GSM/UMTS

Mobile Communications Systems

Quality of Service Assessment

Assessment of QoS of Voice (GSM) and Video-telephony (UMTS) Services, and Network Coverage (GSM and WCDMA) in the main Urban Agglomerations and Major Roads of Mainland Portugal.

December 2008

ACRONYMS

CoDec   Codifier/De-codifier.

CPICH RSCP   Common Pilot Channel, Received Signal Code Power – Level of the signal received by a mobile terminal (WCDMA).

ETSI   European Telecommunications Standards Institute.

GSM   Global System for Mobile communications – Second generation (2G) Mobile Communications System.

ITU   International Telecommunications Union.

MOS   **M**ean **O**pinion **S**core – Quality rate quantifying the effort to understand an end-to-end type conversation. Its limit value is 0 (zero) when there is no communication and 5 (five) when the communication is perfect. Value "zero" never shows on the results since only situations where the connection was established and maintained during a given period are considered. "Five" also never shows on the results because CoDec7, used by mobile networks, renders impossible such high voice or video quality values (the voice or video quality reached with the usually used CoDec has MOS values lower than 4.5).

PESQ   Perceptual Evaluation of Speech Quality – Algorithm used in the analysis of the audio quality of a voice communication (Recommended by ITU: ITU-T Recommendation P.862 (02/2001); ITU-T Recommendation P.862.1 (11/2003)).

ISDN   Integrated Services Digital Network – Technology used on the fixed access network.

RF   Radio Frequency.

RxLev   Received signal level, at a mobile (GSM) terminal (GSM).

Scanner   Measurement equipment that collects radio signal levels for each channel of a frequency band

SQuad-LQ   SwissQual's speech quality algorithm for Listening Quality – Algorithm developed by SwissQual to analyse the audio quality of a communication.

UMTS   Universal Mobile Telecommunications System – Third generation (3G) Mobile Communications System.

VQuad   Objective Model for Video Quality Assessment – Algorithm used in the analysis of the video quality of a communication (developed by *SwissQual*).

WCDMA   Wideband Code Division Multiple Access – Technology used in the radio component of the UMTS communications systems.

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Appendix – Individual results, by urban agglomeration and major road.

I   EXECUTIVE SUMMARY

I.I   GENERAL FRAMEWORK

In October and November 2008, Autoridade Nacional de Comunicações (ANACOM) carried out an assessment of the quality of mobile services – voice (GSM), video-telephony (UMTS) and network coverage (GSM and WCDMA) – provided by operators OPTIMUS, TMN and VODAFONE in the main urban agglomerations and major roads of Mainland Portugal, by analysing technical parameters that translate the quality perception from the consumer's standpoint.

The methodology that was used in this study relies on field tests performed from the user's standpoint, by using an automatic measurement system that reflects the several features affecting the quality of the services (end-to-end measurements). Measurements were carried out on equal terms regarding the three operators, namely at the same time, at the same locations and with the same parameters, thus making it possible to perform comparative analysis of the observed performances.

The main quality indicators were analysed, considering the user's perspective and the services under study:

1. **Network Coverage** – Availability of the GSM and WCDMA (UMTS) radio networks;
2. **Service Accessibility** (voice or video-telephony) – probability of success when setting up calls;
3. **Call set up time** (voice or video-telephony) – period of time that the network takes to establish the communication, after the correct sending of the request (target telephone number);
4. **Call Termination Rate** (voice or video-telephony) – Probability that a call has, after being successfully set up, to be maintained during a period of time, ending normally, i.e., according to the user's will;
5. **Call Audio Quality** (voice or video-telephony) – perceptibility of the conversation during a call;
6. **Call Video Quality** (Video-telephony) – perceptibility of the communication's video feature.

This study contains some changes regarding the studies carried out in previous years. Improvements on the analysis of the video-telephony service's video quality and the inclusion of new major roads on the sample stand out. Video quality assessment is now performed simultaneously in both ways of communication (*full-duplex*), more accurately reflecting the common usage of the video-telephony service. New major roads were included in the locations under analysis: Póvoa de Varzim – Vila Pouca

de Aguiar (A7), Maia – Guimarães – Braga – Esposende (A41 / A42 / A 11), Leiria – Aveiro (A17), Vila Real – Chaves – Vila Verde da Raia (A24) e Lagos – Paderne (A22).

Data collection took place on working days and during normal working hours, from October 6 to November 11, 2008. 23,688 test calls and 4,708,610 radio signal level measurements were made, standing for more than 218 hours of measurements along 9,750 kilometres.

The used sample provided global results, by operator, with a maximum error below 1% on urban agglomerations, and below 2.53% on major roads, for a 95% confidence level.

In view of these services' penetration rate, of the diversity of the terminal equipment that is used, and given each user's subjective view itself, it is impossible to rigorously reproduce each consumer's conditions of interaction with the networks. In this context, the results of this study must thus be understood as an indicator of the networks' global behaviour, while it does not intend to evaluate the fulfilment of licenses by the mobile operators. The transposition/extrapolation of these results to specific situations requires some prudence, at the risk that biased conclusions might be taken.

The technical and methodological options of this study directly influenced its results and must be taken into account when analyzing the results, namely the following ones:

- Tests were exclusively based on a technical solution (equipment + software) and performed in a totally automatic way, thereby setting homogenous conditions for the monitoring of the three operators and eliminating the subjectivity inherent to the human user;

- Given the changes made to the methodology of the video quality analysis, it is not possible to directly compare the results of this indicator during the current study with the results recorded in previous studies;

- It used *NOKIA N95* and *NOKIA 6680* terminal equipment;

- Tests were carried out in moving vehicles and with outdoor antennas (without gain);

- Call duration, both for voice and video-telephony, was 120 seconds;

- Voice tests were made with manual selection of the 2G (GSM) infrastructure, while video-

telephony tests were made with automatic selection of the 2G or 3G (GSM/UMTS) infrastructure;

- Coverage indicators, particularly WCDMA coverage, do not take into account networks' loads (number of simultaneous users and type of services used);

- The results of the study only reflect the behaviour of the networks on the locations and moments of the measurements;

- On the other hand, operators are permanently improving their networks. The technical interventions necessary for these improvements can cause momentary degradations of the service in the geographic area of intervention.

I.II   MAIN RESULTS AND CONCLUSIONS

The results of the quality of service indicators analysed in this study show that GSM mobile communications systems present good coverage levels and a good performance for the voice service, both in urban agglomerations and in major roads.

UMTS systems' performance, although below the GSM system, has a considerably positive evolution since ANACOM included these systems in its analysis (in November/December 2006). There are still considerable differences between urban areas and major roads. While systems show a good performance in urban areas – with the capacity of establishing and maintaining video-telephony calls close to the level recorded for the GSM voice service, the video-telephony service still doesn't have an adequate performance in major roads, as a direct consequence of the areas with poor or even non-existing WCDMA coverage.

GSM e WCDMA Networks Coverage

The studied mobile communication systems present good GSM coverage levels, both in urban agglomerations and major roads, with no significant differences among operators (Figure 1 and Figure 2).. The coverage levels already recorded in the study conducted in September/October 2007 are maintained (Table 1 and Table 2).

WCDAM (UMTS) networks present good coverage levels in urban areas, with no major differences among operators (Figure 1), and maintaining levels similar to those of the 2007 study (Table 1).

In major roads, WCDMA coverage presents lower levels, with some areas still with bad or even non-existing coverage (Figure 2). Differences among operators were observed: OPTIMUS and TMN present the best performance, respectively with 96.7% and 96.0% of measurements with "Good" or "Acceptable" coverage levels, while VODAFONE stands at 88.5%. Operator OPTIMUS improved its coverage regarding last year, while TMN and VODAFONE have worsened regarding this indicator (Table 2).
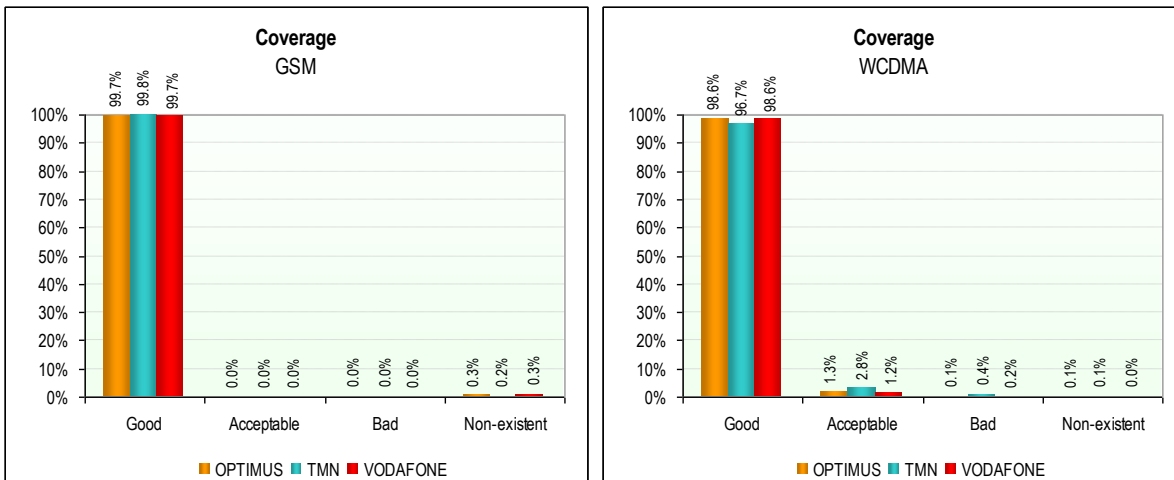
Figure 1 – *Coverage* Indicator, in the Urban Agglomerations of Mainland Portugal.

Table 1 – Evolution of the *Coverage* Indicator, from 2007 to 2008, in the Urban Agglomerations of Mainland Portugal.
(Difference between values recorded in the 2008 study and values recorded in the 2007 study)

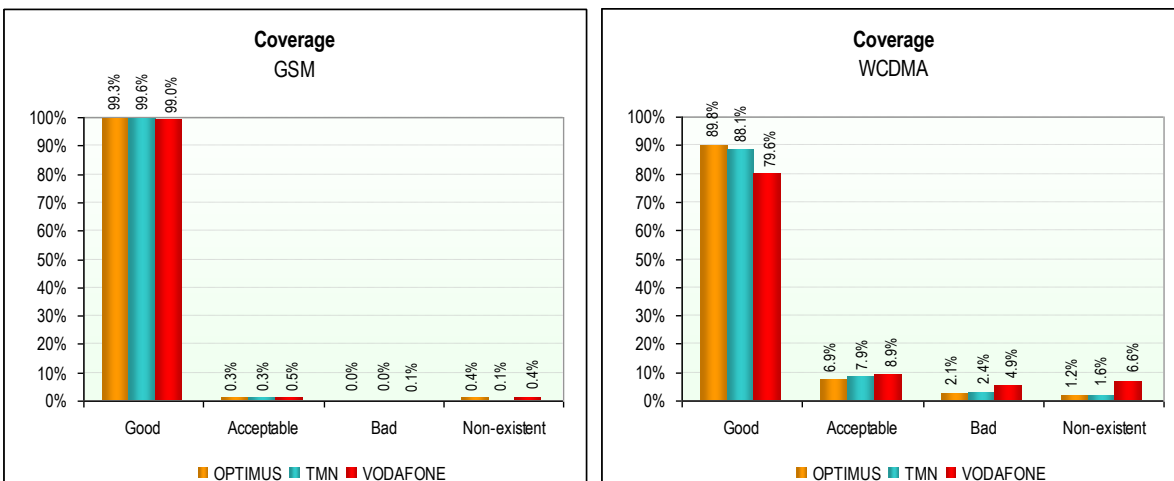|		GSM			WCDMA		
		OPTIMUS	TMN	VODAFONE	OPTIMUS	TMN	VODAFONE
Cobertura Radioeléctrica	Good	0.05%	0.10%	-0.11%	-0.62%	-1.77%	-0.66%
	Acceptable	-0.16%	-0.08%	-0.11%	0.49%	1.41%	0.53%
	Bad	-0.04%	-0.03%	-0.02%	0.03%	0.29%	0.10%
	Non-existent	0.15%	0.01%	0.23%	0.09%	0.07%	0.03%

Figure 2 – *Coverage* Indicator, in the Major Roads of Mainland Portugal.

Table 2 – Evolution of the Coverage Indicator, from 2007 to 2008, in the Main Roads of Mainland Portugal.
(Difference between values recorded in the 2008 study and values recorded in the 2007 study)

		GSM			WCDMA		
		OPTIMUS	TMN	VODAFONE	OPTIMUS	TMN	VODAFONE
Coverage	Good	-0.01%	0.12%	-0.26%	6.29%	-4.72%	-1.74%
	Acceptable	0.02%	0.13%	0.21%	-2.83%	2.98%	0.06%
	Bad	-0.02%	-0.02%	0.02%	-2.26%	1.03%	0.79%
	Non-existent	0.00%	-0.24%	0.03%	-1.20%	0.70%	0.89%

Voice Service (GSM)

The voice service presents good results in all analysed indicators, both in urban agglomerations and in major roads (Figure 3, Figure 4, Figure 5, Figure 6, Figure 7 and Figure 8).

Differences among operators are not relevant in urban agglomerations. However, the *Average Call Audio Quality* of calls routed through operators OPTIMUS and TMN is slightly above VODAFONE's. In major roads the results recorded by operators OPTIMUS and TMN are in general slightly better than those recoded by VODAFONE, namely for the indicators *Call Termination Rate* and *Average Call Audio Quality*.

Comparing the results obtained in this study with those recorded in the study carried out in September and October 2007, no major changes are observed (Table 3 and Table 4).
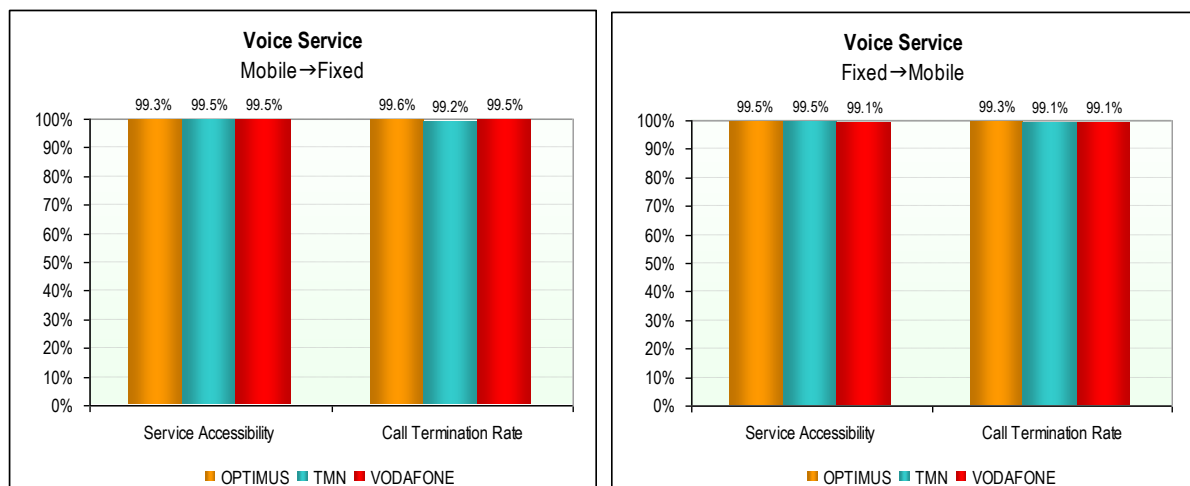

Figure 3 – *Service Accessibility* and *Call Termination Rate* Indicators, in the Urban Agglomerations of Mainland Portugal.

Table 3 – Evolution of the Indicators *Service Accessibility, Call Termination Rate, Average Call Set Up Time* and *Average Audio Quality*, from 2007 to 2008, in the Urban Agglomerations of Mainland Portugal.
(Difference between values observed in the 2008 study and values observed in the 2007 study)

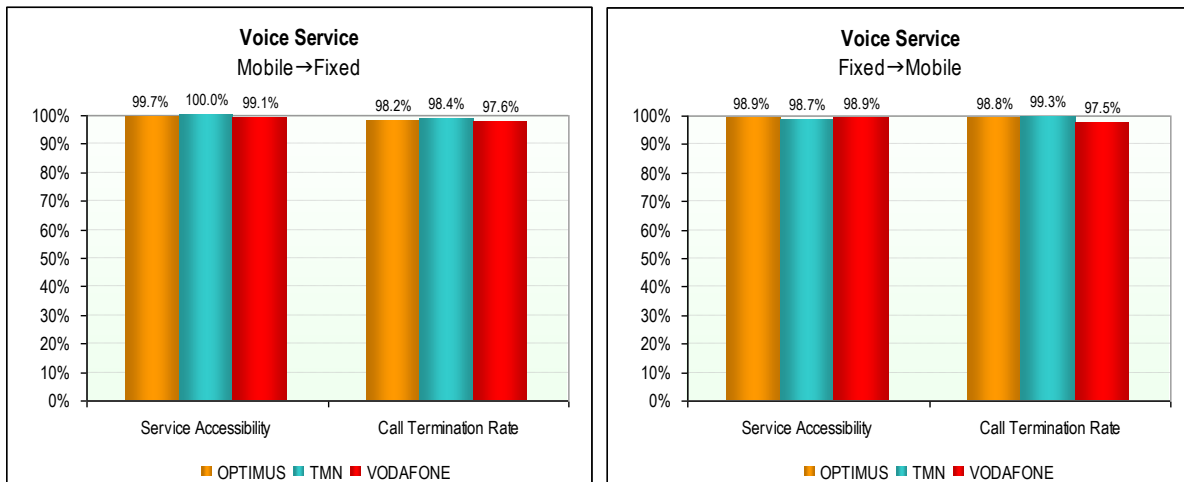|		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Voice Service	Service Accessibility	0.44%	0.79%	1.03%	1.19%	0.12%	-0.21%
	Call Termination Rate	0.26%	0.20%	0.06%	0.00%	0.25%	-0.35%
	Average Call Set Up Time	-0.07	-0.38	-0.88	-1.46	-0.40	-0.64
	Average Audio Quality [MOS]	-0.005	0.085	-0.007	0.070	-0.083	-0.026

Figure 4 – *Service Accessibility* and *Call Termination Rate* Indicators, in the Major Roads
of Mainland Portugal.

Table 4 – Evolution of the Indicators *Service Accessibility, Call Termination Rate, Average Call Set Up Time* and *Average Audio Quality*,
from 2007 to 2008, in the Major Roads of Mainland Portugal.
(Difference between values observed in the 2008 study and values observed in the 2007 study)

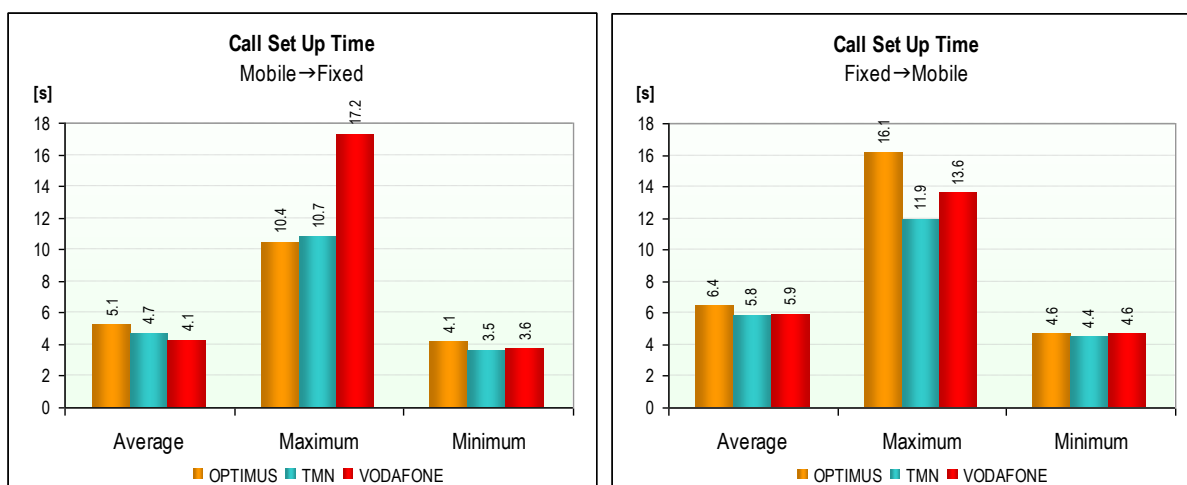|		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Voice Service	Service Accessibility	0.42%	-0.19%	1.83%	0.97%	-0.03%	0.38%
	Call Termination Rate	-0.28%	-0.20%	-0.28%	1.47%	-1.65%	-2.09%
	Average Call Set Up Time	-0.10	-0.34	-0.87	-1.54	-0.46	-0.66
	Average Audio Quality [MOS]	-0.019	0.065	-0.006	0.071	-0.097	-0.044

Figure 5 –*Call Set Up Time* Indicator, in the Urban Agglomerations of Mainland Portugal.
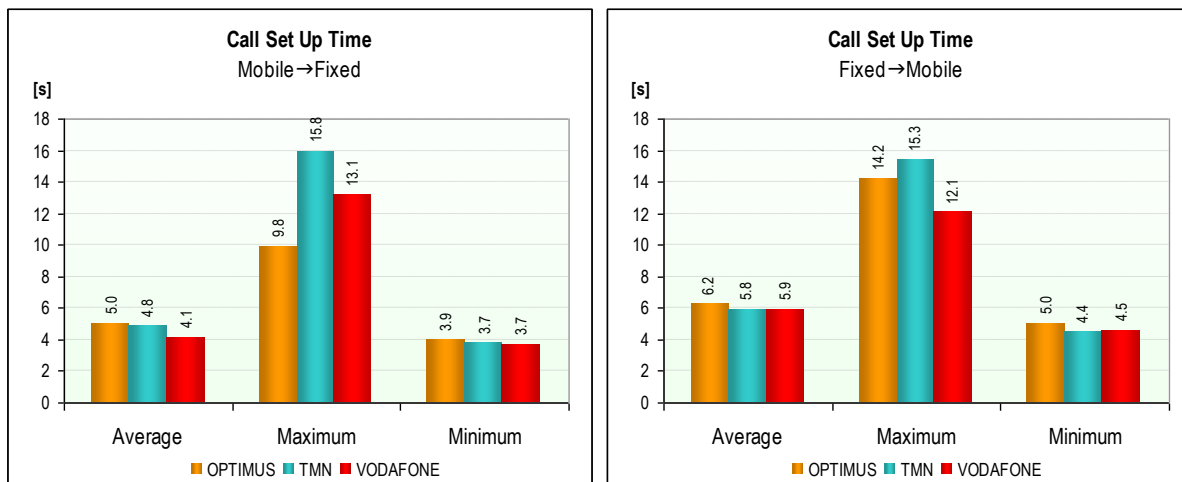
Figure 6 – *Call Set Up Time Indicator*, in the Major Roads of Mainland Portugal.
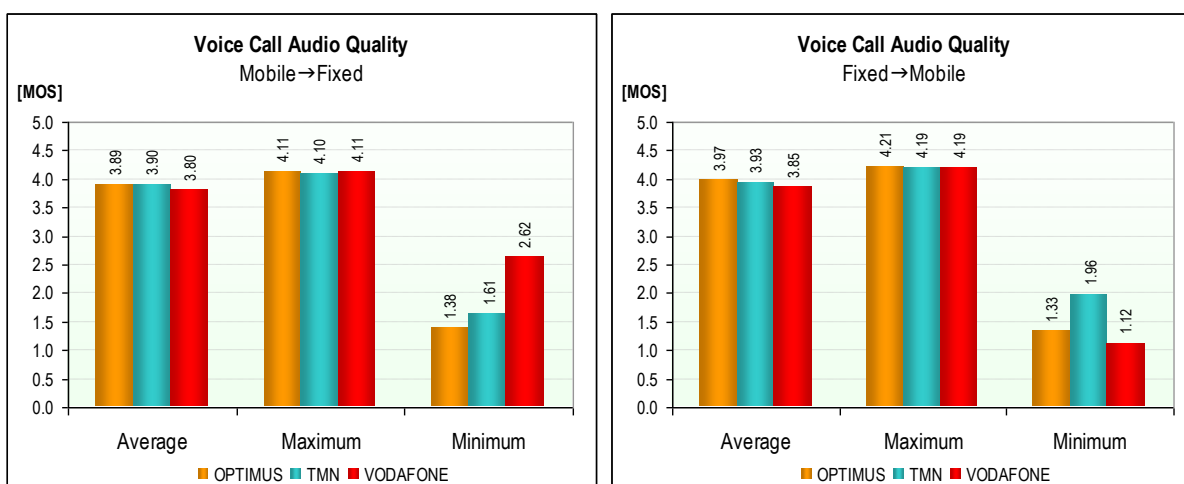

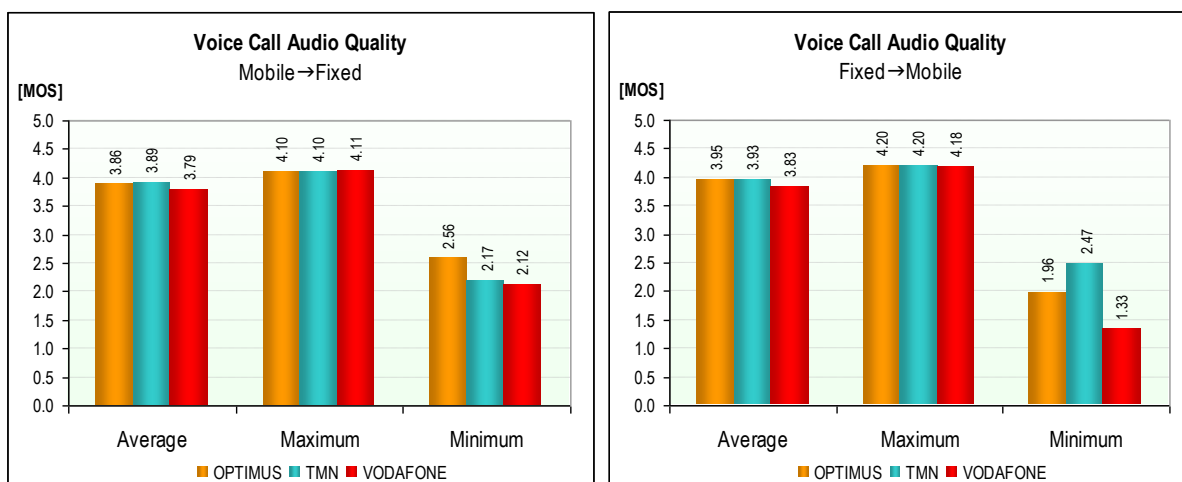Figure 7 – *Call Audio Quality* Indicator, in the Urban Agglomerations of Mainland Portugal.

Figure 8 – *Call Audio Quality* Indicator, on the Major Roads of Mainland Portugal.

Video-telephony Service (UMTS)

The performance of the video-telephony service still stands below the one observed for the voice service. However, it should be noted that there have been considerable improvements over time, particularly concerning the *Service Accessibility Rate* indicator.

The *Service Accessibility* indicator presents acceptable levels in urban agglomerations and considerably lower levels in major roads (Figure 9 and Figure 10). In urban agglomerations, operator VODAFONE registered the best performance, with a 97.3% successful call set up rate. TMN presents the lowest results with a 95.5% successful video-telephony call set up rate. There is a considerable progress regarding 2007, with improvement ranging from 3.75%, for VODAFONE, to 9.45%, for TMN. In major roads, there are greater differences among operators. TMN has the best performance, with 92.1% success in setting up calls, while OPTIMUS and VODAFONE are at 87.2% and 80.1%, respectively. Concerning the study carried out a year ago, there is a considerable improvement for this indicator in major roads, reaching 17.04% for OPTIMUS, 9.84% for TMN and 8.61% for VODAFONE (Table 6).

The *Call Termination Rate* indicator presents better levels than the *Service Accessibility* indicator, with smaller differences between urban agglomerations and major roads (Figure 9 and Figure 10). There are no considerable differences between operators in urban agglomerations, with performance levels above 98.2%. In major roads operator OPTIMUS recorded the best performance, with 96.5% of calls ending normally, while the lowest figure was recorded by VODAFONE, with 92.1% of calls ending normally. This indicator showed no major changes regarding the previous year (Table 5 and Table 6).

The average call set up time does not present major differences between urban agglomerations and major roads, keeping approximately the same values already registered in the study carried out in 2007 (Figure 9, Figure 10, Table 5 and Table 6). The best average time observed was recorded by VODAFONE, with approximately 5.4 seconds. The highest average time was registered by TMN, with about 7.6 seconds.
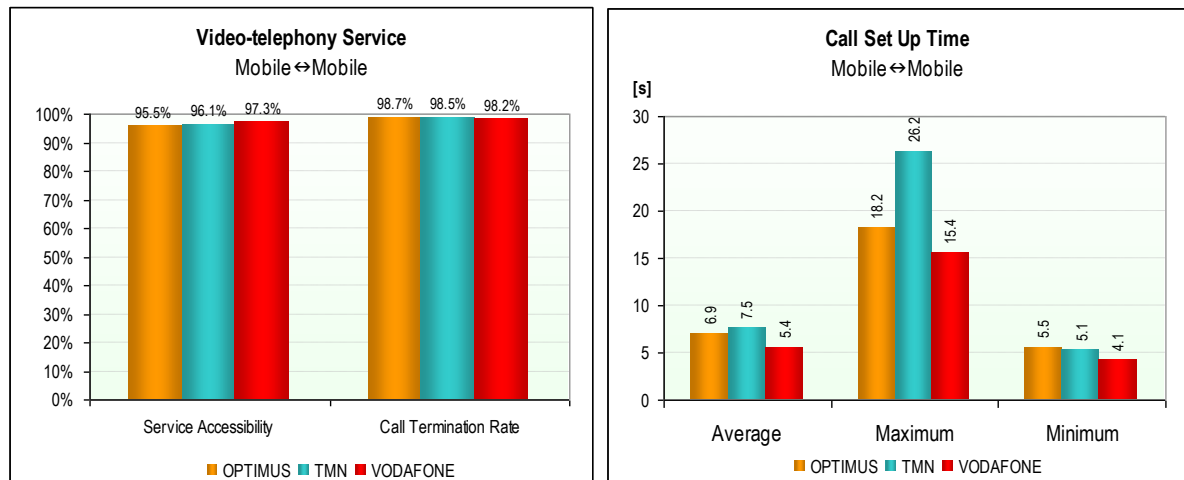
Video-telephony Service
Mobile↔Mobile

Call Set Up Time
Mobile↔Mobile

Figure 9 – *Service Accessibility*, *Call Termination Rate* and *Call Set Up Time* Indicators, in Urban Agglomerations of Mainland Portugal.

Table 5 – Evolution of the Indicators *Service Accessibility, Call Termination Rate, Average Call Set Up Time* and *Average Audio Quality*, from 2007 to 2008, in the Urban Agglomerations of Mainland Portugal.
(Difference between values observed in the 2008 study and values observed in the 2007 study)

		OPTIMUS	TMN	VODAFONE
		Mobile↔Mobile	Mobile↔Mobile	Mobile↔Mobile
Video-telephony service	Service Accessibility	5.41%	9.45%	3.75%
	Call Termination Rate	0.39%	-0.04%	0.85%
	Average Call Set Up Time	-0.12	-1.33	-0.84
	Average Audio Quality [MOS]	0.093	0.029	0.086

Video-telephony Service
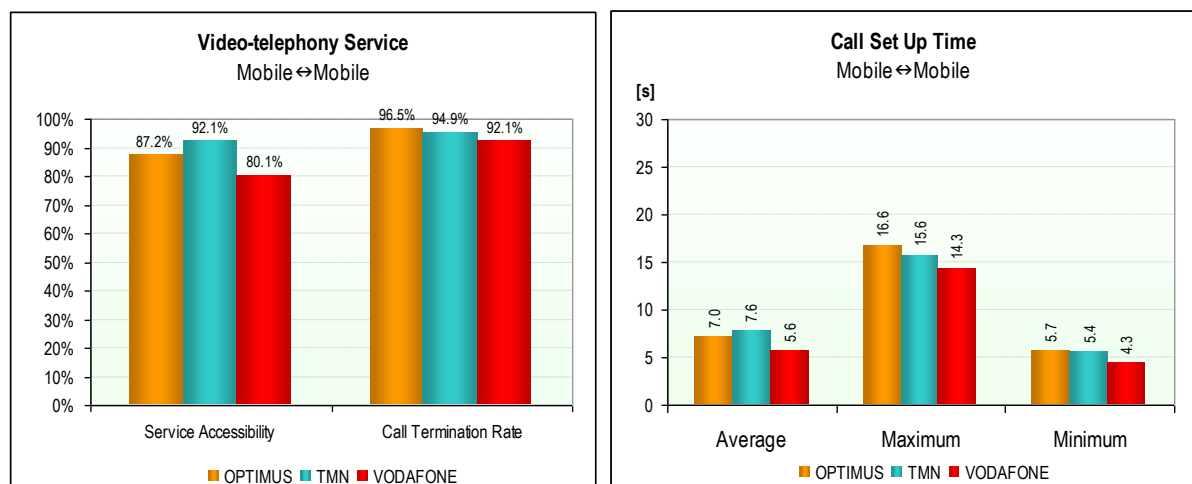Mobile↔Mobile

Call Set Up Time
Mobile↔Mobile

Figure 10 – *Service Accessibility*, *Call Termination Rate* and *Call Set Up Time* Indicators, in the Major Roads of Mainland Portugal.

Table 6 – Evolution of the Indicators *Service Accessibility, Call Termination Rate, Average Call Set Up Time* and *Average Audios Quality* Indicators, from 2007 to 2008, in the Major Roads of Mainland Portugal.
(Difference between values observed in the 2007 study and values observed in the 2006 study)

		OPTIMUS	TMN	VODAFONE
		Mobile↔Mobile	Mobile↔Mobile	Mobile↔Mobile
Video-telephony service	Service Accessibility	17.04%	9.84%	8.61%
	Call Termination Rate	0.94%	-1.06%	1.48%
	Average Call Set Up Time	-0.17	-1.28	-0.95
	Average Audio Quality [MOS]	0.106	0.041	0.095

Normally-ended video-telephony calls (120 seconds long) present good average *Audio Quality*, and acceptable average *Video Quality*. No major differences where observed between operators or between urban agglomerations and major roads (Figure 11 and Figure 12). Regarding the study carried out in 2007, no major changes were observed for these indicators (Table 5 and Table 6).
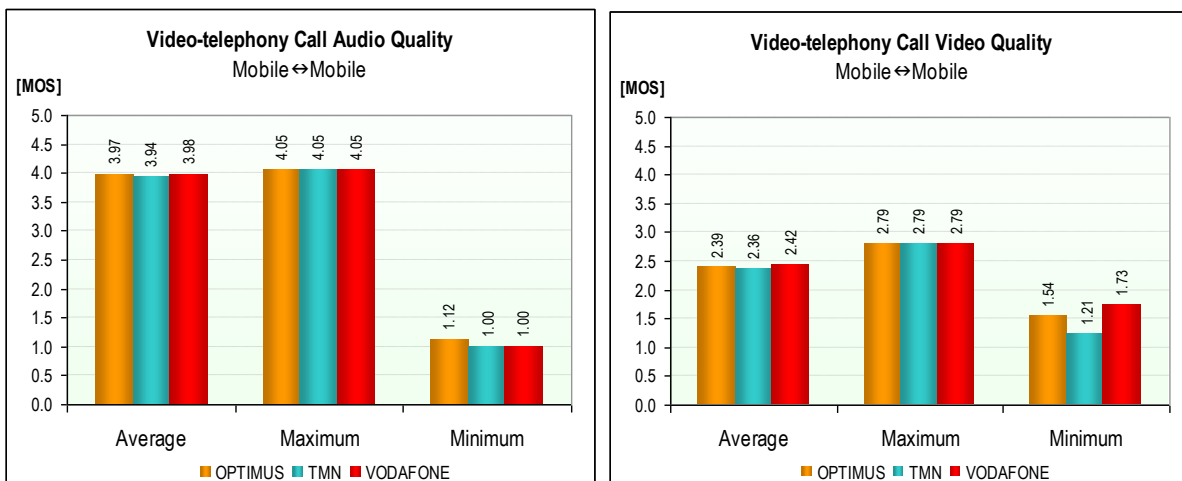

Figure 11 – *Call Audio Quality* and *Call Video Quality* Indicators, in the Urban Agglomerations of Mainland Portugal.
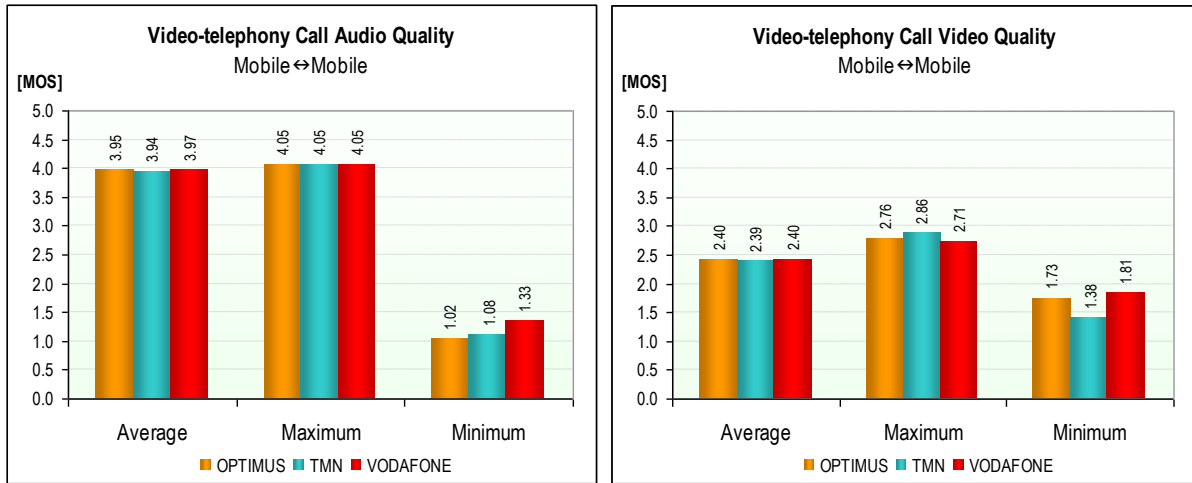
Figure 12 – *Call Audio Quality* and *Call Video Quality* Indicators, in Major Roads of Mainland Portugal.

1 QUALITY OF SERVICE ASSESSMENT

1.1 GOAL

To analyse the quality of the telecommunications services supported on the Portuguese GSM/UMTS mobile networks, from the user's standpoint, by conducting automatic end-to-end tests.

1.2 ANALYSED SERVICES

On an assessment of the QoS, from the user's standpoint, one must consider the services that, for each technology, show a greater relevance for end users, in accordance with national and international market logic, and which are normally provided by all operators on the market.

With this guiding principle, and considering the current reality, the following services were included in this study:

1.2.1 TELEPHONY SERVICES:

a. Voice Service (GSM);

b. Video-telephony Service (UMTS);

1.2.2 REGARDLESS OF SERVICE:

c. Network Radio Coverage (GSM / WCDMA).

2 METHODOLOGY

The methodology is based on the performance of end-to-end automatic tests, thus making it possible to identify the quality of service on the field, giving as much a realistic perspective of the networks' performance as possible, from the user's standpoint.

Measurement collection is made using drive-tests. Besides providing an assessment from the user's standpoint, this approach makes it possible to carry out the tests independently from the correct functioning of the networks themselves, i.e., for example, also analysing the areas with poor or no coverage at all.

On the other hand, the use of a sole testing system to assess the services provided by the three mobile networks makes the results highly comparable, regarding time and space.

2.1 FUNDAMENTALS

This study's methodology is based on three basic characteristics:

a) **End-to-end measurements** – measurements reflect all aspects that impact the quality of a service;

b) **Impartiality** – Measurements are carried out under equal terms for the three operators (OPTIMUS, TMN and VODAFONE);

c) **Objectivity** – Tests are carried out in a totally automatic way, thus eliminating the subjectivity inherent to human intervention or decision.

2.2 MAIN QoS INDICATORS

From the user's standpoint, the use of mobile services presents the following stages (different features of the Quality of Service):

a. **Network Availability** – Shows that the mobile network is present;

b. **Network Access** – Shows that it is possible to use the services (it usually corresponds to the indication of the network's name on the screen of the terminal equipment and the indication of the availability of GPRS and/or 3G);

c. **Service Access** – When the user intends to use a service, the mobile operator provides the access to that service (*e.g.* to set up a voice call);

d. **Service Integrity** – Corresponds to the Quality of Service (QoS) during its use (*e.g.* Audio Quality during a voice call; Video Quality during a video-telephony call);

e. **Service Consistency** – Corresponds to the way the use of the service is ended (according or not to the user's will).

The main Quality of Service Indicators were analysed for each of the QoS features.

2.2.1 REGARDLESS OF THE SERVICE

2.2.1.1 RADIO NETWORK AVAILABILITY (COVERAGE)

Network availability is the probability of the mobile services being available to a user (radio network coverage).

$$\text{Radio Network Availability}\,[\%] = \frac{\text{No. of Measurments with Available Mobile Services}}{\text{Total No. of Measurments}} \times 100\%$$

Mobile services are considered to be available when the radio signals' values are above the minimum levels that make its use possible. These levels may be adjusted by mobile operators and normally present different values for GSM and WCDMA[1].

The used testing and measurement system, using an RF Scanner, makes it possible to continuously measure each network's signal levels. These measurements are geographically referenced, thus rendering possible their representation on maps and making it easy to visualize the coverage levels of mobile networks on the routes under study.

Table 7 – Coverage Levels

Coverage	GSM	WCDMA
Good	RxLev ≥ -85 dBm	CPICH RSCP ≥ -95 dBm
Acceptable	-95 dBm $\leq$ RxLev < -85 dBm	-105 dBm $\leq$ CPICH RSCP < -95 dBm
Bad	-110 dBm $\leq$ RxLev < -95 dBm	-115 dBm $\leq$ CPICH RSCP < -105 dBm
Non-existent	RxLev < -110 dBm	CPICH RSCP < -115 dBm

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[1] Wideband Code Division Multiple Access – Technology used on the radio networks of UMTS communications systems.

2.2.2 TELEPHONY SERVICES

2.2.2.1 SERVICE ACCESSIBILITY (VOICE OR VIDEO-TELEPHONY)

Service accessibility is the probability that the user has of having access to the service (voice or video-telephony), i.e., success probability when establishing a (voice or video-telephony) call.

A call is considered to be "Set Up with Success" if it reaches the called terminal (one hears the "calling signal" on the calling terminal).

$$Service\ Accessibility\ [\%] = \frac{No.\ of\ Successfully\ Set\ Up\ Calls}{Total\ No.\ of\ Attempts\ to\ Set\ Up\ Calls} \times 100\%$$

2.2.2.2 CALL SET UP TIME (VOICE OR VIDEO-TELEPHONY)

Call set up time is the period of time elapsing from the sending of a complete destination address (target telephone number) to the setting up of a call.

$$Call\ Set\ Up\ Time\ [s] = t_{calling\_signal} - t_{address\_sending}$$

$t_{address\_sending}$ – moment when the user presses the send button.

$t_{calling\ signal}$ – moment when the call is successfully set up (one hears the "calling signal" on the caller terminal).

2.2.2.3 CALL TERMINATION RATE (VOICE OR VIDEO-TELEPHONY)

Call termination rate is the probability of a call being maintained, after it is set-up, during a given period of time, ending normally, i.e., according to the user's will.

$$Call\ Termintion\ Rate\ [\%] = \frac{No.\ of\ Normally\ Ended\ Calls}{No.\ of\ Successfully\ Set\ Up\ Calls} \times 100\%$$

2.2.2.4 CALL AUDIO QUALITY (VOICE OR VIDEO-TELEPHONY)

This indicator quantifies how well the conversation is perceived during a (voice or video-telephony) call. Both-ways communication is assessed and only calls with normal termination are considered.

The assessment of this QoS indicator is made by comparing the original audio sample sent, *X(t)*, with

the corresponding degraded sample received, *Y(t)*, on the other end of the call, by applying the *PESQ*[2] algorithm.

The objective audio quality index obtained by applying this algorithm is close to what would be obtained if sample *Y(t)* were submitted to the subjective appreciation of a panel of service users.

$$\text{Call AudioQuality}_{\text{side A}}\left[\text{MOS\_LQO}\right] = f\left\{X_B(t); Y_A(t)\right\}$$
$$\text{Call AudioQuality}_{\text{side B}}\left[\text{MOS\_LQO}\right] = f\left\{X_A(t); Y_B(t)\right\}$$

side A; side B – name of both ends of a voice call.

MOS_LQO – perceived audio quality quantification scale (Mean Opinion Score - Listening Quality Objective)

f – function corresponding to the application of the reckoning algorithm and conversion function of the results in MOS_LQO values.

$X_A(t); X_B(t)$ – original audio sample sent from side A (B).

$Y_A(t); Y_B(t)$ – degraded audio sample received at side A (B), resulting from the transmission of the original sample $X_B(t)$ ($X_A(t)$)

The results of the algorithm application are shown on a MOS (Mean Opinion Score) type scale from 1 to 5 named MOS_LQO
5 named MOS_LQO (Mean Opinion Score – Listening-only Quality Objective), such as shown on

Table 8. The MOS scale quantifies the effort that it takes to understand a conversation. Its limits are 0 (zero) when there is no communication and 5 (five) when the communication is perfect. Value "zero" never shows on the results since they only consider situations where the connection was set up and kept during a given period. "Five" also never shows on the results because the CoDec[3] used by mobile networks does not render possible such high voice quality values (the voice quality reached with the usually used CoDec presents MOS values lower than 4.5).

Table 8 - MOS_LQO / MOS_VQO Scale

MOS	Quality
5	Excellent
4	Good
3	Acceptable
2	Poor
1	Bad

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[2] PESQ – Perceptual Evaluation of Speech Quality. Recommended by the ITU-International Telecommunications Union (ITU-T Recommendation P.862 (02/2001); ITU-T Recommendation P.862.1 (11/2003)).

[3] CoDec – Codifier/De-codifier.

In situations where each direction of the same call sends and receives several audio samples {$X_1(t)$, …, $X_n(t)$; $Y_1(t)$, …, $Y_n(t)$}, the *Call Audio Quality* indicator is reckoned through the arithmetic average of the values obtained by applying the formula shown above to each pair of audio samples, i.e.:

$$\text{Call Audio Quality}_{\text{side A}}\left[\text{MOS\_LQO}\right] = \frac{f\{X_{1_B}(t); Y_{1_A}(t)\} + \ldots + f\{X_{n_B}(t); Y_{n_A}(t)\}}{n}$$

$$\text{Call Audio Quality}_{\text{side B}}\left[\text{MOS\_LQO}\right] = \frac{f\{X_{1_A}(t); Y_{1_B}(t)\} + \ldots + f\{X_{n_A}(t); Y_{n_B}(t)\}}{n}$$

2.2.2.5 VIDEO-TELEPHONY CALL VIDEO QUALITY

This indicator quantifies the communication's visual quality during a video-telephony call. Both directions of the communications are evaluated simultaneously and only calls ending normally are considered.

The evaluation process of this indicator is similar to the one used for *Call Audio Quality*. The difference is that it takes place in **full-duplex**, i.e., simultaneously in both ways of communication and while the test call takes place. This feature reproduces the real video-telephony service usage situation.

$$\text{Call Video Quality}_{\text{side A}}\left[\text{MOS\_VQO}\right] = f\{W_B(t); Z_A(t)\}$$

$$\text{Call Video Quality}_{\text{side B}}\left[\text{MOS\_VQO}\right] = f\{W_A(t); Z_B(t)\}$$

side A; side B – name of both ends of a video-telephony call.

MOS_VQO –perceived visual quality quantification scale (Mean Opinion Score – Visual Quality Objective).

f – f – function corresponding to the application of the reckoning algorithm and conversion function of the results in MOS_VQO values.

$W_A(t)$; $W_B(t)$ – original video sample sent from side A (B).

$Z_A(t)$; $Z_B(t)$ – degraded video sample received at side A (B), resulting from the transmission of the original sample $W_B(t)$ ($W_A(t)$).

There is currently no algorithm being recommended by international standard organizations to evaluate video quality. However, some measurement system manufacturers have developed their own algorithms taking into account the guidelines established by ETSI (ETSI TR 102 493 V1.1.1 (2005-08)) and by *VQEG* – Video Quality Experts Group ("Multimedia Group Test Plan", Draft Version 1.16, February 7, 2007). That is the case with SwissQual, AG, supplier of the testing and measurement system used in this study, which uses in its products its own algorithm, named VQuad - Objective Model for Video Quality Assessment.
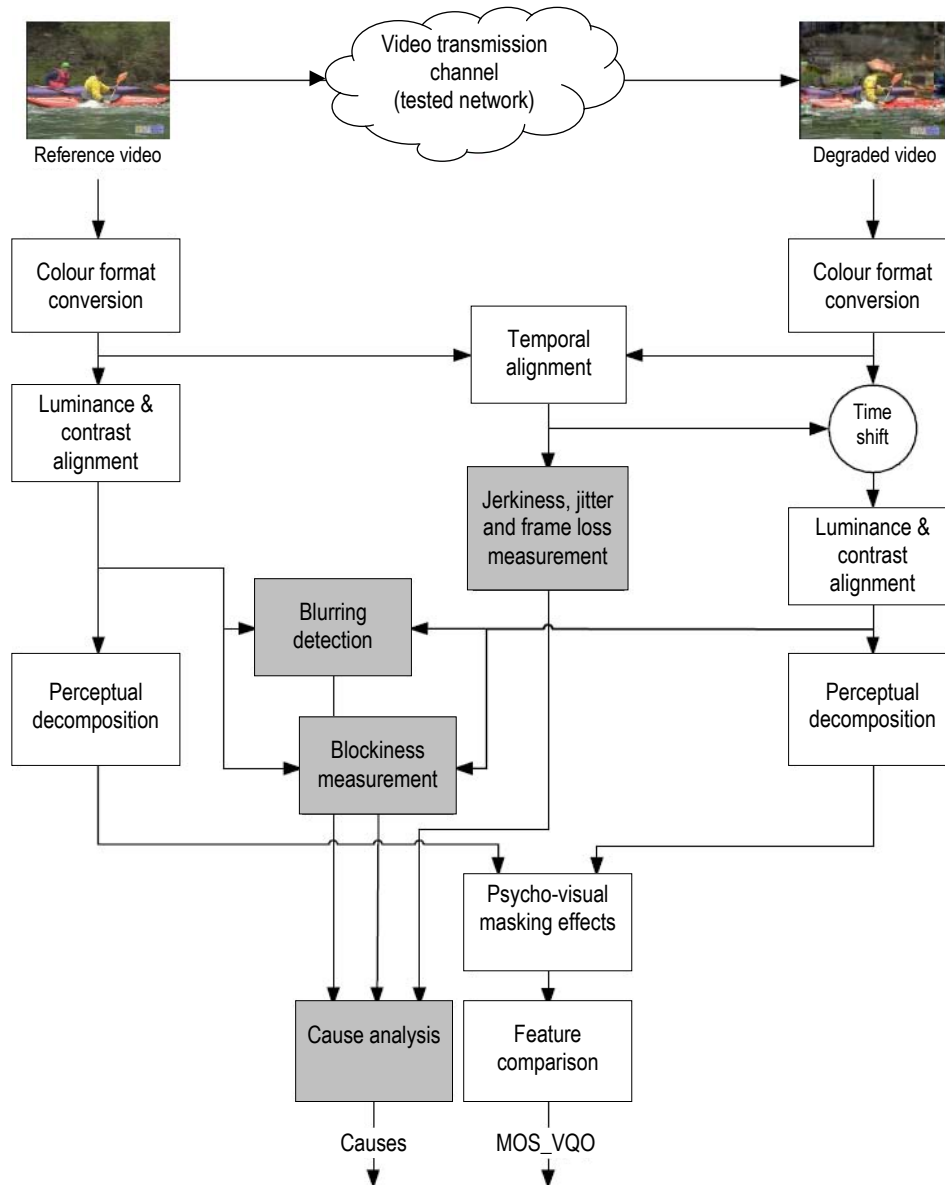
Figure 13 – VQuad algorithm function diagram (*SwissQual, AG*)

Figure 13 shows the functional diagram of the VQuad algorithm. This algorithm is based on a full-reference type model, i.e., on a perceptual comparison of the degraded video sample with its reference. A reference video sequence (sample) is carried through the mobile network being tested. At the destination, the video sequence is captured and objectively validated through the perceptual comparison with the reference video sequence. It results in a global visual quality index (MOS_VQO) and other specific quality parameters (block distortion, blurring, jerkiness, level, PSNR, frame jitter, frame loss, lip-sync, etc.).

The global visual quality index, resulting from the application of the VQuad algorithm, is presented in a MOS (Mean Opinion Score) type scale from 1 to 5 named MOS_VQO (Mean Opinion Score – Visual Quality Objective), such as shown on Table 8.

In situations where each direction of the same call sends and receives several video samples {$W_1(t)$, …, $W_n(t)$; $Z_1(t)$, …, $Z_n(t)$}, the *Call Video Quality* indicator is reckoned through the arithmetic average of the values obtained by applying the formula presented above to each pair of video samples, i.e.:

$$\text{Call Video Quality}_{\text{side A}}\left[\text{MOS\_VQO}\right] = \frac{f\left\{W_{1_B}(t); Z_{1_A}(t)\right\} + \ldots + f\left\{W_{n_B}(t); Z_{n_A}(t)\right\}}{n}$$

$$\text{Call Video Quality}_{\text{side B}}\left[\text{MOS\_VQO}\right] = \frac{f\left\{W_{1_A}(t); Z_{1_B}(t)\right\} + \ldots + f\left\{W_{n_A}(t); Z_{n_B}(t)\right\}}{n}$$

2.3 MEASUREMENT PROFILES[4]

Measurement profiles define a set of conditions that must the verified in order to correctly assess the services' quality and to guarantee the reliability of the tests. They also include process standardization and the definition of testing and measurement parameters, thus making it possible to perform analyses and compare results.

2.3.1 GENERAL FEATURES

Tests are performed automatically and using the *Diversity* system (there is no human intervention or decision during the carrying out of a test).

Voice tests are made by manually selecting the 2G (GSM) infrastructure, while video-telephony tests are performed with automatic selection of the 2G or 3G (GSM/UMTS) infrastructures.

Measurements are carried out on moving vehicles and with outdoor antennas (without gain). All collected parameters are geographically referenced and can be later shown by digital cartography.

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[4] The measurement profiles presented here are supported on the technical specifications ETSI TS 102 250, namely part 5 (ETSI TS 102 250-5 V1.3.1 (2005-11)), and ETSI EG 202 057, namely parts 3 and 4 (ETSI EG 202 057-3 V1.1.1 (2005-04) and ETSI EG 202 057-4 V1.1.1 (2005-10)).

2.3.2 COVERAGE

Network coverage assessment is made by measuring the downlink signal levels, RxLev (Received signal Level) for GSM and CPICH RSCP (Common Pilot Channel Received Signal Code Power) for WCDMA, along each analysed route.

Measurements are made through a RF Scanner device adapted and exclusively dedicated to this task, so that the measured signal levels correspond to the effective levels. The measurement equipment has the ability to collect signal samples from all GSM and WCDMA radio channels used by the operators under analysis, at approximately one second intervals. These samples are later analysed and only the best signal level results obtained for each point, technology and operator are considered.

Each measurement point is geographically referenced so that signal levels can be later represented on digital cartography, thus making it easier to visualise coverage levels of the mobile networks along the routes under study and to identify the locations with poor or non-existing coverage.

2.3.3 TELEPHONY SERVICES

These services are evaluated end-to-end, using a "call" as the basic test unit.

Test calls are made between two mobile terminal devices, where at least one of them is of a mobile type (MS – Mobile Station or UE – User Equipment). This MS or UE moves along the studied route/location, and the calls originated from this terminal equipment are named MOC (Mobile Originated Call).

In order to minimize the uncertainty that always accompanies measurement procedures, the second end of the test calls must present good performance levels and great stability. This end's impact on the services' performance indicators is intended to be the minimum. The solutions include using fixed network terminals (ISDN) to assess the performance of voice services, and to use mobile terminals (UE) to assess the performance of the video-telephony service. UE are kept motionless in locations with proper (good) radio coverage, minimum interference and with a (virtually) 100% probability of accessing the video-telephony service. Calls originated on this end, at the ISDN or UE terminal, and ended at the mobile terminal that is under test, are named MTC (Mobile Terminated Call).

In order to compare the performance of the several operators (benchmark), a fixed time frame is used for making each call during the test sessions. When a call failure occurs, either when establishing a call or in the conversation phase, the next call is only started when the next time frame arrives.

2.3.3.1 VOICE SERVICE

The analysis of the voice service at a given location includes the abilities to establish and to end calls, as well as the communication's integrity.

Since the aim is to study the normal use of the voice service, the duration of test calls is close to the average duration of calls routed on the networks. Besides the call's own duration, the time frame considers time periods that make possible the setting up and ending of a call, and also a 30 second pause between consecutive calls, to prevent possible network constraints regarding signalling or mobility management.

After the test call is started, communication's integrity – audio quality – is analysed both ways, separately, regardless of the end that started the call.

The test parameters used for the analysis of the voice service present the following values:

- ► Relationship between MOC/MTC: 1/1;
- ► Duration of the test calls: 120 seconds;
- ► Time frame for making a test call: 180 seconds;
- ► Maximum call set up time: 20 seconds.

2.3.3.2 VIDEO-TELEPHONY SERVICE

The capacity to establish and end calls, as well as the integrity of communications – audio and video quality - is analysed. Audio quality is analysed separately for each direction of the communication, regardless of the side that started the test call, while video quality is analysed simultaneously, on both directions of the communication.

The test parameters for the analysis of the video-telephony service are similar to those used for the voice service. The difference relies on the time frame, which is larger, since the time needed for establishing calls and negotiating audio/video communications between terminals is longer.

The test parameters used for the analysis of the video-telephony service present the following values:

- ► Relationship between MOC/MTC: 1/1;

- ► Duration of the test calls: 120 seconds;

- ► Time frame for making a test call: 210 seconds;

- ► Maximum call set up time: 20 seconds;

- ► Maximum audio and video communication set up time: 30 seconds.

2.4 TEST/MEASUREMENT AND POST-PROCESSING SYSTEMS

The *Diversity/NetQual* system, conceived and developed by SwissQual, A.G. (Switzerland), was used for measurements on the field and for their post-processing. This is a tool specifically designed for the analysis and benchmarking of mobile communications systems.

The system is made up of the following modules:

a. ***Diversity*** – Mobile Unit, with a RF scanner and commercial mobile terminal devices (NOKIA N95 terminals were used in the study);

b. ***Land Unit*** – Fixed Unit, with ISDN interface cards, used for voice tests;

c. ***Video Call Server*** – Fixed Unit, with commercial mobile terminal devices (NOKIA 6680), used for video-telephony tests;

d. ***Media Server*** – Fixed Unit, server used for data and video streaming tests;

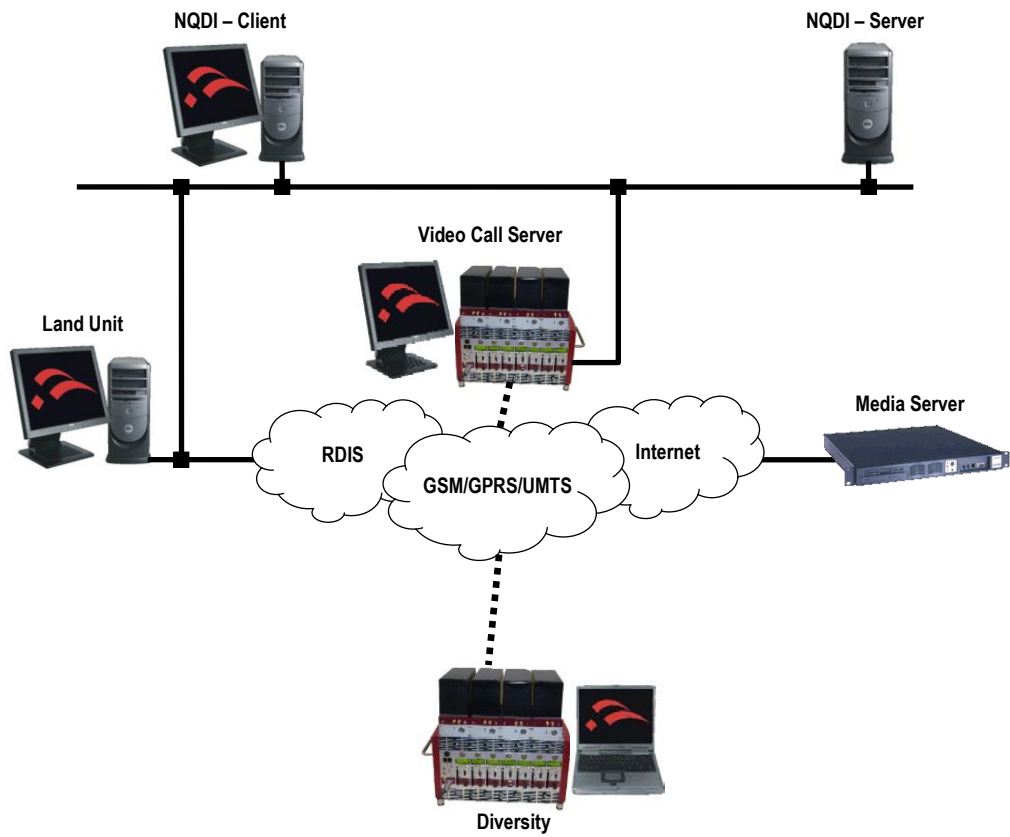e. ***NQDI*** – Post-processing System, for analysis and reporting of the measurements made.

Figure 14 – *Diversity/NetQual* system architecture

3 STUDY SAMPLE

A sample representing the use of these services in the main urban agglomerations and major roads of Mainland Portugal was chosen for a proper assessment of the quality of Voice (GSM), Video-telephony (UMTS) and Network Coverage (GSM and WCDMA).

3.1 TESTED AREAS

This study aims to assess the quality of the services provided by mobile networks, as it is perceived by consumers. It would thus be desirable to conduct measurements in all locations where this type of communications is or could be provided, at the limit, considering the whole of Portugal's geographical area, including the interior of buildings. Understandably, making tests on all these locations is unfeasible.

However, the purpose is not to make exhaustive measures, but to collect an adequate sample that can be used as an indicator of the networks' overall performance. In this sense, locations where the service is more intensely used were chosen, i.e., the larger urban agglomerations and the major roads.

However, the exclusive adoption of this criterion would lead to an excessive concentration of measurements in the coastline's most densely populated areas, and therefore, besides this criterion, we decided to consider a geographical distribution of the locations, as a way to contemplate inland regions.

Thus, tests were made in all of the country's district capitals, the collection area was broadened to the greater Lisbon and Porto peripheral areas, and also to the major roads of Mainland Portugal.

The population of the urban agglomerations that make up the selected sample stands for 41.7% of the Portuguese population, according to the results of the last Census (2001).

Table 9 – Locations and their population.

Territory Unit	Residing Population	Present Population
Aveiro	73,136	76,415
Beja	35,659	37,001
Braga	163,981	165,048
Bragança	34,689	37,170
Castelo Branco	55,909	56,280
Coimbra	148,122	159,039
Évora	56,359	58,564
Faro	57,151	59,527
Guarda	43,759	44,593
Leiria	119,319	119,065
Portalegre	25,814	26,511
Santarém	63,418	63,106
Setúbal	113,480	112,227
Viana do Castelo	88,409	86,355
Vila Real	49,928	52,129
Viseu	93,259	93,041
Total	**1,222,392**	**1,246,071**
Greater Porto		
Porto	262,928	266,790
Gondomar	163,462	159,547
Maia	119,718	117,539
Matosinhos	166,275	162,671
Vila Nova de Gaia	287,597	280,466
Total	**999,980**	**987,013**
Greater Lisbon		
Lisbon	556,797	559,248
Amadora	174,788	169,507
Cascais	168,827	166,539
Loures	198,685	193,320
Oeiras	160,147	157,152
Sintra	363,556	351,976
Almada	159,550	156,746
Seixal	150,095	146,843
Odivelas	132,971	130,569
Total	**2,065,416**	**2,031,900**
Total	**4,287,788**	**4,264,984**

Source: INE - Instituto Nacional de Estatística

Table 10 – Major Roads

Major Roads	Approximate Length (Km)
Aveiro-Viseu-Vilar Formoso (A25)	200
Chaves-Vila Real-Figueira da Foz (A24 / IP3 / A14)	285
Lagos-Vila Real de S^{to}. António-Faro-Lagos (A22 / EN125)	275
Lisbon-Algarve (A2)	245
Lisbon-Cascais-Sintra-Lisbon (A5 / IC19)	60
Lisbon-Évora-Elvas (A12 / A2 / A6)	215
Lisbon-Leiria-Aveiro (A8 / A17)	245
Lisbon-Porto (A1)	315
Maia-Guimarães-Braga-Esposende (A41 / A42 / A11)	120
Oeiras-Castelo Branco-Guarda (A9 / A10 / A1 / A23)	330
Porto-Bragança (A4 / IP4)	260
Porto-Braga-Valença-Viana do Castelo-Porto (A3 / A28)	230
Póvoa de Varzim-Vila Pouca de Aguiar (A7)	110
Total	**2,890**

3.2 SAMPLE SIZE

Table 11 – Sample, for the three analysed operators

		Hours of Measurement	Measurements in	Voice Calls	Video-telephony Calls	Coverage Measurements	
						GSM	WCDMA
Urban Agglomerations	Aveiro	6 h 11	160	360	312	66,187	66,439
	Beja	6 h 11	110	360	312	66,548	66,511
	Braga	6 h 09	190	362	302	66,148	66,797
	Bragança	6 h 15	175	362	314	67,181	67,442
	Castelo Branco	6 h 17	118	369	320	68,272	68,323
	Coimbra	6 h 14	168	363	313	66,441	67,166
	Évora	6 h 09	125	360	310	66,338	66,600
	Faro	6 h 12	143	366	315	67,601	67,876
	Guarda	6 h 25	193	378	325	69,498	69,695
	Leiria	6 h 15	168	368	314	67,597	67,724
	Portalegre	6 h 03	97	352	302	65,299	65,633
	Santarém	6 h 16	143	366	315	67,678	67,838
	Setúbal	6 h 07	153	361	309	65,926	66,415
	Viana do Castelo	6 h 11	151	363	312	66,862	67,449
	Vila Real	6 h 11	154	363	313	67,094	67,108
	Viseu	6 h 14	168	365	316	67,616	67,877
	Greater Porto	18 h 08	490	1,068	919	195,816	197,068
	Greater Lisbon	36 h 10	923	2,130	1,816	390,744	392,511
Total Urban Agglomerations		153 h 38	3,829	9,016	7,739	1,658,846	1,666,472
Major Roads	Aveiro-Viseu-Vilar Formoso (A25)	4 h 22	400	256	218	47,438	47,632
	Chaves-Vila Real-Figueira da Foz (A24 / IP3 / A14)	5 h 28	565	321	272	59,021	59,244
	Lagos-Vila Real de Sto. António-Faro-Lagos (A22 / EN125	7 h 40	545	449	386	82,781	82,716
	Lisbon-Algarve (A2)	4 h 18	489	255	216	46,139	46,386
	Lisbon-Cascais-Sintra-Lisbon (A5 / IC19)	6 h 15	313	368	317	67,841	67,988
	Lisbon-Évora-Elvas (A12 / A2 / A6)	4 h 23	428	254	219	47,270	47,363
	Lisbon-Leiria-Aveiro (A8 / A17)	4 h 24	485	260	221	48,097	48,081
	Lisbon-Porto (A1)	5 h 50	625	340	295	63,093	63,496
	Maia-Guimarães-Braga-Esposende (A41 / A42 / A11)	2 h 15	234	129	110	24,135	24,221
	Oeiras-Castelo Branco-Guarda (A9 / A10 / A1 / A23)	6 h 44	654	393	333	71,641	71,883
	Porto-Bragança (A4 / IP4)	5 h 17	514	304	262	56,854	57,516
	Porto-Braga-Valença-Viana do Castelo-Porto (A3 / A28)	5 h 05	454	294	254	54,828	55,173
	Póvoa de Varzim-Vila Pouca de Aguiar (A7)	2 h 00	215	112	95	21,174	21,281
Total Major Roads		64 h 01	5,921	3,735	3,198	690,312	692,980
Total		217 h 39	9,750	12,751	10,937	2,349,158	2,359,452

3.3 DATA COLLECTION CONDITIONS

Field work took place during normal working day periods from October 18 to November 11.

In the Greater Lisbon and Greater Porto regions, measurement sessions were made from 8h00 to 12h00 and from 16h00 to 20h00. In the remaining urban agglomerations, measurement sessions were made during normal working periods.

On each major road, data collection was made in two series of runs, except for the A5/IC19 route, where several runs were made along one day (6h15).

4 AGGREGATED RESULTS

4.1 URBAN AGGLOMERATIONS

4.1.1 VOICE SERVICE (GSM)

		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Calls Made	Number of Calls	1,523	1,486	1,520	1,484	1,520	1,483
	Dropped on Set Up	10	8	7	8	7	13
	Dropped During Call	6	10	12	14	8	13
	With Normal Terminations	1,507	1,468	1,501	1,462	1,505	1,457
	Service Accessibility	99.3%	99.5%	99.5%	99.5%	99.5%	99.1%
	Call Termination Rate	99.6%	99.3%	99.2%	99.1%	99.5%	99.1%
Call Set Up	Number of Samples (Calls)	1,513	1,478	1,513	1,476	1,513	1,470
	Maximum Time [s]	5.1	6.4	4.7	5.8	4.1	5.9
	Average Time [s]	10.4	16.1	10.7	11.9	17.2	13.6
	Minimum Time [s]	4.1	4.6	3.5	4.4	3.6	4.6
	Standard Deviation [s]	0.8	1.3	0.4	0.9	0.6	0.8
Audio Quality	Number of Samples (Calls)	2,974	2,974	2,962	2,959	2,961	2,961
	Average [MOS]	3.89	3.97	3.90	3.93	3.80	3.85
	Maximum [MOS]	4.11	4.21	4.10	4.19	4.11	4.19
	Minimum [MOS]	1.38	1.33	1.61	1.96	2.62	1.12
	Standard Deviation [MOS]	0.18	0.20	0.20	0.26	0.17	0.20

		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Precision Error	Service Accessibility	0.5%	0.5%	0.5%	0.5%	0.5%	0.6%
	Call Termination Rate	0.5%	0.6%	0.6%	0.6%	0.5%	0.6%
	CallSet Up Time [s]	0.040	0.064	0.022	0.045	0.028	0.041
	Audio Qualiy [MOS]	0.007	0.007	0.007	0.010	0.006	0.007

Confidence Level = 95 %

4.1.1.1 *SERVICE ACCESSIBILITY* AND *CALL TERMINATION RATE* INDICATORS
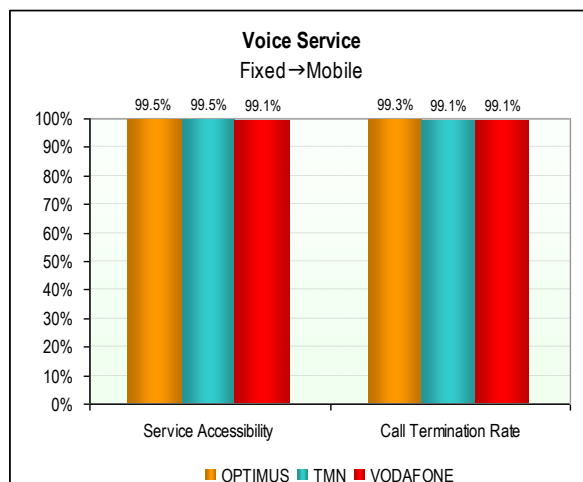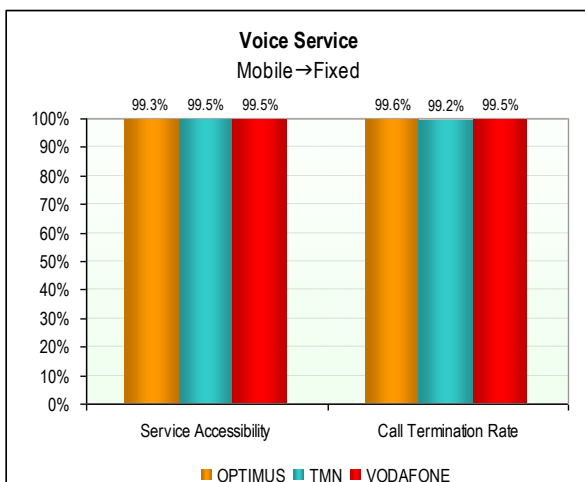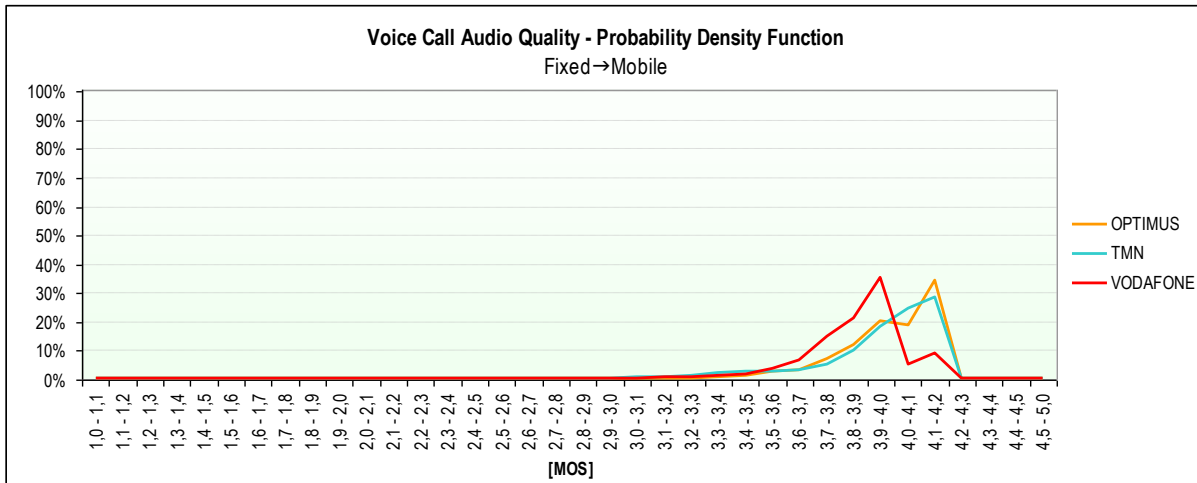
4.1.1.2 CALL SET UP TIME INDICATOR
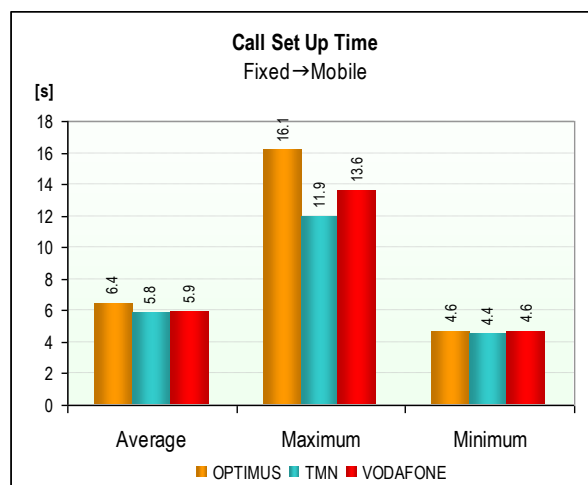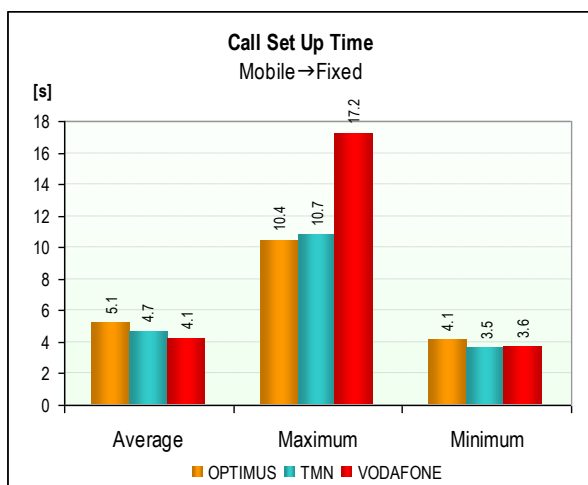
4.1.1.3 VOICE CALL AUDIO QUALITY INDICATOR
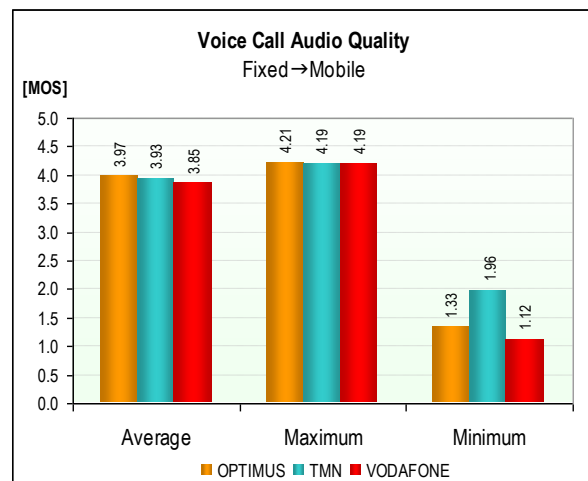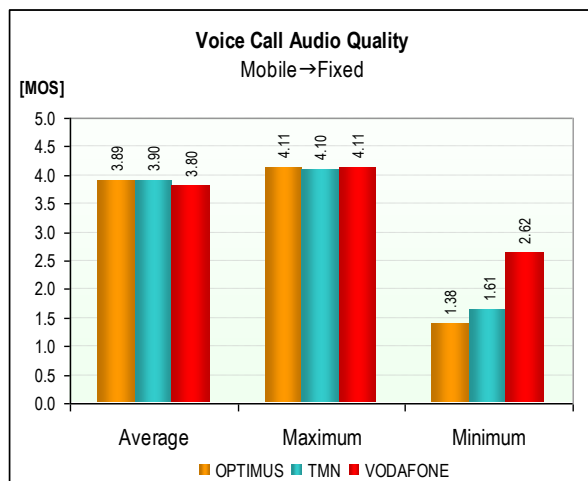
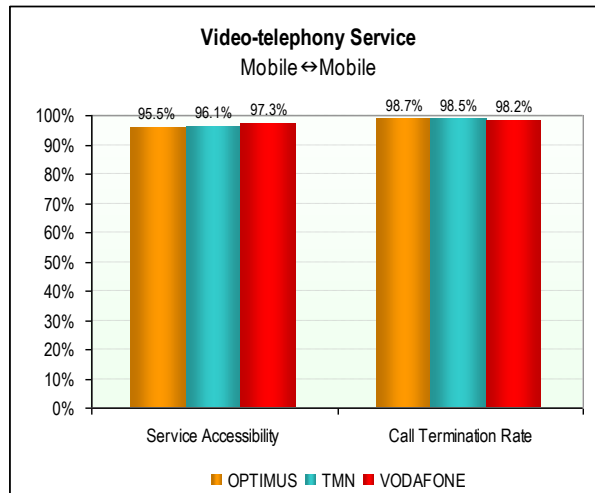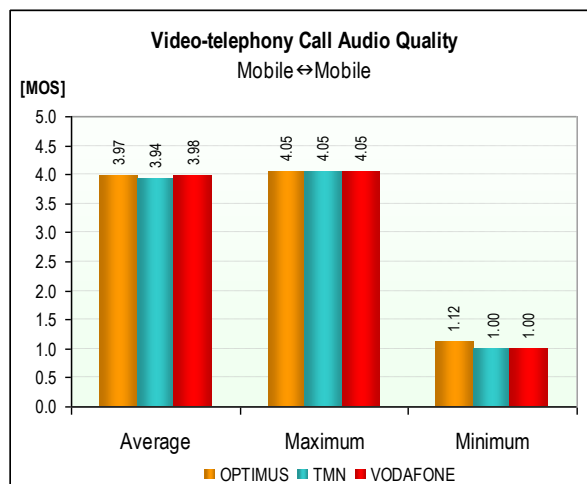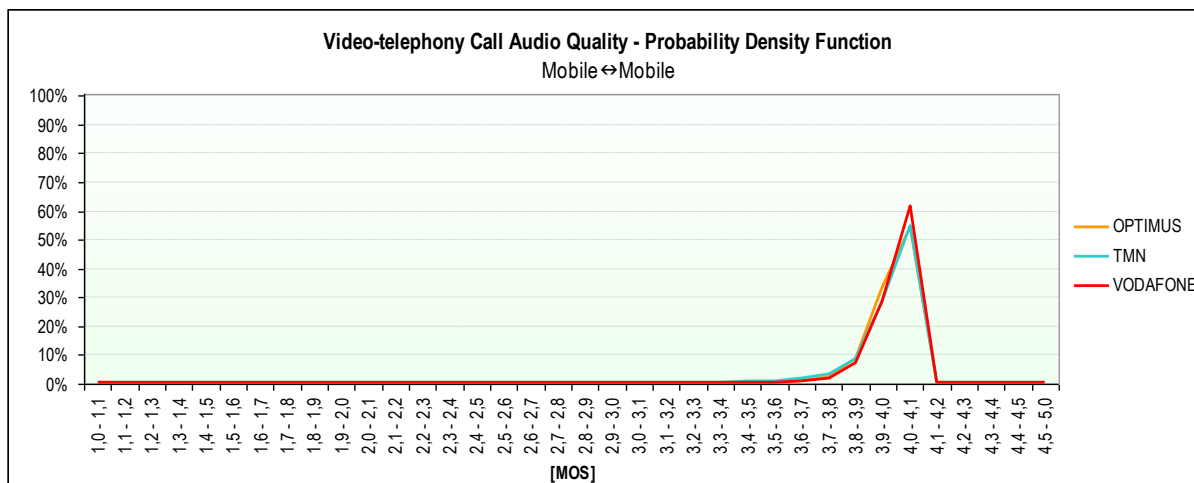## 4.1.1.4 PROBABILITY DENSITY FUNCTION OF THE VOICE CALL AUDIO QUALITY INDICATOR

Voice Call Audio Quality - Probability Density Function
Fixed→Mobile
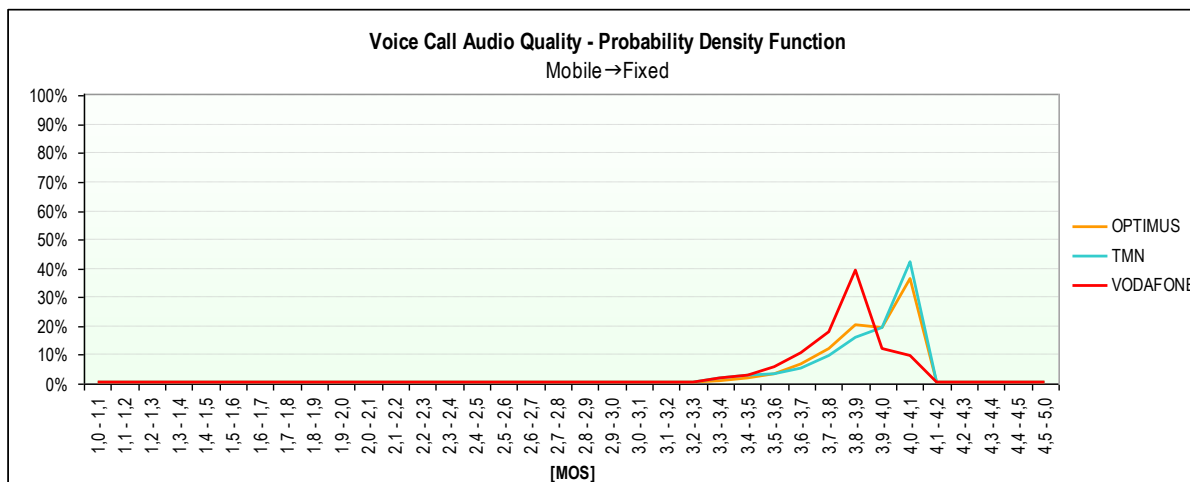
4.1.2 VIDEO-TELEPHONY SERVICE (UMTS)

		OPTIMUS	TMN	VODAFONE
		Mobile⇔Mobile	Mobile⇔Mobile	Mobile⇔Mobile
Calls Made	Number of Calls	2,582	2,574	2,583
	Dropped on Set Up	116	100	70
	Dropped During Call	33	38	44
	With Normal Terminations	2,433	2,436	2,469
	Service Accessibility	95.5%	96.1%	97.3%
	Call Termination Rate	98.7%	98.5%	98.2%
Call Set Up	Number of Samples (Calls)	2,466	2,474	2,513
	Maximum Time [s]	6.9	7.5	5.4
	Average Time [s]	18.2	26.2	15.4
	Minimum Time [s]	5.5	5.1	4.1
	Standard Deviation [s]	1.2	1.5	1.1
Audio Quality	Number of Samples (Calls)	4,865	4,872	4,938
	Average [MOS]	3.97	3.94	3.98
	Maximum [MOS]	4.05	4.05	4.05
	Minimum [MOS]	1.12	1.00	1.00
	Standard Deviation [MOS]	0.14	0.25	0.13
Video Quality	Number of Samples (Calls)	4,866	4,857	4,938
	Average [MOS]	2.39	2.36	2.42
	Maximum [MOS]	2.79	2.79	2.79
	Minimum [MOS]	1.54	1.21	1.73
	Standard Deviation [MOS]	0.14	0.20	0.16

		OPTIMUS	TMN	VODAFONE
		Móvel⇔Móvel	Móvel⇔Móvel	Móvel⇔Móvel
Precision Error	Service Accessibility	0.9%	0.8%	0.7%
	Call Termination Rate	0.5%	0.6%	0.6%
	Call Set Up Time [s]	0.047	0.058	0.043
	Audio Quality [MOS]	0.004	0.007	0.004
	Video Quality [MOS]	0.004	0.006	0.004

Confidence Level = 95 %

4.1.2.1 *SERVICE ACCESSIBILITY AND CALL TERMINATION RATE INDICATORS*
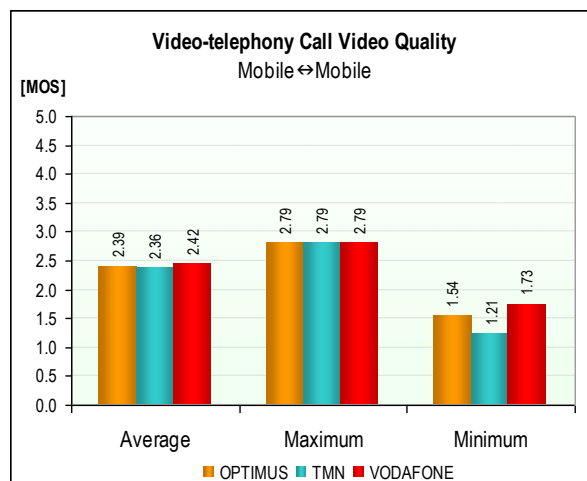

4.1.2.2 *CALL SET UP TIME INDICATOR*
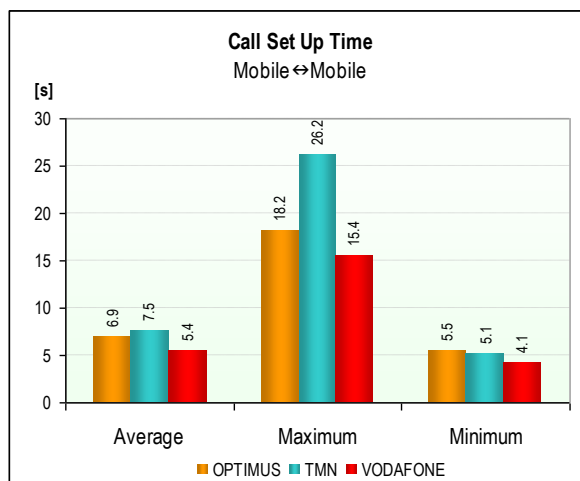
4.1.2.3 *VIDEO-TELEPHONY CALL AUDIO QUALITY INDICATOR*
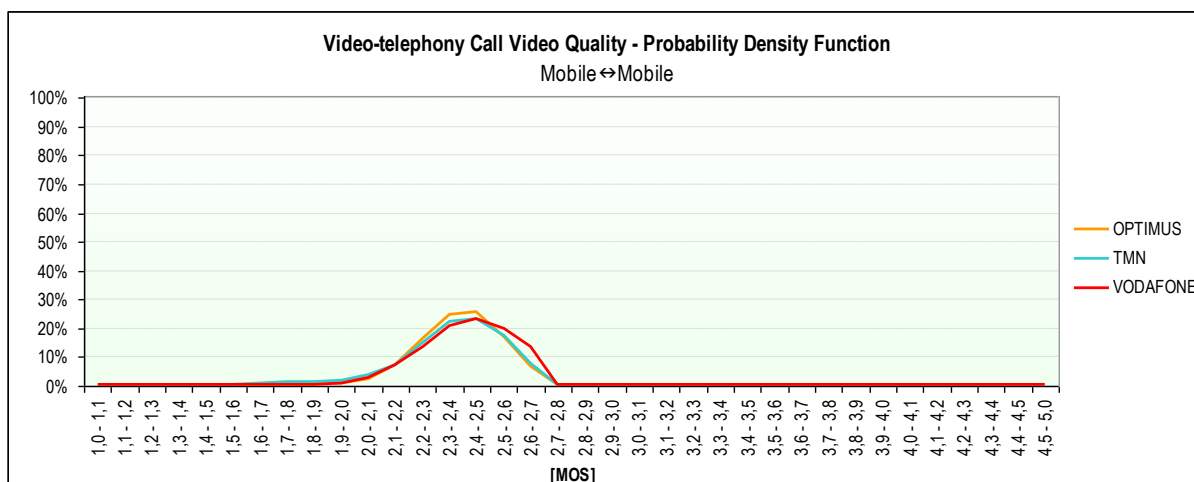
4.1.2.4 Probability Density Function of the *Video-telephony Call Audio Quality* Indicator

4.1.2.5 *Video-telephony Call Video Quality* Indicator

4.1.2.6 Probability Density Function of the *Video-telephony Call Video Quality* Indicator
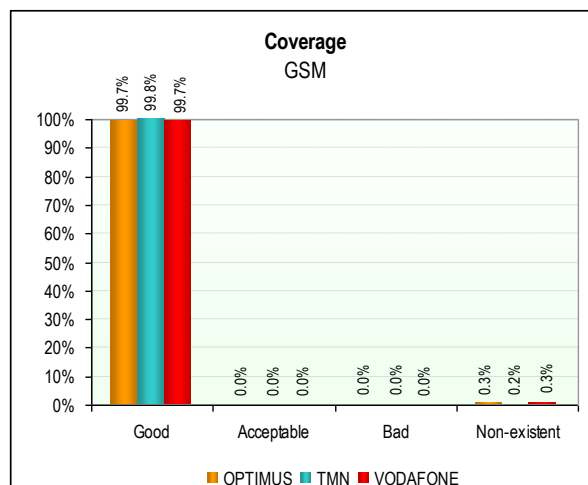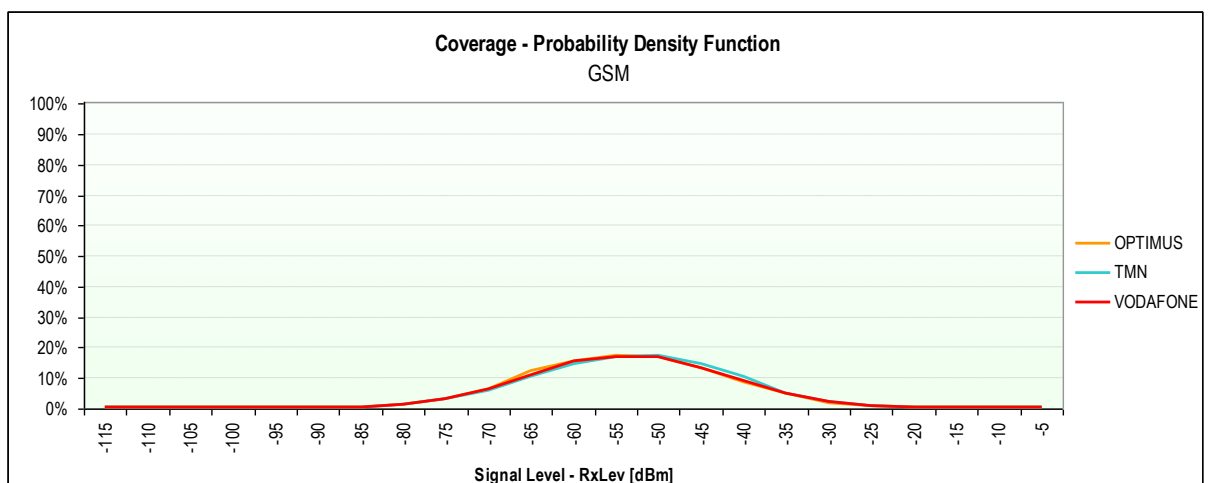
4.1.3 NETWORK COVERAGE

		GSM			WCDMA		
		OPTIMUS	TMN	VODAFONE	OPTIMUS	TMN	VODAFONE
Coverage	Number of Samples (Calls)	553,044	552,776	553,026	555,448	555,600	555,424
	Maximum Time [s]	-51	-50	-50	-71	-72	-69
	Average Time [s]	-20	-14	-11	-30	-24	-29
	Minimum Time [s]	-115	-115	-115	-128	-140	-130
	Standard Deviation [s]	11	11	11	11	13	12
	Good	99.7%	99.8%	99.7%	98.6%	96.7%	98.6%
	Acceptable	0.0%	0.0%	0.0%	1.3%	2.8%	1.2%
	Bad	0.0%	0.0%	0.0%	0.1%	0.4%	0.2%
	Non-existent	0.3%	0.2%	0.3%	0.1%	0.1%	0.0%

4.1.3.1 GSM

4.1.3.2 GSM – PROBABILITY DENSITY FUNCTION

4.1.3.3 WCDMA

Coverage
WCDMA

	OPTIMUS	TMN	VODAFONE
Good	98.6%	96.7%	98.6%
Acceptable	1.3%	2.8%	1.2%
Bad	0.1%	0.4%	0.2%
Non-existent	0.1%	0.1%	0.0%

4.1.3.4 WCDMA – PROBABILITY DENSITY FUNCTION

Coverage - Probability Density Function
WCDMA

Signal Level - CPICH RSCP [dBm]
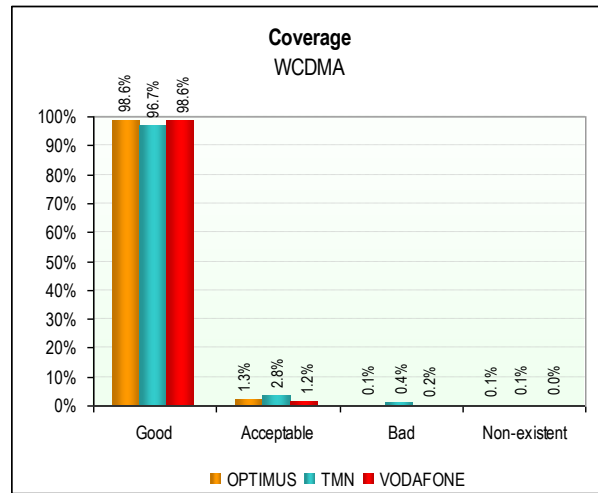
OPTIMUS
TMN
VODAFONE
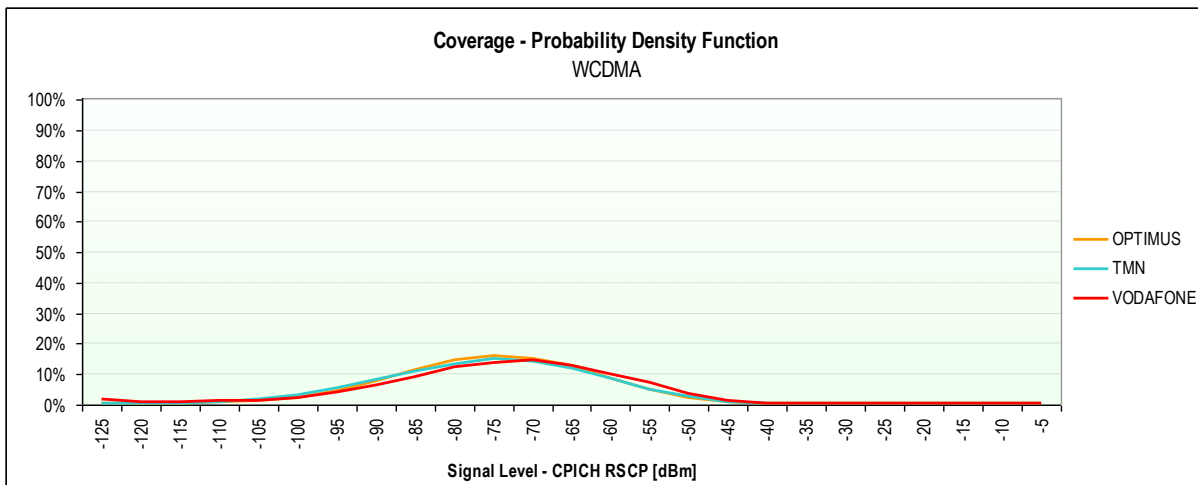
4.2 MAJOR ROADS

4.2.1 VOICE SERVICE (GSM)

		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Calls Made	Number of Calls	630	614	630	614	633	614
	Dropped on Set Up	2	7	0	8	6	7
	Dropped During Call	11	7	10	4	15	15
	With Normal Terminations	617	600	620	602	612	592
	Service Accessibility	99.7%	98.9%	100.0%	98.7%	99.1%	98.9%
	Call Termination Rate	98.2%	98.8%	98.4%	99.3%	97.6%	97.5%
Call Set Up	Number of Samples (Calls)	628	607	630	606	627	607
	Maximum Time [s]	5.0	6.2	4.8	5.8	4.1	5.9
	Average Time [s]	9.8	14.2	15.8	15.3	13.1	12.1
	Minimum Time [s]	3.9	5.0	3.7	4.4	3.7	4.5
	Standard Deviation [s]	0.6	0.9	0.8	0.9	0.5	0.9
Audio Quality	Number of Samples (Calls)	1,216	1,216	1,222	1,222	1,204	1,204
	Average [MOS]	3.86	3.95	3.89	3.93	3.79	3.83
	Maximum [MOS]	4.10	4.20	4.10	4.20	4.11	4.18
	Minimum [MOS]	2.56	1.96	2.17	2.47	2.12	1.33
	Standard Deviation [MOS]	0.19	0.21	0.19	0.24	0.17	0.21

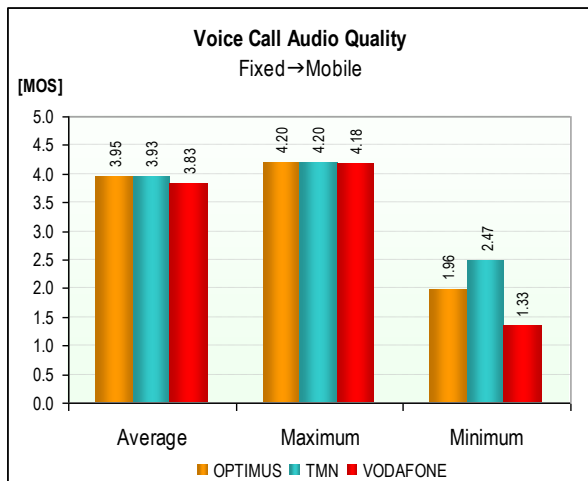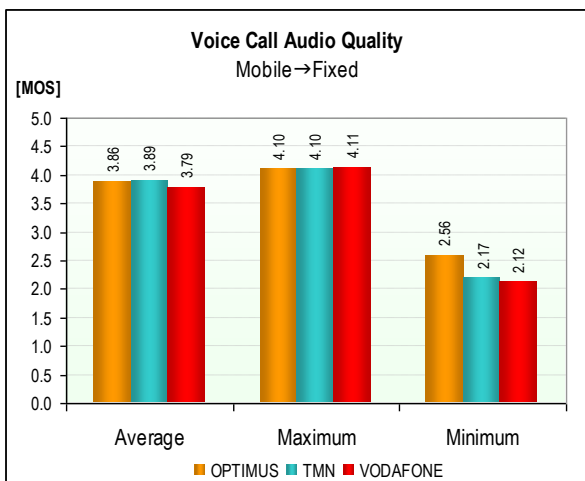|		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Precision Error	Service Accessibility	0.8%	1.2%	0.0%	1.2%	1.1%	1.2%
	Call Termination Rate	1.4%	1.2%	1.3%	1.0%	1.5%	1.6%
	Call Set Up Time [s]	0.047	0.068	0.061	0.070	0.039	0.070
	Audio Quality [MOS]	0.011	0.012	0.011	0.014	0.010	0.012

Confidence Level = 95 %

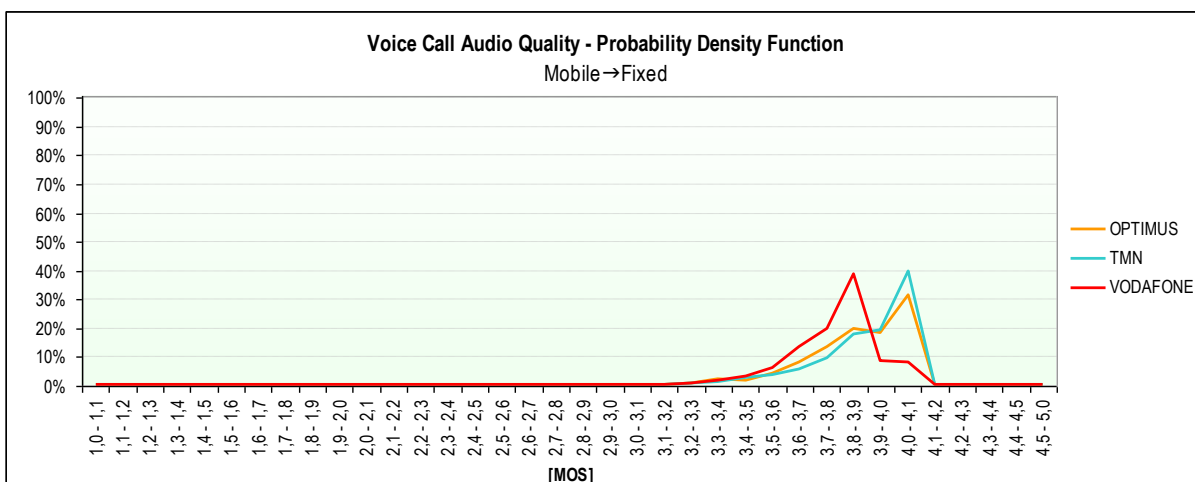### 4.2.1.1 SERVICE ACCESSIBILITY AND CALL TERMINATION RATE INDICATORS

4.2.1.2 CALL SET UP TIME INDICATOR

Call Set Up Time
Mobile→Fixed

[s]

	OPTIMUS	TMN	VODAFONE
Average	5.0	4.8	4.1
Maximum	9.8	15.8	13.1
Minimum	3.9	3.7	3.7

Call Set Up Time
Fixed→Mobile

[s]

	OPTIMUS	TMN	VODAFONE
Average	6.2	5.8	5.9
Maximum	14.2	15.3	12.1
Minimum	5.0	4.4	4.5

4.2.1.3 VOICE CALL AUDIO QUALITY INDICATOR

Voice Call Audio Quality
Mobile→Fixed

[MOS]

	OPTIMUS	TMN	VODAFONE
Average	3.86	3.89	3.79
Maximum	4.10	4.10	4.11
Minimum	2.56	2.17	2.12

Voice Call Audio Quality
Fixed→Mobile

[MOS]

	OPTIMUS	TMN	VODAFONE
Average	3.95	3.93	3.83
Maximum	4.20	4.20	4.18
Minimum	1.96	2.47	1.33

4.2.1.4 PROBABILITY DENSITY FUNCTION OF THE VOICE CALL AUDIO QUALITY

Voice Call Audio Quality - Probability Density Function
Mobile→Fixed

[MOS]

Voice Call Audio Quality - Probability Density Function
Fixed→Mobile

4.2.2 VIDEO-TELEPHONY SERVICE (UMTS)

		OPTIMUS	TMN	VODAFONE
		Mobile↔Mobile	Mobile↔Mobile	Mobile↔Mobile
Calls Made	Number of Calls	1,075	1,061	1,062
	Dropped on Set Up	138	84	211
	Dropped During Call	33	50	67
	With Normal Terminations	904	927	784
	Service Accessibility	87.2%	92.1%	80.1%
	Call Termination Rate	96.5%	94.9%	92.1%
Call Set Up	Number of Samples (Calls)	937	977	851
	Maximum Time [s]	7.0	7.6	5.6
	Average Time [s]	16.6	15.6	14.3
	Minimum Time [s]	5.7	5.4	4.3
	Standard Deviation [s]	1.3	1.5	1.2
Audio Quality	Number of Samples (Calls)	1,808	1,854	1,568
	Average [MOS]	3.95	3.94	3.97
	Maximum [MOS]	4.05	4.05	4.05
	Minimum [MOS]	1.02	1.08	1.33
	Standard Deviation [MOS]	0.20	0.25	0.16
Video Quality	Number of Samples (Calls)	1,808	1,848	1,568
	Average [MOS]	2.40	2.39	2.40
	Maximum [MOS]	2.76	2.86	2.71
	Minimum [MOS]	1.73	1.38	1.81
	Standard Deviation [MOS]	0.14	0.19	0.16

		OPTIMUS	TMN	VODAFONE
		Mobile↔Mobile	Mobile↔Mobile	Mobile↔Mobile
Precision Error	Service Accessibility	2.1%	1.8%	2.5%
	Call Termination Rate	1.4%	1.6%	2.0%
	Call Set Up Time [s]	0.085	0.091	0.081
	Audio Quality [MOS]	0.009	0.011	0.008
	Video Quality [MOS]	0.007	0.009	0.008

Confidence Level = 0.05

4.2.2.1   *SERVICE ACCESSIBILITY AND CALL TERMINATION RATE INDICATORS*
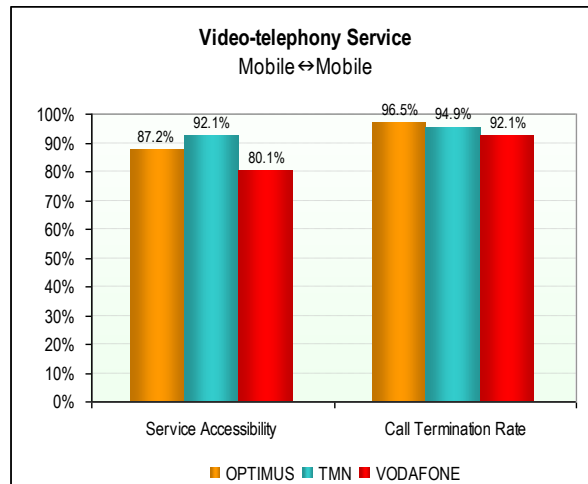
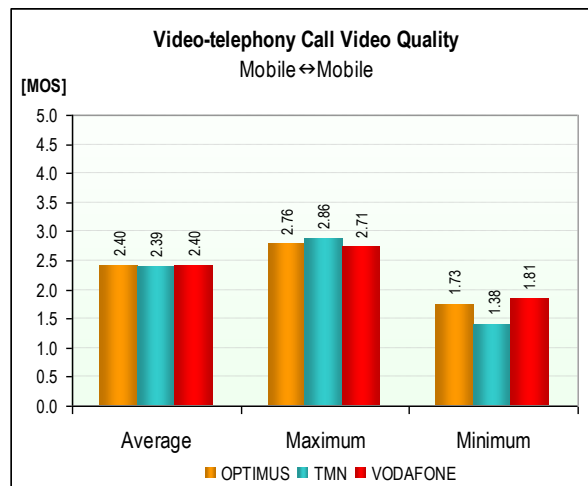**4.2.2.2**   *CALL SET UP TIME INDICATOR*
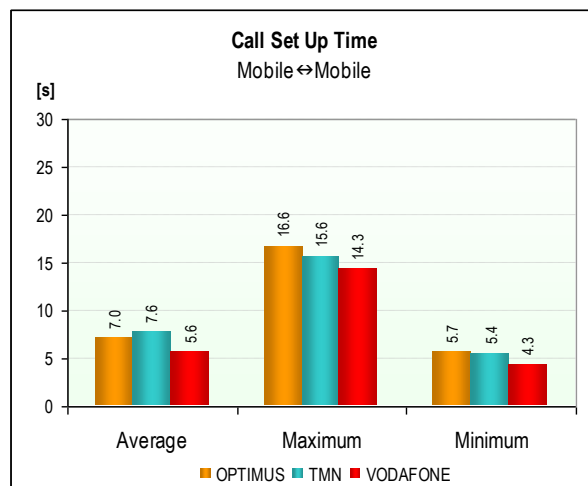
**4.2.2.3**   *VIDEO-TELEPHONY CALL AUDIO QUALITY INDICATOR*
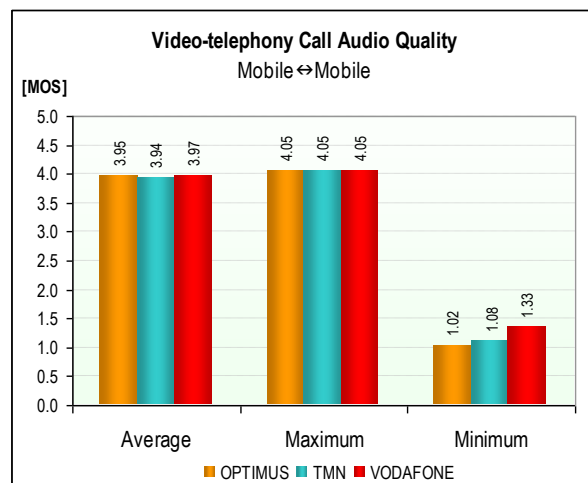
4.2.2.4   PROBABILITY DENSITY FUNCTION OF THE *VIDEO-TELEPHONY CALL AUDIO QUALITY* INDICATOR
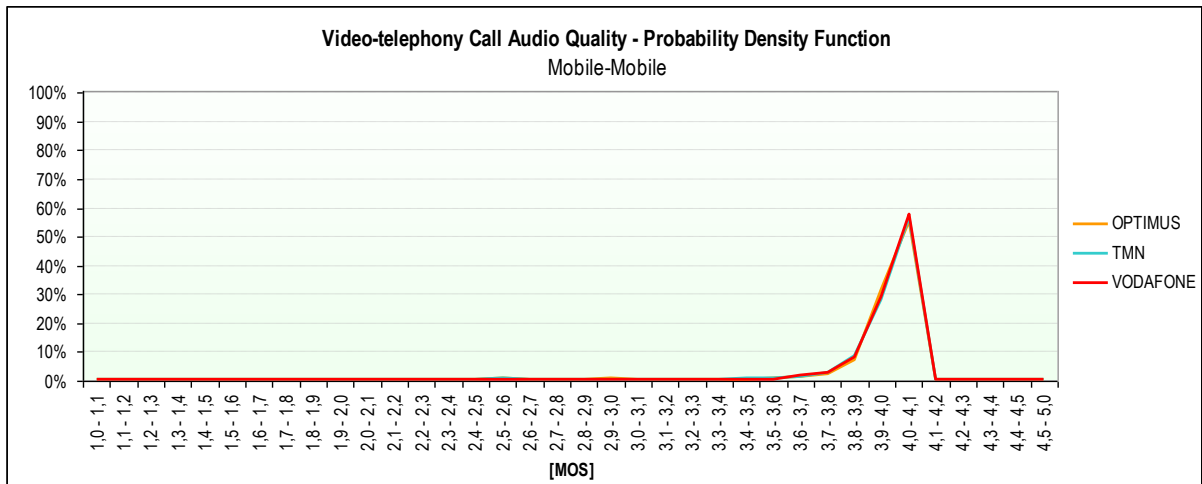
Video-telephony Call Audio Quality - Probability Density Function
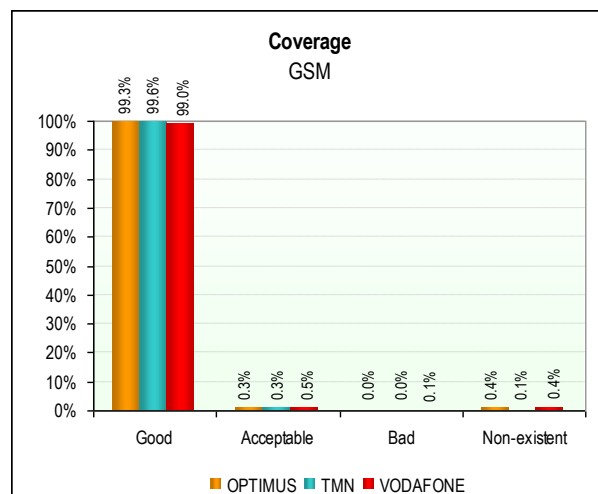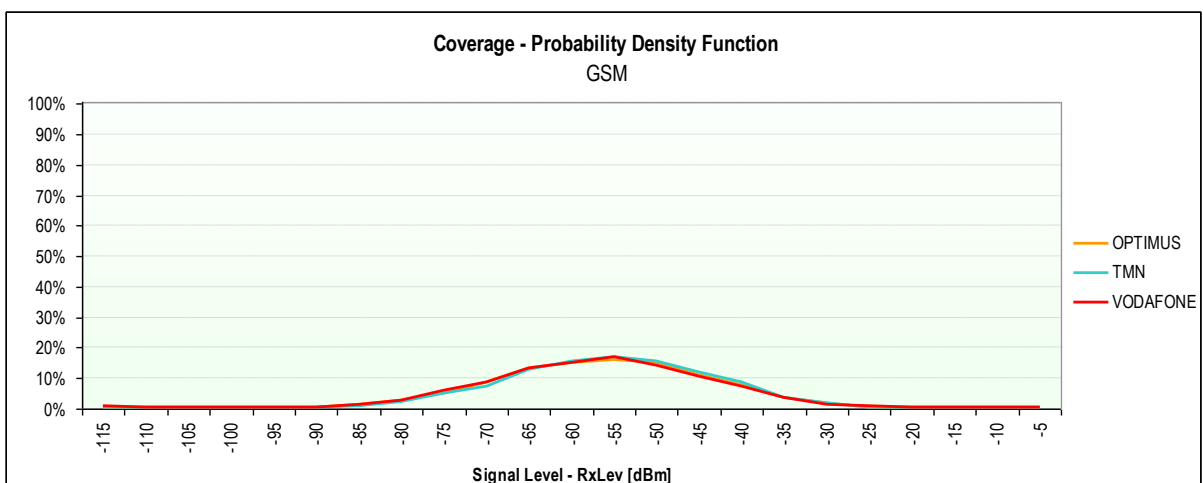Mobile-Mobile

4.2.2.5   VIDEO-TELEPHONY CALL VIDEO QUALITY INDICATOR

Video-telephony Call Video Quality
Mobile↔Mobile

4.2.2.6   PROBABILITY DENSITY FUNCTION OF THE *VIDEO-TELEPPHY CALL AUDIO QUALITY* INDICATOR

Video-telephony Call Audio Quality - Probability Density Function
Mobile-Mobile
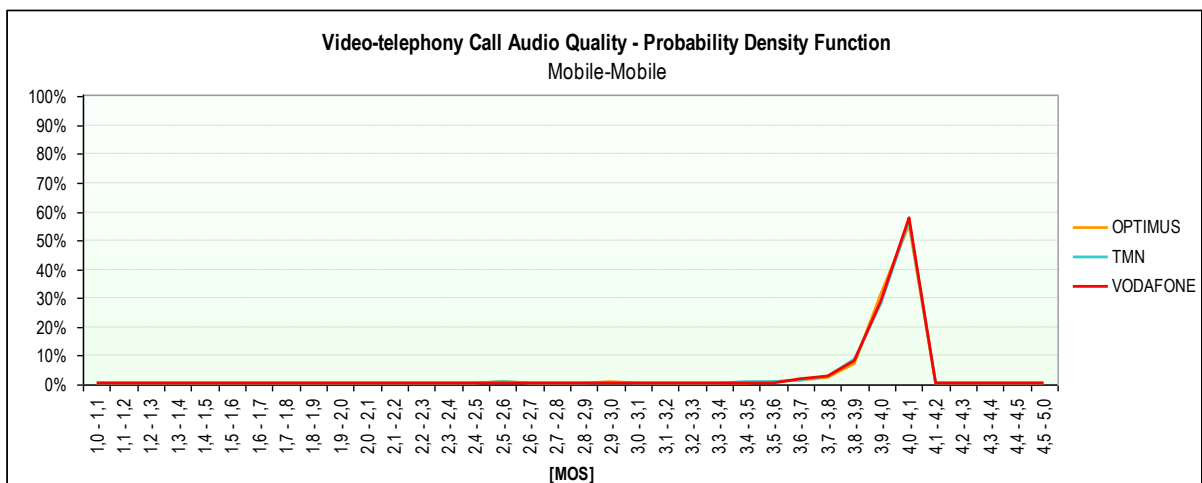
4.2.3 NETWORK COVERAGE

		GSM			WCDMA		
		OPTIMUS	TMN	VODAFONE	OPTIMUS	TMN	VODAFONE
Coverage	Number of Samples (Calls)	230,098	230,098	230,116	230,942	231,114	230,924
	Average [MOS]	-54	-53	-55	-78	-77	-81
	Maximum [MOS]	-21	-23	-17	-30	-34	-32
	Minimum [MOS]	-115	-115	-115	-140	-140	-141
	Standard Deviation [MOS]	12	12	13	14	15	19
	Good	99.3%	99.6%	99.0%	89.8%	88.1%	79.6%
	Acceptable	0.3%	0.3%	0.5%	6.9%	7.9%	8.9%
	Bad	0.0%	0.0%	0.1%	2.1%	2.4%	4.9%
	Non-existent	0.4%	0.1%	0.4%	1.2%	1.6%	6.6%

4.2.3.1 GSM

4.2.3.2 GSM – PROBABILITY DENSITY FUNCTION

4.2.3.3   WCDMA
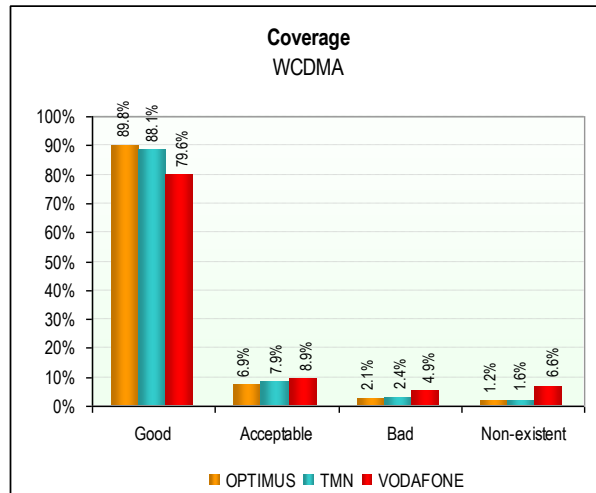
4.2.3.4   WCDMA – PROBABILITY DENSITY FUNCTION
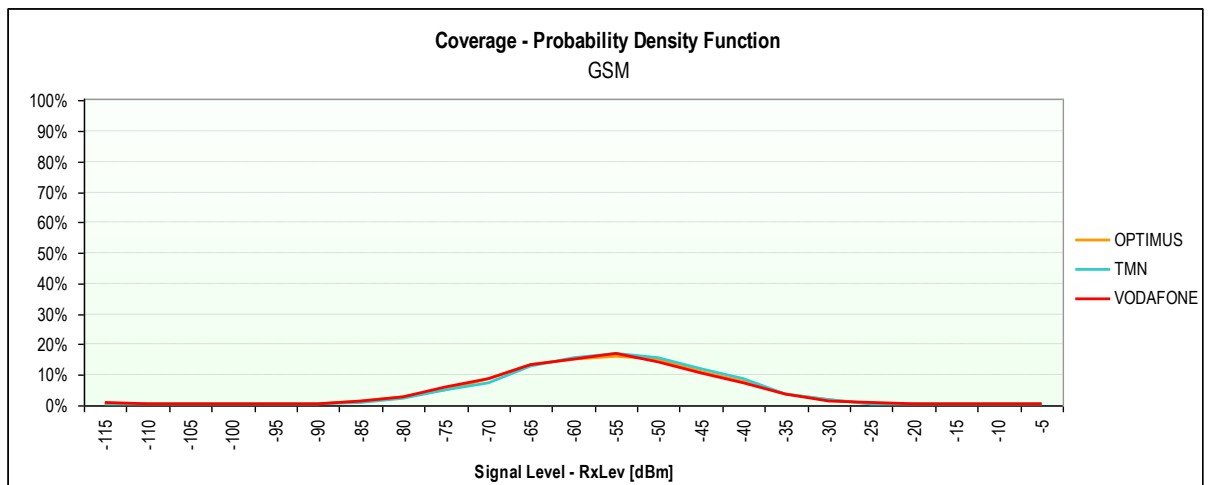
4.3 GLOBAL

4.3.1 VOICE SERVICE (GSM)

		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Calls Made	Number of Calls	2,153	2,100	2,150	2,098	2,153	2,097
	Dropped on Set Up	12	15	7	16	13	20
	Dropped During Call	17	17	22	18	23	28
	With Normal Terminations	2,124	2,068	2,121	2,064	2,117	2,049
	Service Accessibility	99.4%	99.3%	99.7%	99.2%	99.4%	99.0%
	Call Termination Rate	99.2%	99.2%	99.0%	99.1%	98.9%	98.7%
Call Set Up	Number of Samples (Calls)	2,141	2,085	2,143	2,082	2,140	2,077
	Maximum Time [s]	5.1	6.3	4.7	5.8	4.1	5.9
	Average Time [s]	10.4	16.1	15.8	15.3	17.2	13.6
	Minimum Time [s]	3.9	4.6	3.5	4.4	3.6	4.5
	Standard Deviation [s]	0.7	1.2	0.6	0.9	0.5	0.8
Audio Quality	Number of Samples (Calls)	4,190	4,190	4,184	4,181	4,165	4,165
	Average [MOS]	3.88	3.96	3.90	3.93	3.80	3.85
	Maximum [MOS]	4.11	4.21	4.10	4.20	4.11	4.19
	Minimum [MOS]	1.38	1.33	1.61	1.96	2.12	1.12
	Standard Deviation [MOS]	0.19	0.20	0.20	0.26	0.17	0.20

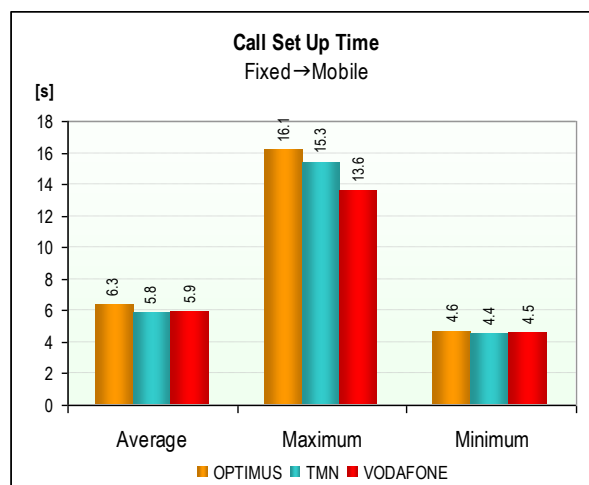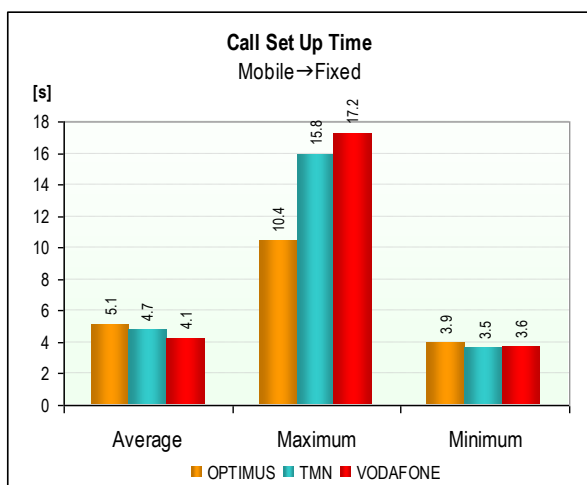|		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Precision Error	Service Accessibility	0.4%	0.5%	0.3%	0.5%	0.4%	0.5%
	Call Termination Rate	0.5%	0.5%	0.5%	0.5%	0.5%	0.6%
	Call Set Up Time [s]	0.031	0.050	0.024	0.038	0.023	0.036
	Audio Quality [MOS]	0.006	0.006	0.006	0.008	0.005	0.006

Confidence Level = 95 %

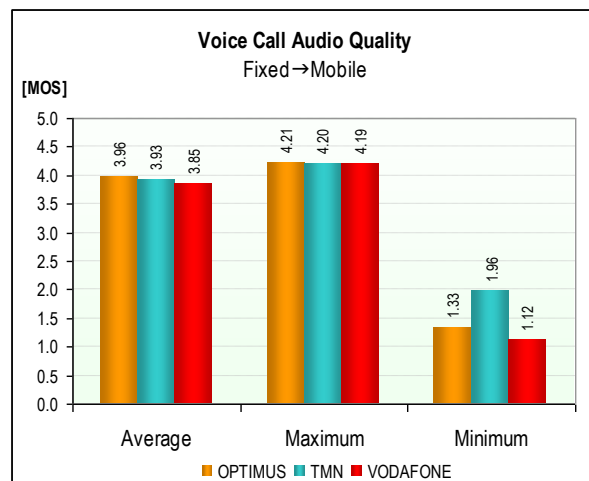#### 4.3.1.1 *SERVICE ACCESSIBILITY AND CALL TERMINATION RATE INDICATORS*
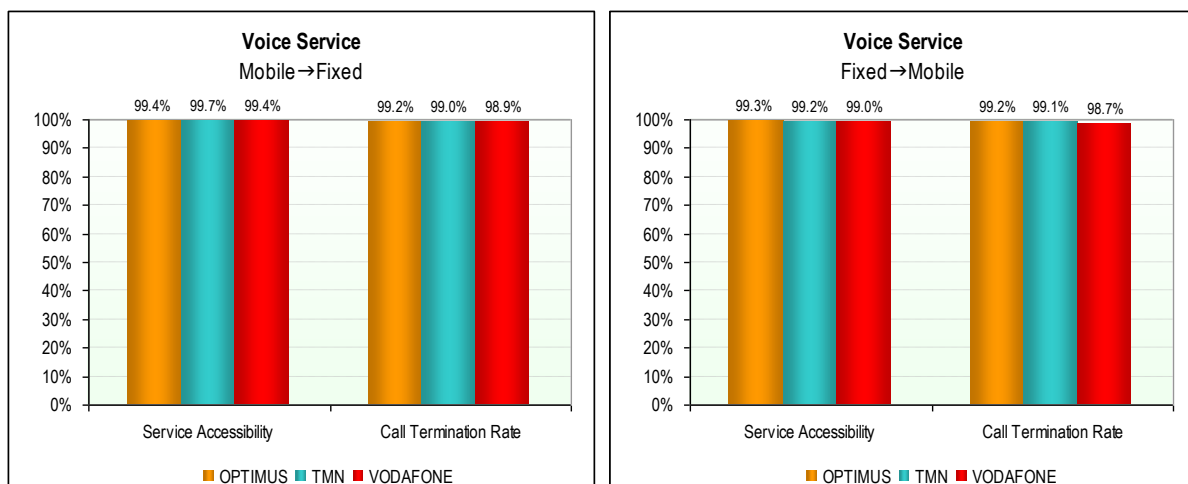
4.3.1.2 CALL SET UP TIME INDICATOR
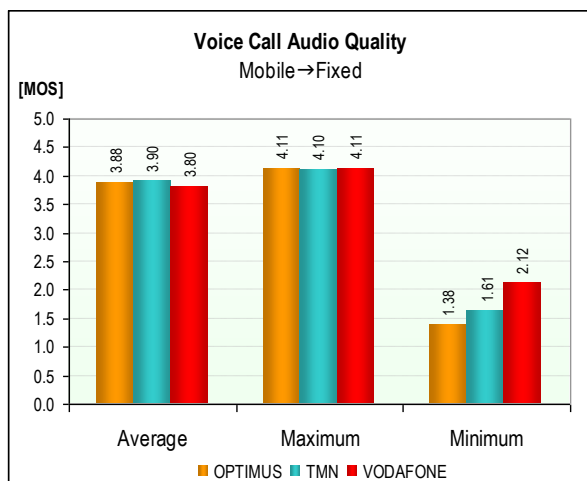
**Call Set Up Time**
Mobile→Fixed

Call Set Up Time
Fixed→Mobile

OPTIMUS TMN VODAFONE

4.3.1.3 VOICE CALL AUDIO QUALITY INDICATOR

Voice Call Audio Quality
Mobile→Fixed

Voice Call Audio Quality
Fixed→Mobile

OPTIMUS TMN VODAFONE

4.3.1.4 PROBABILITY DENSITY FUNCTION OF THE VOICE CALL AUDIO QUALITY INDICATOR

Voice Call Audio Quality - Probability Density Fucntion
Mobile→Fixed

OPTIMUS TMN VODAFONE

Voice Call Audio Quality - Probability Density Fucntion
Fixed→Mobile
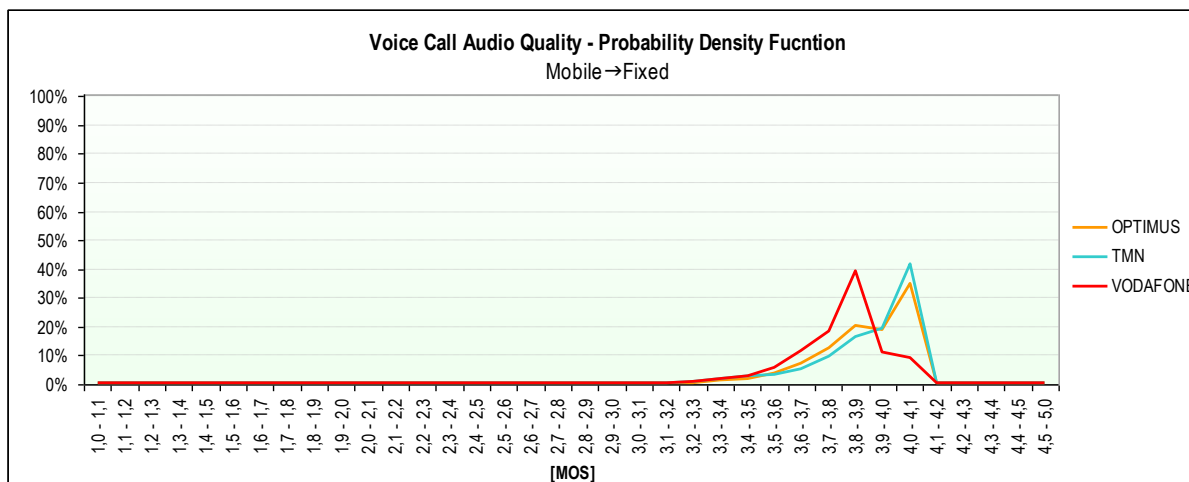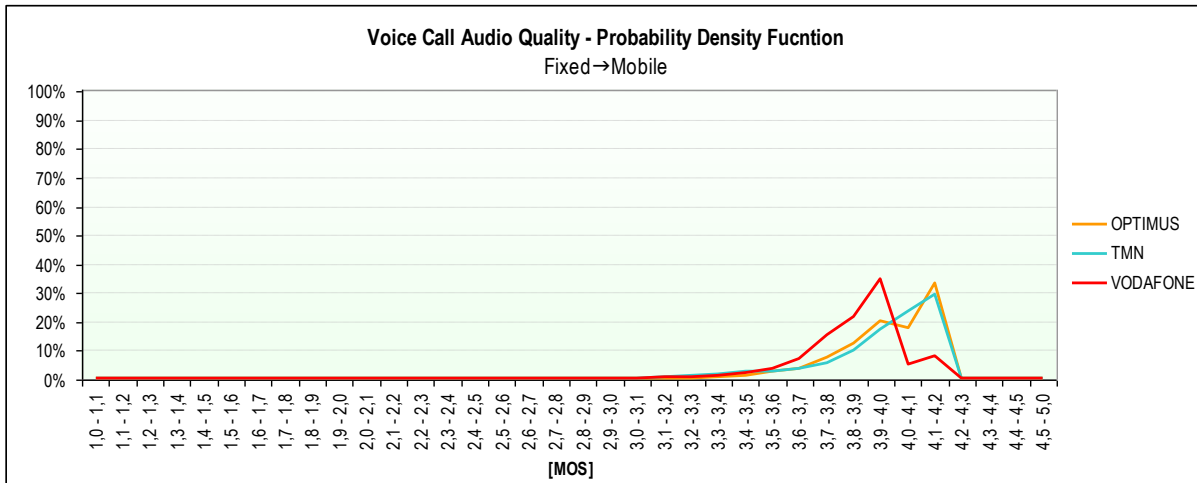
4.3.2 VIDEO-TELEPHONY SERVICE (UMTS)

		OPTIMUS	TMN	VODAFONE
		Mobile↔Mobile	Mobile↔Mobile	Mobile↔Mobile
Calls Made	Number of Calls	3,657	3,635	3,645
	Dropped on Set Up	254	184	281
	Dropped During Call	66	88	111
	With Normal Terminations	3,337	3,363	3,253
	Service Accessibility	93.1%	94.9%	92.3%
	Call Termination Rate	98.1%	97.5%	96.7%
Call Set Up	Number of Samples (Calls)	3,403	3,451	3,364
	Maximum Time [s]	7.0	7.5	5.5
	Average Time [s]	18.2	26.2	15.4
	Minimum Time [s]	5.5	5.1	4.1
	Standard Deviation [s]	1.2	1.5	1.1
Audio Quality	Number of Samples (Calls)	6,673	6,726	6,506
	Average [MOS]	3.97	3.94	3.98
	Maximum [MOS]	4.05	4.05	4.05
	Minimum [MOS]	1.02	1.00	1.00
	Standard Deviation [MOS]	0.16	0.25	0.14
Video Quality	Number of Samples (Calls)	6,674	6,705	6,506
	Average [MOS]	2.39	2.37	2.41
	Maximum [MOS]	2.79	2.86	2.79
	Minimum [MOS]	1.54	1.21	1.73
	Standard Deviation [MOS]	0.14	0.20	0.16

		OPTIMUS	TMN	VODAFONE
		Mobile↔Mobile	Mobile↔Mobile	Mobile↔Mobile
Precision Error	Service Accessibility	0.9%	0.8%	0.9%
	Call Termination Rate	0.5%	0.6%	0.7%
	Call Set Up Time [s]	0.041	0.049	0.038
	Audio Quality [MOS]	0.004	0.006	0.003
	Video Quality [MOS]	0.003	0.005	0.004

Confidence Level = 0.05

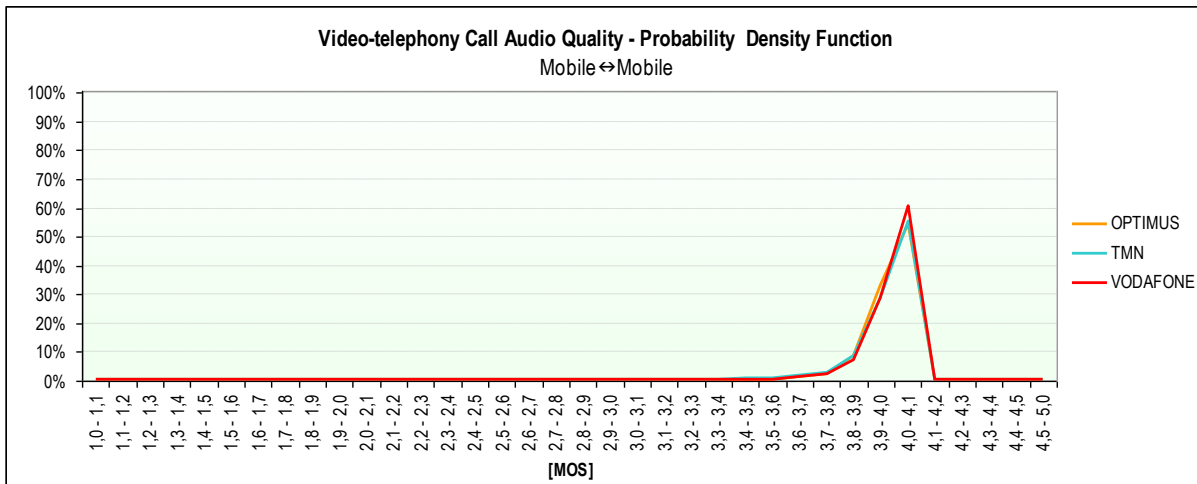**4.3.2.1** *SERVICE ACCESSIBILITY AND CALL TERMINATION RATE INDICATORS*

Video-telephony Service
Mobile↔Mobile

Service Accessibility: OPTIMUS 93.1%, TMN 94.9%, VODAFONE 92.3%
Call Termination Rate: OPTIMUS 98.1%, TMN 97.5%, VODAFONE 96.7%

■ OPTIMUS ■ TMN ■ VODAFONE

4.3.2.2 *CALL SET UP TIME INDICATOR*

Call Set Up Time
Mobile↔Mobile
[s]

Average: OPTIMUS 7.0, TMN 7.5, VODAFONE 5.5
Maximum: OPTIMUS 18.2, TMN 26.2, VODAFONE 15.4
Minimum: OPTIMUS 5.5, TMN 5.1, VODAFONE 4.1

■ OPTIMUS ■ TMN ■ VODAFONE

4.3.2.3 *VIDEO-TELEPHONY CALL AUDIO QUALITY INDICATOR*

Video-telephony Call Audio Quality
Mobile↔Mobile
[MOS]

Average: OPTIMUS 3.97, TMN 3.94, VODAFONE 3.98
Maximum: OPTIMUS 4.05, TMN 4.05, VODAFONE 4.05
Minimum: OPTIMUS 1.02, TMN 1.00, VODAFONE 1.00

■ OPTIMUS ■ TMN ■ VODAFONE

4.3.2.4 PROBABILITY DENSITY FUNCTION OF THE *VIDEO-TELEPHONY CALL AUDIO QUALITY*

4.3.2.5 *VIDEO-TELEPHONY CALL VIDEO QUALITY* INDICATOR
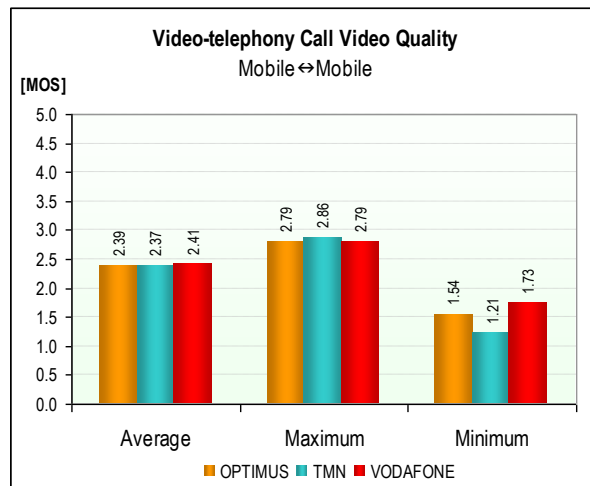
4.3.2.6 PROBABILITY DENSITY FUNCTION OF THE *VIDEO-TELEPHONY CALL VIDEO QUALITY* INDICATOR
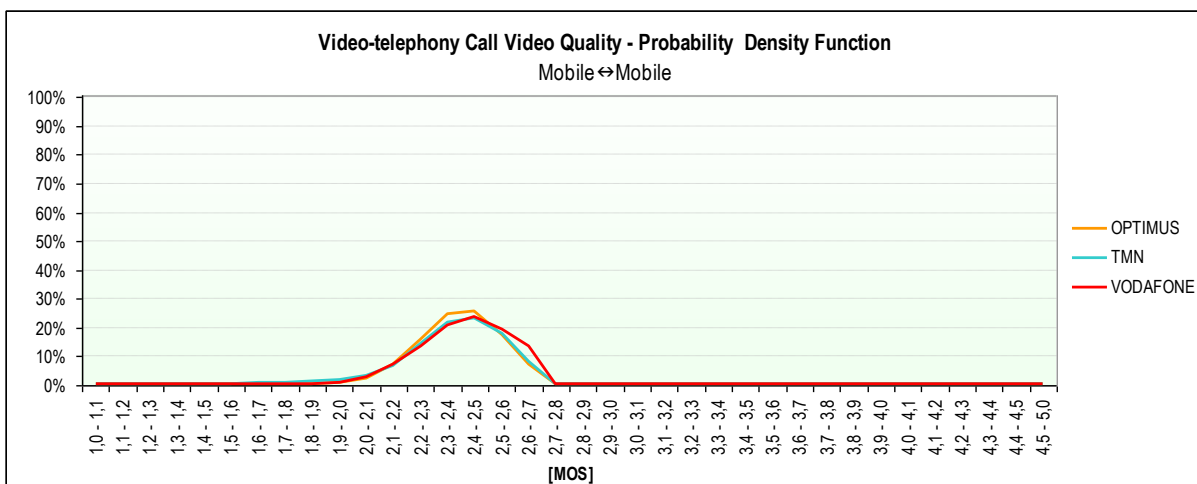
4.3.3 NETWORK COVERAGE

		GSM			WCDMA		
		OPTIMUS	**TMN**	**VODAFONE**	**OPTIMUS**	**TMN**	**VODAFONE**
Coverage	Number of Samples (Calls)	783,142	782,874	783,142	786,390	786,714	786,348
	Average [MOS]	-52	-51	-52	-73	-74	-72
	Maximum [MOS]	-20	-14	-11	-30	-24	-29
	Minimum [MOS]	-115	-115	-115	-140	-140	-141
	Standard Deviation [MOS]	11	11	12	13	14	15
	Good	99.6%	99.7%	99.5%	96.0%	94.2%	93.0%
	Acceptable	0.1%	0.1%	0.1%	2.9%	4.3%	3.5%
	Bad	0.0%	0.0%	0.0%	0.7%	1.0%	1.5%
	Non-existent	0.3%	0.2%	0.4%	0.4%	0.5%	2.0%

4.3.3.1 GSM
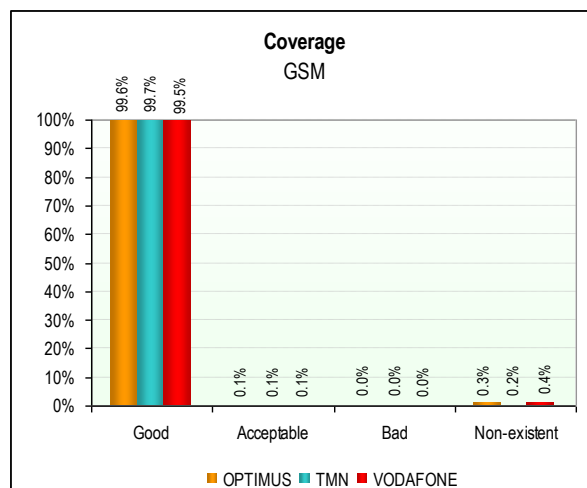
4.3.3.2 GSM – PROBABILITY DENSITY FUNCTION
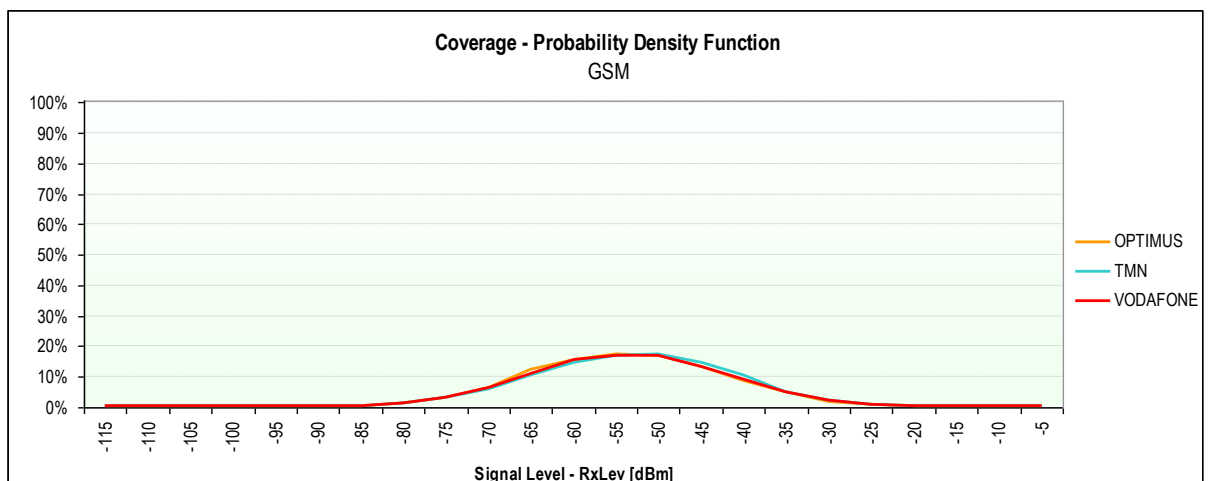
4.3.3.3   WCDMA
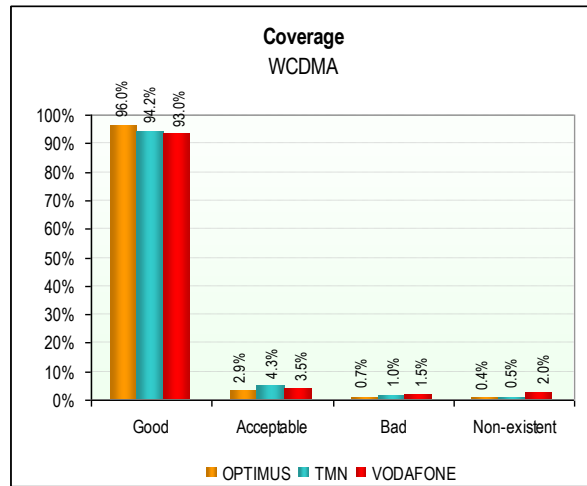
4.3.3.4   WCDMA – PROBABILITY DENSITY FUNCTION
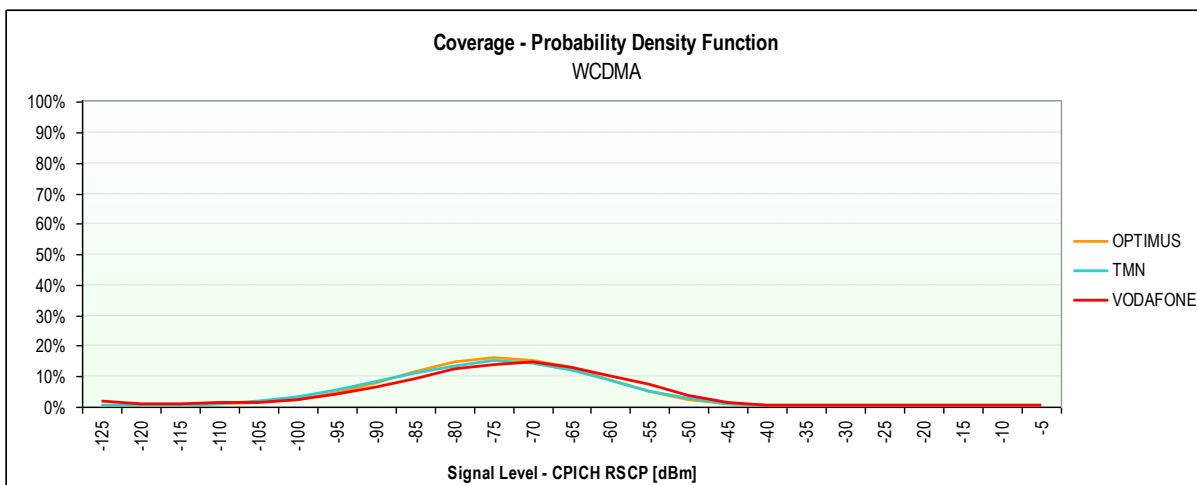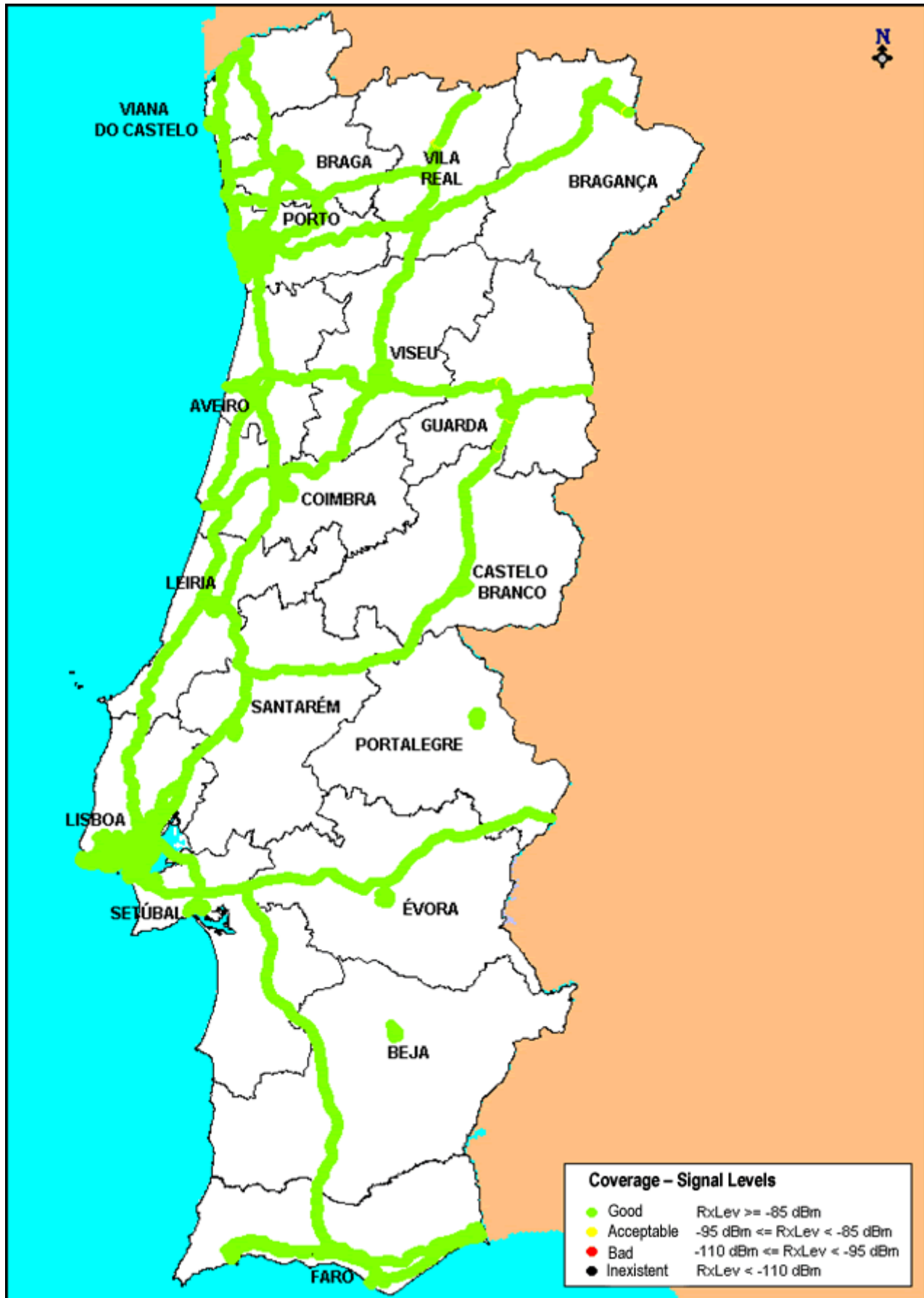

4.3.3.4.1   COVERAGE MAPS

(Following pages)

OPTIMUS – GSM Coverage

Coverage – Signal Levels

● Good	RxLev >= -85 dBm
● Acceptable	-95 dBm <= RxLev < -85 dBm
● Bad	-110 dBm <= RxLev < -95 dBm
● Inexistent	RxLev < -110 dBm
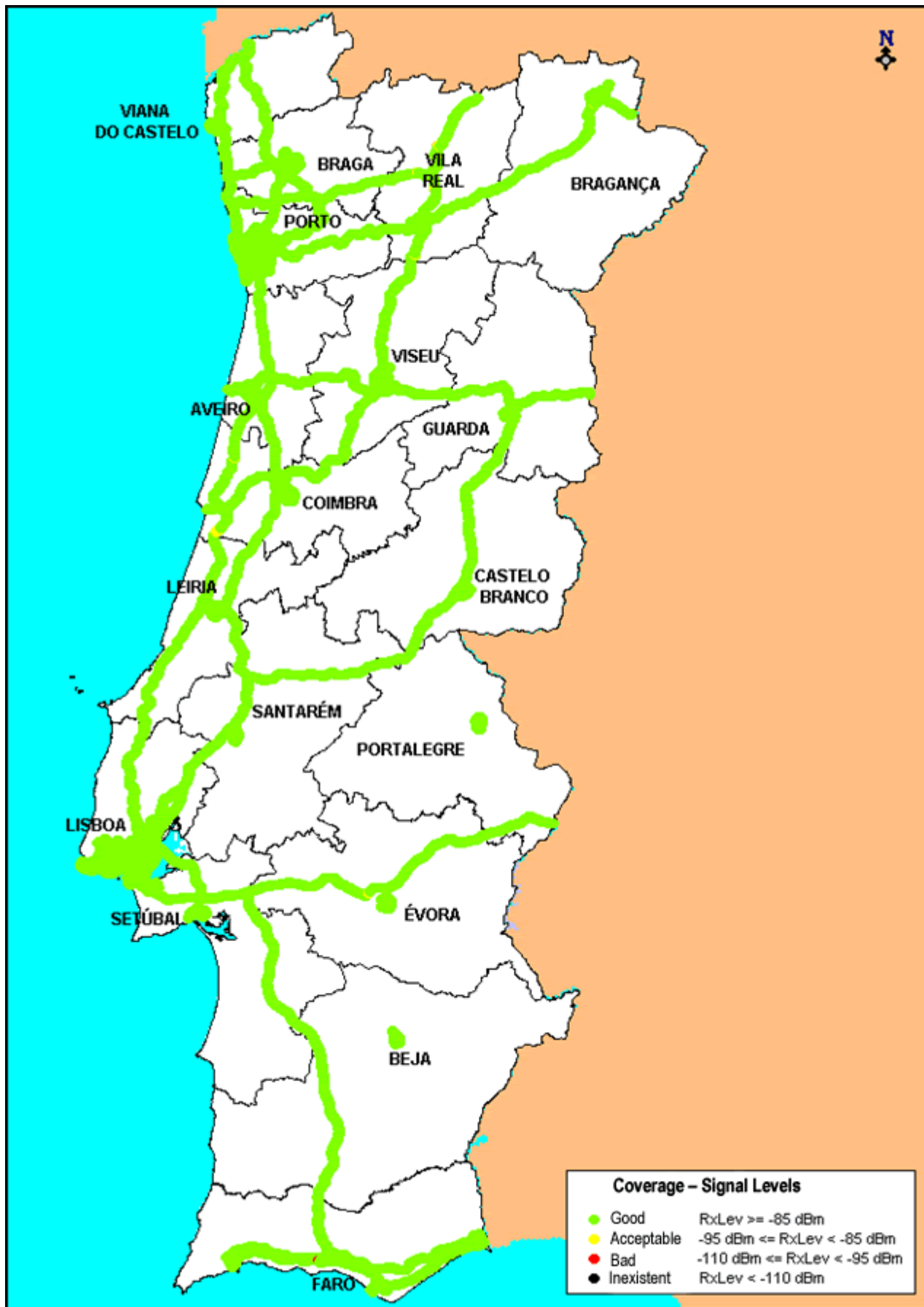
TMN – GSM Coverage

VODAFONE – GSM Coverage

Coverage – Signal Levels

Good	RxLev >= -85 dBm
Acceptable	-95 dBm <= RxLev < -85 dBm
Bad	-110 dBm <= RxLev < -95 dBm
Inexistent	RxLev < -110 dBm
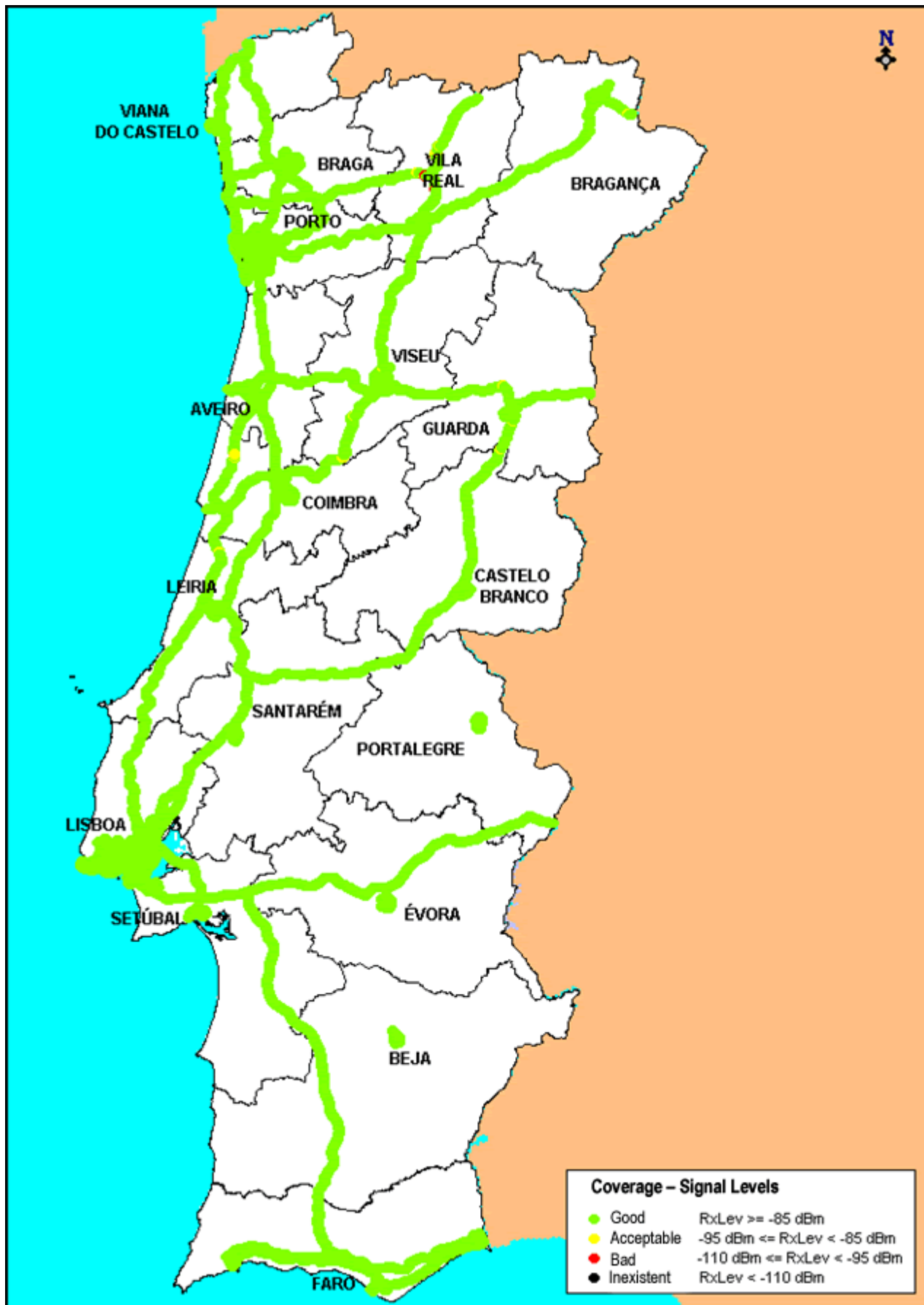
OPTIMUS – WCDMA Coverage

TMN – WCDMA Coverage

Coverage – Signal Levels

Good	CPICH RSCP >= -95 dBm
Acceptable	-105 dBm <= CPICH RSCP < -95 dBm
Bad	-115 dBm <= CPICH RSCP < -105 dBm .
Inexistent	CPICH RSCP < -115 dBm
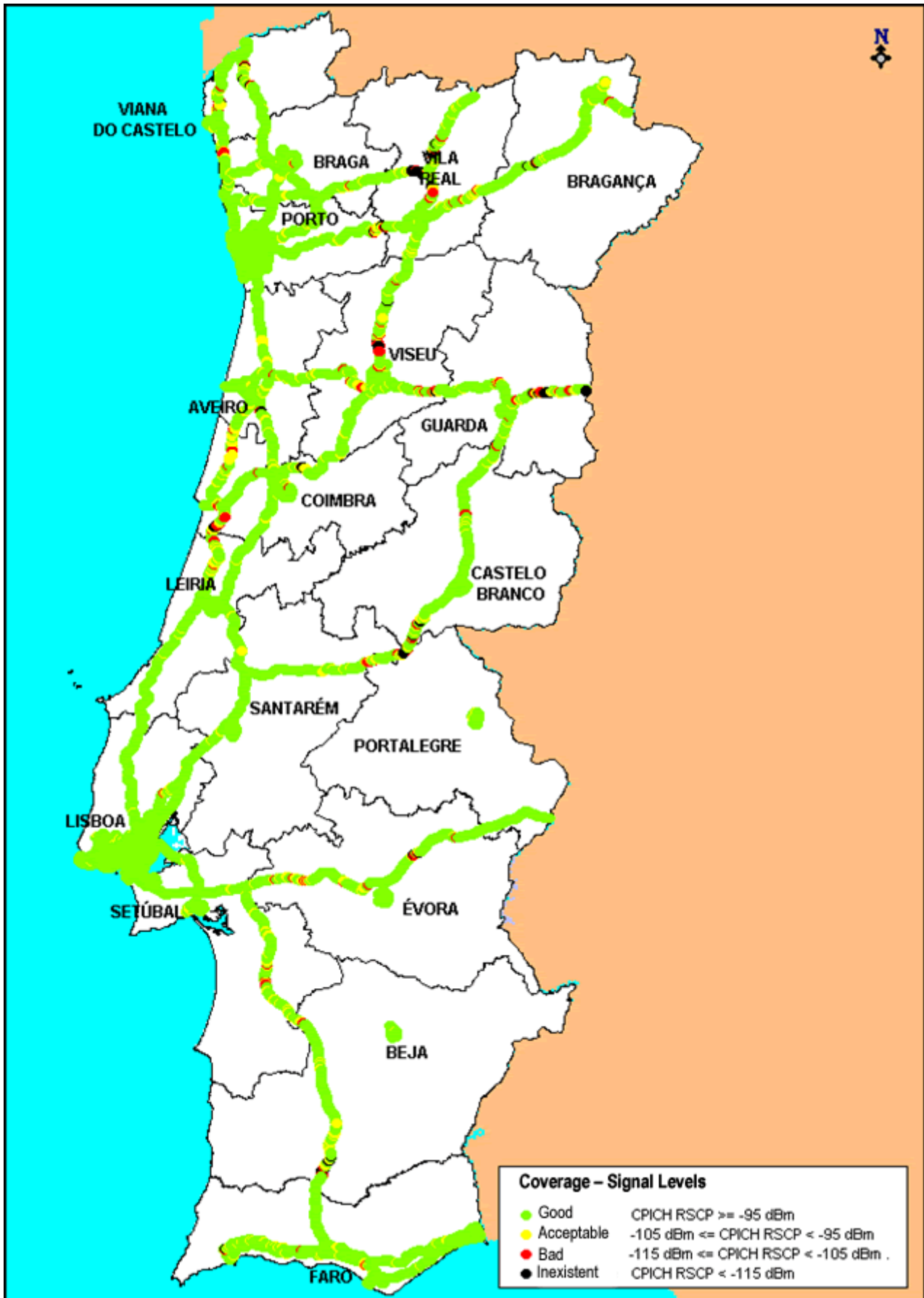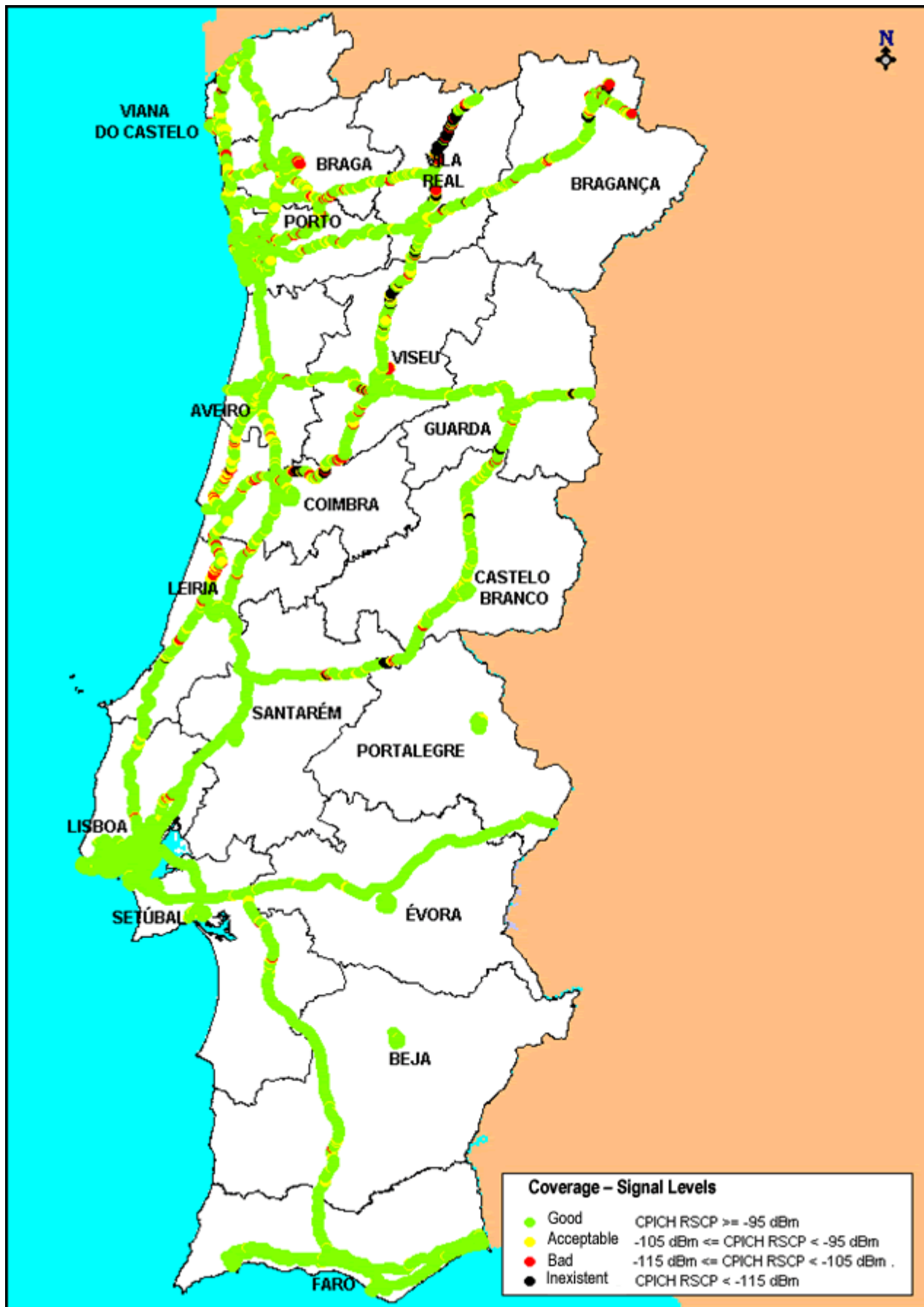
VODAFONE – WCDMA Coverage
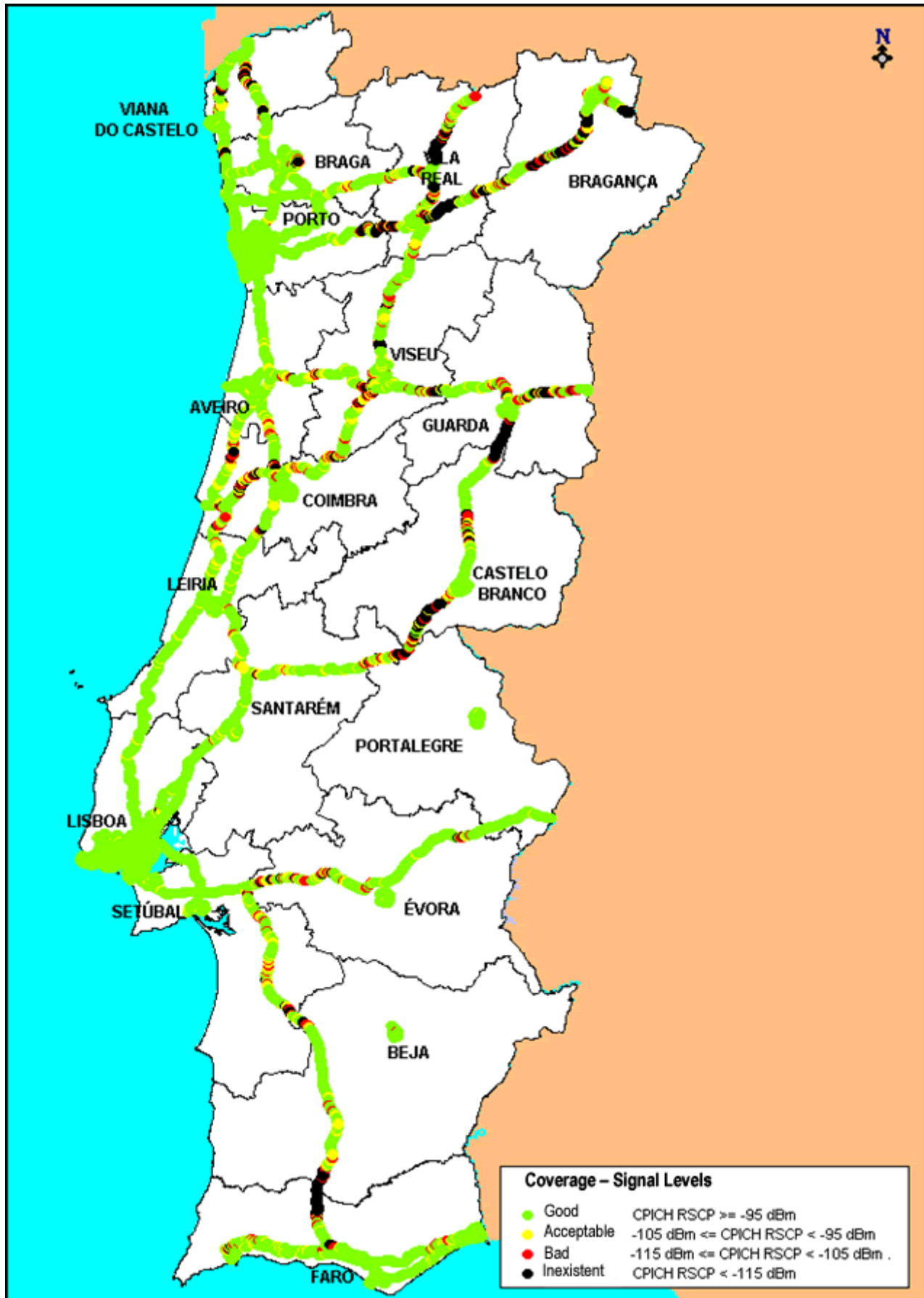
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