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Accurate radio coverage assessment methods investigation for 3G/4G networks

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ABSTRACT

Sufficient wireless coverage is necessary to initiate communication with mobile terminals. Mobile network operators must guarantee good radio coverage. Telecommunication regulatory services (TRS) and technicians are assigned the duty of regularly verifying the conformity of the radio coverage at least once a year. However, it is not possible to collect data at every point in a given area. Therefore, TRS have defined a methodology called Random Drive Test Route (RDTR) to measure the provided radio coverage. The objective of this work is to investigate the weakness of the RDTRs that TRS are using. We used ATOLL for radio planning. The coverage prediction is adjusted to actual field measurements. We propose a novel methodology, called Special Drive Test Routes (SDTR) for assessing the radio coverage level of existing and future mobile network technologies. We defined for the SDTR a set of parameters such as minimum number of samples to be collected, the speed range and the route according to the network density in the considered area. We collected the radio coverage channel performances using TEMS Investigation 15.1 (a tool for 3G/4G). The performance results showed that a type of SDTR processes better than RDTR in a given area (open or with obstacles).

1. Introduction

Telecommunication regulatory services (TRS), private individuals, enterprises, elected officials or specialized observers and the media pay close attention to problems related to mobile services. To deploy and manage a mobile phone network, an operator must obtain a telecommunications license that is subject to specifications. These specifications define the obligations of the network operator. The license is granted for a limited period. The specifications include an operator's geographical footprint, and the radio part is subject to good coverage conditions. Therefore, the assessment of radio coverage [1–4] by a telecom operator is a duty for Telecommunication Regulatory Services (TRS), whereby compliance with the specifications is verified. This ensures access to the network by users. Finalization is usually done in agreement with the telecom regulatory authority, who hires an audit firm and specifies the drive test routes on a random basis. It is not possible to collect data at each point in an area subject to control. Therefore, the methodology adopted for collecting test data related to the radio coverage includes main routes, public places, buildings, and other places. The difficulty is that there is no deterministic approach defining how to browse through an area. The navigation is defined on a random basis. It can be referred to as Random Drive Test Route (RDTR). The reliability of this result suffers from

- the number of samples taken at regular intervals on the axes,
- the actual occupation of the target geographical area,
- the randomness of the axes and target locations,
- the appreciation of the overall coverage under separate assessments.

To overcome these shortcomings, it is essential to provide a better coverage assessment methodology for 3G and 4G technologies. The goal of this work is to investigate the limitations of RDTR as well as evaluate the performance of possible deterministic routes in comparison to a global and accurate radio coverage prediction. We therefore propose an objective novel methodology, called Special Drive Test Routes (SDTR), for assessing the radio coverage level of existing and future mobile network technologies. The types of SDTR investigated are spiral (Sp-SDTR), rectangular (R-SDTR), sawtooth (Sa-SDTR) and zig zag (Z-SDTR). In terms of the needs of the central phase of data collection, each type of SDTR has been theoretically studied and applied to obstructed areas as well as unobstructed areas.

The performance measurement indicators standardized by 3GPP [5] commonly used to evaluate the standard coverage for mobile networks are the following:

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1389-1286/

- RxLev for 2 G network
- CPICH RSCP (Common Pilot Channel Received Signal Code Power) and E_c/No (energy per chip over noise ratio) for 3G FDD (Frequency Division Duplex) network
- P-CCPCH RSCP (Primary Common Control Physical Channel RSCP) for 3G TDD (Time Division Duplex) network
- RSRP (Reference Signal Received Power) and RSRQ (Reference Signal Received Quality) for LTE and LTE advanced (4G) networks.

These performance indicators are configured in the drive test platform. We have also described the minimum number of samples to be taken, the speed to be used. The choice of paths (SDTR) based on the occupation of the geographical area and type of area is discussed in this work.

The rest of this paper is organized as follows: Section 2 is dedicated to the calculation of coverage in a mobile network, Section 3 presents the global approach to make the results of a drive test reliable, experimental results are discussed in Section 4, and then, the paper ends with the conclusion.

2. Calculation of coverage in a mobile network

The first step before the calculation of radio coverage in a mobile network is the data collection. Specific downlink channels depending on the technology are most appropriate. This section provides short explanations regarding these channels. More details can be found in the ITU standards and 3GPP documents [5–15].

2.1. RxLev

The key performance indicator to assess the level of radio coverage with Global System for Mobile communication (GSM) as shown in Table 1 is RxLev or Receive Signal Strength Indicator (RSSI). The value of RxLev is a negative number in dBm, which corresponds to the strength of the downlink radio signal. To be covered, a mobile station (MS) must receive a signal greater than RXLEV_ACCESS_MIN, which specifies the minimum received level required for a MS to access the BSS (Base Sub Station). According to [5,6], we can provide the following observations:

2.2. CPICH RSCP and Ec/No

CPICH RSCP (Common Pilot Channel Received Signal Code Power) and E_c / No (energy per chip over noise ratio) are the most common KPI used to assess the radio coverage of Universal Mobile Telecommunications System (UMTS) networks. Based on [7–13], we can assess the radio coverage, according to CPICH RSCP and Ec / No with Table 2:

CPICH stands for Common Pilot Channel for CDMA (Code Division Multiple Access) communications systems. RSCP [11], the Received Signal Code Power, of a particular CPICH is in dBm.

Table 1
Evaluation of 2 G coverage.

Coverage	RxLev (dBm)
Excellent	−48≤RxLevel
Good	−70≤RxLevel<−48
Bad	−110 ≤RxLevel<−70
Non-existent	RxLevel<−110

RxLev stands for Receive Level for GSM network coverage.

Table 2
Evaluation of FDD 3G coverage.

Coverage	CPICH RSCP [dBm]	Ec/N0 [dB]
Excellent	−25≤CPICH RSCP	−6≤ Ec/No<0
Good	−95≤ CPICH RSCP<−25	−18≤ Ec/No<-6
Bad	−115 ≤CPICH RSCP<−95	−20≤ Ec/No<-18
Non-existent	CPICH RSCP<−115	Ec/No<−20

Table 3
Evaluation of TDD 3G coverage.

Coverage	P-CCPCH RSCP [dBm]
Excellent	−25≤P-CCPCH RSCP
Good	−85≤ P-CCPCH RSCP <−25
Bad	−115 ≤P-CCPCH RSCP<−85
Non-existent	P-CCPCH RSCP <−115

Table 4
Evaluation of 4G coverage.

Coverage	RSRP [dBm]	RSRQ [dB]
Excellent	−44 ≤ RSRP	RSRQ>−3
Good	−110 ≤ RSRP < −44	−12 ≤ RSRQ<−3
Bad	−140 ≤ RSRP < −110	−19.5 ≤RSRQ < −12
Non-existent	RSRP < −140	RSRQ < −19.5

2.3. P-CCPCH RSCP

The channel used to assess 3G TDD radio coverage is P-CCPCH (Primary Common Control Physical Channel). In this case, RSCP is the received power of the P-CCPCH of the current or neighbor cell [11]. According to [12,13], we can interpret the radio coverage according to the P-CCPCH RSCP with the help of Table 3.

2.4. RSRP and RSRQ

With Long Term Evolution (LTE) and LTE Advanced networks, RSRP (Reference Signal Received Power) [15] is defined as the linear average over power contributions of the resource elements that carry cell-specific reference signals within the considered measurement frequency bandwidth.

The carrier RSSI (Received Signal Strength Indicator) [14] measures the average total received power observed.

The RSRQ (Reference Signal Received Quality) [15] is generally used to assess the quality of the radio link in LTE and LTE Advanced networks. RSRQ is defined as the ratio between N×RSRP and E-UTRA carrier RSSI, where N is the number of Radio Bearers of the E-UTRA carrier RSSI measurement bandwidth. According to [6,16,17], we can evaluate the radio coverage according to the P-CCPCH RSCP with Table 4:

2.5. General calculation of coverage in a mobile network

In telecommunications, the coverage of a radio station is the geographical area where the mobile station can communicate. A mobile station of a user can access the services of a mobile operator if it satisfies the conditions of accessibility. According to [6,17,18,19], the selection criteria of a cell for each mobile network technology are shown in Table 5

where

- RXLEV_ACCES_MIN is the minimum power required by a mobile station to access a cell,
- S_{qual} is the cell Selection quality value (dB) applicable only for FDD cells,
- R_{rxlev} is the cell Selection RX (receive) level value (dB).

Table 5
Selection criteria of a cell for a mobile network technology.

Mobile Network	Condition (s) of accessibility
2G	RxLev> RXLEV_ACCES_MIN
3G TDD	$-12\leq$ RSRQ<-3
3G FDD	RxLev > 0
4G	Squal > 0 et RxLev > 0

Table 6
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)

During a drive test, it may happen that many samples that have been collected are bad due to poor GPS reception, and this has a negative impact on the accuracy of the coverage assessment. For example, it is possible to obtain samples with bad GPS coordinates. So, after collecting samples during a drive test, we first need to filter them by removing the wrong samples.

The coverage in a mobile network can be given by the following formula:

$$N_c(\%) = \frac{N_{OK}}{N_f} \times 100 \quad (1)$$

where

- N_{ok} is the number of samples among the total number of filtered samples that satisfy the cell
- accessibility requirements for the mobile network technology
- N_f is the total number of filtered samples collected during a drive test

2.6. Overall mobile network coverage for a service

Assume the following definition: If a user can access a referral service in an area regardless of the technology in place, this area will be considered globally covered. The parameters to consider when calculating the overall coverage rate are

- the received signal level,
- the possibility of accessing a service and using it for a specified minimum duration.

We must make the right choice of referral service while stipulating the appropriate QoS parameters. In our paper, we will focus on “voice and data” as a reference service because they are common to all mobile networks. To evaluate the overall mobile network coverage for voice and data services, we must prepare a calibration graph.

2.6.1. Calibration graph

This graph shows the correspondence between the strength of the radio signal and the probability of successful communication, with the understanding that there was access to the network. The graph is established for a short communication, equal to or less than 3 min [1]. Only actual communications satisfy the following conditions:

- accessibility requirements to the network are met,
- ringtone or connection was obtained.

Communications are grouped by field level of radio signal (in steps of 1 dB), and for each level of the field, consider N_1 the number of communications that satisfy the conditions above. Among these N_1 communications, we also consider N_2 to be the number of communications that were effectively maintained for one minute (1 min) without interruption. For each field level, we obtain the communication rates ($\tau_{\text{com-OK}}$), which were established and maintained for one minute with the knowledge that there was accessibility to the mobile network. It is given by the following expression:

$$\tau_{\text{comm-ok}}(\%) = \frac{N_1}{N_2} \times 100 \quad (2)$$

These rates, taken for each field level of radio signals, make it possible to plot the calibration graph. It is important to focus on the accuracy and reliability of this graph.

2.6.2. Calculation of the overall mobile network coverage for voice service

Let us define the following parameters:

- P_a, the probability corresponding to the network access. It is equal to 1 if there is access to the network and 0 otherwise
- P_b, the probability obtained from the calibration graph by referring to collected data on the corresponding field.
- P_r, the probability of successful access.

For each measuring point, we have

$$P_r = P_a \times P_b \quad (3)$$

The overall mobile network coverage rate for voice service (τ_{ov}) is given by the following expression:

$$\tau_{OV}(\%) = \frac{1}{N_1}\sum_{i=1}^{N_f} P_{ri} \times 100 \quad (4)$$

where

N_f is the total number of filtered samples collected during a drive test,
P_{ri} is the probability of a successful “*i*” access.

3. Global approach to make the results of a drive test reliable

3.1. The vehicle speed

The vehicle speed (V) [2] must be appropriate for the wavelength and desired number of samples to be collected along a periodic distance. Depending on the signal frequency and the applicable shortest time of measurement with the receiver, the speed is limited as follows:

$$V(\text{Km/h}) \leq \frac{864}{[f(MHz)^{*}tr(s)]} \quad (5)$$

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 ITU in [3] for physical operating environments is given by Table 6.

3.2. Number of samples taken at regular intervals on the axes

Based on [4], 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. This method uses 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 can be calculated as follows:

$$N_{min} = \frac{\lambda R}{V} \quad (6)$$

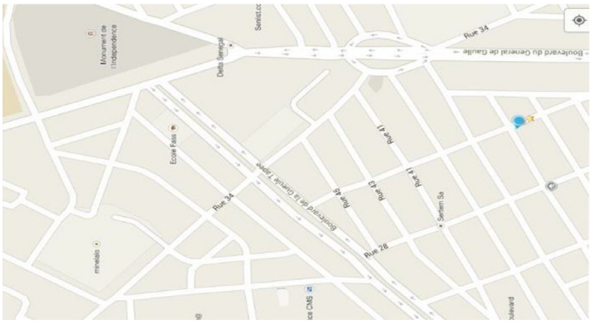

Fig. 1. Example of an urban road network.

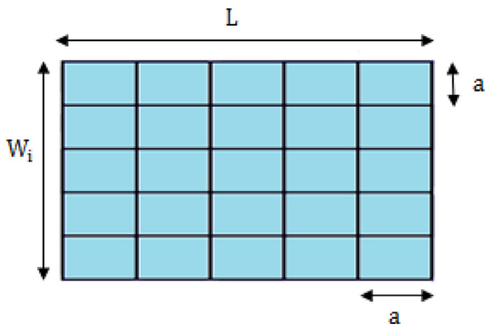

Fig. 2. Theoretical area to cover.

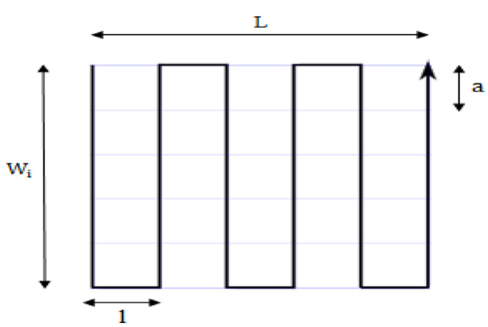

Fig. 3. Rectangular function path or R-SDTR.

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

3.3. Occupancy rate of the geographical space during a drive test

The most common practice during the drive test is to select routes from maps as in Fig. 1 and to cover them (Fig. 2). So, the actual occupancy rate of the geographical space is generally ignored in that case. We define the occupancy rate of the geographical space as the ratio between the actual surface that has been scanned on a regular basis and the total surface of the area to be studied.

3.3.1. Selection of paths to cover during a drive test

With regard to the layout of roads in an urban area, it is desirable to use routes that are characterized by simple geometrical curves, which optimizes the distance and improves the occupation rate of the geographical space. Urban areas have dense road networks, and drive tests are usually conducted on these. So, the axes to be covered may occur as follows:

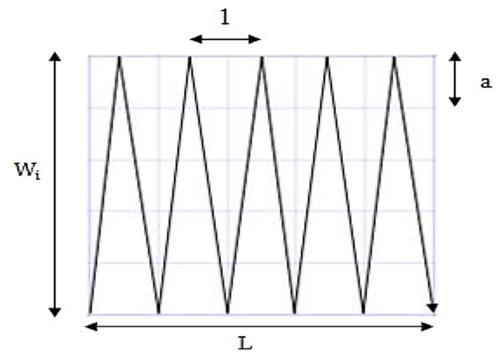

Fig. 4. Sawtooth wave path or Sa-SDTR.

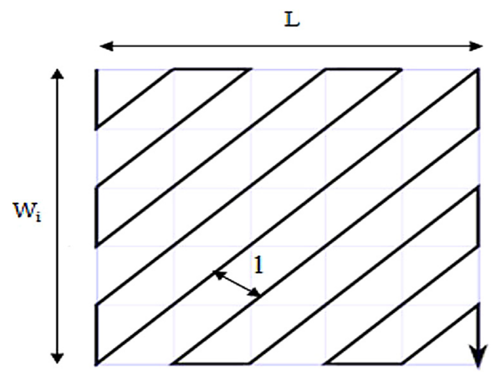

Fig. 5. Zigzag path or Z-SDTR.

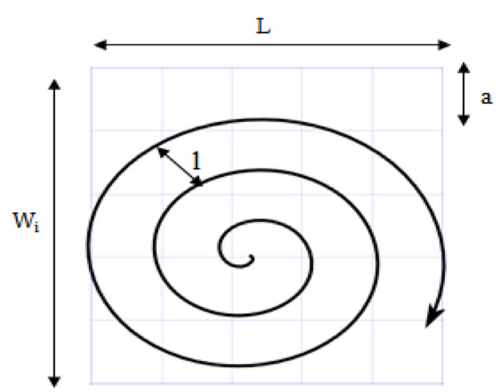

Fig. 6. Archimedean spiral path or Sp- SDTR.

The curves must be continuous to facilitate moving and time saving, and they must offer direct routes. In addition, the spacing between the axes must be constant. We can therefore propose as depicted by Fig. 3–7 the following geometrical curves: sawtooth wave, rectangular function, zigzag, spiral and finally paper-clip.

3.3.2. Comparison of paths based on geometrical curve models

To facilitate this comparison, consider an area without obstacles that consists of square blocks of the same size and is defined as follows:

where **L**, $\mathbf{W_i}$, and $\boldsymbol{a}$ are the length, the width and the square block size of the area, respectively.

For the remainder of this subsection, we will consider the following parameters:

- D_p as the distance of the drive test path,
- l as the periodic space between consecutive axles.

The calculation results of D_p will be used to estimate the actual occupancy rate.

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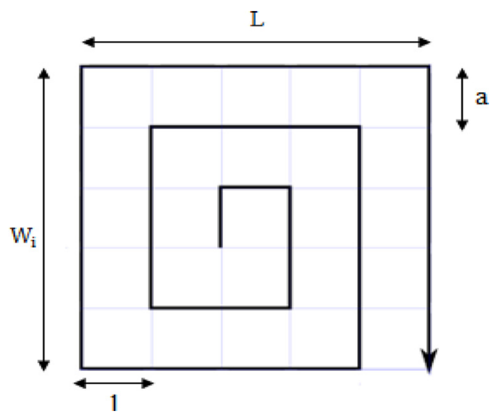

Fig. 7. Paperclip path – P-SDTR.

3.3.2.1. Geometrical curve based on rectangular function. The distance of this path is given by the following expression:

$$D_p = W_i + \left\lfloor \frac{L}{l} \right\rfloor (W_i + l) \tag{7}$$

where ⌊ ⌋ is the floor function.

According to the picture above, if a=l, L=5a and W_i =5a, we finally have

$$D_p = 5a + \left\lfloor \frac{5a}{a} \right\rfloor (5a + l) = 35a \tag{8}$$

3.3.2.2. Geometrical curve based on sawtooth wave. The distance of this path is given by the following expression:

$$D_p = 2\left\lfloor \frac{L}{l} \right\rfloor \sqrt{W_i^2 + \left(\frac{l}{2}\right)^2} \tag{9}$$

where ⌊ ⌋ is the floor function

According to the picture above a=l, L=5a and W_i=5a.

So, we finally have:

$$D_p = 2 \times 5 \times a\sqrt{25 + 0.25} = 5a\sqrt{101} \approx 50.25a \tag{10}$$

3.3.2.3. Geometrical curve based on Zigzag. To have the same space between the paths as previously (l=a), we fixed the length of the square to a. Finally, the distance of the path above can be given by the following expression:

$$D_p = 10a + 25(\sqrt{2} \approx 45.36a \tag{11}$$

3.3.2.4. Geometrical curve based on spiral. There are several types of spirals (logarithmic, parabolic, and Archimedean). The space between two successive axes must be constant. Thus, the most appropriate type of spiral is the Archimedean spiral because any ray from the origin intersects successive turnings of the spiral at points that have a constant distance of separation.

The polar equation of the spiral is given by

$$r(\theta) = \frac{1}{2\pi}\theta \text{ with } \theta : \text{polar angle and } l > 0 \tag{12}$$

The distance of this path is given by the following expression:

$$D_p = \frac{1}{4\pi}\left[\theta\sqrt{1+\theta^2} + \ln(\theta + \sqrt{1+\theta^2})\right] \tag{13}$$

To calculate the distance of the path based on the Archimedean spiral, we must know the values of initial radius R_i and final radius R_f that are for the first and the last turning of this spiral, respectively. So, for

$R_i = \frac{1}{2}l,\ \theta_i = \frac{R_i}{l} = 0.25\,\text{rad}$, and $l = a$, we have

$$D_p(\theta_i) = \frac{a}{4\pi}\left[0.5\sqrt{1+0.5^2} + \ln(0.5 + \sqrt{1+0.5^2})\right] = \frac{1.106211825a}{4\pi}$$

$R_f = \frac{5}{2}l,\ \theta_f = \frac{R_f}{l} = 2.5\,\text{rad}$, and $l = a$, we have :

$$D_p(\theta_f) = \frac{a}{4\pi}\left[2.5\sqrt{1+2.5^2} + \ln(2.5 + \sqrt{1+2.5^2})\right] = \frac{19.77223115a}{4\pi} \tag{14}$$

Finally, the distance of this path based on the Archimedean spiral is given by the following expression:

$$D_p = D_p(\theta_f) - D_p(\theta_i) \approx 15a \tag{15}$$

3.3.2.5. Geometrical curve based on a paperclip. In an urban area, it is very difficult to implement a path based on an Archimedean spiral due to the position of buildings and roads. For this reason, a geometrical model based on a paper clip could be used to solve this issue.

The distance of this path is given by the following expression:

$$L_p = \sum_{k=1}^{\left[\frac{L}{l}\right]} 2kl \text{ where [] is the floor function} \tag{16}$$

According to the picture above, a=l and L=5a. We finally have:

$$L_p = \sum_{k=1}^{5} 2ka = 30a \tag{17}$$

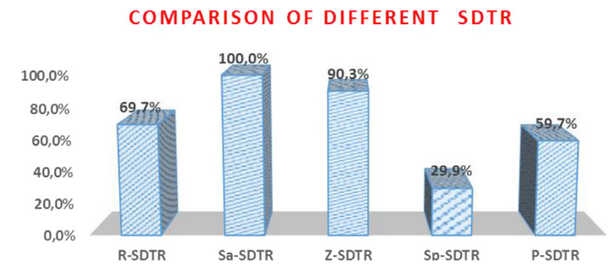

Fig. 8. Comparison of drive test distance between different types of SDTR.

Finally, if we set a=1 for x-SDTR distances considered above, we can obtain the Fig. 8 graph for a comparison of all the distances calculated from the geometrical curve models.

It appears that the distance covered by the Sa-SDTR (sawtooth path) is the longest. It is followed by Z-SDTR (zigzag path), which is 90.3% of the Sa-SDTR. Sp-SDTR has the shortest length. By using Sa-SDTR or Z-SDTR, more samples can be obtained. Sa-SDTR and Z-SDTR cover the geographical area well. These SDTRs exhibit the most reliable final results in an open area with regular radio coverage. However, it might be possible to achieve good results on a shorter route by using spiral path or paperclip in irregular radio coverage caused by obstructions. These questions are discussed in the case studies.

3.3.3. Width of axes and spacing between the axes

The surface that is swept during a drive test depends on the types of SDTR, width of axes, and spacing between the axes. In

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this subsection, the width of axes and spacing are investigated. Let us consider the picture based on a rectangular function. The choice of width and spacing between the axes is assumed to be the same for all the geometrical curve models presented in this paper.

For the rest of this part, we will consider the parameters S_T, Ss, w, and τ_0 as the total surface of the studied area, the surface swept during a drive test, the width of the axis, and the occupation rate of the geographical space, respectively.

3.3.3.1. Width of the axis. To choose the most appropriate width of the axis, the average width of vehicles used during drive tests is considered. Because the drive tests are carried out on roads, it would be wise to consider the width of the roads rather than the average width of the test drive vehicles. If the data on roads are unknown, the ITU recommends in [3] to consider the default value of the width of roads to be between 10 m and 25 m.

3.3.3.2. Spacing between the axes. It is the duty of TRS to set the appropriate value of the occupancy rate of the geographical space during a drive test. Several studies should be performed to determine the most appropriate value of this rate. Based on this value, the correct spacing value between the axes for a drive test can be estimated. In practice, the swept surface during a drive test is given by:

$$S_S = D_p \times w \tag{18}$$

with

Dp: distance to cover during a drive test

To determine the best swept surface during a drive test, we have used Google Maps as the Geographical Information System (GIS). The occupancy rate of the geographical space, specified by the TRS as with Fig. 10, is determined by

$$\tau_0(\%) = \frac{S_s \times 100}{S_T} \tag{19}$$

So, the correct distance to consider during a drive test must be chosen with the following expression:

$$D_p = \frac{S_S}{\text{w}} \Rightarrow D_p = \frac{S_T \times \tau_0(\%)}{100\text{w}} \tag{20}$$

4. Experimental results

4.1. Accurate radio coverage of drive test areas

To obtain accurate radio coverage of drive test areas, let us use radio coverage prediction software. Such software requires knowing the characteristics of radio sites, the propagation model, and the digital terrain models to better simulate the propagation conditions. 2 G/3G networks are generally deployed by operators so that they cover a territory according to the requirements of the TRS. These networks are progressively replaced by new generation networks (4G or 5G). Therefore, for the practical stage, we have focused our results on 3G networks, which have already been launched in most countries around the world. With the radio coverage prediction software, we focused our tests on areas to obtain CPICH RSCP signal levels between −90 and −45 dBm. We used Atoll from Forsk, a primary coverage prediction software for radio planning and optimization.

We have selected the appropriate propagation model, site characteristics and digital terrain models for planning radio coverage using Atoll.

4.1.1. General characteristics of a radio site

A radio site is characterized by a name, a location (longitude, latitude and altitude), an exact address and especially the characteristics of the tower (height, antennas, etc.). The characteristics of antennas located on towers are:

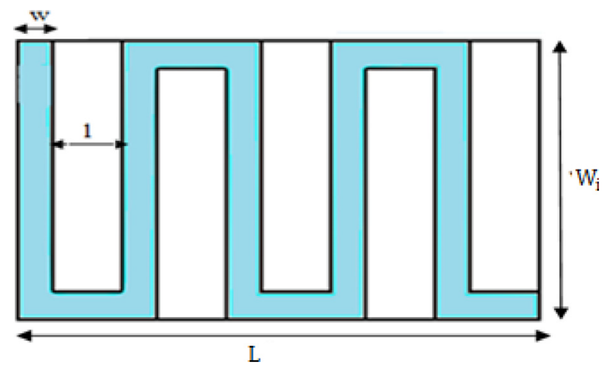

Fig. 9. Real swept surface for a path based on a rectangular function.

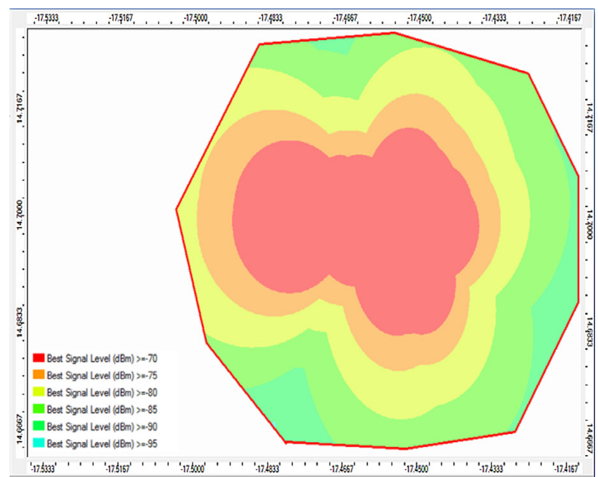

Fig. 10. Real swept surface for a path based on the rectangular function.

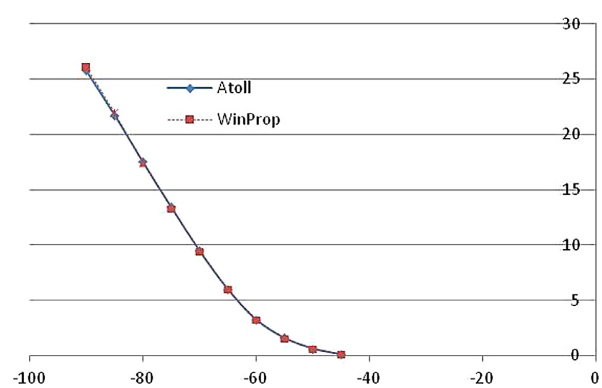

Fig. 11. Comparison of Atoll and WinProp coverages in obstructed areas.

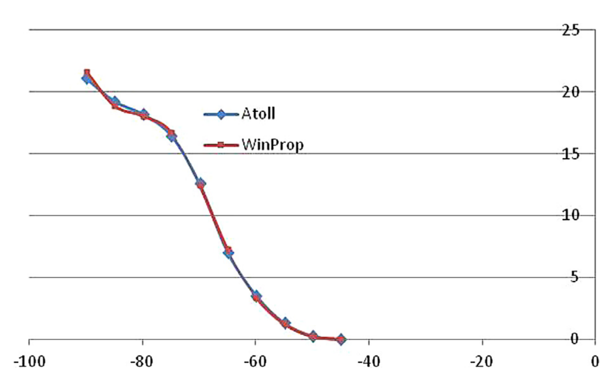

Fig. 12. Comparison of Atoll and WinProp coverages in unobstructed areas.

Fig. 13. (a) Picture of covered random paths, (b) Pictures of covered spiral paths, (c) Pictures of covered zigzag paths, (d) Pictures of covered rectangular function paths, (e) Pictures of covered sawtooth wave model paths.

- the antenna type (directional, sectorial)
- the opening angles 3 dB in horizontal and vertical planes
- the maximum gain and cross-polarization
- the mechanical and electrical tilt angles
- the power per carrier to the input of the antenna
- the height of the antenna relative to the middle ground, the number of carriers, azimuth, and elevation

4.1.2. Propagations *models*

The most appropriate propagation model in 3 G network planning is the Cost Hata Model [20]. The COST 231 model is often cited [21]; it is also called the Hata Model PCS Extension. It is a radio propagation model that extends the Hata Model to cover a more elaborate range of frequencies, and it is appropriate for these coverage features:

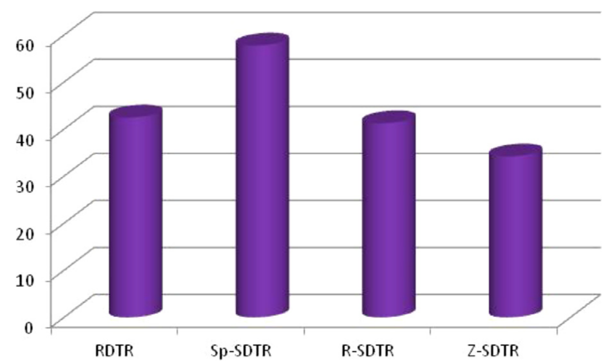

Fig. 14. Distance covered for each drive test in the unobstructed area.

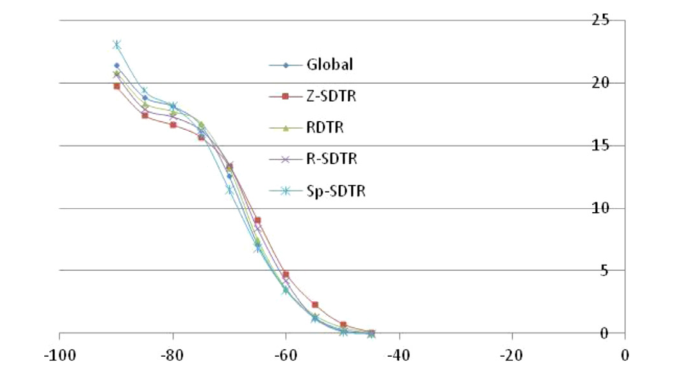

Fig. 15. Variation of RF coverage for levels of CPICH RSCP in the unobstructed areas.

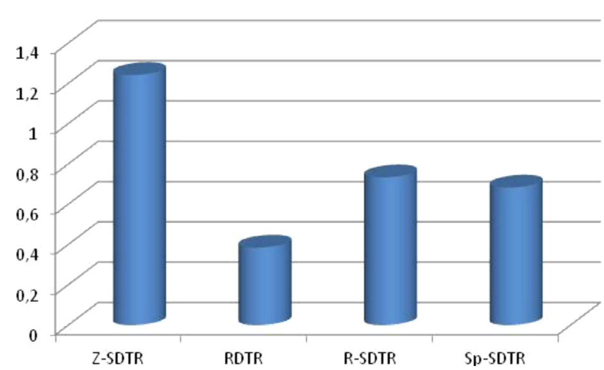

Fig. 16. Standard deviation between global coverage and each drive test in the unobstructed areas.

- frequency: 150 MHz to 2000 MHz
- antenna height of the mobile station: 1 to 10 m
- antenna height of the base station: 30 m to 200 m
- link distance: 1 to 30 km

The formula of the COSTHata model, which extended Hata's model to 2 GHz, is

$$L = 46.3 + 33.9\log(F) - 13.82\log(h_b) \\ -a(h_m) + (44.9 - 6.55\log(h_b))\log(d) + C \quad (21)$$

where

- L (dB) is the median path loss
- F (MHz) is the frequency of transmission
- h_b (m) is the base station antenna effective height (m)
- d (Km) is the link distance
- h_m (m) is the mobile station antenna effective height (m)
- $a(h_m)$ is the mobile station antenna height correction factor as described in the Hata model for urban areas
- C (dB) equals 0 dB for suburban or open environments and 3 dB for urban environments

After choosing the propagation model, we must calibrate it by using the outputs of practical drive tests in the area. The calibration process involves choosing the best value for the variable parameters in a propagation model to achieve theoretical results very close to those predicted. It is possible to do it manually or automatically, but it is better to let the software calibrate these parameters (automatic calibration).

4.1.3. Simulation of accurate radio coverage

The following data maps need to be imported in Atoll to better simulate the propagation conditions:

- Heights (map of the altitude above sea level)
- Clutter classes (type of land used)
- Vector (vector maps).
- Drive test data

Knowing the characteristics of the radio site from the telecom operator and having chosen the most appropriate propagation model, we obtain the following accurate coverage of 3G TDD with the drive test data:

According to the above prediction approach, the simulated radio coverage is globally which is performed with Atoll. It has been compared to another coverage prediction tool called WinProp of AWE. The results have been used for comparison between RDTR and SDTR. This approach has been applied to two kinds of areas. The first kind of area is unobstructed, and the second one is obstructed. The received signal coverage prediction based on ten sites for these areas were simulated with Atoll and WinProp and depicted in Figs. 11 and 12 below

4.2. Results of drive tests

4.2.1. Global practical network coverage

At the moment of the experiments, the population covered by the 3G mobile network in the considered area was 53%. Typical surveys have margin error ranging from less than 1% to 4% and use "95% confidence interval". In order to get the most accurate results for our experimentations, we decide to use a margin error less than 2.5% and 99% confidence interval. According to these, a mean of 330,000 samples have been used for global coverage prediction. For each drive test, a mean of 26,000 samples have been collected.

To obtain reliable results for a given type of area, a good practice is to perform several drive tests in at least ten different areas and determine the global practical network coverage. In this work ten sites were considered. The results of these sites are globally presented. For n drive tests performed in an area, the global practical network coverage for a fixed threshold is given by the following expression:

$$G_c(\%) = \frac{x_1 + x_2 + \cdots + x_n}{y_1 + y_2 + \cdots + y_n} \times 100 \quad (22)$$

where

- G_c is the global practical network coverage
- y_i is the total number of samples after filtering for drive test $i, 1 \le i \le n$
- x_i is the number of samples satisfying the requirements

CPICH RSCP ≥ CPICH RSCP Min among total number of samples after filtering for drive test i, $1 \le I \le n$

To compare global practical network coverage, it may be interesting to calculate the standard deviation (SD), which is given by

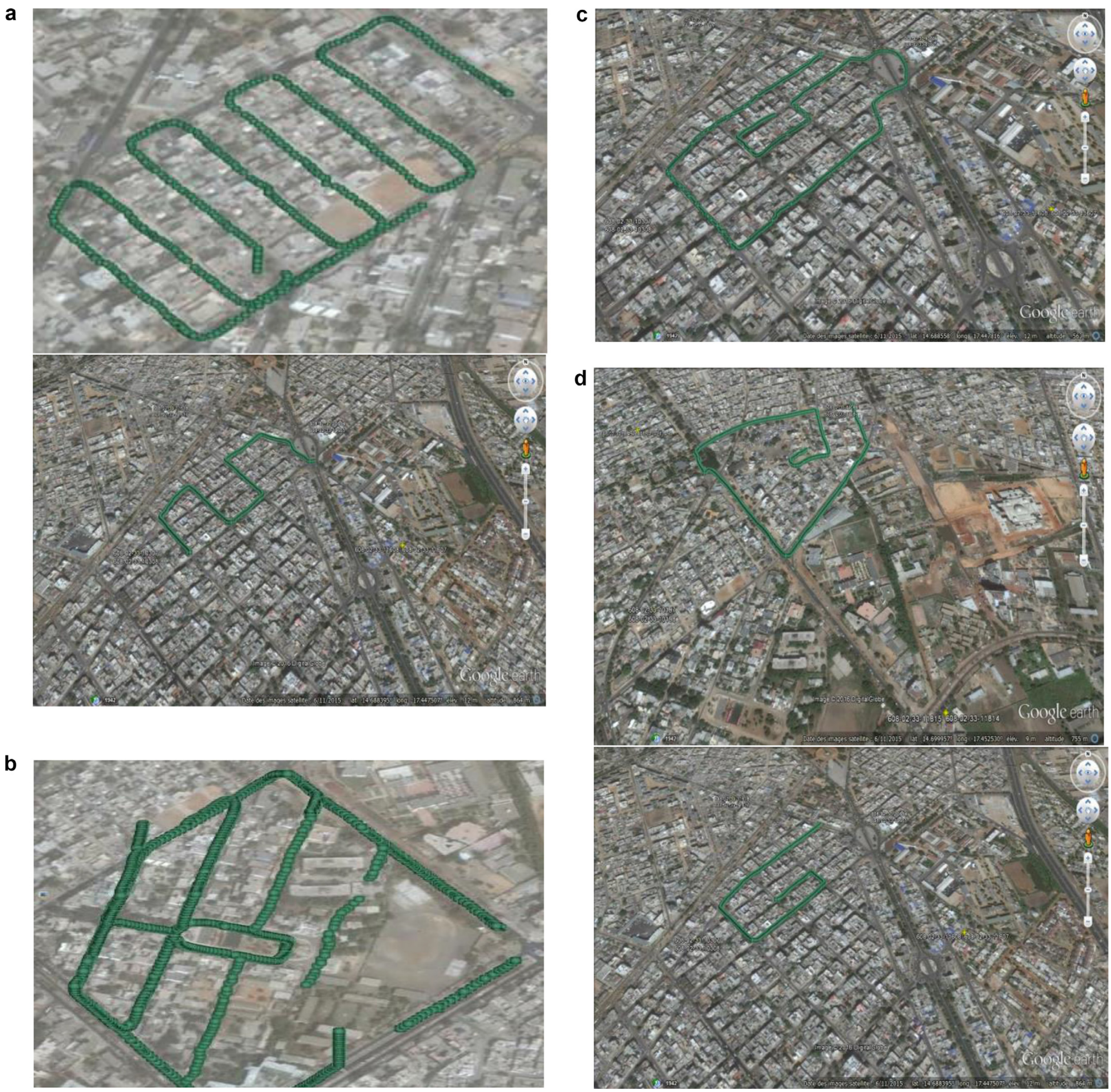

Fig. 17. (a) Pictures of covered rectangular function paths, (b) Picture of covered zigzag paths, (c) Picture of covered random paths, (d) Pictures of covered spiral paths.

the following expression:

$$SD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\left|N_{ci}^{\text{global pratical coverage}}\right| - \left|N_{ci}^{\text{drive test}}\right|\right)^2} \quad (23)$$

where

- i is the range for CPICH RSCP between −90 and −45 dBm in steps of 5 dB
- N_{ci} (%) is the RF coverage for i-range of CPICH RSCP

4.2.2. Unobstructed area

In the same unobstructed area (Fig. 13), we did many drive tests, including one as a random path and the others based on the x-SDTR models shown in section III, where x determines the special function curve.

The distance in Km corresponding to each type of path can be represented by the following graph:

It is interesting to note the gap in radio coverage assessment for the different drive tests for the CPICH RSCP (dBm) data collection as follows in Fig. 15 were the horizontal axis represent the CPICH RSCP power in (dBm) and the vertical axis gives the corresponding percentage.

For the telecom operator, the range of the CPICH RSCP (dBm) is between −97 and −40 dBm. The graph in Fig. 15 above gives the results of the coverage assessment by RDTR in comparison with the different types of SDTR based on the geometrical curves. It can be seen that the different performances are very close. However

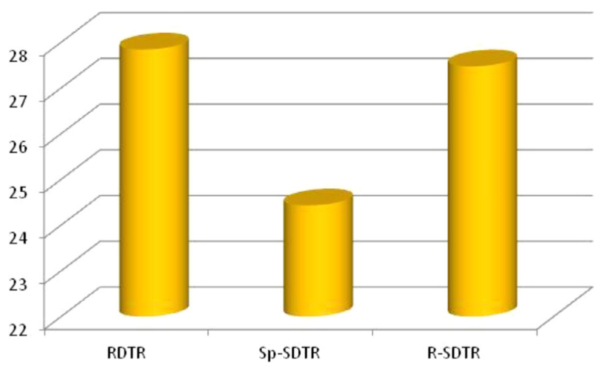

Fig. 18. Global distance for each drive test in areas with obstacles.

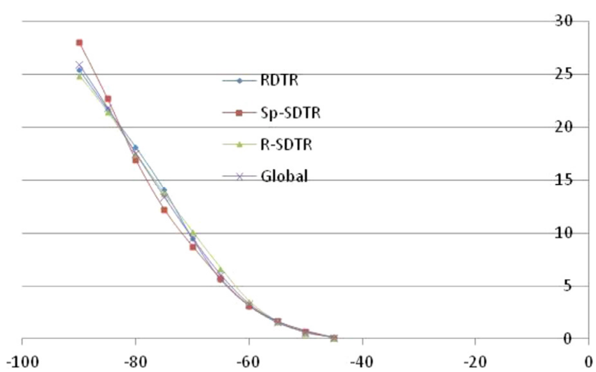

Fig. 19. Variation of RF coverage for levels of CPICH RSCP in the obstructed areas.

RDTR presents good performance because of its longer drive distance. Sp-SDTR is the most x-SDTR close to the global coverage statistics regarding Fig. 16 but the deviation at lower power is great in Fig. 15. This performance of Sp-SDTR slightly better than R-SDTR is also probably due to its longer drive test distance compare to the other x-SDTR. Fig. 16 below depicts the standard deviation (SD) between the global coverage and each path used for the drive tests. Figs. 15 and 16 show that the curve of the R-SDTR performance almost coincides with that of the accurate global assessment with a slightly lower distance compare to RDTR (Fig. 14).

Fig. 16 indicates that the RDTR route has the lowest standard deviation. Fig. 16 depicts the rectangular route (R-SDTR) as the one with the most tradeoff (drive test distance and standard deviation). Thus, it appears that R-SDTR is the best drive test route, as it provides lower drive test distance and good radio coverage assessment. This result also confirms the theoretical assumption that in an unobstructed area, the best occupation rate gives a better coverage assessment.

4.2.3. Area with obstacles

Ten different obstructed areas (Fig. 17) were selected. We have focused on three type of drive test routes including one random path, R-SDTR and Sp-SDTR because the other x-SDTR are not easy to find in obstructed areas.

The distance corresponding to the considered path is represented in Fig. 18. Fig. 19 shows the assessment accuracy between the different x-SDTR and RDTR in comparison with global coverage statistics. The horizontal axe represent the CPICH RSCP power in (dBm). The vertical axis gives the corresponding percentage.

To determine the x-SDTR, which provides more accurate coverage assessment in comparison to the accurate global coverage, Figs. 18 and 20 are provided. Figs. 18 and 20 show that RDTR provides slightly more accurate coverage assessment compare to R-SDTR but longer drive test distance. Fig. 20 shows the standard deviation (SD) between global coverage and each path to confirm the analysis of the accuracy of R-SDTR in comparison with Sp-SDTR and RDTR.

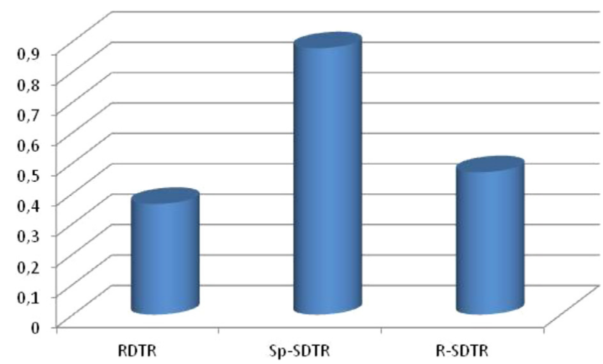

Fig. 20. Standard deviation between global coverage and drive test routes in obstructed areas.

Figs. 18 and 20 show the drive test route and distance impact on accuracy of the coverage assessment results in an area with buildings. However Fig. 20 confirms that RDTR and R-SDTR standard deviations are the lowest. Thus, it appears that the best drive test path with lower distance is the one based on R-SDTR path.

4.2.4. Analysis of results and information's release

We noticed that in both unobstructed and obstructed areas, the drive test path distance and good occupation of the geographical space have an impact on the accuracy of the radio coverage assessment. Longer drive test route with good occupation on covered area provides accurate and reliable results. This is due to the large number of samples collected as well as the fact that the radio coverage is regularly distributed. In obstructed areas, it also appears that the results obtained from the RDTR path are acceptable in comparison to R-SDTR, but it is better to select R-SDTR for its lower drive test distance, good space occupation and good coverage assessment.

5. Conclusion

In this paper, we presented a method for an objective radio coverage assessment for deploying 3G/4G networks. The limitations of RDTR were discussed. A new and objective approach (SDTR) is introduced highlighting the main parameters to consider to improve the reliability and accuracy of the results obtained during a drive test. The proposed types of SDTR were studied in terms of the area occupation rate of the considered geographical space. The accurate global coverage assessment was elaborated for an objective comparison between the different x-DTRs. Our proposed R-SDTR outperformed the traditional RDTR. In case of difficulties applying R-SDTR, the old approach (RDTR) can be used.

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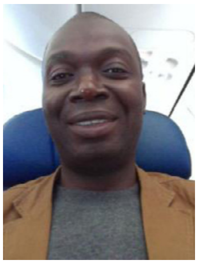

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