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Evaluating the Quality of the Service Components Offered by 4G Wireless Networks

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Abstract

Numerous mobile operators, industry professionals, and researchers throughout the world have various ideas on the potential applications of fourth-generation (4G) technologies. Advanced IPv6 (IPv6) protocol is implemented in 4G networks, and Internet Protocol (IP) is used for signaling. The implementation of a 4G heterogeneous network faces several significant obstacles. The incorporation of many topologies, all-IP networks, authentication, and quality of service (QoS) are just a few of these issues. The key QoS strategies for 4G networks are surveyed and categorized in this research. The Cross-Layer Design (CLD) method and the achievements made in each protocol layer are the basis for classification. Finally, this study discusses survey results, including noteworthy findings, limits, and suggestions for additional research aimed at enhancing QoS in 4G networks.

Keywords: Cross-Layer Design (CLD), Quality of Service (QoS), Internet Protocol (IP), Heterogeneous Networks, Fourth Generation (4G)

Introduction

The Nigerian telecommunication industry is one of the country's most dynamic and competitive sectors, with many service providers. The industry has witnessed tremendous growth over the years, fueled by the increasing demand

for telecommunication services, such as voice, data, and internet. Given the widespread availability of smartphones at low prices in the market as a result of increased competition and the use of social media websites, there is an urgent need for faster data speeds. Mobile broadband rates are already advancing continuously. The terminology "heterogeneous network" refers to a network that combines many network technologies to offer seamless communication.

When it comes to heterogeneous networks and wireless broadband services, Long Term Evolution-Advanced (LTE-A), also referred to as 4G, is the answer. 4G refers to a group of mobile wireless technologies that International Mobile Telecommunication-Advanced (IMT-Advanced) represents. Global network evolution is taking place, and all communications will soon be IP-based. The advanced IPv6 protocol is used for signaling in the 4G network, which has IP at its core. What is commonly referred to as an Evolved Packet Core (EPC) is structured according to Internet Protocol (IP), which also describes the switching technology. In the network layer, IP was primarily known as a general-purpose data transport protocol (Logvinov *et al,* 2022). However, it has now been expanded to serve as a carrier for voice and video services over 4G networks. Presently, wireless networks are heterogeneous. Various access networks, including Enhanced Data Rate for GSM Evolution (EDGE), Wideband Code Division Multiple Access (WCDMA), Code Division Multiple Access (CDMA2000), satellite network, and IEEE 802.15 Wireless Personal Area Network (WPAN), IEEE 802.11 Wireless Local Area Network (WLAN), and IEEE 802.16 Wireless Metropolitan Area Network (WMAN), are integrated. Maximizing the QoS that a user experience is of the utmost importance when choosing the appropriate access network to meet the QoS requirements of a particular application. The capacity of a network to offer good services to a portion of all network traffic using a particular underlying technology is known as quality of service (QoS) (Lee & Lee, 2017).

The QoS measures include packet loss rate, bandwidth, service availability, jitter (change in delay), and delay. Metrics are used to show how well a specific strategy is performing.

Prioritization (differentiated services) and resource reservation (interconnected services) can both improve QoS. When implementing QoS, we can do it either per flow (singular, unidirectional streams) or per aggregate (two or more flows that share a characteristic). Upper layer protocols (transport and upward), built on top of IP, make

up the protocol stack from the perspective of quality of service. Applications in these circumstances might be categorized as elastic or real-time based on the data flows, they communicate. Datagram policing and categorization, flow shaping, and scheduling are all implemented at the network layer by IP traffic control. Through the use of virtual channels or transmission priority, the data connection layer may also provide QoS. The provision of QoS in 4G networks is difficult since these networks frequently switch between heterogeneous wireless networks, handle multiple users using various bit rates, accommodate a variety of applications, and have hostile channel characteristics. Support for QoS can be provided at the switching, network, transport, application, and user levels. In order to fulfill QoS, we must tackle the following issues: encryption methods, security, and "trust of information," various rates, error profiles, latencies, burstiness, dynamic resource optimization, and rapid handoff management (Ravikumar, & Sankar, 2015).

Since 4G networks are more complicated than those of earlier generations, there has been a significant amount of study in this area during the past few years. In this regard, a few research publications about the idea of QoS structures across all protocol levels as they relate to 4G wireless networks will be evaluated.

LITERATURE SURVEY

The proposed QoS solutions for the 4G network can be categorized according to the layer at which the mechanism operates. Although research has been done at the data-link, physical, transport, and application layers to offer QoS in 4G networks, network layer topologies are the most common. Cross-layer design, which aims to optimize architecture across neighboring layers, is an alternative method for delivering QoS in 4G networks. Treating the layers as separate entities has been the conventional method. The implementation of services is unimportant to a higher-layer protocol, which solely uses services at lower layers. Table 1 represents a review of available literature with respect to layers of 4G wireless networks.

TABLE 1: LAYER-WISE METHODOLOGIES

S/N	LAYER	AUTHORS	APPROACH
1	Application, Transport, Presentation	Fadlullah, Wei, Shi, & Kato.	A game-theoretic joint optimization of QoS and security for differentiated services in next-generation heterogeneous networks.

2		Prior *et al*	End to End QoS based on DiffServ
3		Sargento *et al*	IP-based QoS based on intra and inter-domain control approach.
4		Rückelt	QoS signaling based on joint time network selection strategy
5	Transport, Network	Rangankar & Mhala,	QoS based on efficient admission control
6		Zaki *et al*	Multi-QoS-aware fair scheduling for LTE.
7		Li Wen, & Sheng	scheduling schemes with unsaturated traffic
8		Liu, & Dong,	Utility-based scheduling matrix to maintain QoS.
9		Gacanin, & Wagner,	QoE based on Artificial intelligence
10		Pawar, & Patil	used the ECDH algorithm to guarantee secure data transfer.
11	Data Link	El Tanab, & Hamouda,	Effective Capacity
12		Gardasevic *et al*	Cross-Layer QoS Support in Multiservice Heterogeneous Environments
13	Cross-Layer Design (CLD)	Ramis Bibiloni, J	Cross-Layer Design in AMC/ARQ-based wireless networks
14		Zhang, X, Wang, J., & Poor, H. V.	Cross-layer statistical-QoS driven resource allocation over mmWave in the non-asymptotic regime.

For resource optimization, protocols in the CLD technique can be devised to allow direct interaction between elements in nonadjacent levels. Wireless CLD uses a different method than wired CLD. The methodologies used by various studies and a layer-by-layer classification are presented in TABLE I.

(Türk, Zeydan, & Akbulut, 2018) developed an IP-based QoS Architecture that enables situations involving numerous network technologies and network operators. When a network is heterogeneous, it is a method of integrated management for providing services. Authentication, Authorization, Accounting, and Charging (AAA) systems and QoS brokers operate together to provide access to mobile networks. Also

discussed is a QoS signaling framework that unifies resource management with mobility management.

The architecture was created with the idea of a domain resource manager and is sufficient to enable several forms of handover (Sargento *et al*,20055). Core concerns are rarely taken into account when designing QoS mechanisms (Rangankar, & Mhala, 2019). However, they fall short of offering an IP-based communication QoS strategy that is completely integrated and supports a wide range of applications and protocols. Mobility concerns and adaptable applications are typically not taken into consideration.

(Prior et al, 2005) put forth a complete QoS approach for 4G IP-based networks that can promote both legacy and responsive multimedia services. Additionally, it facilitates user mobility within and between domains using different access technologies. This scalable approach uses DiffServ to offer layered resource control. The core manages resources individually for each aggregate. Each Administrative Domain (AD) has a number of access networks (AN), each of which is capable of supporting a variety of access technologies. Additionally, each AD contains a core subdomain that enables connectivity between access networks via subdomain routers (SR). Edge Routers (ER) are used to provide connectivity to other administrative domains. Novel functions are introduced to the Access Routers (AR)to deliver QoS to a range of services. Individual flows are marked and identified by ARs. IntServ and other QoS reservation schemes are also supported by ARs (Badawy, M. M., Ali, Z. H., & Ali, 2020). Requests for QoS Brokers and Differentiated Service Code Point (DSCP) marks are made using the Resource Reservation Protocol (RSVP). Advanced Router Mechanisms (ARM) is the collective name for all of these features (Rangankar, & Mhala, 2019). An Authentication, Authorization, Accounting, Auditing, and Charging (A4C) server is accessible in each domain.

By taking into account multiuser diversity in wireless networks, (Li, Wen, & Sheng) concentrate on a packet scheduling technique. The Knopp and Humblet (KH) scheduling method improves the throughput of such a system, but it may lead to user injustice. Thus, the CKH scheduling algorithm, which is the coarsest form of the KH scheduling algorithm, is applied. Multiuser diversity is used by CKH the most extensively. particular users' packet delay performance, as well as under CKH scheduling, the system throughput is comparable to the scheduling method known as Round Robin (RR). For the highest throughput, CKH scheduling consistently

outperforms RR scheduling. In terms of delay performance, CKH only outperforms RR in extremely difficult conditions.

(Noliya, & Kumar, 2020) recommend examining the quality of service in an LTE network with regard to the cell load and the scheduling method in use. The type of data that needs to be planned, as well as each user's current state, must be known to the scheduler. For instance, how readily accessible user data is for transmission or how long a user-specific packet has been waiting in the queue. Various circumstances cannot be accommodated by traditional schedulers. To resolve this issue, two fresh scheduling techniques built on proportional fair scheduling are suggested. By testing them under traffic-related conditions, the performance of the traditional scheduling algorithms is compared to the new ones in terms of average delay and throughput. In different load situations, different services are utilized.

The user requirements should be evaluated. The bandwidth and cost considerations can be saved by monitoring the times when users are most actively using the services. This suggestion is made by (MUTITU, 208). The design can be modified in accordance with the network usage priorities. The effectiveness of a network's QoS will increase as a result. There are two primary parts to this QoS architecture: 1) The Services Archives Unit (SAU) and 2) Cumulative Services Archives (CSAU). A server machine called the SAU produces a log of the services that consumers utilize and has a database of user records. Users' service logs may be forwarded to the CSAU in order to produce an overview of the services used across various access networks. The statistics, such as the services used, the data rate, the number of bytes spent, and the time slots for service consumption, are determined by this created summary in graphical form. breaks and re-logins, jitter in the network, and congestion conditions. At the moment, communication across layers is constrained by QoS methods. The transport layer connections are initiated by an application layer component (UDP or TCP). For existing connections, it can also set up different QoS metrics. QoS criteria are taken into account by the network layer while implementing IP traffic control. Most of the time, the data-link layer does not receive this information. Additionally, each link layer has unique QoS attributes. In the currently implemented QoS subsystems, this leads to the following fundamental issue: Some tiers of the protocol stack do not have access to QoS configuration information. Therefore, rather than actively contributing to the provision of QoS, they communicate poorly with the QoS subsystem (Dixit, 2019).

QoS guarantees across wireless relay networks were proposed by (Zhang, & Wang, 2018) via a physical-data link cross-layer resource allocation approach. In the cross-layer design approach, the delay information is communicated. Their goal is to reduce QoS constraints and increase relay network throughput. To advance the concept, the information-theoretic findings are linked with the notion of statistical QoS guarantees. Their strategy is based on an influential idea called effective capacity (Amjad, Musavian, & Rehmani, 2019). Effective capacity maximizing is changed from the original throughput maximizing strategy. QoS exponent θ serves as a measure of delay limitation. The assumption is a flat fading channel model. When used with wireless relay networks, the effective capacity-based technique is the effective CLD strategy. Choosing the best relay protocol is a challenge that is not covered in this work. It should be noted that the effectiveness of various relay techniques varies greatly. We can improve network performance if stronger relay protocols are used, as suggested and researched in (Zhang, & Wang, 2018).

Cross-layer QoS design for 4G heterogeneous network services is proposed by (Hwang et al., 2017). The key elements are the cross-layer algorithms and the QoS engine. The control module, QoS agent, and QoS daemon make up the QoS engine. Resource monitoring and alterations are done regularly by Cross-Layer Architecture. Average packet loss and latency are decreased by 2% and 8.5%, respectively when CLA is not present. However compared to the conventional layered technique, the throughput attained with CLA is somewhat lower (Pawar & Patil, 2017).

For multihop IEEE 802.11 networks, (Aydogdu & Karasan, 2016) provided an analytical model to determine how much bandwidth may be used along a channel without breaching the QoS criteria of current rate-controlled traffic flows. A concept known as "Free channel time" is proposed to examine the path capacity. It is the amount of time that a wireless connection may use to deliver data. To achieve this purpose, the model describes the unsaturated traffic state. The node shows how the recently injected traffic interacts with any concealed traffic that could have an impact on it.

The Resource Management in DiffServ (RMD) protocol is suggested and is based on the DiffServ concepts for traffic distinction. It manages resources from edge to edge. Dynamic resource management and admission control are provided by RMD, which is an expansion of the DiffServ concepts. Per Domain Reservation (PDR) and Per Hop Reservation (PHR) are two protocols that the RMD specifies (Hwang et al., 2017).

WiMAX (Worldwide Interoperability for Mobile Access) and LTE are 4G wireless technologies with superior QoS and security frameworks. Both WiMAX and LTE have been identified as having security risks such as Denial of Service (DoS) and the deployment of malicious nodes. Therefore, to combat the security risks in 4G multi-hop wireless networks, powerful security measures and stringent authentication procedures are required. On the other hand, improving security shouldn't harm network QoS. On this line, the Elliptic Curve Diffie-Hellman (ECDH) protocol-based distributed security architecture is suggested by (Tan, 2017). With excellent security, ECDH is a rival to Rivest Shamir Adleman's (RSA) public key method. The 4G wireless networks can use ECDH since it uses less power. According to simulation and testbed findings for WiMAX networks, the proposed system offers robust security and rigorous authentication for handover users without impairing Qos parameters (Rana, Kumar, & Rana, 2021).

Many authors have taken into consideration the current cross-layer solutions in order to achieve the required End-to-End (E2E) QoS in WiMax and LTE networks. The International Telecommunication Union (ITU) defines the Quality of Experience (QoE) as the *"overall acceptability of an application or specific service, as assessed qualitatively by the end users."* Quality of Experience (QoE) is a subjective term that refers to the user's internal condition, the features of the developed system, and the setting in which the service may be used. Both subjective and objective measurements may be used to evaluate the quality of experience (Chen, Deng, Jia, Dohler, & Nallanathan, 2018) WiMAX networks' flat IP design is utilized by the model. The Access Service Network (ASN) is kept up by Network Access Provider (NAP) to provide WiMAX radio access.

For 4G wireless, (Haci, & Abdelbari, 2020) offer a packet scheduling strategy to enhance QoS in wireless networks. To enable Broadband Wireless Access (BWAS) QoS, the new packet algorithm alters the IP and radio layers. Fairness as a concept has been added. Their findings ensure that consumers of various services are treated fairly, produce more profit, and have low packet loss rates during handoffs, packet forwarding rates, and packet delays. The effectiveness of different scheduling plans is evaluated by the "Satisfaction Factor." At each of the BWAS NodeBs is a downlink packet scheduler. Choosing which packet should be delivered at a specific period, controls how the downlink shared channels are distributed to the mobile users. The scheduler has primary influence over these systems' performance properties. Carrier

revenue might be increased as a result. When users have the same value for the fairness measure, the algorithm adds a step to end the conflict between them.

(Kuboye, 2018) discusses wireless system traffic scheduling techniques. Given the unfriendly nature of the wireless medium, scheduling methods for wired networks cannot be used. Scheduling techniques for wireless networks include 1) Centralized or 2). Distributed. When users compete for channel access during ad hoc or uplink operations, distributed scheduling is mostly used. Nodes' opportunistic actions prevent the centralized solution from providing the efficiency, fairness, and QoS it is capable of. An in-depth analysis of centralized wireless scheduling methods is provided in the paper. They are judged according to pertinent performance standards appropriate for next-generation networks.

Voice over IP (VoIP) packet scheduling over LTE-A is provided by (Mugisha, 2014). The optimal overall capacity is presented by such an algorithm that prioritizes the VoIP traffic's delay needs. There are two categories for scheduling algorithms that are discussed: Algorithms with and without QoS differentiation. The services or QoS requirements of a particular user cannot be recognized by non-QoS differentiated algorithms. Every method explains how to "calculate a priority function for each unique user." Non-QoS differentiated algorithms include: 1) the Round Robin Algorithm, 2) Queue Based Max CIR (QBMC) Algorithm 3) The Proportional Fair Algorithm. QoS differentiated Algorithms are 1) The Weighted Proportion Fair (WPF), 2) the Modified Largest Weighted Delay First, and 3) The Exponential Proportional Fair Algorithm. The vast majority of queueing studies that have been done so far use a crude Poisson model and conventional scheduling techniques. However, a performance analysis model for multiple queue systems is presented in a recent study by Shukla and Bhatia. In this case, a potential scheduling technique regulates the entry of traffic. The model is built using the G/M/1 queueing approach since it takes several traffic classes into account. The idea of a translation matrix to ensure QoS for a roaming User is novel and characterized by (Shukla and Bhatia, 2018). When just a small number of parameters are employed to match data, the parsimonious traffic model is utilized. The model reflects an on-and-off procedure. Every network has matrices on hand to monitor how different traffic classes behave in terms of traffic. Matrix-based comparisons are used to compare current flow characteristics to potential new reservation classes as the terminal switches network access. Explained are the methods for creating the matrices and the implementation

scenario for QoS mapping between the two various access network types. A translation mechanism in the Gateway performs the Universal Mobile Telecommunication System (UMTS) to IP QoS mapping. Router for GPRS Serving Node (GGSN), as recommended by the third Project for Generational Partnership (3GPP). Each UMTS packet flow should be classified by the GGSN router in order to be mapped to an appropriate IP QoS class (Iftikhar *et al,* 2012).

It has been suggested to use a 4G network selection algorithm to better user preference implementation. For a variety of accessible services and access technologies, rank based on the distance function is calculated. All parameter values need to be normalized such that they fall between 0 and 1 before utilizing the distance function. Values are assigned in a way that the user will benefit more from higher values. For instance, a network with a value of 1.6 for the billing parameter is often more economical than one with a value of 1.4. Weighted separation In order to implement the additional level of customization required by 4G, the function is employed. Users are permitted to prioritize a small number of parameters. When conducting electronic transactions, users, for instance, favor information security over bandwidth or price (Wang, *et al,* 2017). A vertical handover with QoE awareness is presented by (Bao *et al,* 2018). One methodology used in multi-influence decision-making is the Technique of Order Preference by Similarity to Ideal Solution (TOPSIS). The writers make use of it. With this approach, ideal and negative alternatives are postulated, which are too synthetic. Both positive and negative alternatives are desirable, with positive having the best level for all criteria taken into account. TOPSIS selects the option that is the furthest away from the less-than-perfect alternative and the most closely aligned with the ideal solution.

The term "cooperative architecture" is defined by (Wu, Dong, Tian, & Jin, 2020). They take into account a hybrid interworking strategy made up of overlapping IEEE 802.11 and IEEE 802.16 networks. The WiMAX base station, Wi-Fi access points, mobile nodes (MN), and hybrid units (HU) are the four primary elements of the 802.11 architecture. The HU organization is responsible for maintaining the service quality of each access technology. Hybrid units additionally perform the translation and mapping of the suggested service classes to the Wi-Fi or WiMAX QoS scheme and vice versa. When a user initially enters the architecture, the serving hybrid unit develops its user profile. Handovers may occur because users are mobile. The fundamental objective of

cooperative architecture is vertical handover supported by hybrid units. Each HU has additional characteristics that are introduced to give improved QoS.

RESULTS OF THE STUDY

1) A large portion of the research is conducted in the setting of single-layered structures. Studies mostly concentrate on distributed applications, software platforms, transport mechanisms, communication infrastructure, or access networks. Limited progress has been made in addressing the issue of comprehensive end-to-end QoS compliance in 4G wireless networks.
2) Even though WiMAX and LTE are complete 4G wireless innovations with top-notch QoS and security features, various flaws have been found. Although the majority of 4G network terminals are small devices, strong cryptographic techniques are available. To support intensive cryptographic computations, they are therefore memory and power restricted. The user's QoS may suffer as a result of security being given priority.
3) Some Quality of Service (QoS) plans may work very well for a particular type of traffic but may struggle for other applications. Thus, we must adopt a comprehensive strategy to numerous programs and multi-users are supported. Additionally, the suggested QoS plan should be expandable to accommodate ever-increasing social networking site-generated multimedia traffic.
4) Despite the fact that there is a cross-layer design solution to achieve QoS assurances, it violates the core principle of protocol design. The protocol stack architecture becomes more complicated because protocol layers are permitted to interact freely in order to make the best judgments. Future modifications to any protocol should be profitable.
5) As wireless technologies advance quickly, the wired TCP, which has been reliable for decades, is becoming obsolete. In wired networks, TCP was mostly responsible for delivering QoS. To function with 4G networks, it might be essential to change the basic TCP protocol. Regular horizontal and vertical handoffs should be handled by TCP, together with QoS.
6) In the majority of QoS designs, the standard way to address the source of revenue loss has not been considered. Therefore, depending on the premium

service that consumers need, there is room for improved algorithms to promote revenue generation.

CONCLUSION AND FUTURE WORK

Achieving QoS in 4G networks has been the subject of a plethora of relevant studies since cellular networks have evolved from fixed telephone networks to flexible wireless communications. This paper provides an overview of current QoS solutions for 4G networks. Although there are many approaches, the heterogeneity of the networks, quick handoffs, fluctuating bit rates, propagation issues, and a variety of applications make it difficult to implement QoS in real-world 4G networks. Unlike data traffic, which is expanding rapidly, voice traffic is increasing linearly. In 4G networks, voice-over IP can be handled through QoS and signaling protocols. Traffic engineering is required for IP to accommodate massive data across 4G networks. Notifications of the handover should be sent to the QoS plane. If the traffic and mobility models are considered, the proposed architectural designs would be workable. Further research may be done on the various QoS techniques available for specific applications.

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