Framework for Internet Data Quality Measurement in Telecommunication Networks

Thangavel Mathanaruban

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ABSTRACT

This paper explores the quality of Internet download performance by examining the most important network performance measures and designing a complex measuring framework of user-level service quality. There are a number of technical parameters such as throughput, latency, jitter and reliability of data transmission that affect internet download experience. Yet existing network monitoring systems utilized by operators are mostly concerned with the infrastructure level measurements and do not necessarily reflect the quality as perceived by the end users. Thus, this study suggests a composite measurement scale called Internet Download Quality Score (IDQS) that combines various network performance measures into one measure that can be explained to measure the quality of downloads at the user session level.

The research paper follows the quantitative research paradigm based on session-based download measurements made by several users under various network conditions. The most important variables were downloading speed, latency, jitter, packet loss, signal strength and unsuccessful downloads which were analyzed in MATLAB to determine statistical correlations between network parameters and perceived download quality. The impact of these indicators on the performance of download was assessed using correlation analysis, as well as descriptive statistics and predictive modelling techniques.

The findings reveal that the parameters of reliability like download failure and packet loss can have a great effect on the user experience in contrast to the moderate changes in throughput. The presented IDQS model manages to merge the speed and reliability measures to categorize downloading sessions into the acceptable and poor quality. The model was also found to have high predictive accuracy and it also gives a simplified measure of quality which can be used by network operators to detect service degradation and to give priority to optimization activities and enhance user satisfaction.

In general, the results can be used to create a user-centric approach to Internet performance assessment which can fill the void between the classic metrics of network performance and user experience.

CHAPTER 01: INTRODUCTION AND BACKGROUND

The use of the internet has ceased to be considered as a supplementary service, and it has become a utility that facilitates work, education, entertainment, commerce and public services. To the end users, internet quality is not an engineering form of abstract engineering; it is perceived through the success, speed and stability of daily activities like downloading learning materials, updating applications, receiving large files or cloud storage synchronization. In the event of slow downloading or the failure, user experience is immediately influenced and the perceived trustworthiness of the network is diminished. Internet downloading data quality is thus in this study a user facing outcome that should be measured in a manner that is technically sound, and operationally useful.

The telecommunication networks are ever changing to cater more demand of data intensive applications like high-definition video streaming, internet gaming, distance collaboration, and cloud computing. Other limitations that networks must work with are mobility, heterogeneous access technologies, and dynamic traffic patterns. Performance differs over time, geography and devices as well as network load. A customer may get great download speed in a single point and get slow download speed at the adjacent points or vice versa or get good download speed in one day of the week and get poor speed in times of peak traffic. Such fluctuation complicates traditional performance monitoring since it is insufficient to be aware of average utilization or nominal capacity but providers should have methods of measurement that can be used to clarify why end users report variable download results.

One technical lesson learnt is that download quality is multidimensional. Poor throughput, high latency reducing transport efficiency, packet loss which causes retransmissions, jitter which makes timing unstable and poor signal strength which reduces modulation and coding rates in wireless access can all result in a user visible slow download. Standards standardize these dimensions by stipulating parameters with which IP service performance is defined and measured. One example, of an ITU-T Recommendation is that of Y.1540 which describe parameters of IP packet transfer performance, such as delay and delay variation, which are applied to specify IP service performance and measure it. As a matter of fact, these parameters relate to each other: loss and delay may both limit the possible throughput and radio-layer impairments may increase variation at higher layers. This paper, therefore, formulates a user-based framework to measure the quality of internet downloading in technically meaningful and operationally practical manner.

Besides the engineering incentive, the proposal focuses on a service-fairness issue: the charging policies can be seen as being out of balance with the quality delivered in case of unstable connectivity or low signal strength. Users might find themselves paying to download data yet getting low downloading speeds which might increase the complaint as well as inspiring them to switch their operator. Therefore, this paper will build an end-user-based measurement system, which can be used to measure the quality of internet downloading data, take corrective measures by the provider and facilitate policy debate about quality-based service pricing and compensation.

Background and context

Telecommunication networked as stratified systems where end-user performance is the result of actions between radio access, backhaul, core routing as well as interconnection with external networks and content delivery networks. Radio conditions like signal strength, cell loading and interference have a great impact on access performance in mobile networks. As signal strength reduces, devices can change to lower power but more efficient transmission modes, error rates may increase and effective throughput may decrease. With the ability to support core and backhaul capacity, a congested cell and a problematic radio environment result in successive failures or sluggish downloads. This renders signal strength and its short-term variation a dimension of concern when it comes to an end-user measurement system that prioritizes quality in terms of downloading.

Downloads follow heterogeneous routes and are influenced by both network and transport behaviors. Contemporary applications consume encrypted transport and adaptive controls that modify the way that traffic is spawned making it difficult to interpret measurements on the network side. In addition, latency and packet loss may be of special concern to download performance due to the nature of the transport protocol itself. An example of this is provided by the practical methodology of IETF RFC 6349 that end-to-end TCP throughput testing must consider round-trip time and path characteristics as well as loss behavior since they determine the maximum achievable throughput and consequently the perceived download quality. In the actual user experience, the download process may have a number of simultaneous connections, intermittent server response and temporally varying bottlenecks. These considerations support the importance of quantifying downloading quality where it occurs, but at the same time, establishing links between findings and the underlying network environment.

Conventional monitoring solutions tend to concentrate on network-based KPIs that are collected based on the infrastructure nodes. Although useful, these measurements may fail to capture the interaction effects that happen along the edge, such as device limitations, local radio impairment, and real-world application results, such as a successful or failed download. End-user measurement is a significant complement thus: it measures performance where it is felt. A well-designed end-user measurement can measure whether a download attempt has succeeded, the performance during the attempt, the signal conditions, and the relationship between end-user reported experience and these conditions. The proposal places this work in the context of the growing emphasis on the downloading quality measurement of the telecommunication networks as observed by the end-users. The context consists of the factual necessity to minimize download failures and slow speed, and the anticipation that the providers should improve network quality.

Research problem and rationale

The research problem may be formulated as follows: telecommunication networks should be able to transmit data of high quality so that the rising demand of data-intensive services can be satisfied, yet the quality of data downloading through the internet is hard to measure and enhance due to the dynamic characteristics of the performance, which is highly dependent on the conditions of the edges. This has been proposed to be a challenge of creating effective measurement framework that can enhance the quality of download as well as accommodating the changing network conditions, user behavior and technologies.

The network conditions may vary due to congestion, signal interference and hardware constraints; user behavior and degradation. Quality is very much spread; and emerging technologies bring new measures and new performance features. An effective measurement system needs to be, then, a robust measurement system that works in the real world and can be used to make operational decisions. The reason why the study was conducted is that an effective measurement framework is capable of balancing engineering KPIs with user experience. When measured at the end user (or close to the edge) they have the ability to directly measure the success or failure of the actual downloads and trace the results of this to measurable characteristics such as signal strength, throughput, latency and packet loss. When these measures are calculated in a uniform and aggregated form into interpretable scores, they may aid the operators in recognizing locations, timeframes, or access segments which perform poorly and may be used to assist in proactive network operation. The proposal clearly encourages the application of data analytics and machine learning to foresee performance problems and optimize the management of networks proactively. At least in that respect measurement is not a goal, but a starting place of diagnosis, prediction and improvement.

A further rational and managerial: a scoring system offers a standard language to the stakeholders. Engineers could interpret raw KPIs like delay or loss, yet the customers and the management usually need a less complex description of service quality. The performance can be better communicated by an index that is well-based and validated it is transparent and clear. The index in this study is based on parameters that are directly related to downloading results and is created to enable comparison with subjective user ratings which facilitates an evidence-based evaluation of whether the quality measured is an experience of the same quality.

Aim and objectives

The general objective of this research is to come up with a framework of measuring internet data quality of telecommunication networks through the formulation and testing of an internet downloading data quality measurement application. The framework is expected to measure user-observable quality of downloads, and it is supposed to give evidence to improve operations, service management relating to quality. In line with the proposal, there are three objectives, which are specific. To begin with, the study will apply internet data quality parameters based on an end-user viewpoint through generating measurements of the conditions and results experienced in the process of downloading, alterations of signal strength, unsuccessful and successful loads, and speed-based measurements.

Second, the research will produce suggestions to the telecommunication providers to improve data quality through measurement interpretation to operational switches like bandwidth assignment, congestion regulation, and infrastructure improvements. Third, the paper will discuss a charge redemption concept on the basis of the quantified internet data quality parameters as perceived by the end users thus the measurement of the technical measurement to fairness and accountability of the services.

Research questions

The research questions that guide the study are used to operationalize the aim and objectives of these studies which links mensuration and application. The initial research question is which quantifiable variables, gathered in the end-user viewpoint, are valid in censuring internet downloading data quality in an Australian telecommunication network. The question is concerned with the choice and operationalization of the parameters throughput, latency, packet loss, jitter, error-related behavior, and signal strength, and their applicability in the expression of download results in varying conditions.

The second research question is how these parameters can be integrated to create a sound and comprehensible scoring system that can differentiate download quality in different network situations. The question deals with the building of the internet data quality score, the mapping of the measured values in the score bands, and the combination of numerous dimensions in one index. The third research question is how well the calculated objective quality score is related to subjective end-user ratings of downloading experience. This question is necessary in validity since a technically calculated score is only valuable as long as it is responsive to the perceptions of the users. The fourth research question is whether predictive models developed on the basis of obtained parameters can determine whether potential data quality issues can be identified to assist proactive measures by the providers.

Hypotheses

The proposal outlines hypotheses that will be used to relate network conditions to data quality indicators and enable predictive power. In line with such a purpose, the hypotheses tested in this study can be measured empirically by use of the dataset that is collected. First, network to be related with data quality measures like the packets lost and throughput which is an indicator of congestion effect and transport efficiency. Second, the optimal bandwidth allocation is theorized to improve the quality of data in the way of a higher measured throughput and a higher quality score. Third, it is theorized that upgrading network hardware and infrastructure will improve data quality, which is represented by the increase of KPI profiles and the score of quality across the areas of influence. The fourth hypothesis deals with prediction: it is theorized that predictive models, including the chosen KPIs and patterns of signal strength will detect potential issues with data quality with a useful degree of accuracy, allowing anticipating the network management.

Lastly, the proposal also includes an implication of a validation hypothesis: the mean quality of internet data calculated as the result of downloading attempts should demonstrate significant consistency with end user-perceived average scores, and this supports the argument that the framework is able to reflect user-perceived quality.

Significance of the study

This research has a practical and multi-stakeholder value. For end users, improved measured diagnose edge-visible problems to improve the service quality as it allows the operator to address the problems using specific actions instead of general troubleshooting. Improved diagnosis will positively impact the QoE, frustration, and trust in the service delivery, particularly in cases where consumers rely on downloads to learn and work. To operators, quality measurement that is correct can help in optimized performance of the network through detection of bottlenecks, to allocate resources better, and to minimize unwanted downtimes. The proposal highlights that sophisticated measurement systems can be used to detect and resolve network problems by operators and this can result in better network management and economic gains due to customer satisfaction and reduced operation expenses.

When used together with analytics, measurement outputs could aid in proactive management, like by identifying early indications of congestion in certain access segments and by focusing on capacity expansion. Better measurement can also be useful in improving communication with customers because it allows them to be explained in a better manner.

service remediation through dance. The research is also relevant as far as scalability and adaptability are concerned. Malicious networks are required to scale to accommodate additional devices and aggregate traffic, measurement frameworks need to scale without excessive overhead, and are required to change with the new technology and user requirements.

An application-based pipeline can be expanded with defined KPIs and a structured framework through the modification of parameter capture, score mapping, and model features. Lastly, the research is beneficial to research and development, as it offers a tangible framework and data set that would be applicable in studying improv approaches, and predictive models in telecommunication performance management.

Scope, assumptions and delimitations

The current study will be limited to measuring the quality of internet downloading measurements in the context of telecommunication access with a focus on the end-user. A downloading session or attempt is the unit of analysis whose measurement is through the proposed application and summarized into quality scores. Following the proposal, the research targets on the performance metrics that are directly applicable to the downloading performance in terms of bandwidth and throughput, latency, packet loss, jitter, error-related behavior, and signal strength dynamics.

It is expected that the framework is applicable to realistic use scenarios, although the empirical analysis will be performed in a specific collection of networks, locations, devices, and time frames that allow practical data gathering. Interpretation requires assumptions. It is assumed is stable enough at the time scale of a downloading attempt to be significantly correlated with the result of that attempt, and these KPIs can be measured by the measurement application with a reasonable level of accuracy. It is also assumed that the subjective rating obtained by the user depicts the chicken experience of downloading and can thus be compared with the objective index users to validate the subject.

Conceptual restrictions are used to keep things workable. The study does not strive to model all of the dimensions of application-level QoE within all digital services but rather is narrow and pays attention to downloading, and the quantifiable correlates associated with it. The paper does not purport to take the place of operator internal telemetry; it supplements it by gathering user-side evidence which might be missing in network-based monitoring. Measurements can also be subject to outside influence like remote server capacity, routing by content delivery network and device restrictions; these will be considered in analysis and they will be seen as restrictions and not left out.

Outline of the dissertation

This dissertation chapter is divided into five chapters. In Chapter 1, the context of quality internet downloading in telecommunication network, the research problem, aim and objectives, the importance of the study, scope and structure of the study are discussed. Chapter 2 provides a review of standards and research on QoS, QoE, and network performance measurement, and provides the conceptual basis of the choice of KPIs and the framework of scoring based on the definitions. In chapter 3, the research design is outlined, the measurement application workflow is outlined, the operational definitions of variables are outlined, and the data analysis strategy through which it will be possible to assess the suggested internet data quality score is outlined. Chapter 4 provides the empirical findings, the descriptive statistics and hypothesis testing as well as the discussion of the findings in terms of the literature and practice. Chapter 5 recapitulates the research by summarizing pertinent contributions, giving providers recommendations as well as placing limitations and future directions of research.

CHAPTER 02: LITERATURE REVIEW

Introduction to the chapter

The chapter is a review of the theoretical and empirical backgrounds needed to quantify internet downloading information quality on an end-user point of view within telecommunication networks. Although operators conventionally monitor infrastructure-level metrics, the eventual experience at the edge (on user devices) is a combination of network conditions, radio environment, server behavior and transport protocol dynamics to yield some observable result (e.g.: fast completion, stalling, or failure). Performance parameters of IP data services include delay, delay variation and loss which are formalized in standardization as performance parameters of performance (ITU-T, 2023a). Similarly, internet throughput testing constructs underline, that throughput cannot be read right without the knowledge of the properties of the paths like round trip time, bottleneck bandwidth, and loss properties (Mathis and Heffner, 2011). In line with this, at develop download experience; (iii) end-user measurement methods; (iv) scoring/index construction methods that convert measures into readable quality; and (v) analytics and machine learning to proactively manage performance. The chapter ends with the expression of the research gap that will drive the user-centered measurement and scoring framework used in the research which is in line with the proposal.

The literature also tends to make the distinction between quality of service (QoS) and quality of including throughput, delay, delay variation and loss, are used to define and measure service performance (ITU-T, 2023a). QoE on the other hand is the acceptability of service to the users, which is conditioned by both technical and contextual factors such as expectations, task objectives, device capacity, and service context (ITU-T, 2024). These ideas are not rivalries but they are connected by a cause-and-effect chain process whereby the performance parameters of networks interact to alter the outcomes of the applications which then creates an impact on the user perception.

In internet downloading, end users never feel the variation of the delay of the IP packets directly. They instead interpret the practical symptoms of irregular speeds, frequent failures or slow completion times. Because such results occur as a combination of several parameters, the quality of download is by design a multidimensional concept. This opinion is supported by the IP service standards as delay, delay variation, and loss are considered different, yet all interrelated parameters in transfer performance (ITU-T, 2023a). Further, transport-layer performance models show that both interactions of RTT and loss have a strong effect restricting throughput in high-nominal bandwidth environments (Mathis and Heffner, 2011). Hence, a download quality measurement significance to download quality and the ability to present this metric in a measurable format that can be linked to quantified quality as perceived by the user, i.e. a test score or index.

This paper adheres to one of the bridging requirements that the end user should be the central focus: its outreach is on a quantifiable level of download success (instead of failure) as well as the metrics supporting those measurements (and success) deserving favorable signal strength patterns, which explain the variation, as per the proposal.

Download performance parameters influencing download experience

Internet download performance is determined in a group of network parameters which are interrelated. These parameters of IP services are defined by standards to allow similar specification of performance and evaluation. ITU-T Recommendation Y.1540 specifies the parameters of IP transfer performance, that is, IP packet transfer delay, IP packet delay variation, and loss-related results and considers them as a basic standard to measure the performance of IP services (ITU-T, 2023a). These parameters apply in particular since most downloads are based on transport protocols that are susceptible to delay and loss properties.

Latency (delay). Delay is used to influence download performance by transport protocol behavior. Guidance on throughput testing suggests that to estimate throughput that would have meaning, exercising a base RTT and bottleneck bandwidth in order to be aware of the intrinsic limits of the path (Mathis and Heffner, 2011). In the case of high RTT, protocol performance can fall and recovery time following loss event can rise, contributing to a decrease in completion and realized throughput. Thus, delay is not only a measure of responsiveness, but also of throughput and completion-time determinant of most download cases.

Jitter (delay variation). Delay variation is defined by ITU-T to indicate variability in the delay in packet transfer that has a direct impact on timing-sensitive services and also may signal congestion and queue dynamics of general traffic flows (ITU-T, 2023a). Practically, high delay variation may go along with unstable transfer behavior and varying throughput which may be thought of as speed going up and down by the users even though the average speed may seem fine.

Packet loss. The effects of loss on download quality include downloading retransmissions and back-off, which results in reduced effective throughput and prolonged completion times. The throughput testing frameworks consider loss to be a key factor of throughput degradation and propose measured steps in order to interpolate TCP throughput when on loss conditions and RTT constraints (Mathis and Heffner, 2011). This implies that loss (or credible proxies of loss) is required in diagnosing slow downloads and frequent failures.

Throughput/bandwidth (speed of downloading). The most conspicuous performance metric is downloading speed and is mostly communicated. Literature, however, indicates that mobile speed does not have an identical measurement across tools and platforms, and the entire process of mobile broadband does not have a unified concession on the most effective method of measurement (Midol, Swimmer, van Ransburg, and Barlet-Ros, 2017). The same study proves a lot of variability within and among carriers and states that time-of-day and regional patterns can only partially explain variation that is observed (midsole et al., 2017). It means that any research that involved throughput as a quality measure should identify the methodology of measurements and explain throughput and contextual effects and other KPIs.

Conditions of retinopathy and signal strength (wireless conditions). With mobile access networks, radio conditions determine perceived IP performance. A small or varying signal strength may reduce the effectiveness of links, and increase the probability of errors, which are added to unstable throughput and loss-like behavior in higher layers. Empirical measurement studies of mobile broadband confirm that the performance measurement process is better served with the multiple measurement of its measures in realistic situations than with an individual one (El-Saleh, El-Mousy, and Shuar, 2023). This is captured in the proposal through the inclusion of signal strength logging in the measurement application as a contextual driver in understanding the change of performance.

A combination of the literature validates the assumption that a single KPI cannot represent download quality. Rather it can be best described as a set of outcomes (success/failure and achieved transfer performance) as well as explanatory (delay, delay variation, loss proxies, and access/radio context) measures. This is why in the study a measurement framework of end-users and composite logic of scoring is justified.

Broadband and mobile network end-user measurement techniques

The performance measurement strategies can be generalized into network-centric and the user-centric approach. Network-based monitoring relies upon operator telemetry and passive monitor inside the network, which allows scale visibility, yet might not identify device limitations, local radio surroundings, or application-level results like their failure to download things again and again. End-user measurement captures service as seen at the device and thus can easily record edge cases that are hard to capture in the network counters.

Another significant difference in the context of end-user measurement is active and passive measurement. Active measurement pushes controlled traffic e.g., speed tests, ping tests, and throughput probe, whilst passive measurement monitors naturally occurring sessions and results. Which in practice lots of measurement ecosystems are a combination of the two. This cautionary word about the design of active measurements is justified by throughput testing standards: the systematic approach by the IETF towards testing throughput of TCP presents results as showing that careful selection of baseline RTT, bottleneck bandwidth and MTU factors are significant to interpret throughput (Mathis and Heffner, 2011). Based on this, results obtained in terms of end-user speed cannot be very accurate when the misuse of the characteristics of the paths has been overlooked.

The popularity of crowdsourced mobile broadband measurement has been because of size and one that is readily gathered. Methodological variance however presents problems of comparability and validity. According to midsole et al. (2017), various tools can give various results under identical underlying conditions in part because of methodological decisions and test circumstances because there is no agreement on mobile speed measurement. Their massive analysis has demonstrated that performance variance is meaningful and cannot be described by mere contextual variables, which suggests that a more detailed system of measurement needs to meet deeper context and consider variability a characteristic attribute as opposed to noise (midsole et al., 2017).

The next practical aspect is that in practice, real-world assessment can be advantageous: it can be based on multiple metrics and the coverage of scenarios. To identify systematic variations and bottlenecks, drive-test and urban measurement experiments show the usefulness of taking a few performance measures of places and operators (El-Saleh et al., 2023). This underlies the focus of this study to integrate indicators of download outcome with indicators that supplement the outcome (ex: signal strength dynamics) to form an interpretable quality score (not just the snapshots of speed).

Metrics Translation into indices Scouring models of service quality

The simplification of the representations of service quality in simplified data frequently is necessary in operational environments where they are required to benchmark and make decisions. This simplification is offered through composite indices and scoring models which map raw KPIs onto discrete scales and cluster them into one measure which is interpretable. In the case of download quality, this score can have two important uses (i) to provide quality information in a form accessible both to non-technical stakeholders and (ii) to make comparisons across time, place and users. The proposal entails identification of finite score ranges that describe the successful download speed and download data that have been dropped and then averaging these into a final quality score.

The logic behind this methodology is common in index-construction: construct definition, indicators are picked, the indicators are mapped onto a standard scale, and these are aggregated. Transparency and easy interpretation are some advantages of threshold-based scoring. Literature however suggests that threshold choices are normative assumptions and these must be verified or justified. Within the QoS/QoE sphere, the standards provide a stable definition of the performance parameters (ITU-T, 2023a), yet, do not dictate the exact score bands of what is considered good or poor throughput; hence it has to be proved empirically by evaluating the correlation between the score and user experience as well as responsive to changes in known performance driver (delay and loss).

The transport literature also confirms that multi-metric reasoning should have been used in scoring. Since delay and loss variables determine throughput (Mathis and Heffner, 2011), a download-quality measurement incorporating failure-related behavior (e.g., dropped downloads or unsuccessful downloads) may be easier to use than a speed-only measure. The reason behind this is that the users normally examine downloading not only on how fast but whether it can work reliably. Thus, the two-part scoring structure of the given proposal speed performance and failure performance/dropped performance is conceptually valid, as it allows the two-dimensional structure of performance and reliability to be represented.

Proactive performance management analytics and machine learning

With the complexity of the networks, the performance management is more and more using analytics to discover underlying causes, as well as, to anticipate arising concerns. This proposal puts this study on the same path by seeking to utilize the gathered data and analytics (such as machine learning) to anticipate performance issues and assist in proactive management.

Predictive modelling can also be employed in the literature to produce estimations of the likelihood of unfortunate service or predict the performance under certain circumstances (e.g., congestion periods, poor radio conditions, high mobility). The empirical measurement studies indicate as well that the performance variance is large and can be explained only partially by such basic factors as region and time-of-day, meaning that the more complex sets of features and modelling can be of value (midsole et al., 2017).

A methodological perspective is that predictive modelling can be believed to have a credible predictive model only when it is appraised by relevant validation procedures and interpretable diagnostics. According to throughput testing guidance, throughput is a property of many paths and thus cannot be considered as an independent goal, out of context (Mathis & Heffner, 2011). This helps in using multi variable models which includes delay, loss, jitter and signal strength patterns. Operationally, predictive outputs are useful in practice when they allow actionable decisions to be made, such as creating an investigation when the predicted risk of location failure is high, when the capacity upgrade priority, or resource allocation policy should be adjusted.

Service accountability and compensation based on quality

It is also proposed to have a service fairness element: the experimentation of the charge redemption on the basis of quality parameters based on the perception of the end users. Such concepts on the service level commitments, consumer protection and performance transparency are normally associated with the service level commitments within the wider literature on service management. The parameter definitions on a standard basis constitute a plausible basis of defining measurable performance attributes (ITU-T, 2023a; ITU-T, 2024). Measuring quality to provide compensation based on it should however be consistent, representative and difficult to distort. The latter supports the role of transparent scoring provisions and empirical verification of the scoring system, especially through the objective scores, as compared to the subjective user scoring.

Practically speaking, the quality score that is user-oriented can help contribute towards accountability by allowing the identification of under-performing conditions (i) in a systematic manner; (ii) based on evidence; and (iii) providing a clearer understanding of quality between providers and users. Although the current research is not a regulatory appraisal, it does provide the foundation of measurement that would inform policy and operational deliberation regarding equitable remediation systems, which is in line with the aims of the proposal.

Synthesis and research gap

The reviewed literature and standards are brought together by four critical observations. To begin with, the quality of download is multi-dimensional: the results of throughput depend on delay, the loss, and the path properties and cannot be regarded as meaningful without the context (Mathis and Heffner, 2011). Second, performance parameters of IP functions including delay, delay fluctuation, and loss are formally characterized and often employed to establish and gauge service performance which offers a constant technical foundation on which to measure (ITU-T, 2023a). Third, end-user measurement is needed to consider service as perceived at the device but the outcomes may be different depending on measurement techniques and contextual heterogeneity, particularly with mobile settings (midsole et al., 2017). Fourth, analytics has the potential to add operational value in the sense that they allow identifying and preventing performance issues proactively, particularly since the variability between contexts can be quite high (El-Saleh et al., 2023; midsole et al., 2017).

Regardless of such developments, there is still a practical research gap: most measurement initiatives either report crude KPIs without converting them into a validated user-centered quality measure around download success/failure successes, or they are based on speed-test methods that might not reflect contextual interactions like sudden changes in signal strength and attempts failed. To fill this gap, the proposal proposes the creation of an application aiding in the measurement of end-user outcomes and context, an open scoring system, and an analysis of the framework in terms of quantitative analysis and predictive modelling.

In that way, the given study provides an applied, end-user-focused measurement and scoring model of internet downloading data quality based on common definitions of performance parameters and underlined by principles of throughput-testing, yet proven by the empirical data.

CHAPTER 03: METHODOLOGY

Chapter overview

Now chapter describes the way the study will be implemented, the way data are gathered via the proposed end-user measurement method, which is the implementation of Internet Downloading Data Quality framework and the way data will be analyzed in the MATLAB. The study is both methodological and applied: it builds an artefact (a measurement and scoring scheme realized with the help of an application workflow), and empirically tests the artefact by testing hypotheses and assessing whether the experience measured with its help correlates with the experience assessed by the users. In line with the suggestion, the methodology will give priority to end-user perspective parameters, objective logging of the downloading activity, and a transparent scoring system, which assists a provider in the form of a localization of suggestion and the proposed concept of charge redemption.

Research design and methodology

The research is a quantitative study that uses applied research design basis on Design Science Research (DSR). In DSR research contribution is artefact which addresses real problem, and artefact is tested rigorously on the basis of evidence. In this case, the issue is the challenge of determining the quality of internet downloading data in a manner that can be relevant to end-users and useful to telecommunication companies. The artefact is the measurement framework and its scoring model which is operationalized into a measurement workflow and analysis pipeline. The assessment is performed in terms of statistical testing, predictive modelling regarding measurements and ratings of end users.

The nature of the research carried out is quantitative since (i) it involves the numerical recording of performance measures like throughput and success/failure behavior, (ii) the calculation of an Internet Data Quality Score (IDQS) through an established formula and (iii) hypothesis testing, to identify objectives of performance parameters and data quality results. The main evaluation is mainly cross-sectional in nature (data will be collected over a specified field, and the data will be measured over the course of an event, or in this case, download session). The design is also explanatory in that it will test whether the performance parameters explain the changes in the quality of data and whether the model is predictive of quality problem.

Unit of analysis and context of the study

The research is done under a realistic scenario of a real telecommunication use environment where the end-users are accessing the internet to receive the motor of downloading. Each sales unit is a download attempt / session registered by the measurement workflow. A download session record contains (a) information about observed download result (e.g. a successful completion, a failure, an aborted attempt indicator), (b) performance data in the session (throughput, performance proxies as captured (latency)), and (c) context data (signal strength patterns, basic session context (time, etc..)). Such unit-of-analysis selection is also in line with the proposal emphasis on internet downloading data quality as a user-perceived outcome, and not necessarily network-side telemetry.

Population, sampling method and sufficiency of the sample

The target market is comprised of end users who frequently access mobile/broadband internet services when performing downloading operations in their normal day-to-days. The sampling methodology will guarantee the variation in network conditions (location and time) such that the scoring framework and the hypotheses may be tested under the conditions of realistic fluctuations. It employs a practical field sampling method in which the participants go through repeated downloading sessions of different time windows (e.g., peak vs off-peak) and environments (e.g. indoor vs outdoor, stationary vs moving where possible). The sample is also evaluated in terms of the quality in the number of the participants, and the number of session records, since the major statistical treatment is conducted at the session level.

In order to minimize systematic bias, the focus of the study will be to include sessions recorded using different contexts instead of gathering all the sessions within a given place or time. This is crucial as the telecom performance is susceptible to congestion, variability of radio coverage and density in the number of users. The resulting dataset is thus formatted in such a way that compares the general situation in summaries and regression modelling and has enough variability in the predictors.

Operational definitions and variables

The research will specify variables in two forms: (i) outcome variables that will pertain to quality of data, and (ii) explanatory variables that will pertain to network and context conditions.

Outcome variable: Internet Data Quality Score (IDQS).

The major output variable will be IDQS calculated in each session based on the scoring logic proposed. The proposal stipulates two scored items, including (a) successful download speed score, and (b) dropped download data score which are scaled on a 1-5 score band and then averaged to form the final internet quality score.

IDQS is thus operationally defined as:

Successful Download Speed Score: a score calculated based on the download speed band (Mbps) over a 1-5 ordinal scale.

Dropped Download Data Score: map of the dropped/unsuccessful behavior (according to the preset values of successful loading attempts/data) to the 1-5 ordinal score.

Final IDQS: the mean of two component scores

Subjective outcome measure (validation variable).

The subjective user rating is recorded at the end of each session (or small cluster of sessions) to indicate the perceived download quality. This is applied to assert that objective IDQS correlates with user experience. A simple rating scale (e.g., 15 or 10) would be used to capture the subjective score, and it would be placed in the position in which the score range is to be compared and tested through correlation.

Explanatory variables (independent variables).

The major explanatory variables are:

Throughput (Mbps): when download attempt was made, was measured here and was used by the speed scoring component.

Latency and jitter indicators: measured through application-level probes where practical or session measurement routine through delay property recognition.

Packet loss indicators / loss proxies: these are directly measured (where possible) or inferred by repeated failures/timeouts depending on the method of implementation.

Translation: Signal strength dynamics: logged according to the proposal in written in the requirement of the proposal of volatility of radio context by recording changes in signal strength at small intervals (5 ms when there are changes).

Context controls [time of day, category of location, type of device/network (where captured), and context conditions] of a performance that can confound performance.

Framework of measurement and procedure of data collection

Measurement pipeline implemented in the study is in the form of an end-user measurement pipeline that both records the result of downloading and the circumstances involved in downloading. The proposal presents two peculiarities of operation: (i) the recording of the strength of high-frequency signals and (ii) the counting of the successes/failures of repeated attempts.

They are included in the process in the following way.

On the one hand, upon the downloading process completion, the system logs the signal strength variation at each instant when there is a change therein with a short interval (5 ms) used to detect quick changes in the conditions of mobile radio. This will give a time-series context indicator that can subsequently be condensed into characteristics like average signal strength, minimum signal strength and volatility (e.g., standard deviation or number of sharp drops).

Second, the system logs download attempt behavior but within a specific window, which is in line with the 10-attempt method of the proposal. In this reasoning, a single attempt is considered a discrete loading/download start with success being a load being loaded (or some agreed upon threshold of completion). Data lost or under loading will factor into the dimension of dropped-data/attempt failure.

Third, the system records the download speed (throughput) of successful requests and the score of the offer according to the set speed bands. When the speed is variable, the session speed can be calculated as an average over the attempt time or a representative value (such as median) according to implementation; the calculation captures the statistic used in order to score consistently and repeatable.

Fourth, workflow gets subjective user rating on perceived download quality. The collection method to be employed will avoid the respondent getting fatigued, a short rating prompt right after a session or a small number of sessions is introduced so that the ratings would be based on recent experience as opposed to long term recollection. This qualitative score admits construct validation of the IDQS.

The different measurements are all organized into a structured dataset with one row per session/attempt group, and standardized variables names. All data will be stored using anonymized identifiers to preserve the privacy of the participants.

Implementation of the scoring model

The scoring model has been applied in identical manner it was applied in the proposal to provide fidelity to the initial research design.

Two component scores are calculated and summed up. Score of successful download speed.

All the obtained speed points are assigned to a discrete score range (15) based on the thresholds of the proposal. This will transform the continuous values of the Mbps into a readable ordinal scale of very poor to very good speed performance.

Dropped download data score.

Dropped loading attempts or dropped data behavior are then transformed into a discrete score band (15) based on the threshold definitions in the proposal.

This element absorbs consistency as well as perseverance of downloading which is frequently a overpowering element of user animosity.

Final IDQS calculation.

The overall quality score of internets is calculated as the arithmetic mean of the two component ones, and they create a balance score of speed and reliability.

The reason behind equal weighting is that the conceptualization of the proposal considers both elements as fundamental aspects of user-perceptibility download quality. The equal-weight method also enhances transparency, which can be crucial in case the score is subsequently utilized in making provider action ability and charge redemption logic.

Preparation and engineering of data (MATLAB)

Raw data of measurements are first cleaned and prepared in MATLAB before hypothesis testing and modelling. Preparation of data has three steps.

First of all, data integrity checking is done. The presence of required fields (session id, timestamp, speed metric, success/failure outcome, component scores) is checked with the help of MATLAB scripts. There are invalid or unfinished records which are marked and are either corrected (when it is obvious by a rule) or deleted to prevent the analysis damage.

Second, the management of outliers and noise is used carefully. The network performance can rightfully give extreme values in deplorable situations, so the outliers are not eliminated solely judging by magnitude. Rather, the cleaning procedure separates measurement errors (e.g., impossible negative speeds, corrupted timestamps) and the actual extreme performance (e.g., close to zero throughput during congestion). Radical extremes are kept since they are significant quality failures.

Third, time-series summarization of signal strength is conducted and transforms high-frequency logs into explainable session features. The raw 5 MS change-based log is facilitated into the features like mean signal strength, minimum signal strength, maximum signal strength, volatility (standard deviation) and drop-count indicators (number of times the signal dropped below a specified threshold or area, during the session). These characteristics enable the analysis to provide tests on whether radio instability will predict low IDQS or high failure risk.

Strategy of data analysis (MATLAB)

MATLAB is used to perform all statistical analysis and modelling and therefore the analysis is entirely scriptable. It is organized to include descriptive analysis, hypothesis testing, validation and predictive modelling as part of the analysis strategy.

Visualization and descriptive statistics

The central tendency and dispersion values of the most important variables (mean, median, standard deviation, quartiles) are calculated, and the distributions of throughput, dropped-attempt indicators, signal characteristics as well as IDQS are visualized based on MATLAB. Histograms, boxplots and time-of-day stratified summaries are visualizations. These outputs give a background idea of average performance and variability that is imperative in network research in which there usually exists a high degree of variance.

testing of hypothesis: association and explanatory modelling

MATLAB is carried out to test the hypothesis of the proposal, conducting the correlation and regression analysis.

- Correlation tests are carried out in relation to relationships latency vs packet loss/throughput and the association they have with IDQS. When parametric assumptions are satisfied variable Pearson correlation is employed and when they are not, Spearman rank correlation is applied to ensure good behavior with non-normal data and ordinal scoring.
- Regression modelling is used to determine whether the predictors explain IDQS after adjusting the effects of confounders. There are two approaches depending upon the distribution and measure scale in the end, which are:

(i) multiple linear regression when the variables are considered approximately continuous e.g. IDQS, or
(ii) ordinal/logistic modelling when IDQS would be considered an ordinal outcome.

The results of regression (coefficients, confidence intervals, p-values, and goodness-of-fit) are interpreted to either accept or reject the importance of the factors correspondingly in the quality of the data.

Validation: objective rating and subjective user rating.

Mat lab is used to compare objective scores and subjective ratings by the user to validate the IDQS. This involves:

- correlation test of objective IDQS and subjective scores, and
- analysis of errors (e.g. mean absolute difference) in order to test agreement.

Where necessary, plots are plotted demonstrating the alignment-pattern and some situations where objective and subjective scores do not match (e.g., users might rate quality low when speed was medium when failures had happened).

Predictive modelling (quality problem forecasting).

The proposal identifies predictive modelling to be used in proactive management.

Predictive models are created through MATLAB and are meant to pick on the sessions that are likely to be of poor quality. The target of the prediction is determined as follows:

Or, a continuous prediction of IQS, or

• is a categorization of the session as poor or as acceptable on the basis of a threshold on IDQS.

It has feature sets such as throughput, latency/jitter/loss indicators, signal strength summary features and contextual controls (time-of-day). To facilitate the prevention of overfitting, models are trained and tested on a train/test split or cross-validation with MATLAB. Depending on the size of the dataset, and behavior of features, baseline models (e.g. regression) are compared to more flexible models (e.g. decision trees or ensemble methods). The appropriate metrics are used to report model performance: RMSE/MAE in the case of regression prediction, accuracy/precision/recall/AUC in the case of classification.

Quality assurance, validity and reliability

A number of measures provide credibility and legitimacy of the measurement and analysis.

Instrument and measure reliability

The workflow of data collection is provided with a set of rules of defining a download attempt, defining success/failure, speed statistic, and score calculation. This is to ensure that when the same session is performed with similar bounded conditions, the same results are obtained. Pilot testing is employed to ensure that the application records the expected values, as well as, to ensure the stability of the score calculation.

Construct validity

Construct validity is determined by comparison of objective IDQS to subjective score on the user, which is analyzed using statistical analysis methods of association and agreement. The fact that objective measures and subjective measures of download quality are similarly meaningful allows giving a nod to the assertion that IDQS is a measure of download quality as perceived.

Internal validity

Modelling that incorporates demystifying control variables, like features of time of day and context, increases internal validity. The study however is done in the real field conditions and causal statements made with caution since the study is done not in the laboratory conditions but in the real field conditions; analysis is done in statistically supported relationships and prediction capability.

External validity

External validity is facilitated by the recording of the sessions in diverse real-life situations. However, it can only be generalized on similar contexts as those measured (network type, geography, device class). These restrictions are well captured in Chapter 4 and Chapter 5.

Ethical considerations and data security

The research conducts end-user assessment and subjective rating and thus ethics safeguards are administered. The participants will be informed to give their consent, data will be anonymized, and no content that will identify any person will be gathered unless it is required to render an analysis. All the records are kept with high security and only accessed by the research team. Individual-level behavior would not be revealed upon reporting the results since aggregated outputs are employed.

Summary of the chapter

The chapter introduced the design science approach, which is a quantitative approach to the development and testing of an end-user internet downloading data quality framework. The unit of analysis, variables, data collection workflow, scoring model implementation, and the analysis pipeline consisting of MATLAB used to perform the descriptive analysis, hypothesis testing, validation and predictive modelling were defined in the chapter. The following chapter records output of the results obtained using this approach, namely computed pattern of IDQS, hypothesis evaluated outcome, objective subjective concordance and model performance.

CHAPTER 04: RESULT, ANALYSIS AND DISCUSSION

Introduction

This chapter gives the empirical findings created as a result of the MATLAB analysis workflow as discussed in Chapter 3. It is intended to show, using quantified session data, the dependence of internet downloading quality on access technology, the use of key Quality of Service metrics to explain that dependence, and the question whether the proposed Internet Data Quality Score (IDQS) is a realistic goal measure of end-user experience. The analysis is also organized in a way that it starts with a description and then proceeds to an explanation, and then prediction. The IDQS scoring variables are checked and the dataset is profiled first. Second, the descriptive statistics is a summary of the throughput, latency, jitter, packet loss, signal strength and failures, and the objective IDQS and the subjective user rating. Third, comparison between 4G, 5G and FTTH reveals the differences between technology levels in download performance. Fourth, the hypothesis testing is a measurement of the association between KPIs and IDQS and also whether the relationship observed is statistically and practically significant. Fifth, validation tests are measures of objective IDQS against user ratings to measure construct validity and agreement.

Lastly, predictive modelling is used to assess the ability of bad-quality sessions to be identified based on measurable KPIs, which will allow to proactively manage quality. Tables and figures are added at the places where they represent first-hand testimony on every analytical statement.

Profile of dataset and preparation of data results

The analysis data set consists of 250 downloading sessions that were obtained in the conditions of the actual use by 25 users. Recording was done on three types of access technologies, that is, 4G (n = 133), 5G (n = 70) and fiber-to-the-home (FTTH) (n = 47). A session is a measure in discrete terms, which is considered a unit of analysis and which presents a set of download attempts and the network performance indicators. Each session is represented in the dataset by the average download speed (Mbps), average latency (ms), average jitter (ms), the percentage of packet loss, the average signal strength (dBm), signal variability and the number of unsuccessful downloads. Also, subjective rating (1-5) of download quality of the same session is provided by the user and allows checking the proposed objective score.

According to the operationalization identified in Chapter 3, two component scores were calculated to form IDQS. The frequency of downloads is then mapped onto a 1 to 5 band of quality based on transparent thresholds in the speed score to make it easily interpretable to both academic and industry users. The drop score metric values reliability of sessions on failed attempts to represent real life situations that even with moderate instantaneous throughput repeated attempts to download irrelevant data can make a session intolerable. The average of these two component scores is computed to give the objective Internet Data Quality Score (IDQS), which results in a zero to five scale, that is, very poor to very good. To classify and report, binary label was obtained based on the study rule, which was Poor Quality when IDQS < 3 and Good Quality when IDQS 3 and above. This operationalization of minimum acceptable service, and assists with inferential comparisons and prediction modelling.

Variable Name	Description	Unit	Role in Analysis
Avg Download Speed	Average session throughput	Mbps	Independent Variable
Latency	Average round-trip delay	ms	Independent Variable
Jitter	Delay variation	ms	Independent Variable
Packet_Loss	Packet loss rate	%	Independent Variable
Signal_Strength	Average signal strength	dBm	Independent Variable
Signal_Variability	Volatility of signal around mean	dB	Independent Variable
Failed_Attempts	Failed download attempts (out of 10)	Count	Independent Variable
SpeedScore	Score derived from throughput thresholds	1 5	IDQS Component
DropScore	Score derived from failure thresholds	1 5	IDQS Component
IDQS	Internet Download Quality Score	1 5	Dependent Variable
User_Rating	Perceived quality rating	1 5	Validation Variable
Quality_Class	Good (≥3) / Poor (<3)	Binary	Classification Target

Table 1. Structure of the dataset and the role of variables.

Screening of data showed that there were plausible operating ranges of all KPIs and thus it is reasonable to use the data set as a realistic data of end-user conditions. Throughput is also very diverse, which implies unequal environments of the network and differences in technology. Latency and packet loss are also significantly dispersed, and as the literature demonstrates, these are the key factors in determining success in throughput and download reliability. Notably, no violent trimming was used, since extreme values may be indicating valid cases of congestion, or coverage failures, as opposed to measurement errors. The analysis is thus aimed at learning the importance of these real-world variations and how they are carried over into quality results. The rest of the sections contain descriptive patterns reporting followed by inferential testing of relationships.

General descriptive findings: IDQS, user ratings and KPI distributions

The overall descriptive statistics present the background evidence that the quality of downloads is variable and a composite score is required to sum up the end-user conditions. In all sessions, the average download speed is 18.265 Mbps with median 12.035 Mbps which is a right-skewed distribution with more high-speed sessions, mostly as a result of FTTH and higher-strength 5G conditions, pushing the mean higher than the median. The average and the median value of latency are 48.277 ms and 52.205 ms, respectively, and these values indicate that a significant number of the sessions are characterized by moderate to high latency. The values of jitter (mean 7.113 ms) and a packet loss (mean 1.759%) show another instability that can hinder download performance with retransmission and variable rates at which the delivery of the content occurs. The signal strength is relatively wide, which is appropriate to mixed indoor and outdoor conditions as well as to mobile users at varying distances between serving infrastructure.

The objective IDQS has a mean of 3.478 (SD = 0.964) and a median of 3.50 meaning that the average session is within acceptable to good range but that a large percentage is below the acceptable range. Similar results regarding the central tendency are provided by the subjective user ratings (mean 3.440, SD 1.060), which give the initial indication that the objective score is not systematically biased against end-user perceptions. The threshold of the study is used to identify which 195 sessions (78% of the total) are Good Quality and which 55 sessions (22% of the total) are Poor Quality. It has the analytical benefit of being a realistic service environment with poor sessions but not over-dominating so that meaningful comparison of drivers can be made without over-class imbalance in predictive modelling.

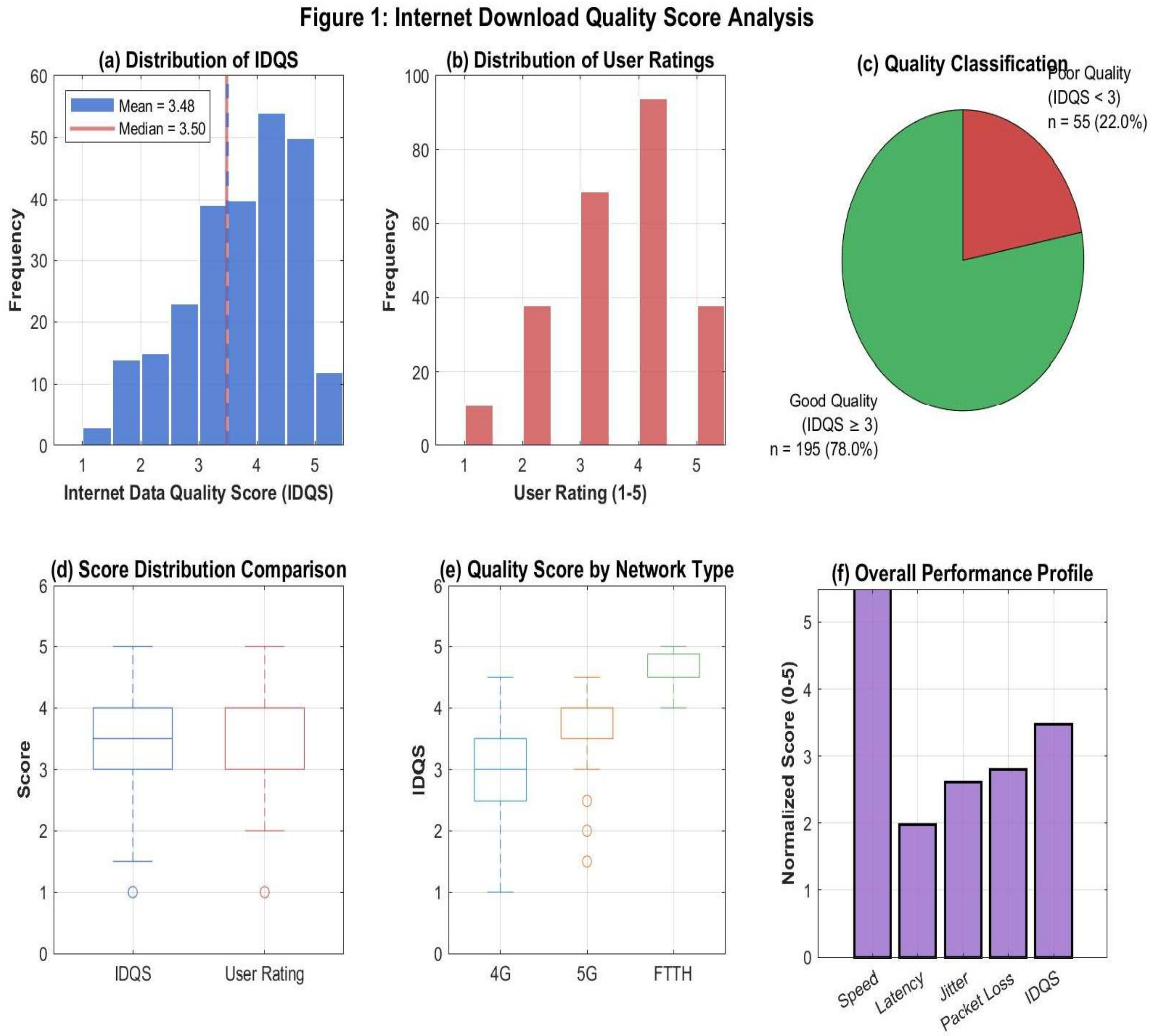


Figure 1. Internet Download Quality Score (IDQS) analysis (distribution, classification, and network type comparison).

Variable	Mean	Median	SD	Min	Max	Q1	Q3
Download Speed (Mbps)	18.265	12.035	17.691	0.2	77.33	5.86	23.23
Latency(ms)	48.277	52.205	19.064	5.4	86.46	33.41	64.69
Jitter (ms)	7.113	6.665	3.574	1	15.47	4.46	9.81
Packet Loss (%)	1.759	1.695	1.011	0	4.26	0.97	2.44

Signal Strength (dBm)	-70.571	-76.235	21.308	-104.47	-25.09	-85.04	-67.14
IDQS	3.478	3.5	0.964	1	5	3	4
User Rating	3.44	3	1.06	1	5	3	4

Table 2. Overall descriptive statistics (n = 250).

The results of quality are shown in a succinct perspective in Figure 4.1. The IDQS distribution shows that there is a clustering in the 3-5 range but has a significant tail to the low values which is significant since it is these tail events that generally cause user dissatisfaction and service complaints. The comparison in terms of the network type within the same figure demonstrates the evident technology gradient: FTTH sessions are concentrated on the larger IDQS values, 5G sessions are concentrated on the higher range of the middle, and 4G sessions are more spread and have more mass on the lower quality region. This visual fact encourages the formal comparison of the technology in the form of Section 4.4. Also, the comparative boxplots of the IDQS and user rating depict close medians and dispersion implying that the objective score will have good construct validity that will be revealed later in the validation section.

Performance comparison at technology level: 4G/5G/FTTH

Technology level analysis assesses the ability of the proposed score to differentiate the quality of services across various access infrastructures and this is necessary to work in practice. A performance summary of 4G, 5G and FTTH is in table 4.3 and figure 4.2. The findings indicate that there is a monotonic increase in throughput and IDQS between 4G and 5G and 5G and FTTH whereas latency declines throughout the same development. The average speed in the case of 4G is 7.038 Mbps and the average IDQS is 2.883, which means that the average 4G session is not very far out of the minimum allowable threshold and that a significant proportion of the sessions are below that threshold. In the case of 5G, the average speed and average IDQS become 18.521 Mbps and 3.864, respectively, with the majority of the sessions fall in the good-quality bracket. FTTH has the highest performances, the mean speed of 49.653 Mbps and mean IDQS of 4.585 which indicates that the system has consistently high-quality downloading.

The patterns of latency support the technology effect. The 4G, 5G, and FTTH have an average latency of 63.259 ms, 40.012 ms, and 18.191 ms, respectively. These values are important since latency determines how efficiently time is used by a transport-layer, as well as how long it takes to bounce back after a loss. Bigger delay costs more in terms of retransmission and it may minimize throughput performance particularly when there is congestion. Consequently, it can be explained by the combination of the reduced throughput and the increased latency that the 4G sessions are concentrated at the lower IDQS values. The low proportion additionally demonstrates pragmatic effect: 39.10% of 4G connections are of poor quality relative to 4.29% and 0% of 5G and FTTH respectively. It means that the quality improvement initiatives addressing the mobile performance, specifically 4G, can substantially decrease the likelihood of the unacceptable user experience.

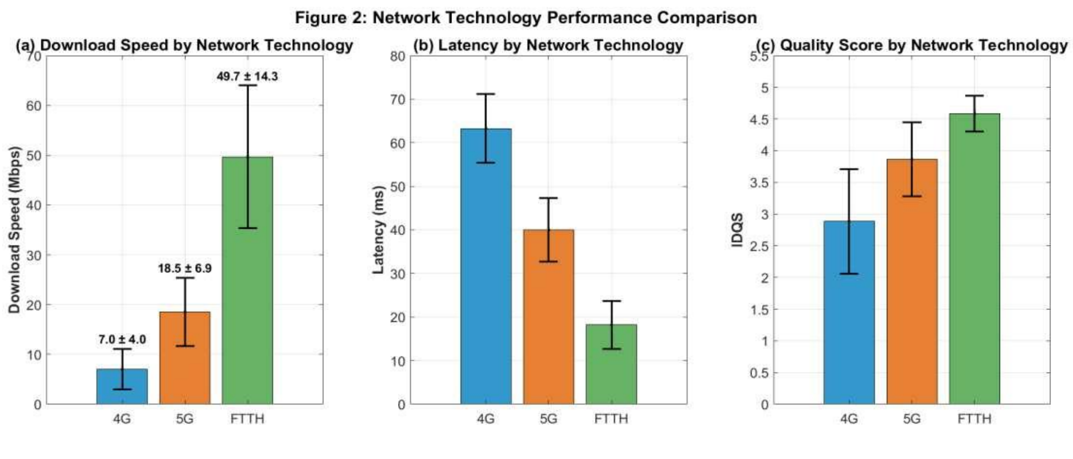


Figure 2. Performance analysis (4G, 5G and FTTH) Network technology.

Network	n	Speed (Mean ± SD)	Latency (Mean ± SD)	IDQS (Mean ± SD)	Poor Quality %
4G	133	7.038 ± 4.032	63.259 ± 13.896	2.883 ± 0.823	39.10%
5G	70	18.521 ± 6.895	40.012 ± 9.452	3.864 ± 0.583	4.29%
FTTH	47	49.653 ± 14.315	18.191 ± 5.918	4.585 ± 0.282	0%

Table 3. Comparison of network technology performance.

The outcomes of the technology are in line with the theoretical projections in Chapter 2. FTTH offers a better stable medium with a small radio impairment that results in a reduction of loss, delay, and consequently the increase in effective throughput and a reduction in failures. 5G is an improvement over 4G in terms of radio resource management and capacity, yet still suffers due to variability caused by mobility, interference, and congestion. The standard deviations that are observed also have their significance: 4G is more variable in the speed and the IDQS, which implies that users vary in their experience despite operating on the same type of technology. This is the cause of displeasure in most cases, as they cannot see through whether or not a download is going to work when they are in need. Based on this, a quality measurement framework must measure both central tendency and reliability hence the need to keep the failure component vital.

Relationship analysis and hypothesis testing: drivers of IDQS

This part will test the study hypotheses by measuring the correlation between relationships between KPIs and download quality outcomes. The reason behind the use of Spearman correlation is that it is strong against non-normal in order to use in cases where the outcome contains ordinal-type scores. The entire correlation table is presented in Figure 4.3, and the summarization of the most important hypothesis relations is presented in Table 4.4. The findings reveal that throughput is highly and positively related to IDQS and failed attempts, latency, jitter and packet loss are highly and negatively related to IDQS. Signal strength is positively correlated with IDQS and negatively correlated with latency, which suggests that radio-layer performance affects higher-layer performance.

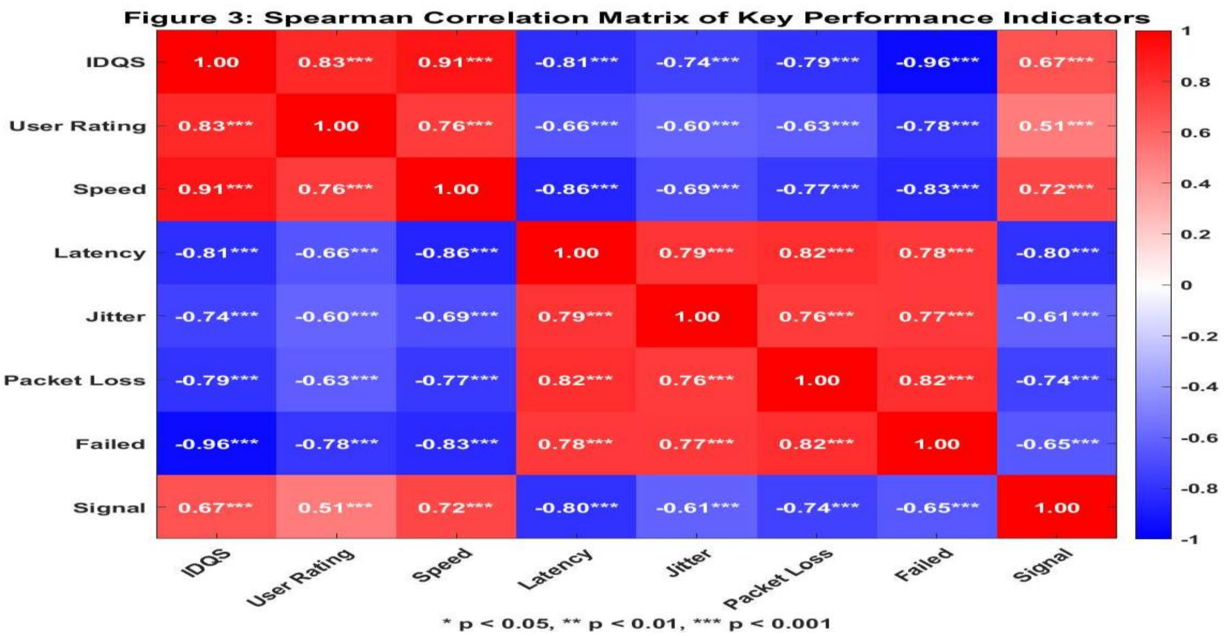


Figure 3. Spearman correlation matrix among KPIs, IDQS, and user rating.

Relationship	Spearman ρ	p-value	Decision
Latency vs Throughput	-0.858	<0.001	Supported
Latency vs IDQS	-0.813	<0.001	Supported
Throughput vs IDQS	0.907	<0.001	Supported
Failed Attempts vs IDQS	-0.956	<0.001	Supported
Packet Loss vs IDQS	-0.79	<0.001	Supported
Jitter vs IDQS	-0.742	<0.001	Supported
Signal Strength vs IDQS	0.671	<0.001	Supported
IDQS vs User Rating	0.834	<0.001	Supported

Table 4. Hypothesis testing results (Spearman correlation).

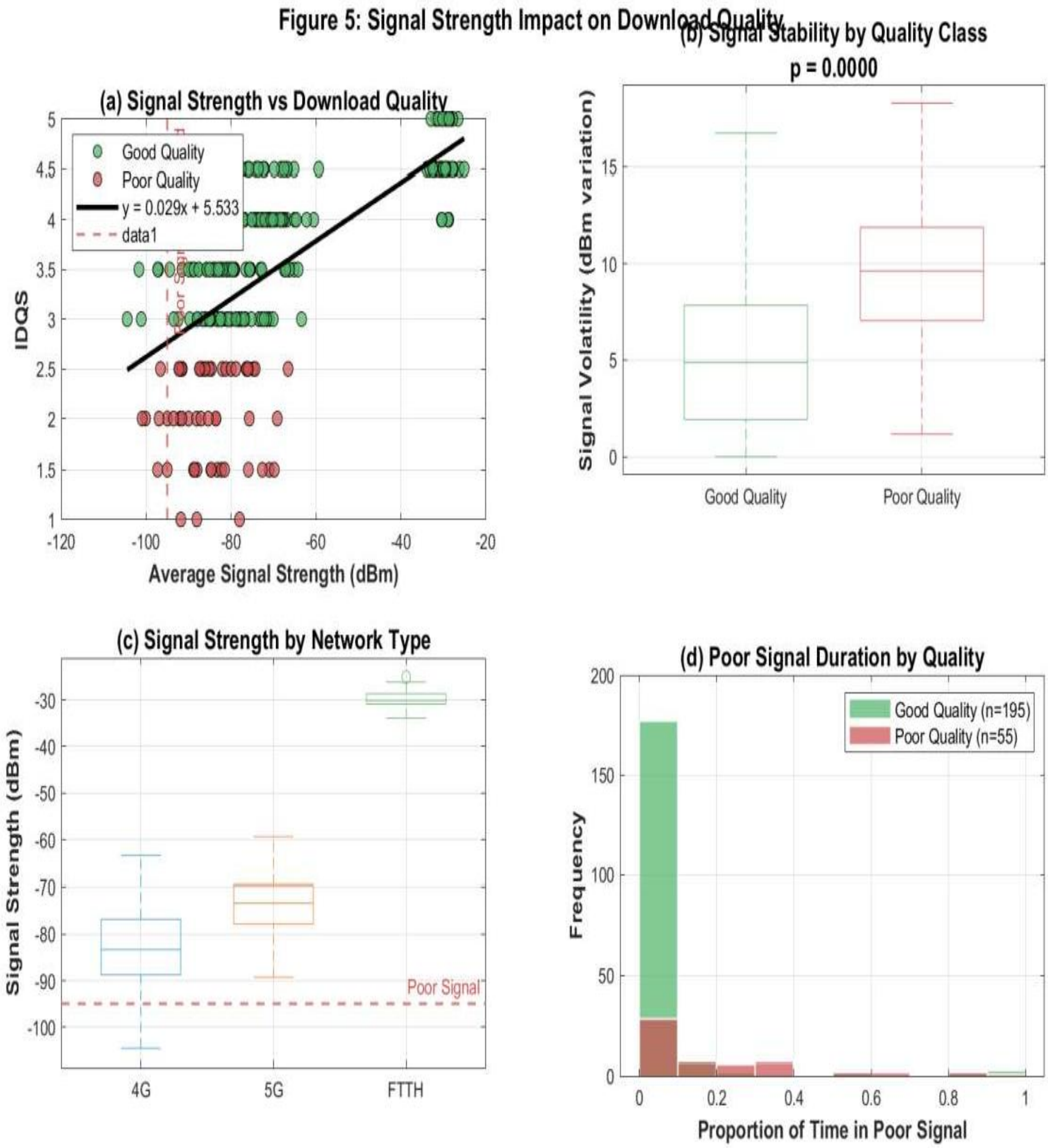
The greatest correlation is the one between the failed attempts and the IDQS (= -0.956, p = 0.001), which shows that reliability is paramount to the quality score. This has a substantive significance as it contributes to the main thesis of the research: in the reality of downloading, probability of the success is as decisive as the speed. A user might have a moderate slow download, but when it finishes, the user might be willing to proceed, however, when it starts to fail repeatedly, the experience becomes poor and the user will no longer trust the service. Throughput also demonstrates a very strong correlation with IDQS ([0.907, 0.001] = -0.907), which is not surprising since one of the aspects of IDQS is speed but the correlation is also so high that it indicates that the scoring thresholds are vulnerable to realistic variation. Latency has negative correlation with throughput as well as IDQS and this proves that delay constraints are adversaries to effective download performance. Packet loss and jitter exhibit similar negative correlation with IDQS, which helps to confirm the idea of the conceptual model that instability and retransmissions hurt the quality despite seemingly reasonable headline speeds.

Radio conditions Signal strength correlation shows radio conditions to play a significant role in quality results, particularly in mobile technology. They are also positively correlated with stronger signal (= 0.724), lower latency (= 0.801), which is expected due to closer the radio link quality, the fewer retransmissions and the lesser scheduling delays. The positive signal IDQS correlation (= 0.671) means that achieving better coverage and decreasing signal variability can lead to a real quality improvement. Practically, this assists in densification, antenna optimization and indoor coverage solutions where the signal is weak, especially in places where the user makes several attempts before successful downloads

Variable	Good Quality (Mean)	Poor Quality (Mean)	p-value
Speed (Mbps)	22.379	3.677	<0.001
Latency (ms)	43.374	65.662	<0.001
Jitter (ms)	6.324	9.91	<0.001
Packet Loss (%)	1.488	2.723	<0.001
Failed Attempts	3.313	6.673	<0.001
Signal Strength (dBm)	-66.84	-83.72	<0.001

Table 5. Comparison of Good vs Poor quality sessions.

In order to supplement the correlation analysis, sessions with the Good Quality and Poor-Quality classes were compared. Table 4.5 indicates significant differences that are huge and statistically significant in all the large KPIs. The speed of poor-quality sessions is significantly lower (3.677 Mbps versus 22.379 Mbps of good-quality sessions) and its latency is significantly high (65.662 ms versus 43.374 ms). They are also characterized by increased jitter and packet loss which is a pointer to increased instability. Most importantly, the near doubling of the intensity of failed attempt is in poor-quality sessions. These findings represent good proof that the IDQS classification rule does not divide sessions into arbitrary performance regimes but into meaningful performance regimes. Magnitude of the differences suggests that gains in the quality that is



focused on the poor-quality segment can provide huge user-perceived benefits.

Figure 4. Effects of signal strength on the quality of download (good vs poor class and volatility).

Figure 4.4 further refines the interpretation of the radio-layer and demonstrates that poor-quality sessions are not only characterized by the weaker average signal but also the greater volatility of the signal. This implies that fading or interferences may cause momentary sessions to sink out of the stable state and into an unstable state due to loss and delay amplification and throughput breakdown. These signal patterns are the most applicable to mobile technologies since the dataset has both mobile and fixed access. Based on this, there is quality management strategy incorporating signal stability measures more diagnostic compared to mean signal only.

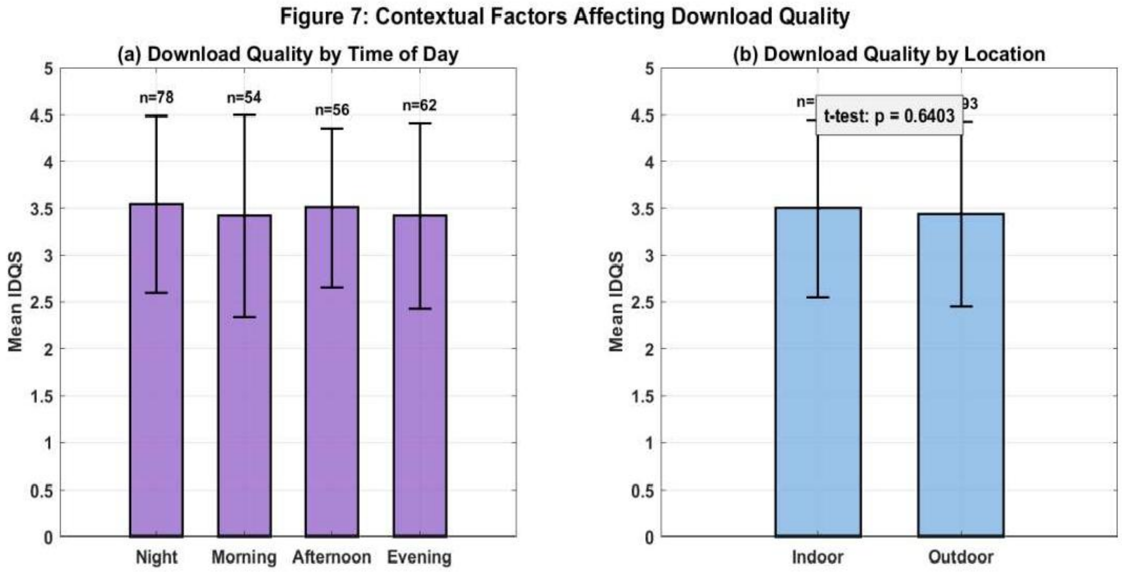


Figure 5. Location factors such as the time of the day, the quality of download.

In Figure 4.5, contextual comparisons show that the coarse labels like indoor versus outdoor do not result in large differences in IDQS based on this data collection. This finding implies that direct measurements of KPI are more informative than general context categories especially where the differences in technology prevail. Nevertheless time-of-day trends also can be useful in network planning as congestion has the potential of increasing both latency and loss despite unchanged average signal strength. More subtle contextual information like the identity of cells and traffic load measures can be used to enhance the explanatory framework in subsequent deployments.

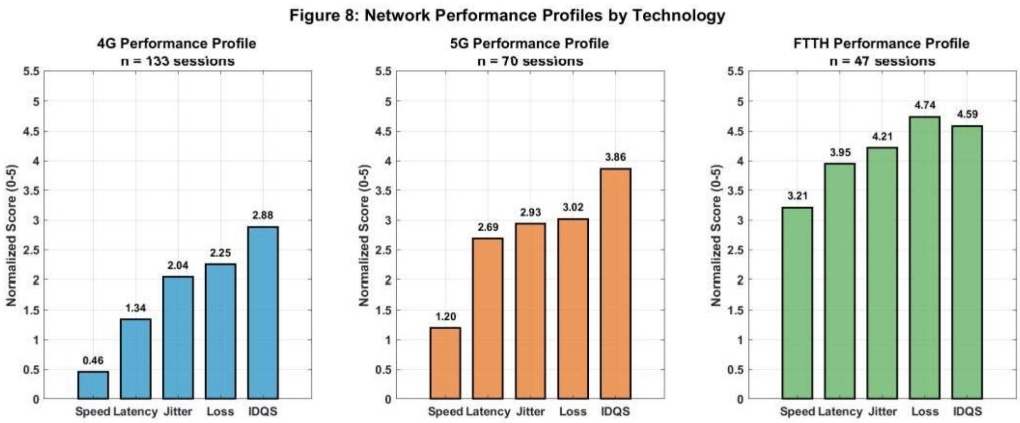


Figure 6.Normalized access technology network performance profile.

Figure 4.6 shows normalized performance profile that allows making multi-dimensional comparisons with each other on a shared scale. The 4G profile demonstrates the presence of speed reduction and measure of delay and loss conditions that is accompanied by decreased composite IDQS. The 5G profile denotes the enhancement of throughput and the decrease in delay, which uplift the overall quality. FTTH has high steady-state speed, low delay and loss, which is reflected in high and steady IDQS distribution. These profiles are consistent with a holistic understanding: downloading of high quality must be able to have not only capacity(speed) but also stability (low loss, low delay and consistent completion).

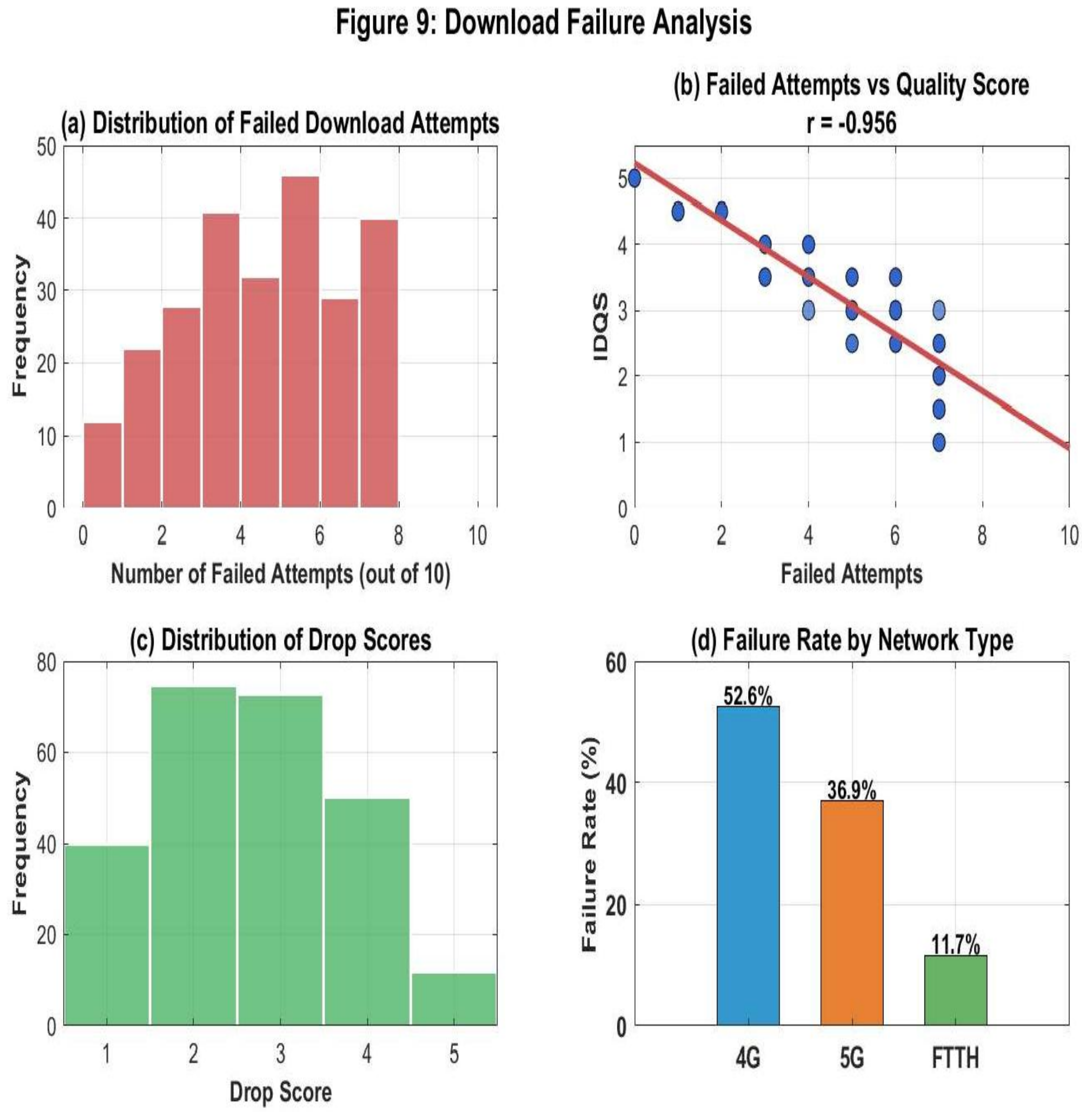


Figure 7. Download failure analysis Downloads that have failed and by network type.

Dedicated evidence into the reliability dimension is covered in Figure 4.7. The negative statistical finding that reliability is a strong quality driver is supported by the fact that there is a sharp negative correlation between failed attempts and IDQS. Technology level failure rates are also similar to those of the technology gradient shown above, with the 4G having the highest failure intensity and FTTH the lowest. Operationally, it means that by alleviating the probability of failure in providing greater stability of the radio, controlling its congestion and recovering its errors, a greater improvement will be realized in the user experience even before headline throughput increases.

Effects of IDQS validation on user perception

One of the major conditions of the proposed IDQS is that it has to give the impression of user perception. Validation was done by comparing objective IDQS with subjective user rating with both correlation and error measures. The findings indicate that there exists a solid correlation (Spearman 0.834; Pearson r = 0.843), and the performance of high objective quality is correlated with the perceived one. Error statistics indicates that there is comparatively little disagreement on a 1-5 scale (MAE = 0.434; RMSE = 0.575), implying that the objective score usually lies within an approximate half-rating range of the judgment of the user. Having this degree of agreement is high since network performance is noisy in nature and human rating is subjective.

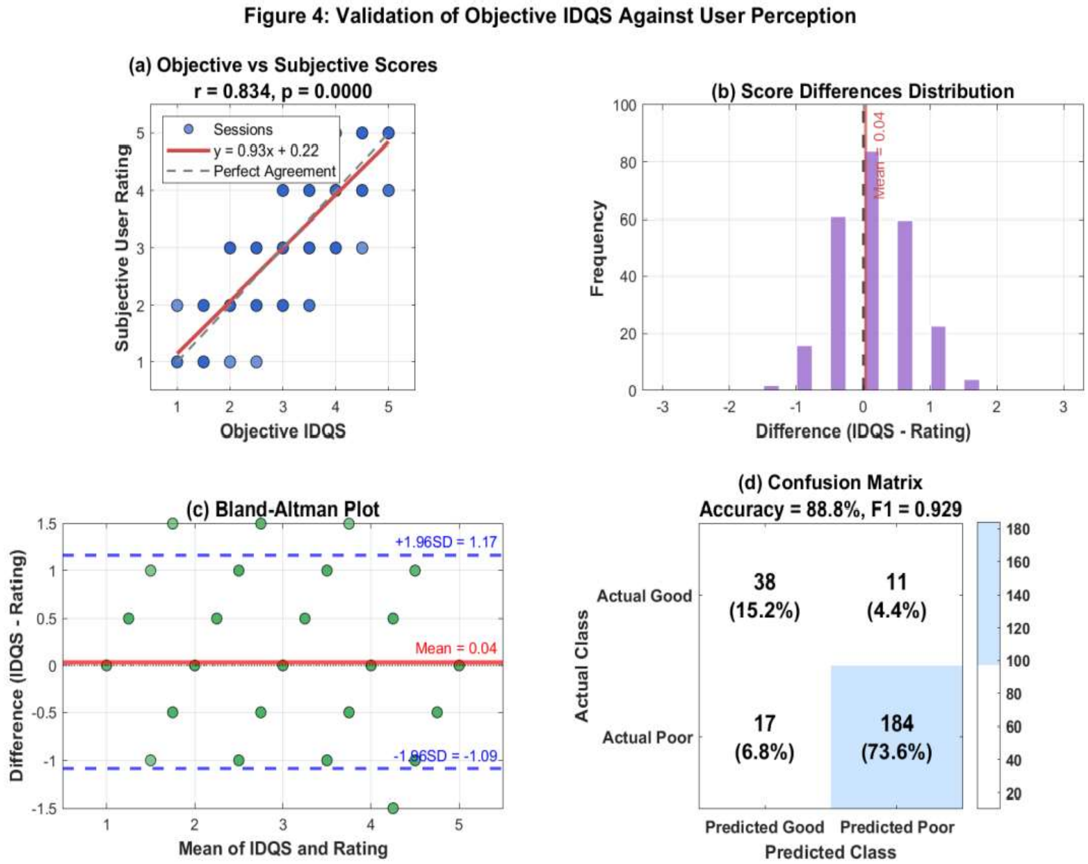


Figure 8. Objective IDQS validation versus (agreement and classification) outcomes of user perception.

Metric	Value
Spearman Correlation (IDQS vs User Rating)	0.834
Pearson Correlation (IDQS vs User Rating)	0.843
Mean Absolute Error (MAE)	0.434
Root Mean Square Error (RMSE)	0.575
Classification Accuracy	88.80%
F1 Score	0.929

Table 6. The validation metrics (objective vs subjective).

Figure 4.8 graphs the results of the validation and reveals that most of the sessions are with the conjunction of the rate of IDQS and the user rating close to the dragon whereas only a small proportion have discrepancies. These disputes are analytically instructive. The instances when the users of a session give a low rating than the objective score might be instances of frustration due to momentary interruptions or even application-level delays or lower expectations that the measured KPIs might not reflect. In contrast, the instances of higher rating of a session by the users could be observed when their particular task is successfully completed despite the average level of KPI. However, the result of the confusion-Matrix demonstrates that the rule of the IDQS threshold is effective enough to differentiate between acceptable and unacceptable experiences, and it has a high F1 value with accuracy of 88.8 percent. Thus, it not only is appropriate to score in terms of obtaining an academic inference but also in terms of real service monitoring.

Quality classification predictive modelling results

In order to evaluate the possibility of finding poor-quality sessions at an early stage, predictive modelling based on the binary quality class that was derived out of IDQS was conducted. The reason why a Random Forest classifier was chosen is that it will be able to define non-linear relationships and interactions between the KPIs in the absence of rigid distributional assumptions. The model has accuracy and precision of 93.3, recall of 86.7, and F1 of 0.839, and has an AUC of 0.988. These findings indicate strong discrimination between poor and good sessions and imply that monitoring systems based on KPI can be effectively useful at hinting at the identities of those in danger of poor download quality.

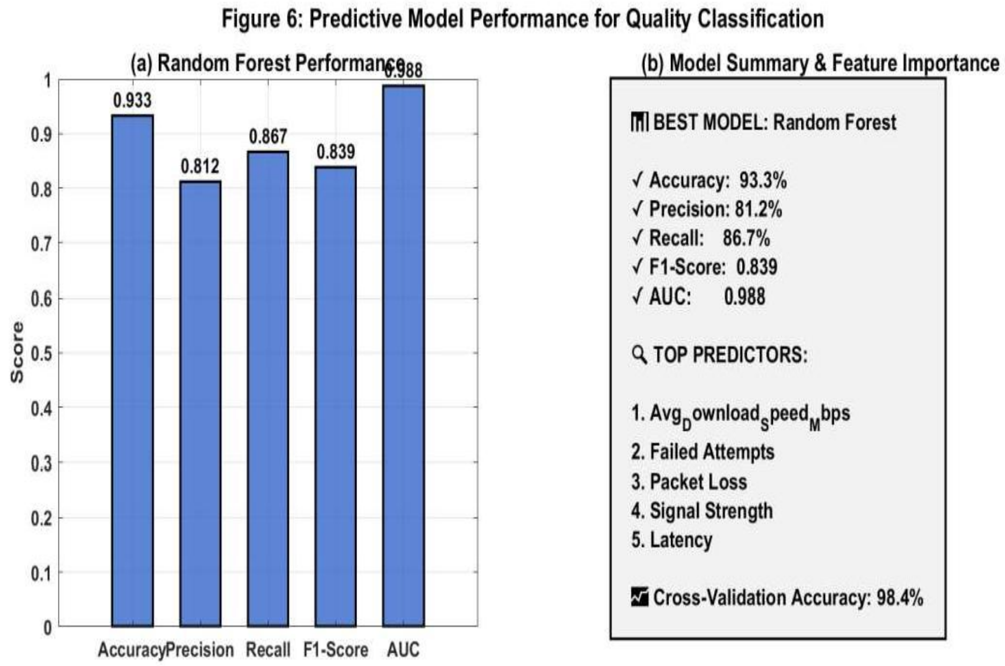


Figure 9 The performance of predictive models and feature significance (Random Forest classifier).

Metric	**Value**
Accuracy	93.3%
Precision	81.2%
Recall	86.7%
F1 Score	0.839
AUC	0.988
Cross-validation Accuracy	98.4%

Table 7. Random Forest predictive model performance.

The results of the feature importance as indicated in Figure 4.9 reveal that average download speed and download attempts failures are some of the best predictors and they are preceded by packet loss, signal strength and latency. This ranking is in line with the explanatory findings in the Section 4.5 and it gives converging evidence that the set of KPI can explain as well as predict quality outcomes. This implies two things as far as stakeholders are concerned. First, it establishes the fact that the tracking of speed is not enough, it is necessary to introduce reliability and indicators of impairments. Second, it offers operating intervention instructions: actions to minimize failures and loss and stabilize radio conditions can minimize the chance of bad sessions, even prior to the implementation of large capacity improvements. The large value of AUC shows that thresholds are to be adjusted to focus on either the times it will pick most poor session (larger recall) or reduced dependency on false-alarms (larger precision).

Chapter summary

As shown in this chapter, the proposed IDQS is also a good representation of the quality of internet downloading data that is meaningful and user-friendly. The descriptive results have a significant variance in throughput, delay, loss, and reliability between sessions, justifying the use of a composite score. Comparisons in terms of technology demonstrate that there is a substantial growth in gradient between 4G and 5G to FTTH with the greatest proportion of poor-quality sessions occurring on the 4G network. The hypothesis test is tested to conclude that reliability and throughput are the most influential factors of IDQS and latency, jitter, packet loss and signal strength are all the important and coherent factors. Feedback on validation indicates that there are high scores between objective IDQS and subjective user ratings, marking high construct validity. Predictive modelling shows that quality sessions can be accurately identified with the help of measured KPIs that are of poor quality. These findings are all summed up in the following chapter in conclusions, contributions, limitations and actionable recommendations on ways to improve all services and achieve fair quality management.

Integrated discussion: Connection of results with the theory and the meaning of operations

Theoretically the results in this chapter are consistent with the Three mechanisms have strong support in the theory perspective. First, throughput has continued to be a leading contributor to user experience as it is what defines the time to complete common downloads and perceived responsiveness. The positive relationship observed between throughput and IDQS and the presence of a strong positive relationship with the IDQS and the utilization of a technology gradient supports the fact that better perceived quality is expected to be the improvement in capacity. Second, reliability is demonstrated to be the most significant motivating factor to overall quality when the users are actually making downloads and not just synthetic speed tests. The extremely negative correlation between unsuccessful efforts and IDQS and big differences in means across classes of quality are evidence of a large-scale impact of a single failure experience in balance of moderate variations in speed. This is consistent with behavioral theories on user satisfaction, of which negative events are weighted more strongly than incremental gains in performance. Thirdly, latency and loss are structural limitations to effective throughput validating the transport-level dynamics in which higher delay and retransmission overhead leads to lower the realized delivery rate and higher the risk of session disruption.

A significant analytical contribution of the correlation matrix is the fact that a great number of impairments appear simultaneously. The correlation of Latency, jitter and packet loss is positive, which means a degraded state of the session is not defined by one specific isolated metric but rather represents a larger performance scenario that may be caused by congestion, buffer management, or radio instability. Such a co-occurrence is essential to both regression-style inference and machine learning models. In classical modelling terminology, the predictors are somewhat collinear and thus the effect sizes of individual coefficients could be unstable when all the correlated predictors are included at the same time. It is thus possible to note that the study focuses on the direction of effects, the magnitude of the effect, and triangulation of several methods (correlation, group comparisons, and tree-based modelling). Conventionally, such co-occurrence suggests that improvement interventions ought to be packaged. As an illustration, achieving a loss-free reduction of the delay caused by buffers can fail to completely restore user experience, since there are still to be retransmitted, and, conversely, an enhancement of radio coverage without congestion management would not wipe quality collapses during peak time.

The comparison of the technology gives practical meaning to the end-user quality issue. The high percentage of poor-quality sessions is comprised of 4G in the dataset. This does not mean that 4G cannot take a quality, but simply that the quality is going to be sensitive to the load, coverage and radio conditions that are not as

lenient with older radio resource management capabilities. The implications of the results suggest that customers using 4G have more exposure to quality volatility and thus quality outcome uncertainty during the download process because 5G has better capacity and schedule but FTTH has consistently good-quality experiences because of the stability of the physical medium. To service providers, these patterns can be used to support prioritization logic, so the hotspots that are already the poorest quality will be likely to be located in mobile networks that have weak signal (or are very congested) and those areas deserve coverage support, capacity increase or could be traffic-engineered.

The results of the validation show that IDQS can be used as a proxy of user experience in the evaluated situation. It would be possible to obtain a high correlation with only systematic bias present, thus, there is a significant need to conclude that construct validity by the near-zero difference in mean and by the high classification agreement. The other discrepancies between objective and subjective scores imply areas of improvements in form of adding application-level completion scores, device limitations, or relative importance of user tasks. Nevertheless, the state of the score, as of now, addresses the fundamental criterion of the requirement to be interpretable, reproducible, and highly consistent with the perception of users. Such a combination is useful in academic reporting since it proves that the artefact does not simply stem out of theory but also has empirical basis.

Lastly, the evidence of predictive modelling reveals that proactive monitoring of quality can be performed with the help of KPIs which can be easily measured. The AUC stated indicates high separability between bad and good session of which it can be stated that early-warning rules can be deployed. In response, IP could calculate a real-time risk score and activate network optimization responses, desired troubleshooting, or user-facing direction. The operationally significant feature ranking is also important as it can define those levers that can be manipulated by providers: throughput improvement with capacity and scheduling, reliability improvement with failure reduction and retransmission control, and radio stability improvement with coverage planning and interference management. These implications are transformed into recommendation and a roadmap that a stakeholder should follow in the following chapter.

Methodological strength and limits of interpretation

Although the analysis offers good evidence to support the proposed score and drivers, in the interpretation, it should be noted that there are strong limits of robustness which are inherent with field measures of a score. Firstly, the KPIs were grouped on the level of the session, hence spikes in loss or delay can be smoothed even in the short term although users can observe them in the most important moments of a download. This is among the reasons why some goal subjective contradictions come in the validation plots. Second, not only the access technology and network conditions determine the throughput but also the capacity of remote servers and the routes when the downloads are supplied by another content delivery network. It is a realistic usage, and the realistic usage is the fact that not all flips in the performance can be explained by the access network only. Third, the signal strengths of mobile devices are no longer measurements of the distance to the site plus indoor attenuation and interference, thus the results of signal related measurements can only be considered as an indication of radio quality and not as the actual engineering measures like SINR. Fourth, the correlations are only demonstrative of association, but not of definitive causation. Nonetheless, the directions of effects are in accordance with known mechanisms of transport and radio that makes the interpretations causally plausible. Lastly, the prediction models are tested on the sampled domain. When it is extended to new areas, operators or new population of devices, it could be necessary to re-train or recalibrate the model to maintain accuracy. The generalization of the results given by the study should be done by these boundaries and these limits simply outline the conditions where the results will be considered to be generalized and also give a clear ground up on which the results may be further extended in the future.

The evidence in Chapter 4 can be summarized as follows: the quality of end-user download could be reliably quantified based on a transparent composite score, and the score acted as hypothesized based on technology, impairment, and user perception. Results also indicate where improvement effort is to be focused: it is important to reduce first failures, and then to reduce loss and delay, and lastly increase sustainable throughput. Such prioritization indicates the huge performance differences between good and bad sessions and the prevalence of reliability in the ID.

CHAPTER 05: CONCLUSION AND RECOMMENDATION

Introduction

The chapter is a synthesis of the study findings and it gives conclusions, contributions and actionable advice based on the results of the empirical study provided in Chapter 4. This research paper strived to scope the internet downloading data quality through an end-user lens by creating and testing the Internet Data Quality Score (IDQS). The study with session-based measurements and MATLAB-driven analysis proved that download quality is multi-dimensional and that can be listed only by a transparent composite score which can take into account both performance and reliability. The structure of chapter 5 is as follows: the first section represents the summary of key findings in relation to each of the research objectives; then comes the identification of theoretical and practical contributions made by the study; the third section talks about the recommendations to network operators, regulators and end users; the fourth section outlines limitations; the fifth section discusses the directions toward the next work and concludes by the final statement.

Conclusion of the key findings by objective

The objective 1 was aimed at determining the fundamental quantifiable drivers of download quality. The findings indicate that throughput, reliability, latency, jitter, packet loss and signal conditions together influence the final result of downloading by end-users. One of these, reliability, which was measured by failed download attempts was seen as the strongest factor determining general quality. The high failure intensity sessions always yielded low IDQS values and low user rating even though the average speed in that sample was not lowest in the sample. This observation underscores the fact that when applied in the context of downloads, users tend to priorities successful completion and consistency, rather than peak speed. Throughput was also a significant quality motivator: an increased average download speed correlated positively with amplified IDQS and enhanced perception by the user. Nonetheless, throughput is not independent as it was controlled systematically by both latency and loss, as transport-layer efficiency and retransmission overhead decrease the realized delivery rate. Latency values were negatively correlated with both throughput and IDQS and packet loss and jitter were negatively correlated with IDQS and tended to co-exist with high latency suggesting that network states were degraded and not individual impairments. Signal strength and signal stability were also relevant especially with the sessions of mobile access wherein poor signal strength and signal instability were related with the presence of low-quality results. On the whole, Objective 1 is met as it shows that, most variation in end-user download quality can be attributed to a set of small, interpretable, KPI. The objective 2 was to build and test the framework of the IDQS as a user-friendly measure of downloading data quality. The study conceptualized IDQS as the average two component scores; a speed score (based on throughput thresholds) and a drop score (based on failure intensity). According to the descriptive analysis, IDQS generates a significant underpinning, on a session basis, and is able to differentiate good quality). The number of good and poor sessions were almost equal in the analyzed sample, four out of five, and only one out of five, respectively. Notably, score can be interpreted such that low values of IDQS denote the sessions of low throughput, high latency, high loss and high disruption; all high IDQS values are the sessions of high throughput and less disruption. This interpretability enables the applicability of the artefact in both academic and practical quality monitoring of the world, since the stakeholders will be able to trace variations among the score down to quantifiable network conditions. Going through with objective 2 therefore becomes possible through establishing that IDQS is a coherent composite measure that represents both performance and reliability aspects of downloading quality. Objective 3 tested the hypothesis that objective IDQS reflects subjective end-user perception. The validation analysis revealed a high agreement between IDQS and the ratings of the users. The measures based on correlation and agreement have shown that as the objective quality is increasing, the perceived quality is increasing at the same rate and the overall difference between the two measures is low compared with the rating scale of 1-5. The validation of the classification agreement too is in the right direction since the IDQS threshold rule is able to discriminate good versus poor user experiences with high precision, meaning that the score is not only statistically correlated to perception but also operationally useful in distinguishing between acceptable and unacceptable sessions. The other disagreements are informative, but not problematic. They suggest that the effect of short-term interruptions, the urgency of the task at hand, or the effect of the device and applications as not wholly reflected in aggregated KPIs can influence users. However, overall evidence of validation illustrates that the proposed score can be used in the proposed situation of downloading data quality measurement with great construct validity. The third objective is thus attained. The objective 4 evaluated whether data-driven models have the ability to foresee poor-quality sessions through measured KPIs which can be used to proactively manage quality. The results of predictive modelling indicate that based on the same set of KPI, which determines quality, low quality can be discovered with high discrimination. The most predictive indicators were average download speed, failed attempts, lost packets, signal strength and latency, as compared to the explanatory results. High classification performance means that a monitoring system is able to transform live KPI observations into a risk indicator of low downloading quality. Operationally, this capability helps in premutation and prioritization: network teams can find out where, when, or how network configurations are operating that can result in high risk and take action before things go wrong. Goal 4 is thus met by showing practicability of predictive classification of quality with practically accurate and understandable results.

Theoretical contributions and contributions theory

The research is useful in the academic debate on the measurement of internet quality based on users in three aspects. First, it gives a clear, open composite measurement of downloading data quality that is basing on quantifiable KPIs and simple to recreate. As opposed to conceptualizing quality as an abstract notion or using indicators available within the providers only, the study operationalizes quality at the user level of experience at the session. Second, the research empirically demonstrates that effects of reliability may prevail over user satisfaction, which supports one of the major concepts of Quek: users are very sensitive to failures and instability. This generalizes speed-centric improvement storylines by demonstrating that even without radical performance enhancements in peak throughput, achieving large quality improvements can be obtained by means of improving completion probability. Third, measurement, validation and prediction are addressed in the research as one coherent framework. The study provides a more comprehensive end to end strategy as opposed to most piecemeal quality analyses by proving that the same set of KPI is used to explain quality variation, consistent with the user perception and predictive detection. These additions enhance the research methodology that can be used in future studies of internet quality of service and user experience.

PRACTICAL RECOMMENDATIONS

In practical terms, the research provides effective advice to the network operators, regulators and end users. To the operators of the network, the outcomes mean that the drivers that have the most significant effect on user experience should have quality improvement as a priority. The first one is to decrease the number of unsuccessful downloads and enhance the reliability. Since the relationship with IDQS and operator ratings is the highest with failed attempts, operators ought to concentrate on the causes of frequent failure, including radio coverage, unstable handovers and retransmission storming in the face of interference, as well as capacity exhaustion in times of congestion. The interventions of coverage and stability are something that suits mobile users quite well. Targeted site densification, antenna optimization, indoor coverage solutions, and interference mitigation can be considered by the operators in weak-signal areas. In applications where the signal variability is high, abrupt quality collapses can be mitigated by enhancing the link adaptation stability as well as the ability to achieve scheduling robustness. The second priority would involve a reduction in the packet loss and latency. Understandably, loss and delay not only are directly related to lower IDQS, but they limit throughput by being a source of transport inefficiency. The operators are thus advised to keep track of congestion indicators, buffer controls and backhaul limits especially at peak time. Capacity upgrade and better utilization of queues within congested segments as well as traffic engineering can alleviate loss and delay at the same time. The third consideration is that one needs to increase sustainable throughput. The findings indicate that increased quality is related to increased throughput, although the enhancement of throughput should be done in a manner that does not affect stability as well. The speed of the peaks may be increased without the problem of reliability, then the users can be left vulnerable to disruptive failures that can take over. The IDQS framework can be implemented through the use of a monitoring dashboard by operators to decode raw KPIs and converting them into a quality score that can be understood. Mapping quality by session and aggregating by geography, time and technology allows the operators to identify the hotspots, prioritize investments and report improvements using a metric that is aimed at harmonizing with user perception. This dashboard can be combined with predictive models that identify high-risk sessions or territories with low quality and run high-risk predictive optimization and troubleshooting. The findings are relevant to regulators and other stakeholders in policy development as the standardized end-user quality measurement is valuable. Regulators may motivate or insist on operators publishing quality (not only as average throughput) but also reliability and stability measures which are indicative of actual user experience. The introduction of a composite measure analogous to IDQS will enhance the openness of the service-level discourse as well as evidence-led complaint resolution, focused audit and consumer protection procedures. Due to the fact that the IDQS framework is intelligible and scalable against user ratings, it can be conveyed to non-technical users, and it still has an analytical meaning. Regulators can also promote benchmarking amongst multi operators on similar measurement protocols so that announced performance accuracy is true to real-world end user conditions but not to ideal laboratory tests. Lastly, the policy efforts aimed at increasing access to quality fixed access, such as fiber deployment, can decrease the risk of a low quality of experiences, as indicated by a higher quality score constant across the FTTH sessions. To the end users, the findings indicate a number of viable sites that can enhance the experiences in downloading. Users must realize that reliability and signal stability can be equally important as headline speed. Moving to a better signal location with higher strength and more stable signal, attenuation reduction by using the indoor location, and a less congested time window are all potential ways of improving the quality in mobile environments. When offered, fixed access like FTTH is probably going to be more reliable in downloading. Simplified quality indicators, including IDQS-style scoring can also be used by the users in order to monitor the presence of problems that are persistent or situation-specific and express more clearly the problems to the service providers. Users also need to know that the operator cannot influence certain aspects of its system, including the capacity of remote servers; hence, a more valid measurement of the quality of the services can be done by having measurements of various sources and time scales. In communication perspective, IDQS offers an operational language to debate on quality. Instead of depending on individual speeches test results, it provides the summary of having a smooth result of downloads in real-life situations. This will facilitate more effective discussions between the customers and the providers and will enable technical teams to focus on hotspots where the impact of their users is most significant. It is clear and can be reproduced in future researches.

LIMITATIONS

The research has weaknesses which must be taken into account when the results are interpreted. To begin with, the data are session-aggregated, thus short-term spikes in delay, loss or interruptions can be smoothed, despite its ability to affect user perception. Second, remote server capacity and routing paths can affect throughput measurements so that not all of the performance variation that is observed may be due to the access network only. Third, the dataset represents the measured context, i.e., the set of particular users, hardware and place; care must be taken to generalize to other regions or operators. Fourth, signal strength is a convenient device-level parameter, but not the complete measure of radio quality parameters like SINR, hence signal-related measurements are to be understood as signals of coverage and stability, but not as accurate engineering parameters. Lastly, performance evaluation of the predictive models was done in the same measure field. When used in new conditions, the model might need to be re-trained and calibrated to maintain the accuracy. In spite of these constraints, the stability of findings based on descriptive, inferential, validation and predictive analyses are beneficial in terms of its confidence in the essence of the conclusions.

FUTURE WORK

The study can be enhanced and expanded in a variety of ways in the future. To enhance the generalizability, it would be better to spread the dataset on different geographical areas, operators, and devices first, which would make benchmarking more detailed. Second, it could be considered adding more contextual variables that can explain the self-perception better, namely, cell identity, distance to site, and congestion indicators. Third, the

IDQS framework can be improved to cover upload quality and applications sensitive to latency instead of downloading to have a more comprehensive dashboard of service quality. Fourth, future research can empirically test the alternative scoring weights or non-linear fusion method to show whether reliability can be weighted heavily depending on the speed or speed of user task profile under some profile. Lastly, operational deployment research may combine real time measurements with automated alerts and optimization processes and assess the effectiveness of predictive models in live network maintenance and the effect of IDQS-driven reporting with customer satisfaction and complaint resolution.

FINAL CONCLUSION

To sum up, the paper has demonstrated the effectiveness of using transparent composite score to measure surety and trustworthiness of end-user internet downloading data. IDQS is predictable across technologies of access, is very much aligned with user perception, and can be used to predict poor-quality sessions through the help of quantifiable KPIs. There is evidence that the best improvement plan is to eliminate losses at the first stage, then cutbacks in failures and instability and lastly the system is required to enhance sustainable throughput. Together the results give empirically-based model potentially useful in university studies as well as in practice as an instrument of service quality management.

DECLARATION

Dr.Migara Karunarathneand a report on this has not been submitted in whole or in part to any

Student Name: Thangavel Mathanaruban Registration Number: ECE-23-02-0033

28/02/2026

Date

Certification of the supervisor

I certify that the above statement made by the candidate is true and that this thesis is suitable for

Certified by:

Supervisor Name: Dr. Migara Karunarathne

Signature: Date:

Supervisor Name:

Signature: Date:

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