

Accurate Radio Coverage Assessment Methods: Investigation of Mobile Networks Based on Subscribers Mobile Phones

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Abstract — The most common used terms by telecommunication actors especially those in the mobile network sector are coverage, signal strength, quality of service etc. These related terms are major source of concern not only for regulators, operators, mobile service providers, but also users of the networks. To verify compliance of mobile networks specifications, measurement campaigns are often carried out and the most used method of which is drive test. This method is considered expensive because of the license software used, including logistics and personnel. Several alternative solutions have been developed but these involve mainly smartphone users. Information collection by these solutions are made from mobile phones, centralized and processed. However, the major obstacles in these solutions are reluctance of users, impact on user equipment and reliability of the results. The objective of this research is to evaluate reliability of these measurement solutions and compared them with drive test. The study further explore the impact of these measurements on the integration of collection applications on the users' phones.

Keywords— 2G,3G, 4G, Radio, Coverage assessment, Drive test, mobile networks, CPICH RSCP, P-CCPH RSCP, RSRP, SRQ.

I. INTRODUCTION

Verification of compliance of mobile network installations is often misunderstood by both regulatory authorities and network operators. These checks are carried out on the basis of operator licence requirements on radio coverage. As usually specified in the license document, regulatory authorities must verify the footprint of the different mobile network technologies deployed. To fulfil this task, a drive test must be carried out. This often requires qualified personnel, a vehicle, computers and a licensed software. These logistics are not only extremely expensive for the network operator but also difficult to evaluate coverage. The existing alternative solutions are often hampered by privacy issues and its impact on user's equipment.

The new solutions collect information from users' mobile phones but do not provide enough information on reliability of the results. The carriers' of application collection tool often complain about continuous abuse of measurements of network parameters. It is important to note that despite its high cost, the results of drive test may also depend on the path [1].

In this paper, radio signal coverage is evaluated and several scenarios have been set up to determine reliability. According to changes in radio coverage due to physical characteristics of electromagnetic waves and climatic condition, several collections activities are made at different times of the day in specific geographical areas.

This method consider the distribution of users on the surface areas concerned, including the number of samples and the recommended threshold values. Among the scenarios, we calculated average of 3 collections, average of 2 collections, evaluated the random path, the low and high density of users carrying out several collections, and users with a spontaneous measure respectively.

The analysis of all these geolocalized measures informs the fast discharge of users' smartphones and the rate of error of the new approach. These scenarios offer better area sharing than drive tests which is mainly limited to major highways and direct overview of the quality of the signal received by the end user. The overall goal of this work is to have real data at low cost through development of a user-oriented measurement strategy. The rest of the paper is organized as follows: section II describes various parameters of radio coverage of the different technologies. Based on the different scenarios discussed, the results of the practical tests and the analysis will be further explored in section III. Section IV will present the conclusion.

II. THE MAIN PARAMETERS OF RADIO COVERAGE

The indicators for the evaluation of standardized coverage by 3GPP in [2], for the different mobile networks technologies are:

- RxLev for a GERAN access network;
- CPICH RSCP and Ec/No for a UTRAN FDD access network;
- P-CCPCH RSCP for a TDD UTRAN access network;
- RSRP and RSRQ for an E-UTRAN TDD access network.

A. RxLev for a GERAN access network

The field level from the BTS measured at the mobile phone is called the RxLev, which stands for Receive Level for GSM network coverage. It is measured on 64 levels, from 0 to 63 representing respectively the powers from -110 to 48 dBm in steps of 1 dB. A distinction is made between the RxLev Full and the RxLev Sub. The former is a measurement on all burrs of the frame without exception, and the latter a measurement on the burrs actually used. To be able to access the network with a mobile phone, a user's terminal must be able to capture minimum power called RXLEV_ACCESS_MIN of the BCCH channel. According to [3] and [4], one can provide the following observations:

TABLE 1. APPRECIATION OF 2G (GSM) COVERAGE

Footprint	RxLevel (dBm)
Excellent	$-48 \leq \text{RxLevel}$
Good	$-70 \leq \text{RxLevel} < -48$
Bad	$-110 \leq \text{RxLevel} < -70$
Non-existent	$\text{RxLevel} < -110$

B. CPICH RSCP and Ec/No for a UTRAN FDD

The indicators for assessing coverage in a third-generation network for FDD mode [5] are CPICH RSCP and Ec/No. The Ec/No parameter represents the energy received per chip of the pilot channel divided by the total noise. The Received Signal Code Power (RSCP) parameter depicts the level of power received from the pilot frequency of a given base station (Node B).

The CPICH RSCP (Common Pilot Channel RSCP) and P-CCPCH RSCP (Primary Common Control Physical Channel RSCP) are referred to respectively the FDD and TDD modes. Based on [6] the power levels corresponding to the CPICH RSCP range from -115 to -25 dBm. The threshold value of the Ec/No parameter is -18 dB. On the other hand, the CPICH RSCP threshold value must be at least equal to -95 dBm or greater [7]. The assessment thresholds for Ec/No are summarised in Table 2:

TABLE 2. APPRECIATION OF 3G (UMTS IN FDD) COVERAGE

Footprint	CPICH RSCP [dBm]	Ec/No [dB]
Excellent	$-25 \leq \text{CPICH RSCP}$	$-6 \leq \text{Ec/No} < 0$
Good	$-95 \leq \text{CPICH RSCP} < -25$	$-18 \leq \text{Ec/No} < -6$
Bad	$-115 \leq \text{CPICH RSCP} < -95$	$-20 \leq \text{Ec/No} < -18$
Non-existent	$\text{CPICH RSCP} < -115$	$\text{Ec/No} < -20$

C. P-CCPCH RSCP for a TDD UTRAN

One important KPI (key performance indicator) for assessing radio coverage in a UMTS TDD UTRA network is the P-CCPCH RSCP. Based on [10] and [11], one can see that the power levels corresponding to the P-CCPCH RSCP range from -115 dBm to -25 dBm. The KPI threshold value for a UMTS UTRA TDD type network in [12], the value of the P-CCPCH RSCP must be greater than or equal to -84 dBm hence the following assessment can be made in (Table 3):

TABLE 3. APPRECIATION OF 3G (UMTS IN TDD) COVERAGE

Footprint	P-CCPCH RSCP [dBm]
Excellent	$-25 \leq \text{P-CCPCH RSCP}$
Good	$-85 \leq \text{P-CCPCH RSCP} < -25$
Bad	$-115 \leq \text{P-CCPCH RSCP} < -85$
Non-existent	$\text{P-CCPCH RSCP} < -115$

D. RSRP and RSRQ for an E-UTRAN TDD

The main coverage assessment indicators for 4G networks [13] are the RSRP and RSRQ. The User equipment measures for each detected cell the signal power level it receives from the cell. This measurement is carried out using the reference signals common to the cell that is called RSRP (Reference Signal Received Power). It is measured on 98 levels [13], from 0 to 97 representing respectively the powers from -140 to -44 dBm in steps of 1 dB.

The RSRQ (Reference Signal Receive Quality) can be defined as the ratio between the RSRP and the RSSI (Received Signal Strength Indicator). The RSSI represents the total power of the received signal, which includes transmitted signal, noise and interference. The RSRQ is measured on 35 levels [13], from 0 to 34 representing respectively the values of -19.5 to 3 dB in steps of 0.5 dB. The assessment thresholds for the RSRP and RSRQ parameters are summarized in Table 4:

TABLE 4. APPRECIATION OF 4G COVERAGE

Footprint	RSRP [dBm]	RSRQ [dB]
Excellent	$-44 \leq \text{RSRP}$	$\text{RSRQ} > -3$
Good	$-110 \leq \text{RSRP} < -44$	$-12 \leq \text{RSRQ} < -3$
Bad	$-140 \leq \text{RSRP} < -110$	$-19.5 \leq \text{RSRQ} < -12$
Non-existent	$\text{RSRP} < -140$	$\text{RSRQ} < -19.5$

III. APPROACH TO MAKE THE MEASUREMENTS RELIABLE

A. Drive Test

Based on ITU recommendations [14], the vehicle speed (V) shall be adapted to the wavelength, the number of tested signals measured simultaneously at different frequencies and shortest applicable measurement interval:

$$V(Km/h) \leq \frac{864}{f(MHz) \times t_r(s)}$$

Where:

- $t_r(s)$ is the minimum time given by the receiver specifications to revisit a single frequency;
- f is the frequency of the signal in MHz

The typical mobile speed recommended by [14] for Physical operating environments is specified in Table 5.

TABLE 5. RECOMMENDED SPEED OF VEHICLES DURING DRIVE TESTS

Environment	Speed of vehicle
Urban high-rise	Typical downtown speeds approximately 50 km/h (14 m/s)
Urban / suburban	approximately 50 km/h (14 m/s)
low-rise	Expressways up to 100 km/h (28 m/s)
Residential	approximately 40 km/h (11 m/s)
Rural	80-100 km/h (22-28 m/s)

B. Number of samples taken at regular intervals on the Axes

In [15], a method for measuring the field strength with sufficient resolution is provided. It makes it possible to collect valid statistics for coverage along the path. Samples of short steps to obtain peak values and average values from the field. The minimal number of samples over a distance according to the wavelength of the signal is calculated as follows:

$$N_{min} = \lambda R/V$$

Where:

- N_{min} is the minimal number of samples over a distance equal to the wavelength of the signal
- $\lambda(m)$ is the wavelength of the signal
- $V(m/s)$ is the vehicle speed
- R is the number of measurements per second.

C. Measurements by a mobile phone

The main parameters recorded during the measurements campaign using Network Cell Info are as follows:

- GPS coordinates of each point;
- The precision of the location of each point;
- The type of network;
- The values of the key parameters related to each technology;
- The battery level.

D. The representative sample

Not all subscribers of an operator have a smartphone. They are not constrained to install an application to collect quality of service parameters for the operator. Determining the statistically representative sample size is critical at this time to obtain conclusive results from this study. This relationship between the sample size and the generalization of the results refers to the density of the population/km².

According to the National Agency for Statistics and Demography, the Dakar region has an area of 547 km² with a population of 3,529,300 inhabitants, i.e. a density of 6,452 hbts/km² in 2017. The inhabitants are unevenly distributed geographically. The selection of the sample of users participating in the collection is then made on a random basis.

$$\text{Representative sample} = \frac{\frac{z^2 * p(1-p)}{e^2}}{1 + \left(\frac{z^2 * p(1-p)}{e^2 N}\right)}$$

Where:

- N is the average number of users over a given area;
- e the margin of error (fixed at 5% for studies);
- p the estimated proportion of the proportion that has the characteristic and
- Z the confidence level (it is 1.96 for a 95% confidence level).

E. Scenario description

Three areas have been selected as shown in Table 6.

TABLE 6. COLLECTING AREA AND REPRESENTATIVE SAMPLE

Collecting Area	Area (m2)	Density (hbts/m2)	Representative Sample (hbts)
Area 1	82 614,35	533	224
Area 2	70 294,07	453	209
Area 3	111 226, 57	718	251

For the assessment of coverage in the 3 selected areas, we proposed a total of 6 collection methods. The first method is the drive test. According to [14], the speed of the vehicle must be less than 50 km/h during tests because we are in a high and low urban environment. It is important to cover as much as possible the entire area. The second method involves evaluating the coverage of mobile networks with a daily collection. The third scenario estimate the coverage with the average of 2 daily collections.

For Scenario 4, it is a question of making 3 collections a day, calculating the average and then evaluating the network coverage. Scenario 5 focuses on increasing the number of collection devices. For this method, we used the maximum number of users that could be found in the area. This value is determined by the average density.

In the last scenario, a small number of users will collect more than one data. The number of users in this case is half of the representative sample. The objective is to see if one can determine or be the closest possible to the actual coverage when a small number of users carry out several collections.

E. Results of scenarios

Fig.1 below shows the maps of the selected zones and the route taken to collect the radio coverage parameters. The post processing tools allowed us to reconstruct the route taken on a map for the data collected.



Figure 1. Map of Area 1



Figure 2. Map of Area 2



Figure 3. Map of Area 3



Figure 4. Area 1 measurements



Figure 5. Area 2 measurements



Figure 6. Area 3 measurements

The following Tables 7, 8 & 9 summarize the data collected on the 3 zones where:

- Lp: the distance covered (meter)
- Ne: the total number of sample
- Ne_OK: the number of sample satisfying the requirements to be excellent or good according to [Table 2, 3, 4]
- COV_{xG}: the radio coverage of x generation of mobile network (%)

TABLE 7. COLLECTED DATA FROM AREA 1

Area 1	Drive test	Method 2	Method 3	Method 4	Method 5	Method 6
Lp (m)	2842,94					
Ne OK	493	73	88	84	180	44
Ne	1356	224	224	224	533	112
COV _{3G}	36,36%	32,59%	39,29%	37,5%	33,77%	39,29%
Ne OK	1414	224	224	224	533	112
Ne	1414	224	224	224	533	112
COV _{3G}	100%	100%	100%	100%	100%	100%
Ne OK	1379	224	224	224	533	112
Ne	1379	224	224	224	533	112
COV _{4G}	100%	100%	100%	100%	100%	100%

TABLE 8. COLLECTED DATA FROM AREA 2

Area 2	Drive test	Method 2	Method 3	Method 4	Method 5	Method 6
Lp (m)	3080,66					
Ne OK	273	55	41	49	111	30
Ne	1190	209	209	209	453	104
COV _{3G}	22,94%	26,32%	19,62%	23,44%	24,5%	28,85%
Ne OK	1143	209	209	209	453	104
Ne	1143	209	209	209	453	104
COV _{3G}	100%	100%	100%	100%	100%	100%
Ne OK	752	121	122	130	269	55
Ne	1196	209	209	209	453	104
COV _{4G}	62,28%	57,89%	58,37%	62,22%	59,38%	52,88%

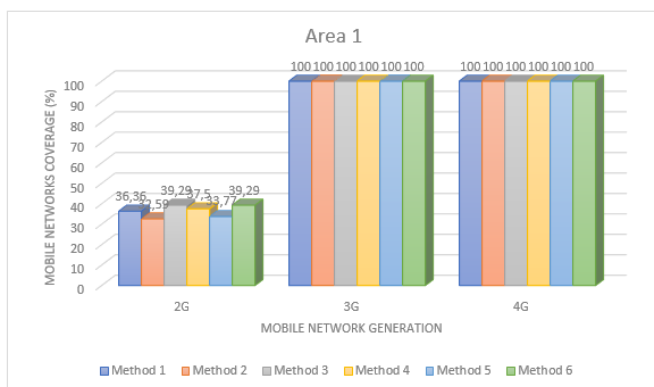
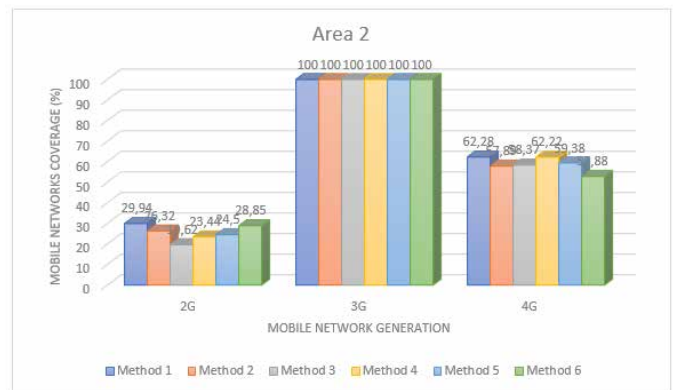
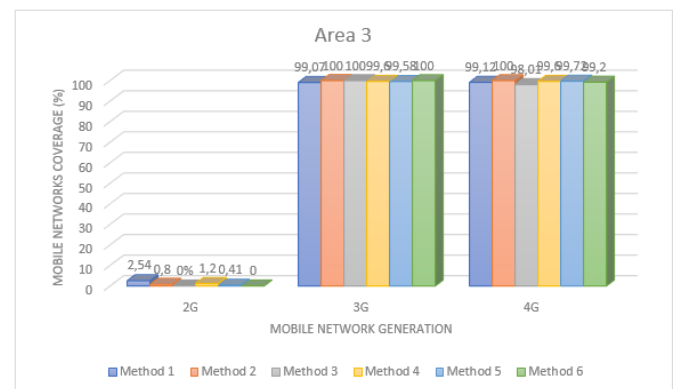
TABLE 9. COLLECTED DATA FROM AREA 3

Area 3	Drive test	Method 2	Method 3	Method 4	Method 5	Method 6
Lp (m)	5527,1					
Ne OK	31	2	0	3	3	0
Ne	1220	251	251	251	718	125
COV _{3G}	2,54%	0,8%	0%	1,2%	0,41%	0%
Ne OK	2444	251	251	250	715	125
Ne	2467	251	251	251	718	125
COV _{3G}	99,07%	100%	100%	99,6%	99,58%	100%
Ne OK	906	251	247	250	716	124
Ne	914	251	251	251	718	125
COV _{4G}	99,12%	100%	98,01%	99,6%	99,72%	99,2%

F. Interpretation of results

A series of 3 collections at different times of the day is performed. It is also an opportunity to recall that the coverage varies according to weather conditions.

The following figures represents a collection of network technology, the GPS coordinates of the point, the powerful signal received according to the technology. Measurements via mobile phones were done in the same way. The smartphones use Android as operating system.

**Figure 7.** Area 1 coverage assessment**Figure 8.** Area 2 coverage assessment**Figure 9.** Area 3 coverage assessment

The different methods of assessments rate the coverage in percentage. The task is to determine the most accurate method in terms of result compared to the drive test. The calculation of the error gap for each method is presented in Table 10.

TABLE 10. CALCULATION OF THE MARGIN ERROR BY AREA AND TECHNOLOGIE

AREA 1						
	Method 1	Method 2	Method 3	Method 4	Method 5	Method 6
COV 2G	0,3636	0,3259	0,3929	0,375	0,3377	0,3929
Error Marging		10,3685369	8,05830583	3,13531353	7,12321232	8,05830583
AREA 2						
COV 2G	0,2294	0,2632	0,1962	0,2344	0,245	0,2885
Error Marging		14,7340889	14,4725371	2,17959895	6,80034874	25,7628596
COV 4G	0,6228	0,5789	0,5837	0,6222	0,5938	0,5288
Error Marging		7,04881182	6,27809891	0,09633911	4,65639049	15,0931278
AREA 3						
COV 2G	0,0254	0,008	0	0,012	0,0041	0
Error Marging		68,503937	100	52,7559055	83,8582677	100
COV 3G	0,9907	1	1	0,996	0,9958	1
Error Marging		0,93873019	0,93873019	0,53497527	0,51478752	0,93873019
COV 4G	0,9912	1	0,9801	0,996	0,9972	0,992
Error Marging		0,88781275	1,11985472	0,4842615	0,60532688	0,08071025

It can be seen that methods 4 and 5 are the most promising collection techniques after calculating margins. The margin of error would have been further reduced if for the representative sample the margin of error is less than 1% and 99% confidence interval.

E. Other constraints

The biggest obstacle to the collection method via subscribers' mobile phones is the duration of battery use. During measurement campaigns, the applications used are not economical. They use GPS software which use satellite data.

When processing the collected data, it is easy to see that some collection points are not located on the collection areas on the map. This is due to GPS accuracy. The best accuracy during measurement campaigns is 4m despite a speed of less than 5m/s. Another major obstacle is the battery's energy consumption. For a continuous collection over 30 minutes, we lose an average 5 to 8% of the battery energy consumption. It would be a good idea to review the collection strategy to minimize as much as possible.

IV. CONCLUSION

It is common knowledge that different mobile network technologies have succeeded each other, but the role of regulatory authorities still remain the same. Their function is meant to regulate operators' services in a society dominated by various technologies. In this context, conducting routine checks on facilities of mobile operators or service providers becomes inevitable.

For regulators to ensure compliance with the terms of the license installations specifications, a lot of financial resources are put in place to carry out the drive tests. In addition, the cost of realizing this periodic compliance checking becomes even more difficult to bear. Therefore, the nation-wide introduction of smart mobile phones appears to be the most cost effective solution. The objective of this paper is to help define the best possible approach for assessing radio coverage of mobile networks in comparison with the drive test method.

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