ANACOM AUTORIDADE NACIONAL DE COMUNICAÇÕES

Mobile Communications Systems

GSM/UMTS

Quality of Service Assessment

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

November 2009

ABBREVIATIONS AND 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 – European Telecommunications Standards Institute.

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

ITU International Telecommunications Union – ITU International Telecommunications Union.

MOS Mean Opinion Score – Quality rate quantifying the effort to understand an end-to-end type conversation. Its limits are 0 (zero) when there is no communication and 5 (five) when the communication is perfect. The value "zero" never shows in the results since only situations where the connection was established and maintained for a given period are considered. "Five" never shows in the results either, because the CoDec7 used by mobile networks, renders impossible such high voice or video quality values (the voice or video quality reached with the CoDec usually used gives 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 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.

Contents

I EXECUTIVE SUMMARY

I.I GENERAL FRAMEWORK

In September and October 2009 the Autoridade Nacional de Comunicações (ANACOM) carried out an assessment of the quality of mobile services – voice, video-telephony and GSM and WCDMA (UMTS) network coverage – 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 for the three operators, i.e. at the same time, in the same locations and with the same parameters, thus making it possible to perform a 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 of a call, once successfully set up, being maintained for 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.

Data collection took place on working days and during normal working hours, from September 14 to October 20, 2009. 23,971 test calls were made and 4,731,307 radio signal level measurements were taken, amounting to approximately 218 hours of measurements over 9,916 kilometres.

The used sample provided global results for each operator, with a maximum error below 1.7% in urban

agglomerations, and below 3% on major roads, for a 95% confidence level.

In view of these services' penetration rate and 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 be understood as an indicator of the networks' global behaviour, since it does not intend to evaluate the compliance with 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 drawn.

The technical and methodological options of this study directly influenced its results and must be taken into account when analysing the results, as follows:

- Tests were exclusively based on a technical solution (hardware + software) and performed totally automatically, thereby setting a level playing field for the monitoring of the three operators and eliminating the subjectivity inherent to the human user;
- It used NOKIA N95 and NOKIA 6680 terminal equipment;
- Tests were carried out in moving vehicles and with outdoor antennas (without gain);
- Call duration, for both voice and video-telephony, was 120 seconds;
- Voice and video-telephony tests were made with automatic selection of the 2G (GSM) or 3G (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 in the locations and at the time the measurements were taken;
- On the other hand, operators are constantly improving their networks. The technical interventions necessary for these improvements can cause momentary degradation 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 have good coverage levels and a good performance for the voice service, both in urban agglomerations and on major roads.

The video-telephony service maintains its positive evolution trend. Mobile communications systems exhibit good performance in urban agglomerations, with the capacity of establishing and maintaining video-telephony calls recording levels close to those for the voice service. But the video-telephony service still does not perform adequately on major roads, as a direct consequence of the areas with poor or even non-existent WCDMA coverage.

GSM and WCDMA Network Coverage

The mobile communication systems studied have good GSM coverage levels, both in urban agglomerations and major agglomerations and major roads, with no significant differences between operators (Figure 1 – *Coverage* Indicator in the Urban Agglomerations of Mainland Portugal.

and Figure 2 – *Coverage* Indicator on the Major Roads of Mainland Portugal.

). The coverage levels already recorded in the study conducted in October/November 2008 are maintained (Figure 1 – *Coverage* Indicator in the Urban Agglomerations of Mainland Portugal.

and Figure 2 – *Coverage* Indicator on the Major Roads of Mainland Portugal.

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WCDAM (UMTS) networks have better coverage levels in urban areas than on major roads (Figure 1 – *Coverage* Indicator in the Urban Agglomerations of Mainland Portugal.

and Figure 2 – *Coverage* Indicator on the Major Roads of Mainland Portugal.

). Comparing with results from the study carried out in October/November 2008, there is a degradation in the good coverage levels, particularly on major roads and for OPTIMUS and VODAFONE (Figure 1 – *Coverage* Indicator in the Urban Agglomerations of Mainland Portugal.

and Figure 2 – *Coverage* Indicator on the Major Roads of Mainland Portugal.

).). In urban agglomerations OPTIMUS exhibits the best performance, with 96.2% of measurements

presenting good coverage levels, while VODAFONE performs worst, with 92.9%. On major roads, WCDMA coverage has lower levels, with some areas still having bad or even non-existent coverage, and significant differences were noted between operators. TMN has the best performance, with 86.9% of measurements showing good coverage levels, while the figure for OPTIMUS is 81.7% and for VODAFONE it is 69.6%.

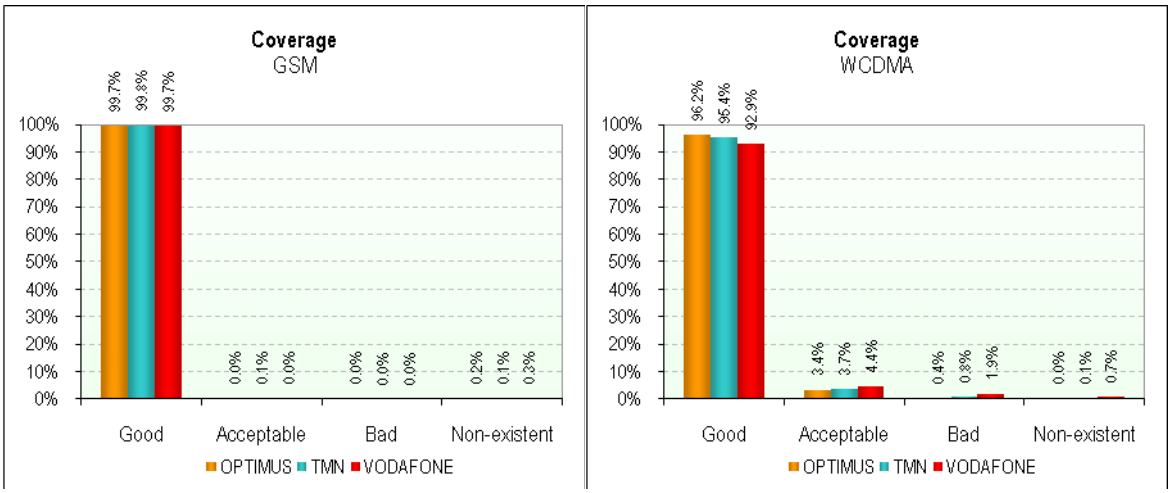

Figure 1 – *Coverage* Indicator in the Urban Agglomerations of Mainland Portugal.

Table 1 – Evolution of the *Coverage* Indicator, from 2008 to 2009, in the Urban Agglomerations of Mainland Portugal.
(Difference between figures from the 2009 study and figures from the 2008 study)

		GSM			WCDMA		
		OPTIMUS	TMN	VODAFONE	OPTIMUS	TMN	VODAFONE
Radio coverage	Good	0.03%	-0.01%	0.02%	-2.33%	-1.25%	-5.67%
	Acceptable	0.02%	0.07%	0.05%	2.13%	0.88%	3.23%
	Bad	0.00%	0.00%	0.00%	0.26%	0.35%	1.75%
	Non-existent	-0.05%	-0.06%	-0.07%	-0.05%	0.02%	0.69%

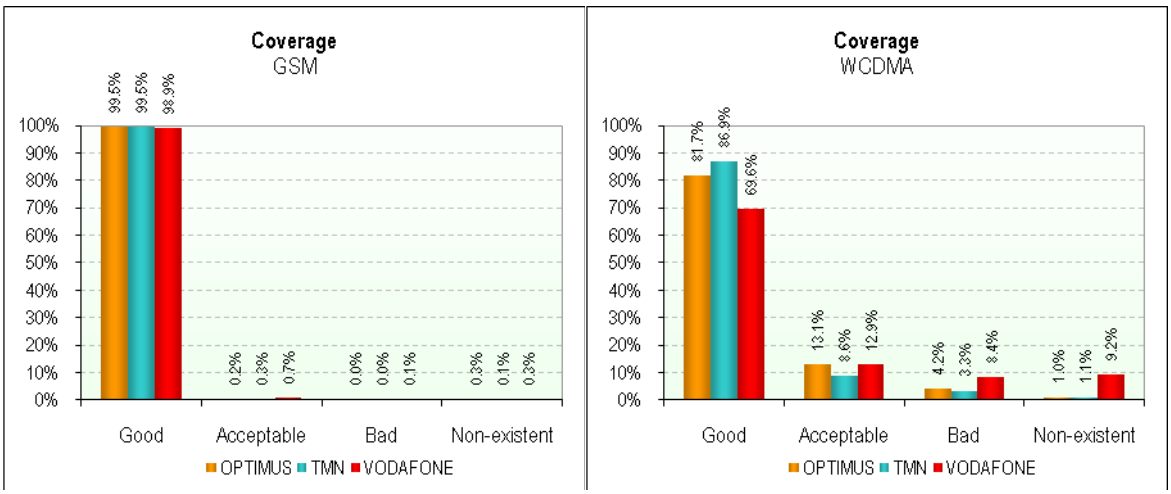

Figure 2 – *Coverage* Indicator on the Major Roads of Mainland Portugal.

Table 2 – Evolution of the *Coverage* Indicator, from 2008 to 2009, on the Major Roads of Mainland Portugal.
(Difference between figures from the 2009 study and figures from the 2008 study)

		GSM			WCDMA		
		OPTIMUS	TMN	VODAFONE	OPTIMUS	TMN	VODAFONE
Radio coverage	Good	0.20%	-0.03%	-0.10%	-8.05%	-1.20%	-10.01%
	Acceptable	-0.08%	0.02%	0.18%	6.23%	0.77%	3.97%
	Bad	-0.01%	0.01%	0.02%	2.09%	0.91%	3.49%
	Non-existent	-0.11%	0.01%	-0.10%	-0.27%	-0.48%	2.55%

Voice Service

The voice service has good results in all analysed indicators, both in urban roads (Figure 3 – *Service Accessibility* and *Call Termination Rate* Indicators in the Urban Agglomerations of Mainland Portugal.

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

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

, Figure 6 – *Call Set Up Time* Indicator on the Major Roads of Mainland Portugal.

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

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

). Comparing the results obtained in this study with those recorded in the study carried out in October/November 2008, no major changes are observed, except for the *Call Termination Rate* indicator of operators OPTIMUS and TMN on major roads, which show a slight degradation (Figure 3 – *Service Accessibility* and *Call Termination Rate* Indicators in the Urban Agglomerations of Mainland Portugal.

and Table 4 – Evolution of the *Service Accessibility, Call Termination Rate, Average Call Set Up Time and Average Audio Quality* Indicators, from 2008 to 2009, on the Major Roads of Mainland Portugal.

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Differences between operators are not relevant in urban agglomerations, but are more significant on major roads, particularly for the *Service Accessibility* and *Call Termination Rate* indicators.

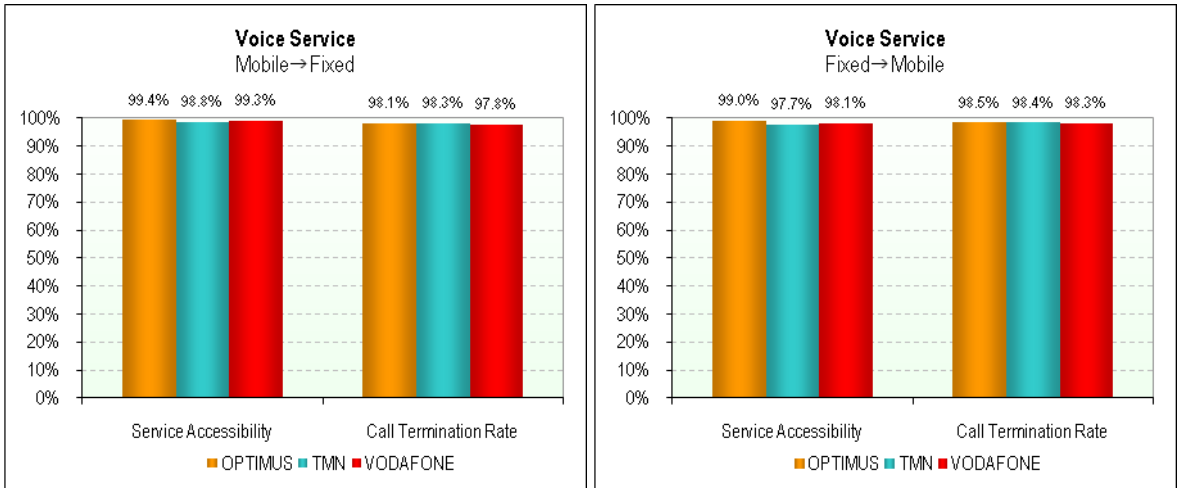

Figure 3 – *Service Accessibility* and *Call Termination Rate* Indicators in the Urban Agglomerations of Mainland Portugal.

Table 3 – Evolution of the *Service Accessibility, Call Termination Rate, Average Call Set Up Time* and *Average Audio Quality* Indicators, from 2008 to 2009, in the Urban Agglomerations of Mainland Portugal.
(Difference between figures from the 2009 study and figures from the 2008 study)

		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Voice Service	Service Accessibility	0.07%	-0.46%	-0.72%	-1.73%	-0.26%	-0.99%
	Call Termination Rate	-1.50%	-0.87%	-0.86%	-0.62%	-1.71%	-0.82%
	Average Call Set Up Time[s]	-0.69	-0.98	0.11	-0.23	-0.60	-0.93
	Average Audio Quality [MOS]	0.027	-0.019	0.032	-0.023	0.171	0.009

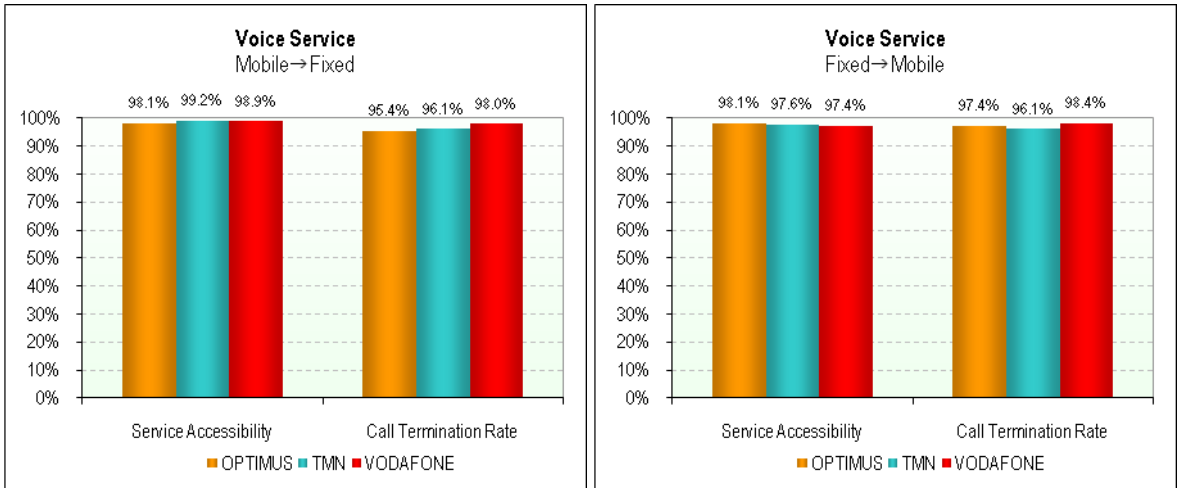

Figure 4 – *Service Accessibility* and *Call Termination Rate* Indicators, on the Major Roads of Mainland Portugal.

Table 4 – Evolution of the *Service Accessibility, Call Termination Rate, Average Call Set Up Time and Average Audio Quality* Indicators, from 2008 to 2009, on the Major Roads of Mainland Portugal.
(Difference between figures from the 2009 study and figures from the 2008 study)

		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Voice Service	Service Accessibility	-1.53%	-0.77%	-0.77%	-1.08%	-0.13%	-1.41%
	Call Termination Rate	-2.81%	-1.44%	-2.30%	-3.25%	0.36%	0.83%
	Average Call Set Up Time[s]	-0.34	-0.50	0.06	-0.17	-0.40	-0.63
	Average Audio Quality [MOS]	0.016	-0.001	0.016	0.017	0.107	0.048

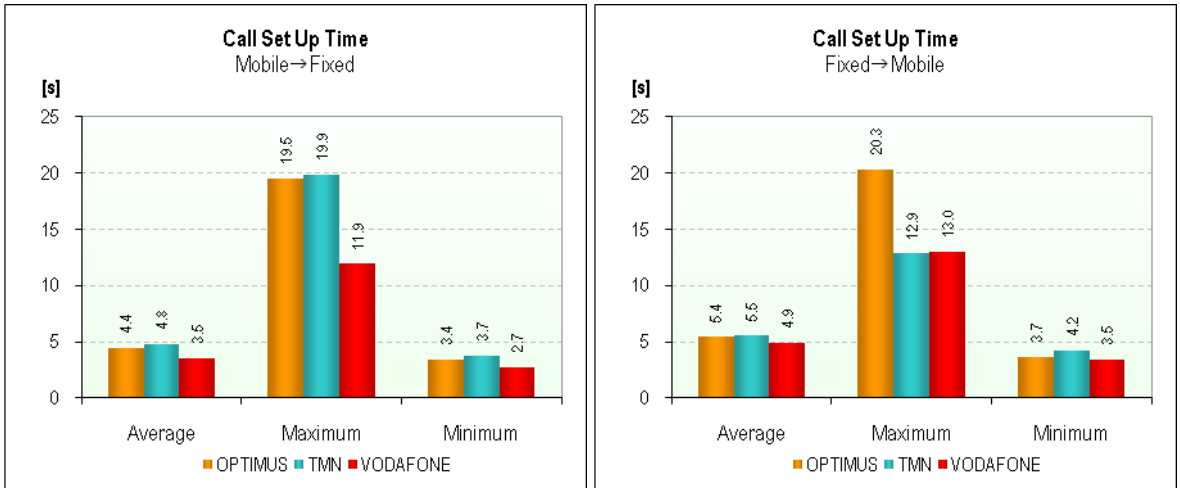

Figure 5 – *Call Set Up Time* Indicator in the Urban Agglomerations of Mainland Portugal.

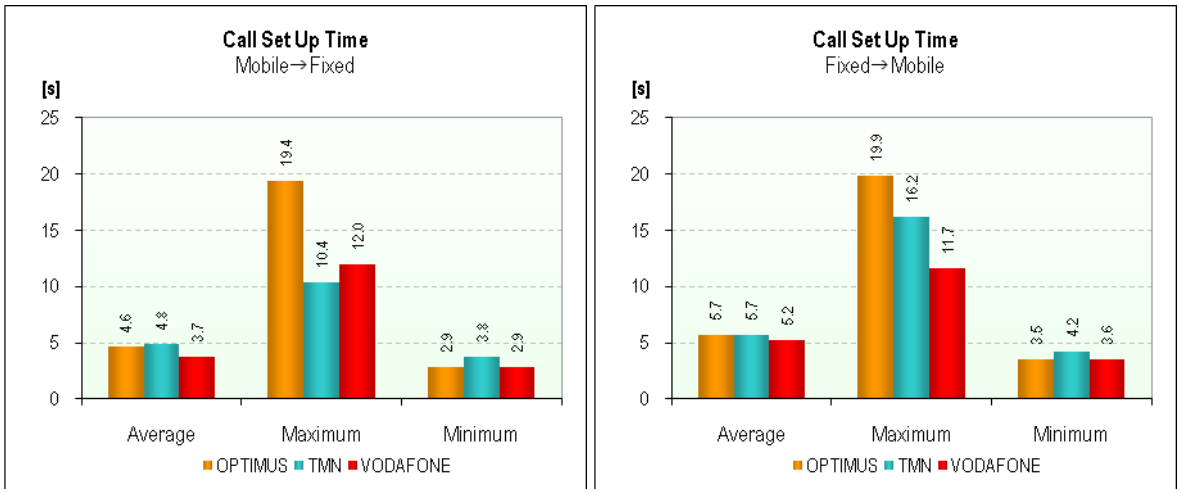

Figure 6 – *Call Set Up Time* Indicator on the Major Roads of Mainland Portugal.

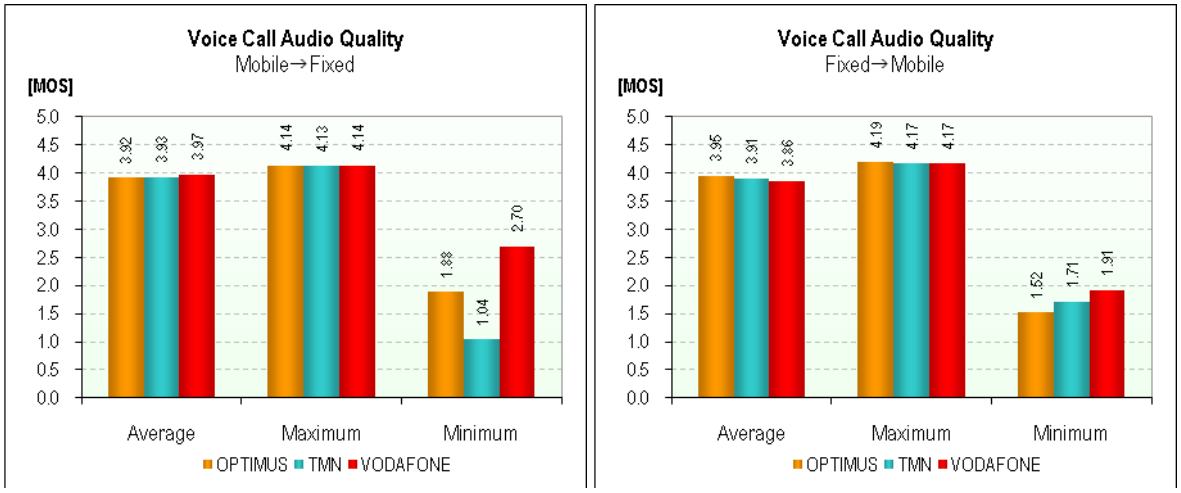

Figure 7 – *Call Audio Quality* Indicator in the Urban Agglomerations of Mainland Portugal.

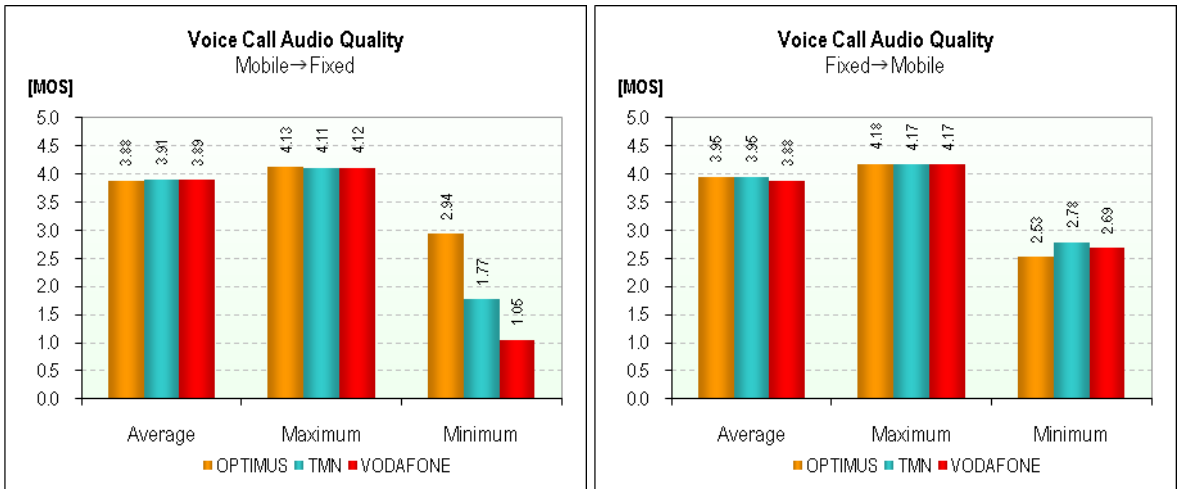

Figure 8 – *Call Audio Quality* Indicator on the Major Roads of Mainland Portugal.

Video-telephony Service

The performance of the video-telephony service maintains a positive evolution trend, particularly in the *Service Accessibility* indicator (Figure 9 – *Service Accessibility*, *Call Termination Rate* and *Call Set Up Time* Indicators in the Urban Agglomerations of Mainland Portugal.

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

, 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 on the Major Roads of Mainland Portugal.

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

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

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Urban agglomerations register a good *Service Accessibility* and *Call Termination Rate*, with levels close to those recorded by the voice service. OPTIMUS and VODAFONE register the best *Service Accessibility*, with levels above 97.4%, while TMN stands at 95.3%. For the *Call Termination Rate*, all operators have very similar levels, above 98%. Comparing this study's results to those of the previous year the most significant evolution was recorded in OPTIMUS' *Service Accessibility*, with an improvement of over 2%.

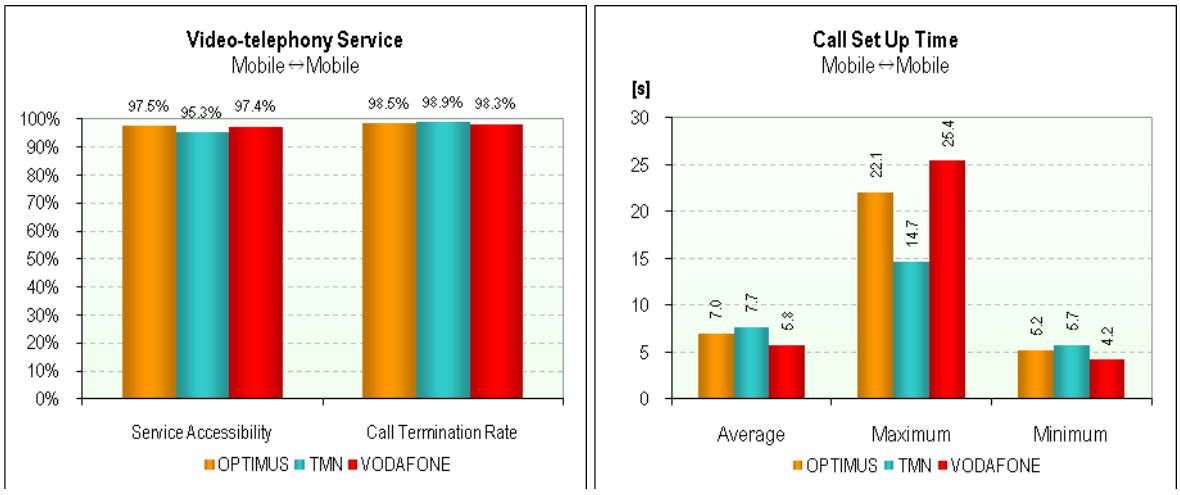


Figure 9 – *Service Accessibility*, *Call Termination Rate* and *Call Set Up Time* Indicators in the Urban Agglomerations of Mainland Portugal.

Table 5 – Evolution of the *Service Accessibility, Call Termination Rate, Average Call Set Up Time* and *Average Audio Quality* Indicators, from 2008 to 2009, in the Urban Agglomerations of Mainland Portugal.
(Difference between figures from the 2009 study and figures from the 2008 study)

		OPTIMUS	TMN	VODAFONE
		Mobile↔Mobile	Mobile↔Mobile	Mobile↔Mobile
Video-telephony	Service Accessibility	2.02%	-0.82%	0.13%

	Call Termination Rate	-0.21%	0.48%	0.09%
	Average Call Set Up Time[s]	0.06	0.21	0.34
	Average Audio Quality [MOS]	-0.022	-0.007	-0.027
	Average Video Quality [MOS]	-0.027	-0.013	-0.081

On major roads, operators OPTIMUS and TMN exhibit the best performances, with *Service Accessibility* levels of 95.1% and 93.7%, respectively, and *Call Termination Rates* of 96.7% and 96.8%, respectively. VODAFONE figures are considerably lower, being 81.4% for *Service Accessibility* and 93% for the *Call Termination Rate*. Regarding the study carried out in 2008, these indicators have a positive evolution, particularly OPTIMUS' *Service Accessibility* which improved by around 8%.

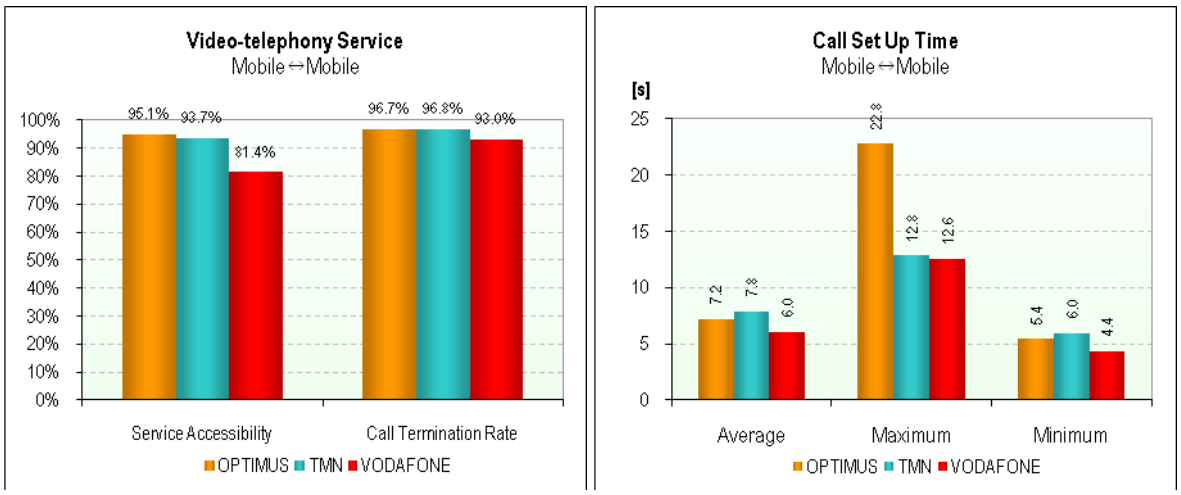


Figure 10 – *Service Accessibility*, *Call Termination Rate* and *Call Set Up Time* Indicators, on the Major Roads of Mainland Portugal.

Table 6 – Evolution of the *Service Accessibility, Call Termination Rate, Average Call Set Up Time and Average Audio Quality* Indicators, from 2008 to 2009, on the Major Roads of Mainland Portugal.
(Difference between figures from the 2009 study and figures from the 2008 study)

		OPTIMUS	TMN	VODAFONE
		Mobile↔Mobile	Mobile↔Mobile	Mobile↔Mobile
Video-telephony service	Service Accessibility	7.97%	1.62%	1.31%
	Call Termination Rate	0.24%	1.90%	0.91%
	Average Call Set Up Time[s]	0.19	0.22	0.40
	Average Audio Quality [MOS]	-0.026	-0.024	-0.026
	Average Video Quality [MOS]	-0.027	-0.044	-0.091

The average call set up time does not differ greatly from urban agglomerations to major roads, with the same values already registered in the 2008 study being more or less unchanged. The best average time observed was recorded by VODAFONE, with 5.8 seconds, and the highest average time was recorded by TMN, with 7.8 seconds.

Normally-ended video-telephony calls (120 seconds long) have a good average *Audio Quality*, and an acceptable average *Video Quality*. No major differences were observed between operators or between urban agglomerations and major roads. Regarding the 2008 study, no major changes were observed for these indicators.

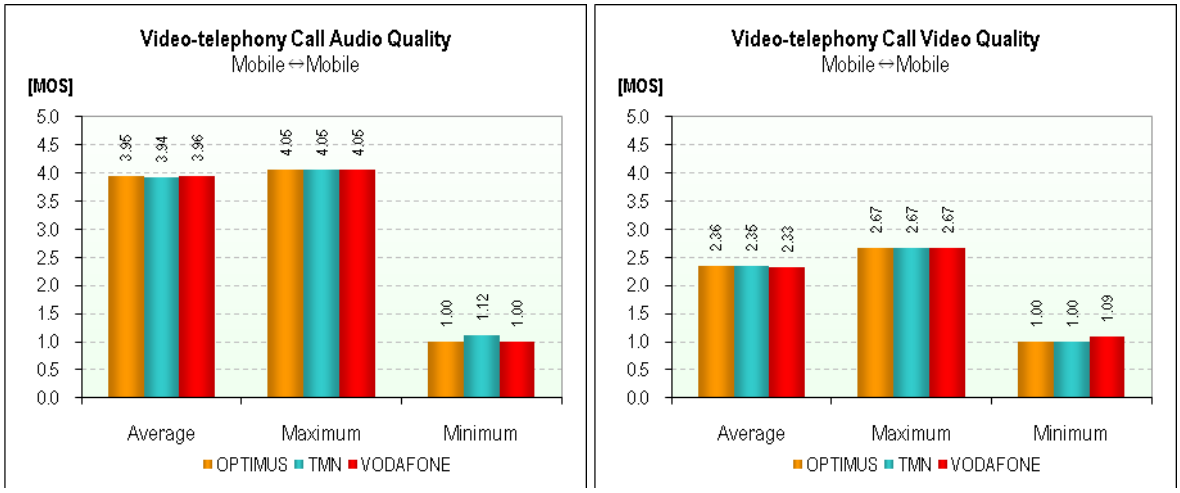


Figure 11 – *Call Audio Quality* and *Call Video Quality* Indicators in the Urban Agglomerations of Mainland Portugal.

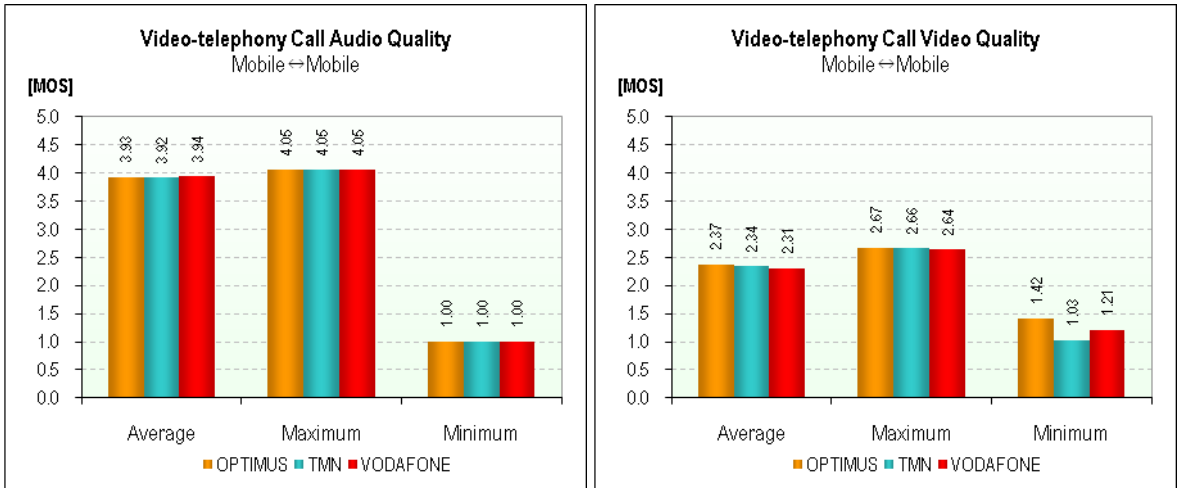


Figure 12 – *Call Audio Quality* and *Call Video Quality* Indicators on the Major Roads of Mainland Portugal.

1 QUALITY OF SERVICE ASSESSMENT

1.1 GOAL

This study intends 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 in the main urban agglomerations and on the major roads of Mainland Portugal.

1.2 SERVICES ANALYSED

In an assessment of the QoS from the user's standpoint, one must consider the services that, for each technology, are more relevant to 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 / UMTS);

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.

Measurements are collected using drive-tests. Besides providing an assessment from the user's standpoint, this approach makes it possible to carry out the tests independently of the correct functioning of the networks themselves, i.e. for example, also analysing the areas where coverage is poor or non-existent.

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, in terms of time and space.

2.1 FUNDAMENTALS

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

a) **End-to-end measurements** – measurements reflect all aspects that impact the quality of a service.
b) **Impartiality** – measurements are carried out in the same conditions for the three operators (OPTIMUS, TMN and VODAFONE).
c) **Objectivity** – tests are carried out completely automatically, 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 involves 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. **Consistency** – Corresponds to how 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).

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

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

The testing and measurement system, which used an RF Scanner, makes it possible to continuously measure each network's signal levels. These measurements are georeferenced, 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 ≤ RxLev < –85 dBm	–105 dBm ≤ CPICH RSCP < –95 dBm
Bad	–110 dBm ≤ RxLev < –95 dBm	–115 dBm ≤ CPICH RSCP < –105 dBm
Non-existent	RxLev < –110 dBm	CPICH RSCP < –115 dBm

[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 of the user having access to the service (voice or video-telephony), i.e. likelihood of success when establishing a (voice or video-telephony) call.

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

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

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.

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

$t_{address\_sending}$ – 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 for a given period of time after it is set up, and ending normally, i.e., according to the user's will.

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

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. Two-way communication is assessed and only calls with normal termination are considered.

This QoS indicator is assessed 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 calculation 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 XB(t) (XA(t),

The results of the algorithm application are shown on a MOS (*Mean Opinion Score*) type scale from 1 to 5 named MOS_LQO (Mean Opinion Score – Listening-only Quality Objective), such as shown in **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. The value "zero" never shows in the results since they only consider situations where the connection was set up and sustained for a given period. "Five" never shows in the results either, because the *CoDec*[3], used by mobile networks does not enable such high voice quality values (the voice quality reached with the CoDec usually used gives 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

In situations where each direction of a call sends and receives several audio samples {X1(t), …, Xn(t); Y1(t), …, Yn(t)}, the *Call Audio Quality* indicator is reckoned through the arithmetic mean of the values obtained by applying the formula shown above to each pair of audio samples, i.e.:

[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/Decodifier.

$$\text{Call AudioQuality}_{\text{side A}}\left[\text{MOS\_LQO}\right]=\frac{f\left\{X1_B(t);Y1_A(t)\right\}+\ldots+f\left\{Xn_B(t);Yn_A(t)\right\}}{n}$$

$$\text{Call AudioQuality}_{\text{side B}}\left[\text{MOS\_LQO}\right]=\frac{f\left\{X1_A(t);Y1_B(t)\right\}+\ldots+f\left\{Xn_A(t);Yn_B(t)\right\}}{n}$$

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 that used for *Call Audio Quality*. The difference is that it takes place in **full-duplex**, i.e. simultaneously in both directions of communication and while the test call is taking place. This feature reproduces the real video-telephony service usage situation.

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

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

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

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

f – function corresponding to the application of the calculation 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 WB(t) (WA(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). SwissQual, AG, is one such firm. It is the supplier of the testing and measurement system used in this study and uses its own algorithm in its products, called VQuad - Objective Model for Video Quality Assessment.

Figure 13 – VQuad (*SwissQual, AG*) algorithm function diagram

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 transmitted through the mobile network being tested. At the destination, the video sequence is captured and objectively validated via perceptual comparison with the reference video sequence. This gives 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.).

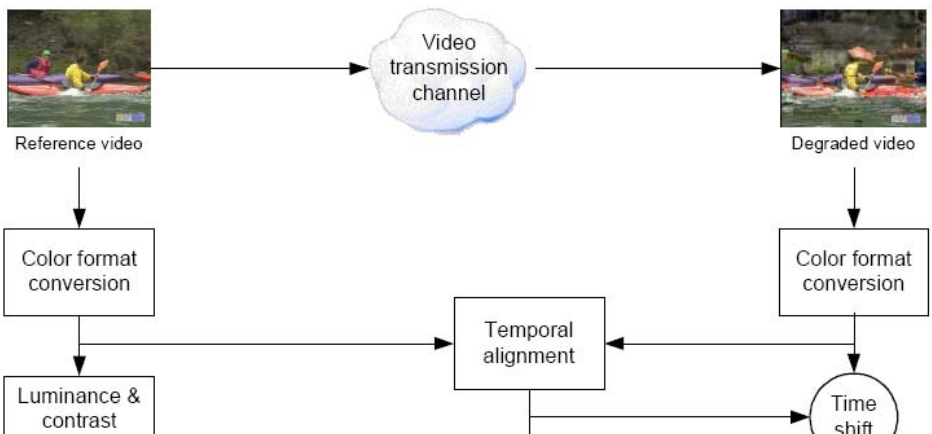


Figure 13 – VQuad (*SwissQual, AG*) algorithm function diagram

The global visual quality index that results 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), as shown in **Table 8**.

In situations where each direction of the same call sends and receives several video samples {W1(t), …, Wn(t); Z1(t), …, Zn(t)}, the *Call Video Quality* indicator is reckoned from the arithmetic mean of the values obtained by applying the formula presented above to each pair of video samples, i.e.:

$$\text{Call Video Quality}_{\text{side A}}\left[\text{MOS\_VQO}\right]=\frac{f\left\{W1_B(t);Z1_A(t)\right\}+\ldots+f\left\{Wn_B(t);Zn_A(t)\right\}}{n}$$

$$\text{Call Video Quality}_{\text{side B}}\left[\text{MOS\_VQO}\right]=\frac{f\left\{W1_A(t);Z1_B(t)\right\}+\ldots+f\left\{Wn_A(t);Zn_B(t)\right\}}{n}$$

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 feasible to perform analyses and compare results.

2.3.1 GENERAL FEATURES

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

Measurements are taken in moving vehicles and with outdoor antennas (without gain), and with automatic selection of the 2G (GSM) or 3G (UMTS) infrastructures. All collected parameters are georeferenced and which allows their subsequent representation in digital cartography.

2.3.2 COVERAGE

Network coverage is assessed 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 taken through an RF Scanner device adapted and exclusively dedicated to this task - so that the measured signal levels correspond to the effective levels. The measuring equipment can 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 georeferenced so that signal levels can be later represented in 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.

[4] The measurement profiles given here are base on the technical specifications ETSI TS 102 250, particularly part 5 (ETSI TS 102 250-5 V1.3.1 (2005-11)), and ETSI EG 202 057, particularly 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)).

2.3.3 TELEPHONY SERVICES

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

Test calls are made between two 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 is part and parcel of taking measurements, the second end of the test calls must have good performance levels and great stability. This end's impact on the services' performance indicators is intended to be minimal. 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. The UE remain stationary in locations with proper (good) radio coverage, minimum interference and with a (virtually) 100% probability of accessing the video-telephony service. Calls originated at this end, in 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 ability 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, the communication's integrity – audio quality – is analysed alternately in each direction, regardless of the end that started the call.

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

- MOC/MTC ratio: 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 in 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 occurs in the time frame, which is larger since the time needed to establish calls and negotiating audio/video communications between terminals is longer.

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

- MOC/MTC ratio: 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 SYSTEM

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 an 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 taken.

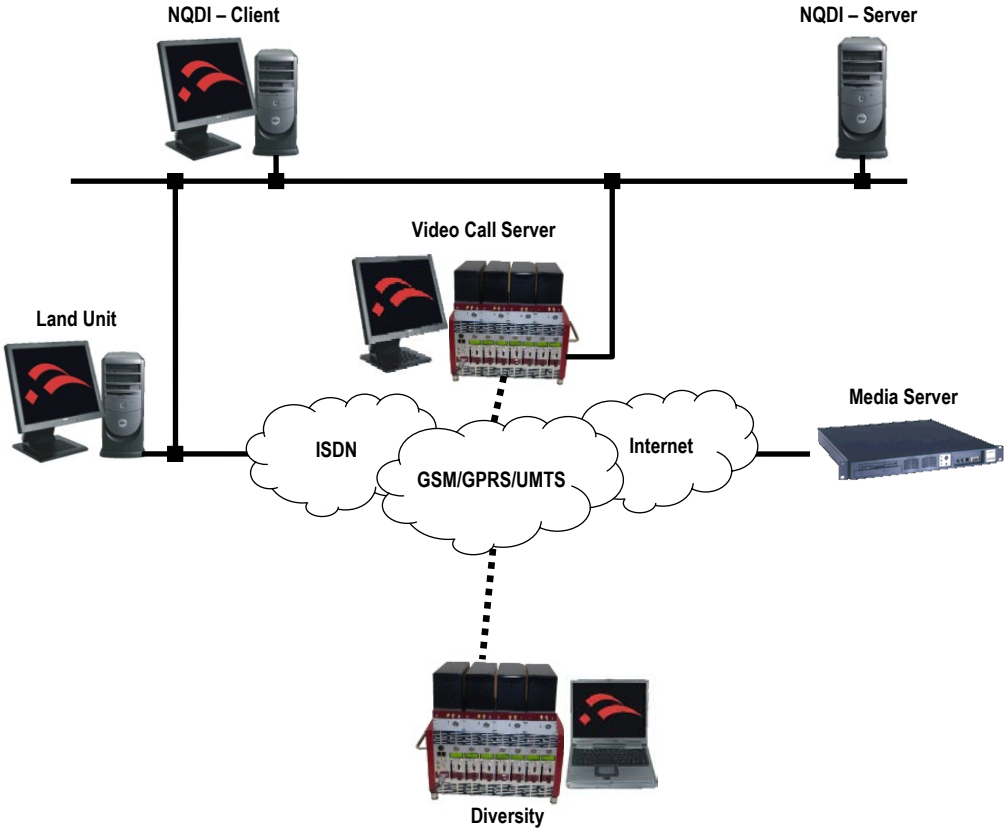


Figure 14 – *Diversity/NetQual* system architecture

3 STUDY SAMPLE

A sample representing the use of these services in the main urban agglomerations and on major roads of Mainland Portugal was chosen for a proper assessment of the quality of Voice, Video-telephony 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 these communications are or could be provided; at least we ought to consider the whole of Portugal's geographical area, including the interior of buildings. Understandably, conducting tests in all these locations is unfeasible.

However, the purpose is not to take exhaustive measurements, but to collect an adequate sample that can be used as an indicator of the networks' overall performance. With this end in view, locations where the service is most used were chosen, i.e. in the larger urban agglomerations and on the major roads.

The exclusive adoption of this criterion would lead to an over- concentration of measurements in the most densely populated areas along the northern coast, and so we decided to consider a geographical distribution of locations in order to take account of inland regions.

Tests were therefore carried out 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 amounts to 41.7% of the Portuguese population, according to the results of the last Census (2001).

Table 9 – Locations and their population

Territorial Unit	Resident 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**
Overall Total	**4,287,788**	**4,264,984**

Source: INE - Instituto Nacional de Estatística

Table 10 – Major Roads

Major Roads	Approximate Distance [Km]
Aveiro-Viseu-Vilar Formoso (A25)	200
Chaves-Vila Real-Figueira da Foz (A24 / IP3 / A14)	285
Lagos-Vila Real de Sto. 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 Kilometres	Voice Calls	Video-telephony Calls	Coverage Measurements	
						GSM	WCDMA
Urban Agglomerations	Aveiro	6 h 06	153	360	309	66.712	66.929
	Beja	6 h 10	120	369	314	66.833	67.008
	Braga	6 h 15	206	369	315	67.269	67.564
	Bragança	6 h 13	143	366	314	67.017	67.204
	Castelo Branco	6 h 02	169	364	312	66.159	66.218
	Coimbra	6 h 16	176	369	318	68.424	68.947
	Évora	6 h 07	138	363	312	65.860	66.190
	Faro	6 h 12	144	369	314	67.471	67.830
	Guarda	6 h 20	151	373	320	69.089	69.364
	Leiria	6 h 12	160	372	316	67.103	67.490
	Portalegre	6 h 01	127	362	311	66.211	66.264
	Santarém	6 h 08	161	368	316	66.788	67.093
	Setúbal	6 h 05	161	362	310	65.946	66.130
	Viana do Castelo	6 h 16	157	369	313	67.474	67.608
	Vila Real	6 h 12	159	365	311	66.578	67.124
	Viseu	6 h 05	162	363	309	66.258	66.634
	Greater Porto	18 h 10	537	1.071	915	196.210	196.886
	Greater Lisbon	36 h 15	892	2.159	1.841	392.016	393.735
	Total Urban Agglomerations	153 h 05	3.916	9.093	7.770	1.659.418	1.666.218
Major Roads	Aveiro-Viseu-Vilar Formoso (A25)	4 h 14	403	255	219	46.680	46.792
	Chaves-Vila Real-Figueira da Foz (A24 / IP3 / A14)	6 h 04	564	352	307	64.809	65.100
	Lagos-Vila Real de Sto. António-Faro-Lagos (A22 / EN125)	6 h 43	548	393	333	72.350	72.510
	Lisbon-Algarve (A2)	4 h 22	491	258	221	47.346	47.707
	Lisbon-Cascais-Sintra-Lisbon (A5 / IC19)	6 h 04	362	366	312	66.312	66.653
	Lisbon-Évora-Elvas (A12 / A2 / A6)	4 h 03	430	240	205	44.152	44.491
	Lisbon-Leiria-Aveiro (A8 / A17)	4 h 42	479	279	241	51.208	51.367
	Lisbon-Porto (A1)	6 h 20	639	369	315	67.534	68.018
	Maia-Guimarães-Braga-Esposende (A41 / A42 / A11)	2 h 15	234	129	112	23.745	23.945
	Oeiras-Castelo Branco-Guarda (A9 / A10 / A1 / A23)	6 h 06	654	372	320	67.786	68.133
	Porto-Bragança (A4 / IP4)	6 h 13	515	365	311	66.635	66.967
	Porto-Braga-Valença-Viana do Castelo-Porto (A3 / A28)	5 h 51	457	345	294	62.730	63.397
	Póvoa de Varzim-Vila Pouca de Aguiar (A7)	1 h 54	224	105	90	19.638	19.666
	Total Major Roads	64 h 51	6.000	3.828	3.280	700.925	704.746
	Overall Total	217 h 56	9.916	12.921	11.050	2.360.343	2.370.964

3.3 DATA COLLECTION CONDITIONS

Field work took place on normal working days from September 14 to October 20.

In the Greater Lisbon and Greater Porto regions, measurements were taken between 8h00 and 12h00 and between 16h00 and 20h00. In the remaining urban agglomerations, measurements were taken during normal working hours.

On each major road, data was collected in two series of runs, except for the A5/IC19 route, where several runs were made in one day (6h04).

4 AGGREGATED RESULTS

4.1 URBAN AGGLOMERATIONS

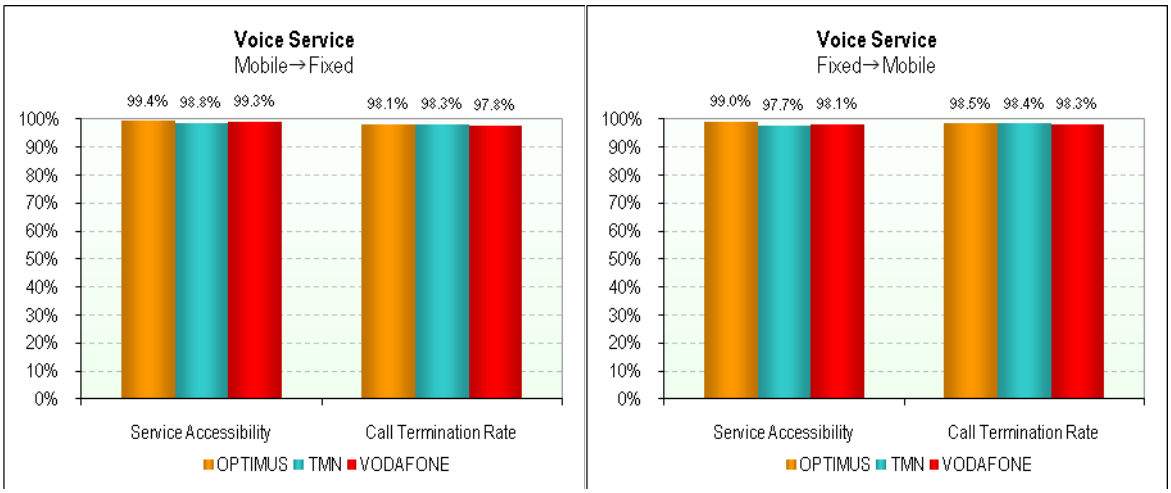
4.1.1 VOICE SERVICE

		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Calls Made	Number of Calls	1,535	1,499	1,531	1,499	1,531	1,498
	Dropped on Set Up	9	15	18	34	11	28
	Dropped During Call	29	23	25	23	34	25
	With Normal Termination	1,497	1,461	1,488	1,442	1,486	1,445
	Service Accessibility	99.4%	99.0%	98.8%	97.7%	99.3%	98.1%
	Call Termination Rate	98.1%	98.5%	98.3%	98.4%	97.8%	98.3%
Call Set Up	Number of Samples (Calls)	1,526	1,484	1,513	1,465	1,520	1,470
	Average Time [s]	4.4	5.4	4.8	5.5	3.5	4.9
	Maximum Time [s]	19.5	20.3	19.9	12.9	11.9	13.0
	Minimum Time [s]	3.4	3.7	3.7	4.2	2.7	3.5
	Standard Deviation [s]	1.0	1.8	0.9	1.3	0.6	1.2
Audio Quality	Number of Samples (Calls)	2,958	2,958	2,930	2,930	2,931	2,931
	Average [MOS]	3.92	3.95	3.93	3.91	3.97	3.86
	Maximum [MOS]	4.14	4.19	4.13	4.17	4.14	4.17
	Minimum [MOS]	1.88	1.52	1.04	1.71	2.70	1.91
	Standard Deviation [MOS]	0.16	0.18	0.17	0.20	0.15	0.17

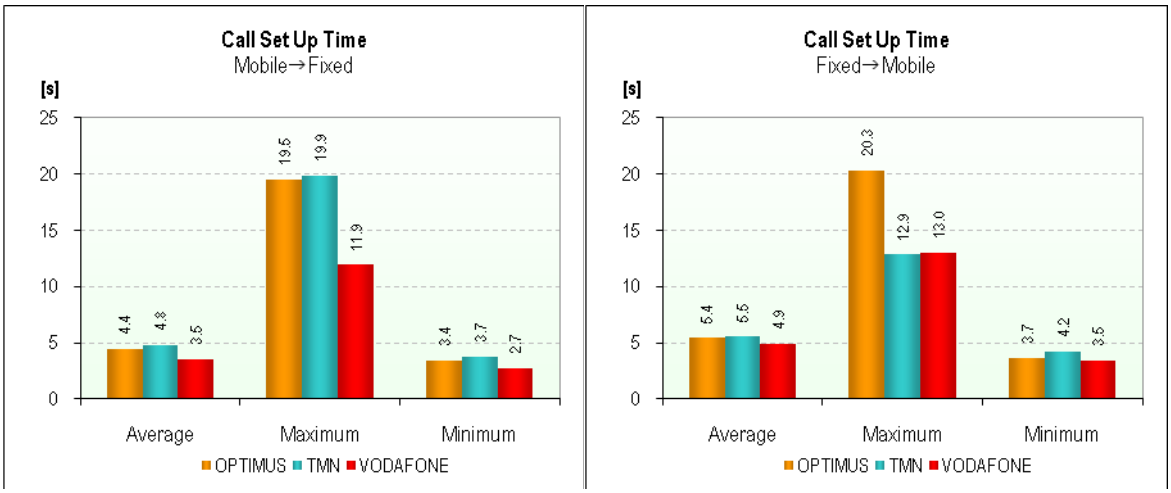
		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Precision Error	Service Accessibility	0.5%	0.6%	0.7%	0.9%	0.6%	0.8%
	Call Termination Rate	0.8%	0.8%	0.8%	0.8%	0.9%	0.8%
	Call Set Up Time [s]	0.049	0.089	0.046	0.066	0.033	0.061
	Audio Quality [MOS]	0.006	0.006	0.006	0.007	0.005	0.006

Confidence Level = 95 %

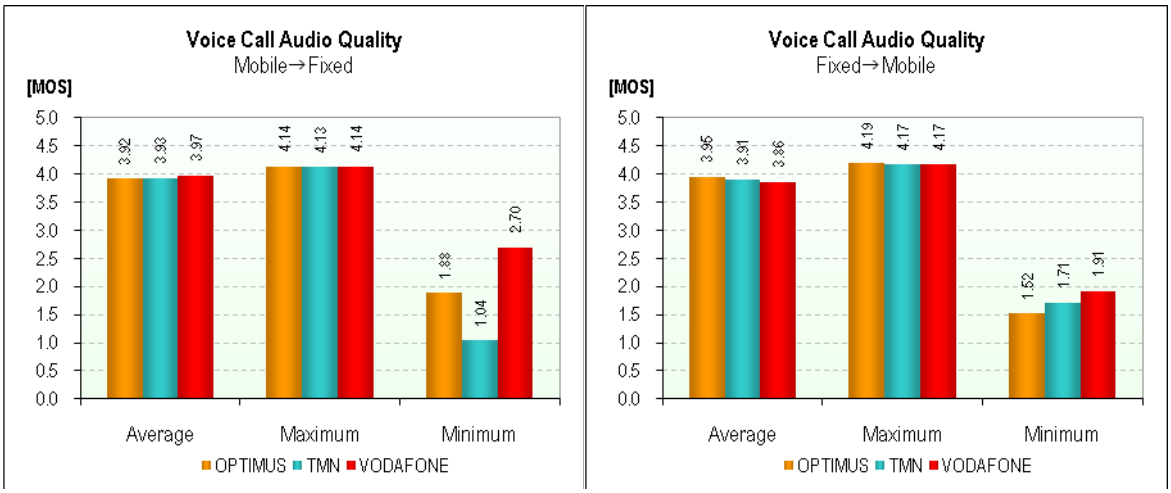
4.1.1.1 *SERVICE ACCESSIBILITY* AND *CALL TERMINATION RATE* INDICATORS



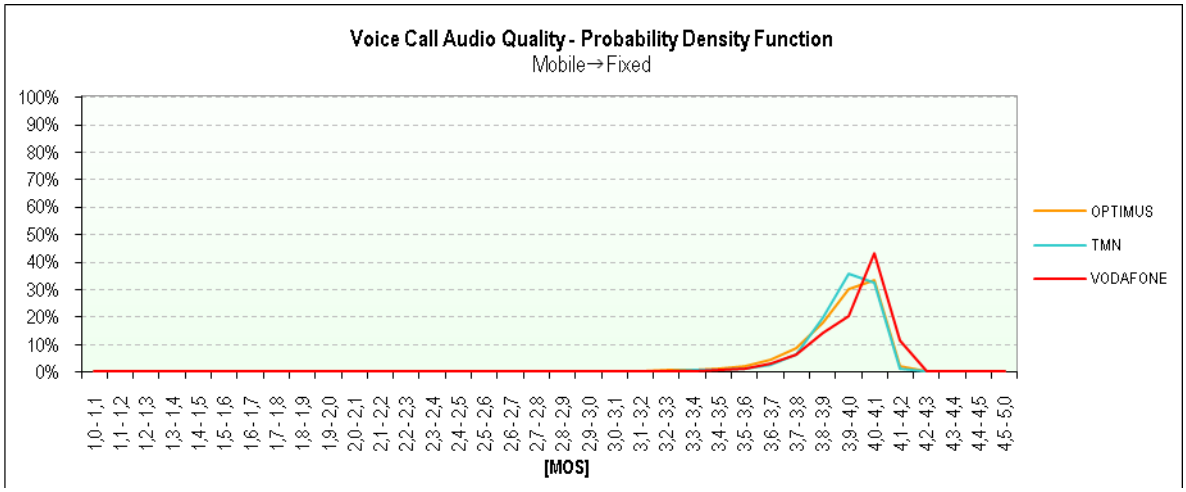
4.1.1.2 *CALL SET UP TIME* INDICATOR

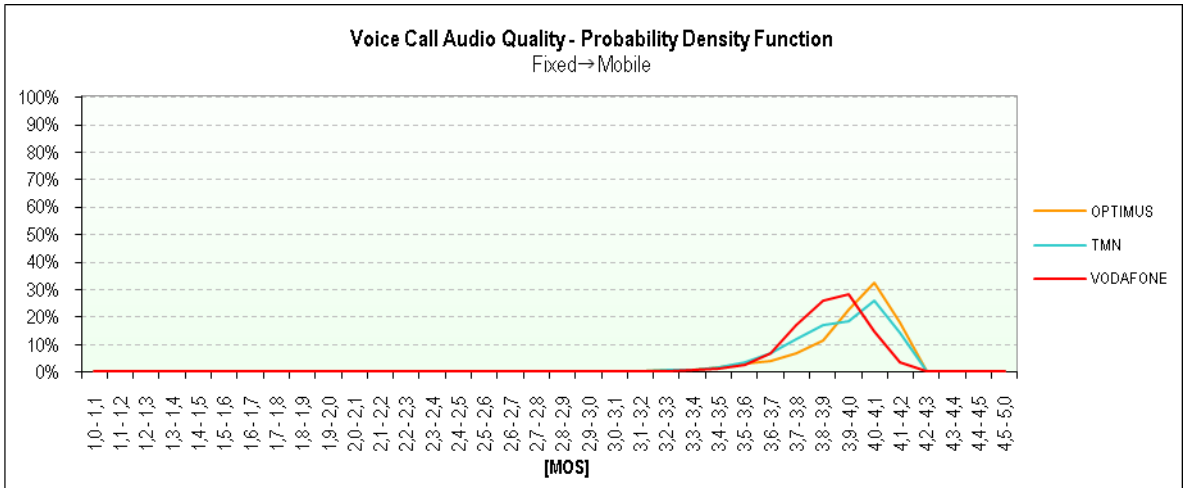


4.1.1.3 *VOICE CALL AUDIO QUALITY* INDICATOR



4.1.1.4 PROBABILITY DENSITY FUNCTION OF THE *VOICE CALL AUDIO QUALITY* INDICATOR





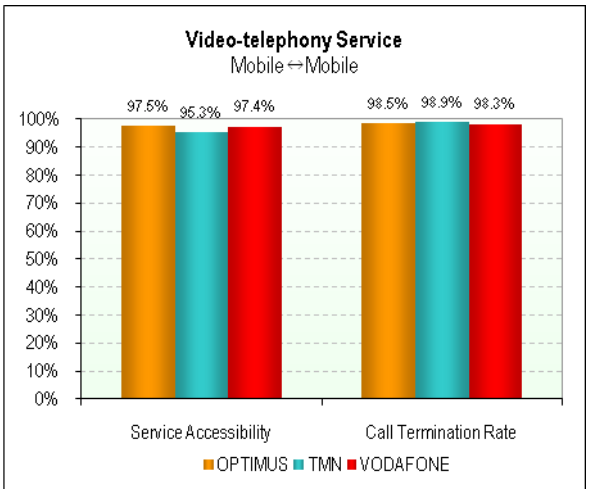
4.1.2 VIDEO-TELEPHONY SERVICE

		OPTIMUS	TMN	VODAFONE
		Mobile↔Mobile	Mobile↔Mobile	Mobile↔Mobile
Calls Made	Number of Calls	2,585	2,593	2,592
	Dropped on Set Up	64	122	67
	Dropped During Call	39	26	42
	With Normal Termination	2,482	2,445	2,483
	Service Accessibility	97.5%	95.3%	97.4%
	Call Termination Rate	98.5%	98.9%	98.3%
Call Set Up	Number of Samples (Calls)	2,521	2,471	2,525
	Average Time [s]	7.0	7.7	5.8
	Maximum Time [s]	22.1	14.7	25.4
	Minimum Time [s]	5.2	5.7	4.2
	Standard Deviation [s]	1.4	1.2	1.1
Audio Quality	Number of Samples (Calls)	4,964	4,889	4,966
	Average [MOS]	3.95	3.94	3.96
	Maximum [MOS]	4.05	4.05	4.05
	Minimum [MOS]	1.00	1.12	1.00
	Standard Deviation [MOS]	0.19	0.21	0.16
Video Quality	Number of Samples (Calls)	4,964	4,890	4,966
	Average [MOS]	2.36	2.35	2.33
	Maximum [MOS]	2.67	2.67	2.67
	Minimum [MOS]	1.00	1.00	1.09
	Standard Deviation [MOS]	0.25	0.30	0.26

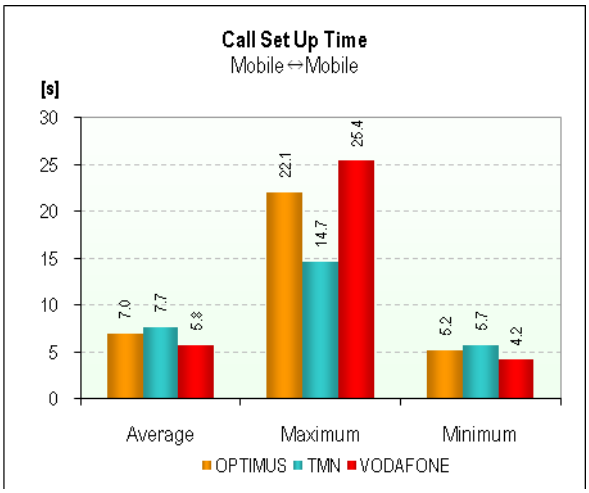
		OPTIMUS	TMN	VODAFONE
		Mobile↔Mobile	Mobile↔Mobile	Mobile↔Mobile
Precision Error	Service Accessibility	0.7%	0.9%	0.7%
	Call Termination Rate	0.6%	0.5%	0.6%
	Call Set Up Time [s]	0.053	0.047	0.044
	Audio Quality [MOS]	0.005	0.006	0.005
	Video Quality[MOS]	0.007	0.008	0.007

Confidence Level = 95 %

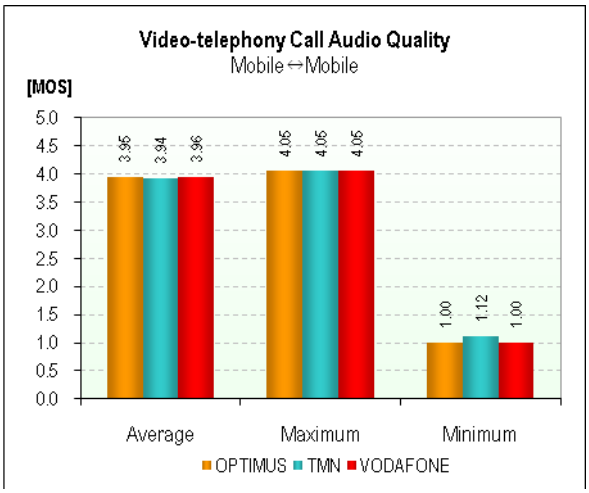
4.1.2.1 *SERVICE ACCESSIBILITY* AND *CALL TERMINATION RATE* INDICATORS



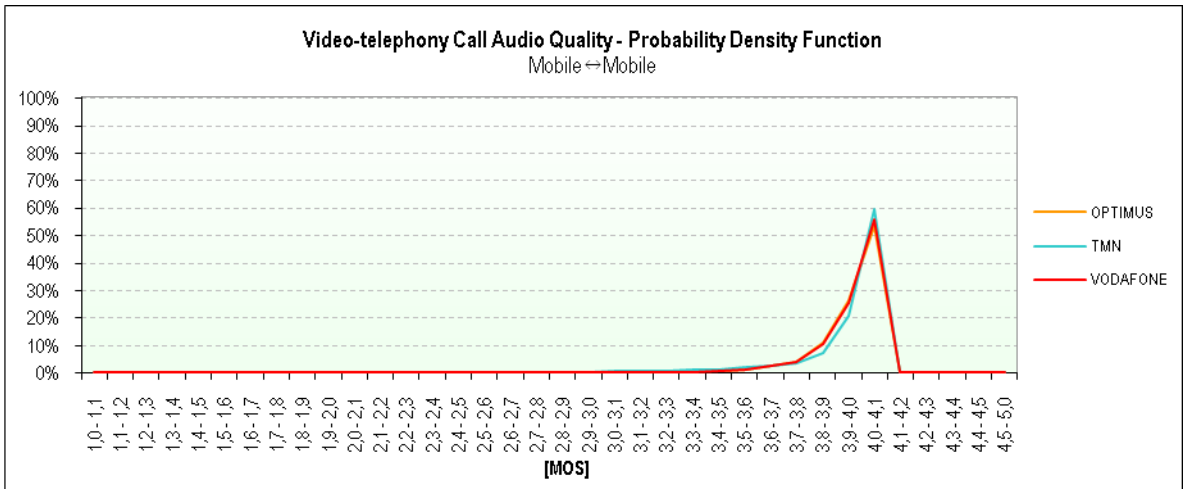
4.1.2.2 *CALL SET UP TIME* INDICATOR



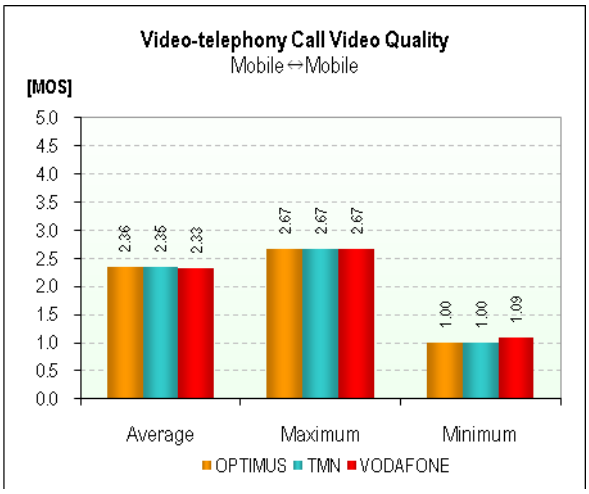
4.1.2.3 *VIDEO-TELEPHONY CALL AUDIO QUALITY* INDICATOR



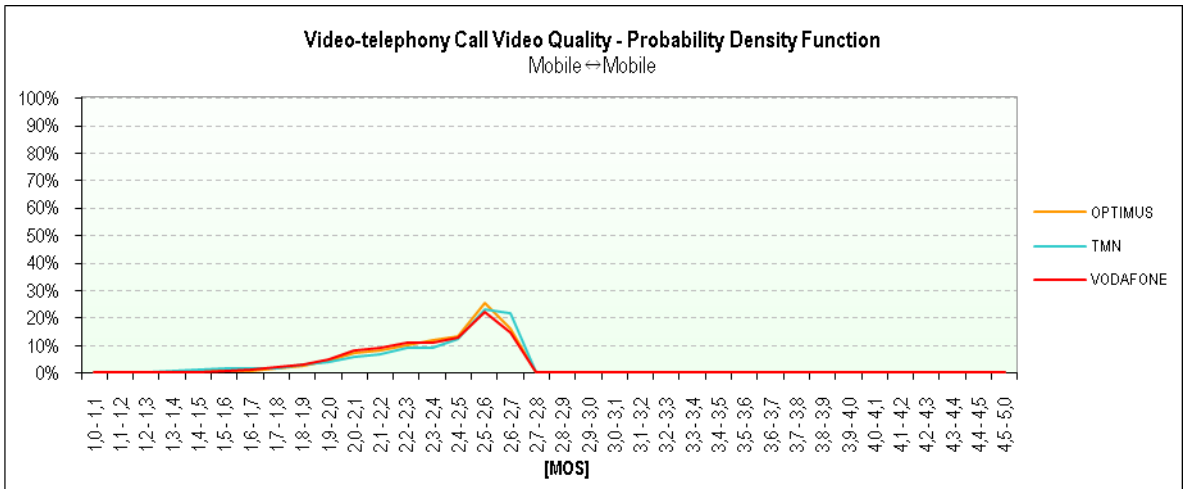
4.1.2.4 PROBABILITY DENSITY FUNCTION OF THE *VIDEO-TELEPHONY CALL AUDIO QUALITY* INDICATOR



4.1.2.5 *VIDEO-TELEPHONY CALL VIDEO QUALITY* INDICATOR



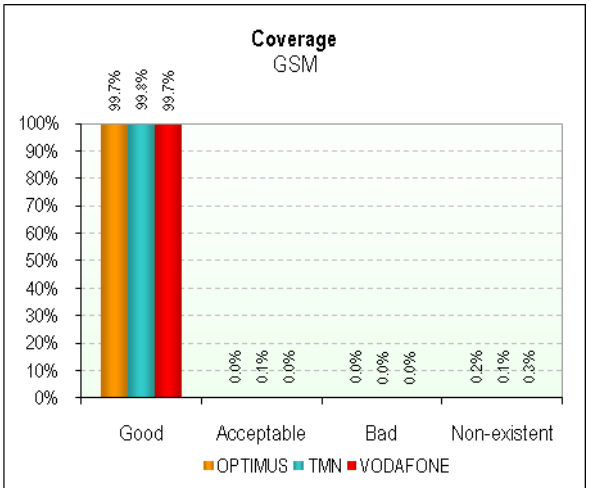
4.1.2.6 PROBABILITY DENSITY FUNCTION OF THE *VIDEO-TELEPHONY CALL VIDEO QUALITY* INDICATOR



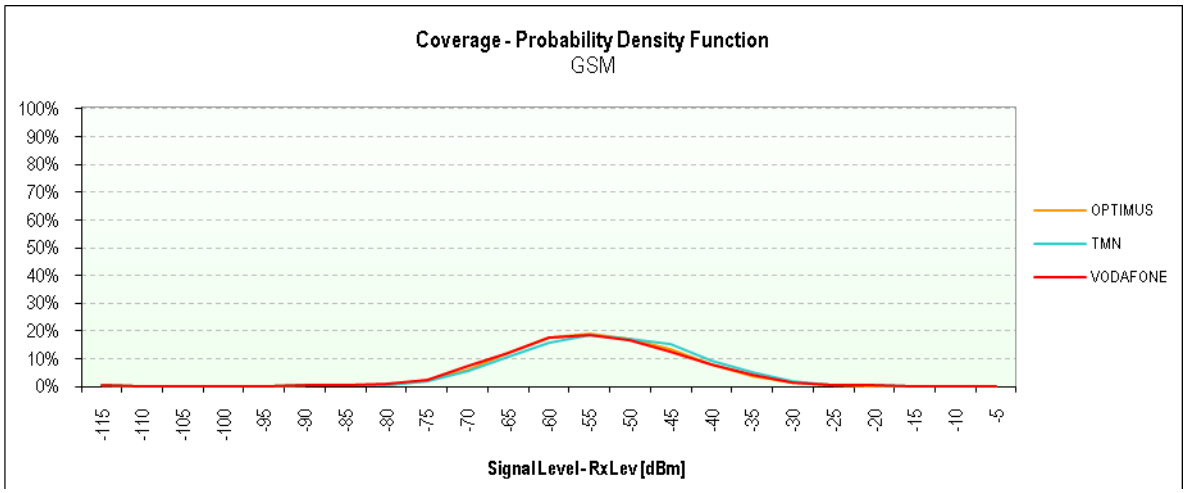
4.1.3 NETWORK COVERAGE

		GSM			WCDMA		
		OPTIMUS	TMN	VODAFONE	OPTIMUS	TMN	VODAFONE
Coverage	Number of Samples (Measurements)	553,226	553,133	553,059	555,364	555,550	555,04
	Average Signal Level [dBm]	-52	-51	-52	-75	-73	-75
	Maximum Signal Level [dBm]	-22	-16	-17	-33	-21	-27
	Minimum Signal Level[dBm]	-115	-115	-115	-125	-132	-131
	Standard Deviation [dBm]	10	10	11	12	13	14
	Good	99.7%	99.8%	99.7%	96.2%	95.4%	92.9%
	Acceptable	0.0%	0.1%	0.0%	3.4%	3.7%	4.4%
	Bad	0.0%	0.0%	0.0%	0.4%	0.8%	1.9%
	Non-existent	0.2%	0.1%	0.3%	0.0%	0.1%	0.7%

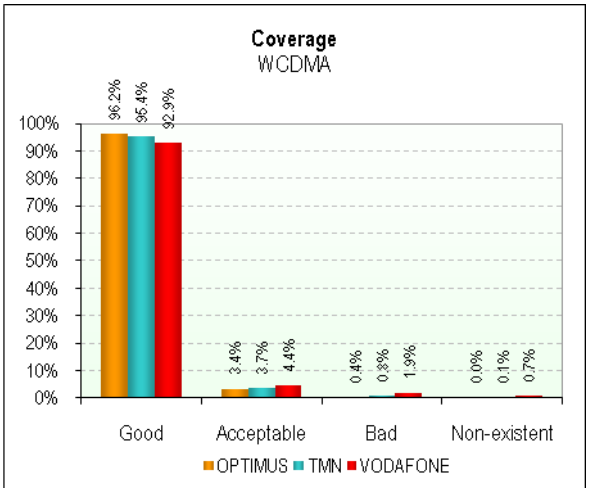
4.1.3.1 GSM



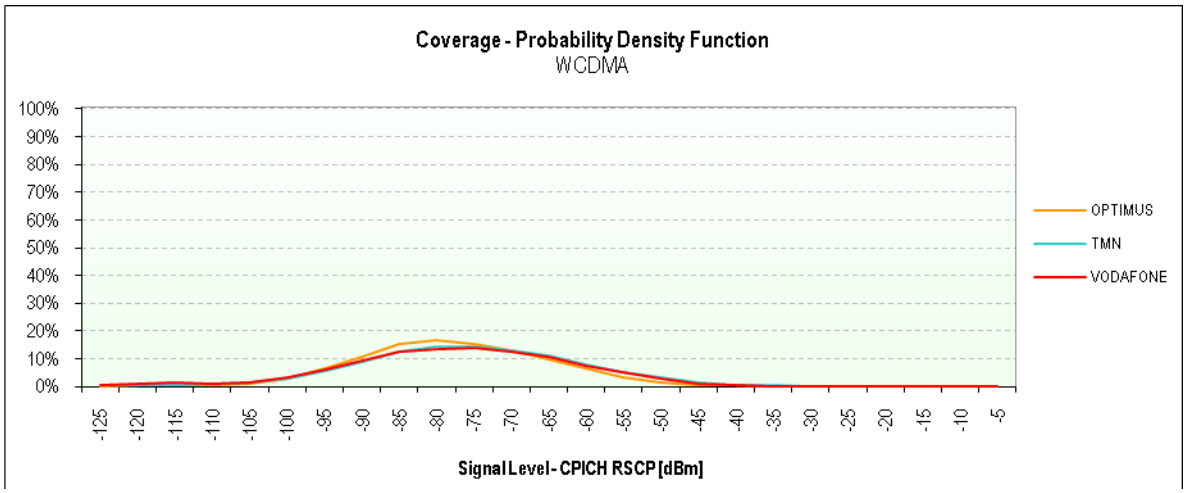
4.1.3.2 GSM - PROBABILITY DENSITY FUNCTION



4.1.3.3 WCDMA



4.1.3.4 WCDMA - PROBABILITY DENSITY FUNCTION



4.2 MAJOR ROADS

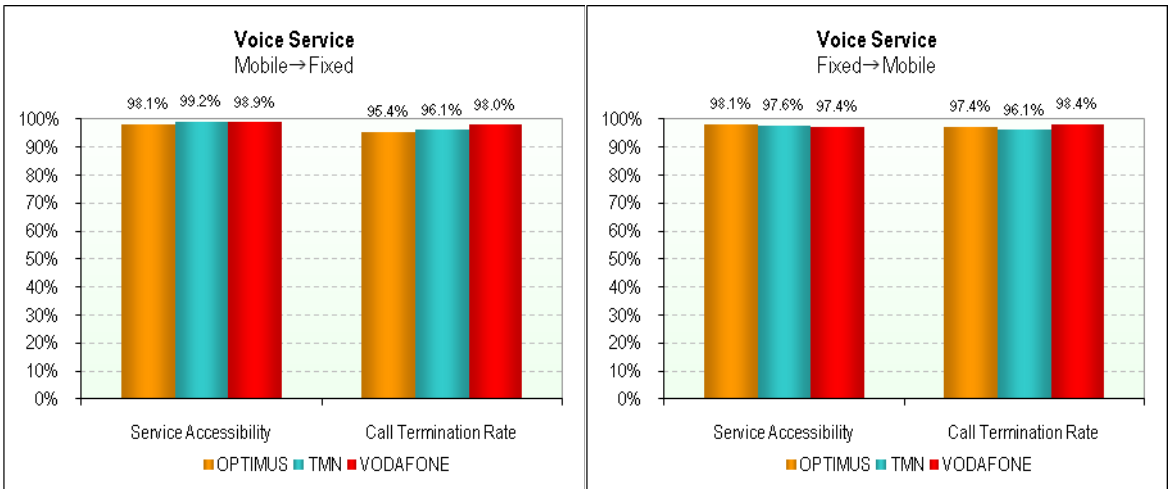
4.2.1 VOICE SERVICE

		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Calls Made	Number of Calls	648	628	648	629	648	627
	Dropped on Set Up	12	12	5	15	7	16
	Dropped During Call	29	16	25	24	13	10
	With Normal Termination	607	600	618	590	628	601
	Service Accessibility	98.1%	98.1%	99.2%	97.6%	98.9%	97.4%
	Call Termination Rate	95.4%	97.4%	96.1%	96.1%	98.0%	98.4%
Call Set Up	Number of Samples (Calls)	636	616	643	614	641	611
	Average Time [s]	4.6	5.7	4.8	5.7	3.7	5.2
	Maximum Time [s]	19.4	19.9	10.4	16.2	12.0	11.7
	Minimum Time [s]	2.9	3.5	3.8	4.2	2.9	3.6
	Standard Deviation [s]	1.5	2.1	0.8	1.4	0.7	1.2
Audio Quality	Number of Samples (Calls)	1,207	1,207	1,208	1,208	1,229	1,229
	Average [MOS]	3.88	3.95	3.91	3.95	3.89	3.88
	Maximum [MOS]	4.13	4.18	4.11	4.17	4.12	4.17
	Minimum [MOS]	2.94	2.53	1.77	2.78	1.05	2.69
	Standard Deviation [MOS]	0.19	0.20	0.15	0.17	0.18	0.19

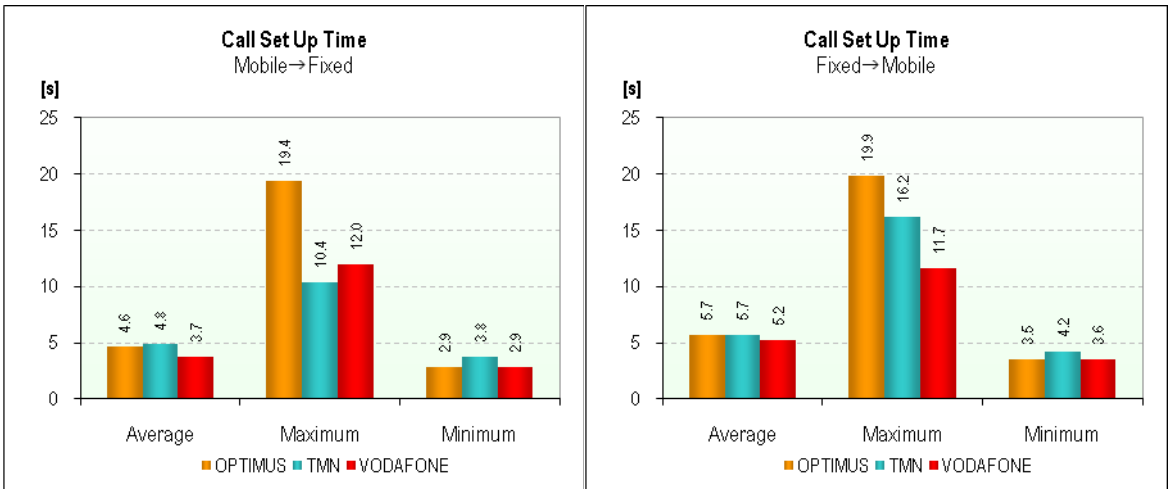
		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Precision Error	Service Accessibility	1.4%	1.4%	1.0%	1.5%	1.1%	1.6%
	Call Termination Rate	1.9%	1.6%	1.8%	1.9%	1.4%	1.4%
	Call Set Up Time [s]	0.113	0.166	0.065	0.110	0.056	0.097
	Audio Quality [MOS]	0.011	0.012	0.008	0.010	0.010	0.010

Confidence Level = 95 %

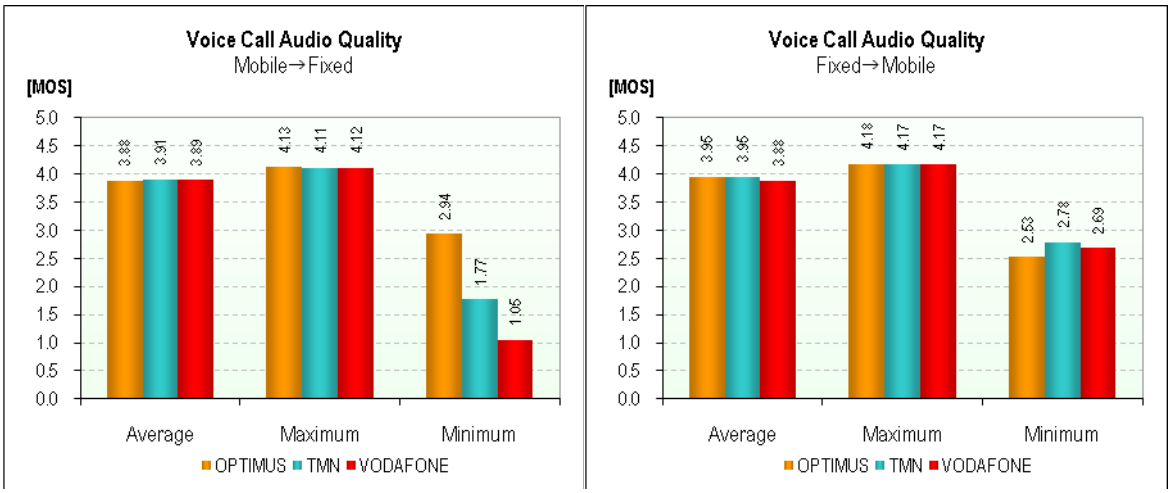
4.2.1.1 *SERVICE ACCESSIBILITY* AND *CALL TERMINATION RATE* INDICATORS



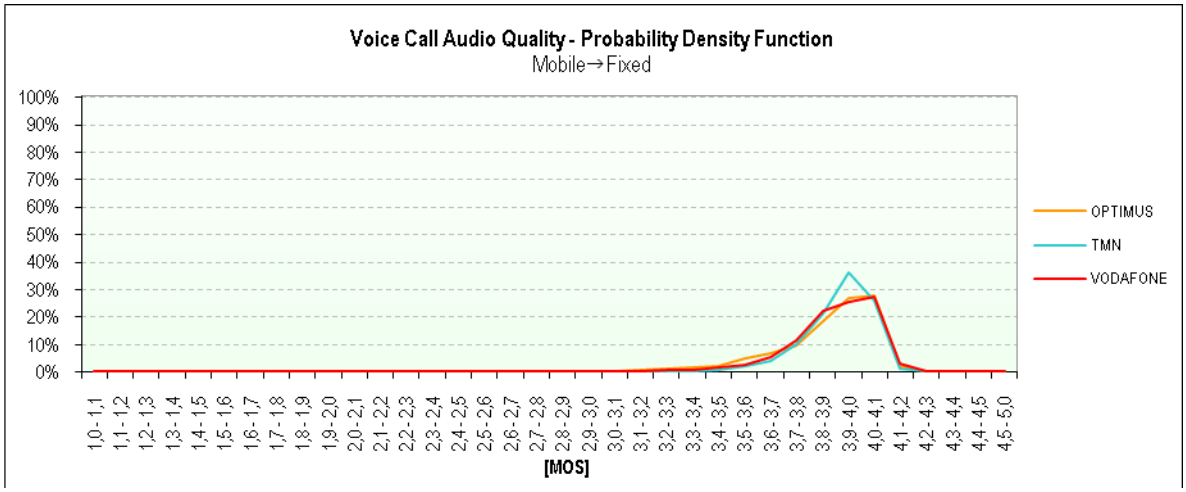
4.2.1.2 *CALL SET UP TIME* INDICATOR

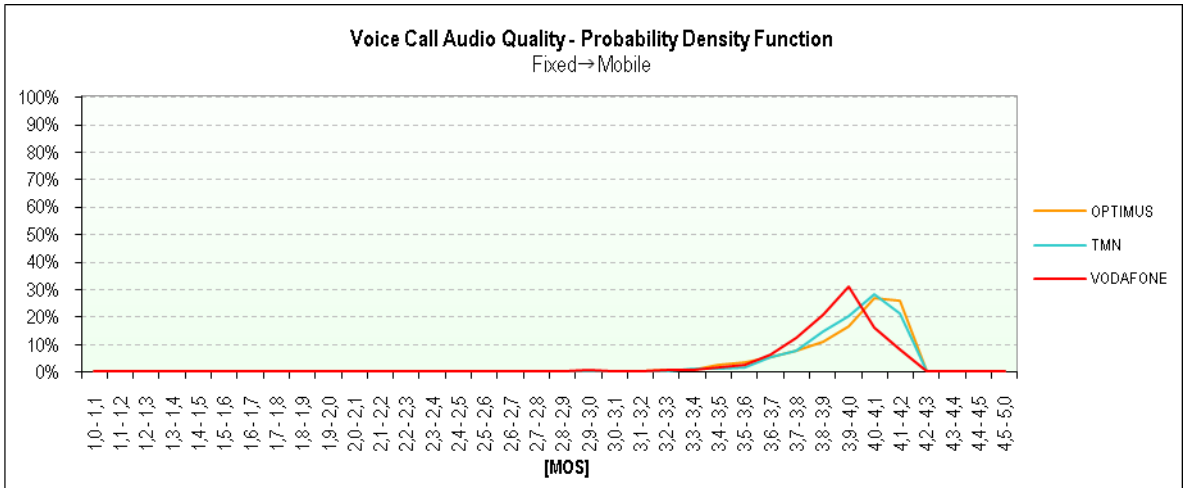


4.2.1.3 *VOICE CALL AUDIO QUALITY* INDICATOR



4.2.1.4 PROBABILITY DENSITY FUNCTION OF THE *VOICE CALL AUDIO QUALITY* INDICATOR





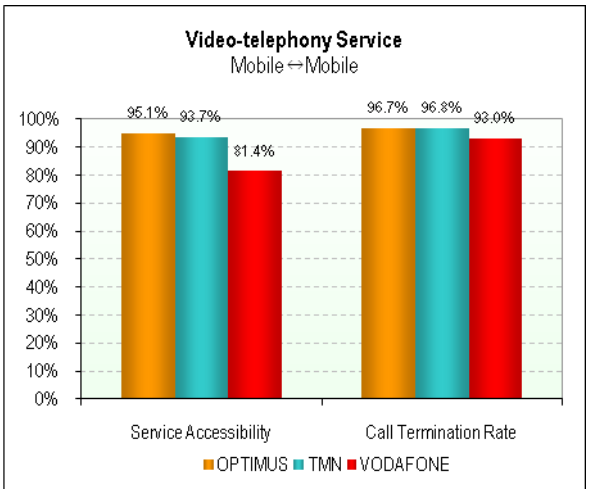
4.2.2 VIDEO-TELEPHONY SERVICE

		OPTIMUS	TMN	VODAFONE
		Mobile↔Mobile	Mobile↔Mobile	Mobile↔Mobile
Calls Made	Number of Calls	1,090	1,096	1,094
	Dropped on Set Up	53	69	203
	Dropped During Call	34	33	62
	With Normal Termination	1,003	994	829
	Service Accessibility	95.1%	93.7%	81.4%
	Call Termination Rate	96.7%	96.8%	93.0%
Call Set Up	Number of Samples (Calls)	1,037	1,027	891
	Average Time [s]	7.2	7.8	6.0
	Maximum Time [s]	22.8	12.8	12.6
	Minimum Time [s]	5.4	6.0	4.4
	Standard Deviation [s]	1.5	1.1	1.0
Audio Quality	Number of Samples (Calls)	2,003	1,988	1,658
	Average [MOS]	3.93	3.92	3.94
	Maximum [MOS]	4.05	4.05	4.05
	Minimum [MOS]	1.00	1.00	1.00
	Standard Deviation [MOS]	0.25	0.23	0.19
Video Quality	Number of Samples (Calls)	2,006	1,988	1,658
	Average [MOS]	2.37	2.34	2.31
	Maximum [MOS]	2.67	2.66	2.64
	Minimum [MOS]	1.42	1.03	1.21
	Standard Deviation [MOS]	0.24	0.31	0.26

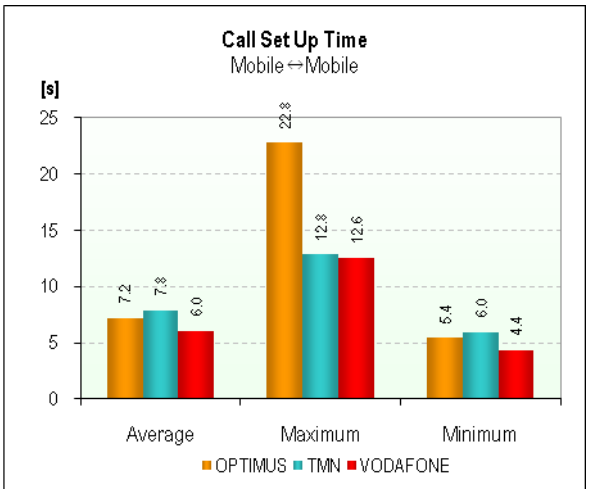
		OPTIMUS	TMN	VODAFONE
		Mobile↔Mobile	Mobile↔Mobile	Mobile↔Mobile
Precision Error	Service Accessibility	1.4%	1.6%	2.4%
	Call Termination Rate	1.3%	1.3%	1.9%
	Call Set Up Time [s]	0.093	0.069	0.069
	Audio Quality [MOS]	0.011	0.010	0.009
	Video Quality[MOS]	0.011	0.014	0.012

Confidence Level = 95 %

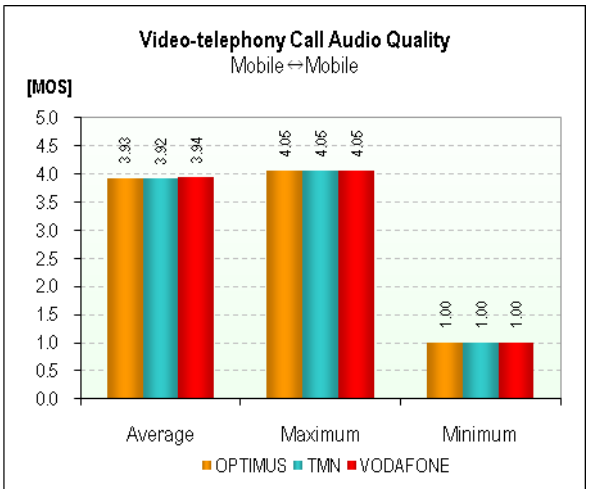
4.2.2.1 *SERVICE ACCESSIBILITY* AND *CALL TERMINATION RATE* INDICATORS



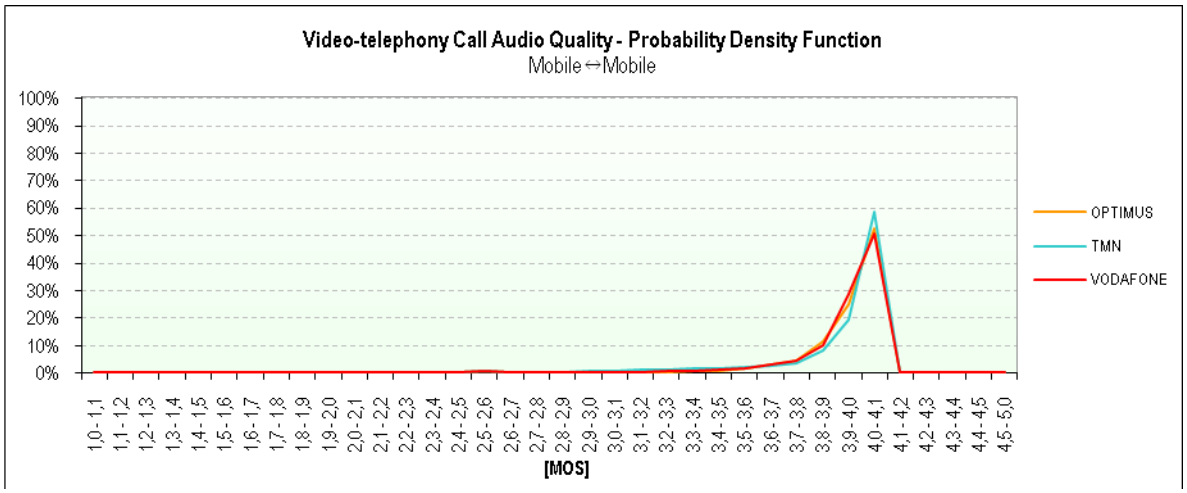
4.2.2.2 *CALL SET UP TIME* INDICATOR



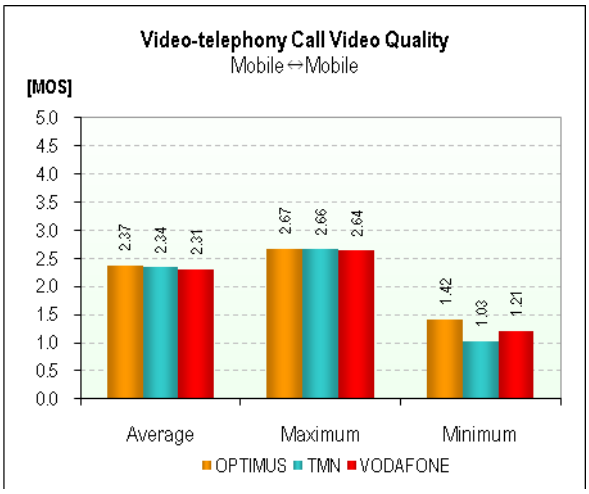
4.2.2.3 *VIDEO-TELEPHONY CALL AUDIO QUALITY* INDICATOR



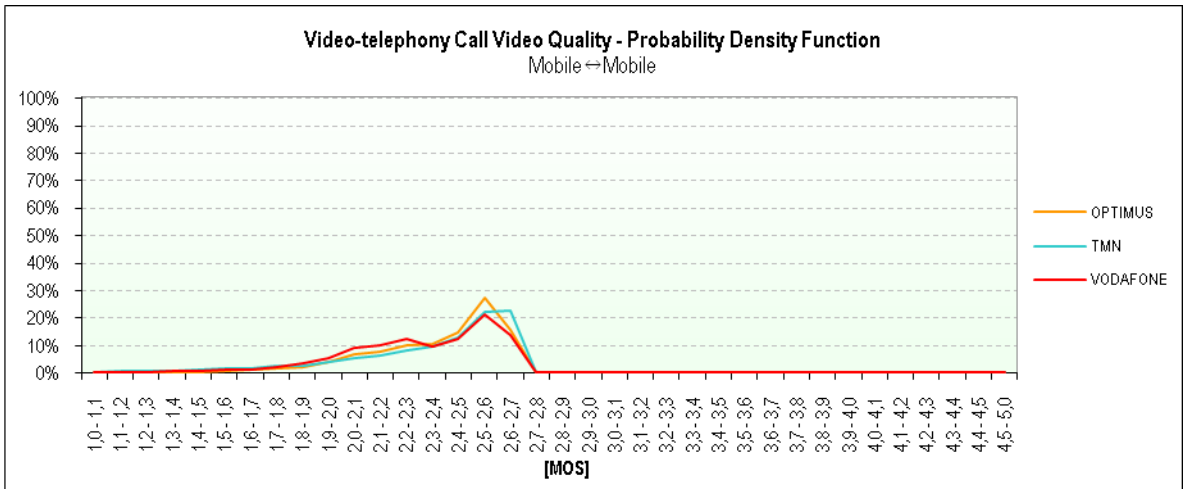
4.2.2.4 PROBABILITY DENSITY FUNCTION OF THE *VIDEO-TELEPHONY CALL AUDIO QUALITY* INDICATOR



4.2.2.5 *VIDEO-TELEPHONY CALL VIDEO QUALITY* INDICATOR



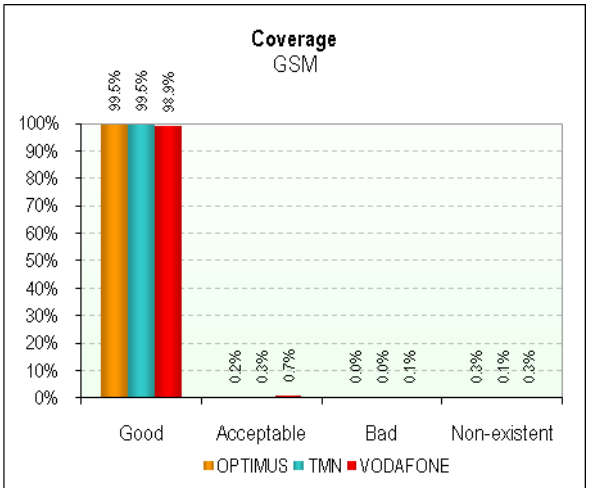
4.2.2.6 PROBABILITY DENSITY FUNCTION OF THE *VIDEO-TELEPHONY CALL VIDEO QUALITY* INDICATOR



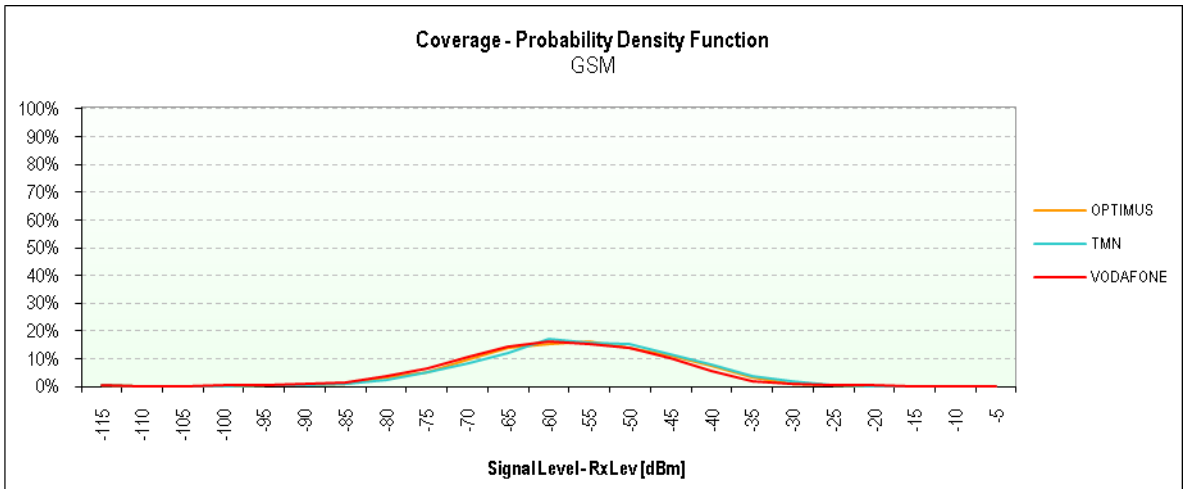
4.2.3 NETWORK COVERAGE

		GSM			WCDMA		
		OPTIMUS	TMN	VODAFONE	OPTIMUS	TMN	VODAFONE
Coverage	Number of Samples (Measurements)	233,628	233,580	233,717	234,866	234,923	234,957
	Average Signal Level [dBm]	-55	-54	-56	-81	-77	-86
	Maximum Signal Level [dBm]	-21	-21	-20	-34	-30	-27
	Minimum Signal Level[dBm]	-115	-115	-115	-136	-138	-139
	Standard Deviation [dBm]	12	12	12	15	16	20
	Good	99.5%	99.5%	98.9%	81.7%	86.9%	69.6%
	Acceptable	0.2%	0.3%	0.7%	13.1%	8.6%	12.9%
	Bad	0.0%	0.0%	0.1%	4.2%	3.3%	8.4%
	Non-existent	0.3%	0.1%	0.3%	1.0%	1.1%	9.2%

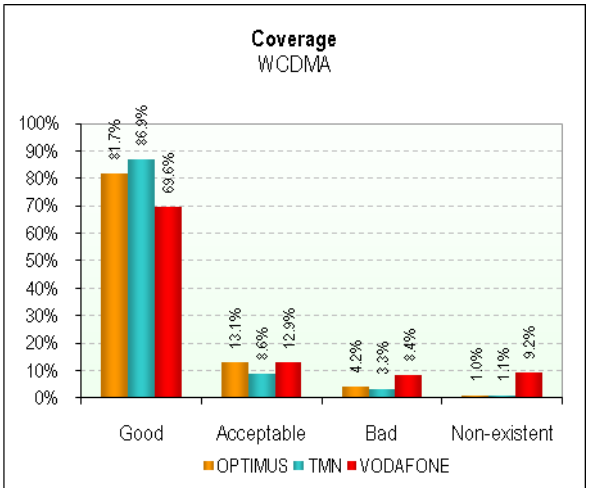
4.2.3.1 GSM



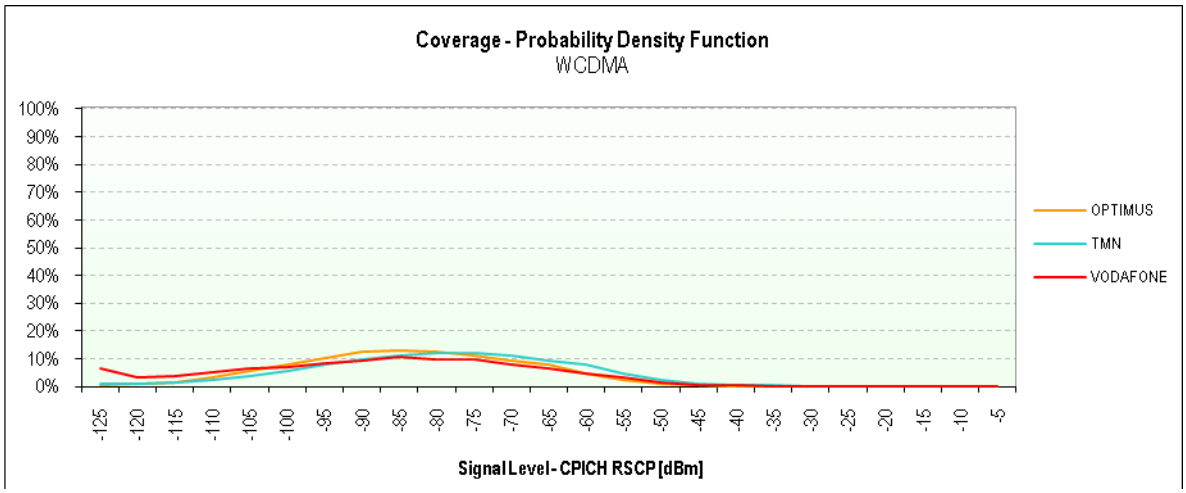
4.2.3.2 GSM - PROBABILITY DENSITY FUNCTION



4.2.3.3 WCDMA



4.2.3.4 WCDMA - PROBABILITY DENSITY FUNCTION



4.3 GLOBAL

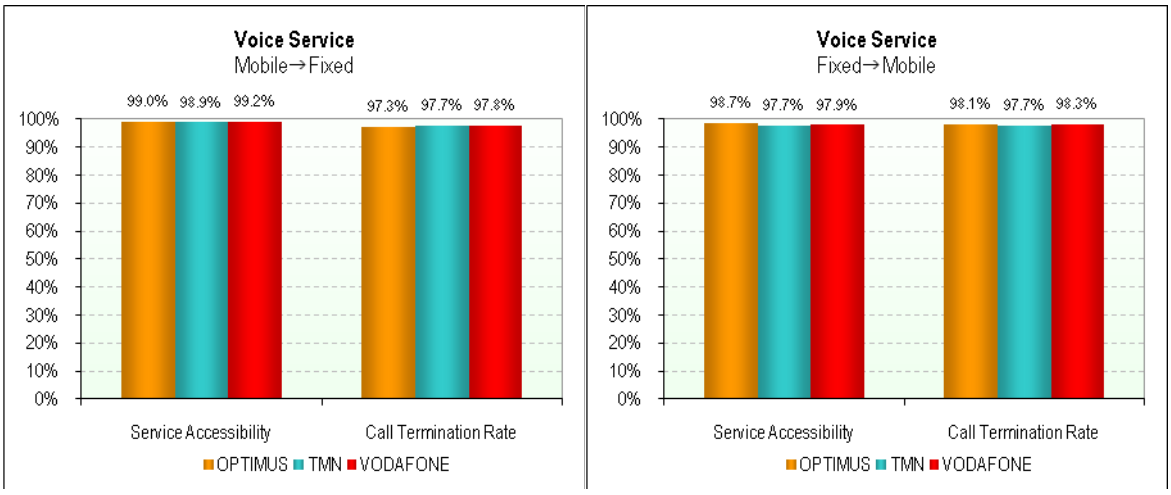
4.3.1 VOICE SERVICE

		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Calls Made	Number of Calls	2,183	2,127	2,179	2,128	2,179	2,125
	Dropped on Set Up	21	27	23	49	18	44
	Dropped During Call	58	39	50	47	47	35
	With Normal Termination	2,104	2,061	2,106	2,032	2,114	2,046
	Service Accessibility	99.0%	98.7%	98.9%	97.7%	99.2%	97.9%
	Call Termination Rate	97.3%	98.1%	97.7%	97.7%	97.8%	98.3%
Call Set Up	Number of Samples (Calls)	2,162	2,100	2,156	2,079	2,161	2,081
	Average Time [s]	4.5	5.5	4.8	5.6	3.6	5.0
	Maximum Time [s]	19.5	20.3	19.9	16.2	12.0	13.0
	Minimum Time [s]	2.9	3.5	3.7	4.2	2.7	3.5
	Standard Deviation [s]	1.1	1.9	0.9	1.3	0.7	1.2
Audio Quality	Number of Samples (Calls)	4,165	4,165	4,138	4,138	4,160	4,160
	Average [MOS]	3.91	3.95	3.92	3.92	3.95	3.87
	Maximum [MOS]	4.14	4.19	4.13	4.17	4.14	4.17
	Minimum [MOS]	1.88	1.52	1.04	1.71	1.05	1.91
	Standard Deviation [MOS]	0.17	0.19	0.16	0.20	0.16	0.17

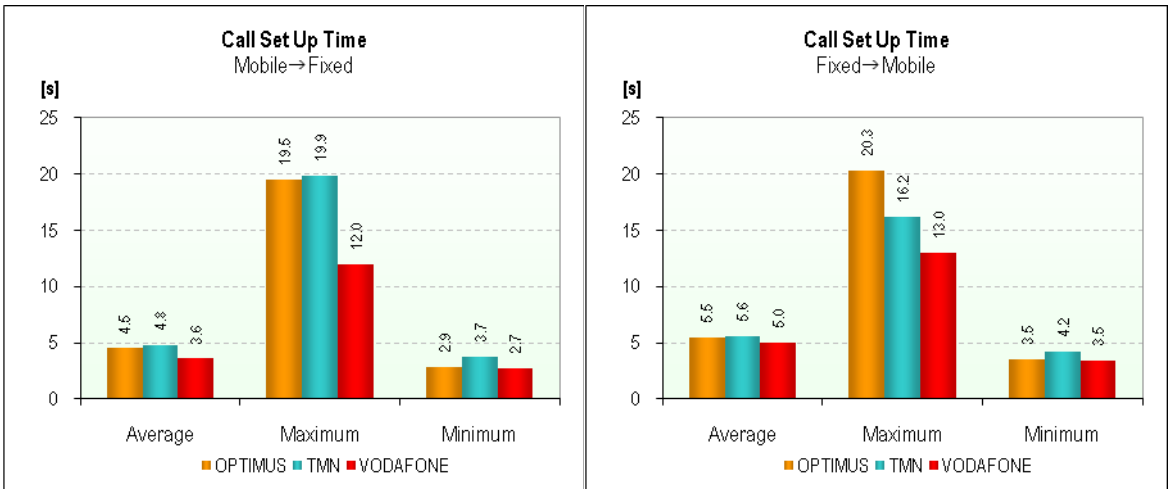
		OPTIMUS		TMN		VODAFONE	
		Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile	Mobile→Fixed	Fixed→Mobile
Precision Error	Service Accessibility	0.5%	0.6%	0.5%	0.7%	0.5%	0.7%
	Call Termination Rate	0.8%	0.7%	0.7%	0.7%	0.7%	0.6%
	Call Set Up Time [s]	0.048	0.080	0.038	0.056	0.028	0.052
	Audio Quality [MOS]	0.005	0.006	0.005	0.006	0.005	0.005

Confidence Level = 95 %

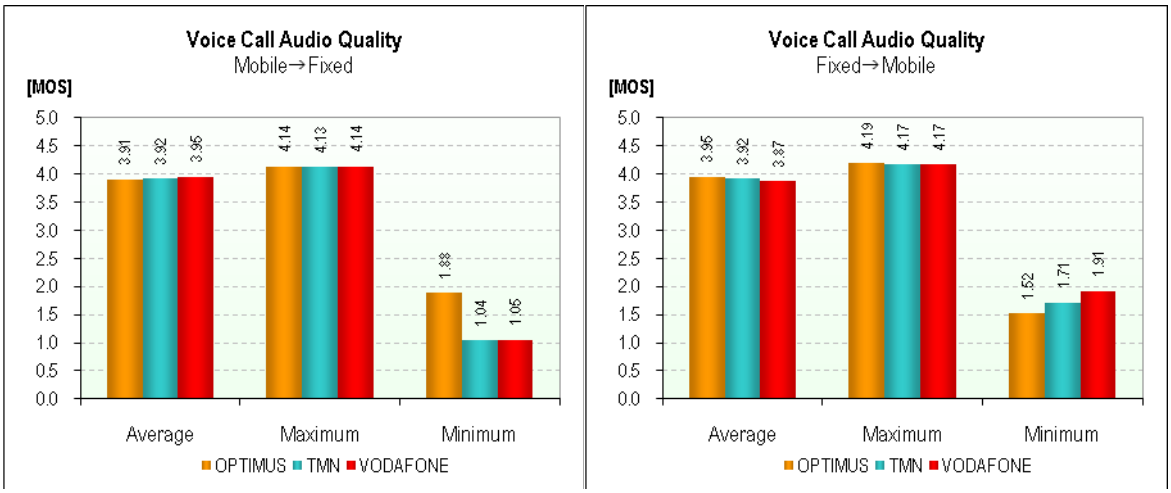
4.3.1.1 *SERVICE ACCESSIBILITY* AND *CALL TERMINATION RATE* INDICATORS



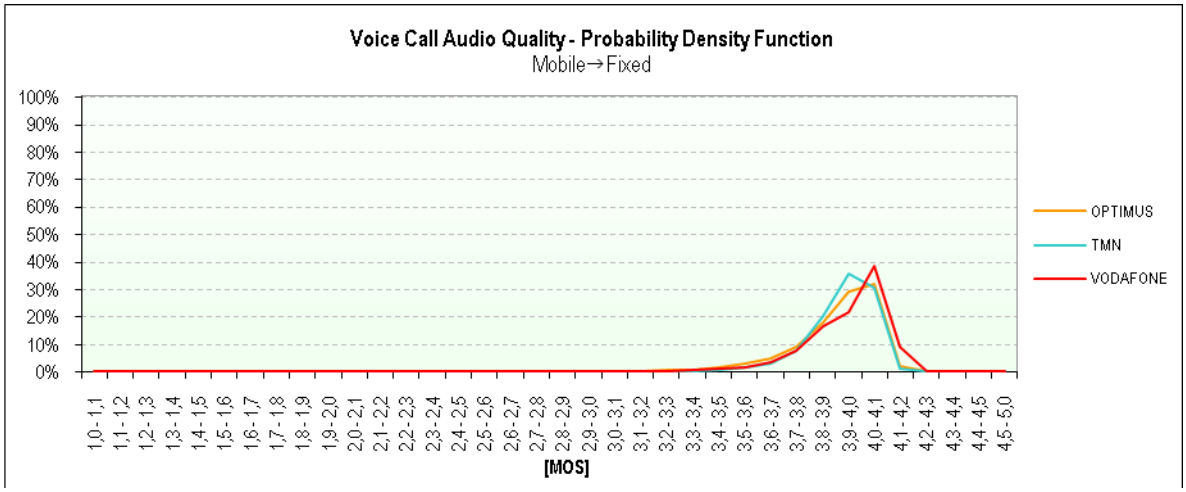
4.3.1.2 *CALL SET UP TIME* INDICATOR

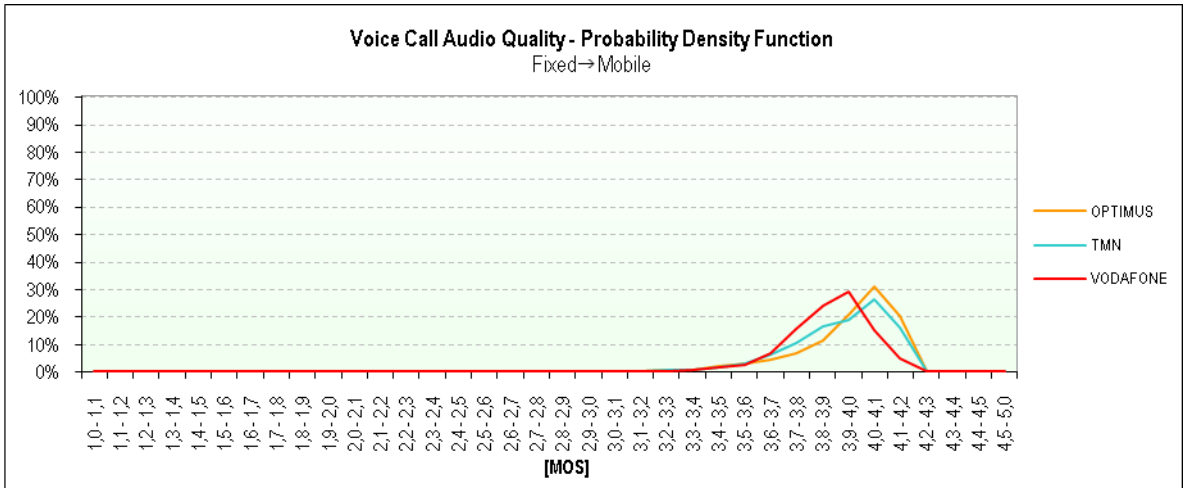


4.3.1.3 *VOICE CALL AUDIO QUALITY* INDICATOR



4.3.1.4 PROBABILITY DENSITY FUNCTION OF THE *VOICE CALL AUDIO QUALITY* INDICATOR





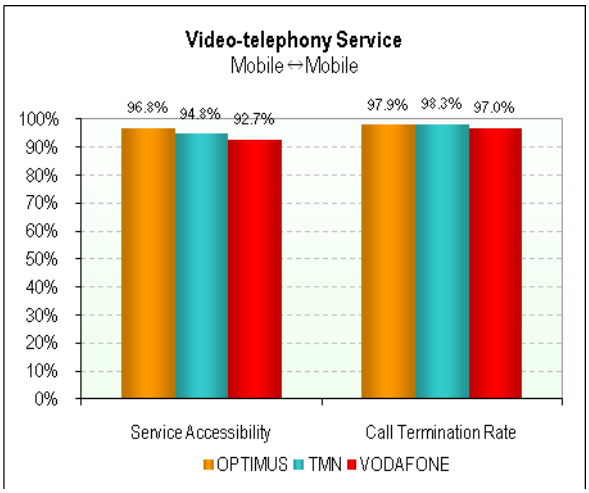
4.3.2 VIDEO-TELEPHONY SERVICE

		OPTIMUS	TMN	VODAFONE
		Mobile↔Mobile	Mobile↔Mobile	Mobile↔Mobile
Calls Made	Number of Calls	3,675	3,689	3,686
	Dropped on Set Up	117	191	270
	Dropped During Call	73	59	104
	With Normal Termination	3,485	3,439	3,312
	Service Accessibility	96.8%	94.8%	92.7%
	Call Termination Rate	97.9%	98.3%	97.0%
Call Set Up	Number of Samples (Calls)	3,558	3,498	3,416
	Average Time [s]	7.1	7.7	5.8
	Maximum Time [s]	22.8	14.7	25.4
	Minimum Time [s]	5.2	5.7	4.2
	Standard Deviation [s]	1.4	1.2	1.1
Audio Quality	Number of Samples (Calls)	6,967	6,877	6,624
	Average [MOS]	3.94	3.93	3.95
	Maximum [MOS]	4.05	4.05	4.05
	Minimum [MOS]	1.00	1.00	1.00
	Standard Deviation [MOS]	0.21	0.21	0.17
Video Quality	Number of Samples (Calls)	6,970	6,878	6,624
	Average [MOS]	2.36	2.35	2.33
	Maximum [MOS]	2.67	2.67	2.67
	Minimum [MOS]	1.00	1.00	1.09
	Standard Deviation [MOS]	0.25	0.30	0.26

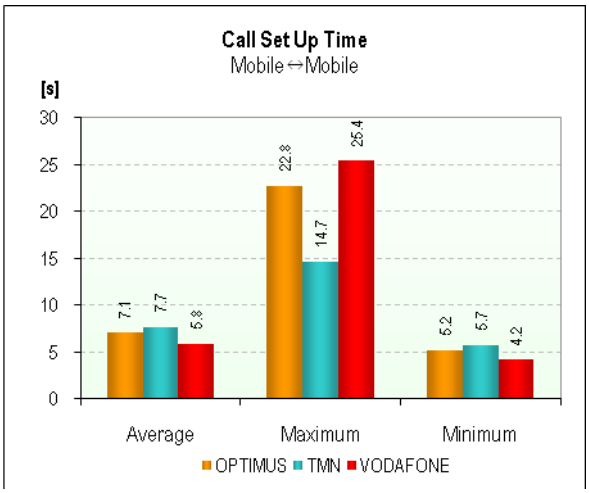
		OPTIMUS	TMN	VODAFONE
		Mobile↔Mobile	Mobile↔Mobile	Mobile↔Mobile
Precision Error	Service Accessibility	0.6%	0.8%	0.9%
	Call Termination Rate	0.5%	0.5%	0.6%
	Call Set Up Time [s]	0.047	0.039	0.037
	Audio Quality [MOS]	0.005	0.005	0.004
	Video Quality[MOS]	0.006	0.007	0.006

Confidence Level = 95 %

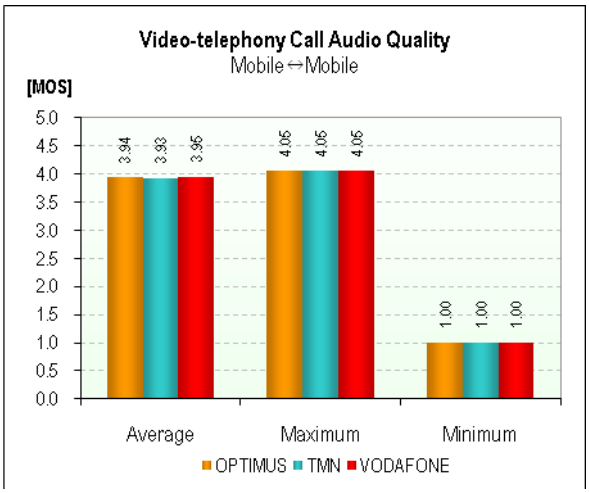
4.3.2.1 *SERVICE ACCESSIBILITY* AND *CALL TERMINATION RATE* INDICATORS



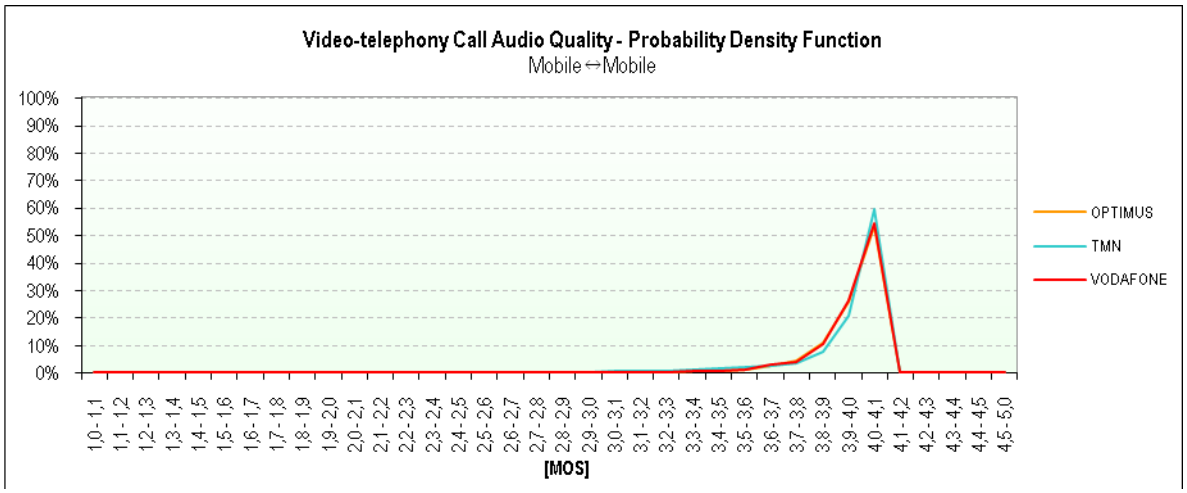
4.3.2.2 *CALL SET UP TIME* INDICATOR



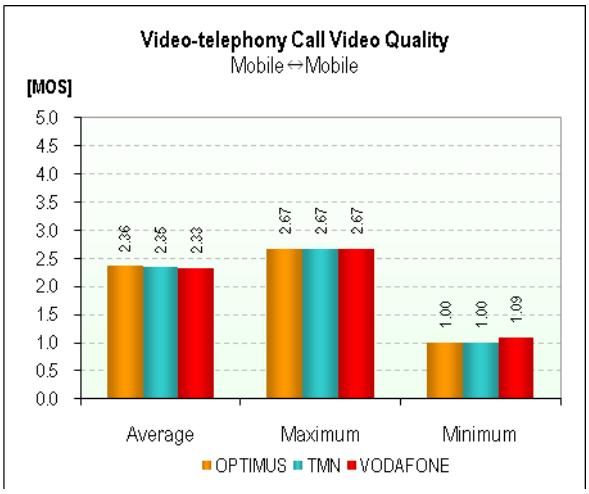
4.3.2.3 *VIDEO-TELEPHONY CALL AUDIO QUALITY* INDICATOR



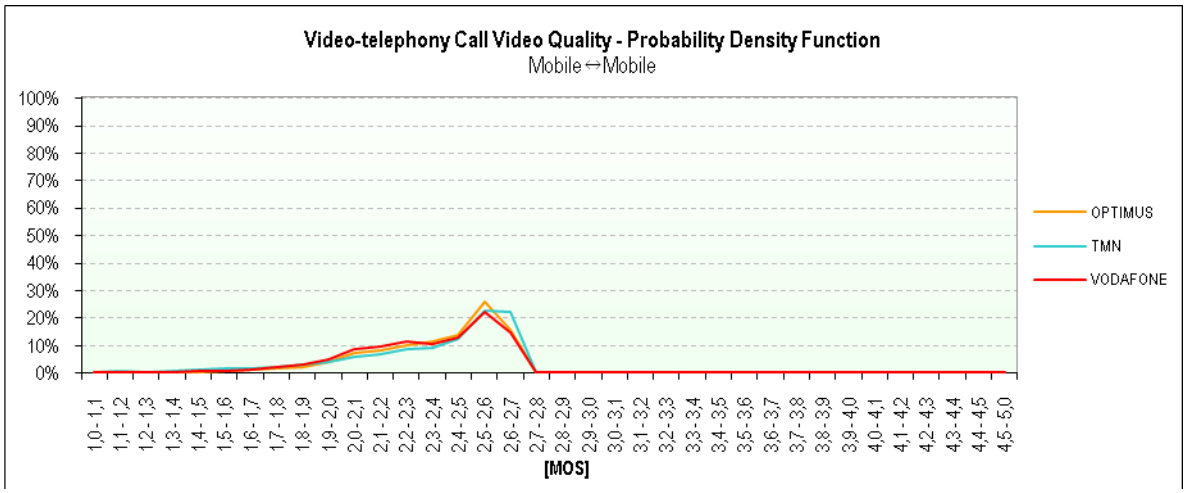
4.3.2.4 PROBABILITY DENSITY FUNCTION OF THE *VIDEO-TELEPHONY CALL AUDIO QUALITY* INDICATOR



4.3.2.5 *VIDEO-TELEPHONY CALL VIDEO QUALITY* INDICATOR



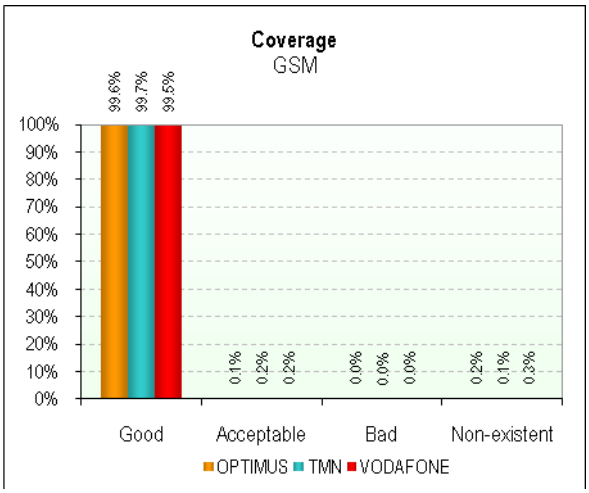
4.3.2.6 PROBABILITY DENSITY FUNCTION OF THE *VIDEO-TELEPHONY CALL VIDEO QUALITY* INDICATOR



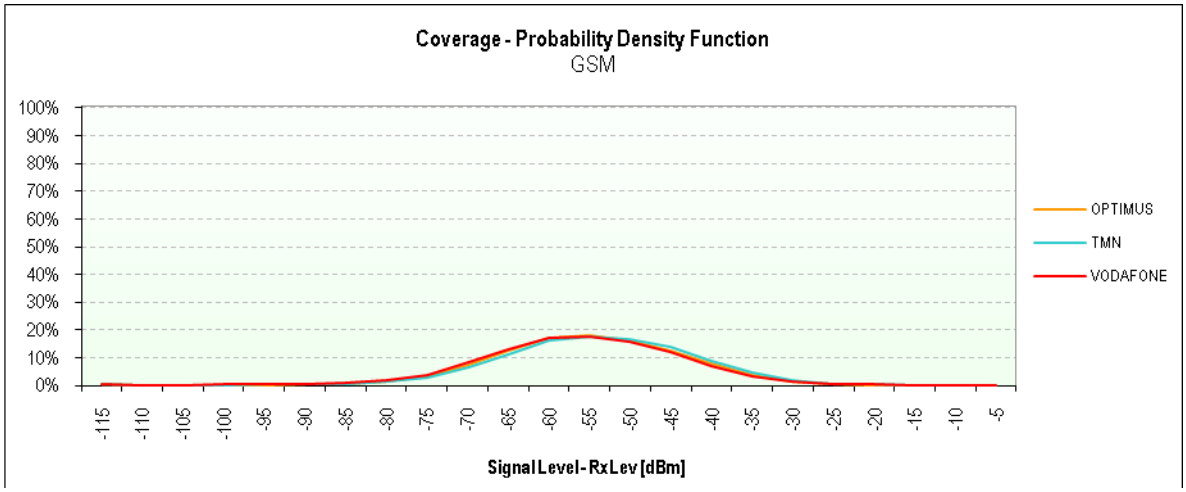
4.3.3 NETWORK COVERAGE

		GSM			WCDMA		
		OPTIMUS	TMN	VODAFONE	OPTIMUS	TMN	VODAFONE
Coverage	Number of Samples (Measurements)	786,854	786,713	786,776	790,230	790,473	790,261
	Average Signal Level [dBm]	-53	-52	-53	-77	-74	-78
	Maximum Signal Level [dBm]	-21	-16	-17	-33	-21	-27
	Minimum Signal Level[dBm]	-115	-115	-115	-136	-138	-139
	Standard Deviation [dBm]	11	11	11	13	14	17
	Good	99.6%	99.7%	99.5%	91.9%	92.9%	86.0%
	Acceptable	0.1%	0.2%	0.2%	6.3%	5.2%	7.0%
	Bad	0.0%	0.0%	0.0%	1.5%	1.5%	3.8%
	Non-existent	0.2%	0.1%	0.3%	0.3%	0.4%	3.2%

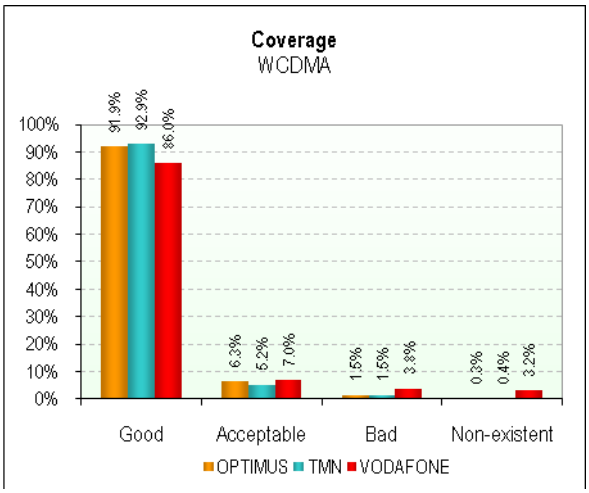
4.3.3.1 GSM



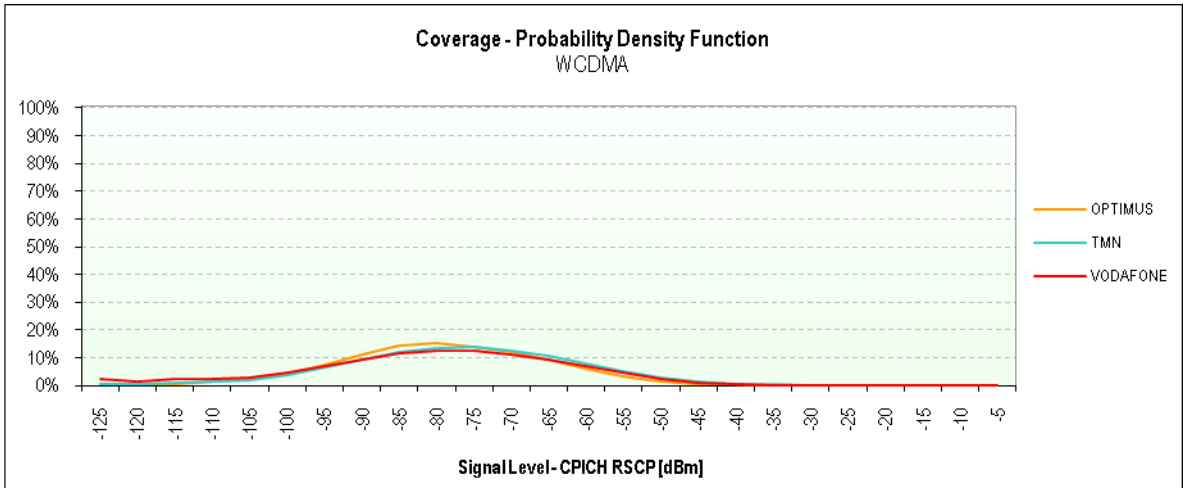
4.3.3.2 GSM - PROBABILITY DENSITY FUNCTION



4.3.3.3 WCDMA



4.3.3.4 WCDMA - PROBABILITY DENSITY FUNCTION

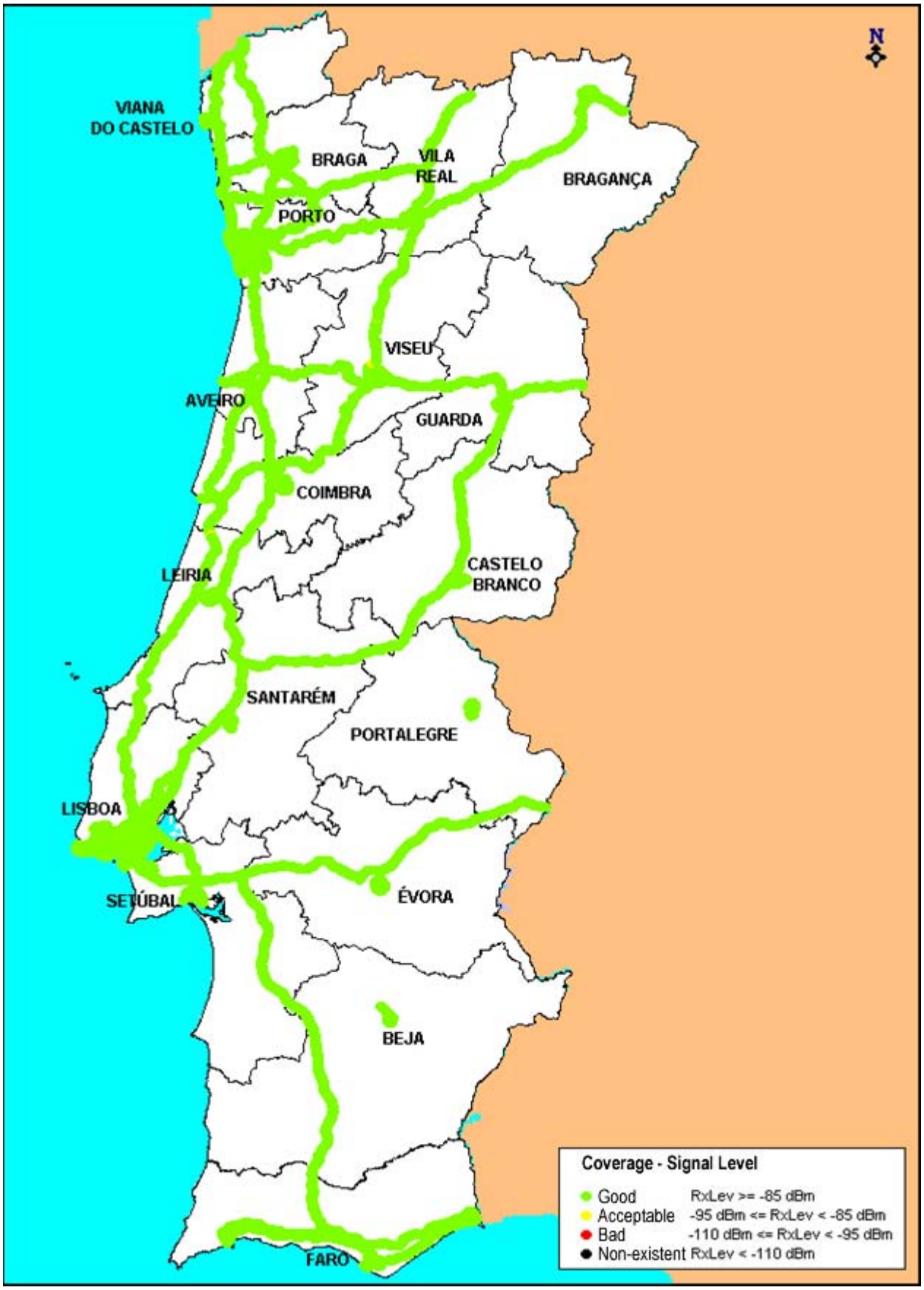


4.3.3.4.1 COVERAGE MAPS

(Following pages)

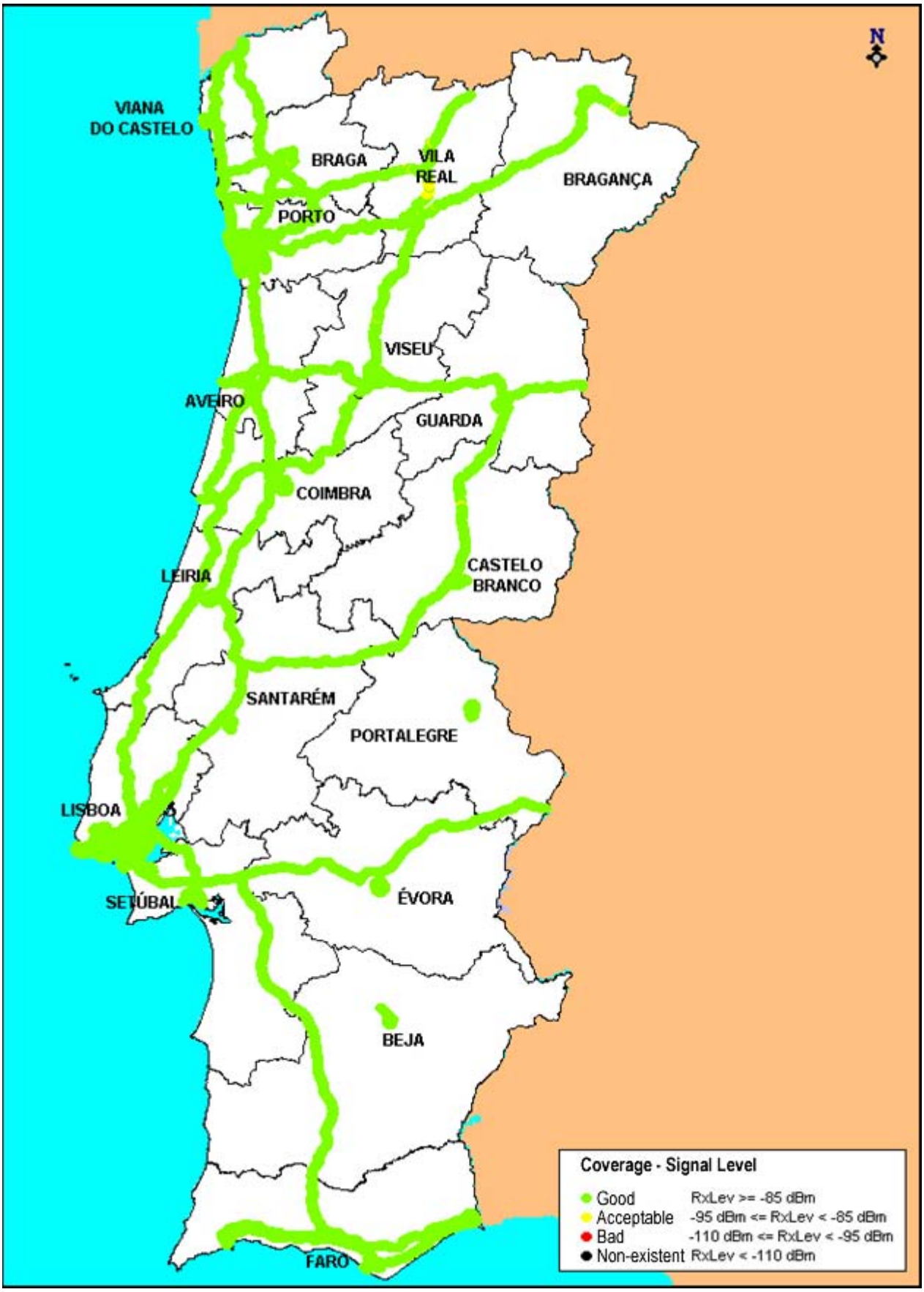
MAINLAND PORTUGAL

OPTIMUS – GSM Coverage



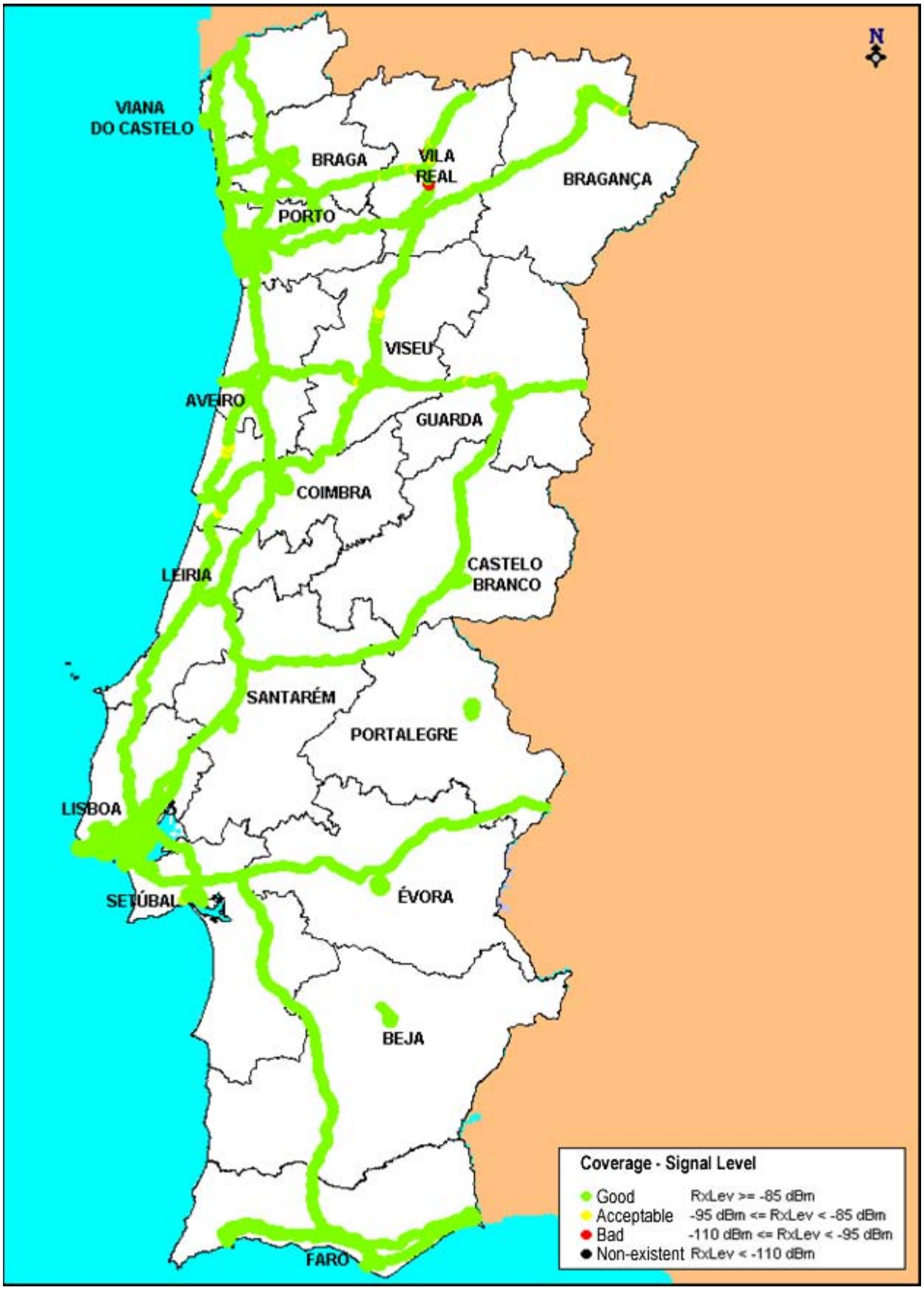
MAINLAND PORTUGAL

TMN – GSM Coverage



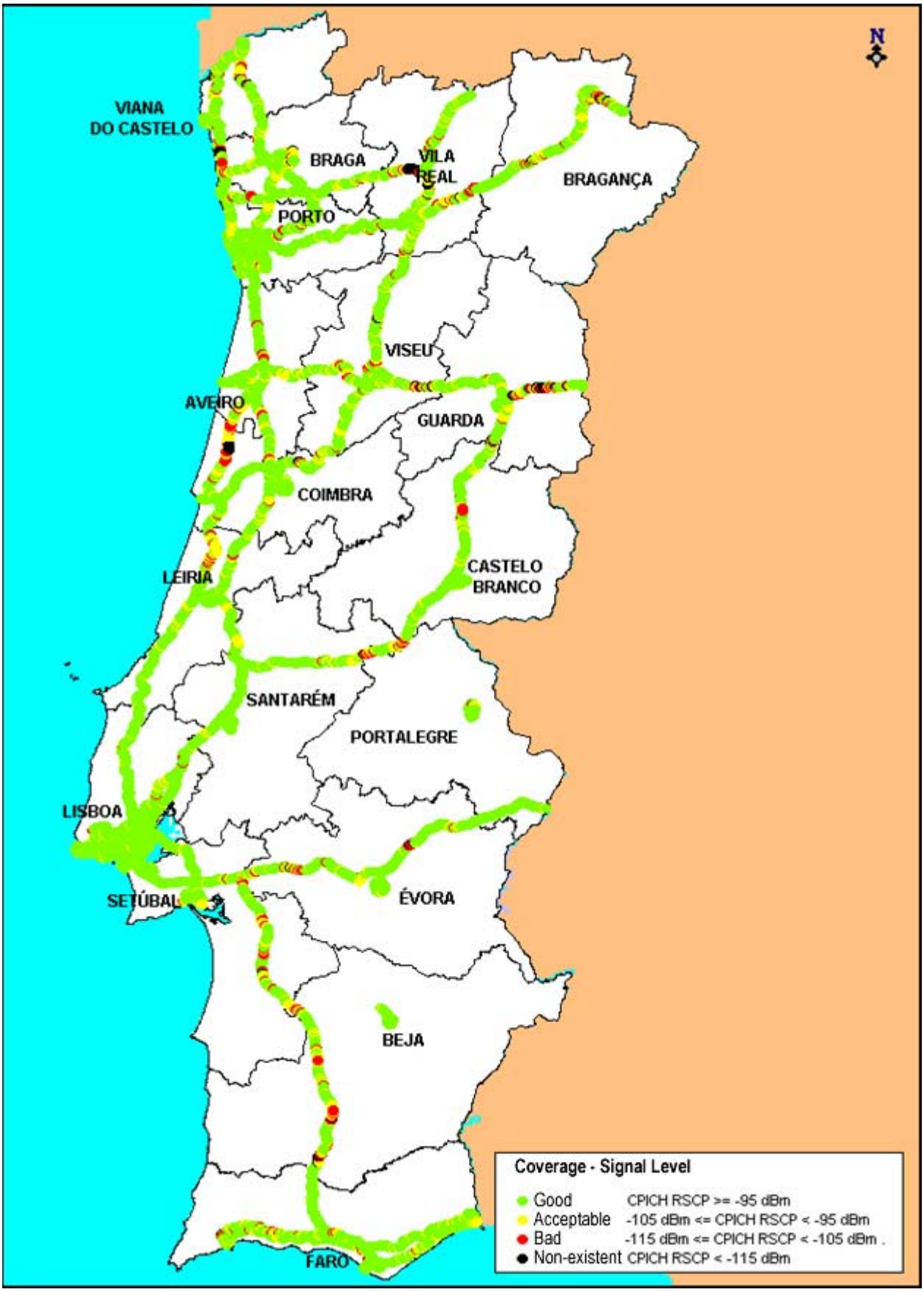
MAINLAND PORTUGAL

VODAFONE – GSM Coverage



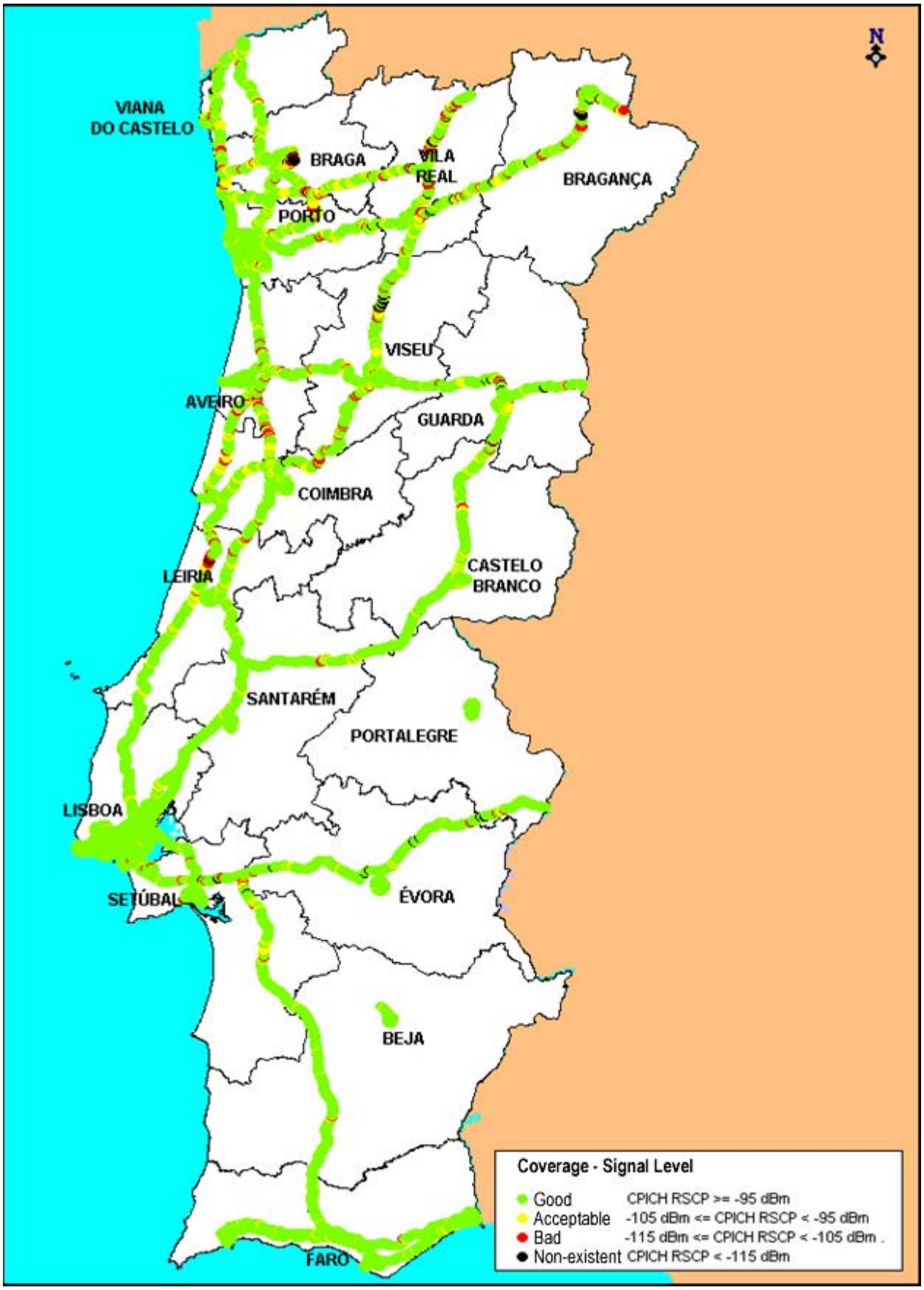
MAINLAND PORTUGAL

OPTIMUS – WCDMA Coverage



MAINLAND PORTUGAL

TMN – WCDMA Coverage



MAINLAND PORTUGAL

VODAFONE – WCDMA Coverage