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REVIEW ARTICLE

Analysis and evaluation of the effectiveness of methods for ensuring the quality of service for software-defined networks of the standard 5G/IMT-2020

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Abstract. The quality of service (QoS) in networking is the process of managing network resources to reduce packet loss and to lower network jitter and latency. QoS has been widely used in traditional network and can also be implemented in the 5G standard based on a software-defined network (SDN). A traditional network carries several challenges, such as vendor dependency, the complexity of managing a large network, dynamically changing forwarding policies, and more. Software-defined networking is a new networking strategy designed to address the challenges of a traditional IP network, such as high levels of complexity and inability to adapt to the new quality of service requirements in a timely manner. The fundamental idea behind SDNs compared to the conventional networking paradigm is the creation of horizontally integrated systems through the separation of the control and the data plane while providing an increasingly sophisticated set of abstractions. Recently, various SDN-enabled QoS frameworks have emerged that offer many possibilities for network reconfiguration and high-level definition of policies. QoS requirements for 5G networks have been defined on the basis of three main categories of use cases: extreme mobile broadband (xMBB), massive machine type communications (mMTC) IoT/M2M devices, and highly reliable M2M-communication (ultra-reliable machine-type communications – uMTC). This paper analyzes and surveys the QoS based on the openflow protocol method and QoS based on open-source SDN controllers method in 5G network. In addition, we discuss various architectural issues of open-source SDN controllers network and examine their impact on the QoS. Furthermore, we outline the characteristics of the QoS parameters such as latency, availability, reliability, jitter, and bandwidth in the 5G network. Finally, the article discusses and compares parameters of the QoS in 5G determined by world's leaders in 5G technology.

Keywords: Software-Defined Network, SDN, Quality of Service, 5G/IMT-2020

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ОБЗОР

Анализ и оценка эффективности методов обеспечения качества обслуживания программно-конфигурируемых сетей стандарта 5G/IMT-2020

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Резюме. Качество обслуживания в сети (QoS) – это процесс управления сетевыми ресурсами для уменьшения потери пакетов, а также уменьшения джиттера и задержки. QoS широко используется в традиционных сетях, а также может быть реализован в стандарте 5G на основе программно-конфигурируемой сети (SDN). Традиционная сеть несет в себе несколько проблем, таких как зависимость от поставщика, сложность управления большой сетью, динамически меняющиеся политики пересылки и многое другое. Программно-конфигурируемая сеть – это новая стратегия, разработанная для решения таких проблем традиционной IP-сети, как высокий уровень сложности и неспособность своевременно адаптироваться к новым требованиям к качеству обслуживания. Фундаментальная идея, лежащая в основе SDN, по сравнению с традиционной сетевой парадигмой, заключается в создании горизонтально интегрированных систем путем разделения уровня управления и данных при обеспечении все более сложного набора абстракций. В последнее время появились различные инфраструктуры QoS с поддержкой SDN, которые предлагают множество возможностей для реконфигурации сети и определения политик на высоком уровне. Требования QoS для сетей 5G были определены на основе трех основных категорий сценариев использования: Extreme Mobile BroadBand (xMBB), Massive Machine Type Communications (mMTC) IoT/M2M-устройства и высоконадежная M2M-связь (сверхнадежная связь машинного типа – uMTC). В статье анализируется и исследуется QoS на основе метода протокола OpenFlow и QoS на основе метода контроллеров с открытым исходным кодом SDN в сети 5G. Обсуждаются различные архитектурные проблемы сети SDN контроллеров с открытым исходным кодом и исследуется их влияние на QoS. Описываются характеристики QoS, такие как задержка, доступность, надежность, джиттер и пропускная способность. Обсуждаются и сравниваются параметры QoS в сети 5G, которые определены мировыми лидерами в данной технологии.

Ключевые слова: программно-конфигурируемая сеть, SDN, качество обслуживания, 5G/IMT-2020

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INTRODUCTION

The global impact of 4G technology has led to increased use of mobile communications and improved network performance. The implementation of 5G technology will enable to make this momentum greater, offering significant improvements in network performance, including faster connectivity, mobility and bandwidth, and communication with low-delay connectivity. Thus, it opens up new use cases and provides promising applications that can positively influence the development of various industries. The 5G networks can create an ecosystem for technical and business innovation, including vertical markets such as automotive, healthcare, manufacturing, energy, food and agriculture, city management, government, public transportation, media, and more. They offer unlimited mobile broadband access, provide extensive connectivity for everything from human-controlled intelligent devices to sensors and machines, and most importantly, have the ability to support critical machine communications with instant action and ultra-high reliability [1].

The 5G technology for mobile communication first appeared in South Korea in 2020 followed by China, the USA, and the European Union. It is expected that by 2025 there will millions 5G connections. The 5th generation internet will be 5 times faster (with 25 times lesser delay) than the current 4th generation system, and will support up to one million devices per square kilometre. Generally speaking, the basis of 5G Internet relies on the following five technologies: millimetres radio-waves, small cellular networks, MIMO (several inputs and outputs), beam formation, and double-sided bytes. A traditional network bears several problems, such as a dependence on providers, complexity in managing a large network, dynamically changing forwarding policies, and much more. What is more important is that a traditional IP-network is not able timely respond to changes and newly emerged QoS requirements. Such failures are caused mainly by the features of traditional IP-networks, in which a control plane and data plane are vertically connected with each other and implemented in the network devices. To overcome the problems of the existing network, a concept of a programmable network has emerged [2, 3].

Its behaviour is controlled by software called Software Defined Networking (SDN). This network, as distinguished from traditional networks, represents a dynamically developing infrastructure, which controls data plane and control plane in a separate way. Based on Open Networking Foundation (ONF) [4] SDN has three levels, namely: the infrastructure level, control level, and application level [5]. SDN architecture is shown in Fig. 1 and is explained below [4].

- **Infrastructure layer** consists mainly of the transfer elements (for example, physical and virtual switches, routers, and points of wireless access), which represent a data plane.
- **Control layer,** also known as control plane (it is the core of SDN architecture), supports communication between the application level and infrastructure level through open interfaces.
- **Application layer** is mainly developed to meet users'. It consists of business-applications of end-users which use network services.

OpenFlow protocol, supported by ONF, is a fundamental element for developing SDN decisions. OpenFlow is the first of the leading communication interfaces, linking forwarding level and control levels in SDN architecture, enables to control both physically and virtually the forwarding level of network devices (for example, switches and routers). It helps SDN architecture to adapt to a high bandwidth capability, dynamic characters of users' applications, and adjust a network in accordance with different business requirements, and, what is interesting, reduce complexity of management and service.

Many factors affect QoS-based SDN in 5G networks, therefore we will further discuss the QoS parameters, which are defined by the 5G technology world leaders in terms of applicability to such networks. We will present the levels of the high-quality service in the context of the following characteristics: speed

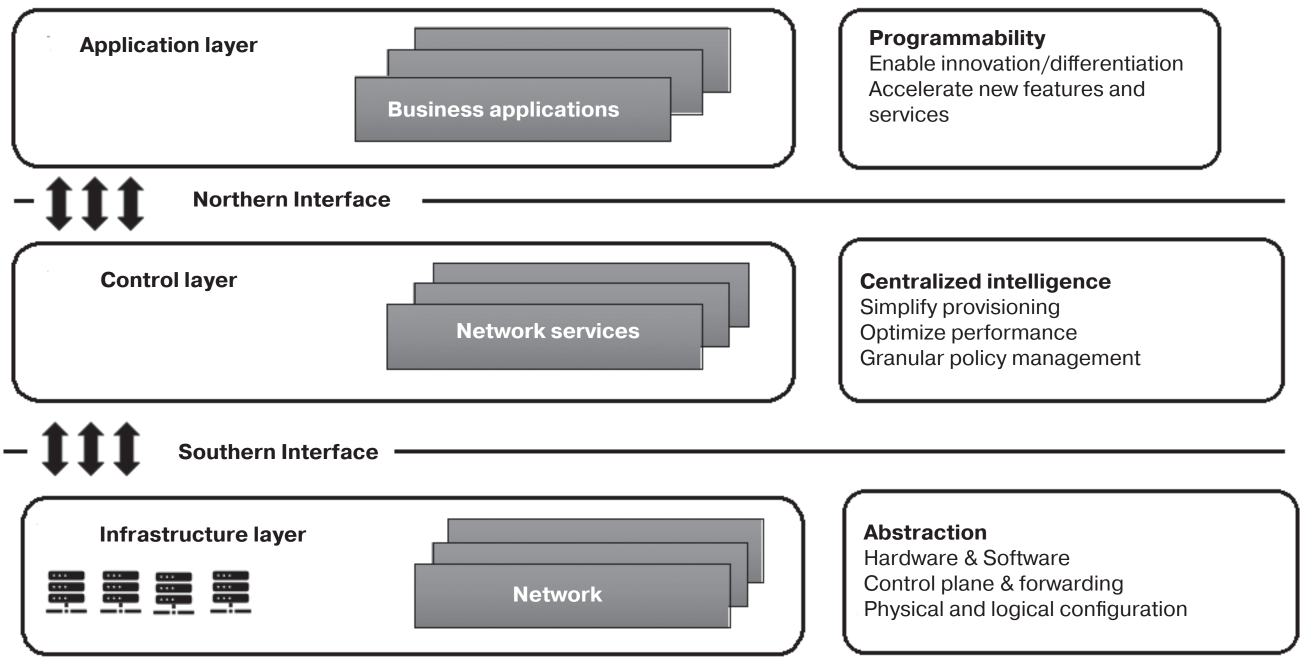

Fig. 1. SDN levels and functions

increase, mobile networks capacity, and growth of wireless devices.

In Section 1, a brief overview of OpenFlow architecture is given followed by two QoS methods based on the OpenFlow protocol and a controller with an open SDN source code. In Section 2, architectural problems in SDN and their influence on QoS are discussed. In Section 3, **Key Performance Indicators (KPI)**, QoS parameters and their influence in the 5G network are given. In Section 4, the QoS parameters for the next generation 5G are analysed and presented in a table.

1. QOS IN OPENFLOW PROTOCOL AND SDN CONTROLLERS WITH OPEN SOURCE CODE

A. OpenFlow architecture and QoS-based OpenFlow protocol

OpenFlow architecture [6] is the proposal of Clean State initiative for the definition of the open protocol, which sets routing tables in switches; it is the base of SDN architecture in which a user can change the network.

Actually, the OpenFlow (infrastructure level) protocol is a communication interface between controllers and OpenFlow routing planes [7]. It is the first standard communication protocol for SDN media. OpenFlow represents a routing path for the flow of transferring packets along programmable networks. A key advantage of this protocol is that it enables to adjust switches of different manufacturers with the help of controllers. Different versions of OpenFlow are available in SDM media.

OpenFlow architecture offers several advantages:

1) OpenFlow centralized controllers can manage all flow decisions thereby reducing complexity of the switches;
2) central controller can “see” all networks and flows providing global and optimal management of network initialization;
3) OpenFlow switches are relatively simple and reliable since direct decisions are determined by a controller but not a micro-program of the controller.

However, OpenFlow unites two characteristics—a unique controller and simple devices—that leads to scalability problems.

In SDN network with switches and the OpenFlow support, a switch consists of three main parts. The components of the OpenFlow architecture are shown in Fig. 2:

- *Data tables* with an action, related to each record of the flow in order to report the switch how to process the flow.
- *Protected channel,* which links switches with the process of remote control (called the controller), enabling to forward commands and packets between the controller and switches.

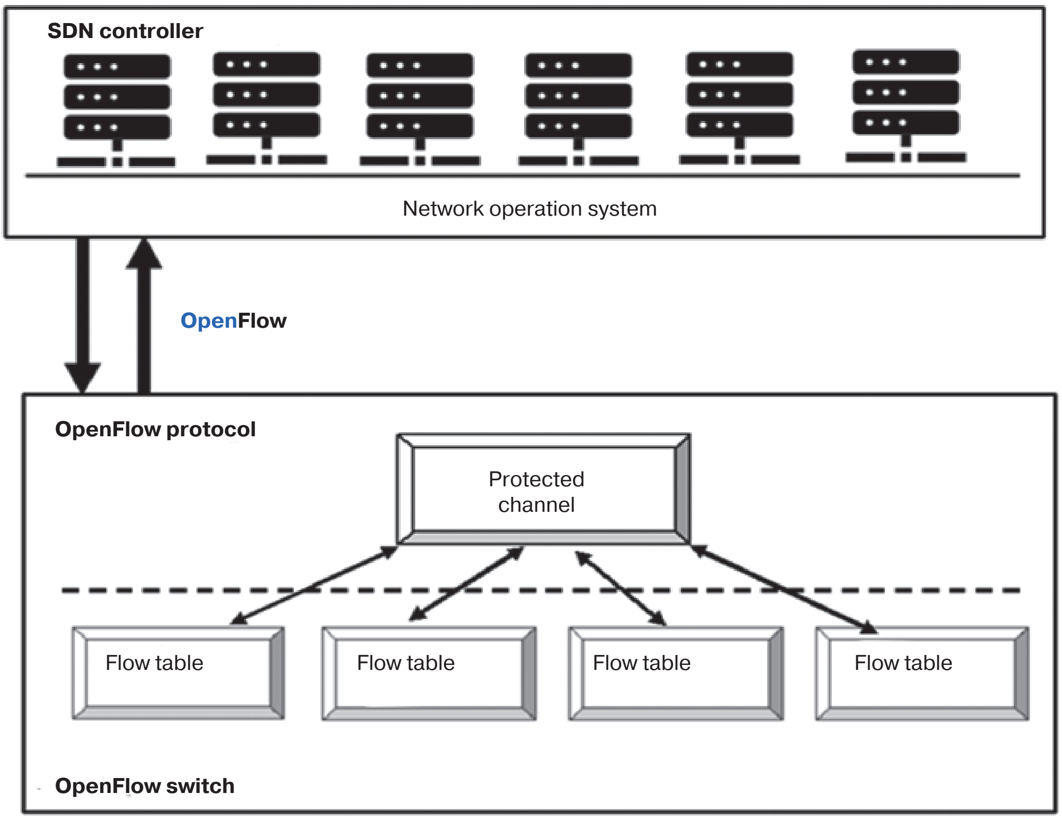

Fig. 2. OpenFlow architecture [8]

- *OpenFlow protocol*, which provides an open and standard method of communication between the controller and switches.

Using OpenFlow protocol, the OpenFlow switch becomes a simple element of the data pathway, which switches packets between ports in a way as defined by the process of remote control.

As the number of OpenFlow switches increases, the use of a single controller for the whole network may become impossible due to several reasons:

1) the number of controlling messages sent to a centralized controller increases with the number of switches;
2) as the network diameter increases some switches will have longer latency for actuation regardless of the controller location [6];
3) the tuning time can increase significantly as the number of switches and the size of the network increase;
4) as the system is limited by the power of the controller's processor, the tuning time may significantly increase with the increase of the number of switches and the network size.

In SDN network for setting a new flow rule, a controller can operate in three modes: Reactive mode, Proactive mode and Hybrid mode [9].

Reactive mode. In the reactive regime, when a new packet arrives to a network device (for example, a switch), the switch executes in its flow tables a search for the flow rule. If no coincidence with a flow is found, the switch (using C-DPI) forwards it to the controller so that the controller decides how to process the packet. After the controller has processed the packet according to the network policies, it creates and forwards the flow record for setting on the network device. Future flows corresponding to this record based on the attribute of the title of the packet will be processed in accordance with the matching rule.

Proactive mode. In the proactive mode, the flows recordings are tuned in switches flows tables before new flows arrive to switches. When a packet arrives to the switch, the latter already "knows" how to process this packet. In this case the switch does not participate in any process of the flow rules tuning.

Hybrid mode. In the hybrid mode, the controller makes use of advantages of both reactive and proactive modes. It is quite possible that network administrators set in advance certain flow records in the devices of data planes, while the switch(s) reactively change (remove/renew) them or even add new flow records based on incoming traffic.

While the proactive mode calls for some worries about invective usage of the switch memory, the reactive mode provides more flexible and dynamic medium for controllers and switches.

B. QoS on the basis of SDN controller with open initial code

The controller throughput is the main issue of OpenFlow architecture. A controller can support a limited number of flow adjustments per second. Software-defined networks employ two types of controllers: centralized and distributed. Classification of different controllers divided into two categories is described in Table 1 [10, 11].

Table 1. Classification of SDN controllers

Types of controllers			
Centralized		**Distributed**	
Centralized controllers implement all of the control plane logic in one place. In such a controller, a single server takes over all actions at the control level. The main advantage of such controllers is the simplicity and manageability since they provide the only one control point. However, their drawback is the scalability problem as each server has limited capacity for the operation with data plane devices. The QoS support in the SDN network became possible due to the component of the centralized logic SDN controller.		The distributed controller has no scalability issues and has the advantage of high performance under heavy traffic loads.	
Controllers	Programming Language	Controllers	Programming Language
NOX	Python	ONOS	Java
POX	Python	Runos	C++
RYU	Python	Hyperflow	C++
Beacon	Java	Onix	C, Python
Maestro	Java	SMaRtLight	Java
FloodLight	Java	OpenMUL	C
OpenDaylight	Java		
Meridian	Java		

In controllers with the open source code the parameters of the service quality include the following ones: reliability, scalability, sequence, and load balance.

2. ARCHITECTURE PROBLEMS IN SDN AND THEIR INFLUENCE ON THE QOS

2.1. Centralized administration

In the SDN medium a switch is separated by controllers and a dump switch. Moreover, all controllers and switches are active for the large network. The design of controllers and their locations remain the subject of research with the aim to improve the network throughput. Other factors—such as flexibility, scalability, delay, safety, and compatibility—are also important for increasing the network throughput [7, 12, 13].

In large-scale SDN networks several controllers are deployed to balance the traffic load and achieve high quality of service [14]. As the number of controllers grows, the concept of centralized management changes. Different controllers can have different functions; therefore, their central administration becomes more difficult [13].

2.2. Network scalability

Due to the presence of several program controllers it can be easily scaled up. However QoS can doubt the scalability because of the load balancing between controllers [13, 14].

2.3. Inconsistency among the controllers

Because there are several controllers in the network, the main problem is the synchronization of information about the state of the network in SDN. This problem is known as the consensus problem [13]. Due to a complex realization and growing delay the consensus approaches do not job. When designing several controllers, it is important to provide matching between them.

2.4. Controller placement

Implementation of only one controller in a software-defined network has many advantages, such as centralized management, checking and monitoring the whole network with the help of only one node. But at the same time such an approach brings the problems of reliability and scalability [13]. As the network grows, these problems worsen throughput. The problem of placing controllers has been known since 2012. In order to reduce the delay of service data and increase total throughput, it is necessary to place in the network an optimal number of controllers at a proper distance [15]. In large-scale networks when deploying the controllers two important issues are being considered: how many controllers are required in the networks, and where should these controllers be placed. Although these are undetermined polynomial-complex problems, they have to be solved for deployment of several controllers [13].

2.5. Controller communication protocol

In a distributed network it is necessary to have several controllers; they directly affect QoS of the SDN network. Therefore, an efficient data interchange between controllers is required. For communication between controllers an interface "eastbound-westbound" is needed, therefore in an SDN network a standard protocol must be developed for such communication. Currently, the global network supports Border Gateway Protocol (BGP) for "eastbound-westbound" interfaces [12].

2.6. Planning deployment of several controllers

QoS can be better at the expense of employing several controllers, but it is necessary to plan ahead the load of various controllers in order to avoid their overload. In this case, the main problem is how to balance the load fast.

3. THE ANALYSIS OF QOS IN DIFFERENT SDN CONTROLLERS

There exist lots of free as well as commercially available SDN controllers. A range of functions of the controllers are suitable for different applications. Descriptions of three SDN controllers are given in Table 2 as examples.

In addition to QoS in controllers, the QoS index is influenced by programming parameters, including QoS in the OpenFlow protocol. Each new version of the OpenFlow specification contains some features with minor and significant changes compared to the previous ones, so QoS varies from version to version.

4. FROM KPI TO QOS IN THE 5G/IMT-2020 NETWORK

The fifth generation network (5G/IMT-2020) is the latest iteration of cellular technology designed to dramatically increase the speed and responsivity of wireless networks. According to [19], the technological goals of 5G are the following indicators: 1000 times more mobile traffic, 10 to 100 times higher transmission speed for users, 10 to 100 times more users, 10 times longer battery life in M2M mass communications, 5x reduction of E2E (end-to-end) delay.

Table 2. Examples of SDN controllers

Controllers	Analyzation and Description of Controllers
OpenDaylight	OpenDaylight (ODL) is a modular open platform for customizing and automating networks of any size and scale. The OpenDaylight Project arose out of the SDN movement, with a clear focus on network programmability. The ODL project includes support for all SDN platforms, including OpenFlow, Open VSwitch (OVS) Database (OVSDB), NETCONF, SNMP, BGP and applications (e.g., DDoS Protection and Virtualization Coordinator), which complement each other to compose a complete reference controller platform for heterogeneous networks. The OpenDaylight Controller exposes open northbound APIs, which are used by applications. These applications use the controller to collect information about the network, run algorithms to conduct analytics, and then use the OpenDaylight Controller to create new rules throughout the network. Packet Cable MultiMedia (PCMM), presented in ODL-Lithium, provides an interface to control and management service flow for CMTS network elements. A service flows constitute a DOCSIS data path between a CMTS and a subscriber's cable modem (CM) guaranteed application specific quality of service (QoS), known as Dynamic Quality of Service (DQoS). PCMM offers (MSOs) the ability to deliver new services using existing cable infrastructure. OVSDB is another southbound protocol for managing and configuring queues in switches and virtual switches. Here is another add-on to the ODL reservation module that aims to provide low-level resource reservations that provide users with network connectivity, bandwidth, and ports for a specific allotted time [2, 9, 16].
ONOS	The open network operating system (ONOS) controller is an operating system (OS) that is designed to help network service providers build carrier-grade SDNs architected for high scalability, availability, and performance. Among the service providers contributing to the ONOS initiative are AT&T, NTT Communications, and SK Telecom. Vendors contributing to ONOS include Cisco, Ericsson, Intel, NEC, Ciena, and Huawei. Likewise, ON.Lab and ONOS partners have found multiple use cases for the OS. ONOS supports the OpenFlow mechanism, and accordingly, the existing switches rarely implement ONOS. Thus, the ONOS platform provides limited QoSs because this implementation supports the functionality of the OpenFlow set_queue. To improve QoS, ONOS libraries have implemented the Set Queue Instruction function, namely, top-level instruction [2, 9, 17].
Floodlight	Floodlight Controller (Java-based) is an SDN controller developed by an open community of developers, many of which from Big Switch Networks are used with the OpenFlow protocol to orchestrate traffic flows in an SDN environment. The Floodlight controller implements a QoS module that provides functionality such as stream deletion, stream insertion, and some policies for handling QoS. These modules are implemented in OpenFlow, version 1.0. The QoS is at its infancy when it comes to OpenFlow. The OpenFlow 1.0 provides a user with a way to simply push the QoS state to switches that support these features. These modules seek to tackle "enqueue" and "SET-NW-ToS" actions. The static flow pusher API calls this "set-ToS-bits." spec includes ways in which one can set the network type of service on a flow, as well as enqueue the packets matching the flow to a specific queue on a specific port. In the Floodlight Northbound interface, module QueuePusher generates the messages for queue configurations for creating, reading, updating, and deleting functions to manage the Open vSwitches [18].

The 5G concept consists of three general services:

1. **eMBB (Enhanced Mobile Broadband).** This requires large capacity, high speed, and dynamic bandwidth allocation. While high speed helps to upload and download video content faster in gigabyte sizes, the bandwidth can be provisioned on demand for ultra high definition (UHD) video, virtual reality, augmented reality, and more.
2. **uRLLC (Ultra Reliable Low Latency Communication).** These services require high reliability, high availability, and low latency. High reliability supports critically important services such as connected robotic factories and remote surgery, while low latency makes services such as autonomous vehicles and remotely controlled drones a reality.
3. **mMTC (machine type mass communication).** This class of service is characterized by high throughput, high speed and dynamic bandwidth allocation and is best suited for Internet of Things (IoT) services such as smart cities serving billions of "things" and "devices" with densities of up to one million per square kilometre [27].

These three generic services should be seen as baseline characteristics covering 5G user scenarios. Key performance indicators (KPIs/KPIs), which, from the point of view of the end user, are used as a basis for assessing the effectiveness of specific scenarios are shown in Table 3.

Most of today's popular applications and applications scenarios will continue within frames of 5G, with KPIs/KPIs and QoS further applying.

Key performance indicators for 5G technology are shown in Fig. 3 [20]:

Table 3. 5G performance characteristics required for each ITU[1] use scenario

eMBB	uRLLC	mMTC
Peak data transfer rate: from 10 to 20 Gbit/s; minimum data transfer rate: 100 Mbit/s	Provides hypersensitive connections	Supports high device density (10^6 per km^2)
Increases traffic capacity/throughput by 100 times	Provides less than 1 ms air interface latency	Supports long rang and low data rate (1–100 Kbit/s)
Supports macro and small cells	Ultra-reliable and affordable with five nines (99.999% of the time)	Takes advantage of ultra-low cost M2M
Supports high mobility of about 500 km/h	Provides data transfer rates from low to medium (50 Kbit/s–10 Mbit/s)	Provides battery life up to 10 years for IoT
Improves network energy savings by 100 times	Provides high speed mobility	Provides asynchronous access

[1] International Telecommunication Union.

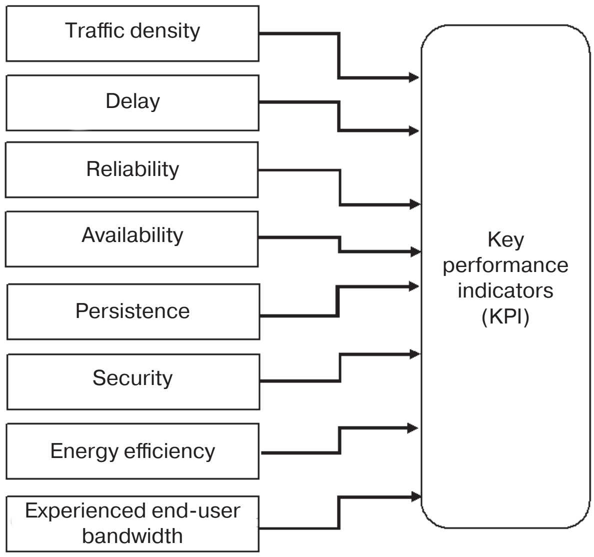

Fig. 3. KIE/KPI for 5G/IMT-2020 technology

New technologies, referred to in this article as 5G Key Technology Enablers (KTEs), play a major role in providing QoS in 5G, and SDN alone is not enough for that. To achieve ambitious QoS values, it is necessary to influence all KTEs listed below:

1. Spectrum and massive MIMO (multi-channel input–multi-channel output).
2. Network function virtualization (NFV).
3. Centralized radio access network (C-RAN).
4. Local offloading.
5. Small cells.
6. Software defined networking (SDN).

Figure 4 illustrates the factors that each concept relies on and which QoS requirements contribute to.

Each of the KTE tools creates a new concept in 5G that directly impacts KPEs/KPIs and therefore impacts 5G QoS. New concepts include:

1. Service chaining.
2. New architecture.
3. New air interfaces.
4. Slicing network.
5. Function allocation and placement.
6. Flexible control.

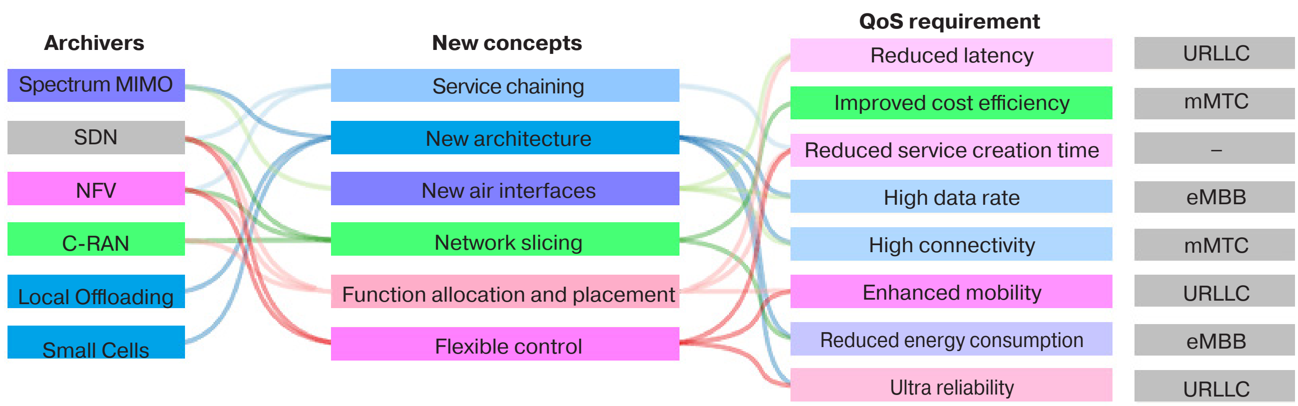

Fig. 4. New concepts, means of implementation and requirements for QoS of the fifth generation (5G)

5. QOS FOR THE NEXT GENERATION OF 5G NETWORKS

The 5G technology should significantly improve service quality in terms of network data volume and service types. There is a huge worldwide effort to define a new 5G architecture with initiatives such as 5G infrastructure public-private partnership (5G-PPP) and the METIS project in Europe [21]; IMT-2020 (5G) in Russia [22]; 5G America in America [23]; IMT-2020 (5G) PG3 in China [24]; The 5G Forum in Korea [25, 26], and the Fifth Generation Mobile Promotion Forum (5GMF) in Japan [26]. The promised values for 5G QoS parameters are shown in Table 4 [28].

Table 4. Promised values for 5G QoS parameters

Speed/throughput	10 Gbit/s, target to 20 GB/s
End-to-end latency	1–10 ms
Network availability	Stretched to 100%
Reliability	Block Error Rate is 0.00001 in an 1-ms period
Jitter	10–100 µs
Bandwidth	100 Kbit/s to several hundred Mbit/s

Table 5 shows the QoS parameters for the basic driving principles of 5G technology.

Within the framework of the METIS project, 12 scenarios for the use of 5G networks have been identified [19]. In the Virtual Reality Office use scenario test, end users should be able to achieve at least 5 GB/s data rates in 20% of office spaces, such as real desks during 99% of busy hours. In all of the above initiatives, the latency between devices (D2D) is less than 5ms. Highest 5G availability and reliability requirements are 100% and 99.999%, respectively, for all initiatives.

Energy consumption, as it can be seen from the table, is an important parameter in 5G technology. This parameter is 10 to 100 times better than that in the previous generation of networks. Another parameter that affects the quality of service is the ratio of packets lost due to errors when receiving data packets IP—Packet Error Loss Rate (PELR). The packet loss rate requirement for video broadcasting in 5G networks is 10^{-9}. For M2M services, the quality will also be determined by the fraction of packets lost during reception. The PELR requirement for M2M service with guaranteed quality of service in 5G networks is 10^{-7}. Another important parameter that determines the QoS requirements in a fifth generation network is the overall packet delay budget (PDB), which is generated at the radio-interface RAN and is considered as the maximum packet delay with a control level of 98%.

CONCLUSIONS

The emergence and implementation of 5G technology is based on remarkably improved key indicators in mobile networks, including end-to-end QoS. A software-configured SDN is an attractive research area for network communications and is also an integral part of the 5G network. SDN promises to provide a powerful way to implement end-to-end quality of service QoS in today's communications networks.

In the 5G technology, customer satisfaction poses many new challenges for the operator. Reliability and scalability are key QoS issues in a programmable network. The article analyzes the QoS method based on the OpenFlow protocol and the QoS method based on open source SDN controllers in the network. The problems of SDN-based architecture and their influence on the parameters of QoS are studied, and key indicators of performance in 5G/IMT-2020 networks are overviewed. In addition, other parameters are analysed for improving QoS in the next generation network: bandwidth, latency, jitter, and losses.

Table 5. QoS parameters for the basic driving principles of 5G technology

QoS	5G-PPP/ METIS	5G Americas	IMT-2020 (5G) PG	5G Forum
Experienced user throughput[1]	Depend on use case test[2]	Depend on use case test	Depend on use case test	Depend on use case test
Latency	5 ms (E2E)	5–100x better	1 ms (E2E)	1 ms (E2E)
Availability	≈100%	≈100%	≈100%	≈100%
Energy consumption	10x better	–	100x better	1000x better
Reliability	five nines 99.999%	high	five nines 99.999%	hyperhigh

[1] Achievable data rate is available ubiquitously across the coverage area to a device/user

[2] Virtual reality office, dense urban areas, shopping malls, and stadiums should provide 5 Gbit/s in downlink and uplink channels.

REFERENCES

1. View on 5G Architecture – 5G-PPP. Version 3.0. Available from URL: https://5g-ppp.eu/wp-content/uploads/2019/07/5G-PPP-5G-Architecture-White-Paper_v3.0_PublicConsultation.pdf
2. Keshari S.K., Kansal V., Kumar S. A systematic review of quality of services (QoS) in software defined networking (SDN). *Wireless Personal Communications*. 2021;116(3):2593−2614. https://doi.org/10.1007/s11277-020-07812-2
3. Moravejosharieh A.H., Lloret J. Performance analysis of quality of service in software-defined networking. *Network Protocols and Algorithms*. 2019;10(4):1. https://doi.org/10.5296/npa.v10i4.14054
4. Nam Tuan Le, Arif Hossain M., Islam A., Do-yun Kim, Young-June Choi, Yeong Min Jang. Survey of promising technologies for 5G networks. *Mobile Information Systems*. 2016; Article ID 2676589. https://doi.org/10.1155/2016/2676589
5. OpenFlow. OpenFlow Switch Specification. Version 1.5.0. 2014. Available from URL: https://opennetworking.org/wp-content/uploads/2014/10/openflow-switch-v1.5.0.pdf
6. Fernandez M.P. Comparing openflow controller paradigms scalability: reactive and proactive. In: *Proc. IEEE 27th International Conference on Advanced Information Networking and Applications* (*AINA*). 2013, p. 1009−1016. https://doi.org/10.1109/AINA.2013.113
7. Masoudi R., Ghaffari A. Software defined networks: A survey. *Journal of Network and Computer Applications*. 2016;67:1−25. https://doi.org/10.1016/j.jnca.2016.03.016
8. McKeown N., Anderson T., Balakrishnan H., Parulkar G., Peterson L., Rexford J., Shenker S., Turner J. OpenFlow: Enabling innovation in campus networks. *ACM SIGCOMM Computer Communication Review*. 2008;38(2):69−74. https://doi.org/10.1145/1355734.1355746
9. Karakus M., Durresi A. Quality of service (QoS) in software defined networking (SDN): A survey. *Journal of Network and Computer Applications*. 2017;200−218. https://doi.org/10.1016/j.jnca.2016.12.019
10. Paliwal M., Shrimankar D., Tembhurne O. Controllers in SDN: A Review Report. *IEEE Access*. 2018;6:36256−36270. https://doi.org/10.1109/ACCESS.2018.2846236
11. Salman O., Elhajj I.H., Kayssi A., Chehab A. SDN controllers: A comparative study. In: *2016 18th Mediterranean Electrotechnical Conference* (*MELECON*). 2016, p. 1−6. https://doi.org/10.1109/MELCON.2016.7495430
12. Wibowo F.X.A., Gregory M.A., Ahmed K., Gomez K.M. Multi-domain software defined networking: Research status and challenges. *Journal of Network and Computer Applications*. 2017;87:32−45. https://doi.org/10.1016/j.jnca.2017.03.004
13. Zhang Y., Cui L., Wang W., Zhang Y. A survey on software defined networking with multiple controllers. *Journal of Network and Computer Applications*. 2018;103:101−118. https://doi.org/10.1016/j.jnca.2017.11.015

СПИСОК ЛИТЕРАТУРЫ

1. View on 5G Architecture – 5G-PPP. Version 3.0. URL: https://5g-ppp.eu/wp-content/uploads/2019/07/5G-PPP-5G-Architecture-White-Paper_v3.0_PublicConsultation.pdf
2. Keshari S.K., Kansal V., Kumar S. A systematic review of quality of services (QoS) in software defined networking (SDN). *Wireless Personal Communications*. 2021;116(3):2593−2614. https://doi.org/10.1007/s11277-020-07812-2
3. Moravejosharieh A.H., Lloret J. Performance analysis of quality of service in software-defined networking. *Network Protocols and Algorithms*. 2019;10(4):1. https://doi.org/10.5296/npa.v10i4.14054
4. Nam Tuan Le, Arif Hossain M., Islam A., Do-yun Kim, Young-June Choi, Yeong Min Jang. Survey of promising technologies for 5G networks. *Mobile Information Systems*. 2016; Article ID 2676589. https://doi.org/10.1155/2016/2676589
5. OpenFlow. OpenFlow Switch Specification. Version 1.5.0. 2014. URL: https://opennetworking.org/wp-content/uploads/2014/10/openflow-switch-v1.5.0.pdf
6. Fernandez M.P. Comparing openflow controller paradigms scalability: reactive and proactive. In: *Proc. IEEE 27th International Conference on Advanced Information Networking and Applications* (*AINA*). 2013, p. 1009−1016. https://doi.org/10.1109/AINA.2013.113
7. Masoudi R., Ghaffari A. Software defined networks: A survey. *Journal of Network and Computer Applications*. 2016;67:1−25. https://doi.org/10.1016/j.jnca.2016.03.016
8. McKeown N., Anderson T., Balakrishnan H., Parulkar G., Peterson L., Rexford J., Shenker S., Turner J. OpenFlow: Enabling innovation in campus networks. *ACM SIGCOMM Computer Communication Review*. 2008;38(2):69−74. https://doi.org/10.1145/1355734.1355746
9. Karakus M., Durresi A. Quality of service (QoS) in software defined networking (SDN): A survey. *Journal of Network and Computer Applications*. 2017;200−218. https://doi.org/10.1016/j.jnca.2016.12.019
10. Paliwal M., Shrimankar D., Tembhurne O. Controllers in SDN: A review report. *IEEE Access*. 2018;6:36256−36270. https://doi.org/10.1109/ACCESS.2018.2846236
11. Salman O., Elhajj I.H., Kayssi A., Chehab A. SDN controllers: A comparative study. In: *2016 18th Mediterranean Electrotechnical Conference* (*MELECON*). 2016, p. 1−6. https://doi.org/10.1109/MELCON.2016.7495430
12. Wibowo F.X.A., Gregory M.A., Ahmed K., Gomez K.M. Multi-domain software defined networking: Research status and challenges. *Journal of Network and Computer Applications*. 2017;87:32−45. https://doi.org/10.1016/j.jnca.2017.03.004
13. Zhang Y., Cui L., Wang W., Zhang Y. A survey on software defined networking with multiple controllers. *Journal of Network and Computer Applications*. 2018;103:101−118. https://doi.org/10.1016/j.jnca.2017.11.015
14. Karakus M., Durresi A. A survey: Control plane scalability issues and approaches in Software-Defined Networking. *Computer Networks*. 2017;112(7):279−293. https://doi.org/10.1016/j.comnet.2016.11.017

14. Karakus M., Durresi A. A survey: Control plane scalability issues and approaches in Software-Defined Networking. *Computer Networks*. 2017;112(7):279–293. https://doi.org/10.1016/j.comnet.2016.11.017
15. Singh A.K., Srivastava S. A survey and classification of controller placement problem in SDN. *International Journal of Network Management*. 2018;28(2):e–2018. https://doi.org/10.1002/nem.2018
16. OpenDaylight Project. Available from URL: https://www.opendaylight.org
17. ONOS Project. Available from URL: http://onosproject.org
18. Floodlight Project. Available from URL: https://floodlight.atlassian.net/wiki/spaces/HOME/overview?mode=global
19. Scenarios, requirements and KPIs for 5G mobile and wireless system. ICT-317669-METIS/D1.1. May 2013. Available from URL: https://cordis.europa.eu/docs/projects/cnect/9/317669/080/deliverables/001-METISD11v1pdf.pdf
20. Banovic-Curguz N., Ilisevic D. Mapping of QoS/QoE in 5G networks. In: *Proc. 2019 42nd International Convention on Information and Communication Technology, Electronics and Microelectronics* (*MIPRO*). 2019, p. 404–408. https://doi.org/10.23919/MIPRO.2019.8757034
21. 5G-PPP. 5G Vision. The 5G infrastructure public private partnership: The next generation of communication networks and services. Available from URL: https://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Brochure-v1.pdf
22. Concept of creation and development of 5G/IMT-2020 networks in the Russian Federation. (in Russ.). Available from URL: https://digital.gov.ru/uploaded/files/kontseptsiya-sozdaniya-i-razvitiya-setej-5g-imt-2020.pdf
23. 5G Americas. Network Slicing for 5G Networks and Services. Available from URL: https://www.5gamericas.org/network-slicing-for-5g-networks-services/
24. IMT-2020 (5G) Promotion Group and 5G PPP Announce Memorandum of Understanding for 5G. Available from URL: https://5g-ppp.eu/imt-2020-5g-promotion-group-and-5g-ppp-announce-memorandum-of-understanding-for-5g/
25. 5G Vision and Requirements of 5Gforum. Available from URL: https://www.itu.int/dms_pub/itur/oth/0a/06/R0A0600005F0001PDFE.pdf
26. 5GMF White Paper. 5G Mobile Communications Systems for 2020 and Beyond. Available from URL: https://5gmf.jp/wp/wp-content/uploads/2016/09/5GMF_WP101_All.pdf
27. Mohandas R., Aravindhar D.J. An intelligent dynamic bandwidth allocation method to support quality of service in internet of things. *International Journal of Computing*. 2021;20(2):254–261.
28. Hind S., Najib E.K., Fatima L. Towards QoS enhancement in wireless network through SDN. In: *2019 7th Mediterranean Congress of Telecommunications* (*CMT*). 2019, p. 1–5. https://doi.org/10.1109/CMT.2019.8931396

15. Singh A.K., Srivastava S. A survey and classification of controller placement problem in SDN. *International Journal of Network Management*. 2018;28(2):e–2018. https://doi.org/10.1002/nem.2018
16. OpenDaylight Project. URL: https://www.opendaylight.org
17. ONOS Project. URL: http://onosproject.org
18. Floodlight Project. URL: https://floodlight.atlassian.net/wiki/spaces/HOME/overview?mode=global
19. Scenarios, requirements and KPIs for 5G mobile and wireless system. ICT-317669-METIS/D1.1. May 2013. URL: https://cordis.europa.eu/docs/projects/cnect/9/317669/080/deliverables/001-METISD11v1pdf.pdf
20. Banovic-Curguz N., Ilisevic D. Mapping of QoS/QoE in 5G networks. In: *Proc. 2019 42nd International Convention on Information and Communication Technology, Electronics and Microelectronics* (*MIPRO*). 2019, p. 404–408. https://doi.org/10.23919/MIPRO.2019.8757034
21. 5G-PPP. 5G Vision. The 5G infrastructure public private partnership: The next generation of communication networks and services. URL: https://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Brochure-v1.pdf
22. Концепция создания и развития сетей 5G/IMT-2020 в Российской Федерации (Проект). URL: https://digital.gov.ru/uploaded/files/kontseptsiya-sozdaniya-i-razvitiya-setej-5g-imt-2020.pdf
23. 5G Americas. Network slicing for 5G Networks and Services. URL: https://www.5gamericas.org/network-slicing-for-5g-networks-services/
24. IMT-2020 (5G) Promotion Group and 5G PPP Announce Memorandum of Understanding for 5G. URL: https://5g-ppp.eu/imt-2020-5g-promotion-group-and-5g-ppp-announce-memorandum-of-understanding-for-5g/
25. 5G Vision and Requirements of 5Gforum. URL: https://www.itu.int/dms_pub/itur/oth/0a/06/R0A0600005F0001PDFE.pdf
26. 5GMF White Paper. 5G Mobile Communications Systems for 2020 and Beyond. URL: https://5gmf.jp/wp/wp-content/uploads/2016/09/5GMF_WP101_All.pdf
27. Mohandas R., Aravindhar D.J. An intelligent dynamic bandwidth allocation method to support quality of service in internet of things. *International Journal of Computing*. 2021;20(2):254–261.
28. Hind S., Najib E.K., Fatima L. Towards QoS enhancement in wireless network through SDN. In: *2019 7th Mediterranean Congress of Telecommunications* (*CMT*). 2019, p. 1–5. https://doi.org/10.1109/CMT.2019.8931396

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