QoS verification for Minimization of Drive Tests in LTE networks

Fedor Chernogorov, Timo Nihtilä
Magister Solutions Ltd., Jyväskylä, Finland
Email: [fedor.chernogorov]@magister.fi, [timo.nihtila]@magister.fi

***Abstract*—Nowadays, operational quality and robustness of cellular networks are among the hottest topics wireless communications research. As a response to a growing need in reduction of expenses for mobile operators, 3rd Generation Partnership Project (3GPP) initiated work on Minimization of Drive Tests (MDT).**

There are several major areas of standardization related to MDT, such as coverage, capacity, mobility optimization and verification of end user quality [1].

This paper presents results of the research devoted to Quality of Service (QoS) verification for MDT. The main idea is to jointly observe the user experienced QoS in terms of throughput, and corresponding radio conditions. Also the necessity to supplement the existing MDT metrics with the new reporting types is elaborated.

***Keywords*: LTE mobile networks, Minimization of Drive Tests, QoS, verification.**

I. Introduction

In modern standards of wireless networks, such as Long Term Evolution (LTE) for Universal Mobile Telecommunications System (UMTS), combination of radio access technology, sophisticated resource management and error correction mechanisms provides high capacity and speed of access. This is the main reason why more and more attention of research community is turned towards improvement of operational quality, reliability and ease of maintenance of cellular networks. Remarkable effort is made by mobile operators to maintain high quality of service, as it includes continuous monitoring of different physical elements, e.g. antennas, amplifiers and cabling, as well as configuration of thousands of network parameters, which define and dramatically affect operational behavior.

Also there is a crucial question related to conditions which should lead to more thorough checks in the network. In that sense, one of the problematic areas is that there are no effective ways for observation of the experienced level of end user QoS associated with a particular location. For that reason most of the measurement statistics is averaged over long time periods for a group of cells, e.g. for a tracking area. Such averaging leads to significant loss of relevant information. To cope with this problem operators have to carry out regular drive tests, described in more details in Section II. General drive tests provide more detailed network performance verification, being however rather expensive and limited in terms of size of examined area, comparing to full coverage of the mobile network. According to the existing standards and ongoing R&D work, automation and minimization of drive testing should lead to increase of operational quality of LTE networks and provide more complete information about the overall network state.

This article is among the first ones where the level of provided QoS is investigated from a radio perspective. In other words correspondence between common radio measurements and characteristics of scheduling algorithms is investigated. Taking into account that the end user quality is analyzed, presented research work can be classified as one of the use cases of MDT family, named QoS verification.

This article starts with introduction presented in Section I. Section II gives description of the notion of drive tests and describes motivation for their minimization. In Section III more detailed information about the QoS verification use case is presented. Section IV is devoted to simulation environment used for the practical part of this research and its setup. Results of the presented work are described in Section V, and Section VI finalizes this article with conclusions and future work perspectives.

II. Drive Tests and their Minimization

Drive testing is a process of manual collection of radio interface performance information in the geographical area of interest. Gathered data can include levels of signal strength, interference, amount of throughput available for users, experienced delays, number of dropped and blocked calls, etc. This is done in order to create a QoS network map. Most commonly, drive tests are initiated by a mobile network operator due to deployment of new base stations, construction of major object, e.g. highway, customers' complaints, or on a periodical basis [1]. Among the main drawbacks of drive tests are their high cost and the fact that they are limited to outdoor areas. This defines the necessity for minimization of drive tests using automatic monitoring algorithms.

The main means for achievement of this goal are User Equipment (UE) reporting, extended with new types of measurements, and advanced analysis methods of the existing data. Selection or creation of new metrics or algorithms is heavily dependent on the target of the network state monitoring. Thus, to reduce the operational expenses and increase the network robustness and maintainability, general MDT use cases have been classified to several groups: coverage, capacity, mobility, quality of service and quality of common channels' operation.

978-1-4673-0990-5/12/$31.00 ©2012 IEEE

III. QoS VERIFICATION FOR MDT

In QoS verification MDT use case the main aim of the performance analysis is to check whether the level of provided service is sufficiently high. The main scope of our research, is to define how well the existing radio measurements, described in Section III-B, are useful for estimation of the experienced QoS level in terms of throughput. Obviously, speed of access is not the only quality metric, but it can be considered among the most important ones. Also quality metrics can be highly correlated. For example, delay experienced by the user depends on traffic distribution, and hence is closely interrelated with the throughput level.

A. *QoS metrics*

In this research collection and reporting of throughput measurements is carried out in two different ways. *Instantaneous data collection* implies logging of the throughput values with resolution of Transmission Time Interval (TTI), which equals to 1 ms. This type of data reveals information about the distribution of the peak throughputs within the network. The downside of this approach to user quality estimation is high variability of the collected results, caused by the nature of resource allocation in LTE. For this reason, instantaneous throughput is heavily dependent on the selection of scheduling algorithm, as it is shown in Section V.

In order to get more complete picture of the user quality in time perspective, another approach to throughput measurement has been employed. In the *time-averaged data collection* throughput measurements are also carried out on a per-TTI basis, but log entry is made only from time-averaged values. Until the user is in active state values averaged over a 4 second time window are added to a measurement log. Selected duration of averaging window allows to smooth the oscillations of individual instantaneous measurements by utilizing large number of samples and at the same time attach the collected measurement to a specific network location, taking into account the UE velocity.

In general, both types of throughput data are gathered along with the location coordinates of the UEs, availability of which is a generic assumption for MDT studies, allowing for creation of measurement network maps, similar to path loss maps.

B. *Network Measurements*

In the presented work estimation of the experienced user quality is made on the basis of certain radio measurements described in this section. The first one is the Reference Signal Received Power (RSRP), which is a pilot measurement, defined as a linear average over the power contributions (in [W]) of the resource elements that carry cell-specific reference signals within the considered measurement frequency band [2]. RSRP is the main measurement for handover and cell reselection procedures. It is also important to note, that RSRP measurements are made during both intra-/inter-frequency Radio Resource Control (RRC) IDLE and CONNECTED modes. In our research collection of RSRP values has been done with resolution of 1 ms, even though in real network this is an averaged measurement with reporting period of 200 ms. This is done to evaluate a one-to-one correspondence between user quality characteristics and radio metrics.

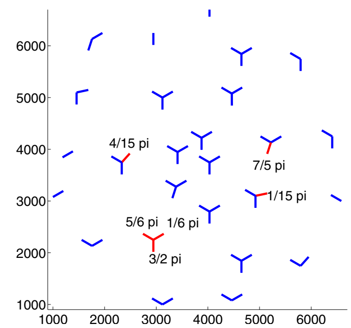


Fig. 1: “Springwald” - non-regular network layout.

Another measurement employed for estimation of user throughput is Channel Quality Indicator (CQI), or more precisely Wideband CQI, which is an average CQI value for the whole system bandwidth. In LTE standard there are 16 CQI levels which correspond to different Modulation and Coding Schemes (MCS). In turn each MCS is selected in such a way that it guarantees BLock Error Rate (BLER) not to exceed 10 % at a given Signal to Interference plus Noise Ratio (SINR) [3]. In this paper CQI is not presented in the form of levels, but instead has a dB scale, what to some extent makes it similar to SINR. Employed WCQI metric can be used as an indication of the data rate supported by the system within a given channel conditions. Periodicity of WCQI reporting in our research is the same as with RSRP, and equals to 1 ms.

IV. SIMULATION ASSUMPTIONS

To achieve realistic results, a fully dynamic system level simulator of LTE mobile network is employed in this research. It simulates Evolved Universal Terrestrial Radio Access Network (E-UTRAN) in accordance to 3GPP Rel. 8 and beyond. This simulator maps link level SINR to system level following the methodology presented in [4]. For both downlink and uplink simulations resolution equals to one symbol of Orthogonal Frequency Division Multiplexing (OFDM). In addition, several radio resource management, scheduling, mobility, handover and traffic modeling functionalities are implemented.

Non-regular network layout, named “Springwald”, employed in this research is shown on Fig. 1. Varying Inter-Site Distances (ISDs) and directions of E-UTRAN Node B (eNB) antennas makes this scenario more realistic, as it includes both urban and rural area types of networks [5].

Parameters used for configuration of the described simulator are presented in Table I.

A. *Scheduling Algorithms*

In the described simulator a decoupled time-frequency domain Packet Scheduling (PS) is implemented. Time Domain (TD) scheduler selects N users on the basis of priority metric of each user, which are then scheduled in Frequency Domain (FD). Final allocation of the Resource Blocks (RBs) for new

TABLE I: General Simulation Parameters

Parameter	Value
Cellular layout	Non-regular ("Springwald")
Number of cells	36 active and 24 interfering sites
Number of eNB sectors	3 sector antenna each
Analyzed data link direction	Downlink
User distribution in the network	Uniform
Maximum BS TX power	46 dBm
Initial cell selection criteria	Strongest RSRP value
Handover margin	3 dB
Handover time to trigger	256 ms
Hybrid Adaptive Repeat and reQuest (HARQ)	Asynchronous, chase combining, maximum 3 retransmissions
Slow fading standard deviation	8 dB
Simulation length	100 s = 1.4 million steps
Number of simulations	60 for each scheduler
Simulation resolution	1 time step = 71.43 μs
Network synchronicity mode	Asynchronous
Maximum number of active users	360
UE velocity	3 km/h
Duration of calls	Negative exponential distribution, mean 30 s
Time averaging window	4 s
Traffic model	Infinite buffer

the transmissions is done in FD. Selection of PS algorithm is always a trade-off between the extent of fairness and the level of provided average user throughput. The following resource allocation algorithms were used in our research:

- Proportional Fair (PF). Serves users with the highest relative channel quality, which is based on CQI measurements.
- Maximum Throughput (MT). Maximum carrier to interference ratio algorithm - users which have the best radio channel conditions would be scheduled for data transmission. For this reason MT is unfair in resource allocation, but supports high data rates for scheduled users.
- Blind Equal Throughput (BET) scheduler tries to give all users the same throughput, regardless of their radio channel quality. BET method can be seen as a form of inverse MT scheduling, since in order to get the same throughput for users with poor radio conditions larger amount of resources is required. This leads to fair user throughput distribution at the cost of a lower average throughput.
- Even Resources (ER) scheduler allocates cell resources equally between the users in the cell, which have some data to send. This leads to a situation, where users at cell border and in proximity to the eNB, get the same amount of resources. ER can only be used for FD scheduling.

Fairness of different scheduler combinations is defined as a ratio $5^{th} percentile/95^{th} percentile$ of mean user throughput. The first scheduler combination employed is TD-PF/FD-MT with fairness value of 0.5, i.e. quite unfair. Another combination of resource allocation algorithms is TD-BET/FD-ER with corresponding fairness of 15, what can be considered rather fair. Such selection is made in order to observe the behavior of user quality for the two explicitly different types of schedulers.

V. Results

A. Methods for Results' Analysis

Results, presented in this section are described from two different perspectives. On the one hand, statistical characteristics of individual measurements are investigated, and on the other hand, mutual dependencies between various quality metrics are analyzed. Extent of statistical correlation is calculated on the basis of Pearson formula for linear correlation coefficient, shown in Eq. 1, [6]:

$$R(x,y) = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \cdot \sum_{i=1}^{n}(y_i - \overline{y})^2}}, \qquad (1)$$

where x and y are two variables between which correlation is calculated, while $\overline{x}$ and $\overline{y}$ are corresponding mean values.

Correlation coefficient may take values in the interval from -1 to 1. When $|R(x,y)| = 1$, distributions x and y are linearly dependent, or 100% correlated, and when $R(x,y) = 0$, they are independent. The sign of $R(x,y)$ shows whether these two variables are changing in different or similar directions.

For the QoS verification graphical interpretation of network maps in 2D space, and calculation of linear correlation coefficient, are used. When the traffic model is such that there is a full network load, the described means of analysis appear to be sufficient.

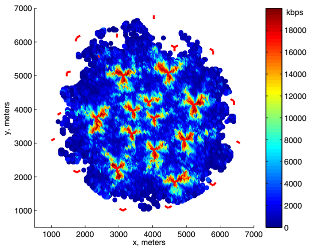
B. Characteristics of User Throughput

Analysis of the QoS by means of network maps allows to get a snapshot of the operational situation from user perspective. Comparison between instantaneous and time averaged throughput network maps for the two scheduling combinations, described in Section IV-A, is shown on Fig. 2.

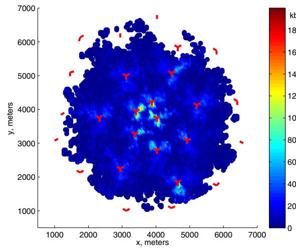
Clear difference between instantaneous and time-averaged user throughput for the more unfair scheduling scheme - TD-PF/FD-MT can be seen from the corresponding network maps shown on Fig. 2a and 2b. In both cases instantaneous throughput has much higher values, as peak data rates usually persist only during a very short time intervals, like several TTIs. In addition, it can be observed that higher instantaneous throughputs take place in the regions with better radio conditions.

Speaking about the averaged throughput, for the users which are in proximity to eNBs, average data rates are also high, though not as high as for the instantaneous throughput. However, in general distribution of averaged data rate has more uniform character.

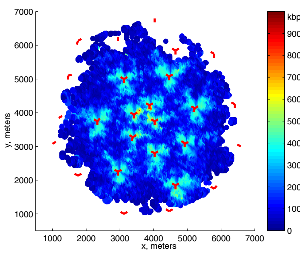
Difference between fair and unfair scheduler combinations can be seen best of all from Figs. 2a and 2c. It is important to note that the color scales of these two figures differ by a factor of 2. In case of TD-PF/FD-MT scheduler, which provides much higher peak values of throughput, cell edge users get significantly lower throughput. This refers to the fact



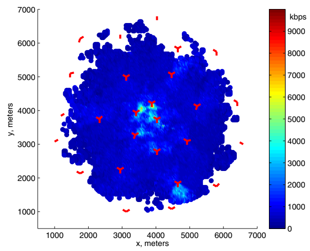
(a) Instantaneous throughput, TD-PF/FD-MT



(b) Averaged throughput, TD-PF/FD-MT



(c) Instantaneous throughput, TD-BET/FD-ER



(d) Averaged throughput, TD-BET/FD-ER

Fig. 2: Network throughput maps for TD-PF/FD-MT and TD-BET/FD-ER packet scheduling schemes

that unfair type of scheduler allocates most of the resources to the UEs in the best network conditions. On the other hand, TD-BET/FD-ER scheduler represents a much more fair combination of resource allocation. The results demonstrate that high fairness is achieved at a price of reduction of available maximum user throughput, i.e. there is no such dramatic difference in user throughput on cell edges and in proximity to eNB as for unfair packet scheduler.

C. Analysis of User Quality via Network Measurements

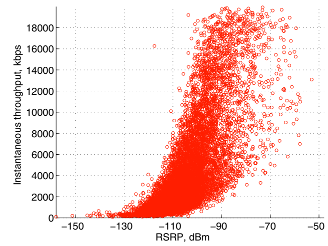
In our research devoted to QoS verification, throughput is analyzed via observation of RSRP and WCQI with resolution of 1 ms, as it is described in Section III. Correlation coefficients between instantaneous and time-averaged datasets of RSRP and WCQI measurements are 99.56% and 99.52% correspondingly. Invariability of these two measurements in time perspective most likely refers to the fact that interference is very static due to the utilization of infinite buffer traffic model, which implies 100% RB occupancy. For these reasons only instantaneous radio measurements are used for mutual analysis of quality metrics.

The extent of dependency between throughput and network measurements varies for different schedulers. With TD-PF/FD-MT scheduler we find that correspondence of RSRP values with throughput, presented on Fig. 3a and Fig. 3b, is much lower than for WCQI values, especially in case of quality estimation in terms of instantaneous throughput. Numerical values of the correlation coefficient for different types of throughput and both RSRP and WCQI can be found from Tab. II.

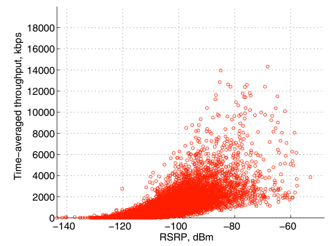
Somewhat similar conclusions can be made from the results

TABLE II: Correlation Coefficients of User Throughput and Network Measurements

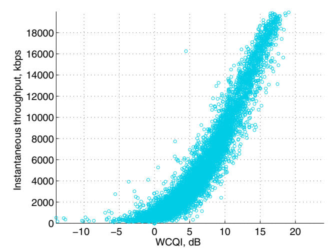
Packet Scheduler:	TD-PF/FD-MT		TD-BET/FD-ER	
Tput type / measurement	RSRP	WCQI	RSRP	WCQI
Instantaneous Tput	73.02 %	94.24 %	80.51 %	97.27 %
Time-averaged Tput	69.37 %	76.96 %	54.04 %	48.48 %
Normalized Inst. Tput	80.82 %	99 %	79.77 %	98.78 %



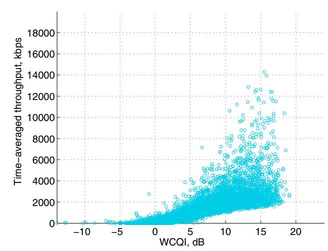
(a) Instantaneous user throughput VS. RSRP



(b) Averaged user throughput VS. RSRP



(c) Instantaneous user throughput VS. WCQI



(d) Averaged user throughput VS. WCQI

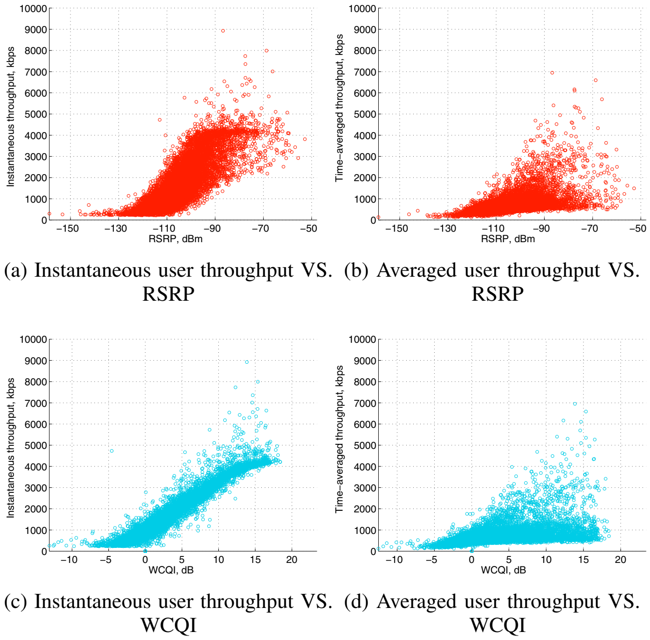
Fig. 3: Correspondence between network measurements and user throughput for TD-PF/FD-MT packet scheduling scheme

for TD-BET/FD-ER scheduling scheme, for which correspondence plots are presented on Fig. 4. Again for instantaneous throughput WCQI values are more reliable estimation measure of the throughput. The main difference from the previously described - unfair scheduler, is that averaged throughput in case of BET-ER cannot be estimated reliably neither on the basis of RSRP, nor WCQI, as correlation coefficients are close to 50 %, which is relatively low.

As it can be seen, both instantaneous, and time-averaged throughputs depend on the scheduler quite much, what can be considered as an expected behavior. This makes estimation of throughput using network radio measurements rather problematic. In order to overcome influence of the scheduling scheme we introduce a resource-normalized instantaneous throughput value, calculated according to the formula in Eq. 2.

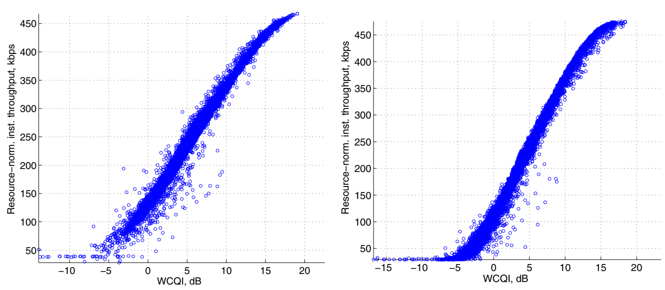
$$T_{inst\_norm} = \frac{T_{inst}}{N_{RBs}}, \tag{2}$$

where for one particular TTI, T_{inst} is instantaneous throughput and N_{RBs} is the amount of RBs allocated to this user. For both fair and unfair schedulers normalized throughput is highly correlated with all network measurements, and its variance is



(a) Instantaneous user throughput VS. RSRP
(b) Averaged user throughput VS. RSRP
(c) Instantaneous user throughput VS. WCQI
(d) Averaged user throughput VS. WCQI

Fig. 4: Correspondence between network measurements and user throughput for TD-BET/FD-ER packet scheduling scheme



(a) TD-PF/FD-MT
(b) TD-BET/FD-ER

Fig. 5: Correspondence of resource-normalized instantaneous user throughput and WCQI for different scheduling schemes

very low, as it can be seen from Fig. 5 and Tab. II. Nearly 100 % correlation of T_{inst_norm} is observed with WCQI, which means that there is almost exact match between these two variables. The importance of this finding is that even thought usual quality metrics are highly dependent on the system configuration, it is possible to create a derivative metric, which would allow to estimate the level of QoS with high precision, using the scheduling information at the eNB and knowledge about radio conditions from the UE.

VI. Conclusions and Future Work

In this paper applicability of different network measurements for estimation of end user quality in LTE networks has been investigated. The idea behind this research is to identify some metric, which could be suitable for MDT reporting. On the other hand, it was necessary to define whether this kind of reporting is needed, or most of the conclusions about the QoS can be derived from the regular network measurements.

In order to achieve the defined aim two common network measurements, described in Section III-A, have been employed for the analysis. In addition, two different scheduling schemes, presented in Section IV-A, have been used. Results show that there is no common measurement for estimation of non-normalized throughput, which would have been independent from the scheduler. However, normalization using knowledge about the resource allocation solves this problem. It can be seen especially well when observing dependency of the normalized throughput with WCQI. In this case the average correlation equals to 98.89 %. Thus, periodical WCQI measurements along with the knowledge about the amount of allocated resources at the network side can be considered a valid combination for estimation of the end user throughput.

It is also necessary to note, that time-averaged throughput is in general less correlated with common network measurements, than instantaneous throughput. The possible UE specific information, not-known in the eNB side is the receiver type, and its capabilities, such as interference and noise cancellation, which is however is already taken into account in CQI reporting [3]. Thus, there is no need to implement an independent reporting for this data either.

Further research in the area of QoS verification in MDT can be devoted to investigation of network behavior under more diverse load conditions, by utilization of a different traffic model and also other types of network scenarios. In addition, some other QoS metrics than throughput can be considered, e.g. delay.

Acknowledgments

Authors would like to thank colleagues from Magister Solution Ltd., Nokia and Nokia Siemens Networks for their guidance, valuable advices and cooperation within the course of the research work.

References

[1] *Technical Specification Group Radio Access Network; Study on Minimization of drive-tests in Next Generation Networks (Release 9)*, 3GPP Std. TR 36.805, 2009.

[2] *Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer - Measurements (Release 9)*, 3GPP Std. TS 36.2414, 2009.

[3] I. T. S. Sesia and M. Baker, *LTE - The UMTS Long Term Evolution from Theory to Practice*. John Wiley & Sons, 2009.

[4] K. B. et. al, “Link performance models for system level simulations of broadband radio access systems,” in *PIMRC-2005*, Berlin, Germany, Sep. 2005.

[5] J. Turkka and A. Lobinger, “Non-regular layout for cellular network system simulations,” *PIMRC-2010*, Sep. 2010.

[6] W. R. Pestman, *Mathematical statistics : an introduction*. Berlin, New York : de Gruyter: Wiebe R. Pestman, 1998.