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Verification of 3G and 4G Received Power Measurements in a Crowdsourcing Android App

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***Abstract*—Many crowdsourcing Android applications are available for measuring network Key Performance Indicators such as received power, latency, and throughput. The data is useful for end-users, researchers, and Mobile Network Operators, but unfortunately the applications' accuracy are rarely verified.**

In this paper we verify the crowdsourcing Android application NetMap's ability to measure LTE Reference Signal Received Power by analyzing the Root Mean Squared Error, being 2-3 dB, and cross-correlation coefficient, being above 0.8, with measurements obtained by use of a professional radio network scanner and measurement phones. In addition, the application is applicable, but less accurate, for 3G Received Signal Code Power measurements. The studies are made for various device speeds and in different scenarios including indoor, urban, and highway, where the NetMap application is showed to perform well.

I. Introduction

Obtaining Key Performance Indicators (KPIs), such as received power, latency, throughput, and mobility performance for mobile networks is of interest to the end-user, researchers, and Mobile Network Operators (MNOs) [1]. The end-user can use the KPIs when selecting MNO subscription, while access to the KPI data enables researchers to study network problems and develop potential solutions. Finally the KPIs can assist MNOs in optimizing their network deployment and setup.

The KPIs can be measured using drive tests, dedicated test beds, network-side-only tools, or user-deployed applications, [1]. The first 3 solutions often rely on professional tools, only cover a limited area, and require many man-hours of work to be conducted. On the contrary the user-deployed applications enable both the end-user, researchers, and MNOs to obtain the KPIs, reflecting the real end-users experience and mobility, at a low cost. Many applications, e.g. [2], [3], [4], [5], [6], have started using crowdsourcing i.e. spreading the applications among many users to gather as much data as possible.

The aforementioned applications are able to measure a large number of parameters including received power, latency, throughput, location, mobility performance, and energy consumption. In addition, they are able to cover a larger geographical area as compared to what drive tests and dedicated test beds can, but unfortunately the developers rarely verify whether the measurements are accurate. In [2] the authors study how accurate the latency and energy consumption measurements are, while [4], [5] compare what they termed "manual measurements" and subsets of their own data without giving further details. In [6] the authors focus on the energy consumption of running the application, which is of high importance as crowdsourcing will be difficult if the application has a reputation of excessive energy consumption. The quality of the received power measurements is discussed in [3] which observed that measurements are averaged by the phone and that some phones seem to report inaccurate numbers. Related to that, the authors of [7] state that it is likely that different phones report with different level of resolution, but the authors don't examine it in further detail.

The received power is important for understanding other network KPIs such as latency and throughput, because it will affect the applied modulation and coding scheme, and the number of retransmissions. However, according to the survey in [1] only 14 of 29 surveyed tools are able to produce coverage maps or report the received power. In fact, the conclusion of [1] specifically mentions that the accuracy of the tools is difficult to compare. This entails a root cause analysis of the observed network KPIs may be difficult to perform.

The contribution of this paper is to verify the received power measurement accuracy of our crowdsourcing Android application, named NetMap, which uses the Android API [8]. Having verified and accurate received power measurements enables researchers and MNOs to understand other KPIs such as latency and throughput in further detail. We perform the verification by comparing the NetMap measurements with 2 professional measurement phones and a radio network scanner in 4 different scenarios including indoor, urban, and highway at speeds from pedestrian to 110 km/h.

The paper is structured as follows; first the NetMap application is described in Sec. II with focus on how received power measurements are made, then the verification methodology including tools, scenarios, data processing, and evaluation is presented in Sec. III. Selected results are presented together with a discussion and future use of the application in Sec. IV and V respectively, followed by the conclusion in Sec. VI.

II. The NetMap Application

The NetMap Android application is designed to capture network performance on the application layer and Radio Access Technology (RAT) specific parameters that affect the end-user experience [9]. The application captures information for 2G, 3G, and 4G while also logging user position via GPS.

The default NetMap application logs throughput, connectivity, network context state, Round Trip Time (RTT) and

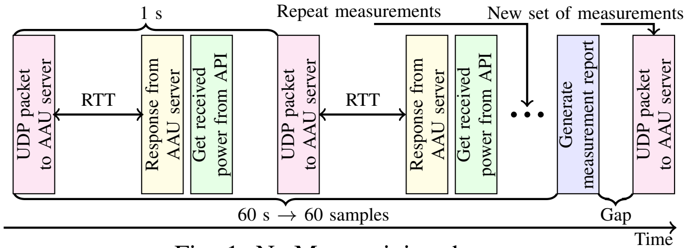


Fig. 1: NetMap activity chart.

received power [9]. In this work, a simplified version logging the two latter parameters was applied. Both the RTT and received power measurement are collected with a frequency of approximately 1 Hz, which entails the mobile terminal is always expected to be actively connected to the serving cell. In between the measurements the application is in a sleep state to reduce the effect on battery life and general resource usage.

The RTT measurement is initiated when the application sends a UDP packet, with a payload containing a packet ID of a maximum of 1024 bytes, to a server at Aalborg University (AAU). When the response is received at the application layer the total RTT is logged. This is implemented using the DatagramPacket and the DatagramSocket APIs in Android [8]. A timeout of 1 s is set on the socket to capture long RTTs.

Every time a RTT measurement is performed the received power is also sampled as illustrated in Fig. 1. When 60 measurements are completed a report is generated after which 60 new measurements are initiated as soon as possible. Depending on the RAT it varies how the received power is calculated and which Application Programming Interface (API) must be used. Furthermore, depending on the state of the phone's screen the APIs act differently, and in addition, different APIs are available in different versions of the Android operating system.

There are two APIs that can be used for extracting the received power values; SignalStrength and CellInfo [8]. The SignalStrength API has been available since Android SDK version 7 (Android 2.1). This API offers a wide range of received power related information, and for 3G measurements NetMap reads the GsmSignalStrength via the call getGsmSignalStrength(). The 3G received power is reported via this API because Android decided it is convenient that the received power for different RATs is reported in the same place. The call returns an Arbitrary Strength Unit (ASU) value representing the 3G Common Pilot Channel Received Signal Code Power (RSCP), and valid values are (0-31, 99) as defined in [10]. The conversion to RSCP is defined as:

$$\text{RSCP} = \text{ASU} - 120 \qquad [\text{dBm}] \tag{1}$$

For Long Term Evoloution (LTE) the call LteRsrp returns the Received Signal Reference Power (RSRP) defined as: [10]

$$\text{RSRP} = \text{ASU} - 140 \qquad [\text{dBm}] \tag{2}$$

Unfortunately the SignalStrength API only report updates while the screen is ON, and therefore the CellInfo API is used while the screen is OFF. The CellInfo API was made available in Android SDK version 17 (Android 4.2), but the subclass CellInfoWcdma was not added until SDK version 18 (Android 4.3) [8]. For 3G the CellInfoWcdma is used to extract received power values via the call .getCellSignalStrength().getDbm(). For LTE the subclass CellInfoLte is used with the call .getCellSignalStrength().getAsuLevel() which returns an ASU value defined between 0-97, and where 99 is unknown [10].

During development and measurements we have observed that the behavior of received power values from the CellInfo API varies from phone to phone from different manufacturers in terms of update frequency and availability. This indicates that different manufacturers implement the received power reported to the Radio Interface Layer from the network modem differently, as also observed by [3], [7].

III. Methodology

The purpose with this work is to verify that NetMap, using the Android APIs on a commercial smartphone, is able to accurately measure 3G RSCP and LTE RSRP received powers. Our methodology is to compare the NetMap measurements, made in 4 different scenarios, with quality references obtained by use of professional measurement tools consisting of a Rohde & Schwarz radio network scanner, from now on referred as the scanner, and 2 Qualipoc measurement smartphones from SwissQual. The details of the tools and scenarios are given in the following Sec. III-A. This allows for the following three comparisons:

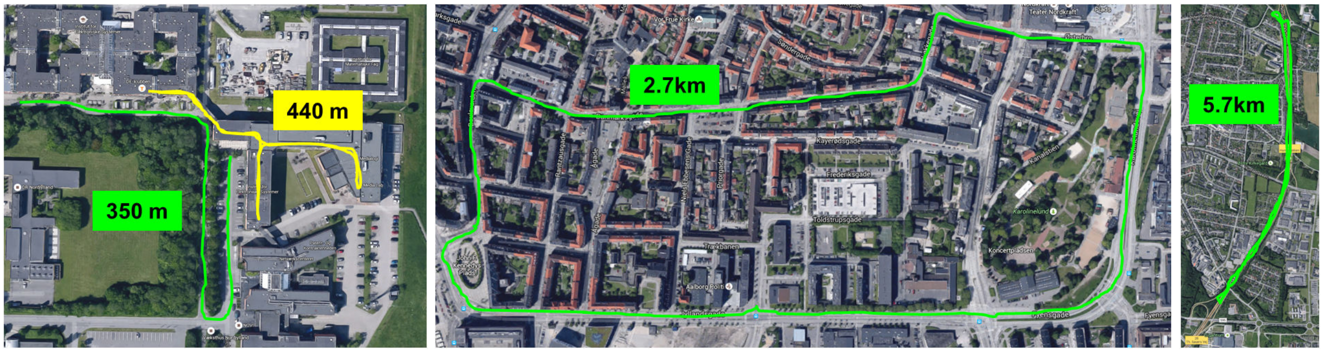
i *Radio network scanner vs. NetMap*
The scanner has the best measurement resolution and sampling time, but it is a passive device unable to connect to a specific network. The scanner is often favored for drive tests due to its ability to monitor multiple carrier frequencies at once. However, it will not reflect the end-user experience, including handover settings, traffic steering, and cell load conditions, as NetMap will.

ii *Qualipoc vs. NetMap running on the same phone*
Running NetMap on the measurement phone entails NetMap and the Qualipoc software should report the same received power, because they have the same origin. However, the measurement phone is rooted and the Qualipoc software optimized to provide better resolution and sampling time as compared to the commercial phone.

iii *Qualipoc vs. NetMap running on a different phone*
Running NetMap on a different phone is expected to result in received power differences, because the two phones will not experience the same fast fading. In addition, the Radio Frequency (RF) front ends and application layers are different. However, since both phones are connected to the same MNO the measurements should be comparable and reflect the accuracy that can be obtained in practice.

A. Tools and Scenarios

The list of phones and measurement tools as well as their key characteristics are given in Table I. To illustrate NetMap's potential to crowdsource coverage, latency, and other network KPIs the application was installed on 3 identical, commercial



(a) AAU scenarios (b) City center (c) Highway

Fig. 2: The measurement routes in the 4 scenarios.

TABLE I: KEY PARAMETERS FOR THE PHONES AND MEASUREMENT TOOLS. RAT SPECIFIC PARAMETERS ARE GIVEN AS 3G; LTE.

ID	Model	Software	Android version	Operator & bands	Sampling time [s]	Resolution [dB]
A	Google Nexus 6	NetMap	5.1.1	X: 900,2100; 800,1800,2600	1; 1	2; 1
B	Google Nexus 6	NetMap	5.1.1	Y: 900,2100; 800,2600	1; 1	2; 1
C	Google Nexus 6	NetMap	5.1.1	Z: 2100; 1800,2600	1; 1	2; 1
D	Samsung GS3	Qualipoc 13.0.0.25	4.1.2†	X	0.32; 0.52	1; 0.1
E	Samsung GS5	Qualipoc 15.0.0.53	4.4.4†	X	0.29; 0.53	1; 0.1
F	R&S TSMW radio scanner	Romes 4.82	-	passive X,Y,Z	1.1; 0.11	0.1; 0.01

† SwissQual provided a modified version of Android to run Qualipoc

phones (A,B,C), which were connected to 3 major MNOs (X,Y,Z) in Denmark. The measurement phones (D,E) were connected to operator X, while the scanner (F) passively monitored the received power from all 3 MNOs simultaneously.

As indicated in Table I NetMap's resolution is 10-100 times worse than the professional tools (D-F), and therefore it especially interesting to analyze whether the received power measurements are comparable, because NetMap will then provide a cheap and easily deployable alternative. NetMap's sampling time is also lower than Qualipoc's and the scanner in LTE mode. For 3G the scanner, used in high accuracy mode, has a sampling time similar to NetMap because it monitors a large number of bands. NetMap's lower sampling time and resolution may be more of an issue in some scenarios than in others and therefore the 6 devices were deployed in 4 different scenarios; indoor & outdoor at AAU campus, in Aalborg city center, and on the local highway. The details of the scenarios are listed in Table II and they clearly provide different propagation conditions as reflected by the device speed, number of observed cells, and dynamic range of the received signal. The number of observed cells and received powers are based on reports from the Qualipoc phones (D,E). Fig. 2 illustrate the measurement routes in the 4 scenarios. Note that the yellow line in Fig. 2a corresponds to the indoor scenario, while the green line is the outdoor scenario.

TABLE II: SCENARIO DETAILS WITH SPECIFIC PARAMETERS AVERAGED FROM QUALIPOC PHONES (D,E). RAT SPECIFIC PARAMETERS ARE GIVEN AS 3G; LTE.

Scenario / Parameter	AAU indoor	AAU outdoor	Aalborg city center	Highway E45
Fig. reference	2a yellow	2a green	2b	2c
Device speed [km/h]	6 (pedestrian)	6	30	110
Distance [km]	0.44	0.35	2.7	5.7
Observed cells [-]	2; 1	2; 1	14; 12	9 ; 6
Minimum power [dBm]	-100; -110	-87; -96	-96; -114	-106; -117
Maximum power [dBm]	-61; -72	-62; -79	-41; -56	-47; -62

(a) The trolley (b) The car

Fig. 3: The measurement tools and transportation devices.

In order to eliminate effects of the devices moving differently or experiencing different gains due to hand grip effects [11], the devices were mounted in a measurement rack and then moved either by use of a trolley (in the AAU scenarios) or car (city center and highway) as illustrated in Fig. 3.

B. Data Processing and Evaluation

After the measurements are completed they are post-processed in Matlab to determine how well NetMap's measurements match those of the Qualipoc phones and the scanner. The processing procedure is as follows:

1) data from the Qualipoc phones and the scanner (devices D-F) are filtered to remove any fast fading effects, because the

purpose is to verify whether NetMap captures the overall coverage (mean path loss level) and shadow fading (slow variations of the path loss).

2) data from devices D-F is downsampled (if necessary) to fit the sampling rate of NetMap.
3) comparisons according to the methodologies (i,ii,iii), described in Sec. III, are performed as follows:
   i NetMap phones (A-C) are compared with the scanner (F) capturing all 3 MNOs (X,Y,Z). The results are averaged across operators for each of the 4 scenarios. The scanner measures the received power of all cells within its dynamic range while NetMap only measures the received power of the current serving cell. The NetMap measurements are therefore compared with the maximum received power of the scanner, which is determined sample by sample. A hysteresis of 5.5 dB and 3 dB is used for 3G and LTE respectively, to emulate a handover margin between the current serving cell and a stronger neighbor cell.
   ii NetMap measurements of phones D and E are compared with the Qualipoc measurements of the same phones. The results are averaged for the two Qualipoc phone D and E connected to MNO X.
   iii NetMap in phone A is compared with Qualipoc measurements of phones D and E. The 3 phones are connected to the same operator (X), but they may experience small differences in fading, in addition to the different RF front end and antenna gains.
4) the comparisons are based on a parameter search to determine the time- and power-offset between NetMap and reference data. This is necessary because the 6 devices were not started simultaneously and due to the devices' different antenna and RF front end gains.
5) the best fit, depending on the time- and power-offset, is the one resulting in the lowest Root Mean Squared Error (RMSE) and the highest cross-correlation coefficient ρ. Definitions of these metrics are given in the appendix.

Fig. 4 illustrates the original data after it is time-aligned (thin line) and after it has been filtered (thick line), but not compensated for power-offset. The Fig. also illustrates a potential handover case, where carrier 2 observed by the scanner is stronger than carrier 1. However, during the measurements (not illustrated in Fig. 4) it was observed that NetMap and Qualipoc phones may be connected to a carrier with lower received power as compared to the maximum value observed by the scanner. The reason is traffic steering and handover policies implemented by the MNO to suit the specific scenario, and differences in antenna and RF front end gains.

The power-offset calibration coefficients for NetMap on phone A vs Qualipoc phone D and E are given as an example in Table III. In order for the measurements to be valid the power-offset should be constant across the scenarios when compared with a specific device for a specific RAT, because the power-offset only depends on antenna and RF front end gains. The results in Table III reflect this as the standard

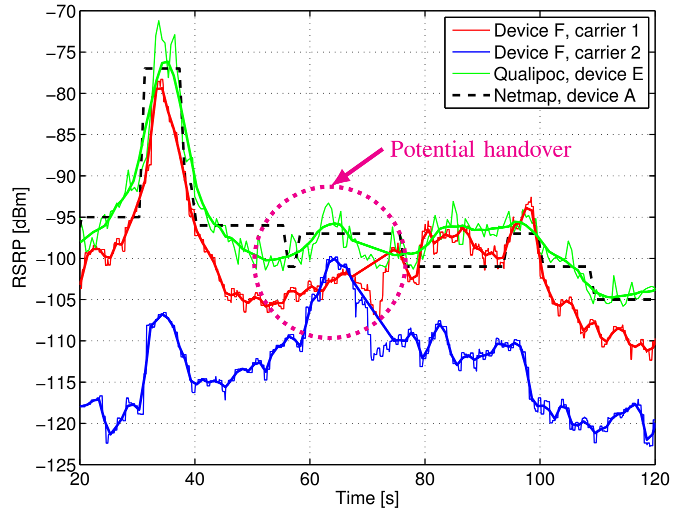


Fig. 4: Data processing steps. Thin lines are original, time aligned data. Solid lines are filtered and downsampled data. The scenario is indoor LTE.

TABLE III: Calibration coefficients for NetMap on phone A vs Qualipoc phones D and E. Values in dB.

Scenario	3G		LTE	
Phone	D	E	D	E
Indoor	-8.5	-4.8	-0.8	0.7
Outdoor	-8.3	-5.2	-0.5	1.0
City center	-6.2	-5.9	*2.5*	1.6
Highway	-8.5	-4.5	-0.9	0.8
Average	-7.9	-5.1	-0.73	0.83
Standard deviation	1.12	0.61	0.21	0.15

deviation is around 1 dB for 3G, while it is only about 0.2 dB for LTE i.e. a very constant offset is applied for all scenarios in LTE. In the city center scenario phone A, connected to operator X, performed a handover from LTE to 3G shortly after the measurement was initiated. Therefore the result, marked with *italic*, is unreliable and not included in the calculation of average values. It is not possible to force the phones to LTE, because Voice over IP is not fully implemented in Denmark yet and therefore it would make voice calls to the specific LTE-only phone impossible.

IV. Results

In this section the RMSE and cross-correlation coefficient ρ results are presented for the 3 comparisons defined in Sec. III. The 2 KPIs: RMSE and ρ are defined in the appendix.

The results for the 4 scenarios when using 3G is given in Table IV. As expected comparison ii (NetMap and Qualipoc on the same phone) results in the best fit with an average RMSE close to NetMap's resolution of 2 dB (see Table I), and a high cross-correlation coefficient of 0.88. The comparisons i and iii with the scanner and Qualipoc running on a different phone yield less accurate results for 3G as the correlation on average is below 0.7 while the RMSE is above 4 dB.

The indoor and outdoor AAU scenarios show the smallest

TABLE IV: NETMAP 3G MEASUREMENTS COMPARED WITH SCANNER AND QUALIPOC.

Comparison	i (scanner)		ii (same phone)		iii (different phone)	
Scenario	RMSE	ρ	RMSE	ρ	RMSE	ρ
Indoor	4.1 dB	0.52	2.1 dB	0.88	3.7 dB	0.68
Outdoor	4.8 dB	0.57	1.8 dB	0.73	3.3 dB	0.44
City center	6.1 dB	0.72	2.3 dB	0.97	7.0 dB	0.66
Highway	6.8 dB	0.71	4.3 dB	0.92	4.6 dB	0.87
Average	5.4 dB	0.63	2.6 dB	0.88	4.6 dB	0.66

TABLE V: NETMAP LTE MEASUREMENTS COMPARED WITH SCANNER AND QUALIPOC.

Comparison	i (scanner)		ii (same phone)		iii (different phone)	
Scenario	RMSE	ρ	RMSE	ρ	RMSE	ρ
Indoor	3.0 dB	0.83	2.1 dB	0.88	2.6 dB	0.87
Outdoor	3.0 dB	0.72	0.8 dB	0.93	2.0 dB	0.67
City center	5.8 dB	0.80	1.9 dB	0.99	4.5 dB	0.85
Highway	7.3 dB	0.74	1.8 dB	0.99	4.5 dB	0.91
Average	4.7 dB	0.77	1.7 dB	0.95	3.4 dB	0.83

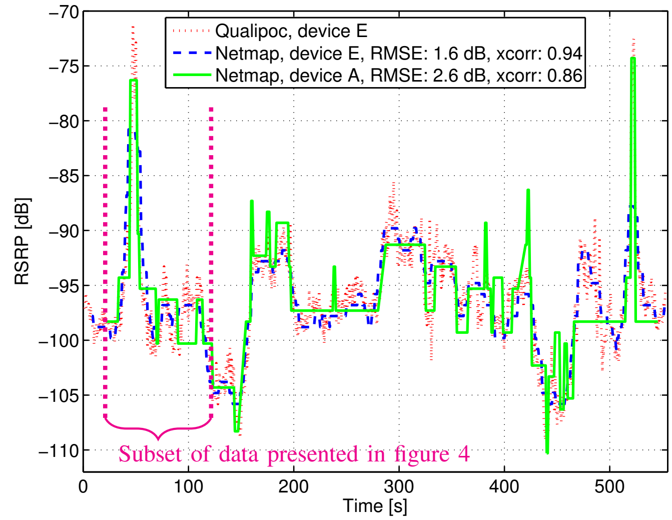


Fig. 5: NetMap measurements from Qualipoc phone E and commercial phone A compared with the Qualipoc measurement. The scenario is indoor LTE.

dynamic range of the received power according to Table II, and this is reflected in the results in Table IV where those scenarios result in the lowest RMSE. However, on average the smaller variations also entail a lower cross-correlation coefficient as compared to the city center and highway scenarios.

The results for LTE are given in Table V. As in 3G the comparison ii provides the best results, but for LTE the comparisons i and iii also provide accurate results with an average cross-correlation coefficient around 0.8 i.e. a good match between NetMap and the professional tools.

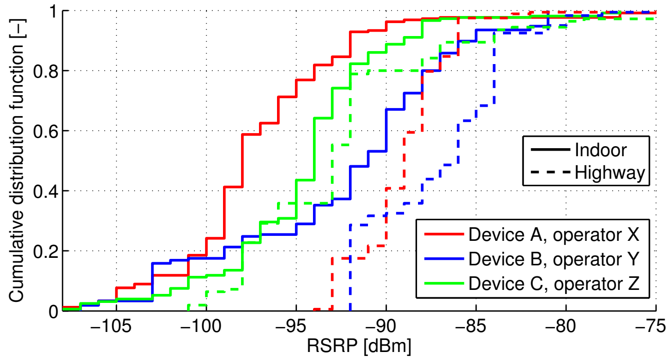
Fig. 5 illustrates the filtered, downsampled, and time- and power-offset results for Qualipoc and NetMap measurements on phone E compared with NetMap measurements on phone A i.e. all connected to the same operator (X). The scenario is indoor LTE. The NetMap measurement on phone E seems to vary slightly more than the NetMap measurement on phone A. Since NetMap was configured to provide one measurement per second for both phones, see Table I, the difference is expected to be due to the model and configuration of the chipset and processor.

V. DISCUSSION

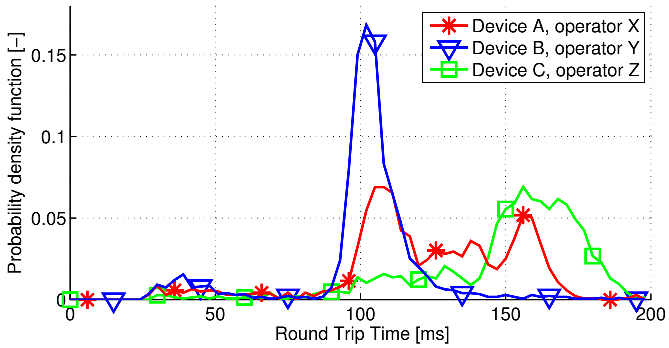
The results, presented in the previous section, verified that NetMap, running on a commercial smartphone, is able to measure LTE RSRP with sufficient accuracy to track shadow fading and path loss. It provides a cheap alternative to the professional tools even though the resolution and sampling time are significantly lower. In addition, NetMap reports the measurements of a connected phone as opposed to the scanner, which in some cases may overestimate the coverage, because it is not able to capture phenomenons caused by MNO traffic steering. NetMap's 3G measurements are less accurate, partly due to the Android API, but still reliable. The RMSE of 3-5 dB (see Table IV) is not critical when considering that empirical path loss models and ray-tracing tools compared with received power measurements may result in RMSEs of 4-6 dB [12].

The NetMap measurements were calibrated towards either the scanner or the Qualipoc phones and therefore the power-offset is relative to the antenna and RF front end gain of these devices. This entails the absolute values are not accurate, while the relative measurements are calibrated. This is especially important for the crowdsourcing results, because as the measurements show the average power-offset in Table III is as high as 8 dB between phones A and D. Thus, there may be significant differences in crowdsourced data from different phones, which must be compensated in the final analysis. This variability was also observed by [3], [7].

Having verified the NetMap received power is an important achievement, because it enables the further analysis of statistics such as latency and throughput, and why those parameters in some cases are worse than expected. In addition, the received power measurements can be used to study and compare the coverage of various MNOs. As an example Fig. 6a shows the Cumulative Distributive Function of the received power for phones A-C connected to operators X, Y, and Z respectively. The measurements are made for LTE in the indoor AAU and highway scenarios. Operators X and Y seem to benefit from having a sub-GHz carrier in the highway scenario, while operator Y in general provides the best coverage for both scenarios. Fig. 6b illustrates the combined NetMap LTE RTT measurements for each of the 3 operators averaged across the 4 scenarios. Significant variations can be observed and if low RTT is of importance to the end-user, operator Y seems like the best choice. Future work includes a correlation analysis of the RSRP and RTT measurements. In addition, the authors of [7] also noted that the use of the signal-to-interference-and-noise ratio metric can be useful, when correlating RTT and throughput measurements with coverage.



(a) NetMap RSRP for LTE indoor and highway scenarios.



(b) NetMap RTT for all LTE scenarios combined.

Fig. 6: NetMap LTE measurements.

VI. Conclusion

NetMap is an Android application developed for crowdsourcing Mobile Network Operator statistics as observed by the user, e.g. received power, latency, and throughput.

The purpose of this work, being a measurement campaign, was to verify the ability of NetMap to correctly measure received power in 3G and LTE cellular networks. Received power is important when analyzing metrics such as latency and throughput because it affects the modulation and coding scheme that can be applied and the number of retransmissions.

The measurements were performed by connecting commercial smartphones running NetMap to 3 operators in Denmark, while also monitoring the received power using professional measurement phones from SwissQual and a Rohde & Schwarz radio network scanner. The diverse measurement scenarios included indoor & outdoor pedestrian speed traces, and driving on the highway and in the city center of Aalborg.

The results show that NetMap yields accurate LTE measurements with a Root Mean Squared Error of 2-3 dB and cross-correlation coefficient above 0.8, even for high speeds. The 3G measurements result in an error of 3-5 dB and a cross-correlation coefficient of 0.6-0.8, partly due to lower measurement resolution in the Android API. Furthermore, the results show a constant power-offset between NetMap and the professional tools and thus indicate consistent measurements.

Future work includes recording the cell ID concurrently with received power measurements, and presenting the measurement results to the end user, e.g. a coverage map. This will help attract new users, which is vital for crowdsourcing.

Appendix

The Root Mean Squared Error is defined as:

$$\text{RMSE}\left(x,y\right)=\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(x_{\text{i}}-y_{\text{i}}\right)^{2}}\qquad[\text{dB}]\qquad(3)$$

where x and y are the signal of interest and reference, respectively i.e. a NetMap measurement and a scanner or Qualipoc measurement. The length of the signals is N.

The cross-correlation coefficient ρ is defined as:

$$\begin{aligned}\rho\left(x,y\right)&=\frac{cov\left(x,y\right)}{\sqrt{\sigma_x^2\sigma_y^2}}\qquad[-]\\&=\frac{E\left[\left(x-\mu_x\right)\left(y-\mu_y\right)\right]}{\sqrt{E\left[\left(x-\mu_x\right)^2\right]E\left[\left(x-\mu_x\right)^2\right]}}\qquad[-]\qquad(4)\end{aligned}$$

where $cov\left(x,y\right)$ is the covariance of x and y, σ_x^2 is the variance of x, E is the expectation, and μ_{x} is the mean defined as $\mu_{\text{x}}=\frac{1}{N}\sum_{i=1}^{N}x$ for discrete values.

Acknowledgment

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