ITUPublications

International Telecommunication Union
Standardization Sector

ITU-T Technical Report

(09/2023)

ESTR-NUI

Radio frequency level-based single number indicator for mobile network usefulness for a given range of applications

Technical Report ITU-T ESTR-NUI

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Summary

Technical Report ITU-T ESTR-NUI describes a framework and methodology for a spatially-resolved single number indicator expressing mobile network usefulness for a given range of purposes. The spatial resolution can be adjusted by respective aggregation; practical ranges start at 25 to 50 m depending on the quality of GNSS data. The spectrum of purposes includes single network assessment (e.g., expected speech quality or call stability), as well as assessment of coverage for emergency calls, where coverage of multiple networks is combined into a single indicator.

Single number indicators are used in QoS and QoE contexts to express an overall assessment of a system or service from a given perspective. Such indicators are used routinely, e.g., in mobile network benchmarking, where a number of QoS KPIs are aggregated towards a single rating. This Technical Report describes a methodology which works in the same way but is using low-level measurement data, i.e., RF level values. The particular instance, i.e., the actual type of input value, depends on the radio network technology, e.g., RxLev for 2G, RSCP for 3G and RSRP for 4G and 5G, respectively.

The indicator which is the result of data processing expresses a quantity from the QoS domain, namely the usefulness of the network coverage for a given range of purposes. The algorithm uses mapping relations which link the input quantity to component quantities from the QoS domain, such as telephony call setup success, call stability or call quality, or respective QoS KPI for packet data services. These mapping relations are typically created from empirical data, e.g., from analysis of sufficiently large amounts of actual measurement data.

It is understood that the respective indicator does not assume the same level of accuracy or relevance as a primary QoS quantity from active measurements. The degree of prediction accuracy will depend on input data available for respective characteristic curves, e.g., visualized by a scatter plot or a heatmap-style density visualization. The indicator is however providing additional value in situations where only data from passive measurements, i.e., measurement of said RF levels, is available, or to create additional insights from data produced otherwise. It is meant to work with diverse data sources, such as RF level values provided from industrial-grade testing tools, apps, RF scanners and even crowdsourcing.

It is important to understand that this Technical Report does not attempt to provide actual fixed numbers, target values, thresholds or concrete mapping functions, as such absolute relations would not reflect the diversity of applications and situations in mobile network operation worldwide. Rather, it provides a solid methodological framework to create such implementations, as well as accompanying guidance and considerations on reliability of data in relation to properties of data sources.

Keywords

Call stability, metrics, mobile communication, QoE, QoS, spatially-resolved information.

Note

This is an informative ITU-T publication. Mandatory provisions, such as those found in ITU-T Recommendations, are outside the scope of this publication. This publication should only be referenced bibliographically in ITU-T Recommendations.

Change log

This document contains Version 1 of the ITU-T Technical Report ESTR-NUI on "RF level-based single number indicator for mobile network usefulness for a given range of applications" approved at the ITU-T Study Group 12 meeting held in Mexico City, 19-28 September 2023.

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Radio frequency level-based single number indicator for mobile network usefulness for a given range of applications

1 Scope

This Technical Report establishes a framework for a single number indicator expressing the usefulness of a mobile network of a service provider for a given range of purposes, e.g., telephony or a range of packet data applications. The Technical Report also provides a methodology to calculate such indicators from basic measurement data, using transformation functions derived from empirical data.

Potential users of this Technical Report are all stakeholders interested in respective metrics. It can be assumed that mobile network operators have corresponding metrics used internally for purposes such as network optimization, which typically are even more complex and use multiple input values for enhanced precision. Therefore, the main benefit for these user groups may be that this Technical Report presents a universal metric of a type which is non-proprietary and is suitable for communicating performance characteristics to a wider audience. However, other stakeholder groups do not have access to the wide spectrum of information available to network operators. For them, the Technical Report provides a robust toolbox to create respective metrics. The principal input quantity is easily measurable (with passive measurement systems, scanners or through means of crowdsourcing); the transformations used are based on empirical data; and the output quantity, being a scalar value, can easily be visualized in many different ways, in particular on maps. Also, the methodology allows us to expand the dimensionality of input quantities, allowing for extending the methodology by, e.g., using machine-learning techniques.

In addition, the construction of the Network Usefulness Index (NUI) allows for a level beyond a single mobile network. An example application is the assessment of the probability that emergency calls, which use all available networks, can be performed in a given location.

2 References

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

[ITU-T G.1034] Recommendation ITU-T G.1034 (2020), *Quality of Experience metrics for mobile telephony communication during rail travel*.

[ITU-T P.10] Recommendation ITU-T P.10/G.100 (2017), *Vocabulary for performance, quality of service and quality of experience*.

[ITU-T P.863] Recommendation ITU-T P.863 (2018), *Perceptual objective listening quality prediction*.

3 Definitions

3.1 Terms defined elsewhere

This Technical Report uses the following terms defined elsewhere:

3.1.1 quality of experience (QoE) [ITU-T P.10]: The degree of delight or annoyance of the user of an application or service.

3.1.2 quality of service (QoS) [ITU-T E.800]: The totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service.

3.2 Terms defined in this Technical Report

This Technical Report defines the following term:

3.2.1 network usefulness index (NUI): A numerical indicator for the usefulness of a mobile network for a given range of purposes (see full definition in clause 7). The framework includes the possibility of using textual extensions (NUI_X) for a particular range X.

4 Abbreviations and acronyms

This Technical Report uses the following abbreviations and acronyms:

GDPR General Data Protection Regulation

GNSS Global Navigation Satellite System

KPI Key Performance Indicator

OTT Over The Top

RAT Radio Access Technology

RF Radio Frequency

RSCP Received Signal Code Power

RSRP Reference Signal Received Power

RxLev Reception Level

SpQ Speech Quality

5 Introduction

Single number indicators are practical instruments for many purposes. Of course, meaning and function of such highly aggregated data needs to be well understood and applied with care. When doing so, such indicators have many useful applications, such as providing easy to digest status information and guidance for optimization. Also, such indicators can be helpful in the visualization of data, in particular in spatial or geographic contexts.

Mobile network performance assessment, and benchmarking in particular, is one of the fields where single number indicators are applied routinely, e.g., when creating rankings. The underlying principle is rather straightforward, with two main ingredients: mapping of basic Key Performance Indicators (KPIs) to a score value, e.g., a value between 0 and 100, and aggregating these scores by applying a system of weights. There are several degrees of freedom in the creation of actual algorithms, which has led to a number of commercially-used proprietary indicator systems, as well as published frameworks and best practice guidance documents.

The degrees of freedom on actual algorithms include the way original KPIs are (typically nonlinearly) being mapped to generic or score values; pre-selection of values; and categorization by mode of mobility such as drive (subdivided into individual/public transport), walk, stationary, categorization by spatial categories such as urban, sub-urban, rural, etc. The principle can also be used to create different single number indicators taking different mixes of usage into account (telephony-centric, packet data-centric, etc.).

However, single number indicators used in mobile network performance testing and benchmarking use input data obtained from active testing, using a scenario composed from use cases of some kind.

The indicator defined in this document uses data obtained from basic measurements, i.e., RF levels for respective radio access technologies, which can also come from passive measurements that can be performed with rather moderate effort and cost. In this sense, this Technical Report presents a new way to use such data in the context of a single number approach.

6 Categorization of RF level data in the context of usefulness

RF level data comes in different formats. For further discussion, it is assumed that Radio Access Technology (RAT)-specific values are being used, which implicitly also carries information on the available RAT itself. The means that the data objects currently to be considered are RxLev for 2G, RSCP for 3G, and RSRP for 4G and 5G. Therefore, the minimum extent of input information for the metric will be the RAT-specific RF level with its respective native unit and value range. An "RSSI" value of some type is considered to be insufficient for the purpose, unless employed as a kind of low-value emergency replacement information. There are several practical ways to present these values. Without loss of generality, two useful formats are assumed to be a time-stamped data item with a single value and RAT information, or as a time-stamped row with columns for each RAT. In this case, the composition, including the empty or NULL-valued ones, would carry the RAT information implicitly.

Geographic information (longitude/latitude) is understood to be optional but an important requirement for a meaningful application of the RF level metric as geo-coordinates are needed to analyse data by area, region or using geo-tiles, and also to create geo-visualizations.

In the special context of crowdsourcing, there are additional aspects with respect to geo-coordinates. From a purely technical point of view, the presence of absence of geo-coordinates can help to identify in-house situations (by the lack of GNSS information); this is also relevant for correct interpretation of RF levels which are typically significantly attenuated in such cases. Moreover, and more importantly, information on geolocation may face some limitations, either with respect to sensitivities of users or due to extant legal frameworks in concerned Member States with regard to privacy (e.g., GDPR or similar personal data protection framework). In such scenarios, crowdsourcing applications may consider using data minimization or data anonymization techniques to capture geolocation references.

The main question for the metric is, of course, what this metric should express: a measure of usefulness of network coverage at a particular location. "Location" is to be understood as a certain area; its dimension will depend on the amount of available data and the spatial resolution of the data source itself. For instance, a value could represent the usefulness of mobile network coverage in a square of 500 × 500 or 100 × 100 m. As in other cases of data aggregation, it is of course important to keep in mind that for valid assessments a certain minimum number of data points, and a sufficiently even distribution across the coverage square, will be required.

This new metric will be termed NUI, standing for network usefulness index, from here on.

From the viewpoint of usefulness, two use cases may be derived immediately. Firstly, NUI can seamlessly represent the property of network coverage itself. This is actually optional; separating the two situations of "no network coverage" and "very weak signal", which would both lead to a usefulness of practically zero, can be treated differently but NUI offers the choice to be a true single number indicator by integrating this property.

Secondly, it is clear that there is no universal, radio technology-independent usefulness. A 2G network can have perfect usefulness for voice communication and will still be completely inadequate for any packet data usage which goes beyond the most basic requirements, as achievable data rates are limited to 200 kbit/s at best by the underlying technology. So, it makes sense to understand NUI as having different "flavours" depending on the choice of services or functions. In naming, this is reflected by respective name extensions, e.g., NUI_T for the "telephony" flavour.

7 Essential properties of the NUI concept

The essence of the NUI concept is its openness with respect to actual working metrics for a wide range of purposes. It is assumed, however, that there will be different families of NUI indicators, starting with the main categories for telephony (NUI_T) and packet data-centric usages (NUI_D), and respective more specialized indicators for different purposes, i.e., based on different usage scenarios (such as NUI_D_01, NUI_D_02) with purpose-adapted naming within the entities which are using these indicators.

As mentioned above, using a single number indicator in a professional way requires a clear understanding of its capabilities, as well as its limitations. Mobile networks may be configured to keep a mobile device in a low-performance configuration unless it becomes clear that a use case needs higher performance. In such a case, an RF level-based approach would not "see" the presence of high-performance networks. Also, if RF level information comes from scanners, a high RF level does not automatically mean that the respective network is accessible to a user in this area. In order to properly interpret results, such information needs to be known and to be integrated in the evaluation process accordingly. Also, with respect to the operation of mobile networks in different frequency bands, the accuracy of estimations will depend on the level of detail known.

Finally, with all sophistication which can go into the design of actual NUI mappings, it should still be kept in mind that NUI is a surrogate which is not a full replacement of active measurements, but just a construct which makes the best use of available information.

8 Practical basic examples

The following figures show some constructed examples of mappings from RF levels to NUI values.

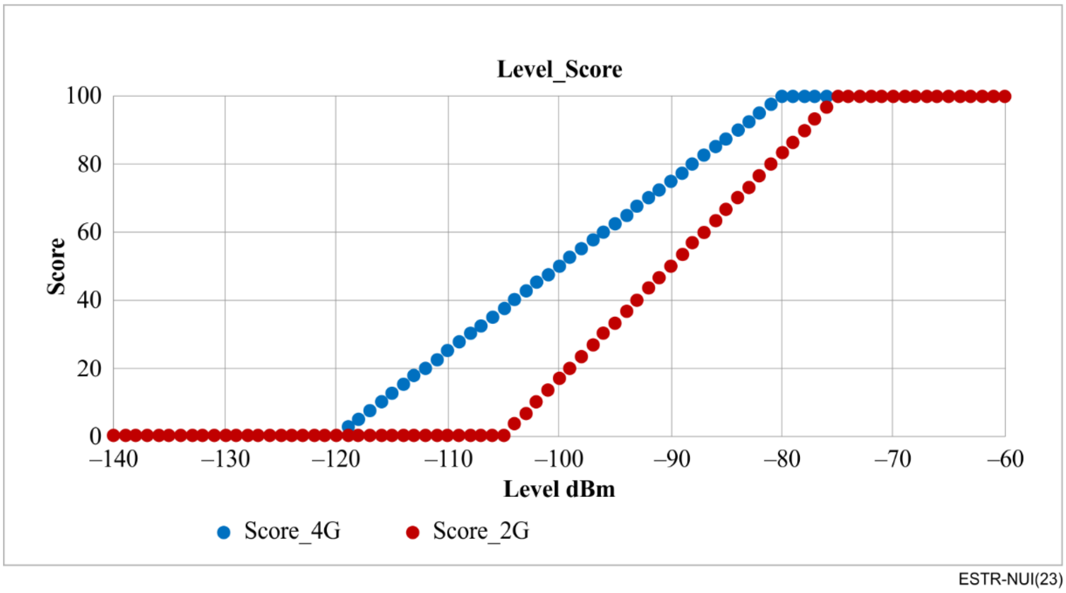

Figure 1 – Example: Mapping of 2G and 4G to NUI values, with simple segment-wise linear functions

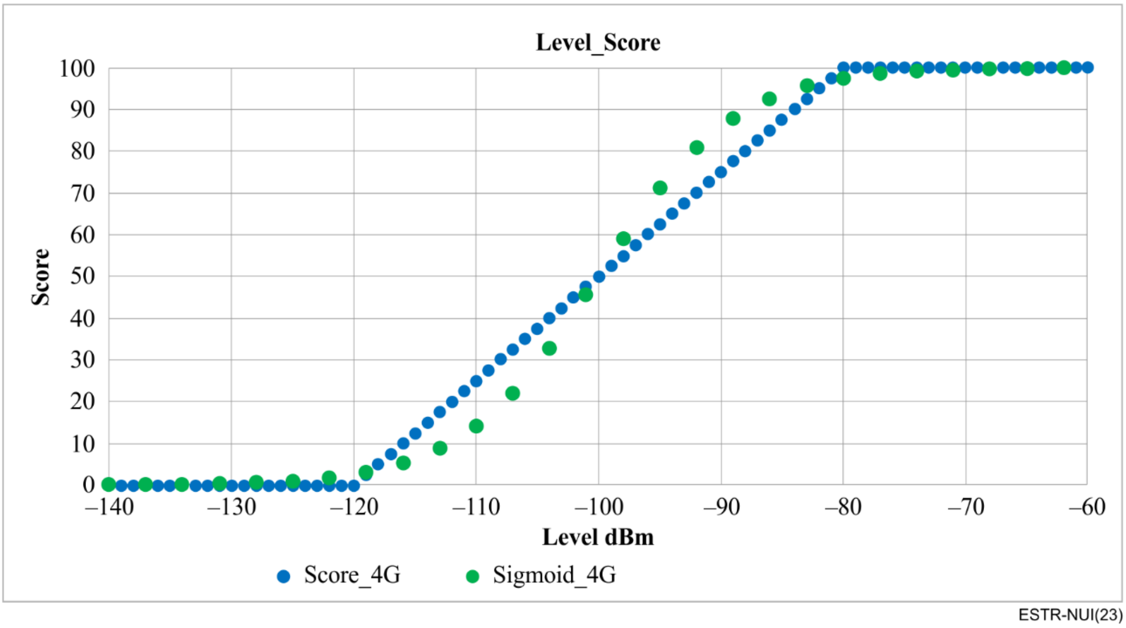

Figure 2 – Example: Comparison of segment-wise linear function with sigmoid function

In Figure 1, a segment-wise linear function is used to map RxLev (for 2G) and RSRP (for 4G) to NUI values. Each mapping curve has two parameters: a lower cut-off point (L0), a saturation point (L1) and a linear slope between those points.

Remark: Parameter values have been chosen to demonstrate the principle of mapping. These values are in a reasonable range but do not attempt to be proposals for actual mappings.

Figure 2 shows a sigmoid function as an example of a closed mathematical representation of a mapping. The parameters have been chosen to approximate the cut-off and saturation values for the linear mapping. Consequently, the slope in the middle part is somewhat higher than for the linear mapping.

In the simplest case, the final NUI mapping curve is using a single characteristic curve, e.g., the relation between a technology-specific RF level and a single QoS KPI. In practice, NUI mapping curves are combined from several characteristic curves. Both figures are assumed to represent the combination of component characteristics curves. For instance, a practical NUI for telephony would use characteristic curves for speech quality and/or call stability (inverse of call drop rate).

In an actual implementation of NUI mapping would typically be performed by generated look-up tables, as part of a database-based post-processing chain.

9 Mapping relations for telephony

Regardless of the actual shape and way of implementation, the mapping should use empirical data to express the target quantity, i.e., the actual usefulness. In the case of telephony this includes two aspects: call stability and call quality. In both cases, relations between the RF level and respective KPI (i.e., call drop rate and speech quality) can easily be created by applying mass-data analysis. In the case of call drop rates, this would be the probability of call drops vs RF level. In the case of speech quality expressed by POLQA [ITU-T P.863], a characteristic curve of, e.g., POLQA values against RF level is used. Empirical data cannot be shown here due to confidentiality; however, it is reasonable to assume that the relation between POLQA values and RF level also resembles a sigmoid-like function. Creating an appropriate first-order mapping relation would only require finding a matching set of parameters.

10 Mapping relations for packet data applications

In the case of NUI for packet data applications (NUI_D), the method is applied analogously. In this case, the characteristic curve would be data rate vs RF level. Again, different RATs can easily be mapped to a common scale using this approach. In this case, scores values for, e.g., 2G would of course be significantly lower than even in the best case.

For a comprehensive quantitative result in case of packet data usage, additional information is required, namely the actual RF bandwidth of a section of radio spectrum, because available maximum data rate depends, for a given radio access technology, primarily on that bandwidth.

However, in many actual QoS contexts, the data rate will not be the quantity of interest. When expressing the usefulness of network performance for a given purpose, the final output quantity of an assessment process will take the type of usage into account.

For instance, one and the same data rate may be considered fully sufficient for OTT telephony or web-browsing purposes, while for high-definition video streaming or augmented-reality purposes, it may be rated as inadequate. Also, in some cases, as for straightforward upload or download applications, a quantity more suitable for QoS purposes is the transaction time because this is what human users perceive. In such cases, a mapping relation may also show a sigmoid-like behaviour because the perceived additional benefit of even higher data rates will, in many practical cases of data volume to be transferred, result in only a very small subjective improvement of download or upload time.

Also, the NUI methodology as such does not depend on the mathematical type and shape of the chosen mapping relation. A sigmoidal shape can be understood as a reasonable starting assumption in many cases but is not a binding requirement.

The NUI methodology allows a single-step expression of usefulness by convoluting QoS-related mappings with the primary quantity of a data rate, into a single integrated mapping relation. In this sense, NUI_D should be seen as a family of relations rather than a single universal one, with usage-related subtypes for different use cases, e.g., NUI_D (web browsing) or NUI_D (video streaming).

When taking these considerations into account, even the effect of inaccuracies in the primary mapping from RF level to data rates (e.g., if information on RF bandwidth is not available or left aside for simplification), can be mitigated at least in the saturation regions of sigmoid-like NUI mapping relations.

11 Geographic representation

Implicitly, NUI is a geography-related quantity, i.e., the result of spatial aggregation or binning. If a grid of given dimension is being used, this process is also called "tiling". The following example shows NUI_T geo-visualization examples with a tile size of 50 × 50 m.

Remark: In [ITU-T G.1034], the more general term "Geographical Unit" or GU has been introduced in connection to spatial binning. A GU describes a general geographical object which can, in the case of a railway track, also be effectively one-dimensional and have an arbitrary orientation in the map plane. "Tile" is used to distinguish the more specialized approach of equidistant grids.

Figure 3 – Example of a tiled geo-visualization for NUI_T (color-coded) and three mobile networks. Symbol size according to a binarized version of NUI_T

In these examples, NUI is represented by a different colour-coded symbol for each network. In order to show no-coverage tiles clearly, symbol size is also proportional to a binarized NUI value. In Figure 3, all networks are shown superimposed on the same map. This representation is useful, e.g., to clearly show tiles where not even an emergency call would work. Figure 4 shows data from the same region (slightly different area) in an alternative per-operator coverage view.

Figure 4 – Example of a tiled NUI_T geo-visualisation separated per mobile network

12 Auxiliary quantities and further aggregation

As for other types of data coming from measurements, the question of reliability needs to be addressed and is primarily determined by the number of samples. In a practical implementation of NUI, this can be easily done by calculating a respective measure of certainty, derived from the number of data points in a given unit of aggregation, e.g., a geographic tile.

An NUI value relates to a given mobile network. The concept of NUI can be easily extended to cases of roaming, by considering all mobile networks available for a given subscriber profile. Also, if the interest is on overall network availability as in the case of emergency-call situations, all-net NUI can be defined which considers this particular use case. Respective concrete definitions are subject to further study.