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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

Quality of experience metrics for mobile telephony communication during rail travel

Recommendation ITU-T G.1034

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Recommendation ITU-T G.1034

Quality of experience metrics for mobile telephony communication during rail travel

Summary

Recommendation ITU-T G.1034 presents a novel high-level end-to-end key performance indicator (KPI) for telephony intended to be used in rail and other route-based public transport scenarios where movement is a constituting factor. The methodologies and metrics described in this Recommendation will allow generation of a holistic view of the end-user experience and solid predictions for a wide range of use case parameters based on measurement data, while at the same reducing resources and efforts needed to collect this measurement data. It will extend the existing range of quality of service (QoS) metrics by leveraging the particular properties of public transport scenarios that are defined by repeatability and reproducibility. While the described methodology focuses on telephony, it is easily possible to extend it to cover other types of service tests. This Recommendation will benefit all stakeholders in public transport: rail passengers who will encounter a high QoE, railway operators who will be enabled to provide competitive and attractive services and last but not least the network operators, who will be able to optimize their efforts and resources.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
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Keywords

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

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Introduction

Accessing mobile network services while using public transport has become a popular way to use travel time, and can also be a motivation in selecting a specific transport system. A good usage experience is a prerequisite to that; however, especially in the case of railway travel, mobile network coverage or quality still has, in many places, considerable room for improvement, due to several factors such as inadequate trackside coverage or capacity-related issues when providing services to a train with a large number of passengers.

In order to improve mobile network service quality, quality of service (QoS) metrics provide guidance for efficient resource usage e.g., for network optimization or expansion of network capabilities. This Recommendation defines novel metrics which are utilizing specific characteristics of route-based travel, namely the high degree of spatial and temporal repeatability of individual journeys.

The root of the considerations leading to the definition of these metrics is the use case of a mobile telephone subscriber on board a public transport vehicle (for the sake of simplicity, in the following descriptions railway travel is used, with the understanding that other route-based forms of travel can be seen as equivalent).

If there are places with poor or no network coverage or other issues along the track, users will experience dropped calls. Typically such effects will be localized, so the user experience will also depend on the distribution of such locations. This is visualized in subsequent figures. Figure 1 shows a case where such 'drop points' are evenly distributed, while Figure 2 shows a case where these points are clustered.

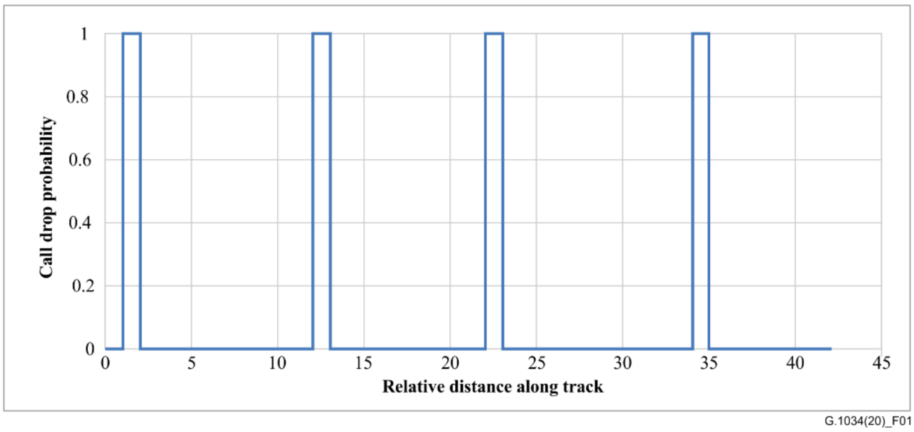

Figure 1 – Idealized situation with even distribution of problematic points where a telephone call may drop along a route

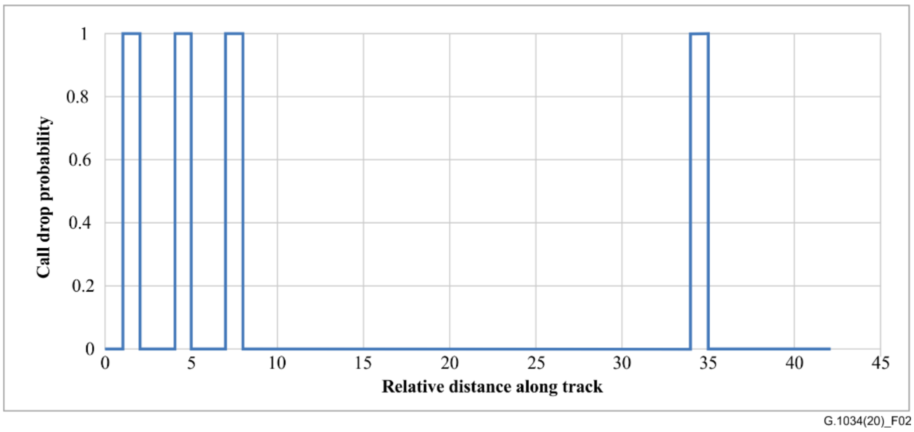

Figure 2 – Idealized situation for a telephone call drop probability along a route with clustered problematic points

A standard key performance indicator (KPI) such as a call drop rate (CDR), which is calculated over the entire route, would yield the same value in both cases. From the perspective of a user actually travelling along one of these routes, the experience would, however, be significantly different. With evenly distributed 'drop points', no uninterrupted call with a duration longer than the travel time between two such points would be possible. In a mobile network with clustered 'drop points', uninterrupted longer phone calls would be possible for a large part of the journey. It follows that there is a need for a QoS metric which is able to express such differences.

This Recommendation defines two metrics, after establishing the required definitions and conventions in clauses 3, and 5. The first metric, termed local drop probability (LDP), which is computed directly from measurement data, provides spatially resolved information about call stability along a route and provides information about the location and severity of problematic places along a track. LDP is described in detail in clause 6.

The second metric, termed call completion probability (CCP), uses this data to compute indicators which express the probability that a telephone call of a given duration can be completed successfully. The basic use case for this indicator is that of a subscriber seated in a rail or street vehicle, conducting a telephone call while travelling along a pre-defined route from A to B. CCP is described in detail in clause 7.

An important property of CCP is that the assumed call duration is a parameter in the calculation process; therefore the methodology not only provides a single indicator for one particular call duration, but can produce a range of indicator values covering an entire range of call durations.

In that sense, the methodology goes beyond standard KPIs describing telephony-call stability by utilizing specific properties of use cases which include a high degree of temporal and spatial repeatability of movement, which is a typical property of rail-based travel in particular, but also other means of public transport. One of the consequences is that network structure or topology becomes a macroscopic property of the use case as randomness of use cases is effectively reduced.

The methodology is a two-step process which is rooted in actual measurement data. The result of the first step can be seen as an abstraction layer for subsequent processing, but also constitutes robust spatially resolved information of key network performance properties. Overall, the methodology is able to generate robust predictions of end-to-end experience for a wide range of use case parameters, solidly based on measurement data.

The methodology and related KPIs provide a holistic view of mobile telephony communication availability and QoE metrics for corresponding use cases.

QoE indicators generated by this methodology can be used to improve resource utilization in network optimization in a targeted way, by focusing on the use cases typical for rail travel in parts of the network dedicated to respective mobile network coverage. This can support the achievement of high levels of QoE for such use cases at a significantly lower effort than by less targeted measures which may lead to overprovisioning. This will be beneficial for all stakeholders, rail passengers encountering high QoE, railway operators being enabled to provide competitive and attractive services and last but not least the network operators, who can optimize their efforts and resources.

The recommended methodology provides an intuitive view on those use cases, with KPIs that are easy to adapt and to communicate for a wide range of conditions. It also is modular and scalable in the sense that indicators can be generated from a basic set of data for a wide range of travel situations and routes.

The methodology is not limited to the telephony use case, or the call stability aspect. Using the same process, it is possible to also create QoE indicators for other types of usage. Respective definitions are for further study.

Recommendation ITU-T G.1034

Quality of experience metrics for mobile telephony communication during rail travel

1 Scope

This Recommendation provides the methodology for the assessment of metrics for the end-to-end quality of service (QoS) of mobile communication services on board vehicles moving along a defined route, i.e., trains as well as road vehicles, and in particular public transport. This metric is a measure for call stability or retainability, i.e., it represents the probability that a telephone call with a pre-defined duration can be completed successfully.

The metric exploits specific properties of respective use cases and allows for a holistic, end user centric point of view on related mobile network performance characteristics. The underlying model consists of two parts:

- a computation methodology which derives spatially resolved information from measurement data acquired by conventional mobile network testing, and
- a methodology which uses the data created to compute respective high-level QoS indicators.

The methodology also produces spatially resolved information about local call stability and is therefore useful for network optimization.

The recommended methodology focuses on aspects of voice telephony. However, an extension of this methodology to aspects of mobile data communication is possible and will be taken into account in a future revision of the present Recommendation.

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.113] Recommendation ITU-T G.113 (2007), *Transmission impairments due to speech processing*.

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

[ITU-T E.840] Recommendation ITU-T E.840 (2018), *Statistical framework for end-to-end network performance benchmark scoring and ranking*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

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

3.1.2 quality of service (QoS) [b-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 Recommendation

This Recommendation defines the following terms:

3.2.1 geographical unit (GU): 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.

3.2.2 route profile: A data object, based on an ordered list of geographical units (GUs). A route profile provides spatially resolved information about mobile communication related properties for a given route. One example of data contained in a route profile is the local drop probability (LDP).

3.2.3 local drop probability (LDP): An indicator, computed from drive test data, to indicate the call-drop probability for a given geographical unit (GU).

3.2.4 call completion probability (CCP): The probability that a telephone call started at a given location can be completed as intended (i.e., without being dropped).

3.2.5 virtual call: 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.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CCP Call Completion Probability

CDR Call Drop Rate

GNSS Global Navigation Satellite System

GU Geographical Unit

KPI Key Performance Indicator

LDP Local Drop Probability

QoE Quality of Experience

QoS Quality of Service

RAT Radio Access Technologies

VC Virtual Call

5 Conventions

5.1 Chosen variant for call drop rate (CDR)

For the purpose of this Recommendation, the following applies:

The primary definition is being the inverse of an end-to-end call success ratio, with reference to Figure 8-1 in [ITU-T E.804].

The definition of CDR therefore combines the key performance indicators (KPIs) **Telephony service non-accessibility** and **Telephony cut-off call ratio** as defined in [ITU-T E.804]. This corresponds to an end-user perspective where call attempts are made without previously checking if the mobile device is camped on a network (i.e., network coverage and service availability agnostic).

In that sense, the call set-up phase is subsumed in the definition.

The mathematical definition is:

$$CDR[\%] = 1 - \frac{Number\ of\ successfully\ completed\ calls}{Number\ of\ call\ attempts} \times 100 \quad (1)$$

NOTE 1 – this definition is functionally equivalent to the definition of the call drop rate alternative 1 defined in clause 7.4.3 of [b-ITU-T E.807].

NOTE 2 – In future refinements of the present Recommendation, the methodology could be used to also define a local call failure probability.

5.2 Geographical entities

For the purpose of this Recommendation, the following applies:

Track

Physical road or rail element.

Routes and nodes

A transportation network is understood as a directed graph consisting of routes and nodes. A node can be of two general types: stations, and general junctions in the network. The distinction is made on a functional level where in station-type nodes, passengers can enter or leave vehicles.

NOTE – For the sake of simplicity, text of this Recommendation may make reference to railway tracks and related elements of a railway network only. It is understood that similar considerations also apply in the case of road networks.

A route may subsume several tracks in cases where multiple tracks are running in spatial vicinity. The distinction whether physical tracks are treated as separate routes is made on a functional level, with respect to mobile network properties. If the spatial separation is such that different network conditions have to be assumed, different routes need to be used. This may lead to the introduction of additional nodes, i.e., location where it is assumed that relevant mobile network properties are becoming different.

Special case: If a given route is systematically been driven through with significantly different velocities, it can be represented by different data objects of type route, designated by corresponding attributes. An example would be a station where part of the vehicles stop, and other vehicles drive through. This distinction is required for subsequent combination of routes to describe end user experience.

A route may exclude the immediate physical vicinity of nodes. In that case e.g., a station itself is not part of a route. This distinction is made to avoid zero-velocity effects or to ensure modularity and does not affect the general concept.

Geographical unit (GU)

A geographical unit (GU) is the smallest unit in the representation of routes (typical dimensions: 100 to 200 m). A route is equivalent to a set of GUs arranged in proper order.

A GU is a uniquely identified data object. If geographical positions of routes are available, a GU is typically a one-dimensional object, i.e., a logical segment of a route. Otherwise, a GU can also be a two-dimensional entity associated with a given rectangular area, typically a square. A way to create respective data object information is to use a grid overlaid on a map and record the sequence of grid tiles corresponding to the route.

To express a position along a given route, a respective relative index of a list of the route's component GUs can be used.

If the representation of a transportation network is overlap-free, a GU also is unambiguously associated with one (centre) or two (start and end point of associated track segment) geographical location(s).

Journey

Instance of an end-to-end travel use case. A journey has a start and an end point which are station-type nodes in the transportation network. A journey is a set of routes arranged in proper order. On a data-evaluation level, a journey can be understood as the union of the GUs of its component routes.

Figure 3 provides an overview of the geographical entities described in this clause.

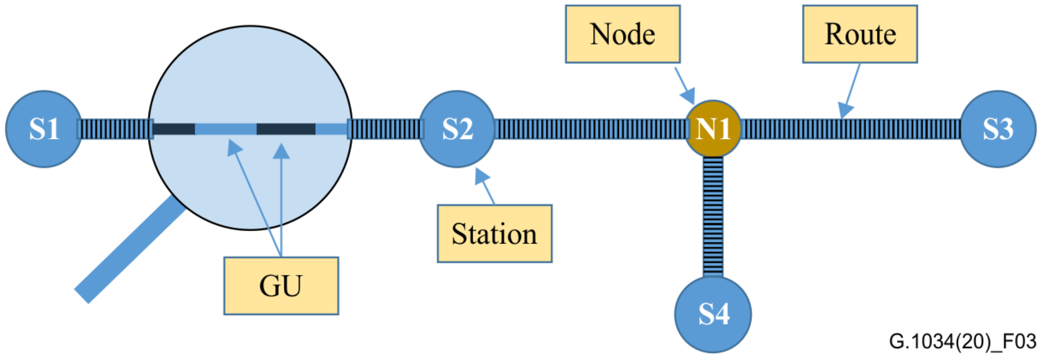

Figure 3 – Nomenclature for entities used in this Recommendation

5.3 Geo or spatial binning

For the purpose of this Recommendation, the following applies:

Method to assign measurement data to specified geographical units (GU) for aggregation, using geographical positions associated with that data. Each data element is assigned to a GU, using shortest-distance or other algorithms. Data elements are then aggregated per GU.

The process is equivalent to temporal binning (aggregation of data in units representing a given time range) or distributions where data is assigned and aggregated by categories relating to defined attribute ranges.

This method of data representation allows for a mapping of use cases to actual travel along a given route. It is therefore the enabler for subsequent steps in data processing towards route-specific indicators.

6 Metric for local drop probability (LDP)

6.1 Basic considerations

Current standards (e.g., ITU-T Recommendations, ETSI standards) define a large portfolio of QoS KPIs for mobile network services. These key performance indicators (KPIs) are general-purpose in the sense that they are applicable to a broad spectrum of cases. However, this general applicability also prevents specific properties related to particular usage scenarios from being utilized.

Mobile network usage on board public transport vehicles represents such usage scenarios with specific properties. On the one hand, such specific properties provide additional possibilities for richer, more useful KPIs. On the other hand, there are special aspects which need to be taken into account.

Routes are essentially fixed in space, particularly in the case of trains moving along given tracks but also in the case of buses which also follow well-defined routes. In the time domain, motion has also a high degree of repeatability, again in particular in railway travel where the velocity of trains is prescribed within a rather narrow margin.

This has some consequences for related user experience when using mobile-network services under these conditions.

To elaborate this point with a practical example, Figure 2 and Figure 3 show in two different ways how problematic points (low KPI values) may be distributed along a track in a mobile network.

For the sake of simplicity, the problematic points are described as locations with a 100% call drop probability. In practice, such situations can be encountered in no-coverage areas, streets or railway tunnels without adequate mobile network coverage, or in places where handovers regularly fail due to network-related causes.

A graphical representation of two possible patterns is shown in Figure 1 and Figure 2.

As far as network degradations are due to basic network architecture issues, it can be expected that this situation of low QoE will persist for some time. Travellers taking this journey repeatedly could therefore build up experience and adapt their calling behaviour accordingly. Likewise, this may take place if mobile network users have relevant information. This modifies user expectation and has the potential to influence the perception of network quality in a positive way.

NOTE – This relates to the issue of the 'advantage factor' and related aspects discussed in [ITU-T G.113].

If the information on such route-specific behaviour is sufficiently robust, railway operators could even provide useful services to their customers in terms of customer experience management. A metric based on route-specific user experience would also allow mobile network operators to optimize the usage of resources for network optimization and improvement to achieve the highest possible user satisfaction per unit of investment. In this sense, a respective metric provides benefits for all stakeholders.

The fact of high spatial and temporal repeatability also has consequences with respect to the mathematical foundation of KPI definitions. The basic assumption is that individual samples are statistically independent, i.e., represent random samples from a basic totality. Therefore, an average can be expected to predict the outcome of a specific test with a statistical reliability which improves with total sample count.

When motion is quite strictly spatially confined and also has a high degree of temporal repeatability, the assumption of randomness becomes questionable. In a typical situation of a long-distance train, with a velocity of 180 km/h (3 km/min), a 2-minute telephone call covers a distance of 6 km, and a 5-minute call has a spatial dimension of 15 km. This is the same order of magnitude of cell sizes in a cellular network. A use case of this type therefore becomes a macroscopic object with respect to network topology. As far as network performance is influenced by effects linked to geography, this means a high degree of repeatability for subsequent runs of the same use case.

As a consequence, the actual route taken through an area becomes significant, and, through its repeatability, a meaningful, tangible quantity. While indicators representing only route-wise averages have limited usefulness, it becomes possible to extract more useful information from the set of measurement data than just an average over the entirety of data points.

6.2 Computational concept

The metrics for rail-based traffic as defined by this Recommendation are based on measurement data from conventional mobile network tests.

The process has two stages. In the first stage, a spatially resolved representation of call-related characteristics for a given route is extracted from primary measurement data. The resulting data entity is called a route profile.

The second stage uses this output and creates the actual metrics in the form of single-number QoS indicators for a particular route or track. By using the concept of virtual calls which will be explained in the next clause, these indicators can be generated for a wide parameter range of the underlying use case.

The overall process is depicted in Figure 4.

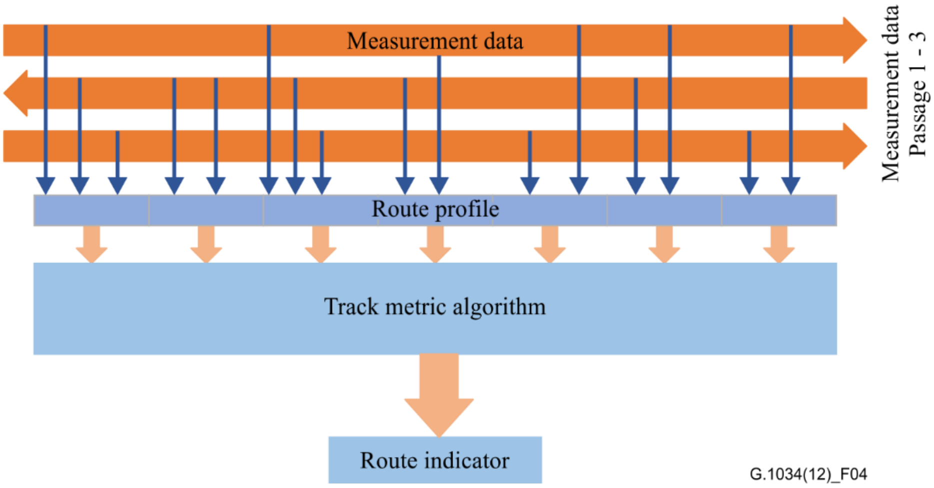

Figure 4 – Symbolic description of the two-stage process which generates route metrics from measurement data

The methodology with its underlying principle of route profiles can be extended to other indicators using the same general process, as shown in Figure 5. This applies for other indicators for a given service type (e.g., speech quality) as well as for other services, in particular those which need continuity of service delivery (e.g., video telephony, audio or video streaming).

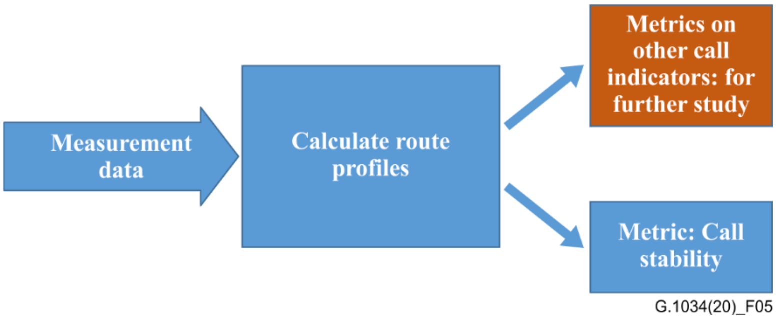

Figure 5 – Current and future uses of the methodology

With reference to the conventions in clause 5.2, the route profile is a data object in the form of an ordered set of GUs which spatially represents the route. It carries data elements describing properties of the route, as described in detail in clause, 6.3.

Apart from providing input for the second stage of the overall process, a route profile is also useful on its own as it provides spatially resolved information about mobile network performance along that route. A route profile also provides information on local network performance and can therefore be used to support network optimization.

A route profile constitutes an abstraction layer which isolates measurement data from QoE metrics and establishes modularity. The abstraction layer property of route profile means that equal sample counts or weighing is not required, in contrast to computing KPIs such as CDR from component sets of data.

6.3 Calculating local drop probability (LDP)

Figure 4 in the previous clause shows the entire computational process. The upper part of Figure 4 depicts the aggregation process from drive test data. This data comes from subsequent drive-test passes through the given route (in the example shown in Figure 4, three such passes have been made).

The underlying model to describe call stability is based on the general methodology of drive testing in a straightforward way. Each call, originating from a mobile device, will be established in a specific location. Subsequently, the device moves along its route until the call either drops, or terminates regularly after the target call duration has been reached.

Correspondingly, the data object representing a GU has two event counters, termed *nTouch* and *nDrop*[1].

nDrop counts the number of cases a call drops in this GU. *nTouch* counts calls which either originate in, pass through, or drop in this GU. Incrementing both counters in case of a dropped call is necessary for consistency.

From the counters, a quantity "local drop probability" (LDP) is computed which is defined as

$$LDP(x)[\%] = \frac{nDrop(x)}{nTouch(x)} \qquad (2)$$

In this context, x is the respective (relative) index, i.e., *LDP(x)* is the x-th GU (GU_x) along a route which is segmented into corresponding geographical units.

Figure 6 shows an example, assuming that data is collected over two passes where in each pass a call is made. One of the calls ends successfully, the other one drops. The figure shows the state of counters after the first and the second call.

GU index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
					Call 1											Success
		Call 2							Dropped							
nTouch	0	1	1	1	2	2	2	2	2	1	1	1	1	1	1	1
nDrop	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
LDP		0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0

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Figure 6 – Example for geo binning of a route consisting of indexed GUs. Counter values are shown after two calls have passed this route

The first call starts in GU 4 and ends successfully in GU 15. The second call starts in GU 1 and drops in GU 8. After these two calls, counters nDrop and nTouch contain information about all GU the calls have passed ("touched"). The GU with index 0 has not been touched by any call and consequently both counters are zero, indicating that nothing is known about this GU.

By increasing the amount of input data, i.e., the number of calls being geo-binned, the reliability of call-related information increases, in the same way as the statistical reliability of a KPI value increases with an increasing number of samples.

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[1] The data object will also carry elements for spatial binning of global navigation satellite system (GNSS) related data, in particular velocity. In addition, it can easily be extended by other elements for spatial binning of other performance related content of measurement data.

By this definition, LDP is an ordered list of values (i.e., a vector). This entity is termed a route profile. The order is defined by the sequence in which the GU are passed (0…N) when a vehicle travels along the given route. Of course, the inverse direction of travel is also possible which simply means that the index runs in reverse order (N…0).

Following from the way the data is processed, a route profile contains the same amount of information as a KPI for that route, and i.e., each call drop incident leads to exactly one count in one of the nDrop elements. The way of processing just additionally utilizes the geographical information which is contained in the data. With an increasing number of samples, information about spatial properties of the network, visible in the shape or structure of a route profile, increases. If, for instance, dropped calls are caused by spurious effects, a route profile will show some kind of "noisy" unarticulated structure, as well as pronounced structures in a route profile localizes root causes such as weak network coverage or systematic problems with call hand-over.

A route profile can be visualized as an x-y diagram where x is the travelled distance and y is the LDP value. Figure 2 or Figure 3 are simplified versions of such route profiles with LDP values being either 0 or 1 which means that either no or all calls drop in a particular GU. There are cases where this is actually true, e.g., in sufficiently long tunnels where no mobile network coverage exists. In reality, and additionally also taking into account that location information typically has a certain degree of imprecision, LDP will in most cases be between those values, i.e., is an analogue quantity.

In actual mobile network situations, the LDP value may depend on the direction of travel. Also, in a more complex route network, there may be a dependency on the motion history as far as call drops caused by effects linked to handover processes are concerned. These practical aspects are discussed in clause 8.

Route profiles on their own can be used as a tool to find and/or visualize location-dependent degradations in mobile network performance. Furthermore, they are the essential basis of the second step of computation towards the QoS metric.

7 Metric for entire routes: Call completion probability (CCP)

7.1 Basic definitions

CCP, the metric defined in this Recommendation, is the probability that a telephone call of pre-defined duration will be completed successfully, i.e., does not drop prematurely.

A standard KPI expressing call stability is calculated from original test case data, i.e., for the call duration used in that particular test. For the methodology described in this Recommendation, the call duration is an input parameter in the calculation process, i.e., the methodology can produce indicators covering a whole range of use cases.

This part of the methodology is termed the "virtual call method". The underlying model assumption is a user making a phone call while traveling along the given route. The overall stability of this call will be governed by the local call drop probability encountered during the call. Therefore, the route profile is used as input data for this model.

The first step in this methodology is to transform the spatial positions provided by a route profile into time positions. This is done by using the velocity information also taken from input data from which route profiles are generated (typically, GNSS speed information). As each GU has a defined spatial size, the corresponding (average) time per GU is calculated using the average velocity by:

$$t_{avg} = \frac{d}{v_{avg}} \tag{3}$$

where *d* is the spatial dimension of the GU along the direction of motion.

When the route and its profile are represented by an ordered, indexed sequence of GU, a virtual call (VC) may start at any position x in the route profile and then progress along the route[2]. For subsequent indices of the route profile, the probability that the call will drop is calculated using the profile's LDP values. The number of route segments used in the calculation is determined by accumulation of times per segment, until the intended duration of the VC is reached.

The value produced by this calculation represents the cumulated probability that a call started in position x along the route can be completed successfully. This quantity is termed call completion probability (CCP).

$$CCP(x) = \prod_{i=x}^{y}(1 - LDP(i)) \quad (4)$$

CCP is calculated for every possible starting point along the route. The single-number metric which represents the overall probability for the entire route is calculated by averaging these CCP values.

Figure 7 provides a simplified example to further explain the basic principles of the VC method.

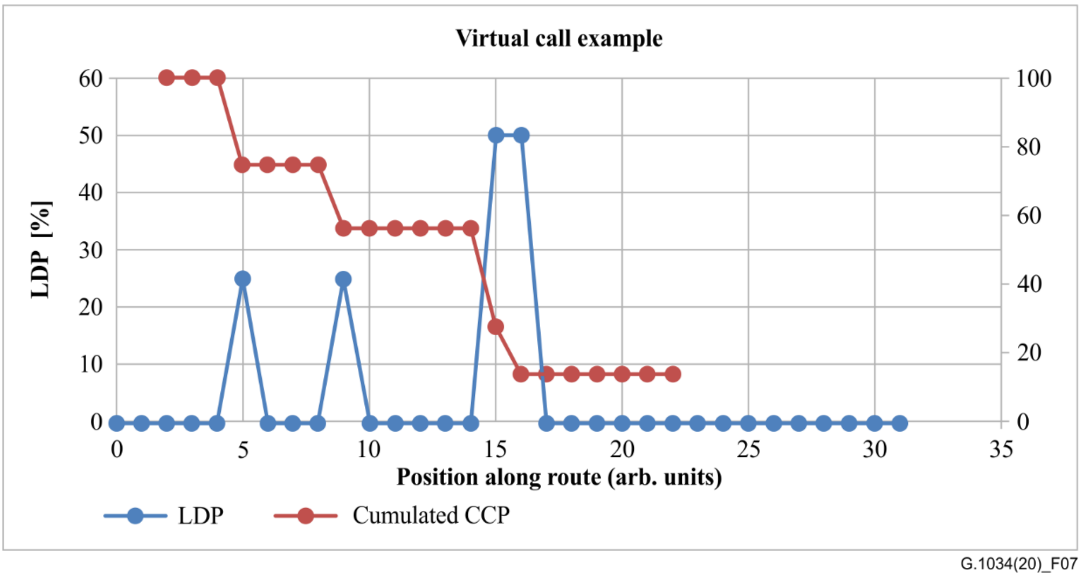

Figure 7 – Simplified example for the virtual call (VC) method

In this example, for ease of understanding the route profile is quantized, having only distinct LDP values, and the speed of travel is uniform, i.e., the time per GU is constant. The lines are only drawn for better identification of data; the route profile consists of discrete values for each GU.

The red points indicate the cumulated CCP for a VC started at position 2. For the first GU along the route from this point, LDP values (blue curve) are zero. After encountering, at position 5, an LDP of 25%, CCP decreases to 75%. On further progressing through the profile, CCP is reduced successively each time a GU with non-zero LDP is encountered as defined by Equation 3.

The target duration of the virtual call is reached at position 22, with a resulting CCP value of approximately 14%. This value, CCP(x), is assigned to the starting position of that virtual call, i.e., x = 2. The overall process is run for all positions in the route profile. Finally, the indicator for the entire route is calculated by averaging over all CCP(x).

[2] Depending on the direction of motion, subsequent indices will either increase or decrease until the spatial end point of the VC is reached.

7.2 Modularity

The virtual call methodology is intended to create a QoS metric, i.e., indicators from a customer's perspective which in this case means an entire journey, from a starting point A to a destination B.

In a railway or street network, such a journey is described by a sequence of nodes, which can be bus or train stations, or just road intersections or railway switches. The journey leads along the sections between those nodes.

A modular approach which allows indicators for arbitrary journeys to be created is therefore based on an overlap-free set of route profiles which represent the road or track sections between respective nodes. With the isolation-layer property of route profiles with respect to measurement data, route profile information can be created regardless of the origin of source data, as long as it covers the routes from which the journey is composed. The related CCP is then computed from the joined route profiles for this journey, i.e., the LDP values in Equation 4 are those for the entire journey in the respective sequence.

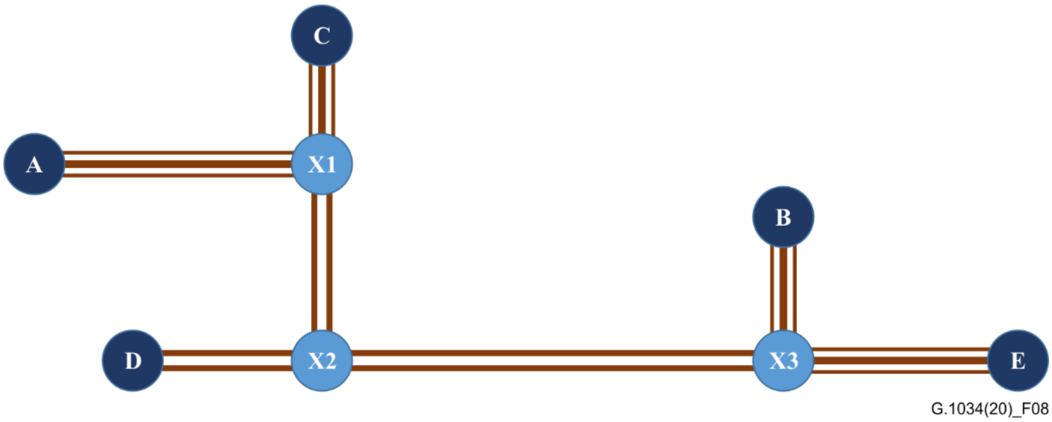

Figure 8 – Composition of journeys from routes

Figure 8 provides a visualization of the concept of modularity. It shows part of a transportation network where nodes A to E are stations or stopping points and X1 to X3 are junctions. Therefore, edges represent the non-overlapping routes from which a journey is composed. For instance, the journey from A to B leads via nodes X1, X2 and X3. Route profiles are computed from measurement data which can come from vehicles which actually travel from A to B, but may actually, or additionally, also come from vehicles travelling from other journeys, such as A to C, or D to E.

8 Aspects of practical application

8.1 Overview

The previous clauses describe the methodology in general. There are, however, some implementation details which need to be aligned in order to facilitate comparability of results produced by different implementations. In order to provide flexibility, the following text offers, for some cases, more than one recommended alternative. Respective selections need to be part of the documentation when results are being reported.

Practical aspects of actual implementation of the methodology are treated in subsequent clauses. Aspects related to accuracy and statistical error considerations are treated in clause 9.

8.2 Direction dependencies and modes of computation

If a route geographically connects points A and B, the input data used to compute route profiles typically comes from measurements either taken by vehicles running from A to B, or from those travelling from B to A.

There are cases where call stability depends on the direction of travel (actually, on the history of a call), for instance if a call drop is caused by handover failures.

The situation should be dealt with by either:

a) Calculation of direction-specific route profiles, and subsequent calculation according to the virtual call based metrics. This will produce one CCP(x) vector and corresponding single-number CCP indicator per direction. These quantities can be used as separate, direction-specific entities, or corresponding averaged values can be calculated, or

b) Calculation of a single route profile by using measurement data from both possible directions of travel. Subsequently, two direction-specific CCP(x) and single-number indicators are calculated by running the track profiles in either direction. These two direction-specific quantities can again be used separately, or averaged to a single indicator.

A systematic comparison between these variants is for further study. In order to maintain reproducibility, whenever respective indicators are computed, the method used shall be part of the related documentation.

8.3 Behaviour of the algorithm near end points of journeys

Route profiles, and journey profiles composed from them, have finite length. In the vicinity of the end points, virtual calls will not complete, i.e., the end of the route is met before the pre-defined duration of the virtual call is reached. The portion of the journey where this condition is met increases with the duration of virtual calls.

The corresponding situation in actual end-user QoS is a subscriber who starts a call shortly before a train or bus reaches its destination. It is recommended to use one of the following variants:

- Make the assumption that mobile network service quality at journey end points is in most cases good; this models users leaving the vehicle and completing the call at this location. On this basis, a VC which reaches the end of a route profile would be assigned the CCP value reached at this point.
- Do not calculate CCP values for virtual calls which cannot be completed before reaching the route profile's end. A corresponding user experience would be a subscriber who is aware that the destination will be reached soon and does not start a telephone call anymore in preparation to leave the vehicle. In case of further aggregation towards a single CCP value for both directions of travel, CCP values used as input would be copies of CCP values calculated for the opposite direction of travel. Mathematically, this is equivalent to using these opposite-direction CCP values with double weighting.

Other variants are for further study.

In a particular implementation, the variant of choice should be determined by considering the best fit between the structure of the respective network, and the desired end user perception. It can be expected that differences will be moderate due to the fact that those sections only constitute a minor part of the entire journey. However, in order to maintain reproducibility, the method used shall be part of the related documentation.

The travel distance between the route end points A and B will not be an integer multiple of the GU dimension. Assuming the origin of the GU rasterization is point A, the last GU towards B will, due to geo mapping of data, receive less data than the other GU along the route. In general, the effect is negligible if route length L is large against the dimension of a GU. In addition, the effect of having a GU with a lower than average sample count is qualitatively similar to fluctuations of sample count for other reasons, such as variations in measurement data density. These cases are accounted for by the considerations on error margins and minimum requirements of sample count, as described in clause 8.4.

8.4 Geographical mapping of measurement data and related accuracy considerations

Spatial binning requires assignment of geographical positions to measurement data. This information usually comes from a GNSS device during measurement. As such information has a limited accuracy and is usually noisy, i.e., has random fluctuations superimposed, there will be a certain blurriness of information with respect to GUs. This limits the useful range of sizes; practically a GU dimension in the order of 100 to 200 m is reasonable.

It is further recommended that methods to improve the reliability of position information are being used, such as removal of artefacts caused by irregular operation of GNSS devices, for instance when a vehicle leaves a tunnel, or in areas with natural or artificial structures which degrade GNSS position accuracy. In order to improve position accuracy, algorithms such as map matching can be used which utilize e.g., position information from existing road or railway track data bases.

In addition, techniques should be used which are using the entire time sequence information of measurement data files to find the best-matching set of track segments. This prevents "jumping" between tracks which can take place with map-matching based on local coordinates if several candidate tracks are present within close range.

In practice, trains may not use the same tracks every time. In areas where many railway tracks exist, even perfect mapping to railway tracks will lead to a dilution of measurement data to different valid routes. In order to prevent this, algorithms should either use and aggregate information available for neighbouring tracks or close-by locations to be utilized in a particular route profile. This is equivalent to the assumption that the properties of mobile networks can be assumed to be same within a certain distance. For practical purposes, this distance is assumed to be in the order of 100 m.

8.5 Physical and logical nodes in track networks

The basic principle of modularity and its use to create indicators for an entire journey has been discussed in clause 7.2 on a macroscopic level. The present clause extends these considerations by looking at practical aspects on a more detailed level, i.e., typical local track structures.

Physical nodes in a transportation network are junctions or switches. They can be located in or near stations (in which case they may have a more complex form, e.g., a system of parallel tracks and switches), but also elsewhere in the network.

For practical purposes, it is not required to have a fully detailed representation of the transportation network down to individual tracks as it can be assumed that the mobile network characteristics for nearby tracks are sufficiently similar. The geographic condition for vicinity, i.e., the dimension of an 'equivalence corridor' with respect to network properties, is a matter of definition in the course of the concrete implementation of the methodology and needs to be part of the associated documentation.

Following this definition, respective nodes do not necessarily have to be identical with physical elements of the track network.

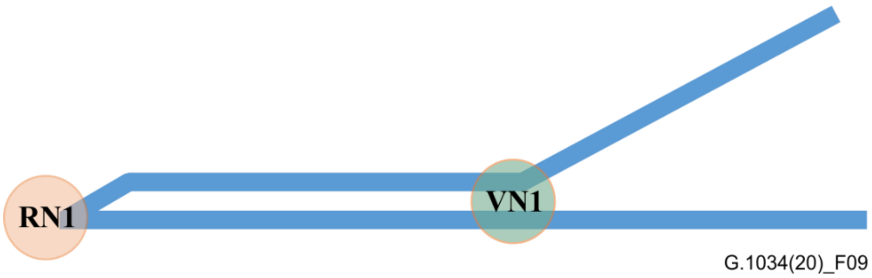

Figure 9 – Concept of 'virtual node'

Figure 9 shows a situation where RN1 is a physical node in the network. The tracks run, however, close to each other up to the point marked VN1 from where their physical distance becomes larger than the 'equivalence corridor'. Therefore, in the route profile representation of the transportation network, the physical node RN1 is replaced by the virtual node VN1.

Virtual nodes provide simplicity in subsequent steps of data processing. For the section between the point given by RN1 and the position of VN1, input measurement data coming from drive tests along the lower and the upper route are combined in the resulting single route section in the basic set of route profile.

There is one additional distinction to be made when using data to create indicators for a selected journey. For nodes in the transportation network which represent stations, the train can stop at this station, or pass through it without stopping. If the route profile contains problematic spots (having non-zero LDP), the resulting user experience will be different, as the user stays for a prolonged time in such spots, or passes them quickly.

These alternatives are systematic ones, as stopping at a given station, or passing it, is part of a given journey's timetable (e.g., a regular and an 'express' variant for the same connection from A to B). It is recommended to select one of the following alternatives for processing:

a) Since the data from which route profiles are computed contains velocity information, these modes can be taken into account by calculating two indicators for each type.

b) Alternatively, if this differentiation is not required, an averaged indicator can be calculated. If the input data for route profiles are representative of the mix of variants, data can be taken directly.

c) Otherwise, profiles differentiating by velocity are calculated, and subsequently composed into the desired relation between variants.

8.6 Aspects of handling in low-velocity areas

Routes or journeys will typically contain stations, i.e., places where vehicles stop. Depending on the duration of the stop-over, virtual calls reaching such GUs will end there, and virtual calls starting in these GUs may even terminate in this same GU. As far as such stopovers are a regular part of the journey[3], resulting CCP are correctly expressing the customer experience. There may, however, be the case where only part of the vehicles stop at a given location (e.g., "express" connections which do not stop at every station along their route). Provided input data contains samples from both cases, a decision has to be made about using these data.

When all data is used to compute the route profile, average velocity will represent a mix of both cases, as will the CCP calculated from that route profile. If more differentiation is required, two route profiles, and subsequent CCP, need to be computed from the corresponding subset of input data.

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[3] In particular in case of terminus-type stations, but also in through stations.

9 Considerations on accuracy and error margins

9.1 Requirements on minimum sample counts for input data

As with other KPIs based on aggregation of measurement data, considerations about accuracy when using a limited set of samples need to be made. This can be done in full analogy to other KPIs based on the same type of input data, namely call drop rates (CDRs). The underlying input quantity is the outcome of a call which is in this case either 'successfully completed' or 'dropped', i.e., a binary result.

In the case of quantities like CDR, the confidence interval should be assessed by using respective clauses of [ITU-T E.804] or [ITU-T E.840]. Appendix I of this Recommendation provides a numerical example.

CCP is proportional to CDR, so its error margin can be reasonably assessed using the number of samples used in the route profiles from which it is computed. There is, however, also a geographical dimension. The distribution of information along the route may not be homogeneous. In order to determine if a given CCP actually provides a meaningful description of the user experience along a given route or journey, additional criteria need to be defined.

These criteria are categorized according to the components of the methodology:

– Overall sample count per GU, with respect to the number of use cases covered by the measurement data.

– Aspects of macroscopic spatial coverage, i.e., requirements that each part of a route profile should be represented in the data set.

– Aspects of microscopic spatial coverage, i.e., dealing with local fluctuations of data density (spatial homogeneity of information), including the possibility that individual GU do not possess any data.

The first aspect is covered by looking at the total number of calls involved in the data set. It is however desirable, due to the property of LDP being an isolation layer with respect to actual measurement data, to formulate requirements without the need to know the number of original call samples used in the route profile. This is achieved by making reasonable assumptions about the relation between information elements involved in the analysis.

According to the processing described in clause 6.3, each call increments the nTouch counter in each GU which are passed while the call is active. If the call drops, the nDrop element of the last GU in that series is also incremented. This means there is a direct relation between the number of nTouch counts a single call creates, the GU dimension, the speed of motion, and the duration of the call. For the simplest case of constant velocity during the call, a non-dropped call creates a total of N nTouch counts. If the call drops, assuming randomness with respect to the duration of the call up to this point in time, the expectation value of nTouch counts produced by this call is N/2.

The general formula is

$$N = \frac{v}{D*L*60} \tag{5}$$

where v is the velocity of travel in km/h, D is the duration of the call in minutes, and L is the dimension of the GU in km.

The first criterion, for the average nTouch value per GU of a given route, links directly to the corresponding sample count for a given confidence interval.

The second aspect relates to spatially resolved CCP(x) values, i.e., results on individual virtual calls along the route. It defines that such values are only valid (i.e., should be used in respective reports) if the average nTouch for this virtual call is above the corresponding threshold value.

The third criterion is rooted in the fact that actual call sequences will have times where no call is active, due to call set-up and guard times after ending a call. Even after aggregating measurement data from a number of passes along a given route, there is a finite probability that a single GU will not have been touched at all. This criterion defines an upper limit of the fraction of GU with an nTouch value of zero.

The macroscopic homogeneity aspect actually also relates to usage of particular GU in calculation of a CCP for the entire route. If nTouch for a given GU(x) is below the respective threshold, its LDP(x) will be assumed to be zero; respective traversing time information for this GU will however be used.

The actual threshold values for validity are recommended to be set according to the actual usage of related indicators, in full analogy of respective considerations for sample count requirement in other cases of KPI computation. If only first-order, indicative information on a given journey or route is required, useful threshold values may set rather generously. If indicators are used to decide on infrastructure investments or other decisions of comparable significance, requirements on the amount of data will be higher.

9.2 Discussion on the overall prediction accuracy of the methodology

While route metrics are firmly anchored in actual measurement data, the methodology uses some simplifications. Many mobile networks are made up of regions with different radio access technologies (RAT). There are RAT-specific restrictions with respect to inter-RAT handovers of calls, for instance, there is no procedure which hands over a 2G call to 3G, or an active call in 3G to VoLTE. This means that in mixed-RAT networks, there is a tendency of a call to end up in 2G, with a subsequent call drop if 2G coverage becomes unavailable.

When route profiles are created using call lengths of 2 minutes, a typical value used in many conventional performance tests, mobile units will reconfigure to locally available RAT. Therefore, in cases where network coverage is strongly inhomogeneous with respect to RAT, and/or has a high portion of 2G coverage, it can be expected that the long-call stability predictions of the methodology are too optimistic.

With the evolution of mobile networks towards 4G and beyond, it is assumed that such considerations become less significant. It is recommended, however, to consider correction factors on a case by case basis, determined by validation measurements, to take care of this situation.

10 Variants and related terminology

The base methodology derives a single number track indicator by averaging the metric's profile. Hence, it is also called "analogue method", because it operates with floating point values. The resulting quantity can be directly linked to the call drop rate.

The numerical value is governed by the absolute quality of the service (in this case expressed by the call drop rate) as well as by the spatial structure of the network performance along a route. For a given call drop rate along a route, the numerical value of the indicator will be in a corridor between V1 and V2, where V1 represents a case with evenly distributed problematic points, and V2 represents a structure where all problematic points along the route are clustered within a small region.

It may be desirable to employ a variant which is more sensitive to the spatial structure of the track. The means to this end is, to extend the methodology by a threshold value, i.e., an additional, independent parameter of an extended algorithm.

NOTE – Appendix II contributes to further elaboration of this aspect by discussing ways to control the sensitivity of the metric against the LDP "structure" of a route.

In order to facilitate the future introduction of additional variants of the metric, the following framework terminology is defined:

Mx: track indicator, track metric value (single number). The index x indicates the variant of the methodology, i.e., the specific set of algorithms, that has been used to compute the indicator.

Currently defined variants:

M1: Product of success probabilities (1-LDP) per GU

M2: Based on metric's profiles according to method M1; additional transformation into binary values using a threshold. The result is the proportion of values above the threshold in per cent; high values indicate higher quality. A maximum value of 100 indicates that there are no dropped virtual calls. This variant uses a parameter representing the threshold value.

If a method variant uses parameters, the numerical value of a metric computed by this algorithm will depend on the actual values of the parameters used. Therefore, the parameter values need to be part of the naming of this metric, i.e., $Mx(p_1 \ldots p_n)$ where p_i is the i-th parameter of the algorithm.

Appendix I

Numerical examples for error considerations

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

This appendix refers to the considerations outlined in clause 9 of this Recommendation.

Using the sample count as the input quantity, an error margin can be computed.

TableI.1 shows two example sets of data for a nominal CDR of 10%, where limits of the 95% confidence intervals were taken from [ITU-T E.804], Tables IX.1 and IX.2. The asymmetry results from the model used, i.e., Pearson-Clopper.

Sample basis, number of calls	Lower limit of confidence interval	Upper limit of confidence interval	Span approx.
100	4.9%	17.6%	±6%
1000	8.2%	12.0%	±2%

Table I.1 – Selected examples for limits of confidence intervals according to Pearson-Clopper

[ITU-T E.840], using a different model, predicts, for the same nominal CDR, the same standard error for the 100-sample case and a slightly different value of ±1.9% for the 1000-sample case.

With the relation between transaction count, velocity and call duration as given by Equation 4, nTouch can be estimated which leads to the following numerical example:

- A 2-minute (non-dropped) call produces approximately 17 "touches", i.e., nTouch increments in 17 GU.
- Assuming a call-set-up, clear down and guard time of 30 s total duration, a single pass through a given route of 100 km at 100 km/h would produce approx. 24 call samples per hour of travel.

By this estimation, 4 passes of the given route are required to reach the same limits of the confidence interval as a sample count of 100 calls for computation of a call drop rate.

Appendix II

Sensitivity of the metric against the shape of route profiles

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

According to the considerations provided in this Recommendation, the single-number CCP value is proportional to the call-drop rate for the corresponding route. The actual structure of a route profile, i.e., the spatial shape of local drop probabilities, determines the actual CCP. This means, for a given CDR, there is a corridor of CCP values. This Appendix provides some considerations on how the lower and upper boundaries of this corridor can be derived, and shows a way how the metric's sensitivity to the LDP structure can be adapted to different requirements.

Considerations start at a simplified model with a "binary" route profile: there are points x_n where all calls drop (LDP(x_n=1); the 'drop points' as introduced in clause 6.1), and elsewhere the LDP(x) is zero. Also, constant velocity is assumed which helps to keep this initial consideration simple without prohibiting subsequent refinement.

The resulting route profile can be interpreted such that each drop point has a zone of effect, i.e., a call started within this zone will drop. This means that, for a given drop rate, call duration and velocity, there is a certain percentage of the route profile which belongs to this zone. As long as the (velocity-dependent) temporal distance between drop points is larger than the duration of a call, the actual position of these points does not have an effect on the CDR, i.e., as long as the overall density of drop points is the same, the CDR and also the CCP will also be the same.

If drop points move closer together, i.e., for clustering of drop points, zones of effects start to overlap. In the extreme case of total clustering (all drop points converge), there is only a single zone of effect, and with a route length going towards infinity, the resulting CCP approaches the value 1. While this extreme is clearly a violation of constraints for homogeneity of route profile information density (as outlined in this Recommendation), it follows that for a given CDR, the CCP corridor ranges from 1 to the value given by CDR, depending on route profile structure.

In other words, for a calculation of CCP, according to the basic algorithm, as an average of local CCP(x), the sensitivity is fixed, and the width of this corridor is proportional to CDR.

The previous examples were derived from a "binary" route profile, i.e., only LDP values of either 1 or 0. In reality, LDP can have any value between these extremes. To provide a step-wise approach, Figure II.1 shows a binary profile (Profile 1) and a profile with the same overall CDR, but with LDP distributed into twice the number of locations but with LDP(x)=0.5 (Profile 2).

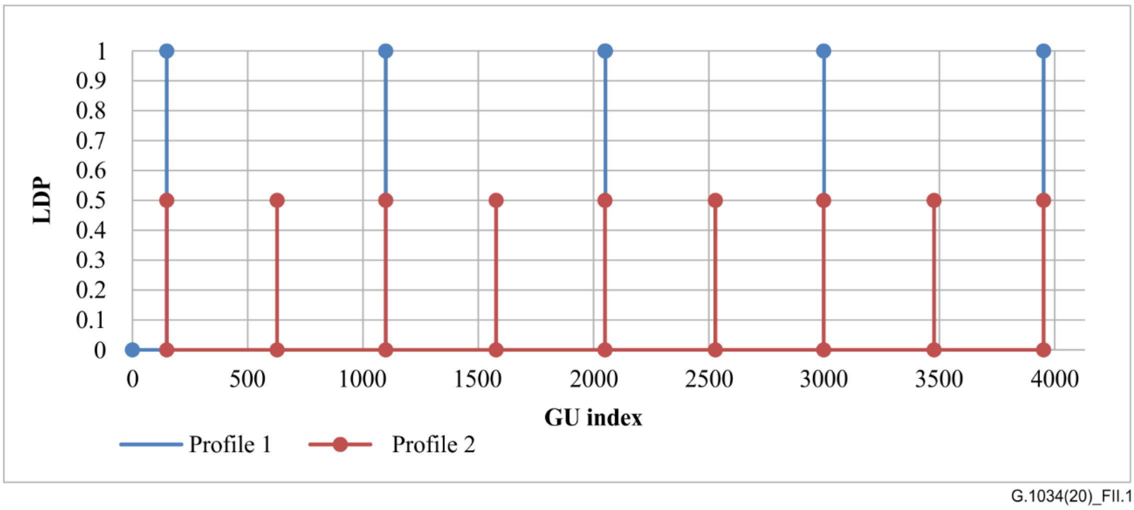

Figure II.1 – Idealized route profile examples

This offers the option to increase the sensitivity to the spatial structure of route profiles, e.g., due to QoE considerations. This is achieved by introducing a threshold value. A virtual call with a CCP above this threshold, is rated as dropped, i.e., its resulting CCP value is mapped to 0. A route metric variant may then be calculated as the ratio of virtual calls having a CCP of 0, to that of virtual calls with a non-zero CCP.

Appendix III

Considerations on the function of motion in area-testing of network performance

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

Motion is the fundamental means to the end of performance or quality testing of mobile communication networks. However, motion may be serving two purposes and the way motion is realized affects the meaning of measurement results.

Motion could cover actual use cases (i.e., users travelling in a car, bus or train), but also could be used for just conveniently collecting many data points within a given region e.g., by a drive test or by other means delivering spatially resolved network performance information.

Figure III.1 depicts a simplified situation which nevertheless stands for many real-world situations. It depicts a region where mobile network performance is – expressed by a KPI such as call drop rate or data rate – locally different with KPI values low or high in a given area. This may be caused by a mix of different radio access technologies (RAT), or by different network capacity with respect to demand.

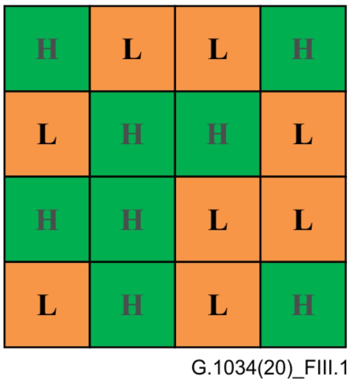

Figure III.1 – Symbolic description of a geographic region with locally different mobile network performance. Labels L and H indicate areas with either low or high performance in a selected discipline

If a drive test is performed in this region which collects a representative number of samples for each area, the KPI value for the entire region would be M, standing, in this symbolic example, for the average of 8 H and 8 L values; this value would, as long as the network topology or capacity does not change, be fairly reproducible by subsequent measurements. The corresponding performance assessment would predict the experience of users moving around in this region quite well. It would, however, not be able to predict the QoS experienced by a stationary user, or a user with a low radius of movement. For this type of usage, the KPI would either constantly over- or underestimate the available network performance.

It follows from the above, that the way motion is utilized in network testing needs to be reflected against the intended angle of view on the network's properties, and as well the interpretation of results may depend on the way motion is realized in practice.

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