The Concept of Application of the Wroclaw Taxonomy for QoS Assessment in Mobile Networks

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Abstract: Measurement and analysis of the QoS/QoE parameters of the 5G network are of great importance for telecommunications operators, telecommunications market regulators, and end users of networks. The assessment of the preparation of the network infrastructure and cellular systems for the provision of 5G services has become particularly important. METIS II project defined the functional requirements for each of the five service use case scenarios. Benchmark measurements of cellular networks operating in the same area using drive tests make it possible to estimate the key performance indicators (KPI) value for every use case scenario. They also provide data to calculate each use case's aggregated values and thus compare the network in terms of readiness for 5G services. The paper aims to present the concept of using the Wroclaw Taxonomy method to assess the QoS of the network and to determine an aggregated measure characterizing the mobile network for readiness for 5G services.

1 INTRODUCTION

The quality of services in mobile networks is currently of immense importance both for telecommunications infrastructure operators, its end users (subscribers and subscribers of services), and regulators of telecommunications markets (DRP, 2020).

In the literature on the subject, standards, and recommendations, both ETSI and ITU-R, but also in the so-called "good practices", there are visible methodologies of research and quality assessment based on QoS (Quality of Service) and perceived quality of QoE (Quality of Experience) measures (Berger, 2019), (Falkowski-Gilski & Uhl, 2020). QoS indicators allow you to research, analyze and evaluate the technical aspects of the functioning of the network providing services in terms of meeting the requirements set by them (Mellouk et al, 2013). QoE parameters are used to characterize the services of a given network from the user's perspective (Pierucci, (2015).

When deciding on the user's choice of the selected mobile network and the specific services it offers, it is important to have QoE data for individual services. Such a knowledge is also important for the telecommunications market regulator to indicate to users and to compare individual networks available to them (DRP, 2020). In addition, the regulator may use the conclusions of QoS and QoE analyses when assessing the compliance of a given operator with declarations submitted in auction and concession procedures in terms of network and service development, their scope, range, and quality (3GPP, (2022).

For the network operator, knowledge of QoS and QoE is a valuable tool for assessing the network and the level of services provided by it, but it is also used to determine the causes of network failures, unavailability of services, and their performance fluctuations. In addition, operators can use the conclusions from the analysis of QoS and QoE measurements to assess the performance of devices and systems offered by suppliers at the stage of PoC (Proof of Concept) pilot studies of new network solutions (ETSI, 2019).

The key problem is to use computationally efficient methods to compare networks (Kolenda,

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2006), (Loska &Dąbrowski, 2014) in terms of QoS and QoE offered in them.

2 ASSESSMENT OF QOS IN 5G NETWORKS

Scoring operational aspects of the mobile network by comparing the current values of representative key performance indicators (KPIs) obtained from operational measurements should allow for evaluating individual areas of its activity. In addition, it is possible to assess the readiness of a given network and its components to meet the functional and system requirements, such as readiness for operation, continuity, and integrity of service provision, operational reliability, for the indicated areas of its use by current and future users, and utility applications (Soós et al.,2020). These requirements were defined by standardization institutions such as ITU-R (ITU-R, 2015), ETSI (ETSI, 2019), as well as teams of researchers of 3GPP (3GPP, 2022), 5G PPP (5GPPP, 2022), and METIS I and II projects (Boccardi, et al 2014). The indicators for each of the services, as well as the method of their measurement and evaluation, have been defined (ETSI, 2009), (ETSI, 2011), (ETSI, 2014), (ETSI, 2018), (ETSI,2018-10), and are widely used by telecommunications operators, market regulators, companies that perform professional QoS/QoE measurements, and research & development institutions.

As part of the METIS, and METIS II projects, use cases (UC) were defined that relate to their use by 5G network users in end-to-end connections (Elayoubi et al., 2016). In 2013, METIS project working groups appointed twelve UCs for five service scenarios named (METIS D1.1, 2013):

- amazingly fast,
- great service in a crowd,
- ubiquitous things communicating,
- best experience follows you,
- super real-time and reliable connections.

The revision and update of service requirements were the results of the work of the METIS II project. Finally, completed in the 2016 year by the development of the Deliverable D 1.1 “Refined scenarios and requirements, consolidated use cases, and qualitative techno-economic feasibility assessment” (METIS-II D1.1, 2016). This resulted in the identification of the following three Use case families: Extreme Mobile BroadBand (xMBB), Massive Machine-Type Communications (mMTC), and Ultra-reliable Machine-Type Communications (uMTC). The structure of service use case families with the requirements for them and assigned to the UC is presented in Table 1.

The following five UCs were distinguished: UC1- Dense urban information society, UC2 - Virtual reality office, UC3 - Broadband access everywhere, UC4 Massive distribution of sensors and actuators, UC5 Connected cars. Each UC has defined quantitative requirements expressed in the values of the KPIs assigned.

Table 1: The structure of families of service use cases (METIS-II D1.1., 2016).

Use Case (UC)		Scope of requirements (network/user perspective)	Scope of services (service perspective)	Source
xMBB mMTC	Dense urban information society	Experienced user data rate / Traffic vol. per subscriber / Nb. of users and devices / Energy efficiency	Broad range of communication services covering needs related to both indoor and outdoor urban daily life (excl. office and factory)	METIS-I test case enriched by NGMN UC Mobile video surveillance
xMBB	Virtual reality office	Experienced user data rate / Traffic volume per subscriber / Latency	Broad range of communication services in the (indoor) office context	METIS-I test case
xMBB	Broadband access everywhere	Experienced user data rate / Availability / Mobility / Energy efficiency	Full coverage topic addressing outdoor/indoor communication needs especially in rural areas	NGMN use case 50+ Mbps everywhere incl. METIS-I test case Blind spot
mMTC	Massive distribution of sensors and actuators	Availability / Number of devices / Energy efficiency	Broadest range of IoT services covered	METIS-I test case Massive deployment of sensors and actuators
xMBB uMTC	Connected cars	Latency/ Reliability / Mobility	Strong expectation from the (automotive) industry Belong to the first uMTC services expected to be commercialized	METIS-I test case Traffic efficiency and safety complemented by MBB aspects

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The requirements for KPIs specified in Table 2. may be used as reference values for:

- 5G network services implemented,
- perceived performance (experienced user throughput),
- system performance (E2E RTT latency, traffic volume per device, E2E one way latency),
- density of saturation by end user devices (device density),
- availability of the network (availability),
- the ability to manage objects in motion (vehicle velocity).

The assignment of service UC to groups of 5G network services is shown in Figure 1.

KPI benchmarks also assess the readiness of a given network to support a set of 5G services (ITU-R, 2015), (METIS-II D1.1, 2016), (METIS D1.5, 2015), (METIS-II D2.3, 2017).

It makes it possible to classify every single network in terms of the degree of their adaptation to quantified requirements by evaluation using statistical methods based on 5G network measurements. Obtaining high compliance values is a significant measure of the market position of a network. End-users perceive such a network as attractive in terms of service. Networks achieving higher values of individual UCs are recognized as more adapted to the current and future users' needs. It may directly influence the end user's decision to select a service provider. The assessment of the network in terms of its QoS and QoE parameters is dealt with by:

- specialized teams of mobile network operators,
- regulators of telecommunications markets,
- specialized test & measurement entities with knowledge, experience, and technical equipment that can prepare and conduct tests in conditions as close to reality as possible in the environment where the services are delivered.

Operators are interested in the possibility of assessing and comparing the quality parameters of the operated and managed networks because they can:

1) compile the results of own measurements of network devices and systems as well as data from management and maintenance systems with the results of measurements carried out by specialized companies,
2) compare their network with the networks of competing operators operating in the same area,
3) assess the quality of services provided to end users,
4) use measurement data to analyze the current use of services, plan the development of service infrastructure,
5) use data in the form of KPIs for operational analyzes, such as:

- analysis of traffic trends,

Table 2: Summary of main KPIs and requirements for each METIS-II use case (METIS-II D1.1., 2016).

Use Case (UC)	Key Performance Indicator (KPI)	Requirement
UC1 Dense urban information society	Experienced user throughput	300 Mbps in DL and 50 Mbps in UL at 95% availability and 95% reliability
	E2E RTT latency	Less than 5 ms (augmented reality applications)
UC2 Virtual reality office	Experienced user throughput	5 (1) Gbps with 20% (95%) availability in DL 5 (1) Gbps with 20% (95%) availability in UL both with 99% reliability
UC3 Broadband access everywhere	Experienced user throughput	50 Mbps in DL and 25 Mbps in UL at 99% availability and 95% retainability
UC4 Massive distribution of sensors and actuators	Availability	99.9%
	Device density Traffic volume per device	1 000 000 devices/km^2 From few bytes per day to 125 bytes per second
UC5 Connected cars	E2E one-way latency	5 ms (traffic safety applications)
	Experienced user throughput	100 Mbps in DL and 20 Mbps in UL (service applications) at 99% availability and 95% reliability
	Vehicle velocity	Up to 250 km/h

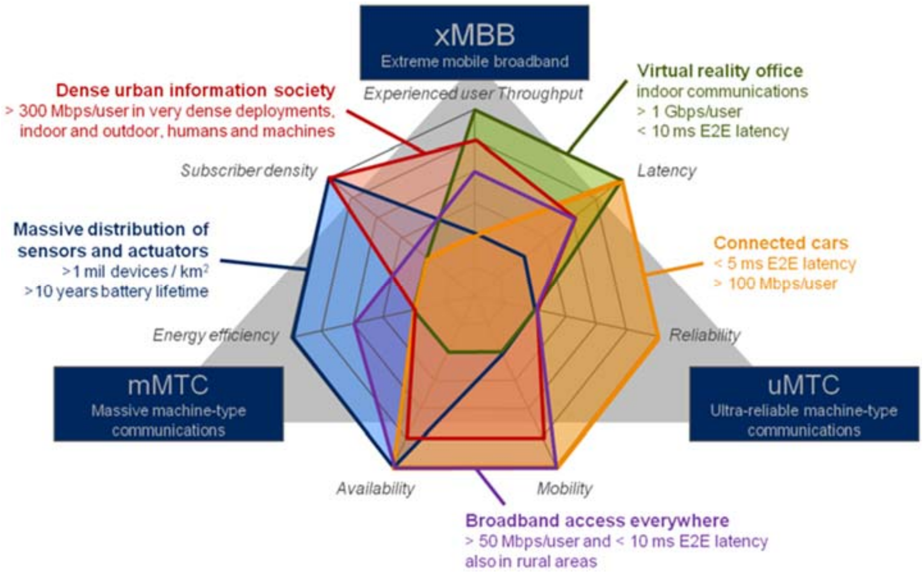

Figure 1: Mapping service use cases to the service groups of 5G network (METIS-II D1.1., 2016).

- multi-profile analysis of service use,
- analysis and evaluation of anomalies,
- interruption of the service,
- damage of the infrastructure, etc.

Regulators of telecommunications markets:

1) define the rules of operation of the telecommunications services market in a given country or area,
2) state the legal and technical framework for the operation of telecommunications systems and networks,
3) organize and manage relations between telecommunications operator and end-user.

They are also supervising, designating, controlling, and managing the requirements for the minimum conditions for the provision of telecommunications services.

Measurements, monitoring, and analysis of the current state of telecommunications services and assessment of their quality are major aspects of the regulator's present and long-term activity.

Based on the results of measurements and analysis, regulators determine:

- the scale of compliance with the requirements for operators in concession procedures,
- the quality of telecommunications services,
- resolves disputes regarding services and their quality,
- plans and supervises investments aimed at improving the coverage of the country's territory with services with the assumed minimum efficiency and quality parameters.

Taking into account the previously mentioned standards and recommendations, each of the above entities measures the quality of telecommunications services, considering "good practices" resulting from environmental experiences and using measuring equipment and analytical tools.

Telecommunications operators and regulators of telecommunications markets often use the services of specialized companies that perform QoS and QoE measurements, which perform comparative measurements of many networks, process and analyze data, prepare lists of quality parameters of the networks reviewed, and prepare conclusions and recommendations for the networks tested.

This type of measurement is called network benchmarking.

These diagnostic activities in the mobile network environment are performed through "drive test" testing.

These tests are conducted by using passive and active network service analyzers.

The tests cover all relevant services of the mobile network. The results are statistically processed. Implemented mechanisms of artificial intelligence, machine learning, and rules of selection "big data" make data post-processing much more effectively from time and cost perspectives. Concluding, they allow to find patterns and dependencies and speed up the process of selection and processing of measurement data.

As the result of the data processing process, the measured values of KPIs, UC values, summaries of these parameters for individual measurement periods, and various measurement conditions are obtained.

Numerical calculations are available for estimating the output parameters as aggregated network quality metrics.

The form of displaying processed data depends on the purpose of the research and the selection of an effective way to present it. Sample charts are shown in Figures 2-3.

Employing the approach presented in (METIS-II D1.1.,2016), based on data gained from benchmarking measurements, you can assess how each of the tested mobile networks operating in the same area is ready to fulfill the requirements for 5G services.

Systemics -PAB Sp. z o.o., which has been carrying out comparative studies of mobile operator networks in many countries of the world for over 15 years, has made available for research measurement data on the preparation of the infrastructure of two mobile network operators to support 5G services.

The measurements were carried out using the SwissQual Diversity Smart Benchmarker and SwissQual QualiPoc equipment (R & S., 2016) and the Iperf3 application (Iperf3., 2022).

Based on the obtained data, the radar chart was prepared, shown in Figure 2.

Each edge of the pentagram of the graph in Figure 2 represents a value from 0 (center) to 100% for each use case. Figure 3 presents a more detailed view that shows the percentages for each KPI included in each UC for two compared networks.

This representation allows you to compare values of KPI between mobile telco operators and locations.

3 CHARACTERISTICS OF THE RESEARCH PROBLEM

Designated both values of KPI parameters and the services UCs will allow you to evaluate the compared mobile networks in terms of their preparation to support the operation and features of families of 5G services (METIS-II D1.1., 2016), (METIS-II D2.3.,2017).

The research problem is to define a metric that uniquely characterizes the readiness of mobile networks to support 5G services and a method of its enumeration. Such a metric supports a comprehensive assessment of the readiness of a given mobile

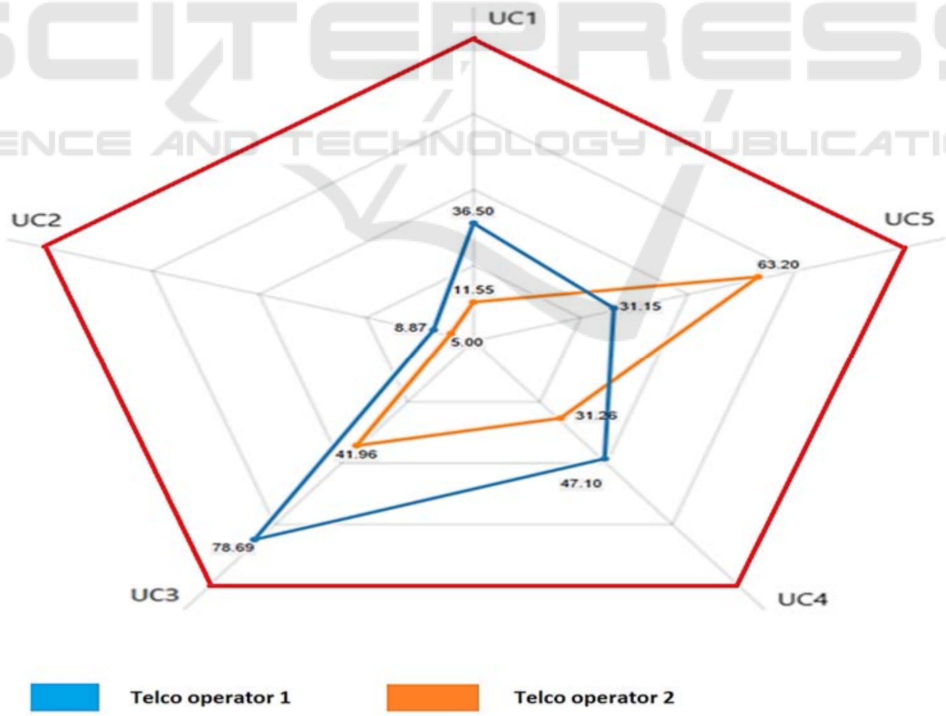

Figure 2: Comparison of the readiness of the networks of two mobile telco operators to the implementation of 5G services (SysPAB, 2021).

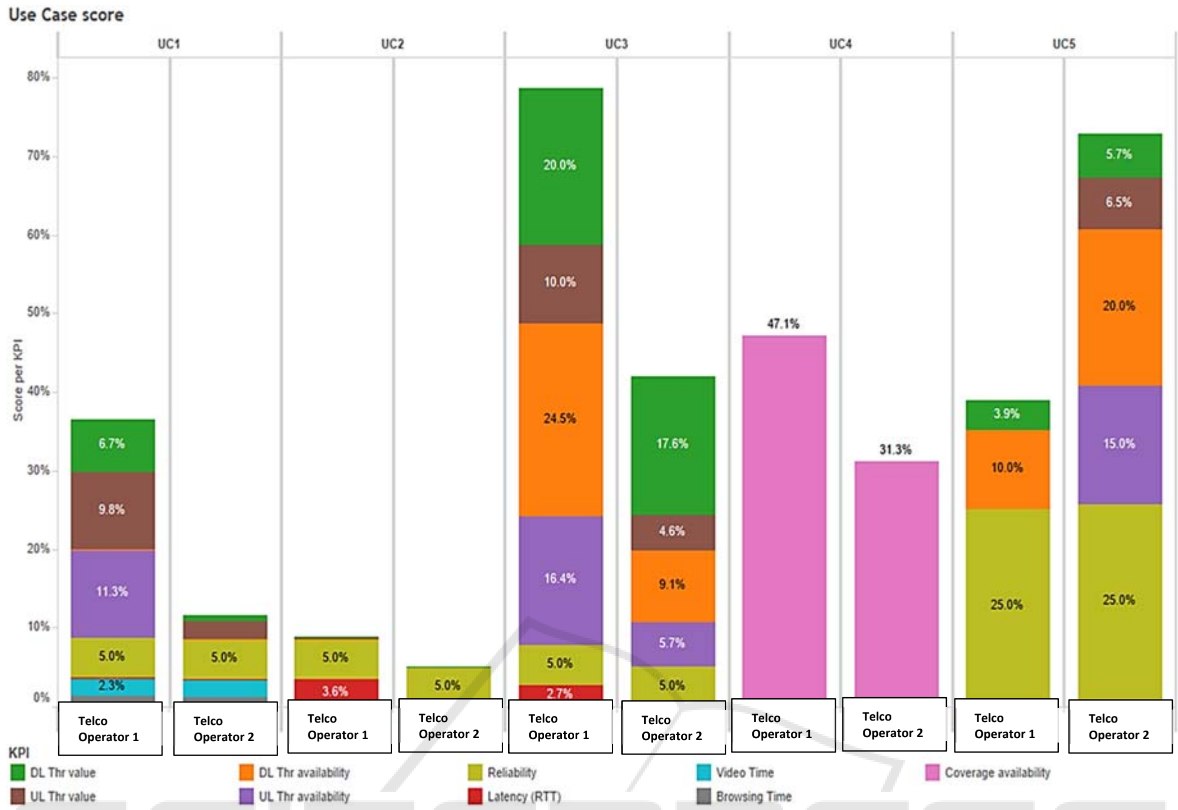

Figure 3: Values of KPI of the compared mobile networks (SysPAB, 2021).

network for the operation of the services described by the set of services use cases:

$\{UC_1, UC_2, UC_3, UC_4, UC_5\}$.

There are two cases of metrics to consider:

1) time related:

$$\{UC_1(t), UC_2(t), UC_3(t), UC_4(t), UC_5(t)\} \quad (1)$$

2) with a constant value over some time:

$$\{UC_{1T_x}, UC_{2T_x}, UC_{3T_x}, UC_{4T_x}, UC_{5T_x}\} \quad (2)$$

Comparing the metrics for different networks operating in the same area and their analysis may simplify the decision-making processes of telecommunications operators and market regulators about the issues described in point 2.

Having values of services use cases UC for territorially different places and areas of the network will allow for the designation and development of 5G QoS awareness maps (Skokowski, 2021).

The spectral awareness maps have become established in the operational practice of entities operating in the telecommunications market, so perhaps the idea of the 5G QoS awareness maps will be positively received and widely used in practice.

The end user of the mobile network and its services, knowing the practical interpretation of the designated metric values, would have a chance to consciously evaluate the market offer before deciding on the choice of a given network or further use of its services.

This paper presents a proposed method for calculating the aggregate metric of a mobile network based on UC values obtained from benchmarking measurements and post-processing data processing. The concept of applying the Wroclaw taxonomy (Perkal, 1953), (Kolenda, 2006). for the assessment of the QoS of mobile networks is presented in Figure 4.The input data are sets of calculated values: $Z_1(t)$, $Z_2(t), \ldots . Z_k(t)$ KPI making up the service use cases (1) for each network from the set of evaluated mobile networks:

$$M = \{m_1, m_2, \ldots m_k\}, \quad (3)$$

where: m_k *– indication* k *– number of mobile network* $k \epsilon N$ *and* N *is a set of natural numbers.*

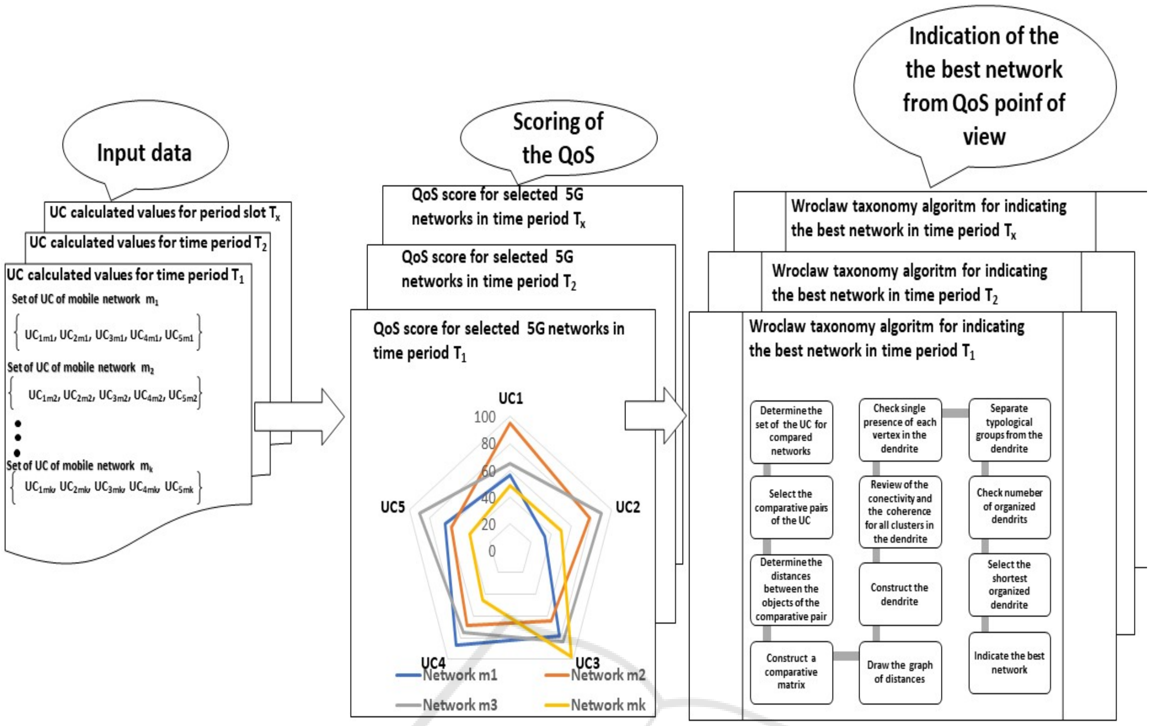

Figure 4: An idea of use of the Wroclaw taxonomy in the QoS assessment of mobile networks (own study, 2022).

For the general case, taking into account that the values included in the sets are time-dependent, we take the following formula:

$$S_1(t) = \{UC_1(t)_{m_1}, UC_2(t)_{m_1}, \ldots, UC_5(t)_{m_1}\} \quad (4)$$

$$S_2(t) = \{UC_1(t)_{m_2}, UC_2(t)_{m_2}, \ldots, UC_5(t)_{m_2}\}$$

$$\ldots$$

$$S_k(t) = \{UC_1(t)_{m_k}, UC_2(t)_{m_k}, \ldots, UC_5(t)_{m_k}\}$$

where: $S_1(t), S_2(t), S_k(k)$ are sets of values: $UC_1(t)_{m_1} \ldots\ldots UC_5(t)_{m_k}$;
$t \epsilon (0, +\infty)$;
$UC_1(t)_{m_1} \ldots\ldots UC_5(t)_{m_k} \epsilon R$;
m_k *–mobile network numbered by* $k \epsilon N$.

If the comparison of several mobile networks is conducted on data determined during one measurement campaign, which is collected simultaneously for the measured networks, then you can consider setting metrics for individual periods of campaign duration. The output data sets then are described by the formula:

$$S_{1T_1} = \{UC_{1T_1m_1}, UC_{2T_1m_1,}, \ldots, UC_{5T_1m_1}\} \quad (5)$$

$$S_{2T_2} = \{UC_{1T_2m_2}, UC_{2T_2m_1,}, \ldots, UC_{5T_2m_2}\}$$

$$\ldots.$$

$$S_{kT_x} = \{U_{1T_xm_k}, UC_{2T_xm_k,}, \ldots, UC_{5T_xm_k}\}$$

where: S_{1T_1}, S_{2T_2}, S_{kT_x} are sets of values: $UC_{1T_1m_1,}$ -> $UC_{1T_xm_k,}$ *respectively in the range of*: T_1, T_2, T_x
$UC_{1T_1m_1,} \ldots UC_{1T_xm_k,} \epsilon R$;
m_k *–mobile network numbered by* $k \epsilon N$.

After calculating the values of services use cases UCs for each of the evaluated networks, the next step is to compare them.

It consists in plotting the determined values on the radar diagram. It allows you to find out about the features of the compared mobile networks. For example, the network named Telco operator 1, represented in blue in Figure 2, is the most adapted to support UC 3 services, that is broadband access everywhere, as the percentage of adaptations of this network to support broadband access services is 78.69% concerning the value of references that represent the value of 100%, drawn in red.

The Wroclaw taxonomy method allows for the determination of an aggregated metric $Q_{m_k}(t)$ that determines the variability of the quality of QoS services of the mobile network m_k over time.

However, for the periods: $T_1, T_2, \ldots, T_x$ in which KPI measurements were made, it allows for calculating the values of the metrics $Q_{m_kT_x}$ respectively.

It is possible to distinguish from the compared sets $S_k(t)$ of the evaluated networks m_k, a set $S^*(t)$, which represents the highest value ${Q^*}_{m_k}(t)$. The considered method assumes operating on points of the multi-dimensional space representing objects, phenomena, and values that are classified according to the verifiable pattern.

We assumed that such points would be the values of the service use cases: $UC_1(t)_{m_1} \ldots\ldots UC_5(t)_{m_k}$ respectively for networks : $m_1 \ldots\ldots m_k$.

Therefore, the multidimensionality of the location of these points will be determined by:

- the identifier of the network,
- time of the value measurement of the UC,
- coordinates of the location of measurement points.

Thanks to this, it is possible to construct a coherent graph on the elements of sets in the multidimensional space: $S_1(t), S_2(t), \ldots, S_k(t)$.

The constructed graph connects all points with $n-1$ edges.

Each edge connects two points and has a metric length defined by a Euclidean distance in a multidimensional space.

The method assumes mapping all points of a multidimensional space on a plane.

When constructing a coherent graph, it is necessary to attach its closest neighbor to a specific point, that is closest to it.

The mapping criterion is the arrangement of points on the plane that the sum of the distances between them is as small as possible. The graphic image of such a mapping is a coherent, unclosed graph called a dendrite (Jarocka, 2013), (Loska & Dąbrowski, 2014), the graphic representation of a dendrite is a broken, continuous line, which may branch but may not contain cycles (closed) (Ćwiąkała-Małys, 2009). Then a matrix of distances between points is constructed. In the graph under consideration, vertices are points represented by the values of service use cases:

$$UC_1(t)_{m_k}, UC_2(t)_{m_k}, UC_3(t)_{m_k}, UC_4(t)_{m_k}, UC_5(t)_{m_k}$$

of the network m_k, that is the subject of evaluation, and the edges measure the distance between them.

The method allows for computationally effective determination of QoS metrics of the evaluated networks and the assessment of their value concerning the pattern.

The pattern is a representative reference value for service use cases presented in Table 2 (METIS-II D1.1.,2016). The metrics of the QoS of networks: $m_1 \ldots\ldots m_k$ are determined by dividing the dendrite by eliminating the longest edges in it, which indicate the highest distances between the points of the dendrite. This division of the dendrite into clusters is called natural (Kolenda, 2006).

The dendrite divides the set of K service groups of use cases $S_k = \{S_1, S_2, \ldots, S_k\}$ into typological groups, due to the 5 selected features UC_l $(l = 1,2, \ldots, 5)$.

The algorithm for determining the QoS and readiness of networks for 5G services is as follows (Ćwiąkala-Małys, 2009), (Zmysłowski, 2021).

A. Determine the set of 5 parameters adopted for the description of the service use case to be assessed → the compared sets of parameters UC_l of service use cases from the set $S_k(t)$ should be clearly described in numbers;

B. Determine the distances between the objects of the comparative pair d_{ij} $(i, j = 1,2, \ldots, K)$ – the distance between the i th and j th objects → use the Euclid metric:

$$d_{ij} = \left[\sum_{p=1}^{n} \left(Z_{ip} - Z_{jp}\right)^2\right]^{1/2} \tag{6}$$

where Z_{ip} and Z_{jp} are standardized UC_l feature values in S_i and S_j objects, respectively.

1. Construct a comparative matrix:

$$D_K = \begin{bmatrix} 0 & d_{12} & \ldots & d_{1K} \\ d_{21} & 0 & \ldots & d_{2K} \\ \ldots & \ldots & 0 & \ldots \\ d_{K1} & d_{K2} & \ldots & 0 \end{bmatrix} \tag{7}$$

2. Construct dendrite via:

a) Assigning to each of the K-tested S_i and S_j objects most similar to it, i.e., one for which the distance d_{ij} has the smallest value;
b) Connecting the edges of the vertices corresponding to S_i and S_j – obtaining K connections of nearest units;
c) Eliminating one connection from each pair of redundant connections;
d) Determining clusters of examined objects, i.e., combining connections with the same single vertices into sets, so that each vertex occurs only once;
e) Arranging the clusters to obtain a connected graph.

3. Check if all the clusters of the dendrite have been connected with each other and formed a coherent graph.
4. Check if each vertex (i.e., tested disturbance) is present only once in the dendrite.

5. Separate typological groups from the dendrite. It is achieved by removing (i.e., cutting off) the next longest edges of the dendrite.
6. The obtained clusters were connected with each other according to the principle of the smallest distance between them. As a result, they resulted in a dendritic arrangement.
7. Assess which of the scored mobile networks meet the 5G readiness pattern requirements.

4 CONCLUSIONS

Information is a key to being more competitive and attractive in today's telecommunications market. The state of art regarding QoS and QoE, as well as trends that change their values, are important not only from a technical but also from a business point of view. Methods and ways of getting it are under consideration by R&D teams, operators, and regulators.

The paper presents how to avail the measurement data collected along the drive test campaigns to compare the QoS of evaluated mobile networks. The QoS measurements were represented by the services use cases defined in the METIS II project. We proposed the idea of applying the Wroclaw taxonomy for assessing and scoring the readiness of the mobile network for operating 5G. The Wroclaw taxonomy is widely used for comparing complex objects to find the best pattern or select the most representative item from the group of evaluated objects. We assumed that 5G mobile networks are also complex objects characterized by many varied parameters, so using this method will be justified.

The input data was obtained from benchmarking tests collected during drive test campaigns and then were processed following the described algorithm.

However, the applied method does not allow calculating the aggregated QoS metric characterizing each network.

We are going to research it deeper later on.

The article presents the theoretical assumptions of the method and the general concept of its application, so we plan to verify described idea practically at the next stage of development.

It is also worth considering ways of implementing this proposed idea in the virtual cloud to allow faster access to post-processed data.

Shortly, the authors are planning to conduct research of relationships between measurement conditions and values of KPIs for every single UC of compared networks (Zmysłowski & Kelner, 2022).

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