) and software (SW). The HW energy consumption can be reduced by choosing power efficient components and by performing power management e.g. by applying sleep modes to power down inactive HW parts. In LTE Discontinuous Reception and Transmission (DTX) [5] have been standardized to enable energy saving sleep modes [6]. Furthermore the energy consumption can be reduced by adjusting the phone's resources, e.g. display brightness and processor speed, to the individual applications. By combining and/or reducing the transmitted data from each application via SW control, energy savings are also possible. Finally, the phone's energy consumption can be minimized by adjusting the network controlled parameters which affect the User Equipment (UE) modem.

In this study UE transmission power and Physical Resource Block (PRB) allocation in uplink are examined. Both are network controlled and much effort has been put into adjusting the parameters to increase channel capacity, throughput and coverage. In literature focus is however rarely on how the parameters affect UE power consumption. Therefore the effect of PRB allocation on transmit power and total modem energy consumption is examined in the present paper.

First the Uplink Power Control (UPC) and the system analysis including assumptions are introduced together with the simulation setup in sections I-A to I-C. Then simulation results are presented in section II, and finally conclusions and guidelines are given in section III.

A. Uplink Power Control

The LTE UE's transmission power P_{Tx} in a subframe of the Physical Uplink Shared Channel is [7]

$$P_{\text{Tx}} = \min(P_{\text{MAX}}, P_0 + \alpha \cdot PL + 10\log_{10}(M) + \Delta_{TF} + f) \qquad \text{[dBm]} \qquad (1)$$

where P_{MAX} is the maximum transmission power, which is 23 dBm ± 2 dB for a class 3 UE [8], P_0 is a power offset [dBm], $\alpha \in \{0, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1\}$ is the path loss compensation factor [7], PL is the downlink path loss estimate [dB], M is the number of assigned Phsyical Resource Blocks, Δ_{TF} is a closed loop UE specific parameter which is based on the applied Modulation and Coding Scheme (MCS), and f is another closed loop UE specific parameter.

In literature several closed loop schemes such as Interference Based Power Control [9] and Load Adaptive Power Control [10], [11] have been presented. The schemes are often compared and combined with the open loop Fractional Power Control (FPC), where $\alpha < 1$, e.g. [12], [13], [14]. The FPC was examined in [15]. Usually the focus is on cell capacity i.e. average cell throughput versus coverage. The problem is that the effect on the UE power consumption is rarely

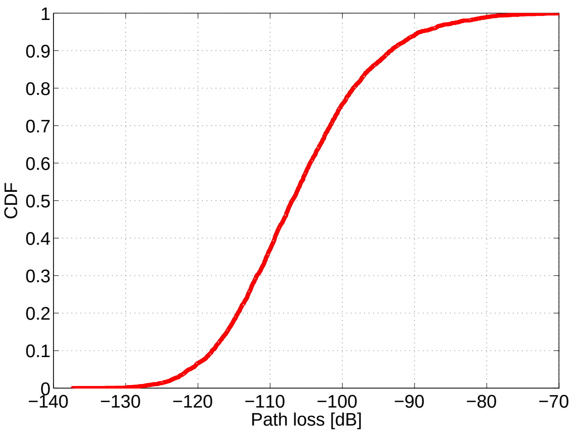

Fig. 1. CDF for the Macro1 propagation scenario.

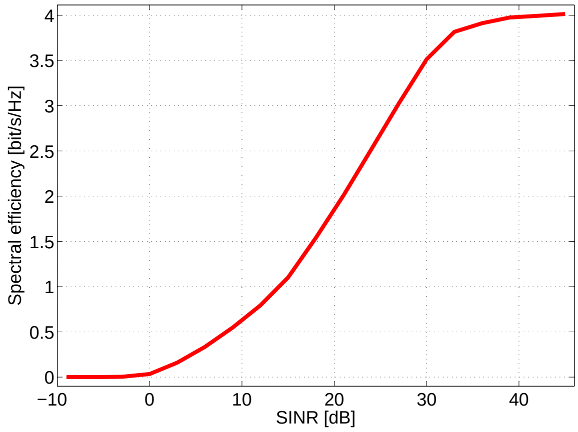

Fig. 2. SINR vs. spectral efficiency. Based on a simulation of single input single output uplink transmission, where adaptive MCS is applied to achieve a BLER target of 10 %. The channel model is ITU's Typical Urban 20 paths.

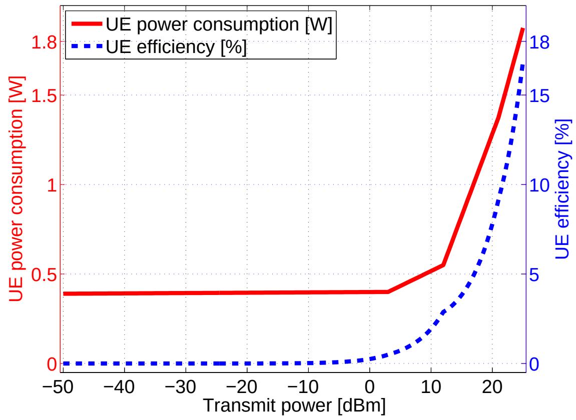

Fig. 3. Transmission power versus total UE power consumption & efficiency. The total consumption covers RF including power amplifiers, base band, power management units and external memory. Based on a polynomial fit to the '2011 UE model' curve in [18, Fig. 20.30].

examined hence an energy inefficient UPC scheme may be selected. In this study the open loop FPC is used and the values of P_0 and α are broadcasted i.e. they are identical for all UEs. Based on a review of the literature concerning FPC and macro1 propagation scenario simulations the set $[P_0 = -54.5 \text{ dBm}, \alpha = 0.6]$ is used.

B. System Analysis

To calculate the UE's transmit power a downlink path loss estimate PL is required. In this study the estimates are based on the macro1, [9], [10], [11] propagation distribution illustrated in figure 1. Each user is assigned one path loss value from the distribution for the entire transmission. In the simulations, path loss values above

$$PL_{\text{max}} = \frac{P_{\text{MAX}} - P_0 - 10\log_{10}(1)}{\alpha} = \frac{24 + 54.5 - 0}{0.6} = 130.8 \text{ dB}$$

are removed because the UE will be power limited i.e. $P_{\text{Tx}} > P_{\text{MAX}}$ even for $M = 1$ with the selected P_0, α. Usually the UE will reduce M one-by-one until $P_{\text{Tx}} \leq P_{\text{MAX}}$ but that is not possible when M is already at its lowest value.

The number of allocated PRBs M depends on the cell channel bandwidth, the number of users, and the allocation scheme, which is determined by the network operator. The channel bandwidth is 10 MHz and as in [16] 48 PRBs are available to the users, because 2 PRBs are used for control signaling such as the Sounding Reference Signals. The maximum number of simultaneously active uplink users is set to 10 based on the limitations imposed by the Physical Downlink Control Channel as described in [17]. Furthermore simulations are made where the maximum is 6 and 8 users as in [16]. The PRB allocation is based on an equal opportunity turn-based scheme. The scheme allocates PRBs user by user, who then either will be limited by UE transmission power or maximum allowable PRBs per user, until all PRBs in the Transmission Time Interval (TTI) are allocated or the maximum number of simultaneous users (SU) is reached. In the following TTI the next user in the queue is scheduled and so forth. It is assumed that there is no packet loss i.e. no retransmissions.

When P_0, α, M, and PL for the current user have been determined the transmit power P_{Tx} is calculated using (1) without the closed loop parameters Δ_{TF} and f, and then the spectral efficiency for the user is determined via the Signal-to-Interference-and-Noise Ratio (SINR) as illustrated in figure 2. If the SINR is below -3 dB, transmission cannot occur because the spectral efficiency is equal to 0 bit/S/Hz. Interference is assumed to be non-existent within the cell, because of the orthogonal structure of LTE uplink SC-FDMA signals. The same UPC scheme is assumed to be used in the neighbor cells. If e.g. the transmit power in a cell increases it will cause an increase in inter-cell interference, but likewise the transmit power will have increased in the neighbor cells. This means the relative signal-to-interference ratio will remain the same independently of the maximum PRBs and users. Based on this reasoning the interference is set to a constant (0) in the simulations even though the users' relative positions in a real live network would entail the instantaneous inter-cell interference to fluctuate.

When the transmit power has been calculated the total energy consumption is determined via the curve in figure 3. The curve predicts the power consumption of a year 2011 WCDMA UE, but it is believed to approximate an LTE UE as well. When the UE is active, but not scheduled, in the current TTI its idling power is set to 255.5 mW based on the LTE UE power consumption model presented in [6]. Before and after the UE conducts the uplink transmission it is considered to be in a DTX light sleep mode, which based on [6] is set to 11 mW. The i'th user will be in DTX mode for $t_{\text{DTX},i}$ seconds to ensure that all users are compared over the same time interval

$$t_{\text{DTX},i} = \max_{j \in [1,N]} (t_{\text{tx},j}) - t_{\text{tx},i} \qquad [\text{s}] \qquad (2)$$

where $t_{\text{tx},j}$ is the transmission time for the j'th user and N is the total number of simulated users.

In this study the traffic model is a single video file with a constant data rate equal to 400 kbps and a duration of 200 seconds. The values are based on the results in [19], [20], where the authors have used webcrawlers on the Youtube site.

C. Simulation Setup

To analyze the total UE energy consumption's dependency on the number of PRBs two simulation methods are applied. In the first simulations only one user exist. The user is assigned a path loss value from the CDF and then allocated a pre-specified number of PRBs every TTI until the user finishes uploading the video file. The number of PRBs are only changed (in this case reduced) if the user is power limited i.e. exceeding P_{MAX}. This simulation will provide insight into transmit power distributions, maximum achievable throughput and energy consumption, and each PRB setting is simulated 50.000 times. In the second batch of simulations an upper limit is again imposed on the number of allocated PRBs, but furthermore the users now exist and transmit simultaneously. New users arrive according to a pre-specified probability and the target is 4 active users per TTI on average. The probability is based on an iterative examination of the average number of users. In total 5.000 users are simulated in the second batch.

The maximum number of PRBs are in the range 2 to 48 in the single user simulations. If the user only get 2 PRBs the transmission channel will look like Frequency Division Multiple Access (FDMA), where many users are active concurrently but allocated a few resources in the frequency domain. If the user is allocated up to 48 PRBs the transmission channel changes towards Time Division Multiple Access (TDMA), where the users are active in a short time frame and occupying a large amount of the available bandwidth. In the simultaneous users simulation the minimum number of PRBs is increased to 8 in order to fully utilize the 10 MHz channel (48 PRBs), when the maximum number of simultaneous users is set to 6. If one or more users are power limited and unable to utilize all 8 PRBs, channel capacity is wasted, but then it is caused by user limitations. Table I contains the simulation parameters.

II. Simulation Results

Figure 4 illustrates the single user throughput and as expected it increases when the number of PRBs increases because the larger bandwidth enables the user to transmit more data per TTI. The curves' continuous part is caused by the user's SINR, which affects the spectral efficiency hence the capacity per PRB. The curves' step-like bottom part indicate that the user is power limited i.e. transmitting P_{MAX} and forced

TABLE I
Simulation Parameters.

Parameter	Value
Propagation scenario	Macro1
Network size	1 cell
System bandwidth	10 MHz
PRB size	180 kHz
PRBs available to the users	48 (2 are used for control signaling)
Traffic model	1 file (200 s · 400 kbps = 80 Mb)
Maximum simultaneous users	[6,8,10]
Maximum number of PRBs/user	[2,4,8,16,24,48][a], [8,12,16,24,48][b]
Max transmission power P_{MAX}	24 dBm
P_0	-54.5 dBm
Path loss compensation α	0.6
Antenna gain	UE Tx 0 dB, eNodeB Rx 14 dB
Interference	0
Noise	-174 dBm/Hz (thermal)
Noise figure	10 dB

[a] PRBs per user in single user simulations
[b] PRBs per user in simulations with several simultaneous users

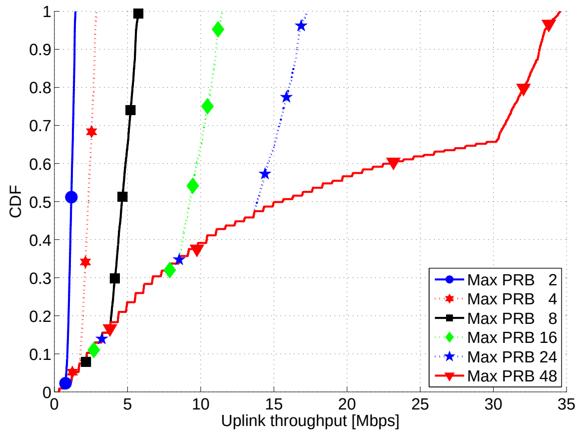

Fig. 4. Single user uplink throughput.

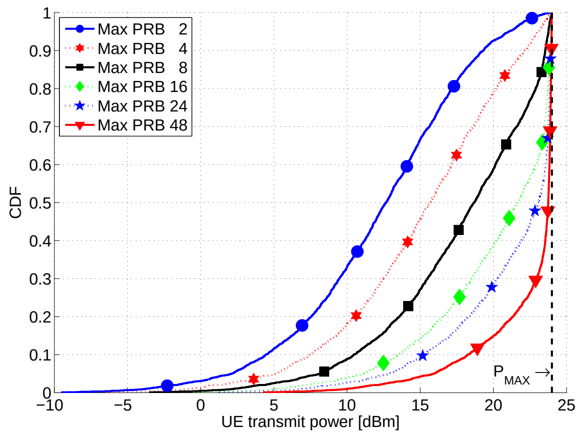

Fig. 5. Single user uplink transmission power.

to reduce the number of PRBs one-by-one as the path loss increases. The transmission power distributions in figure 5 consolidates this point, because they illustrate that e.g. the ~35 % of the users with 16 PRBs, who had a step-like throughput curve, are power limited. The transmit distributions are based

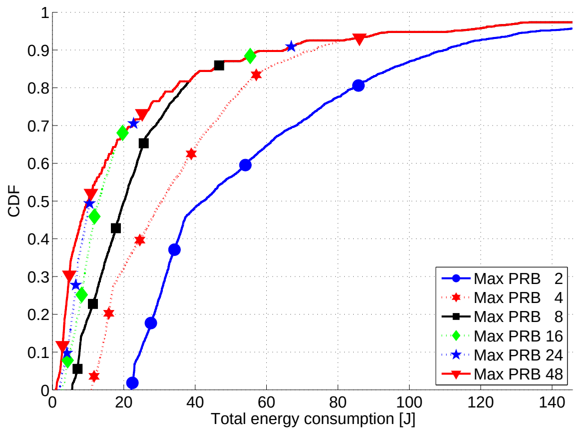

Fig. 6. Single user total energy consumption.

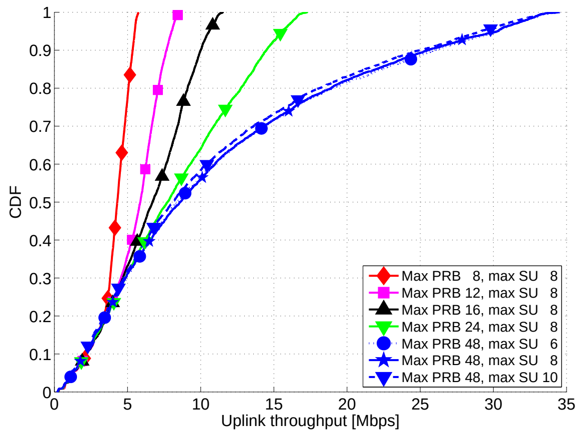

Fig. 7. Simultaneous users' (SU) uplink throughput.

on the UPC formula, (1). Note that doubling the bandwidth, e.g. from 4 to 8 PRBs causes a 3 dB increase in transmission power and that the curves' slopes are equal because of the common path loss compensation factor α.

Figure 6 shows the users' individual energy consumption. Since the simulations are made for one user at a time the user is scheduled every single TTI, hence the energy consumption can be directly based on the numbers from figure 5 and the transformation from transmit power to total power in figure 3. The energy consumption curves show that it is more energy efficient to allocate many PRBs even though it leads to a higher transmission power as shown in figure 5. The reason is that the transmission time is shorter for a user with many PRBs and high transmission power than for a user with few PRBs. Furthermore the UE is more efficient when transmitting with higher power as illustrated in figure 3. Analyzing figure 6 in further detail it is evident that users with either 16 or 24 PRBs do not consume much more energy than users with 48 PRBs, and the benefit is that using 16 or 24 instead of 48 PRBs will leave resources for triple and twice as many users respectively. The top part of the curves combine because they are constituted of the users, who experience large path loss. This means they are forced to reduce the number of PRBs because of transmit power limitations, effectively leading to users with the same low number of PRBs no matter how many they were initially allocated.
Having established that allocating as many PRBs as possible is more energy efficient for the single user case, it is interesting to examine the results where users exist simultaneously and the equal opportunity turn-based scheduler is applied.

The simultaneous user throughput is shown in figure 7 and as expected the resource sharing amongst the users reduces the throughput. The conclusion however remains the same i.e. more allocated resources per user lead to higher transmission throughput. Again the step-like pattern, which was discussed for figure 4, where users are power limited, can be identified. Simulations were performed for a maximum of 6, 8, and 10 simultaneous users, but as the three curves for 48 PRBs show, the difference between the three setups is small and therefore the results for 6 and 10 users are not plotted for other PRBs.

TABLE II
AVERAGE USER TRANSMISSION TIME.

		Maximum PRBs					
		8	12	16	24	48	$\Delta T^{\dagger}$
Max. SU	6	30.1 s	21.8 s	20.5 s	19.4 s	18.8 s	38 %
	8	25.2 s	21.8 s	20.5 s	19.5 s	18.9 s	25 %
	10	25.7 s	22.1 s	21.0 s	20.2 s	19.5 s	24 %

† ΔT denotes the time difference between 8 and 48 PRBs

The cell throughput for all simulations was ~15 Mbps.

Table II contains the average transmission time for the combinations of maximum simultaneous users and maximum number of PRBs. The average transmission time decreases at least 24 %, when the maximum number of PRBs is changed from 8 to 48. The advantage decreases as the number of users increases because more users lead to longer waiting time for the individual user. The transmission time for 6 users and 8 PRBs is significantly higher than any other setup. The reason is the low probability of allocating all 48 PRBs in each TTI because of power limited users. Therefore a new resource block scheduler is suggested for future work. The idea is to frequently allocate large path loss users to mitigate the effect of them only being able to use a few PRBs per TTI because of transmit power limitations. Increasing the maximum number of users from 6 to 10 increases the average transmission time with ~4 %, when the results for 8 PRBs are excluded.

Figure 8 illustrates the simultaneous users' total energy consumption while transmitting the video file. The conclusions from the single user simulation are still valid i.e. more PRBs per user lead to lower energy consumption because the UE is more energy efficient, when it transmits with high power, and because the transmission time decreases. The 15 % most energy consuming users show the same trend independently of the PRB and user settings and are therefore not plotted. The average energy consumption is given in table III and the results consolidate that more PRBs lead to reduced energy consumption. At least 24 % energy can be saved if the users are allocated 48 PRBs instead of 8. Based on table II it was discussed that an increase in the number of users does not increase the average transmission time with more than ~4 %

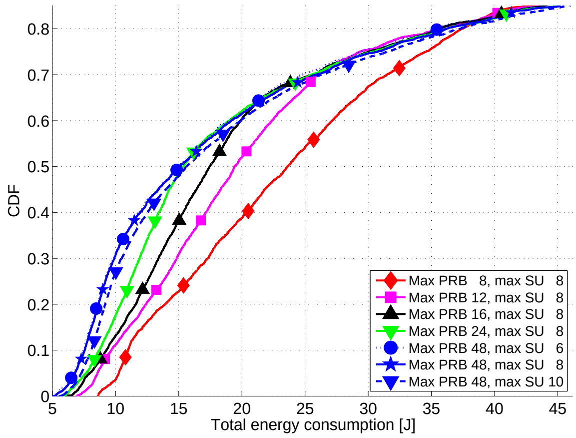

Fig. 8. Simultaneous users' total energy consumption.

TABLE III
AVERAGE ENERGY CONSUMPTION FOR 85 PERCENTILE USERS.

		Maximum PRBs					
		8	12	16	24	48	ΔE ‡
Max. SU	6	23.1 J	18.8 J	17.6 J	16.9 J	16.0 J	31 %
	8	22.0 J	19.1 J	17.9 J	17.0 J	16.3 J	26 %
	10	22.2 J	19.4 J	18.1 J	17.2 J	16.9 J	24 %

‡ ΔE denotes the energy difference between 8 and 48 PRBs

and examining table III it is concluded that the average energy consumption similarly only increases ~6 %, but because the cell throughput is the same for all simulations there is no incentive to allow more than 6 simultaneous users.

III. CONCLUSION

Physical Resource Block (PRB) allocation effects on LTE UE transmission power and energy consumption were examined. The simulation results, based on a mapping from transmission power to energy consumption, show that it is more energy efficient to allocate as many PRBs as possible to a single user instead of assigning several users less PRBs. On average at least 24 % energy can be saved if a user is allocated an entire 10 MHz channel (48 PRBs) instead of 8 PRBs. LTE's Uplink Power Control entails that users with more PRBs will transmit with higher power, but the throughput increases concurrently and therefore energy can be saved. Furthermore the applied power consumption model entails that the UE's efficiency increases when the transmit power increases.

An equal opportunity turn-based PRB scheduler was implemented to evaluate how scheduling of maximum 6, 8, and 10 simultaneous users affect the energy consumption. The results show scheduling maximum 10 users instead of 6 increases the average transmission time with ~4 % and the average energy consumption with ~6 %. Yet there is no incentive to allow more than 6 users because the cell throughput is independent of the number of users. The conclusion is that one user should be allocated as many PRBs as possible, while limiting the number of simultaneous users to reduce the average waiting time.

The findings are valuable to network operators since the presented conclusion provides insight into how the network can be adjusted to prolong the users' battery time.

Future work can focus on other traffic types, UPC parameters, and modeling of interference and packet loss.

ACKNOWLEDGEMENT

The authors would like to thank Frank Frederiksen, Claudio Rosa, Jens Steiner, & Jeroen Wigard, Nokia Siemens Networks for valuable discussions. The work is partly funded by the Danish National Advanced Technology Foundation and the 4th Generation Mobile Communication and Test Platform (4GMCT).

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