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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Multimedia Quality of Service and performance – Generic and user-related aspects

Framework for capacity assessment of packet data services in mobile networks

Recommendation ITU-T G.1023

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Recommendation ITU-T G.1023

Framework for capacity assessment of packet data services in mobile networks

Summary

Recommendation ITU-T G.1023 establishes a framework for capacity assessment of packet data services in mobile networks.

Mobile network capacity is an underlying factor in all quality of service (QoS) aspects of a packet data-based mobile network due to the shared-resource properties of such networks. It is therefore desirable to achieve a basic understanding of related properties and corresponding performance indicators. Measuring network capacity takes, however, significantly more effort and resources, in the sense that a direct measurement of capacity requires a massive effort in terms of resources, which practically creates the requirement to use assessments.

Recommendation ITU-T G.1023 therefore provides a systematic approach to describe and characterize methods for assessment of packet data-based mobile networks and presents the appropriate framework.

Spatial resolution is an important element of this framework, i.e., the recognition that network capacity is not a quantity which is uniform over the entire network or large areas of it. Rather, due to the cellular nature of such networks, capacity, and therefore also QoS and quality of experience properties, are spatially different.

History

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Keywords

Capacity, mobile networks, packet data, performance, QoS, spatially resolved information.

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

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Introduction

Estimating or validating the capacity of packet data services is required in many situations, ranging from private sector issues such as service level agreements and methods of validating appropriate commitments, up to regulatory contexts e.g., relating to conditions for licensing of frequency spectrum.

A systematic framework for this task has two components. The first deals with the spatial element, i.e., definitions allowing measurement data processing towards spatially resolved indicators. The second consists of methodologies and metrics for capacity itself.

Quality of service key performance indicators for mobile networks include one for data rate. However, caution is needed when drawing conclusions from this data rate, which is usually measured through some end to end upload or download scenario, to actual network capacity. First, a single end-user access may be data rate-limited in some way; second, today most of the measurement methodologies use the hypertext transfer protocol, i.e., a service based on the transmission control protocol (TCP), for measurement. [b-BBF MR-471.2] has shown that TCP may systematically underestimate actual mobile network capacity (which is usually defined in terms of maximum Internet protocol layer section capacity). If this is just a systematic offset, it could probably be compensated for by appropriate correction factors, but empirical data also show that fluctuation of values is considerably higher as compared to user datagram protocol-based measurements. The whole area is currently under intense study.

The framework described in this Recommendation therefore treats the method of measurement, and consequently the usage of results in subsequent processing steps, as a modular, adaptable element.

Recommendation ITU-T G.1023

Framework for capacity assessment of packet data services in mobile networks

1 Scope

This Recommendation establishes a framework for spatially resolved estimation of the capacity of packet data services in mobile networks. It uses an end-to-end model for packet data performance that allows categorization of effects. This Recommendation identifies different classes of measurement methodologies, discusses them with respect to their properties, including their tendency to under- or overestimate network capacity, and provides guidance on how to obtain robust estimations of capacity.

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

[ITU-T Y.1540] Recommendation ITU-T Y.1540 (2019), *Internet protocol data communication service – IP packet transfer and availability performance parameters*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 call completion probability (CCP) [ITU-T G.1034]: The probability that a telephone call started at a given location can be completed as intended (i.e., without being dropped).

3.1.2 geographical unit (GU) [ITU-T G.1034]: A segment of road or railway track, or a square or rectangular shaped area, with given coordinates on a map. Used to aggregate measurement data based on their geographical coordinates.

3.1.3 local drop probability (LDP) [ITU-T G.1034]: An indicator, computed from drive test data, to indicate the call-drop probability for a given geographical unit (GU).

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

3.1.5 quality of service (QoS) [b-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.

3.1.6 virtual call [ITU-T G.1034]: A concept using the local drop probability (LDP) values in a route profile to compute the call completion probability (CCP) for a call of given duration.

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 maximum Internet protocol layer section capacity: For a population of interest, the maximum section capacity, $C(t, \Delta t)$, corresponds to the maximum value of n_0 (the number of Internet protocol layer header and payload bits) measured in any sub-interval $[\mathrm{d}t_n, \mathrm{d}t_{n+1}]$ within time interval $[t, t + \Delta t]$, divided by the duration of the sub-interval.

NOTE – Based on Annex A of [ITU-T Y.1540].

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CCP Call Completion Probability

GU Geographical Unit

IP Internet Protocol

LDP Local Drop Probability

QoE Quality of Experience

QoS Quality of Service

RAN Radio Access Network

RF Radio Frequency

SLA Service Level Agreement

TCP Transmission Control Protocol

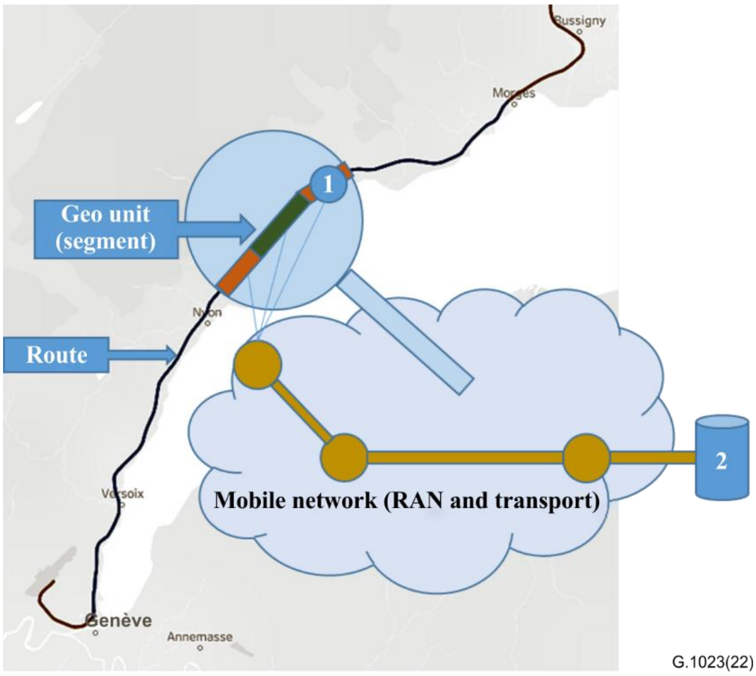
5 Conventions

None.

6 Background from Recommendation ITU-T G.1034

For the spatial components, the same definitions and related explanation in clauses 3.2 and 5.24 of [ITU-T G.1034] are used: A route is composed of GUs, which are also the elements used for assignment and aggregation of measurement data. In the example shown in Figure 1, this GU is a one-dimensional object, i.e., a rail or street segment with a typical dimension of 100 m to 1 000 m. It could also be a geographical square (tile) with appropriate dimensions.

Figure 1 also shows the symbolic data path for data flow through the mobile network. In this data path, principal nodes are boundary elements of the radio access network (RAN) and the core network towards the general internet. In addition, Figure 1 shows an internal node representing the boundary between a RAN and a core network. The data path is composed of the path elements between those nodes.



Key

1 end user/device

2 entity providing the service, typically a server connected through the general Internet

Figure 1 – Nomenclature for geographic objects and symbolic data path through a mobile network

7 Differences between quality of service and capacity measurements

In a QoS context, the focus is on the experience of a single customer. In this context, the exact structure of the data path between endpoints 1 (the end-user device or rather the application on that device) and 2 (typically a server delivering or receiving the data, which constitutes the appropriate end-user service) is of no particular interest. If the data rate is lower than the nominal or expected value, it does not matter to the end user which element in the data path causes a degradation of QoS.

In a capacity-related context, it likely does matter which part of the data path is limiting the maximum data rate because it has an impact on responsibility or liability with respect to values agreed by a service level agreement (SLA) or requirements in the regulatory context, e.g., for licensing of spectrum. In this sense, the determination of 'network under test' will differ, depending on the actual context.

QoS and capacity views have common elements, and elements where they differ. The necessity to consider statistical issues linked to noisy measurement data, such as confidence intervals and their dependence on sample count, are common to both views. Selection of the most appropriate and the most efficient type of measurement, i.e., application of use cases or key performance indicators and their points of observation, will likely lead to different choices in the QoS and the capacity domain. Furthermore, QoS measurements are very generally performed using a single access to the network under test (i.e., a single mobile device and a single use case running at the same time) while for measurements in the capacity domain, usage of multiple devices or multiple data streams is at least common (with some transport layers), if not required to fulfil the measurement task.

8 Data processing for spatially resolved assessment of network capacity

Figure 2 shows the basic principle of data processing. Primary data is assigned to appropriate GUs, using associated geographical information.

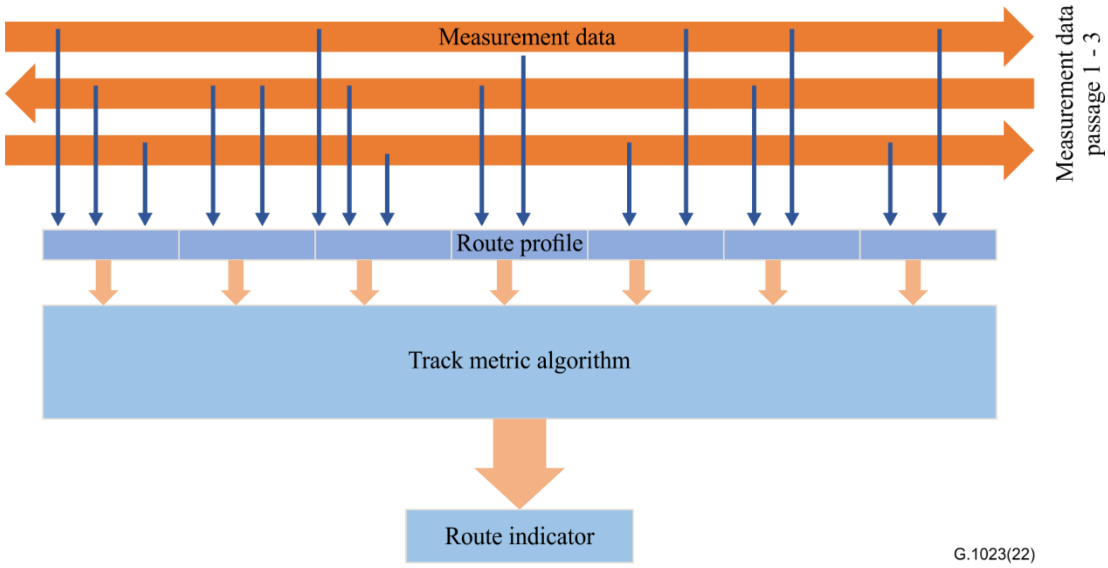


Figure 2 – Symbolic description of spatially resolved data processing. Measurement data taken on subsequent drive tests on a route are aggregated into the corresponding geographical units

9 Framework specifications

The framework is based on the following elements.

- The suggested structure of separating geo-mapping and data sources for capacity assessment is used, in which data sources are a modular component of the methodology, i.e., they can be exchanged while preserving the overall framework.
- Limitations of accuracy can be further categorized into randomness and systematic deviations from the true value. Randomness can be reduced by aggregating or averaging multiple measurement data points.
- The intrinsic randomness can further be divided into three main categories of fluctuations due to:
  – physical effects in wireless transmission;
  – the shared medium nature of packet data networks, i.e., changing demand for bandwidth from other users;
  – the packetized nature of data, e.g., artefacts caused by short-time windows in data rate measurements;
  – all kinds of effects in the terrestrial path between the RAN and the end point.
- Different methodologies have different systematic deviations of the values they produce from the ground truth of the actual capacity of the system under test. Compensation is possible (within given limits) but requires a solid understanding of relevant characteristics.

These basics can be used to derive a first approach to a robust approximation, provided that a single precondition is fulfilled, namely, that a measurement does not overestimate the capacity (or at least, that there is a very small probability for overestimation). In that case, every measurement data value is either below or at the ground truth value.

If this premise is assumed to be valid, it follows that, assuming N measurements that are otherwise meaningful and valid, the lower boundary of actual capacity is given by the maximum value of these measurement data points.

NOTE 1 – The definition of a meaningful and valid local effective data rate depends on data rate, which is derived by dividing transferred data volume by time interval. Packet data transfer has a bursty nature; if the time interval is too short, artefacts in the form of spikes in values can occur. It is assumed that the time interval is chosen reasonably to avoid such overshoots, see also Annex A.2.1 of [ITU-Y 1540]. In the context of this Recommendation, the default value of 1 s, as specified in Annex B of [ITU-T Y.1540], is assumed to provide sufficient smoothing.

Generally, the number of packets received within the relevant time interval should be large enough to ensure that the fluctuation in packet count is tolerable within the limits of the required precision of measurement. Ideally, the point of observation for packets is chosen at a low protocol stack level, where packet sizes are typically in the order of 1 kB (i.e., near or at the Internet protocol (IP) layer). If such a point of observation is not available, e.g., due to device-related restrictions, the time interval should be chosen accordingly. The appropriate time interval is a function of the typical data rates and packet sizes, and the tolerable noise caused by granularity.

Table 1 provides some examples of the effect of granularity.

NOTE 2 – The parameters used for these examples applies to application-level packet sizes; packet sizes for lower protocol stack layers are typically much smaller, i.e., granularity effects are much smaller at given time intervals.

For assessment of the fluctuation in measured data rate, the number of packets differs by 1 due to fluctuation. Case A shows an extreme case with large packets and small data rates. A difference of one packet can lead to a difference in calculated data rate as large as a factor of two. At higher data rates (case B) or with smaller packets (case C), this effect becomes smaller but still can lead to significant fluctuation of values between time intervals.

Table 1 – Some examples of the effect of packet data granularity on variation of measurement values

		Case A	**Case B**	**Case C**
Packet size	kB	1 000	1 000	100
Time	s	1	1	1
Packets received A		1	10	100
Packets received B		2	11	101
Data rate A	Mbit/s	8	80	80
Data rate B	Mbit/s	16	88	80.8

The user-level reasoning behind these considerations is the following. Assuming that there are elements limiting the data rate, they must be somewhere along the path. If a data rate has been observed at least once, it proves that the path is capable of supporting this data rate under similar conditions in the future. A practical example would be the question whether, for a mobile network, the air interface or the data connection between a base station and the core network limits the maximum capacity. Under practical conditions of a shared medium and non-exclusive access to the RAN, competing traffic may reduce the data rate that can be obtained by the testing process. A measured data rate is therefore proof that the system under test can at least deliver that capacity, but may be higher if there is less or no competing traffic.

10 Taxonomy of data sources for capacity measurements

There are several possible sources of measurement data for the assessment of mobile network capacity in a region or along a given trajectory or route. They can broadly be classified as follows.

1 Direct **active measurements** of capacity **under controlled conditions** (no competing mobile network traffic). The test case used should be designed to match as closely as possible the conditions outlined in the underlying requirement (SLA, regulatory requirement, etc.).

2 Direct **active measurements under "as is" conditions** (e.g., presence of other users of network services, radio conditions different from those assumed in the requirement).

3 **Measurement of "proxy" quantities**, e.g., measurement of radio frequency (RF) levels and application of mapping relationships (model-based or empirical).

NOTE – This classification determines the principal coordinate system for a description of actual methodologies. In practice, a given methodology, while generally belonging to one category, may use elements from others as well. For instance, an "as is" measurement may be carried out outside busy hours in order to reduce competing load effects or a measurement using proxies may be supplemented by active measurements for additional calibration.

This list orders sources with decreasing degree of reliability. This shall not be understood as a general negative statement towards less direct methods as they may, under given economical and technical conditions, constitute the best possible compromise between effort and result. However, using less ideal methods requires subsequent steps of processing data through models or other types of mapping, and awareness of relevant effects on accuracy. Such processing steps need to be robust, capable of validation and transparently documented.

Table 2 provides an overview of data source-specific characteristics. At this stage, Table 2 is meant to provide an example; not to give a final listing of characteristics.

Table 2 – Overview of data-source specific characteristics

Type of data source	Main characteristic or points to observe
Direct active measurement of capacity under controlled conditions	Probably the most reliable way to assess capacity; may be difficult to implement.
Direct active measurements under "as is" conditions	Accuracy and tendency to under- or overestimate capacity depends on method used (e.g., based on the transmission control protocol (TCP) vs. user datagram protocol). Ideally, additional tests or suitable additional data sources are used to estimate background load or load created by other users.
Measurement of "proxy" quantities	Requires a suitable, validatable model to map relevant quantities to expected capacity (e.g., RF level to expected data rate). Considerable risk of overestimating capacity if there are bottlenecks in subsequent elements in the of data path (e.g., interlink between RAN elements to core network); additional measurements highly recommended.

In simple cases, correction of systematic errors can be done by using mathematical transformations, such as applying an offset and a scaling factor (linear transformation) or using likewise higher-degree nonlinear functions. Such functions and their parameters can be derived in different ways; they are either explicitly or implicitly model driven. Practical examples use mathematical analysis of data (explicit modelling) or machine-learning approaches (implicit modelling, potentially without a direct, validatable expression of the underlying model).

Mapping from RF levels to network capacity is done using look-up mechanisms based on characteristic curves or tables. These can be created from systematic theoretical modelling or using empirical data from other measurements.

These approaches constitute models that usually also include additional assumptions, e.g., external knowledge about the system under test. It is therefore highly advisable to monitor the continued validity of such assumptions. In particular, this refers to the introduction, removal or modification of processes in the data path, e.g., fair-use policies, load balancing and other mechanisms that modify available data rates.

In the radio domain, usage of multiple input-multiple output, carrier aggregation or modified resource-allocation strategies, including new coding schemes, may also lead to reduced applicability of mapping, e.g., RF levels to data rate if the data base used has been created under different conditions.

Capacity management may also be driven by subscriber behaviour, leading to time-dependent data rate shapes. For instance, several seconds of high capacity are offered to a new subscriber's flow at the start, and subsequent seconds are restricted to a lower capacity. Such mechanisms are known as opportunistic schedulers, favouring the early part of a connection with more capacity, slightly penalizing long-lived flows. Other forms of access are advertised to have "turbo mode" exhibiting increased capacity for a few seconds or a limited number of octets transferred.

Such dynamics mechanisms are repeatable and therefore can be characterized by appropriate measurements. As the underlying algorithms can change at any time without notice, this is another reason why regular monitoring of the related dynamic behaviour of the network under test should be done.

11 Considerations on acquiring primary measurement data

Packet data networks are commonly described as a shared resource, implying that a single user may be able to get all resources (i.e., all data bandwidth) available. Likewise, capacity measurements could be performed by a single device running a single use case.

In practice, there may be a limitation to the maximum data rate available to a single data stream (socket connection, device or use case). In such cases, measurements seeking to attain maximum capacity would have to be run concurrently on multiple devices or at least with multiple concurrent data streams.

From an economic point of view, it is important to determine the required extent of resources required to obtain reliable measurement data and to avoid unjustified overallocation of resources.

A proven way to achieve this goal is to systematically probe the system under test with an increasing number of concurrent channels (devices or data streams) and to determine the saturation point, i.e., the number of channels where a further increase does not change the result significantly anymore. Tests like the one whose output is symbolized in Figure 3 determine how many parallel streams are required to assess the overall capacity of a system.

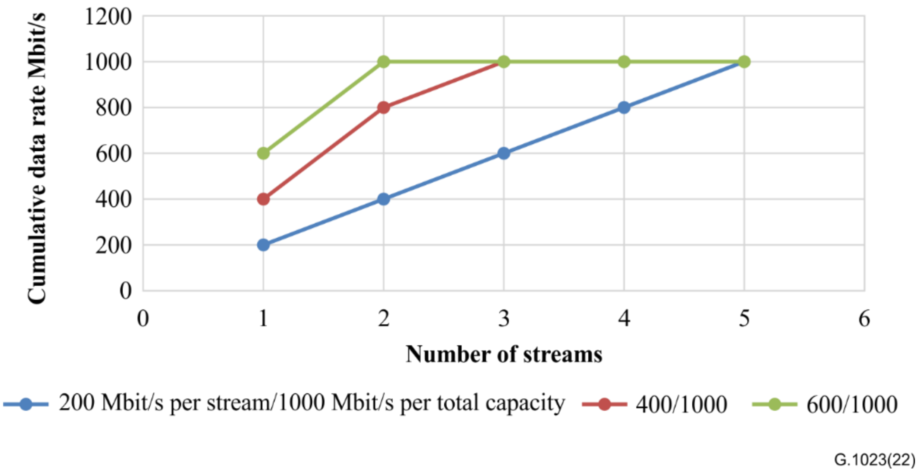


Figure 3 – Example of cumulative data rate obtained with a number of parallel streams if data rate per stream is limited

NOTE – The example shows a simplified situation where data rates per stream can be simply added. In reality, effects such as TCP congestion control or saturation of resources lead to a more complex situation. It is assumed that, given finite testing times and fluctuations in measurement data, the ideal saturation behaviour, i.e., zero further increase, is unlikely to be observed. Therefore, a practical definition of saturation considering these factors will have to be determined.

When using multiple devices using wireless access, radio aspects have to be observed and considered. If devices are in close proximity, they may cause (also depending on the radio access technology they use) some interference that impacts the measurement. The actual set-up used may also take the special circumstances and contexts of testing into account. An example would be, in the spectrum-licensing, i.e., regulatory, context, a test on network capacity along railway lines. In that case, the spirit of this context – typically many users in close proximity, i.e., on board a train – would determine the contextual frame of a suitable set-up for testing.

12 Considerations on absolute accuracy and measurement data fluctuations

Methodologies to measure mobile network capacity are characterized by two general properties: their accuracy, i.e., their ability to provide correct values with respect to a given "ground truth"; and the degree of uncertainty for a single measurement, i.e., fluctuation of values ("noise").

Accuracy with respect to a ground truth also includes cases where the correct value varies with time, network load, weather, i.e., the method should follow those variations. This may sound trivial; however, if accuracy is obtained by applying some kind of mapping, it cannot be assumed to be automatically given.

If the network has different modes of operation, a method should also be able to distinguish these in the sense of producing correspondingly correct values.

It is necessary to look separately at these two properties. Consider the case where methodology A delivers systematically "wrong" numbers but the fluctuations in measurement values are small, while methodology B can produce correct numbers but with a considerable amount of fluctuation. A way to reduce fluctuations is averaging over a sufficient number of measurements; however, every measurement has a time budget, and under mobile conditions, constraints on available time for a measurement may be especially tight.

NOTE 1 – The term "random fluctuations" is deliberately not being used here because it would suggest a too-narrow understanding of the range of possible underlying effects. Variations in measurement data may be due to some processes within the data path under test that are entirely deterministic. With sufficient knowledge of such processes and an appropriate model, such variations can largely be compensated for.

Of course, the best case is a methodology that is not only able to provide correct values, but also to deliver low-noise output. A methodology that delivers systematically wrong data may nevertheless be useful if compensation is possible. A simple case would be a constant offset, but even a nonlinear dependency, if the mapping relation is known and stable over time, can be compensated for with little computational effort.

NOTE 2 – There are also cases where singular conditions may cause measurement errors. For instance, there may be situations where the general load on the data path the network is exceptionally high (e.g., during a sports event), or where network elements are faulty beyond a degree of poor functioning considered to be "normal". With respect to raw data processing, such cases are subsumed under the general topic of "data cleansing", which generally requires common sense and reasonable decisions. In general, however, it can be assumed that a large enough basis of measurement data (i.e., a sufficient number of samples taken for the data path under test) is a good first-order protection against artefacts caused by such unusual situations.

The way measurement data is processed is also associated with the respective methodology. For instance, a result value can be calculated by the arithmetic mean, by a median, or another percentile. Also, there may be rules to exclude extreme values from the data set. Typically, such processing algorithms also reflect insights about the dynamic of the underlying measurement process.

Understanding the dynamics of fluctuations is therefore important. Data paths typically include all kinds of resource optimization mechanisms and policies. Therefore, it is very likely that fluctuations do not just follow some simple patterns, such as a Gaussian distribution. It follows that it may not be possible to use appropriate formulae to calculate confidence levels from sample counts. Empirical tests and appropriate data analysis should be used to understand the dynamics of the system under test. With this understanding, it is possible to provide robust estimates of the number of measurements (or the minimum duration of a measurement) required to obtain a given confidence level of the output of a measurement.

13 Examples for capacity estimation through data processing

In the general discussion in previous sections, it was assumed that a simple way to estimate capacity under conditions of non-exclusive measurements on a shared resource can be to use the maximum value of sample values taken for a given location and network under test.

Under practical conditions, it can never be excluded that the set of samples is "contaminated" by a small number of outliers for whatever reason. Therefore, a robust way to process data is to use a percentile, such as the 95th percentile, i.e., the value below which 95% of all values are found. This will remove outliers, but still maintain the principle that measured single-user values of data rate on a shared medium provide a lower boundary for overall capacity.

14 Further considerations

When doing spatially resolved measurements, conducting them while in motion is the usual way to efficiently generate the required amount of data. A characteristic of mobile networks supporting different radio access technologies is the possibility that related properties, i.e., data rates or latency, can change on a short spatial scale. When in motion, this translates to a short time scale, depending on velocity. When comparing different methods of measurement, this needs to be taken into account.

Likewise, techniques are known that use multiple devices creating specially designed load patterns to reduce measurement time or data noise.

As, for the time being, evolution of appropriate methods is still very dynamic, they are excluded from discussion in this Recommendation and are for further study.

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