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SERIES E: OVERALL NETWORK OPERATION, TELEPHONE SERVICE, SERVICE OPERATION AND HUMAN FACTORS

Quality of telecommunication services: concepts, models, objectives and dependability planning – Models for telecommunication services

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Quality measurement in major events

Recommendation ITU-T E.811

ITU-T

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Recommendation ITU-T E.811

Quality measurement in major events

Summary

Recommendation ITU-T E.811 addresses the quality assessment of mobile broadband and voice services provided during major events, such as FIFA World Cups and Olympic and Paralympic Games, by creating a useful international reference to be considered by operators and regulators when preparing to host such events.

History

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FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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Introduction

To ensure a quality of service (QoS) and quality of experience (QoE) in mobile broadband and voice services in and around crowded and large venues, with thousands of people sharing pictures, videos and accessing social networks simultaneously, is a big challenge for operators and regulators worldwide. This scenario comes as a result of the fast penetration of smartphones and the increase of quality thresholds necessary to guarantee user satisfaction. Taking into account that monitoring strategies to be adopted by regulators are not well defined yet, the efforts to measure QoS and QoE parameters to assure good quality during major events are based more in empiricism than in standards and trusted technical references.

The reports from FIFA World Cup Brazil 2014 and Rio 2016 Summer Olympic Games showed the explosion of voice, data and SMS traffic during the events, not just inside the game venues at the host country but in many regions around the world, due to the massive sharing of pictures and videos in social media and streaming applications. In this scenario, the biggest challenges faced by operators is to forecast the traffic demand and then deploy an infrastructure that mix 2G, 3G, 4G, 5G and Wi-Fi offloading approaches to ensure the quality of mobile services during the events, especially inside and around the crowded stadiums. Given the lack of technical references for this specific context of service provision, the successful experiences and main issues faced by the previous host countries is sometimes the unique reference.

Recommendation ITU-T E.811

Quality measurement in major events

1 Scope

This Recommendation addresses the quality assessment of mobile broadband and voice services provided during major events, such as FIFA World Cups and Olympic and Paralympic Games, by creating a useful international reference to be considered by operators and regulators when preparing to host major events.

This Recommendation covers the following:

1) traffic forecasting and network dimensioning applied to major events
2) establishing strategies of QoS and QoE measurements during major events
3) identifying the relevant key performance indicators (KPIs) to be measured
4) establishing network capabilities and reasonable thresholds that should be achieved to assure users satisfaction in the context of major events.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T E.800] Recommendation ITU-T E.800 (2008), *Definitions of terms related to quality of service.*

[ITU-T E.802] Recommendation ITU-T E.802 (2007), *Framework and methodologies for the determination and application of QoS parameters*.

[ITU-T E.803] Recommendation ITU-T E.803 (2011), *Quality of service parameters for supporting service aspects.*

[ITU-T E.804] Recommendation ITU-T E.804 (2014), *QoS aspects for popular services in mobile networks.*

[ITU-T E.807] Recommendation ITU-T E.807 (2014), *Definitions, associated* measurement *methods and guidance targets of user-centric parameters for call handling in cellular mobile voice services.*

[ITU-T E-800 series] ITU-T E-800 series Supplement 9 (2013), *Supplement 9 to ITU-T E.800-series Recommendations (Guidelines on regulatory aspects of QoS).*

[ITU-T P.10] Recommendation ITU-T P.10/G.100 (2006), *Vocabulary for performance and quality of service.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 benchmark [ITU-T E.804]: Evaluation of performance value(s) of a parameter or set of parameters for the purpose of establishing value(s) as the norm against which future performance achievements may be compared or assessed.

3.1.2 call [b-ETSI EG 202 009-2]: Any connection (fixed or temporary) capable of transferring information between two or more users of a telecommunications system. In this context a user may be a person or a machine.

3.1.3 customer [ITU-T E.800]: A user who is responsible for payment for the services.

3.1.4 measure [ITU-T E.800]: A unit by which a parameter may be expressed.

3.1.5 multimedia services [ITU-T E.800]: A telecommunications service that supports the simultaneous use of multiple media types (e.g., voice, data, video).

3.1.6 network operator [ITU-T E.802]: An organization that provides and operates a telecommunication network for the purpose of transporting bearers of telecommunication services.

3.1.7 quality of experience [ITU-T P.10]: The overall acceptability of an application or service, as perceived subjectively by the end-user.

NOTE 1 – Quality of experience includes the complete end-to-end system effects (client, terminal, network, services infrastructure, etc.).

NOTE 2 – Overall acceptability may be influenced by user expectations and context.

3.1.8 quality of service [ITU-T E.800]: Totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service.

3.1.9 service [ITU-T E.800]: A set of functions offered to a user by an organization.

3.1.10 session [ITU-T E.804]: Continuous usage of a given service, e.g., a speech call or a data session.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 data PoI congestion: The cumulated data session block rate of all serving cells in the point of interest (PoI), during the desired measurement interval considering all data technologies.

3.2.2 data service availability: The numerical measurement of the service uptime on a data network where network resources for the service are available and functional. Mathematically, Data Service Availability = Service Uptime (hrs) / [Service Downtime (hrs) + Service Uptime (hrs)].

3.2.3 data session block rate: The ratio of the number of rejected data session requests to the total number of data session requests.

3.2.4 data session drop rate: The ratio of the number of dropped data sessions to the total number of established data sessions.

3.2.5 delay variation (jitter): The difference between the actual end-to-end delay measured and the minimum end-to-end delay observed.

3.2.6 download/upload data rate: The volume of downloaded/uploaded data traffic per second.

3.2.7 end-to-end delay: The length of time it takes for a data packet to be sent to the destination plus the time it takes for an acknowledgement of that data packet to be received. This is also known as the round-trip time (RTT).

3.2.8 packet data traffic utilization: The ratio of the cumulative utilized packet data resource elements (REs) on the e-NodeBs and EPC to the available packet data resources.

3.2.9 RF traffic channel utilization: The ratio of the cumulative occupation of RF traffic channels on the access network to the available RF traffic channels in a specific cell.

3.2.10 voice block call rate: The ratio of the number of blocked calls to the total number of call attempts.

3.2.11 voice call drop rate: The ratio of the number of dropped calls to the total number of established calls.

3.2.12 voice PoI congestion: The cumulated voice block call rate of all serving cells in the PoI, during the desired measurement interval considering all voice technologies.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

BTS	Base Transceiver Station
CE	Channel Elements
COW	Cell On Wheels
CQI	Channel Quality Indicator
CRH	Cell Reselection Hysteresis
DAS	Distributed Antenna System
EPC	Evolved Packet Core
KPI	Key Performance Indicator
LAC	Location Area Code
MNO	Mobile Network Operator
NMS	Network Management System
OTT	Over The Top
RB	Resource Blocks
PoI	Point of Interest
PM	Performance Management
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RF	Radio Frequency
ROA	Recognized Operating Agency
SDCCH	Stand-alone Dedicated Control Channel
SMS	Short Message Service
TCH	Traffic Channel
TFQ	Traffic Forecasting Question
TRX	Transreceiver

5 Conventions

Regulator: telecommunications regulatory governmental body, for example a telecommunications agency, authority or ministry.

Operator: recognized operating agency (ROA) or operating agency licensed to provide telecommunications mobile voice and/or data services in the country that is hosting a major event.

6 Traffic forecasting and network dimensioning applied to major events

6.1 Considerations for traffic forecasting in major events

Defining the correct traffic forecasting strategy to estimate the demand for voice and data services is the first key step to ensure the provision of service quality in major events. The following actions are recommended in order to estimate the traffic of voice and data services in major events:

a) Operators should begin performing a comprehensive mapping of the events schedule, the games specific characteristics and the locations used, in order to know when, where and how long the crowds are supposed to be at the main venues and surrounding areas, training centres, public transport lines and popular squares (points of interest (PoI)). The event sponsor may provide information about the expected audience, as well as the expected user profile.

b) After mapping the event details the operators should better understand users' expectations for the usage of mobile networks during the games and plan their networks to provide the best possible experience. Defining an average user usage profile based on the mapping information may simplify the network design.

c) In order to tackle the challenge of estimating usage profiles that better approximate the prepaid, post-paid and roaming users' behaviours in the scenario of major events, where the demand for telecommunication services is disproportionately excessive when compared with the regular demand faced by operators, the use of interactive forecasting methods is recommended. For example, the Delphi Methodology [SACKMAN, H. (1974)] has been used by telecommunication experts who are experienced in demand analysis, traffic management and network planning and operation, and engaged by mainly operators and vendors with know-how in service provision in stadiums and concert arenas. It is also recommended to collect information directly from users through customer surveys, in order to directly capture what their preferences would be during the games.

d) As well as deciding which information gathering methodology should be adopted, the operators must precisely define which sort of information is important for traffic dimensioning in this scenario. In order to comprehensively understand users' behaviours and elaborate accurate usage profiles for voice and data services, it is recommended for operators to, at the least, answer the traffic forecasting questions (TFQs) below:

Table 1 – Traffic forecasting questions (TFQs)

ID	Question	Methodology
TFQ1	What is expected to be the percentage of mobile prepaid/post-paid/roaming users from a given operator inside each relevant location related to the major event, e.g., the game venue and its surrounding areas?	Delphi
TFQ2	What is expected to be the smartphone penetration among these prepaid/post-paid/roaming users?	Delphi
TFQ3	What is expected to be the distribution of the prepaid/post-paid/roaming users among the mobile network technologies available (e.g., 2G/3G/4G/5G)?	Delphi

Table 1 – Traffic forecasting questions (TFQs)

ID	Question	Methodology
TFQ4	What is expected to be the percentage of roaming users willing to use only Wi-Fi networks to access the Internet?	Delphi
TFQ5	How many traditional voice calls are the prepaid/post-paid/roaming users expected to make?	Delphi/Customer survey
TFQ6	How long (in seconds) on average are the prepaid/post-paid/roaming users expected to take on each call?	Delphi/Customer survey
TFQ7	What percentage of their voice plan are the prepaid/post-paid/roaming users willing to use in one game?	Delphi/Customer survey
TFQ8	What smartphone applications are the prepaid/post-paid/roaming users expected to use?	Customer survey
TFQ9	How many pictures are the prepaid/post-paid/roaming users expected to download/upload?	Customer survey
TFQ10	How many videos are the prepaid/post-paid/roaming users expected to download/upload?	Customer survey
TFQ11	What percentage of the data plan are the prepaid/post-paid/roaming users willing to use in one game?	Delphi/Customer survey

e) Having collected the information to answer TFQs 5 to 11, the operators, when precisely modelling the users' voice and data traffic usage profiles per contract type and technology used, and making the correlation with theses profiles and the information collected to answer TFQs 1 to 4, can then predict the peak traffic demand that should be supported by the network in each relevant location related with the major event.

6.2 Considerations for network dimensioning in major events

After conducting a forecast of the voice and data traffic demand, the operators' network dimensioning should be targeted to provide satisfactory QoS and QoE results, mainly in those KPIs identified in clause 8. In this regard, the following actions are recommended to be considered by the operators:

a) complementary deployment of macro-cells, small cells and cells on wheels (COWs);

b) conservative choosing of the network contention ratio (e.g., less than 1:10);

c) provisioning of Wi-Fi networks for data traffic offloading;

d) possibility of dynamic changing in radio access network (RAN) parameters to guarantee coverage and capacity for moving crowds.

e) interference management among the RAN elements and also the professional media equipment (e.g., intermodulation issues) to avoid degradation in spectral efficiency.

7 Strategies of QoS and QoE measurement during major events

One of the main roles of the government in the preparation for hosting a major event is to ensure that the installed telecommunication network capacity in all the relevant locations related to the major event is adequate to meet the higher than typical peak demands from a large amount of users making voice calls, sending SMSs, downloading and uploading pictures and videos and accessing social media at the same time. Also, it is recommended for the government to monitor the results of the QoS and QoE main KPIs during major events in order to guarantee that the voice and data traffic demand and profile experienced during the events are aligned with the prior traffic forecasting and network planning, thus reducing response time in case of performance degradation.

7.1 Considerations for network quality audit prior the major events

Network quality audit, in principle, seeks to highlight major issues and provides all the necessary background for further analysis, investigation and in-depth prognosis of the major potential performance-impacting problems in the network. The network quality audit requires a methodical process and should be systematic in its approach with regard to data collection and analysis. The following questions are recommended to regulators in the network quality audit:

1) What parameter(s) are we trying to audit?
2) Why are we auditing it/them and what is the relevance of the measurement to network quality?
3) How will the audit findings be presented, and in what kind of graph and format?
4) What possible conclusions can be drawn from the results?
5) Based on observations and conclusions, what actions can be done for solving the problem or for further investigation?

Furthermore, the following principles are recommended to be considered by regulators in order to verify the capability of the operators to deliver satisfactory quality telecommunication services during major events:

a) An operator's network planning for the venues and their vicinities should be known by the regulator in order to better identify critical points, bottlenecks and to select the right elements to monitor. The network plans provided should contain detailed information about the existing sites (such as technologies used, links and base stations' capacity, transmission planning, routes, redundancies, risk mitigation plans, etc.), sites to be commissioned and COWs, whilst also outlining shared infrastructure when applicable.
b) Based on the information provided by the operators, the regulator may evaluate if the existing and planned network resources will be sufficient to meet the estimated demand. If it is not, the regulator must instruct the network operator to present an action plan to upgrade its network capacity or provide a temporary solution (such as the installation of mobile cell sites).
c) Also based on the operator's network planning, the regulator can decide which network elements and main KPIs should be monitored to assess the usage level of the base stations and its backhaul links' capacities. The regulator may set thresholds to these KPIs based on the references provided in clause 8, in order to trigger interactions with the operators before quality degradation becomes perceptible by the users.
d) A last-minute network audit is recommended just before the kick-off of major events in order to assure the readiness of the planned infrastructure.

7.2 Considerations for network quality monitoring during major events

Monitoring the results of QoS and QoE main KPIs during major events is extremely important to ensure that all the planning work made previously is adequate to real voice and data traffic demand experienced during the events, thus reducing response time to mitigate the risks of performance degradation or even telecommunications blackout. For this, the network quality monitoring is recommended to consider the following principles:

1) Cause and effect analysis: Identify the problem nodes, locations and points of failure in the network, as well as their level of impact on subscriber experience.
2) Trend analysis: an in-depth breakdown on general and specific incidental network problems and how to resolve them.
3) Recommendations: Directives from the regulator may be issued to enforce operator's network coverage/capacity expansion in response to potential risks identified in the cause and effect analysis and trend analysis.

4) Results transparency: Quality monitoring releases may be issued and published by regulators periodically (daily short reports are appropriate) in order to give transparency on the quality of services being provided during major events.

Furthermore, the following principles are recommended to be considered by regulators in order to monitor service quality during major events:

a) Regulators may have real-time access or at least daily reports from operators, outlining in detail the profile of the traffic carried, by service and technology, the KPIs results and the unplanned events that have happened. This enables the regulator and also the network operators to plan in advance responses for the risks of where traffic exceeds the expected demand, and to jointly deploy contingency plans. Reporting and verification procedures may include the following:
   1) Verify if all required network statistics data have been sent by each operator.
   2) Monitor incoming and outgoing traffic volumes and RAN utilization and congestion figures.
   3) Monitor site's backhaul utilization and congestion figures.
   4) Prioritize the handling of service interruption notifications.
   5) Observe and verify the trend of line charts of radio parameters in mapping correspondence with license or optimal network operating thresholds.

b) In order to obtain the aforementioned real-time access, regulators may deploy a network performance monitoring system that connects to the network operator's monitoring centre and get timely feedback of network quality data on a 24/7 basis. Alternatively, a regulator official may be placed at the network operator's monitoring centre during the major events. Such a high level of oversight on network operators during major events is justified by the criticality of having quick responses to network degradation figures.

c) Regulators may perform measurements from the user's perspective, mainly using drive-test tools, probes and walking tests, in order assess QoS and QoE effectively delivered by the networks.

8 Relevant KPIs to be measured in the context of major events

The following quality parameters have been identified as useful metrics in crowded areas in major events, for both the regulator and the network operator to assess the user experience of mobile voice and data services, ensuring the system is performing satisfactorily. These KPIs can be divided into two categories:

8.1 Critical KPIs

The following list contains a set of the critical KPIs to be monitored by the regulator. The monitoring of these parameters is essential to evaluate if the operator's network is delivering the desired quality during the events. If any of these exceeds their defined threshold, the user is very likely to notice the network quality degradation, therefore, the regulator must demand immediate action from the network operator:

- voice block call rate
- data session block rate
- voice call drop rate
- download/upload data rate

One of the biggest challenges to providing network quality in such crowded areas as in major events is the ability of the network to withstand the increased traffic without constantly experiencing congestion. Thus, it is recommended to evaluate the blocking rate in such a way that the whole PoI servicing network (all cells) is considered for a faster and more effective monitoring analysis of overall voice and data performance. This can be done using two parameters that aggregate the voice and data blocking KPIs of all cells and all technologies available in a given PoI:

- data PoI congestion
- voice PoI congestion

Once these KPIs are calculated, a key factor to be evaluated is if there are discrete congestion peaks or if the congestion is persistent during consecutive intervals.

8.2 Diagnostic KPIs

Degradation in the following KPIs are not necessarily perceived by the users as a degradation of service quality. However, these KPIs are recommended to be monitored, since they can provide useful insights on whether the network is close to its limits and may fail to deliver the expected quality.

- data session drop rate
- packet data traffic utilization
- RF traffic channel utilization
- data service availability
- end-to-end delay (RTT)
- delay variation (Jitter)

As previously mentioned in clause 7.2, to obtain a clearer picture of the user's real experience it is recommended to conduct a field test, such as walking tests and drive tests simulating the usage of popular applications (e.g., web browsing, chatting, pictures and video transferring, etc.). Furthermore, other QoE KPIs related to popular applications may be monitored through field tests in order to assess a user's perspective on the services provided.

9 Capabilities and levels to assure users satisfaction in the context of major events

In order to ensure QoS/QoE of mobile voice and data services, it is necessary to timely monitor and evaluate the performance of critical and diagnostic KPIs defined in clause 8. In this regard, it is recommended to regulators the definition of minimum/maximum thresholds for each aforementioned KPI in the context of major events, in order to serve as references for telecommunication risk management during the events. These thresholds may be used in cause and effect analysis and also in trend analysis, thus empowering regulators to issue comprehensive recommendations and directives to operators requesting QoS and QoE improvements during major events.

Below is a table of recommended thresholds for each KPI identified in clause 8. These thresholds may be considered as references for operators and regulators in the context of major events, and have been used for some countries in network design and monitoring in such a context. On the other hand, the values presented may differ depending on the local regulations and the estimated average user profile.

Table 9-1 – Relevant KPIs and thresholds[1]

Critical and diagnostic KPIs	Threshold[1]	How to measure?
Voice call drop rate	Equal to or less than 2%	Network PM counters, walk test and drive test
Voice block call rate	Equal to or less than 2%	Network PM counters
Data session block rate	Equal to or less than 2%	Network PM counters
Data session drop rate	Equal to or less than 2%	Network PM counters
Download/Upload data rate	256 kbps or greater	Network PM counters
Download/Upload data rate	2 Mbps or greater	Walk test and drive test
Data service availability	Equal to or higher than 99.9%	Network PM counters
Packet data traffic utilization	Equal to or less than 85%	Network PM counters
RF traffic channel utilization	Equal to or less than 85%	Network PM counters
End-to-end delay	Less than 200 ms (except 2G)	Walk test and drive test
Delay variation (Jitter)	Less than 80 ms	Walk test and drive test
Voice PoI congestion	Equal to or less than 2% (less than 4% in non-consecutive peak hours)	Network PM counters
Data PoI congestion	Equal to or less than 2% (less than 4% in non-consecutive peak hours)	Network PM counters

Among the KPIs shown in the Table 9-1, some of them deserve special consideration based on their potential to frustrate user's expectations about service quality. Call drop rate and block call rate are of particular interest, since they are linked with network coverage/capacity limitations and co-channel and/or adjacent channel interferences. Thus, in order to avoid issues with these sensitive KPIs, network optimizations are recommended to be carried out focusing on identifying and addressing performance abnormalities, like network coverage, capacity and/or interference issues.

Also, congestion in RAN resources may be addressed by adding more transceivers if RF traffic channels (TCHs) and when the limit of adding more transceivers to a specific cell is reached, COWs, femto, pico and/or sectored cells may be set up quickly to increase RF spectrum re-utilization. For indoor environments, solutions like Wi-Fi offloading are recommended to meet users' traffic demand.

Another aspect affecting a cell's capacity and coverage is antenna up-tilting or down-tilting. The cell's tilt may be dynamically tuned during the event to fit capacity and/or coverage requirements that can be changed by crowds' movements during a game day (temporal and spatial traffic variations). Thus, the heterogeneity of mobile voice and data traffic loads require repeated optimizations as cells are underutilized and over-utilized during major events, with RF traffic channels in cells with underutilization being relocated to other cells with more traffic demands.

1 Provisional values based on FIFA World Cup 2014, African Cup of Nations 2008and Rio 2016 Summer Olympic Games experiences are detailed in appendices 1, 2 and 3.

Appendix I

Quality measurement in 2014 FIFA World Cup

(This appendix does not form an integral part of this Recommendation.)

I.1 Introduction

In 2014 Brazil hosted the FIFA World Cup 2014 and the biggest challenge to Anatel, the Brazilian telecommunications regulator, was to ensure the quality of mobile networks in order to allow thousands of fans to enjoy 3G and 4G mobile data services satisfactorily; for example, by enabling the sharing of videos and photos of games on social networks.

For this, a new strategy for quality assessment was deployed in the 12 arenas, which enabled the monitoring in real time of the quality indicators during the games.

What follows is a report of this measurement strategy and also some insights into the preparations and monitoring for the quality of telecommunication services during the Olympic and Paralympic Games in 2016 are given.

I.2 FIFA World Cup 2014 context

I.2.1 Traffic monitoring and quality KPIs

Monitoring performance indicators during the matches was achieved with the data received by each base station installed in the arenas in real time. For these stations, data was sent up to 10 o'clock on the morning after each game. For real-time monitoring the strategy was to access the operator systems remotely to measure the quality of the services being provided. But for reporting and records to the regulator, data was accordingly submitted and processed daily.

In addition to the performance indicators referred, standardized spreadsheets were also received consolidating traffic volume information in erlangs, Mbps and MB for each game.

The table below shows the capacity of each arena, indicating the number of simultaneous users for voice calls, simultaneous calls for data to 1Mbps, users using Wi-Fi and available technologies.

Table I.1 – Summary of the capacity of mobile telephony by stadium

City	Arena	BTS	Sectors	Voice hour	Data users simultaneous	WI-FI	Public	Technologies
Manaus	Arena Amazônia	46	147	268967	22043	8716	39000	2G-3G-4G-WIFI
Curitiba	Arena da Baixada	44	126	234600	11352	0	39000	2G-3G-4G
Salvador	Arena Fonte Nova	57	147	300333	22823	9104	52000	2G-3G-4G-WIFI
Cuiabá	Arena Pantanal	42	138	239133	19406	8344	40000	2G-3G-4G-WIFI
Recife	Arena Pernambuco	44	123	230200	9450	0	42000	2G-3G-4G
Porto Alegre	Arena Beira Rio	55	171	453867	26420	10801	43000	2G-3G-4G-WIFI
Fortaleza	Arena Castelão	50	137	259500	9892	0	60000	2G-3G-4G
Natal	Arena das Dunas	43	126	236100	9317	0	39000	2G-3G-4G
Rio de Janeiro	Arena Maracanã	61	187	390633	32303	13934	75000	2G-3G-4G-WIFI
Belo Horizonte	Arena Mineirão	55	156	314933	12609	0	58000	2G-3G-4G
São Paulo	Arena Corinthians	51	144	316533	15720	0	62000	2G-3G-4G
Brasilia	Arena Estádio Nacional	46	142	265333	24541	12502	69000	2G-3G-4G-WIFI

Therefore, game by game, carrier by carrier, traffic volume data could be consolidated in erlangs, Mbps and MB. The example below shows dropped and blocked voice and data.

Table I.2 – Summary of the capacity of mobile telephony by stadium (in red: out of threshold)

1 ªFase	Dropped Call (%) (Meta < 2%) - Voice	Blocked Call (%) (Meta < 2%) - Voice	Dropped Call (%) (Meta < 5%) - Data	Blocked Call (%) (Meta < 5%) - Data
ARENA CORINTHIANS- 12/06	2,64	0,79	3,32	1,14
ARENA DAS DUNAS- 13/06	0,99	1,43	1,81	4,45
ARENA FONTE NOVA-13/06	1,52	4,35	1,63	1,12
ARENA PANTANAL-13/06	0,73	0,52	1,37	0,56
ARENA MINEIRÃO- 14/06	3,37	5,1	4,51	0,65
ARENA CASTELÃO- 14/06	2,68	1,44	3,89	0,75
ARENA AMAZÔNIA- 14/06	4,18	3,72	4,51	2,66
ARENA PERNAMBUCO- 14/06	1,14	0,81	2,87	0,68
ARENA ESTÁDIO NACIONAL- 15/06	2,51	2,6	7,09	2,13
ARENA BEIRA-RIO- 15/06	4,27	0,8	3,26	1,04
ARENA MARACANÃ- 15/06	1,94	0,65	3,45	2,15
ARENA FONTE NOVA- 16/06	1,79	1,45	3,14	1,21
ARENA DA BAIXADA-16/06	2,05	0,67	3,89	0,77
ARENA DAS DUNAS-16/06	1,2	0,43	3,22	0,67
ARENA MINEIRÃO-17/06	1,87	7,87	2,92	2,09
ARENA CASTELÃO-17/06	1,75	3,2	4,41	1,41
ARENA PANTANAL-17/06	1,32	2,64	2,55	1,48
ARENA BEIRA-RIO-18/06	2,25	0,78	2	1,11
ARENA MARACANÃ-18/06	1,91	1.08	3,38	1,27
ARENA AMAZÔNIA-18/06	2,59	3,06	4,12	1,52
ARENA ESTÁDIO NACIONAL-19/06	2,32	1,77	6,59	1,53
ARENA CORINTHIANS-19/06	3,32	0,67	4,76	0,8
ARENA DAS DUNAS-19/06	0,86	0,6	4,12	0,55
ARENA PERNAMBUCO-20/06	1,22	1,46	2,29	0,72
ARENA FONTE NOVA-20/06	1,55	2,34	2,52	0,66
ARENA DA BAIXADA-20/06	1,96	0,41	3,25	0,45
ARENA MINEIRÃO-21/06	1,32	1,98	3,44	0,65
ARENA CASTELÃO-21/06	1,9	1,91	2,61	0,66
ARENA PANTANAL-21/06	0,69	0,62	2,64	0,37
ARENA MARACANÃ-22/06	1,36	6,4	3,04	1,1
ARENA BEIRA-RIO-22/06	1,33	0,89	2,25	0,76
ARENA AMAZÔNIA-22/06	2,52	1,26	3,96	1,62
ARENA DA BAIXADA-23/06	2,01	0,45	3,61	1,25
ARENA CORINTHIANS-23/06	2,9	0,71	4,25	1,45
ARENA PERNAMBUCO-23/06	1,05	0,41	1,92	0,61
ARENA ESTÁDIO NACIONAL-23/06	2,22	0,77	6,72	2,57
ARENA DAS DUNAS-24/06	1,08	0,43	5,73	1,82
ARENA MINEIRÃO-24/06	1,33	1,19	3,1	1,46
ARENA PANTANAL-24/06	0,72	0,55	3,66	1,76
ARENA CASTELÃO-24/06	1,35	1,23	2,15	0,98
ARENA FONTE NOVA-25/06	1,27	0,31	2,16	0,87
ARENA BEIRA-RIO-25/06	1,23	0,37	2,52	1,02
ARENA AMAZÔNIA-25/06	1,54	0,7	2,93	1,41
ARENA MARACANÃ-25/06	1,62	3,04	3,43	1,72
ARENA ESTÁDIO NACIONAL-26/06	1,87	0,59	6,19	2,17

For ease of reference, the performance information of the arenas was published on a web page, with a selection of stadiums, games and mobile operators. Thus, a full report with all network performance information from operators could be seen at various occasions, consolidated and segmented by each station.

Figure I.1 – Web pages for FIFA World Cup 2014

The next tables contain additional consolidated data by arena:

Table I.3 – Consolidated quality indicators by cup phase

Phase	Voice drop call rate (%) (threshold < 2%)	Block voice call rate (%) (threshold < 2%)	Data drop call rate (%) (threshold < 5%)	Block data call rate (%) (threshold < 5%)
1st phase	1.79	1.54	3.44	1.31
Round of 16	1.25	0.88	1.73	1.53
Quarter-finals	0.84	0.72	3.56	1.30
Semi-finals	1.66	1.42	2.76	1.6
Third place	0.96	0.47	4.39	1.82
Final	1.45	0.58	2.83	0.90
Consolidated results	1.325	0.935	3.12	1.41

Table I.4 – Consolidated data traffic by cup phase

Phase	Number of games	Data traffic	
		Total of TB/hour (game)	Total em TB/4 hours
1st phase	48	4.101	16.4
Round of 16	8	0.866	3.5
Quarter-finals	4	0.465	1.9
Semi-finals	2	0.249	1.0
Third place	1	0.153	0.6
Final	1	0.165	0.7
Consolidated results	64	6.02	24.1

Table I.5 – Consolidated information of photos, SMS capacity and average speed

Phase	Number of games	Data traffic		
		Total photos (0,55MB) per hour (Upload)	SMS capacity	Kbps average per user
1st phase	48	3.484.432	1.496.303.046,13	165
Round of 16	8	755.960	324.826.592	134
Quarter-finals	4	388.682	167.011.961	157
Semi-finals	2	185.489	79.702.512	125
Third place	1	123.261	37.325.887	190
Final	1	117.832	50.631.326	130
Consolidated results	64	5.055.656	2.155.801.324	150

Table I.6 – Consolidated information of total connections, Total GB/hour and utilization rate

Phase	Number of games	Data traffic				
		Data connection/ hour	Total GB/hour (up+down) HMM	Average GB/ hour	Total Gbps/ hour (up + down) HMM	Utilization rate
1st phase	48	152.691.250	4.101	85	9.11	55.0%
Round of 16	8	29.128.358	866	108	1.93	44.7%
Quarter-finals	4	13.819.584	464	116	1.03	52.3%
Semi-finals	2	10.232.923	249	125	0.55	41.7%
Third place	1	2.830.573	153	153	0.34	63.7%
Final	1	5.219.553	165	165	0.37	42%
Consolidated results	64	213.922.241	5.998	Avg: 93.7	13.33	Avg: 49.90 %

Table I.7 – Consolidated information of total voice traffic, erlangs average and utilization rate

Phase	Voice traffic analysis			
	HMM traffic	Completed calls per hour	Average mErlang	Utilization rate
1st phase	35163	2.910.500	12	20.7%
Round of 16	9567	597.395	16	23.6%
Quarter-finals	4842	270.850	18	22.3%
Semi-finals	2831	202.952	14	32%
Third place	810	60.807	13	22.92%
Final	870	67.239	12.9	17.26%
Consolidated results	54.083	4.109.743	Avg: 14 mErl	Avg:23.13%

Table I.8 – Indicators comparison – FIFA South Africa World Cup 2010 versus FIFA Brazil World Cup 2014

Event	Operators	Average of GB/Arena	Erlangs	Voice completion rate	Data completion rate
South Africa 2010	3	10	51.046	99.20%	97.92%
Brazil 2014	4	95	54.083	98.68%	96.88%

Table I.9 – Data traffic total volume and quantity of sent and received photos

Phases	Number of games	Data traffic (4 hours)	
		Total em TB (uplink + downlink)	Photos (uplink + downlink)
1st phase	48	16.4	29.818.182
Round of 16	8	3.5	6.363.636
Quarter-finals	4	1.9	3.454.545
Semi-finals	2	1.0	1.818.182
Third place	1	0.6	1.090.909
Final	1	0.7	1.272.727
Consolidated results	64	24.1	43.818.182

In conclusion, the actions to share internal infrastructure in arenas and the action plan to meet the traffic demand for the FIFA World Cup 2014 were essential to meet and exceed quality indicators and capacity expectations. The quality of the mobile services was regarded as on or above expectations by the public. There were few occurrences of problems and complaints. Although, it is important to state that in 2014 the penetration of 4G services, which is responsible for the higher peaks of traffic demand, was very low.

Appendix II

Traffic forecasting and network dimensioning in African Cup of Nations 2008

(This appendix does not form an integral part of this Recommendation.)

II.1 Pre-event network audit

Prior to kick-off of the African Cup of Nations 2008, network operators performed a preliminary audit of the existing network infrastructure in terms of the prevailing coverage and capacity conditions of the access and transmission nodes and links within and around the event venue and lodging areas of patrons from visiting countries. The operator aimed to find out if the various network quality and performance indicators such as (TCH/SDCCH congestion and busy hour traffic utilization etc.) on the access, transmission and interconnect links reflected the desired operational levels of efficiency.

This was done non-intrusively using drive-test monitoring tools and intrusively using probes/OMC collection and aggregator nodes. This activity was undertaken in precedence over the traffic forecasting in order to obtain hindsight knowledge of the preparedness of the operator to ably provide mobile telephony and associated value-added service offerings during the event.

II.2 Traffic demand estimation

Having undertaken an audit of the portions of the network directly serving the event and residing locations of patrons the following action was taken to quantify traffic demand levels.

Identify the maximum capacity of event location(s)

There is first the need to estimate the maximum number of people that can fill the various stadia, concert arenas, conference halls, durbar grounds etc. Mobile network operators (MNOs) can then correlate this with peak hour traffic volumes and distribution trends from their OMC-R statistics under quasi-numerical conditions of existing subscribers, in order to anticipate the reality of having to meet the capacity demand of huge numbers of event patrons at any given time during the event.

Use of traffic prediction simulation software

Network diagnostic simulation tools, like OPNET and Monte Carlo (with in-built Matlab capability) was used by MNOs to pseudo-compute the traffic volume having obtained information on the number of patrons that will fill up the event venues. The word "pseudo-compute" was used cautiously here in the sense that the prediction models programmed in these tools allow for a fairly tolerable margin of error in the output generated by these software.

Estimating radio access signalling load

Immediate assignment and location area update signalling messages contributed to about eighty percent (80%) of the signalling load that normally pre-empts call flow procedures for both mobile-originating and terminating cases. In-call and off-call mobility situations meant that there was the need to adaptively retune the configuration parameters that control excessive control-plane signalling messages exchanged between the mobile equipment of event patrons and the operator's network.

Trend analysis of peak hour traffic volumes

Peak or busy hour times depict a significant strain on the network resources of every telecommunication operator. Traffic volumes being highest during such periods can clog traffic channel elements in the access nodes to such congestion levels, which if not controlled can cause a dip in performance levels and consequently affect user service satisfaction. Operators performed a trend analysis of the traffic volumes as they came in and then placed a cap, e.g., Tmax, on the traffic-time graph chart to inform how much capacity could be added to the network efficiently.

II.3 Network resource provisioning and expansion

The following resource provisioning and expansion measures have been identified as practical useful lessons obtained from a post-tournament assessment of Ghana's CAN 2008 event.

Implementing cell-on-wheels (COW) concept

Cell on Wheels (COW) refers to a portable base station used to provide temporary cellular network coverage for high-profile events and emergency situations where existing base stations have become damaged, or during natural disasters such as bushfires and floods.

MNOs analysed the traffic mix and user profiles for voice, data and other multimedia services as obtained from the operator's NMS within the first few days of the event. This established a particular usage trend which informed the integration of a COW into the existing network to meet particular service needs and user profile requirements. The residential facility of event officials received special consideration of a well-resourced COW to ensure optimal service quality at all times.

Expansion of TRXs, CEs and RBs for 2G/3G/4G sites respectively

Network resource elements at the access level required some expansion to a reasonable extent that could accommodate traffic flow without any foreseeable congestion challenges. Configured capacity on each technology platform could be utilized efficiently in accordance with a target utilization threshold.

Antenna parameter configuration

The tilt (electrical and mechanical) and azimuth parameters of the antenna on the various BTS and NodeBs provided MNOs options to leverage on a cost-effective basis the load-balancing capabilities of the network.

This technique was a limiting factor to control excess traffic picked up by the cells serving high-profile delegates or event officials, as well being used for the purpose of optimizing coverage to reduce call drop incidences due to "black spots" in and around the event locations. In addition, change to the "Rx_Lev_Access_Min" parameter also complemented tilt reconfiguration to reduce traffic overload on the access component of the network.

LAC border redesign

Location areas were designed by network planning engineers to provide a resource allocation control mechanism for the base station controllers in the access part of the network and were by standard practice preset to demarcated boundaries.

However, for scenarios where a LAC border lies between the location of the venue and lodging vicinity, there was the likelihood that the mass movement of event patrons, especially those from visiting countries could produce a lot of location area updates. There was therefore the need to do a physical border redesign and a parameter configuration of the cell reselection hysteresis (CRH) in order to extend the LAC boundaries to a reasonable extent that could reduce the signalling overload on the access links of the network. In effect, this became a control mechanism against excessive location area updates which if not checked could result in increased delay in call setup time and SDCCH congestion at the same time.

Administering QoS profiling and admission control policies

System load in multiservice cellular network environments varies from time to time though it is possible to cap the maximum load the network can support at a time. Two classes of services often come into play: priority and non-priority services. Non-priority services have two different QoS levels. In normal load both high QoS level for non-priority traffic and QoS level for priority traffic can be met, so the system works efficiently. When load increases and these QoS levels cannot be attained anymore, the QoS target for non-priority traffic is switched to low level. In this way, when the system enters the high load condition non-priority traffic QoS keeps degrading while priority traffic QoS is kept at its minimum level. A design approach was performed which allowed MNOs to efficiently meet the QoS demand of both service classes depending on the system load: normal load or high load.

Migration from microwave backhaul to fibre

It was expected that most network operators during the event desired to compete not only on price but on end-to-end service quality. Suffice to say that there was the need to ensure that the capacity limits on the transmission links connected to cell sites serving the event venues were removed to reduce or forestall any capacity crunch at the various hub sites of the network.

Appendix III

Quality measurement in 2016 Summer Olympics

(This appendix does not form an integral part of this Recommendation.)

III.1 Introduction

The 2016 Summer Olympics was held in Rio de Janeiro, Brazil in August 2016, about 2 years after the 2014 FIFA World Cup. The event was a big challenge for both network operators and Anatel, the Brazilian telecommunications regulator, to ensure a satisfactory quality of mobile voice and data services.

In comparison to the 2014 FIFA World Cup also held in Brazil, the networks were designed considering an increased consumption profile from the World Cup, since there was an increase in smartphones adoption, deployment of new technologies (LTE) and a different user profile, with users circulating for longer periods in the communal areas around the venues before and after the competitions, instead of in concentrated areas, for shorter periods of time like in the football games of the 2014 FIFA World Cup.

By using the experience acquired during the 2014 FIFA World Cup, and considering the different requirements for this event, another quality assessment strategy was set, as described in the following clauses.

III.2 2016 Summer Olympics context

Most of the competition venues were located in the city of Rio de Janeiro and divided into four regions: Barra da Tijuca, Copacabana, Deodoro and Maracanã, in addition to the Olympic football host cities: Brasília, Belo Horizonte, Salvador, Manaus and São Paulo. These regions were divided into clusters (groups of competition facilities) containing the Olympic venues (competition arenas).

The event sponsor provided all information about the competition schedule, maximum audience and PoI locations. The network operators' projects for the Olympics were required to comply with the obligations established by the International Olympic Committee (IOC) in Rio de Janeiro's Candidature File to host the 2016 Olympic Games, which states the specific number of simultaneous communications supported by a provider, per cluster (group of competition venues).

In contrast with the situation in the 2014 FIFA World Cup, where the main deployed network solutions used to provide the service in football arenas were based on a shared distributed antenna system (DAS) infrastructure for all operators. Also, the installed base for the 2014 major event was intended to be left as legacy for network operators to provide the service for future events in the stadiums.

In the Olympics, there were many different types of facilities used during the games, from football stadiums to temporary installations. In this scenario, considering the different nature of the facilities, the choice of the network deployment solution was dependent on the PoI characteristics of its future destination.

III.3 Considerations for the assessment of coverage and capacity

III.3.1 Audience estimation and market share

The audience estimation at the facilities were based on IOC (International Olympic Committee) data and on the Olympic sports competition held at that particular facility, considering the following numbers:

- **Maximum capacity**: the sum of all capacities of all the facilities at that location.

- **Worst case audience**: higher than the maximum capacity, considering the possibility of people circulating in the region adjacent to the facilities.
- **Audience considered**: the audience expected by the sponsors, which is determined subjectively and taking into consideration the maximum capacity, the audience in previous events and the Olympic Games schedule in that region.

Table III.1 – Example of the audience estimation data

Region	Cluster	Maximum capacity	Worst case audience	Audience considered
Barra da Tijuca Region	Barra Olympic Park	140000	140000	80000
Barra da Tijuca Region	Riocentro	27455	30000	24000
Barra da Tijuca Region	Pontal	3532	5000	4000
Barra da Tijuca Region	Olympic Golf Course	15000	17000	13600
Copacabana Region	Beach Volley Arena and Fort Copacabana	15472	35000	28000
Copacabana Region	Lagoa Stadium	10000	12000	9600
Copacabana Region	Marina da Glória	3500	8000	6400
Deodoro Region	Olympic Shooting Center	2000	3000	2400
Deodoro Region	Olympic Equestrian Center	14279	18000	14400
Deodoro Region	Youth Arena, Deodoro Stadium, Olympic Hockey Center and Deodoro Aquatics Center	32814	50000	40000
Deodoro Region	Mountain Bike Center, Olympic BMX Center and Whitewater Stadium	40458	50000	40000
Maracanã Region	Maracanã	78079	78079	62000
Maracanã Region	Maracanãzinho	11424	11424	9000
Maracanã Region	Olympic Stadium – Engenhão	59618	59618	47000
Maracanã Region	Sambadrome	3864	5000	4000
Football Cities Region	Amazonia Arena – Manaus	39000	39000	31200
Football Cities Region	Fonte Nova Arena – Salvador	52000	52000	41600
Football Cities Region	Corinthians Arena – São Paulo	62000	62000	49600
Football Cities Region	National Stadium Arena – Brasília	69000	69000	55200
Football Cities Region	Mineirão Arena – Belo Horizonte	58000	58000	46400

The market share of each telecommunications operator was also considered as a relevant parameter since some of the network operators are part of groups with a relevant global presence. Also, a correction factor was added considering the operator which is the games sponsor and provides the necessary network infrastructure to the Olympic Games staff and considering also the increase in audience uncorrelated to the current market share due to roaming agreements and other variables.

Table III.2 – Example of the market share estimation[2]

Operator	Market share (RJ)	Estimated market share
Operator A	35%	45%
Operator B	28%	35%
Operator C	17%	25%
Operator D	16%	20%
Operator E	4%	7%

III.3.2 Traffic demand estimation

The average voice and data traffic per user was estimated based on the data collected during the 2014 World Cup, as described in Appendix I. Data from the most relevant games (finals and semi-finals) were used, adding an increase factor due to increased data consumption profile.

The used factor for forecasting average traffic per user was from two to four times that of those registered in the 2014 FIFA World Cup based on exchanged experiences between network operators and network equipment manufacturers.

III.3.3 Coverage and capacity

Due to the high demand expected for data services during the Olympic Games, mobile service providers carried technical optimization projects for the Olympic facilities with the aim of improving the system's coverage and capacity to better fit the expected demand.

One key aspect considered was to verify the existence of adequate radio frequency (RF) coverage in Olympic facilities. However, since almost all PoI were in urban areas, they were already covered by operators' networks. Thus, the challenge was to deploy new solutions to increase capacity and optimize coverage, in order to offer adequate quality to users of the personal mobile service.

In 3G and 4G technologies, especially for data services, the quality of the radio link between the mobile station and the radio base station had a fundamental role in service quality, to enable high data rates, interference control and consequently, a capacity increase. In such telecommunications systems coverage and capacity cannot be analysed separately.

Nevertheless, in order to consider the PoI served by the technology in terms of coverage, the following references were used:

2 Note that the estimated market share sums more than 100% because it is used as factor to be multiplied by the audience considered at each point of interest. The effect of this consideration may overestimate the calculated audience.

Table III.3 – Coverage thresholds by technology

Coverage thresholds	For indoor coverage	For outdoor coverage
GSM technology (minimum RSSI – BCCH RxLevel)	Predicted outdoor level –75 dBm or better	Predicted outdoor level –95 dBm or better
UMTS technology (minimum Pilot RSCP in dBm)	Predicted outdoor level –84 dBm or better	Predicted outdoor level –97 dBm or better
LTE technology (minimum RSRP in dBm)	Predicted outdoor level –88 dBm or better	Predicted outdoor level –105 dBm or better

The first step to evaluate capacity and coverage was to collect details regarding the network project of the operators on each PoI detailing the number of deployed carriers in each technology as well the network solutions adopted. This allowed Anatel to assess the expected quality to be offered during the Olympic Games. Furthermore, this data was used to audit the roll-out of network deployments, provide assistance to the operators in negotiations with multiples stakeholders (public and private) and to select the monitoring strategy to be used during a major event.

An assessment of networks planned capacity was made in order to evaluate what quality level would be expected. In order to simplify this analysis a few considerations were made that were applied to two different methodologies.

Table III.4 – Premises by technology

Technology	Service	Consideration
GSM	Data	The ability to transmit data over GSM is not considered.
	Voice	Codec – Half Rate – 1 carrier = 16 voice channels
UMTS	Voice	Per carrier roughly 20% of capacity for VOICE VOICE: 12 simultaneous voice connections per 5 MHz carrier, Erlang capacity (soft capacity); 8 Erlang
	Data	Depends strongly on network solutions to balance coverage and capacity. In Methodology A, described below, there were set 4 ranges of data capacity per carrier based on the project's details.
LTE	Data	Depends strongly on network solutions to balance coverage and capacity. In Methodology A, described below, there were set 4 ranges of data capacity per carrier based on the project's details.

Methodology A

Based on technical references ([b-Nokia], [b-Rysavy Research], [b-Holma & Toskala]) in 3G technology, channel quality indicator (CQI) reports are used mainly for the adaptation of radio links and for packet scheduling algorithms, but they can also be used to estimate the maximum air interface capacity for network sizing purposes.

Considering the expected distribution measurements in a cell, the maximum air interface capacity can be directly inferred; for example, in 25 CQI measurements 1 would have 8.3 Mbps of HSDPA throughput to be offered to all users of that cell. Also, to assume the average data transmission rate during the busiest hour, a factor of approximately 50% was recommended over the maximum available instant data rate; for example, 50% of 8.3 Mbps HSDPA.

Therefore, in the case of data transmission over third and fourth generation networks, four levels of average spectral efficiency were stipulated for each available technology according to the estimated network solution, and the maximum available instant data rate resulting from the chosen spectral efficiency was converted to all users in a projected average data rate made available by the cell in gigabytes per hour.

Methodology B

Based on the experience acquired during the 2014 World Cup the following empiric capacity references were used:

- One 5 MHz UMTS carrier supports 800 users. It is assumed a rough estimate of 8% simultaneous users since it is known that normally there is a ceiling of 64 simultaneous users due equipment/software capacity limits.
- One 4G 10 MHz carrier supports 2 400 users. It is estimated a rough 50% increase in capacity of one 4G carrier in relation to a 3G carrier of the same bandwidth. Therefore, since the considered LTE carrier has the double bandwidth (10 MHz), it should be expected (1,5*800*2) = 2 400 users.

Note that these references were required as minimum thresholds for the network projects.

III.3.4 Traffic monitoring and quality KPIs

The monitoring of quality KPIs was done in a similar manner to the 2014 FIFA Wold Cup. Despite the continuous monitoring of the network performance by the network operators, Anatel performed its own monitoring by periodically collecting KPI data from the operators and also through independent walking tests and drive tests, with the main objective to keep the government informed about the network quality from users' perspectives, prevent misinformation about the networks quality, better informing the users and media vehicles, also benchmarking the operators against each other, demanding further information and taking necessary measures when needed.

Hopefully, in the 2016 Olympic Games only preventive measures were necessary, since the networks' quality of service, field measurements and the overall subjective perceived quality seemed as very satisfactory. Figures III.1 to III.4 below illustrate the quality of service offered during this major event.

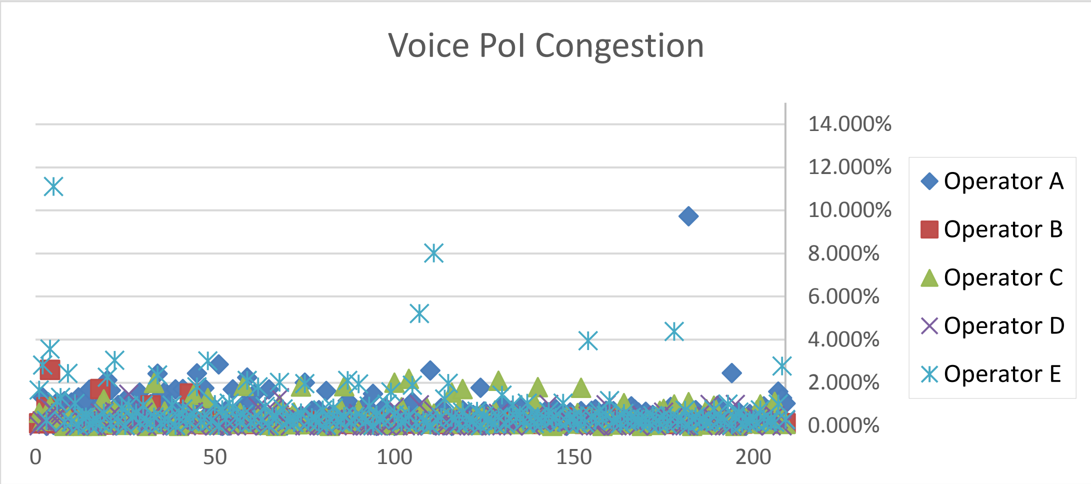

Figure III.1 – Voice PoI congestion

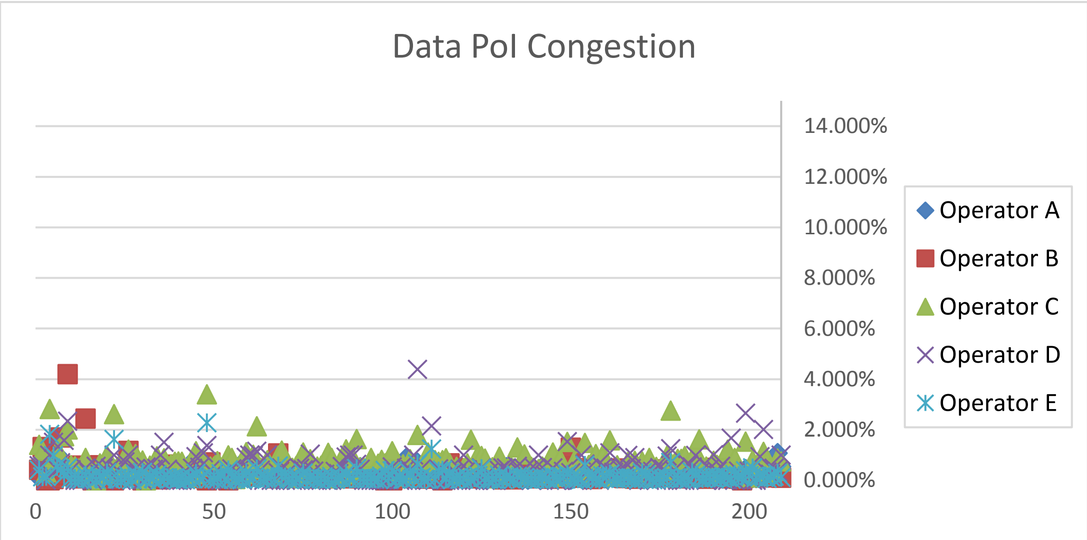

Figure III.2 – PoI congestion per day of each network operator

Note that considering the events schedule and the number of PoIs selected for analysis (209 in total, considering each specific PoI in a particular date for a given operator), some PoIs only had events on a few days. Thus, in order to get a big picture of the network congestion for the public in general, the following graph shows the PoI congestion pondered by the volume of carried traffic (of each PoI) by every network operator.

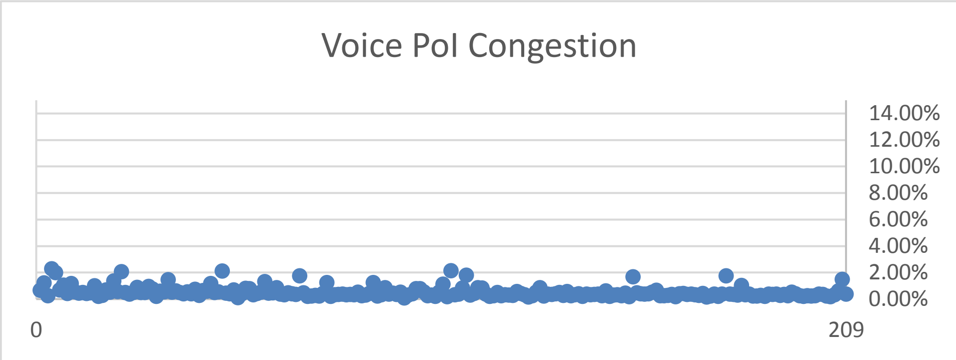

Figure III.3 – Voice PoI congestion pondered by the volume of traffic carried, of each PoI, per day (all operators)

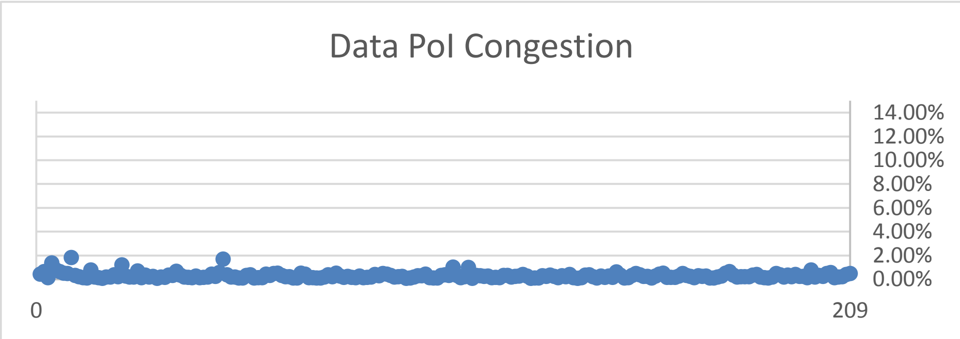

Figure III.4 – PoI congestion pondered by the volume of traffic carried, of each PoI, per day (all operators)

Also, the walking tests and drive tests provided a good picture of the quality experienced by the users, as shown below:

Table III.5 – Application-specific walking test – Ookla speedtest on Rohde & Schwarz equipment – Summer Olympics opening ceremony (Maracanã 08/05/2016)

Network operator	Network	Speedtest – Ookla – Rohde & Schwarz	
		Upload (kbps)	Download (kbps)
Operator A	LTE	663	10 128
Operator B	LTE	3 439	10 376
Operator C	LTE	2 361	13 759
Operator D	LTE	3 793	9 715

The walking tests were conducted during the events using the following test cases: Ookla Speedtest (download and upload), Facebook (login and post one 1MB photo), Youtube (watching a 5MB video) and Voice Mobile Originating Calls. During these tests the mobile phones were configured to use any mobile technology (GSM, UMTS or LTE) and with its Wi-Fi capabilities turned off (the Wi-Fi offloading strategy was not part of the test). In general, the results had a very satisfactory performance in the application-specific.

In comparison to the 2014 FIFA World Cup, there was a considerable increase in downloaded/uploaded data traffic, about 10 times higher, as expected, due to a bigger audience, longer duration of the events, and also following the tendency of increased data consumption, as well as the popularization of smartphones and LTE commercial expansion, as shown below:

Table III.6 – Comparison between traffic measured during the 2014 FIFA World Cup and the 2016 Rio Olympics

What	2016 Summer Olympic Games	2014 FIFA World Cup
Tickets	~7.5 M	~3.5 M
Mobile networks data traffic (upload + download, without Wi-Fi data traffic)	~255 TB	~24 TB

Also, one of the main key points for the success of the monitoring was the detailed network information gathered by the regulator, even though the complexity and extension of the analysis was a challenge due to the number of PoIs, its different characteristics and number of operators.

In conclusion, the early commitment of Anatel to closely follow the operators' network planning, combined with its previous experience was fundamental to enable the regulator to properly audit the network deployment and actively participate in multilateral negotiations with public and private parties regarding logistical difficulties, bureaucratic and governmental issues.

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