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Call Admission Control algorithm and Bandwidth Allocation Scheme for The 6G Network

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Acknowledgments

Abstract

The expected increase in the number of network subscribers and the development of new technology enforces create more complex and stricter requirement for network resources. This enforces the need for more efficient resource allocation strategies by network operators. The emergence of novel technology like extended reality, smart factories, and automated vehicles, encourages research going into the next generation network. There is a lot of literature that covers slice admission control in the next generation network. This study considers a slice admission control algorithm that gives priority to handoff calls. The performance metrics used to evaluate the algorithm include new call bocking probability, handoff call dropping probability, and bandwidth utilisation within the slices. The results show that the handoff call dropping probability is lower than the new call blocking algorithm.

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Chapter 1

Introduction

1.1 Background to the study

Ever since the inception of mobile communication technology there has been a rapid growth in the development of new technologies accompanied by an increase in mobile wireless network subscribers. The development of the next generation of networks is crucial in meeting these demands. The current network generation (5G) introduced a novel paradigm that comprise of important features such as network function virtualization (NFV), software-defined network (SDN), and network slicing [15]. These features allow multiple logically independent virtual mobile networks, called slices, to be deployed on a shared physical infrastructure in order to provide network resources that are tailored for services with certain network resources requirements. The main slices that the current generation network supports are enhanced mobile broadband (eMBB), ultra reliable low latency communications (uRLLC), and machine type communication (MTC) as defined by the International Telecommunication Unio (ITU) [15].These developments come with the challenge of efficient resource allocation within and amongst network slices to realize efficient network resource utilization[20].

There is an expected large increase in the number of devices that will need continuous connection in the near future and the current generation network will not be able to satisfy all requirements [21]. This encouraged research going into the next generation network, which is envisioned to introduce new technology and enhance the technology that the current network generation uses and allow it to support the next generation of services that will have requirements that the current generation network cannot support. Subsequently, the increase in the demand for limited network resources requires network operators to allocate network resources efficiently. To do this network operators use Bandwidth allocation schemes to allocate bandwidth amongst slices and within slices, and call admission control algorithms to decide which calls to admit with a certain objective [17].

1.2 Objectives of this study

1.2.1 Problems to be investigated

The next generation network will service a large number of devices with different network requirements. Network resources are limited, there is a need to match the number of services admitted with the available network resources in a manner that ensures consistent quality of service, and bandwidth must be allocated efficiently among and within slices. The efficient allocation of limited resources is a challenge that will be tackled in this study using a call admission control and bandwidth allocation scheme.

1.2.2 Purpose of the study

This study proposes a call admission control and bandwidth allocation algorithm and evaluates it using three performance metrics namely, new call blocking probability, handoff call dropping probability, and bandwidth utilisation. Since there is an expected significant increase in the demand for network resources in the near future, the admission control algorithm designed should minimise new call blocking probability and handoff call dropping probability while maximizing bandwidth utilisation within the slices.

1.3 Scope and Limitations

This study considers the design and implementation of a call admission control and bandwidth allocation algorithm for the 6G network.The algorithm is simulated using Matlab and evaluated using three performance metrics, namely new call blocking probability, handoff dropping probability, and bandwidth utilisation.

1.4 Plan of development

The report is structured as follows:

Chapter2 : This chapter covers a literature review on the evolution of mobile networks, The next generation network, slice admission control and bandwidth allocation.

Chapter 3: This chapter provides a system model, the design of the slice admission algorithm and the outline of the simulation.

chapter 4: Shows the results obtained from the simulation

chapter 5: The discussion of results is done on this chapter

Chapter 6: Conclusion are meade in this chapter.

Chapter 7: This chapter covers the recommendations.

Chapter 2

Literature Review

2.1 Evolution of Wireless Networks

This section gives an overview of the evolution of wireless networks, going into detail about each generation of Networks that goes back to the 1980s when the first generation network was deployed. The next generations of networks show an increase in performance, an increase in supported use cases and increased number of devices supported by the network. With the development of new technologies there is an increased need for better network architectures that will be able to provide communication channels for these different type of machines. There is a rapid increase in the number of users in the network which gives rise to traffic congestion in the network, this is solved by developing the next generations of wireless network to support this demand, consequently the introduction of new applications brings about new requirements that need to be satisfied.

2.1.1 First generation Network(1G)

This network generation was invented in the early 1980s in the metropolitan of Tokyo in Japan. This network used analog transmission for this service and only supported voice calls. Analogue systems that were widely used by this generation of network were advanced mobile phone system (AMPS), Nordic mobile telephone (NMT) and total access communication systems (TACs). This generation network used frequency reuse and cell splitting to fulfill its objectives. Splitting the cell spectrum into different channels was not efficient when it comes to utilizing the available radio spectrum, consequently this limited the number of calls that could made simultaneously. NMT-450 used the 450 MHz band and deployed macro cells to provide larger cell coverage, however there were size and transmission power constraints. As the technology gained more and more user reaching nearly 20 million subscriber decade after its introduction. This increase in demand of the network exposed its short comings namely Low capacity, poor call hand-off, not much security and poor voice links [4].the load became too much for the network as a result a decline in quality of service was prevalent.

2.1.2 Second generation Network(2G)

This network generation was introduced in the early 1990s just about a decade after the introduction of 1G network. In this generation network analog communication was replaced with digital communication , by using digital multiple access technology. The network uses time division multiple access (TDMA) and code division multiple access (CDMA) to exploit higher spectrum efficiency than 1G [2]. In TDMA the channel is first split into different frequencies (FDMA), then each frequency slot is divided into multiple time slots. This enables more user to use the network resources simultaneously. Each wireless radio signal can contain multiple data transmissions where the user transmits and receives data using a unique code. According to [4], the introduction of digital communication provided a lot important features such as supporting advanced channel and source coding, higher resistance to interference and channel fading, and more efficient spectrum utilization.

The Global System for Mobile communication (GSM) is the most popular 2G wireless technology that supports a higher number of users and supports additional services, such as data communication. Each GSM channel had a bandwidth of 200KHz and each frame had 8 time slots. Data communication was introduced by this generation, users were able to use short message services (SMS), which allowed users to send and receive messages in a cheap and easy way. Consequently, Other features came with that improvement, to provide security in transmission of these messages encryption was introduced and subscriber identity modules for user authentication and to give unique identity to each mobile station. In accordance to [?], GSM Leverages CDMA to simultaneously transmit data on a single communication channel, increasing channel utilisation while providing the users interference free calls. Consequently, an increase in network capacity and less call interference was prevalent. However, the network does not support high data rates and it is unable to handle complex data.

For GSM networks to support higher data transmission rates an improvement to the network was made, the network was upgraded from GSM to General Packet Radio Service(GPRS), which works on the same network infrastructure, with the addition of two entities namely Serving GPRS Support Node(SGSN) and gateway GPRS Support Node (GGSN). GPRS adds packet switching protocols, where information is broken down into small packets that are routed by the network to the designated address, with that end-to-end IP services are by the network . According to [4], GPRS support flexible data transmission rates and continuous network connection to its users.

2.1.3 Third generation Network (3G)

This network has the same design standards globally, where the network encompasses a collection of standards that work together. It is based on the International Telecommunication Union (ITU) family of standards and it was deployed in the early 2000s. The initiation of the network generation started in Europe and North America using wide-band CDMA (WCDMA) and multi carrier CDMA. Although it used the same designs standards across the globe, the network generation used different technologies in different regions of the world namely UMTS, DECT and CDMA-2000.

As the successor of GSM the Universal Mobile Telecommunication System (UMTS) was proposed. The use of these technologies allows the 3G network to exploit faster data rates and higher capacity than its predecessor. With these improvements more services were supported namely multimedia applications such as video calling, video conferencing for mobile devices, high speed mobile internet access, mobile television, global positioning system (GPS) and most importantly lower cost of using the network. The network provides a range of data rates depending on the user's mobility, provides up to 144 kbps for high mobility users, up to 384 kbps for low mobility users and up to 2Mbps for stationary users [4].

There were improvements to the base 3G network, with the aim of efficiently supporting these different services, High-speed Downlink Packet Access(HSDPA) was developed. HSDPA was named 3.5G which is packet-based data service in WCDMA downlinkk with data transmission up to 10 Mbits/s over a 5MHz bandwidth. Similarly, High-Speed Uplink Packet Access (HSUPA), also known as 3.75G, is a packet-based data service in WCDMA uplink. HSUPA enhances user-user data applications with higher and symmetric data rates [4].

2.1.4 Fourth generation Network(4G)

The increase in data requirements caused by a rapid increase in the demand for the internet and the development of mobile devices were to an extent that the data rates provided by the 3G network could not meet this demand. This encouraged the deployment of 4G network in 2010, which provide data rates of up to 100 Mbps for high mobility users and 1 Gbps for low mobility users. The 4G network is flexible and integrates all the mobile technologies before its deployment, it uses an All-IP network which allows users to use different mobile technologies in different circumstances.

The network uses Orthogonal Frequency Division Multiple Access (OFDMA) for downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink and support frequency-division duplex(FDD) and time-division duplex (TDD). LTE-A is regarded as the major standard for 4G network. The network has features that allows it to be dynamic and exploit higher spectral efficiency, high voice quality, and lower latency. At the physical layer, the network uses adaptive coding and modulation (ACM), where the modulation order and coding rate are fine-tuned based on channel state information to exploit efficient use of radio channels [4]. Channel aggregation is also used to further enhance data rate, by assembling multiple channels to transfer data over a wider bandwidth. For cell-edge users the network allows them access to 4G-level quality of service by adopting relaying, where single antenna mobile stations transmit signals to relay station that are closer to the cell-edge [4]. The use of these technologies reduces the power consumption of mobile base stations.

2.1.5 Fifth generation Network(5G)

The never ending technological development and the introduction of new technology greatly increases the demand for network resources. This influenced research going into beyond 5G and B5G communication network, which uses network slicing as its architecture. This network provides heterogeneous services to meet different user requirements, which are categorised based on bandwidth, latency, reliability and connection density. This means that the new generations of networks transition from a generic network that provides services to different users in a one size fits-all manner to the implementation of dedicated services. The 5G networks supports The three main services with heterogeneous requirements, namely enhanced Mobile Broadband (eMBB), massive Machine Type Communication (mMTC) and Ultra-Reliable and Low Latency Communication (uRLLC).

The eMBB service requires the network to support large bandwidth transmission and high user mobility, this service enhances the network capacity by providing its user high data rates while maintaining a stable connection [21]. The mMTC service requires massive device connections and transmits small packets of data securely and efficiently, this service offers a large number of IoT devices with guaranteed cost efficient connectivity. The uRLLC service requires extremely low latency, provides up to 1 millisecond over-the-air latency and high reliability for critical services [14], mostly used by critical services such as health care systems. This is done by using logically independent virtual network functions, known as slices, which can be configured to support a certain service type. Software-defined networking, network function virtualisation and network slicing allows the network to allocate resources efficiently and cost effectively [15].

2.2 Next Generation Network(6G)

The development of new technologies and the introduction of a large number of devices that need ubiquitous connectivity and complex requirements that the 5G network may not be able to meet, encourages research of the next generation network namely B5G/6G network. This network generation is envisaged to employ different paradigms and technologies, namely Mobile Edge Computing (MEC), Radio Access Technologies, cellular base stations (BSs), Dedicated Short-Range Communication(DSRC), Unnamed Areal Vehicles(UAVs), Low Earth Orbit satellites and Device-to-Device (D2D) [26]. It is proposed to combine Terrestrial network and non-Terrestrial network to provide higher transmission rate, more connections and support more intelligent applications.The network is an integration of satellites,airborne platforms(UAVs) and terrestrial networks. Non-terrestrial network technologies are are expected to provide additional fronthaul and backhaul options, providing ubiquitous coverage to remote areas, sea and airspace [29] . This network generation should offer ubiquitous coverage and ultra-wide-area broadband access capabilities to support a large number of future devices and systems.

2.2.1 6G Vision

6G network is planned to further enhance the mobile internet and internet of Everything (IoE) and will promote the integration of AI to provide intelligent IoE. The Network aims at providing ubiquitous intelligent connection between virtual and real network. Subsequently, an intelligent connection between humans and machines is envisioned.

The current technology is mostly passive and requires user input, the envisioned future technology is one that will have situational awareness and use large amounts of intelligently connect devices to allow active interactions between humans and machines. This will require a level of intelligent connection that the current network generation cannot fully afford. Figure2.1 shows the vision of the next generation network.

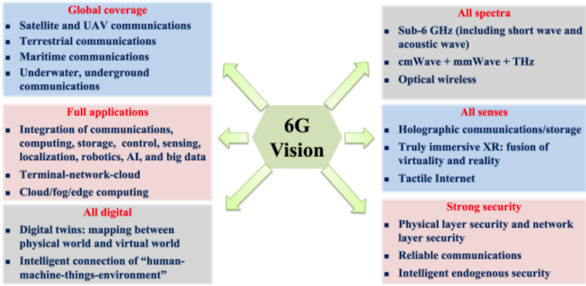


Figure 2.1: [3] 6G Vision

According to [3], The 6G network is envisioned to have global coverage that will be allowed by the integration of non-terrestrial and terrestrial network. This includes deep ocean and underground coverage, meaning 6G will be an integrated space-air-ground-sea communication network. The current network is mostly limited terrestrial communication, Leaving remote areas and some applications scenarios with little to no network coverage. The expansion from terrestrial communication to space-air-ground-sea communication will allow the network ubiquitous network coverage. To achieve a seamless three-dimensional ubiquitous network coverage and connectivity, the 6G network will integrate satellite communication, terrestrial communication, UAVs communication, maritime communication, and underground communication networks. This architecture will allow coverage to areas that are outside the range of terrestrial network, such as underground communication in mines, remote areas will have internet access, this will be done using non-terrestrial networks. In the event of a natural disaster where the terrestrial networks are disrupted the non-terrestrial networks will be able to provide fast, stable and high quality connection [3].

The current network is facing the challenge of spectrum congestion in the radio frequency (RF) band, which is proven to be insufficient for high data rate services. According to [3], 5G has already exhausted sub-6GHz, and started exploring millimeter(mm) Wave band. Since the network is expected to handle huge traffic and a large number of connection the network is envisioned to utilize a full spectrum, including sub-6 GHz,centimeter(cm) Wave mmWave, THz and optical wireless bands. The THz band allows has huge bandwidth and supports ultra-high data rates, this introduces an avenue for new applications like augmented reality, holographic communication and interconnection between nano-machines

[33]. The optical band used for optical wireless communication includes infrared, visible light, and ultraviolet bands, which provides thousands of free bandwidth to be utilized by the network generation to service different applications and provide coverage. Another advantage to the optical band is that visible light is green and economical with little to no spectrum regulation and electromagnetic interference, it also has high security [3]. In areas where RF communication is limited the optical band can mind that gap and offer coverage with a series of optical communication technologies such as visible light communication (VLC), light fidelity (LiFi), optical camera communication (OCC) and a few others [3].

Diversification of services and continuous technological development and that of communication systems has massive data implications for the 6G network. The utilization of AI and big data is considered for the next generation network to explore the intelligent potential of 6G networks and to provide services to a myriad of intelligent applications. According to [3], the use of these technologies to develop more advanced and intelligent communication systems, providing new ideas and paradigms in the research of wireless channel modelling, network multiple access, rate control, caching and reloading, secure and stable connections. Subsequently, the ubiquitous intelligent 6G networks will provide a myriad of intelligent applications, such as smart agriculture, intelligent healthcare and smart transportation. Not only will the next generation network provide communication services but other services that combine communications, computing, storage, control, sensing, localization and robotics, this shows the diversification of services that 6G will provide.

The interconnection between people has been realised by the previous network generations, the growth in technological development brings about a need for people to connect with machines. The next generation of network is envisioned to support a variety of communication technologies and users will be able to experience full sensory through technologies like holographic communication, extended and virtual reality. Through the next generation of network the reproduction of all the human's five sense, namely sight, hearing, touch, taste and smell, is enable. The large bandwidth and low latency provided by 6G will allow the integration of virtuality and reality. With that, the next generation of network will allow multi-sensory interconnection, which will open an avenue of new applications in the medical health, entertainment, education and many other fields [3]

The advancement of communication systems, sensing, computing, storage and the development of AI and big data is driving the world to a digital era. The digital twin technology, a digital recreation of the real world that enables real world interactions, will further develop digitizing the physical world as we see it [33].With this technology all the information and communication in the physical world can be transmitted in the digital world using the virtual representation of the 6G physical system . The digital twin is envisioned to use communication technologies, machine learning, MEC technologies for computing and block-chain technologies for privacy and security [29]. The digital world maps to the physical world and accurately reflects and predicts it in real time. Subsequently, the digital world can serve as a reference for decision making in the physical world [3]. With this an intelligent connection of "human-machine-things-environment", opening an avenue of new applications such as human body and city digital twin.

The level of complexity of attacks increases with the development of new technologies, machine-learning empowered attacks will be prevalent. This means that next generation of network needs to take security into consideration on its design to provide strong security, including physical layer and network layer security. Quantum communication technology, block-chain technology and other security technologies should be utilized by the next generation network to realize strong security and ensure credibility . The use of AI in 6G will realize intelligent endogenous security with the goal of independently identifying and solving network security problems [3].

2.2.2 6G Potential Use Cases

The projected technological developments shows an introduction of new application scenarios that the 5G network will not be able to fully service. The significant advancement of technology and the growing use of artificial intelligence and machine Learning technology allows greater technological innovations which will bring about new applications. The next generation network will have to fully support these applications and their strict requirements to afford the users QoS and quality of experience (QoE). There are a lot of potential use cases for the next generation network with a lot of industries adopting intelligent systems that handle large amounts of data. Figure2.2 shows a few examples of potential 6G use cases.

Example of technologies

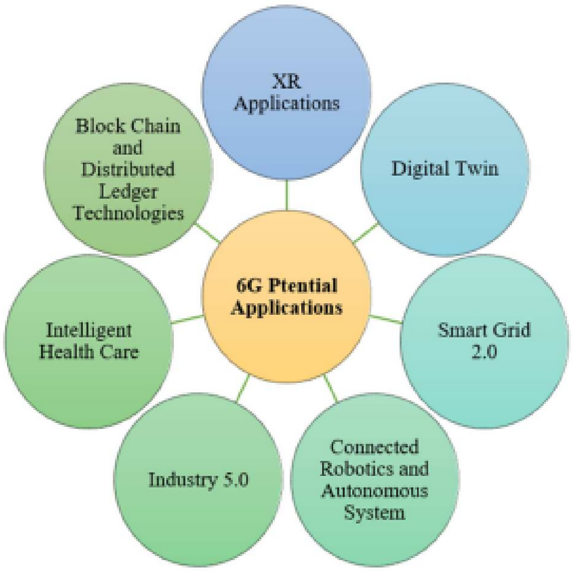


Figure 2.2: 6G potential applications [33]

Extended reality (XR) a collective for virtual , augmented and mixed reality, is one technology that utilizes the current network generation, with the advance in such technologies the current network will not be able to fully service it. The number of XR use cases will rise with an increasing use in the healthcare, education and entertainment industries. The VR allows a user to interact with an entirely digital world, while AR provides the user interactive experience of virtual objects in the physical world[3].The MR integrate VR and AR, providing the user an entirely digital experience with interactions with the physical and digital world. Holographic communication, a holographic image of a person or substance that reflects interactions in real time, which will allow people to communicate as if they were face to face will utilize the next generation network. The next generation network will achieve immersive XR, with all the five human sense reproduced in the digital world.

Application Scenarios

A better classification of these application needs further research, according to [3] a classification of these application scenarios is needed to be discussed using the key performance indicator of the next generation network. Indeed in literature [33, 32, 34] the classification of these application is not done using key performance indicators. The need for classification of these applications like in the current generation network will provide the network with a dynamic resource allocation strategy meaning some of the current generation network strategies are to be applied in the next generation network. The next generation network is envisioned to enhance the current generation network application scenarios and support new technologies that will be classified under the enhanced application scenarios. The next generation network will support Strengthened-enhanced Mobile Broadband/ further-eMBB (feMBB), ultra-massive Machine Type Communication (umMTC), enhanced-ultra-Reliable Low Latency Communication(euRLLC). These will meet the current generation key performance indicators, such as data rate, connection density and others, and further meet the next generation network key performance indicators, such as imaging, sensing, security capacity, intelligence level and more. Figure 2.3 shows the different application scenarios in the next generation network.

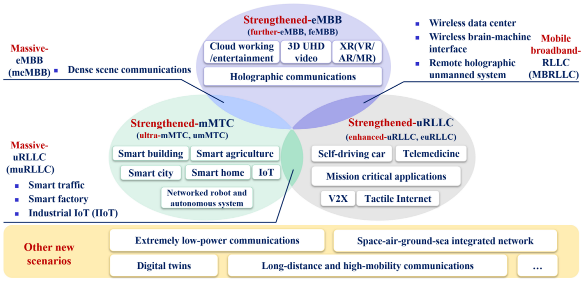


Figure 2.3: 6G Application scenarios [3]

The development and integration of technologies affords the potential development of a combination of characteristics of different application scenarios to serve some applications in the next generation network. According to [3], 6G will possibly provide additional scenarios such as;1) massive enhance Mobile Broadband (meMBB), with the aim of providing high data rates, large bandwidth, and large connection density, to service dense scene communication; 2) mobile broadband reliable and low latency communication (MBRLLC), with the aim to provide low latency, high reliability, high data rates, large bandwidth, to service applications like wireless brain-machine interfaces and wireless data centers; 3) massive ultra-reliable and low latency communication (muRLLC), with the aim to provide low latency and high reliability while having a large number of connections, to service large-scale machine-type communication like smart transportation and smart factories. There will also be other envisioned applications such as long-distance and high-mobility communication, low-power communications, digital twin applications.

2.2.3 6G Requirements

This section shows the requirements of the next generation network as it is expected to employ new services and innovative technologies.

ubiquitous coverage

This means that a user can have QoS anywhere in the world, the mobile network coverage required for future technologies is greater.With a huge amount of IoT devices in isolated areas, sensors in buoys in the antarctic for example, such technologies will need wide coverage. Subsequently, the need for deep sea coverage arises with the increase in human activities in oceans. The area traffic capacity of the next generation network is expected to increase up to 10 Gbps/m^2 and the density of connections is expected to also increase up to 10^8 devices/km^2, providing users broader and seamless coverage[3]. Emergency communication requires a guaranteed connection for emergency relief and necessary communication required in an emergency anywhere in the world. Future technologies will need a wide and stable network coverage. The development of AI technology is increasing at a high rate and it is deployed in different industries, such as healthcare, agriculture and IoT. This further increases the need for ubiquitous coverage to keep these technologies connected.

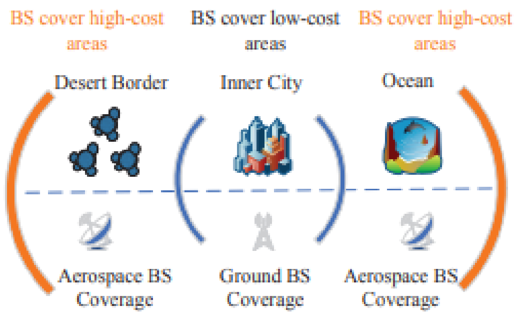


Figure 2.4: ubiquitous coverage [29]

Figure2.4 shows the envisioned use of space-air-ground integrated network's ubiquitous coverage, three- dimensional coverage to be precise. This allows the next generation network to increase the area traffic capacity, defined as the product of device density, bandwidth and the average spectral density, of the current generation by 10-100 times more [32]. The rapid development of sensing technology and IoT, connected devices will increase significantly, with a projected development of smart cities and factories that will increase the number of connected devices per square meter. The next generation's envisioned space-air-ground integrated network will afford more device connection per square meter.

Higher data rate

The new services that the next generation network is proposed to support demand higher data rates, for example in holographic communication the size of a holographic image is approximately 56-64 Gbit if the video will include all five sense that will further increase computing and storage demanding up to 1 Tbps [3]. The current network generation has peak data rates of 20Gbps in the down-link and 10Gbps in the up-link making it impossible for it to support that type service. Therefore the peak data rates of the next generation network should be in Tbps, this means that the increase data rate for the next generation network is more than 50 times that of the current network. The continuous development of technologies, the prospective introduction of holographic communication, extended reality with all the human five senses and a myriad of other 6G applications, the data rate that should be afforded a single user at any-point in time and anywhere in the world should increase significantly to at least 10Gbps and up to 100Gbps [3]. This is known as the user experienced data rate, defined as the maximum rate GB/user that can be guaranteed with a probability of over 90% when required. Next generation network's user experience should be higher than the current generation network to allow users high-quality experience anywhere and anytime.

Spectral and Energy Efficiency

Spectral efficiency refers to the average data throughput per unit of spectrum resource [3]. The spectral efficiency of the next generation network is expected to be 2-3 times more than the current generation network. The next generation of network is proposed to provide 3D network coverage supporting terrestrial and airborne users, ranging from mobile devices to flying vehicles that will require large volumes of bandwidth. Luckily, the spectral efficiency of the next generation network will allow it to support these devices. The development of spectrum management technologies will allow the next generation network to exploit up to 90 bps/Hz [3], which is triple that of the current generation network. Energy efficiency refers to the number of bits that can be transmitted over a joule of energy. The energy consumption of the next generation network should be significantly less than that of the current generation, an increase in energy efficiency by about 100 time is envisioned for the next generation network to provide more efficient services at lower or the same power consumption [32]. The next generation network will also consider cost efficiency, which is the ratio of user's data consumption benefit and its data traffic cost, this will help network providers to consider the profitability of the communication industry while providing good QoS to users. The overall spending on communication for users is expected to decrease and is expected to be less than 1% of the gross domestic product (GDP) per capita. The cost efficiency of the next generation network is expected to be 500Gb/$ as compared to 10Gb/$ of the current network generation with an increasing GDP per capita the cost efficiency of the next generation network is expected to be more than 100 times more than the current generation network [3].

Reliability and security

The reliability of the next generation network is expected to be application specific, with the overall reliability of 6G transmissions is envisioned to reach 99.99999% level. The envisioned reliability of the next generation network is expected to resemble the reliability of wired transmissions. In the paper [3], reliability is defined as the percentage of packets successfully received under a certain upper delay limit. The development of the Internet of things induces a high demand for communication network reliability, this is further emphasized for critical services such as healthcare services. Stringent application scenarios such as strengthened ultra-reliable and low latency communications, only one bit error is allowed in 10 million transmitted bits [3]. It is believed that the next generation network will afford endogenous security through the introduction of new technologies such as quantum communication and block-chain technology, giving the network higher levels of security.

Low Latency

In [3] latency is defined as the minimum delay of air interface access. The current generation network can serve latency-critical applications by using dedicated network resources, from a pool of limited resources, that are readied in advance to serve these applications with little or no mobility afforded. With rapid technological development the latency offered by the current generation network will not be able to serve the stringent latency requirements of these technologies. To serve specific services like self-driving vehicles, remote surgery, industrial control systems, holographic communication and many other technologies will require ultra-low latency which can be afforded by the next generation network. The next generation network is envisioned to achieve 1 microsecond latency. Future technologies further reduce the need for human input with intelligent devices that work autonomously, most of these devices are latency-critical. According to [32] the next generation network architecture makes it possible to further reduce latency from the control plane and user plane.

Mobility

The increase in human mobility and the development of autonomous vehicles requires the next generation of network to afford such mobility. the mobility of a network is define in [3] as the maximum speed at which a defined Qos and seamless transmission of data between radio nodes can be achieved. The next generation network is envisioned to provide twice the mobility of the current generation network affording mobility of 6G transceivers of more than 1000 km/h. The next generation network will be able to serve ultra-high speed trains and aircrafts. Smart highways with autonomous vehicles is one of the projected next generation network application and it requires connected and autonomous mobility ultra-reliability and low latency.

2.2.4 6G Enabling Technology

The next generation network is envisioned to utilise all the available spectrum and provide it's users global coverage, this will be achieved by adopting a new paradigm that integrates communication, sensing, and computing with guaranteed security.This section shows the technologies that will enable the next generation network. Since there will be quite a number of technologies used to realize the next generation network, classifications of the type of technology gives a holistic view, as classified in [35] as different clusters of enablers. The enabling technologies are divided into 8 clusters, namely Energy, sensing and actuation, communication, softwarization, immutability, intelligence, security, and quantum.

The energy cluster is a collective for enabling technologies that deal with energy supply, consumption and transfer, it includes all the enablers that are responsible for power supply in the next generation network. There is ongoing research towards the development of technologies like energy harvesting, wireless power transfer (WPT) and green technology.

Energy harvesting technology is an alternative to batteries as devices that utilize power harvesting devices provide a longer battery lifespan as compared to batteries [35]. The capacity of harvesting energy from the environment using vibration energy, thermal energy, and radio frequency radiation should increase the power supply to energy-constrained IoT devices [36]. WPT technology allows a device to receive energy transmitted by a source using a wireless communication channel as a connection. This technology is important especially with the projected increase in the number of IoT devices, in a smart environment to ensure longer device battery lifespan this technology will play a vital role.The rapid technological development raises environmental concerns, Using technology with the aim of reducing the impact of information and communication systems on the environment is known as green technology. It aims at sustainable development of industries and the reduction of the human impact on the environment[35].

The sensing and actuation clusters includes ubiquitous sensing and IoT-based sensing technologies, with the aim of providing the network with real world data in real-time. Ubiquitous sensing technology afford the network the ability to sense the physical world everywhere, providing remote control, discovery, data aggregation, and management of large-scale networks of sensors ad actuators[35]. This will provide applications like XR the physical world data in real-time.IoT based sensing aims at providing thousands of small devices that work together to perform certain tasks, like remote monitoring and controlling of mining equipment in a smart mine.

The communication cluster is concerned with connectivity among architectural components, including physical, link and network layers [35] .includes the traditional network technologies that provide data communication, further enhancing the current generation network architecture and integrating it with novel communication technologies. These include UAVs, THz communication, Visible light communication (VLC), Optical wireless communication (OWC), 3D networks, device-device and a variety of other data communication technologies are reviewed in depth in[35, 3]. There is ongoing research on ways to exploit all the available communication spectrum for the next generation network to provide enhanced services and ubiquitous coverage. communication using large intelligent surfaces and smart environments that provide these surfaces for wireless communications [34].

Softwarization of communication systems has been incorporated in the current network and further development is planned. This refers to programmability, virtualization, network slicing, functional fragmentation, and new realities[35]. This cluster includes software defined network (SDN), Temporospatial SDN (TS-SDN), network function virtualisatin (NFV), network slicing, open radio access network (O-RAN), Digital Twin, network caching, cloud elasticity, and other softwarization enablers[35]. Network Function virtualisation

(NFV), network slicing (NS), Software defined networking (SDN) and MEC are the core technologies that dominate the next generation network. The NFV packages the network functions that may perform on hardware devices, this eliminates the high coupling between hardware and the network, which is a bottleneck. MEC reduces backhaul network congestion, thus improving network performance, user experience and resource optimization. Also it allows high data throughput and low latency while reducing bandwidth usage. NS is used to instantiate additional network functions on top of MEC cloud servers, this allows the network to support diverse applications in the same physical infrastructure and efficiently manage slice resources. SDN brings programmability to networks by orchestrating and controlling services. TS- SDN will play a vital role in the inter-operation and coordination of NTN and TN, as it allows services to make network decisions based on the location, movement and orientation of devices. Subsequently providing greater flexibility in the network. Cloud elasticity mitigates resource over-loading and helps decrease energy consumption.

The Immutability enabler cluster are technologies that promote a persistent, unchangeable and reliable registry and a decentralised computing paradigm by mainly using digital ledger technology (DLT) in the form of smart contracts. Smart contract are defined in [35] as immutable and executable programs that act o the terms and conditions set by the contract using a computing infrastructure. Blockchain technologies are the most common immutable technologies that promote a reliable and secure decentralised network. Tangle is another system that can be used for IoT devices, to employ distributed and immutable cost free contracts. These technologies are envisioned to revolutionize digital markets by allowing the commercialization of data, connected things, Electromagnetic spectrum, Virtual network functions, and network slices[35].

The intelligence enabler cluster includes technologies that are based on decision making in the next generation network, which includes AI, machine Learning (ML), Self-organized network (SON), self-evolving network (SEN), Zero-touch management and Neuromorphic computing. A full AI driven network is envisioned to satisfy the ever growing requirements of user applications, where intelligence will integrate the network instrumentation, management, signal processing, resource management and service orchestration [35]. The aim is to minimize human intervention in network management tasks such as provisioning, monitoring and optimization of network resources. These technologies will be used to maximise QoS afforded to user by using QoS policies to reduce latency, increase reliability and improve efficiency.

The security enabler cluster includes technologies that promote security and privacy. The use of traditional security methods is planned to be integrated with novel security methods in the next generation network, with the aim of increasing the standards of such methods. This cluster includes homomorphic encryption, privacy and identification technologies. homomorphic encryption is where mathematical operations can be performed on the ciphertext, an encrypted version of the data, rather than the data itself, consequently data confidentiality is retained. Using homomorphic encryption the use of cloud computing and storage gets guaranteed security. Privacy technologies are concerned with the right to usage, sharing and control of personal information.

The Quantum enabler cluster includes technologies like quantum computing (QC) , quantum-assisted computing (QAC), quantum internet(QI), quantum machine-learning (QML) and post-quantum security[35]. QC is a novel computing theory that uses the principles of quantum mechanics to perform operation on data, this theory considers a computer as a physical system governed by physical laws at small scales[35]. QAC enhances traditional telecommunication systems by increasing the capacity and adding more functionalities using quantum exchange. Quantum algorithms improve channel estimation, multi-user detection, and data routing, they will help solve computationally complex problems in the next generation network related to optimization. QI aims at enhancing physical sensors using quantum systems, further using distributed quantum computing and quantum key distribution. QML deals with the integration of quantum computing and machine learning, it will further cover areas such as medical research, creation of new materials using molecular and atomic maps [35]. This technology contributes in promoting intelligence in the next generation network. Post-quantum security deals with security concerns of quantum computing, by the development of encryption algorithms that are secure against quantum computers.

2.2.5 Slice Admission Control in 6G Network

Although network slicing provide a more efficient and flexible way for network operators to keep up with different services due to a large number of users requesting resources for each service, the demand for limited network resources becomes too great the network can be overwhelmed and provide poor QoS. Admitting all the request in the network is not always possible [10], to prevent this problem slice admission control and bandwidth allocation algorithms are developed to control inter-slice and intra-slice traffic congestion, optimize network provider revenue, QoS control, promote slice admission fairness, and ensure an efficient allocation of radio resources [15]. This section reviews literature on Slice admission control/call admission control and bandwidth allocation algorithms for 5G/B5G networks.

Due to an increase in popularity of the internet and its use, the number of devices that use communication systems is increasing exponentially. That constitutes a resource access problem, as physical resources are limited, admission control is needed to match the amount of available resources to the admitted number of users. It is a means to to ensure quality and service isolation when the network is under burden, to prevent the network from getting overwhelmed by excessive user requests. Slice admission control is important, as it works as a decision making mechanism that determines which requests to accept, delay or reject when the network is under heavy load, ensuring performance of slices, avoiding high resource competition and manage the isolation and stability of the slice . Due to the architecture of the network admission control is done by the Slice provider when admitting tenant's slice requests and by the tenants when admitting end-user's service requests these are called inter-slice and intra-slice admission control respectively. Figure2.5 shows inter-slice and intra-slice admission control.

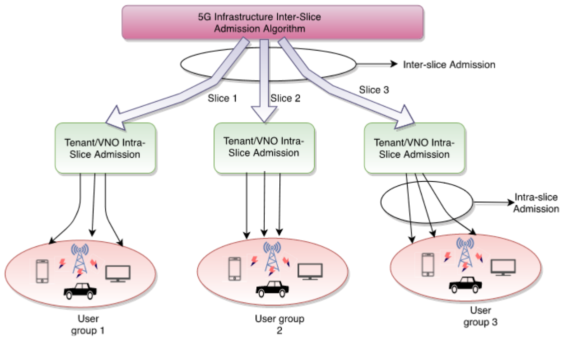


Figure 2.5: [15]An illustration of Inter-slice and Intra-slice admission control

According to [15] Inter-slice admission facilitates the admission of heterogeneous slice requests from tenants and these request require isolated and distinct logical resources. while intra-slice admission concerns the admission of end-user requests to be admitted into a common slice by tenants. As shown extensively in [15] Different slice admission control algorithms are used to achieve different network objectives in the current generation network. Slice providers(SPs) use these algorithms to ensure QoS of each admitted request and to ensure efficient radio resource allocation [14].

Objectives

Slice admission control is carried out by the virtual network operator to achieve certain objectives. These objectives include inter-slice congestion control, QoS control, optimization of revenue, and slice fairness assurance. These objectives are further discussed below.

There is a large number of connections expected in the next generation network, consequently the network will receive a large number of service request with heterogeneous requirements. when the requests are directly channeled to the orchestrator without an admission policy the network would be congested, consequently providing low quality services or no services. When SAC algorithms are deployed in the network traffic congestion can be controlled and radio resources allocated efficiently, preventing the orchestrator from being overwhelmed, thus ensuring QoS [15]. Inter-slice Congestion control is one of the main objective of SAC, it is with congestion control that the network can maintain and ensure the satisfaction of user requirements.

An important role of slice admission control is to ensure that the user's QoS requirements are met, which is done by providing and maintaining a service level agreement (SLA). QoS requirements include user experienced data rate, latency and delay jitter. For a slice to provide resources for QoS-intense services, like intelligent healthcare, the slice provider can deploys SAC algorithms that accept slice requests when it can guarantee their QoS. QoS provisioning primarily deals with ensuring the additional accepted request does not deteriorate the QoS provided so as to maintain service level agreement (SLA) between the slice provider, tenant or end-user[14]. SLA is only guaranteed when the minimum quantity of resources is provided by the network . The next generation network is expected to service a large number of devices with heterogeneous service requirements and the introduction of new applications with stricter requirements such as XR and holographic communication, the SAC algorithms need to ensure ubiquitous QoS.

The ultimate goal for the infrastructure provider and slice tenants is to generate revenue, therefore they deploy a SAC algorithm that allocate network resources in order to maximizes revenue. The network operator associates slice admission with revenue accumulation, in a multi-tenant network the infrastructure provider may admit slice request in a manner that maximizes it's revenue by using a greedy policy to admit slice request [15]. This can be done by giving higher priority to requests that will generate higher revenue for the network operator. However, greedy algorithms tend to starve requests that offer the network operator the least profit.

Ensuring level of priority in the network is also important and should be considered in admission control. Some request are critical to the QoE of the user, for example hand-off requests due to user mobility should be prioritized over new calls to ensure user QoE and QoS. Another important role of this consideration is to provide ubiquitous coverage and QoS for urgent requests such as emergency communication, giving them higher priority than general application requests [17]. It is important to efficiently assign priority and admit requests in a manner that does not starve lower priority request of network resources.

To overcome resource starvation of lower priority requests a SAC algorithm should ensure a level of fairness. This is important as the next generation network will service a large number of service request with different requirements, thus different priorities. This is a challenge for network operators as some network operators deploy SAC algorithms that are biased and give high and fixed priority to some requests and rejects lower priority ones.Another factor that makes fairness optimization more complex is the heterogeneity of service requirements. An efficient SAC algorithm is one that considers all the requests in the network and maintains a level of fairness to ensure that all the requests are considered [15]. Fairness optimization achieves a balanced resource allocation and ensures that each request gets the opportunity to be served . According to [17], the level of fairness is believed to impact the performance of the network and QoE of services, subsequently fairness optimization can conflict with other SAC objective such as revenue optimization and level of priority.

Slice Admission strategies

SAC algorithms are design by network operators using certain strategies to realize their objectives. SAC strategies are categorized into six types, namely first-come-first-served strategy, the priority based strategy, the random strategy, the greedy strategy, and the optimal strategy.

The first-come-first-served admission strategy is the simplest strategy as it admits requests as they come until resources are depleted, after which it rejects the rest of the incoming requests until a resource is free. In the next generation network this strategy will not be feasible for slice admission control as the requests have heterogeneous requirements.However, it can be used in a queue scenario of requests of the same slice [17]. According to [15] this strategy is not popular because of lack of optimization method applied during slice request admission. The resources are not efficiently utilized by this strategy.

The priority based strategy is used by the infrastructure provider to give preference to certain types of slice requests[15], for example if the InP wants to admit requests that require large bandwidth they will prioritize the feMBB and meMBB slice from figure 2.3. This strategy is deployed for inter-slice prioritization for slice request priority. It is commonly done by assigning weights, higher weights for higher priority [17]. In the current and possibly next generation network , slices with stringent requirements (euRLCC,muRLLC, MBRLLC) are associated with high priority, therefor more expensive.

When infrastructure providers aim to optimize revenue they tend to use this strategy giving high priority to slice requests that generate the most profit. A Purely priority based strategy has no consideration of fairness when admitting requests, meaning requests of low priority might be starved of resources.The priority based strategy's performance is highly dependent on the frequency and duration of high priority slice requests. For a network operator aiming to maximize revenue that strategy may prove to be inefficient, when these slices are in short demand and last for a short duration.

The greedy based strategy is a popular strategy used for revenue maximization. The strategy is highly exploitative .The authors in [15] state, " As an illustration, a greedy based algorithm exploits a policy π that always meet a slice admission objective. This policy is determined after several iterations or learning process. It is used to tune a well defined objective function to exploit the evaluated policy without consistent exploration". Greedy algorithms are not always optimal, semi-greedy algorithms can be deployed to occasionally explore other requests [15]. In the next generation network a large number of slice requests will have different requirements and thus different revenue implication, using a semi-greedy or fine-tuning greedy algorithms to occasionally consider all the slice requests will be important to ensure resources are utilized efficiently.

For a network operator with the objective of ensuring overall admission fairness amongst all slice types following fairly normal distribution of slice type admission, they may deploy the random admission control strategy. This strategy aims to reduce unfairness in the admission of slice type requests admitted in the network and affords the network operator less computational costs. Although a normal distribution of slice type request admission may seem fair, fairness in the current and next generation network is request requirement specific, for example an algorithm that gives high priority to emergency communication and rejects general application request in times of natural disaster can be considered to be fair. This strategy is not popular because it offers no optimization [15].

It is however possible to use a strategy that gives optimal slice admission decisions, the optimal based admission control strategy is such a strategy. It employs a well-tuned SAC algorithm, with the goal of defining an admission control objective and performing a complete optimization of the algorithm to achieve the best results [15]. The use of intelligent algorithms and the use of machine learning to learn optimal admission decisions in this strategy is popular. The implementation of this strategy, fine-tuning and optimization to be precise, is complex and consumes time as a large amount of tuning is needed to improve the results. For the next generation network the use of intelligent algorithms will prove to be important for deploying such strategies.

Bandwidth Allocation Strategies

Bandwidth is a limited resource this means network operators should allocate this resource efficiently to satisfy user requirements.They use Bandwidth allocation strategies to allocate resources efficiently. These strategies can be classified into four groups namely,complete sharing, complete partitioning, handoff call prioritization, and service class prioritization.

The complete sharing strategy allocates bandwidth to every call that enters the network, until the network's maximum capacity is reached. It does not prioritize any type of call, meaning handoff calls and new calls are not differentiated. It is an easy to implement first come first serve strategy. The strategy has good radio resource utilisation. However high handoff call dropping probability is prevalent, thus poor QoS is provide to users.

The complete partition strategy allocates pools of bandwidth dedicated to different types of calls. Each type of call has an isolated pool of bandwidth, new calls and handoff calls are allocated bandwidth from their respective pool. The strategy can give priority to a type of call by allocating more bandwidth to the pool dedicated to serving the call. This strategy can achieved low handoff call dropping probability by allocating more bandwidth to the resource pool dedicated to handoff calls . However can suffer from poor resource utilisation in case where the resource pool for new calls has reached it's capacity and the resource pool for handoff calls is under utilised.

Handoff prioritization is motivated by high user mobility within the network. when a user moves from one cell coverage to another, the call gets transferred to the other cell as a handoff call to keep the connection of the call. It is more annoying for users to get a handoff call dropped than to get a new call blocked. handoff prioritisation is classified into four groups namely, guard channel, fractional guard channel, queuing priority scheme, and QoS degradation scheme.

- The guard channel scheme reserves bandwidth for handoff calls, this is done by setting a threshold for allocating bandwidth to new calls. The threshold is set such that the handoff call dropping probability is minimal.
- The fractional guard channel prioritizes handoff calls by admitting new calls according to a probability p determined by the number of busy channels. like the guard channel a threshold exist, after the number of ongoing calls are past the threshold new calls are admitted according to p.
- In the Queuing priority scheme new calls and handoff calls are admitted until

maximum capacity is reached, then a queue of one type of call is implemented. Handoff calls are prioritized by keeping incoming handoff calls in a queue when maximum capacity is reached until bandwidth is released by ongoing calls or the queue period of the call is due.

- The QoS degradation scheme is composed of two methods namely, bandwidth degradation and delay degradation.The bandwidth degradation method calls are classified as adaptive and non adaptive calls, adaptive have flexible QoS requirements. This methods allows for more calls to be admitted when there is network congestion by reducing bandwidth of ongoing adaptive calls.

This strategy promotes a low handoff call dropping probability, however this results to a high new call dropping probability.

The Service class prioritization strategy is used in a network that supports multiple service classes. The bandwidth is shared by every service class user, unlike complete sharing preferential treatments among users of different service classes is prevalent. This treatment arises due to certain service classes having stringent QoS requirements and users in a certain service class are willing to pay more for better QoS.

Related Work

Debbabi et al. [26] provides an extensive overview of inter-slice and intra-slice Resource allocation algorithms, in the mentioned paper different slice admission control algorithms with different objectives are compared. In [26] Inter-slice resource allocation is classified into two approaches namely Radio Access Network (RAN) based inter-slice resource allocation and End-to-End (E2E) based inter-slice resource allocation. Consequently, Intra-slice resource allocation is classified into three approaches namely RAN based intra-slice resource allocation, E2E intra-slice resource allocation and Core Network (CN) based intra-slice resource allocation. Further approaches are explored in [26] that include both Inter-slice and intra-slice resource allocation, these algorithms are said to use a Hybrid slice resource allocation scheme, they also consider RAN, E2E ad CN slicing.
Tenant slice interference is dealt with by the SP while user network resource isolation is dealt with by the tenant.

The paper [11] focuses on maximizing revenue using machine learning technology. the network model of the above mentioned paper considers elastic and inelastic services within slices, the authors considered the eMBB and mMTC slices provide resources to elastic

services and uRLLC slice provides resources to inelastic services. the concept of network service elasticity is considered in literature [15, 11, 17]. Elastic services do not have strict resource requirements but require a minimum average resource allocation, they can be dynamically allocated network resources depending on the service demand. Inelastic services have strict resources requirement, a fixed resource allocation for these services is needed at all times, a short supply of network resources deteriorates the network performance.
In [11] the authors propose an algorithm that gives high priority to inelastic services and the elastic services get the remaining network capacity after the inelastic services have been admitted. It can maximise revenue but it is doing it at the cost of fairness, if there is high inelastic traffic the elastic services will be starved of resources.
Villota-Jacome et al.[25] propose an admission control algorithm that introduces two solutions ,namely Slice request Admission and Resource Allocation (SARA) and Deep SARA (DSARA) based on Reinforcement Learning and Deep Reinforcement Learning respectively, to optimize the profit of the network while avoiding over-utilization of the network. The Slice provider's drive for profit ends up starving some requests when there is a high demand for network resources. These papers [11, 25] both propose greedy slice admission strategies and offer little to no fairness when admitting slice requests and they only consider inter-slice admission decisions.
Dai et al.[14] a Slice admission control algorithm for multiple tenants and slice providers to maximize long-term revenue, in an environment where there is competition for resources and the interaction between tenants and SPs is strategic. Unlike in [11, 25], in [14] algorithm accounts for meeting heterogeneous slice resource requirements, maintains a priority relationship across slices by accounting for inelastic and elastic slices and assign priority accordingly and achieves fairness within slices. The Multi-participant Slice Admission Control (MPSAC) algorithm works in two stages it first handles inter-slice admission decisions heuristically and lastly, satisfies intra-slice admission quotas by using a single-parameter auction mechanism [14].

Apart from maximising revenue, Qos control is another explored slice admission objective [15]. Where a level of service based on customer service level agreements (SLAs) is maintained at all times, for this to be achieved slice admission algorithms have to consider SLAs when making admission decisions. QoS control is provided in [14], for the maximum revenue to be guaranteed in the long-term, resource demands of each slice must be satisfied. in [13] a slice admission control and allocation framework that allows users to request a network slice from an End-to-End Orchestrator(EEO) in advance by specifying a slice completion deadline. Online and offline scheduling algorithms are used with the aim of maximizing revenue for the SP while maintaining QoS.The offline scheduling algorithm that presents an optimal and sub-optimal solution is based on the assumption that the EEO has all the information about every slice request.However the offline scenario does not hold for real-world environment. The paper [13] only considers inter-slice admission decisions, it furthers studies discount dependent slice requests where the network receives greater traffic due to users taking advantage of the discounted prices. In the described scenario there is a higher blocking probability. The study of discounts helps SPs in selecting the correct discount parameters to maximise revenue.

Most of the papers [13, 14, 25, 11] consider revenue maximization, a revenue driven network starves slice request that provide the network operator low revenue, low revenue generating slice requesting tenants end up cancelling their request due to long waiting time [15]. In such networks greedy admission decisions have little to no regard for network slice fairness, consequently inefficient admission algorithms are said to be prevalent. The level of fairness is believed to affect the performance of a network. In [17] the heterogeneity of slice services is explored where resource requirements and priority of slices are different. the paper considers priority and fairness concurrently using a multi-queue- based heuristic SAC called Prioritized Slice Admission Control Considering Fairness (PSACCF) that improves fairness of admission decisions while keeping slice service priority, this is done by using a cumulative service acceptance ratio (CSAR) that is adopted to differentiate and explicitly evaluate the priority levels. Fairness in this case is shown by the uniformity of the CSAR gaps between adjacent priority levels [17] .

The authors in [18] developed a distributed inter-cell inter-slice resource partition (DIRP) algorithm, build from their previous work [23], with the objective of optimizing service quality across all slices and cells while adhering to network resources capacity constraints. They [18] use an algorithm that allows information sharing between cells and use deep reinforcement learning and transfer learning models to help with the optimization. The optimization in the paper [18] is based on two objectives max-min fairness over all slices and maximizing the average logarithmic utility over all slices. with max-min fairness ensuring the best fairness guarantees while the latter ensures all slice-specific requirements for throughput and delays are satisfied. The motivation behind the system is to ensure that all the slices comply with the service level agreement (SLA) thus ensuring QoS, however it does not specify the revenue implication for the SP.
In [24] an optimal radio resource allocation method in 5G LTE networks based on adaptive selection of channel bandwidth depending on QoS requirements and priority traffic aggregation in machine-to-machine gateways is developed. However only mobile and machine type users are considered, in real life conditions there will be resource requests from uRLLC services as well.
The authors in [21] formulate a Multiple Knapsack Problem and propose a greedy heuristic algorithm solution for a single tenant network, they use an auction based model. Their

network model include an additional namely, massive internet of things (mIoT). The objective of the scheme is to maximize profit on multiple slice scenarios namely residential areas, business area and industry coverage. However with so many users demanding continuous connection a single-tenant network is not feasible.

In [27] a hybrid multiple access scheme using Non-Orthogonal multiple access (NOMA) and Orthogonal multiple access (OMA) with multiple transmit antennas is proposed. The resource allocation of the proposed system is flexible but and this is due to the combination NOMA and OMA in the same bandwidth. The use of multiple transmission antennas enhances transmission performance due to maximum ratio transmission and enjoys greater throughput than NOMA and OMA alone [27].
Similarly the paper [22] proposes a generalized multi-acces dynamic bandwidth allocation (GMA-DBA) scheme that uses NOMA and OMA simultaneously to allocate resources for future generation passive optical networks (PON). The objectives of the scheme is to maximize throughput and minimize drop ratio, jitter and delay. The GMA-DBA scheme does not consider the heterogeneity of the 5G infrastructure but rather allocate resources based on the general requirements of the network generation. This can prove to be inefficient in a cases where the users have different network requirements.
In [12] the author's formulated joint eMBB/URLLC resource allocation problem, a joint resource allocation algorithm is proposed to allocate resources to eMBB and uRLLC users. It uses scheduling framework that creates eMBB mini slots for URLLC traffic to satisfy uRLLC's low latency requirement. the paper does not consider machine-type communication which in real-world systems adds greater capacity implication on the network.
Similarly in [8] an optimal joint resource allocation scheme for eMBB and uRLLC services is proposed with fairness and minimum data rates for eMBB users guaranteed to solve the eMBB/uRLLC resource allocation problem. The aim is to maximize throughput of eMBB users in the presence of uRLLC traffic and enforce a fairness level with guaranteed minimum data rate. In addition to that they [8] propose a knapsack-inspired punctured resource allocation algorithm. The algorithm iteratively checks the qualities of both services at each time slot to select a resource block to puncture while minimizing the decrease in eMBB service performance.
The authors in [12] formulate a partial task computation offloading problem in the mobile edge computing environment their objective is to allocate bandwidth to edge user for task offloading for the servers to do part of the computation, consequently reducing task computation time. They model the problem as a Stackelberg game model. However the paper doe not propose an algorithm to efficiently allocate bandwidth between edge users and mobile users.

Chapter 3

System Model

This chapter shows the design of a call admission control and bandwidth allocation algorithm for the next generation network.

3.1 Network Model

The next generation network utilizes network slicing to leverage the same physical infrastructure to provide virtually isolated services to satisfy heterogeneous requirements. The owners of the shared physical infrastructure are called infrastructure providers(InP) , They provide radio resources, bandwidth, to tenants. Tenants receive network resources from InPs and service end-user's network resource requests, They are called virtual network operator (VNO). The VNO allocates resources to end users in the form of slices, where user requests are admitted to specific slices using a slice admission control algorithm.

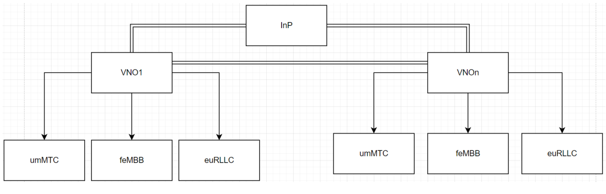


Figure 3.1: Network model

Figure 3.1 shows the hierarchical model of the network, the slice admission control is implemented in the VNO level. As shown in the 6G application scenarios subsection of the literature review and figure 2.3, the next generation network supports the following slices, feMBB, meMBB, euRLLC, muRLLC, MBRLLC and umMTC. Each slice has different requirements and the resources allocated to each slice is tailored for the specific slice requirements. In this paper the main application scenarios extended from the current generation network will be considered, namely feMBB, euRLLC and umMTC.

Application scenario	Service Type
Further Enhanced Mobile Broadband (feMBB)	Virtual Reality
Enhanced Ultra Reliable Low Latency Communication (euRLLC)	self-driving car
Ultra-Massive Machine Type Communication (umMTC)	Smart building devices

Table 3.1: Use cases

For the purpose of this paper the type of services that the slices provide resources for are virtual reality, self-driving cars and smart building devices as shown in table3.1. In the modeled network the slices receive homogeneous service requests for simplicity. The work presented in this paper is derived from the following papers [20, 31].

3.2 Resource Allocation

Radio resources are provided in terms of frequency channels and/or time-slots depending on the access technology, this report deals with the allocation bandwidth radio resource. Each Virtual network operator n = {1, 2,... N} has a capacity C_n which denotes the maximum bandwidth units available, this is divided amongst the slices that the VNO supports. Each type i = {1, 2,.. I} slice is allocated C_{in} capacity of bandwidth in each VNO. The total bandwidth for each VNO is given by :

$$C_n = \sum_{i=1}^{I} C_i n$$

Each slice services a set of users U_i = { u_1, u_2,...u_i} , u_i denotes the total number of users that request an amount of basic bandwidth unit, B_i from the slice type i. The set of active slices is represented by s={ s_1, s_2,.. s_i}, where s_i denotes the number of active type i slices. Each intra-slice resource allocation is confined to the capacity of the slice:

$$C_i n - B_i u_i \geq 0$$

Each slice prioritizes handoff calls over new calls by reserving an amount of bandwidth for handoff calls. The dropping of ongoing calls is most annoying for users and greatly deteriorates the QoE, therefore prioritizing handoff calls ensures that ongoing calls are maintained by the network when the user moves from one coverage area to the next. A handoff call prioritization guard channel scheme is proposed, where a threshold T_i for admitting new calls is set for slice type i. This means that new calls are accepted in the network given that the bandwidth used in the slice is less than the new call threshold. This will ensure available bandwidth for handoff calls. The bandwidth available for new calls is shown by:

$$NC_i = T_i - B_i u_i$$

and the bandwidth available for handoff calls is shown by:

$$HC_i = C_i n - B_i u_i$$

3.3 Admission Control

The proposed slice admission algorithm has the following objectives:

- To guarantee QoS requirements for all admitted requests
- Minimise new call blocking and handoff call dropping probabilities
- Prioritise handoff calls
- Optimize channel utilisation

User requests in the real world arrive in a random manner, but for the purpose of this model the requests are assumed to arrive as a Poisson distribution. Each user request arrive as a Poisson distribution with arrival rate of λ_i^{nc} and λ_i^{hc} for new and handoff requests respectively. The lifetime of each service requested is modeled as an independent mean exponential random variable μ_i^{nc} and μ_i^{hc} for new and handoff services respectively.

The VNO allocates bandwidth as a resource to user upon request in each slice that it provides. The requests sent by users are either accepted or declined by the VNO, the action taken by the VNO with regards to requests for resources from slice type i is denoted by a_i:

$$a_i = \begin{cases} 0; & \text{reject request} \\ in; & \text{accept request in slice type } i \text{ in VNO n} \end{cases}$$

The admission decision of the VNO is subject to the capacity of the slice and the slice utilisation, u_{in}, of the slice that supports the requested service. Slice utilisation is represented as the fraction of used bandwidth in slice type i over the capacity of slice type i:

$$u_{in} = \frac{B_i u_i}{C_{in}}; \quad 0 \geq u_{in} \leq 1$$

SAC algorithm flow chart

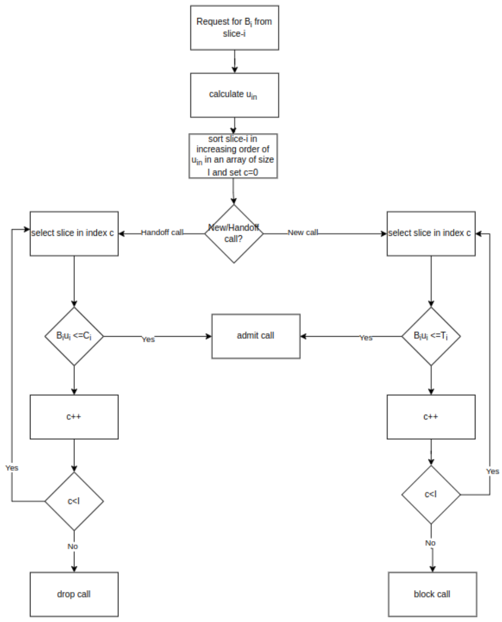


Figure 3.2: SAC flowchart

Markov Model

The systems described in this section can be modeled as a multi-dimensional Markov chain model, where the next state of the network only depends on the current state. The state space of the network is given by:

$$\Omega = (n_{in}, h_{in} : i = 1, ..., I; n = 1, ..., N)$$

n_{in} and h_{in} represent the number of ongoing new and handoff calls in slice type i, respectively. The set of all possible network states can be represented by the admissible state vector S. This shows the set of all the possible number of new calls and handoff calls combinations that can be serviced by the network at the same time. The admissible state S is given by:

$$S = \left\{ \Omega : \sum_{i=1}^{I} B_i n_{in} \leq T_i \, \forall n \wedge \sum_{i=1}^{I} B_i (n_{in} + h_{in}) \leq C_{in} \, \forall n \right\}$$

The probability $P(s)$ of the network being in state $s(s \subset \Omega)$ is given by:

$$P(s) = \frac{1}{G} \prod_{i=1}^{I} \prod_{n=1}^{N} \frac{(\rho_{in}^{n})^{n_{in}}}{n_{in}!} \frac{(\rho_{in}^{h})^{h_{in}}}{h_{in}!}$$

G is the normalisation constant and it is given by:

$$G = \sum_{s \in \Omega} \prod_{i=1}^{I} \prod_{n=1}^{N} \frac{(\rho_{in}^{n})^{n_{in}}}{n_{in}!} \frac{(\rho_{in}^{h})^{h_{in}}}{h_{in}!}$$

The arrival of the slice requests in the network is assumed to be Poisson distribution with arrival rate of λ_i^{nc} and λ_i^{hc} for new and handoff requests respectively. The lifetime of the services provided by slice i is a mean exponential variable μ_i^{nc} and μ_i^{hc} for new and handoff calls, respectively. ρ_{in}^{h} and ρ_{in}^{n} represent the traffic intensity in slice type i generated by handoff and new calls, respectively. The respective traffic intensity is given by:

$$\rho_{in}^{h} = \frac{\lambda_{in}^{hc}}{\mu_i^{hc}} \quad \forall i, n$$

$$\rho_{in}^{n} = \frac{\lambda_{in}^{nc}}{\mu_{in}^{nc}} \quad \forall i, n$$

3.4 Performance metrics

To evaluate the performance of the algorithm and to check whether or not the above mentioned objectives are satisfied performance metrics are used. These include new call blocking probability, handoff call dropping probability and bandwidth utilisation.

New Call Blocking Probability

The network admits new calls into slice type $i$until the threshold, T_i, for new calls is reached or the capacity of the slice, C_i has been reached. When these constraints have been reached the following new call request will be block due to not enough bandwidth to support the call. The new call blocking state , $S_{in}^b(S_{in}^b \subset S)$, is given by:

$$S_{in}^b = \left\{ s \in S : \left(B_i + \sum_{i=1}^{I} B_i n_i n > T_i \vee B_i + \sum_{i=1}^{I} B_i (n_{in} + h_{in}) > C_i \right) \forall n \right\}$$

The new call blocking probability, $P_i^b(s)$, is given by:

$$P_i^b(s) = \sum_{s \in S_{in}^b} P(s)$$

Handoff Call Blocking Probability

The network admits handoff calls into slice type i until the capacity of the slice, C_i is reached. SInce handoff calls are prioritised in the network there is no threshold for admitting handoff calls. The handoff call dropping state,$S_{in}^d(S_{in}^d \subset S)$, is given by:

$$S_{in}^b = \left\{ s \in S : B_i + \sum_{i=1}^{I} B_i (n_{in} + h_{in}) > C_i \, \forall n \right\}$$

The handoff call dropping probability, $P_i^d(s)$, is given by:

$$P_i^d(s) = \sum_{s \in S_{in}^b} P(s)$$

Bandwidth Utilisation

It is one of the SAC objectives to optimize slice utilisation, meaning that the allocation of bandwidth by the network must be exhaustive. The amount of available bandwidth in the network before the blocking/ dropping of the first call should not be enough to service the call in question. The bandwidth utilisation, U_b, is given by:

$$U_b = \frac{\sum_{i=1}^{I} \sum_{n=1}^{N} u_{in}}{IN}; \quad 0 \geq U_b \leq 1$$

3.5 Simulation

For the purpose of the implementation and simulation of the designed algorithm, a network model consisting of a VNO providing three slices namely, umMTC, feMBB and euRLLC is proposed. The network model is simulated using Matlab.

3.5.1 Slice Parameters

Each slice within the network is defined by certain parameters namely, capacity, basic bandwidth units, and threshold.

Capacity (C)

Each slice is can hold up to a certain number of bandwidth units, this maximum number is the capacity of the slice. This number may depend on the size of the physical infrastructure, and/or the amount demanded by the VNO; it can also be different for different slices The capacity of a slice determines the number of calls that the slice can service at a point in time.

Basic Bandwidth Unit (bbu)

The bandwidth requirement of a call is described using basic bandwidth units. Different types of calls have different bbu requirements since they support different services.The Capacity of the slice is the total bandwidth that the slice can offer, thus total bbus available for calls. A call arriving in the network requests a number of bbus if the concerned slice has the bbus requested, then the call is admitted and allocated bbus.

Threshold (T)

It is common knowledge in literature that wireless network subscribers can tolerate the blocking of new calls than the dropping of ongoing calls due to handoff call dropping. To ensure that less handoff calls are dropped, when there is traffic congestion, prioritization of handoff calls need to be prevalent. The use of a threshold to prioritize handoff calls makes this possible. A Threshold for new calls is set, where new calls are admitted simultaneously with handoff calls until the threshold is reached after they are blocked.

3.5.2 Simulation environment

The simulation was done using matlab online on a desktop running windows 10 operating system. The desktop has an installed RAM of 8GB, and a 12th Gen Intel(R) Core(TM) i3-12100 3.30 GHz processor.

Chapter 4

Results

This chapter shows the results produced from simulating the system model and algorithm developed in chapter 3. The algorithm was simulated under the condition outlined in section 3.5 using Matlab.The performance metrics used to evaluate the algorithm under different scenarios are new call blocking probabilities, handoff call dropping probability and bandwidth utilisation. The graphs presented were generation using Excel and the tables appended at the end.

4.1 Effect of Call Arrival Rate

In this section, the arrival rate for new and handoff calls were varied.The parameters in table4.1 were kept constant during the simulation:

	feMBB	euRLLC	umMTC
Capacity	30	30	30
Threshold for new calls	15	15	15
BBU	4	3	2
Departure rate	1	1	1

Table 4.1: Slice Parameters for Section 1

The effect of call arrival rate was investigated using three scenarios, where in all the scenarios the call arrival rate is increased. An increase in call arrival rate means that the network gets more calls per unit time.

4.1.1 Scenario 1: Varying arrival rate equally among slices

In this scenario, the call arrival rate in all the slices is incremented by 1 from 1 to 12. Figure4.1 below shows the effect of increasing the arrival rate of new calls and handoff calls equally across the slices.

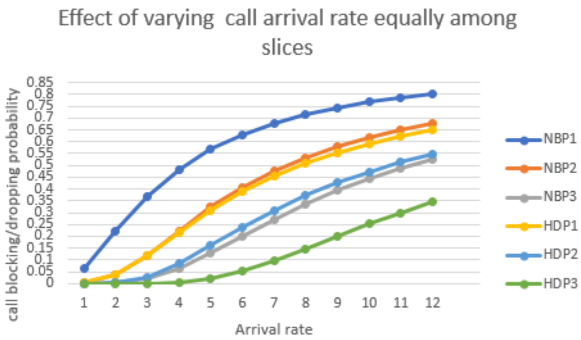


Figure 4.1: Effect of Increasing Call Arrival Rate

Figure4.1 was generated using the table in fig.A.1, this was done using Excel.

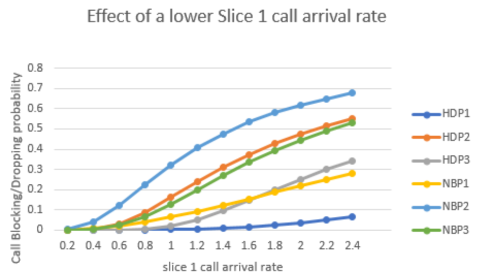
4.1.2 Scenario 2: Lower arrival rate at each slice

In this scenario, the call arrival rate is increased in all the slices, but with one slice having a lower arrival rate. The slice with lower arrival rate, the rate is incremented by 0,2 from 0,2 to 2,4. Figure4.2 shows the effect of lower arrival rate on each slice.

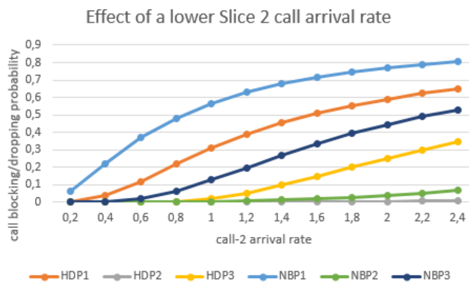
Figure4.2 was generated using the tables in fig.A.2, this was done using Excel

4.1.3 Scenario 3: Higher arrival rate at each slice

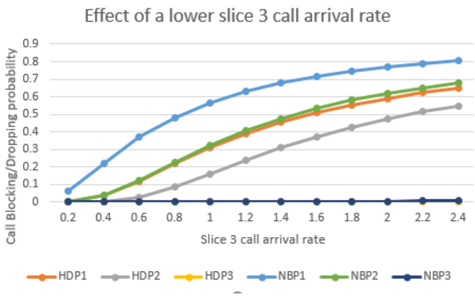
In this scenario, the call arrival rate is increased in all the slices, but with one slice having a higher arrival rate. The slice with higher call arrival rate, the rate is incremented by 5 from 5 to 60, while in other slices it is incremented by 1 from 1 to 12. Figure4.3 shows the effect of higher arrival rate on each slice. Figure4.3 was generated using the tables in fig.A.3, this was done using Excel.



(a) Effect of lower feMBB call arrival rate.



(b) Effect of lower euRLLC call arrival rate.



(c) Effect of lower umMTC call arrival rate.

Figure 4.2: Effect of lower arrival rate.

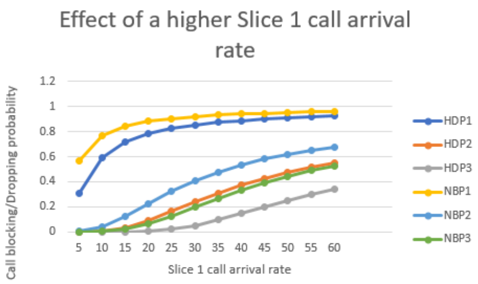
4.2 Effect of Capacity

This section involves investigating the effect of slice capacity on new call blocking probability, handoff call dropping probability, and bandwidth utilisation, the Capacity of each slice was varied. The parameters in table4.2 kept constant during the simulation.

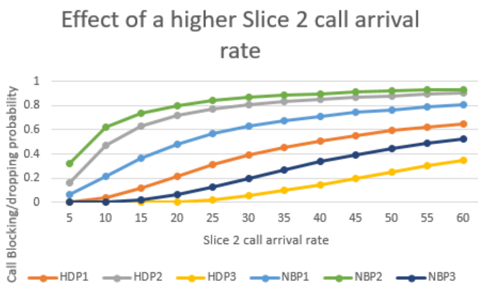
	feMBB	euRLLC	umMTC
Arrival rate	5	5	5
Threshold for new calls	15	15	15
BBU	4	3	2
Departure rate	1	1	1

Table 4.2: Slice Parameters for Section 2

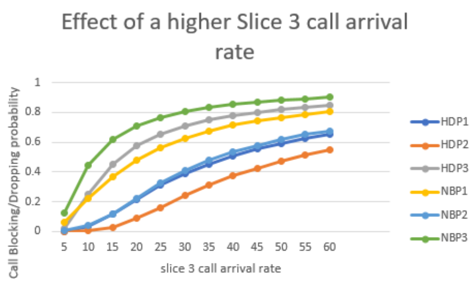
The Effect of Capacity was investigated using two scenarios, where in both scenarios the capacity of slices is increased. An Increase in slice capacity means that the network can support more calls at any point in time.



(a) Effect of higher feMBB call arrival rate.



(b) Effect of higher euRLLC call arrival rate.



(c) Effect of higher umMTC call arrival rate.

Figure 4.3: Effect of higher arrival rate.

4.2.1 Scenario 1: Varying Capacity equally among slices

In this scenario, the capacity in all the slices is incremented by 5 from 5 to 60. Figure4.4 below shows the effect of increasing the capacity of the slices.

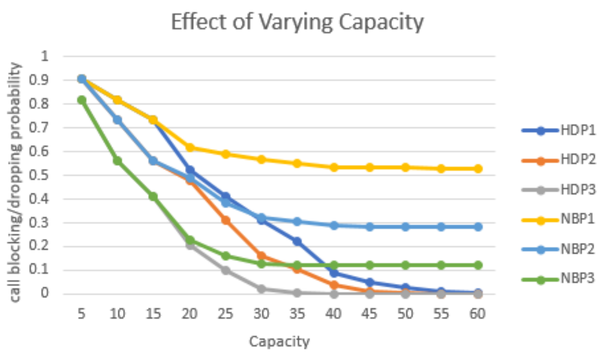
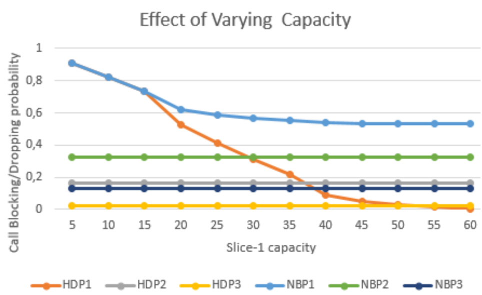


Figure 4.4: Effect of Increasing Capacity

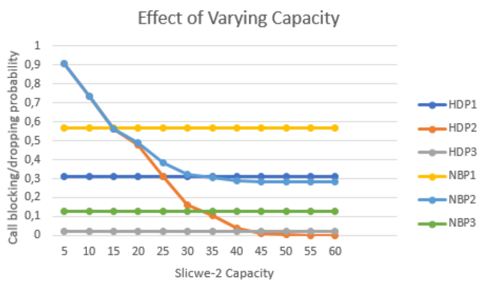
Figure4.4 was generated using the table in fig.A.4, this was done using Excel.

4.2.2 Scenario 2: Varying Capacity in each slice

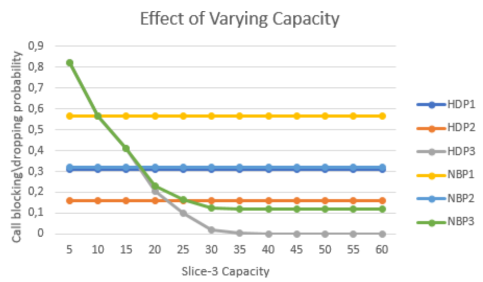
In this scenario, the capacity is kept constant as 30 bbus in the other slices while it is incremented by 5 from 5 to 60 in the investigated slice. Figure4.5 show the effect of increasing the capacity of a single slice. Figure4.5 was generated using the tables in



(a) Effect of increasing feMBB slice capacity.



(b) Effect of increasing euRLLC slice capacity.



(c) Effect of increasing umMTC slice capacity.

Figure 4.5: Effect of increasing slice capacity.

fig.A.5, this was done using Excel.

4.3 Effect of Threshold

In this section, the effect of varying threshold on new call blocking probability, handoff call dropping probability, and bandwidth utilisation is investigated. the parameters in table4.3 were kept constant during the simulation. The effect of varying threshold was investigated using two scenarios, where the threshold for new calls is increase until it reaches the slice capacity. An increase in the threshold hold for new calls means that more new calls will be admitted.

	feMBB	euRLLC	umMTC
Arrival rate	5	5	5
Capacity	30	30	30
BBU	4	3	2
Departure rate	1	1	1

Table 4.3: Slice Parameters for Section 3

4.3.1 Scenario 1: Varying Threshold equally among slices

In this scenario, the threshold for new calls in all the slices is incremented by 5 from 0 to 30. Figure4.6 below shows the effect of increasing threshold in all the slices on the call blocking and dropping probability.

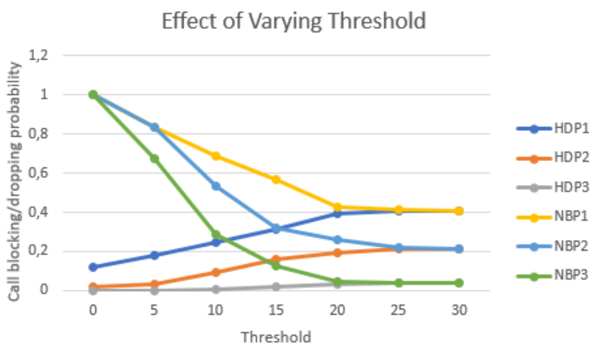
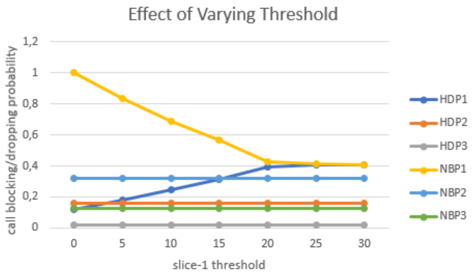


Figure 4.6: Effect of Increasing Threshold

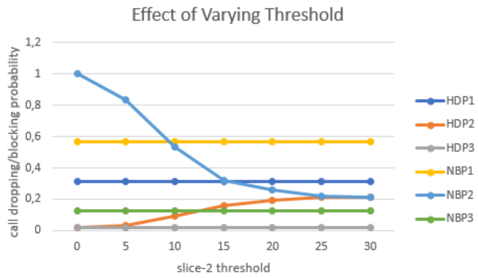
Figure4.6 was generated using the table in fig.A.6, this was done using Excel.

4.3.2 Scenario 2: Varying Threshold in each slice

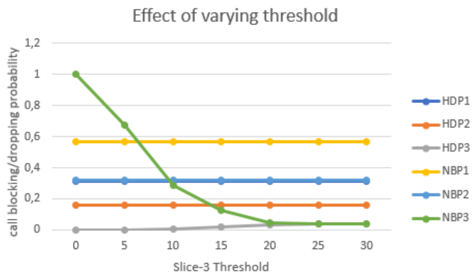
In this scenario, the threshold for new calls is kept constant and equal to 15 in other slices and incremented by 5 from 0 to 30 in the investigated slice. Figure4.7 shows the effect of increasing the threshold for new calls in each slice. Figure4.7 was generated using the tables in fig.A.7, this was done using Excel.



(a) Effect of increasing feMBB threshold for new calls.



(b) Effect of increasing euRLLC threshold for new calls.



(c) Effect of Effect of increasing umMTC threshold for new calls.

Figure 4.7: Effect of increasing threshold for New Calls.

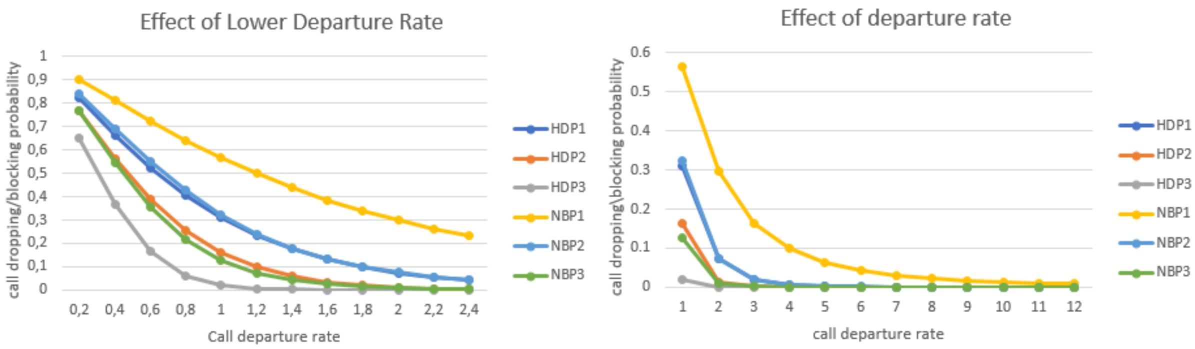
4.4 Effect of Departure Rate

This section shows the Effect of varying call departure rate on new call blocking probability, handoff call dropping probability, and bandwidth utilisation. the parameters in table were kept constant during the simulation. The departure rate for new and handoff calls

	feMBB	euRLLC	umMTC
Arrival rate	5	5	5
Capacity	30	30	30
BBU	4	3	2
Threshold for new calls	15	15	15

Table 4.4: Slice Parameters for Section 4

is assumed to be the same, the effect of increasing the call departure rate was investigated. The Call departure rate in each slice was increased, the effect is shown in figure4.8. In figure4.8a the departure rate was incremented by 0.2 from 0.2 to 2.4, while in figure4.8b the departure rate is incremented by 1 from 1 to 12. Figure4.8 was generated using the tables in fig.A.8, this was done using Excel.



(a) Effect of a lower increase in call departure rate. (b) Effect of a higher increase call departure rate.

Figure 4.8: Effect of increasing call departure rate.

4.5 Effect of Basic Bandwidth Unit

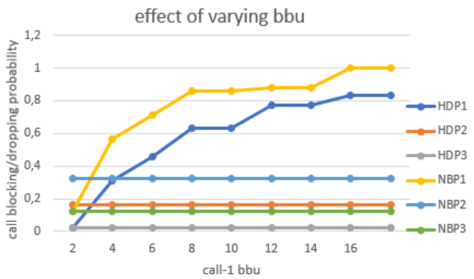
In this section, the results from investigating the effect of varying basic bandwidth unit demanded by users in each slices on the new call dropping probability, handoff call blocking probability, and bandwidth utilisation. The parameters in table4.5 were kept constant during the simulation.

	feMBB	euRLLC	umMTC
Arrival rate	5	5	5
Capacity	30	30	30
Departure rate	1	1	1
Threshold for new calls	15	15	15

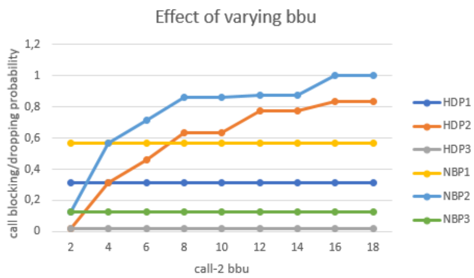
Table 4.5: Slice Parameters for Section 5

For this investigation the bbu required by each user in one of the slices was incremented by 2 from 2 to 18, while the bbu required by user in other slices is kept constant. The constant bbu is 4, 3, and 2 for the feMBB, euRLLC and umMTC slice, respectively. Figure4.9 show the effect of varying bbu required by each user in their respective slices. Figure4.9 was generated using the tables in fig.A.9, this was done using Excel.

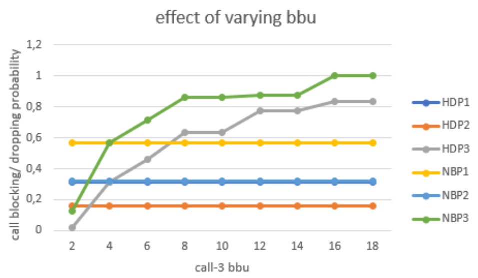
Figure4.10 shows the effect of increasing the demanded bbu on the utilisation of each slice. These results were taken along with the results in fig.4.9.



(a) Effect of increasing feMBB bbu.

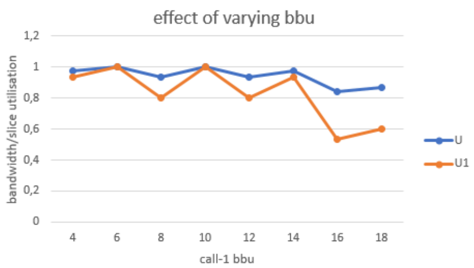


(b) Effect of increasing euRLLC bbu.

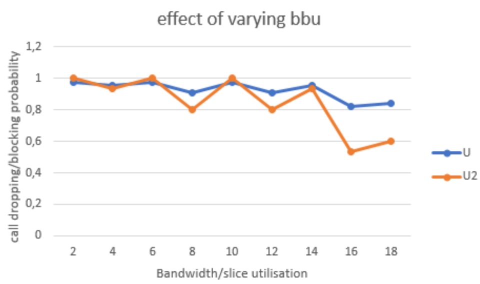


(c) Effect of Effect of increasing umMTC bbu .

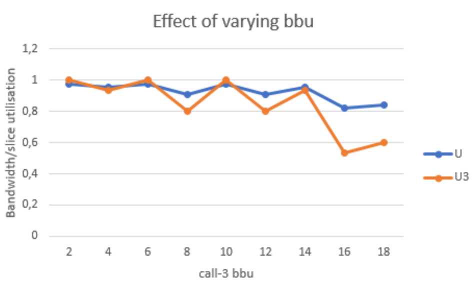
Figure 4.9: Effect of increasing BBU required by supported services on call blocking/dropping probability.



(a) Effect of increasing feMBB bbu.



(b) Effect of increasing euRLLC bbu.



(c) Effect of Effect of increasing umMTC bbu .

Figure 4.10: Effect of increasing BBU required by supported services on slice utilisation.

Chapter 5

Discussion

In this chapter, the results presented in chapter 4 are discussed.

5.1 Effect of Call Arrival rate

Figure4.1 shows the change in call dropping and blocking probabilities as the arrival rate also changes. The increase in the call arrival rate means that the network receives more calls per unit time, network subscribers demand more network resources. Since the algorithm uses a threshold for new calls in the network with the aim of prioritizing handoff calls, the new call blocking probability is higher than handoff call dropping probability for each slice. The new call blocking and handoff call dropping probability for the umMTC slice (NBP3) are the lowest since the service supported by this slice require less bbu compared to the other slices. Both handoff call dropping probabbility and new call dropping probabilty increase with an increase in the rate of call arrivals, this is due to more calls demanding limited resources. The highest probability is the new call blocking probability for the feMBB slice, with a new call blocking probability of up to 80% when the arrival rate is 12.

Figure4.2 shows the effect of increasing a lower arrival rate in each slice. Lower arrival rates mean that there are less calls requesting network resources, consequently resulting to lower blocking and dropping probability. This is seen in figures**??** where the new call blocking probability and handoff call dropping probability were higher in fig.4.2a and lower in fig.4.2b due to a lower arrival rate. The umMTC slice affords the lowest call dropping and blocking probability of at lower arrival rates, it affords its subscribers good

QoS. . When the network deals with low levels of traffic it affords its subscribers good QoS.

This is further enforced by the third scenario of the section. In figure4.3 each slices deals with high arrival rates, consequently the call dropping and blocking probability is high. during this scenario the network deals with higher levels of network traffic on the same amount of network resources , in the feMBB slice in fig.4.3a at the highest arrival rate of 60 the new call blocking probability and handoff call blocking probability is 96% and 92% respectively. Even with the threshold for new calls at high arrival rates the handoff call blocking probability is high.

5.2 Effect of Capacity

Figure4.4 shows a decrease in new call blocking and handoff call dropping probability as the capacity of each slice increases. An increase in slice capacity means that there are now more resources to be allocated to users. This scenario has a threshold for new calls set as a constant, 15, in fig.4.4 the call blocking and dropping probabilities are equal in each slice before and at the capacity of 15, this is because both calls are completely sharing the network resources at capacities lower or equal to the threshold. It is also observed that after the threshold the handoff dropping probability becomes significantly lower than the new call blocking probability, This is due to the prioritisation of handoff calls over new calls.

In figure4.5,it is shown the feMBB slice has the highest call dropping/blocking probability, at capacity 15 (the threshold) the probability for dropping/blocking calls is 73% while the probability for dropping/blocking calls is 56% and 40% for the euRLLC slice and umMTC slice, respectively. This difference is due to the bbu demand in the feMBB slice. A higher slice capacity affords the users better QoS, this further enforces the need for research and the use of new spectrum as outline in chapter 2.

5.3 Effect of Threshold

Figure4.6 shows a decrease of the new call blocking probability in all the slices as the threshold for new calls increases approaching the slice capacity. As the threshold for new calls increases more new calls can be admitted in each slice. Increasing the threshold for new calls also causes an increase of the handoff call dropping probability, more new calls are admitted. The increase of new call threshold means handoff calls are not given as much priority and are now getting dropped. When the threshold is equal to the capacity of the slice the resources of the slice are completely shared between new and handoff calls meaning they have the same blocking/dropping probability.

Figure4.7 shows the effect of varying threshold in each slice. when the threshold is equal to the capacity of the slice the bandwidth is allocated using complete sharing strategy, both probabilities are equal as shown in fig.4.7a at the capacity 30bbus the call blocking and dropping probability according to fig.A.7a is 40%. this scenario does not provide good QoS as subscribers are intolerant of a handoff call getting dropped than getting a new call dropped.

5.4 Effect of Departure Rate

Figure4.8 shows the effect of increasing the new call and handoff call departure rate on the call blocking/dropping probability. An increase of the call departure rate means that more calls release network resources, thus more resources are available for admitting calls. An Increase in the call departure decreases call blocking/dropping probability. In fig.4.8b the departure rate is higher and a significantly low call blocking/dropping probability is prevalent. In fig.4.8a the departure rate is lower and a much higher call dropping/dropping probability is prevalent.

5.5 Effect of Basic Bandwidth Unit

Figure4.9 shows the effect of increasing basic bandwidth unit required by the services support in each slice on the call blocking/dropping probability. It is prevalent that an increase in the demanded bbu increases the call blocking/dropping probability. An increase in the demanded bbu means that calls require more network resources to service them, thus an increase in the demanded bbu means less calls will be admitted in each slice, consequently more calls will be block/dropped. The algorithm prioritises handoff calls this can be seen in fig.4.9a, when the demanded bbu is higher than the threshold for new calls, in fig.A.9a the bbu is 16, the probability for blocking new feMBB slice calls is 1.

Figure4.10 shows the effect of varying bbu on slice utilisation. From figures?? it is reasonable to deduce that slice utilisation is dependent on the bbu demanded by services supported by the slice and the capacity of the slice. In fig.A.9a we can see that for the utilisation of the feMBB slice (U1) all slice resources are used up when the demand bbu is a factor of the capacity. The slices that have services demanding bbu that is a factor of the capacity all the resources of the slice will be used, in tyhe case of this network model the euRLLC slice and umMTC slices

Chapter 6

Conclusions

A slice admission control algorithm is presented in this study. The algorithm is simulated using Matlab and a network model that is compsed of three slices namely, feMBB slice, euRLLC slice, and umMTC slice. The algorithm considers the type of call and QoS requirements, giving priority to handoff calls using a bandwidth reservation strategy.

When priority is not given to handoff calls by means of a bandwidth reservation strategy the handoff call dropping probability and the new call blocking probability are equal, which give rise to higher handoff call blocking probability.This results in high rates of packet loss, thus low QoS. When priority is given to handoff calls by the use of a bandwidth allocation strategy, in this study a guard channel strategy was used.That resulted in lower handoff call blocking probabilities amongst the slices.

Increasing the capacity of slices decreases call blocking/dropping probability, more subscribers can be admitted in the network, and provided good QoS. However, network resources are limited although there are strides taken to explore more frequency spectrum for the use of telecommunication. A service demanding bbu that is a factors of the respective slice capacity the resources can be fully utilized affording efficient resource allocation. Slices that support services demanding little amounts of bbu can afford good QoS due to lo call blocking/dropping probability.

Increasing the departure rate of calls improves QoS by decreasing call blocking/dropping probability. However, it is not entirely possible to predict the exact time that subscribers will stay on the call. when subscribers make short calls that will improve the Qos, the opposite also applies.

Chapter 7

Recommendations

The following recommendations should be considered for future work:

- This study considers a simple network model that only comprises of three slices that only support one service, a network model with more slices and services within each slice is more practical and should be investigated.
- In this study a service can only get resources from one slice, a model with services that get resources from different slices should be considered.
- This study uses a fixed resource allocation strategy, a dynamic resource allocation strategy should be investigated , to especially maximise slice utilisation. to allocate slice capacity and possibly threshold dynamically according to slice conditions
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Bibliography

[1] M. H. Ahmed, "Call Admission Control in Wireless Networks: A Comprehensive Survey", *IEEE*,**vol.7(1)**, 2005

[2] P. Sharma, "Evolution of Mobile Wireless Communication Networks-1G to 5G as well as Future Prospective of Next Generation Communication Network" *Internnational Journal of Computer Scieces and Mobile Computing*, **vol.2(8)**, pp.47-53, 2013.

[3] C. X. Wang, X. You, X. Gao, X. Zhu, Z. Li, C. Zhang, H. Wing, J. S. Thompson, E. G. Larsson, M. D. Renzo, W. Tong, P. Zhu, X. Shen, H. V. Poor and L. Hanzo, "On the Road to 6G: Visions, Requirements, Key Technologies, and Testbeds" *IEEE Communications surveys and Tutorials* **Vol.25(2)**, 2023

[4] I. A. Balapuwaduge, F. Y. Li,"Cellular networks: an evolution from 1g to 4g." *Centre for Integrated Emergency Management*, 2018.

[5] S. U. Jamil, M. A. Khan, S. U. Rehman, "Resource allocation and task off-loading for 6G enabled smart edge environments"*IEEE*, **vol.10**, 2022.

[6] S. U. Jamil, M. A. Khan and S. U. Rehman, "Intelligent task off-loading and resource allocation for 6G smart city environment"*IEEE 45th conf. Local Comput. Netw.(LCN)*, Nov.2020,pp

[7] M.Afhamisi and M. R. Palattella, "Salsa: a scheduling algorithm for LoRa to LEO satellites"*IEEE access*, **vol.10**, pp. , 2022.

[8] M. Al-Ali, E. Yaacoub, "Resource allocation scheme for eMBB and uRLLC coexistance in 6G networks", *Wireless Network*,**29**, 2519-2538, 2023.

[9] X. Huang, K. Wu, M. Jiang, L. Huang and J. Xu, "Distributed Resource Allocation for General Energy Efficiency Maximization in Offshore Maritime Device-to-Device Communication", *IEEE Wireless Communications Letters*, **Vol.10(6)**, 2021.

[10] S. Kianpisheh and R. H. Glitho, "Joint Admission Control and Resource Allocation with Parallel VNF processing for Time-Constrained chains of Virtual Network Functions", *IEEE Access*, 2021

[11] D. Bega, M. Gramaglia, A. Banchs, V. Sciancalepore and X. Costa-Perez," A Machine Learning Approach to 5G Infrastructure Market Optimization", *IEEE Transactions on Mobile Computing*, **Vol.19(3)**, 2020.

[12] S. Zhou, W. Jadoon, "Jointly optimizing Offloading Decision and Bandwidth Allocation with Energy Constraint in Mobile Edge Computing environment", *Computing*, **103(99)**,2021.

[13] R. Prasad and A. Sunny, "Scheduling Slice Requests in 5G Networks" *IEEE/ACM Transactions on Networking*, 2023.

[14] M. Dai, G. Sun, H. Yu, D. Niyato, "Maximize the Long-term Average Revenue of Network Slice Provider via Admission Control Among Heterogeneous Slices", *IEEE/ACM Transactions on Networking*, 2023.

[15] M. O. Ojijo and O. E. Falowo, "A survey on Slice Admission Control Strategies and Optimization Schemes in 5G Network",*IEEE Access*, 2020.

[16] Q. T. Luu, S. Kerbeouf and M. Kieffer, "Admission Control and Resource Reservation for Prioritized Slice Requests with Guaranteed SLA under Uncertainties", *IEEE Transactions on Network and Service Management*, 2022.

[17] M. Dai, L. Luo, J. Ren, H. Yu and G. Sun, "PSACCF: Prioritized Online Slice Admission Control Considering Fairness in 5G/B5G Networks", *IEEE Transactions on Network Science and Engineering*, **vol.9(6)**,2022.

[18] T. Hu, Q. Liu and G. Carle, " Inter-Cell Network Slicing with Transfer Learning Empowered Multi-Agent Deep Reinforcement Learning" *IEEE Communication Society*, 2023

[19] I. Vila, J. Perez-Romero, o. Sallent and A. Umbert, "Characterization of Radio Access network Slicing Scenarios with 5G QoS Provisioning" *IEEE Access*, 2020.

[20] B. Hahn, D. Feng, H. D. Schetten, "A Markov Model of Slice Admission Control", *IEEE Networking Letters*, **Vol.1(1)**, 2019.

[21] F. Debbabi, R. Taktak, R. Jmal, L. C. Fourati and R. L. Aguiar. "Inter-slice B5G Bandwidth Resource Allocation" *IEEE 21st International Symposium on Network Computing and Applications*, pp.157-163, 2022.

[22] E. Inaty, R. Raad and M. Maier, "Generalized Multi-Access Dynamic Badwidth Allocation Scheme for Future Generation PONs: A Solution for Beyond 5G Delay/Jitter Sensitive systems", *Journal of Lightwave Technology*, **Vol.40(2)**, 2022.

[23] T. Hu, Q. Liao, Q. Liu, D. Wellington, and G. Carle,"Inter-cell slicing resource partitioning via coordinated multi-agent deep reinforcement learning", *IEEE ICC*, 2022, pp.3202-3207.

[24] H. Beshley, M. Beshley, M. Medvetskyi, and J. Pyrih, "QoS-aware optimal radio resource allocation method for machine-type communications in 5G LTE and beyond cellular networks," *Wireless communication for network slicing*,2021.

[25] W. F. Villota Jacome, O. M. Caicedo Rendon and N. L. S. da Fonseca, "Admission control for 5G Network Slicing based on (Deep) Reinforcement Learning", *TechRxiv*, 2021. [online] `https://www.researchgate.net/publication/351239776_Admission_Control_for_5G_Network_Slicing_based_on_Deep_Reinforcement_Learning`

[26] F. Debbabi, R. Jmal, L. C. Fourati and R. L. Aguiar, "An Overview of Interslice and Intraslice Resource Allocation in B5G Telecommunication Networks" *IEEE Transactions on Network and Service Management*, **Vol.19(4)**, 2022.

[27] N. Sasaki, F. Tanaka, S. Saito, H. Suganuma and F. Maehara, "Hybrid Multiple Access Scheme Employing NOMA and OMA Simultaneously Under Non-uniform user Distribution and Multiple Transit Antennas", *Joint European Conference on Networks and Commuications and 6G Summit(EuCNC/6G Summit)*, pp.1-5, 2023.

[28] M. Mamman and Z. M. Hanapi, "Call Amission Control Algorithm With Efficient Handoff for both 4G and 5G Networks", *International Journal of Wireless and Mobile Networks*, **Vol.13(2)**, 2021

[29] H. Cui, j. Zhang, Y. Geng, Z. Xiao, T. Sun, N. Zhang, J. Liu, Q. Wu, and X. Cao, "Space-Air-Ground Integrated Network (SAGIN) for 6G: Requirements, Architecture and challenges", *China Communications Magazine*,**Vol.19(2)**, 2021.

[30] W. Jiang, Y. Zhan, G. Zeng, and J. Lu, "Probabilistic-Forecasting-Based Admission Control for Network Slicing in Software-Defined Networks", *IEEE IoT Journal*, **Vol.9(15)**, 2021

[31] M. Glabowski, and M.Sobieraj, "Analytical Modeling of the influence of connection Handoff on Blocking probabilities in 5G Mobile Networks", *17th International Conference on Telecommunications*, 2023

[32] G. Liu, Y. Huang, N. Li, J. Dong, J. Jin, Q. Wang, and N. Li, "Vision, Requirements and Network Architecture of 6G mobile Network beyond 2030", *China Mobile Research Institute*, 2020.

[33] P. Kamble, and A. N. Shaikh, "6G Wireless Networks: Vision, Requirements, Applications and Challenges", *International Conference on Advances in Science and Technology (ICAST)*, 2022.

[34] A. Hassebo, "The Road to 6G, Vision, Drivers, Trends, and challenges" *IEEE CCWC*, 2022.

[35] D. G. S. Pivoto, T. T. Rezende, M. S. P. Facina, R. Moreira, F. D. O. Silva, K. V. Cardoso, S. L. Correa, A. V. D. Araujo, R. S. E. Silva, H. S. Neto, G. R. D. L. Tejerina, and A. M. Alberti, "A Detailed Relevace Analysis of enabling technologies for 6G Architectures", *IEEE Access*, 2023.

[36] Q. Pan, J. Wu, X. Zheng, W. Yang, and J. Li, "Differential Privacy and IRS Empowered intelligent Energy Harvesting for 6G Internet of Things", *IEEE IoT Journal*, Vol.9 (22), 2022.

Appendix A

Tables used to generate graphs

Arrival rat	NBP1	NBP2	NBP3	HDP1	HDP2	HDP3
1	0.0631	0.0031	0.0001	0.0018	0	0
2	0.2191	0.0382	0.0034	0.0354	0.0034	0
3	0.3678	0.1201	0.0221	0.1184	0.0286	0.0005
4	0.4821	0.2236	0.0645	0.2178	0.0864	0.0048
5	0.5663	0.3226	0.1267	0.3101	0.162	0.0204
6	0.6289	0.4071	0.1983	0.3887	0.2393	0.0518
7	0.6766	0.4764	0.2698	0.454	0.3104	0.0962
8	0.7138	0.533	0.3359	0.5081	0.3728	0.1477
9	0.7436	0.5794	0.3944	0.5532	0.4268	0.2007
10	0.7679	0.6179	0.4455	0.5912	0.4733	0.2519
11	0.788	0.6502	0.4897	0.6235	0.5135	0.2998
12	0.805	0.6776	0.528	0.6512	0.5484	0.3437

Figure A.1: Effect of Increasing Call Arrival Rate

Capacity	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
5	0.9091	0.9091	0.8197	0.9091	0.9091	0.8197
10	0.8197	0.7321	0.564	0.8197	0.7321	0.564
15	0.7321	0.564	0.409	0.7321	0.564	0.409
20	0.5227	0.4806	0.2063	0.6192	0.4897	0.229
25	0.413	0.3108	0.1018	0.5877	0.3814	0.1631
30	0.3101	0.162	0.0204	0.5663	0.3226	0.1267
35	0.2198	0.1057	0.0046	0.552	0.3065	0.1217
40	0.0898	0.0355	0.0003	0.5367	0.2907	0.1206
45	0.0511	0.0086	0	0.5333	0.286	0.1205
50	0.0267	0.0037	0	0.5314	0.2853	0.1205
55	0.0128	0.0006	0	0.5304	0.2849	0.1205
60	0.0023	0.0001	0	0.5298	0.2849	0.1205

Figure A.4: Effect of Increasing Capacity

Arrival rat	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
0.2	0	0	0	0.0011	0.0031	0.0001
0.4	0	0.0034	0	0.0072	0.0382	0.0034
0.6	0.0001	0.0286	0.0005	0.0199	0.1201	0.0221
0.8	0.0005	0.0864	0.0048	0.0389	0.2236	0.0645
1	0.0018	0.162	0.0204	0.0631	0.3226	0.1267
1.2	0.0043	0.2393	0.0518	0.0911	0.4071	0.1983
1.4	0.0086	0.3104	0.0962	0.1217	0.4764	0.2698
1.6	0.0152	0.3728	0.1477	0.1538	0.533	0.3359
1.8	0.0241	0.4268	0.2007	0.1865	0.5794	0.3944
2	0.0354	0.4733	0.2519	0.2191	0.6179	0.4455
2.2	0.0488	0.5135	0.2998	0.2511	0.6502	0.4897
2.4	0.0642	0.5484	0.3437	0.2822	0.6776	0.528

(a) Effect of lower feMBB call arrival rate.

Arrival rat	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
1	0.0018	0	0	0.0631	0	0.0001
2	0.0354	0	0	0.2191	0.0001	0.0034
3	0.1184	0	0.0005	0.3678	0.0004	0.0221
4	0.2178	0	0.0048	0.4821	0.0012	0.0645
5	0.3101	0	0.0204	0.5663	0.0031	0.1267
6	0.3887	0.0001	0.0518	0.6289	0.0063	0.1983
7	0.454	0.0003	0.0962	0.6766	0.0112	0.2698
8	0.5081	0.0008	0.1477	0.7138	0.0181	0.3359
9	0.5532	0.0017	0.2007	0.7436	0.0271	0.3944
10	0.5912	0.0034	0.2519	0.7679	0.0382	0.4455
11	0.6235	0.0059	0.2998	0.788	0.0513	0.4897
12	0.6512	0.0096	0.3437	0.805	0.0663	0.528

(b) Effect of lower euRLLC call arrival rate.

Arrival rat	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
0.2	0.0018	0	2.75E-19	0.0631	0.0031	0
0.4	0.0354	0.0034	6.04E-15	0.2191	0.0382	0
0.6	0.1184	0.0286	1.77E-12	0.3678	0.1201	0
0.8	0.2178	0.0864	8.90E-11	0.4821	0.2236	0
1	0.3101	0.162	1.70E-09	0.5663	0.3226	0.0001
1.2	0.3887	0.2393	1.75E-08	0.6289	0.4071	0.0002
1.4	0.454	0.3104	1.19E-07	0.6766	0.4764	0.0005
1.6	0.5081	0.3728	5.89E-07	0.7138	0.533	0.0011
1.8	0.5532	0.4268	2.31E-06	0.7436	0.5794	0.002
2	0.5912	0.4733	7.53E-06	0.7679	0.6179	0.0034
2.2	0.6235	0.5135	2.11E-05	0.788	0.6502	0.0055
2.4	0.6512	0.5484	5.22E-05	0.805	0.6776	0.0083

(c) Effect of lower umMTC call arrival rate.

Figure A.2: Effect of lower arrival rate.

Threshold	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
0	0.1205	0.0184	0.0002	1	1	1
5	0.1786	0.0342	0.001	0.8371	0.8339	0.6757
10	0.2447	0.0898	0.0086	0.6896	0.5367	0.286
15	0.3101	0.162	0.0204	0.5663	0.3226	0.1267
20	0.3954	0.1899	0.0345	0.4286	0.2609	0.0429
25	0.4071	0.2129	0.0364	0.4116	0.2174	0.0368
30	0.409	0.2146	0.0365	0.409	0.2146	0.0365

Figure A.6: Effect of Increasing Threshold

Arrival rat	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
5	0.3101	0	0	0.5663	0.0031	0.0001
10	0.5912	0.0034	0	0.7679	0.0382	0.0034
15	0.7148	0.0286	0.0005	0.8429	0.1201	0.0221
20	0.7817	0.0864	0.0048	0.8814	0.2236	0.0645
25	0.8234	0.162	0.0204	0.9048	0.3226	0.1267
30	0.8518	0.2393	0.0518	0.9205	0.4071	0.1983
35	0.8723	0.3104	0.0962	0.9318	0.4764	0.2698
40	0.8878	0.3728	0.1477	0.9402	0.533	0.3359
45	0.9	0.4268	0.2007	0.9468	0.5794	0.3944
50	0.9098	0.4733	0.2519	0.9521	0.6179	0.4455
55	0.9179	0.5135	0.2998	0.9564	0.6502	0.4897
60	0.9246	0.5484	0.3437	0.9601	0.6776	0.528

(a) Effect of higher feMBB call arrival rate.

Arrival rat	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
5	0.0018	0.162	0	0.0631	0.3226	0.0001
10	0.0354	0.4733	0	0.2191	0.6179	0.0034
15	0.1184	0.6294	0.0005	0.3678	0.7394	0.0221
20	0.2178	0.7157	0.0048	0.4821	0.8029	0.0645
25	0.3101	0.7698	0.0204	0.5663	0.8416	0.1267
30	0.3887	0.8067	0.0518	0.6289	0.8677	0.1983
35	0.454	0.8335	0.0962	0.6766	0.8864	0.2698
40	0.5081	0.8537	0.1477	0.7138	0.9004	0.3359
45	0.5532	0.8696	0.2007	0.7436	0.9114	0.3944
50	0.5912	0.8824	0.2519	0.7679	0.9202	0.4455
55	0.6235	0.8929	0.2998	0.788	0.9274	0.4897
60	0.6512	0.9017	0.3437	0.805	0.9334	0.528

(b) Effect of higher euRLLC call arrival rate.

Arrival rat	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
5	0.0018	0	0.0204	0.0631	0.0031	0.1267
10	0.0354	0.0034	0.2519	0.2191	0.0382	0.4455
15	0.1184	0.0286	0.452	0.3678	0.1201	0.6164
20	0.2178	0.0864	0.5747	0.4821	0.2236	0.709
25	0.3101	0.162	0.6539	0.5663	0.3226	0.7659
30	0.3887	0.2393	0.7087	0.6289	0.4071	0.8044
35	0.454	0.3104	0.7487	0.6766	0.4764	0.832
40	0.5081	0.3728	0.7791	0.7138	0.533	0.8528
45	0.5532	0.4268	0.8029	0.7436	0.5794	0.869
50	0.5912	0.4733	0.8222	0.7679	0.6179	0.882
55	0.6235	0.5135	0.838	0.788	0.6502	0.8927
60	0.6512	0.5484	0.8513	0.805	0.6776	0.9016

(c) Effect of higher umMTC call arrival rate.

Figure A.3: Effect of higher arrival rate.

Capacity	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
5	0.9091	0.162	0.0204	0.9091	0.3226	0.1267
10	0.8197	0.162	0.0204	0.8197	0.3226	0.1267
15	0.7321	0.162	0.0204	0.7321	0.3226	0.1267
20	0.5227	0.162	0.0204	0.6192	0.3226	0.1267
25	0.413	0.162	0.0204	0.5877	0.3226	0.1267
30	0.3101	0.162	0.0204	0.5663	0.3226	0.1267
35	0.2198	0.162	0.0204	0.552	0.3226	0.1267
40	0.0898	0.162	0.0204	0.5367	0.3226	0.1267
45	0.0511	0.162	0.0204	0.5333	0.3226	0.1267
50	0.0267	0.162	0.0204	0.5314	0.3226	0.1267
55	0.0128	0.162	0.0204	0.5304	0.3226	0.1267
60	0.0023	0.162	0.0204	0.5298	0.3226	0.1267

(a) Effect of increasing feMBB slice capacity.

Capacity	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
5	0.3101	0.9091	0.0204	0.5663	0.9091	0.1267
10	0.3101	0.7321	0.0204	0.5663	0.7321	0.1267
15	0.3101	0.564	0.0204	0.5663	0.564	0.1267
20	0.3101	0.4806	0.0204	0.5663	0.4897	0.1267
25	0.3101	0.3108	0.0204	0.5663	0.3814	0.1267
30	0.3101	0.162	0.0204	0.5663	0.3226	0.1267
35	0.3101	0.1057	0.0204	0.5663	0.3065	0.1267
40	0.3101	0.0355	0.0204	0.5663	0.2907	0.1267
45	0.3101	0.0086	0.0204	0.5663	0.286	0.1267
50	0.3101	0.0037	0.0204	0.5663	0.2853	0.1267
55	0.3101	0.0006	0.0204	0.5663	0.2849	0.1267
60	0.3101	0.0001	0.0204	0.5663	0.2849	0.1267

(b) Effect of increasing euRLLC slice capacity.

Capacity	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
5	0.3101	0.162	0.8197	0.5663	0.3226	0.8197
10	0.3101	0.162	0.564	0.5663	0.3226	0.564
15	0.3101	0.162	0.409	0.5663	0.3226	0.409
20	0.3101	0.162	0.2063	0.5663	0.3226	0.229
25	0.3101	0.162	0.1018	0.5663	0.3226	0.1631
30	0.3101	0.162	0.0204	0.5663	0.3226	0.1267
35	0.3101	0.162	0.0046	0.5663	0.3226	0.1217
40	0.3101	0.162	0.0003	0.5663	0.3226	0.1206
45	0.3101	0.162	0	0.5663	0.3226	0.1205
50	0.3101	0.162	0	0.5663	0.3226	0.1205
55	0.3101	0.162	0	0.5663	0.3226	0.1205
60	0.3101	0.162	0	0.5663	0.3226	0.1205

(c) Effect of increasing umMTC slice capacity.

Figure A.5: Effect of increasing slice capacity.

Threshold	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
0	0.1205	0.162	0.0204	1	0.3226	0.1267
5	0.1786	0.162	0.0204	0.8371	0.3226	0.1267
10	0.2447	0.162	0.0204	0.6896	0.3226	0.1267
15	0.3101	0.162	0.0204	0.5663	0.3226	0.1267
20	0.3954	0.162	0.0204	0.4286	0.3226	0.1267
25	0.4071	0.162	0.0204	0.4116	0.3226	0.1267
30	0.409	0.162	0.0204	0.409	0.3226	0.1267

(a) Effect of increasing feMBB threshold for new calls.

Threshold	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
0	0.3101	0.0184	0.0204	0.5663	1	0.1267
5	0.3101	0.0342	0.0204	0.5663	0.8339	0.1267
10	0.3101	0.0898	0.0204	0.5663	0.5367	0.1267
15	0.3101	0.162	0.0204	0.5663	0.3226	0.1267
20	0.3101	0.1899	0.0204	0.5663	0.2609	0.1267
25	0.3101	0.2129	0.0204	0.5663	0.2174	0.1267
30	0.3101	0.2146	0.0204	0.5663	0.2146	0.1267

(b) Effect of increasing euRLLC threshold for new calls.

Threshold	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
0	0.3101	0.162	0.0002	0.5663	0.3226	1
5	0.3101	0.162	0.001	0.5663	0.3226	0.6757
10	0.3101	0.162	0.0086	0.5663	0.3226	0.286
15	0.3101	0.162	0.0204	0.5663	0.3226	0.1267
20	0.3101	0.162	0.0345	0.5663	0.3226	0.0429
25	0.3101	0.162	0.0364	0.5663	0.3226	0.0368
30	0.3101	0.162	0.0365	0.5663	0.3226	0.0365

(c) Effect of increasing umMTC threshold for new calls.

Figure A.7: Effect of increasing threshold for New Calls.

departure	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
1	0.3101	0.162	0.0204	0.5663	0.3226	0.1267
2	0.0725	0.0119	0.0001	0.2973	0.0744	0.01
3	0.0179	0.001	0	0.1647	0.0209	0.0013
4	0.0052	0.0001	0	0.0986	0.0074	0.0003
5	0.0018	0	0	0.0631	0.0031	0.0001
6	0.0007	0	0	0.0426	0.0015	0
7	0.0003	0	0	0.03	0.0008	0
8	0.0001	0	0	0.0219	0.0004	0
9	0.0001	0	0	0.0165	0.0003	0
10	0	0	0	0.0127	0.0002	0
11	0	0	0	0.01	0.0001	0
12	0	0	0	0.008	0.0001	0

(a) Effect of a lower increase in call departure rate.

departure	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3
0.2	0.8234	0.7698	0.6539	0.9048	0.8416	0.7659
0.4	0.6637	0.5641	0.3641	0.8125	0.6898	0.5453
0.6	0.5241	0.3917	0.1654	0.7245	0.5495	0.3562
0.8	0.4062	0.2578	0.0619	0.642	0.4258	0.2165
1	0.3101	0.162	0.0204	0.5663	0.3226	0.1267
1.2	0.234	0.0982	0.0064	0.498	0.2409	0.0737
1.4	0.1752	0.0583	0.002	0.4373	0.1787	0.0434
1.6	0.1306	0.0342	0.0007	0.384	0.1326	0.026
1.8	0.0973	0.0201	0.0002	0.3376	0.0989	0.016
2	0.0725	0.0119	0.0001	0.2973	0.0744	0.01
2.2	0.0542	0.0071	0	0.2626	0.0565	0.0064
2.4	0.0407	0.0043	0	0.2325	0.0434	0.0042

(b) Effect of a higher increase call departure rate.

Figure A.8: Effect of increasing call departure rate.

slice1 bbu	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3	U	U1
2	0.0204	1.62E-01	0.0204	0.1267	0.3226	0.1267	1	1
4	0.3101	1.62E-01	0.0204	0.5663	0.3226	0.1267	0.9778	0.9333
6	0.4579	1.62E-01	0.0204	0.712	0.3226	0.1267	1	1
8	0.6321	1.62E-01	0.0204	0.8597	0.3226	0.1267	0.9333	0.8
10	0.6321	1.62E-01	0.0204	0.8597	0.3226	0.1267	1	1
12	0.7732	1.62E-01	0.0204	0.8763	0.3226	0.1267	0.9333	0.8
14	0.7732	1.62E-01	0.0204	0.8763	0.3226	0.1267	0.9778	0.9333
16	0.8333	1.62E-01	0.0204	1	0.3226	0.1267	0.8444	0.5333
18	0.8333	1.62E-01	0.0204	1	0.3226	0.1267	0.8667	0.6

(a) Effect of increasing feMBB bbu.

slice2 bbu	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3	U	U2
2	0.3101	0.0204	0.0204	0.5663	0.1267	0.1267	0.9778	1
4	0.3101	0.3101	0.0204	0.5663	0.5663	0.1267	0.9556	0.9333
6	0.3101	0.4579	0.0204	0.5663	0.712	0.1267	0.9778	1
8	0.3101	0.6321	0.0204	0.5663	0.8597	0.1267	0.9111	0.8
10	0.3101	0.6321	0.0204	0.5663	0.8597	0.1267	0.9778	1
12	0.3101	0.7732	0.0204	0.5663	0.8763	0.1267	0.9111	0.8
14	0.3101	0.7732	0.0204	0.5663	0.8763	0.1267	0.9556	0.9333
16	0.3101	0.8333	0.0204	0.5663	1	0.1267	0.8222	0.5333
18	0.3101	0.8333	0.0204	0.5663	1	0.1267	0.8444	0.6

(b) Effect of increasing euRLLC bbu.

slice3 bbu	HDP1	HDP2	HDP3	NBP1	NBP2	NBP3	U	U3
2	0.3101	0.162	0.0204	0.5663	0.3226	0.1267	0.9778	1
4	0.3101	0.162	0.3101	0.5663	0.3226	0.5663	0.9556	0.9333
6	0.3101	0.162	0.4579	0.5663	0.3226	0.712	0.9778	1
8	0.3101	0.162	0.6321	0.5663	0.3226	0.8597	0.9111	0.8
10	0.3101	0.162	0.6321	0.5663	0.3226	0.8597	0.9778	1
12	0.3101	0.162	0.7732	0.5663	0.3226	0.8763	0.9111	0.8
14	0.3101	0.162	0.7732	0.5663	0.3226	0.8763	0.9556	0.9333
16	0.3101	0.162	0.8333	0.5663	0.3226	1	0.8222	0.5333
18	0.3101	0.162	0.8333	0.5663	0.3226	1	0.8444	0.6

(c) Effect of Effect of increasing umMTC bbu .

Figure A.9: Effect of increasing BBU required by supported services.

Appendix B

Addenda

B.1 Ethics Forms

```
%Thesis Project: Call admission control and Bandwidth Allocation scheme
%Uses static threshold to prioritise handoff calls
% Supervisor: O.E Falowo

U=zeros(12,1);              %Bandwidth utilisation of the network
%feMBB slice
Cap11=5:5:60;
Cap11=transpose(Cap11);
le=length(Cap11);
%Cap1=30;          %capacity of the feMBB slice
T1=[15 15 15 15 15 15 15 15 15 15 15 15]';
%T1=0:5:30;
%le=length(T1);
%T1=fix((1/2)*(Cap1));          %threshold for new calls
b1=[4 4 4 4 4 4 4 4 4 4 4 4 4]';
%b1=2:2:24;
%b1=transpose(b1);
%le=length(b1);
%b3=b1;
U1=zeros(12,1);              %feMBB slice utilisation

%euRLLC slice
Cap22=5:5:60;
Cap22=transpose(Cap22);
%le=length(Cap22);
%Cap2=30;         %capacity of the euRLLC slice
T2=[15 15 15 15 15 15 15 15 15 15 15 15]';
%T2=0:5:30;
%le=length(T2);
%T2=fix((1/2)*(Cap2));          %threshold for new calls
b2=[3 3 3 3 3 3 3 3 3 3 3 3 3]';                    %basic bandwidth uni
%b2= 2:2:24;
%le=length(b2);
%b2=transpose(b2);
%b2=3;                          %basic bandwidth unit required by service
U2=zeros(12,1);              %euRLLC slice utilisation
%T2=T1;

%umMTC slice
```

```
Cap33=5:5:60;
Cap33=transpose(Cap33);
%le=length(Cap33);
%Cap3=30;            %capacity of the umMTC slice
T3=[15 15 15 15 15 15 15 15 15 15 15 15]';
%T3=fix((1/2)*(Cap3));        %threshold for new calls
%T3=0:5:30;
%le=length(T3);
%T1=T3;
% T2=T3;
%b3= 2:2:18;
%le=length(b3);
%b3=transpose(b3);
b3=[2 2 2 2 2 2 2 2 2 2 2 2 2]';                          %basic bandwidth un

U3=zeros(12,1);           %umMTC slice utilisation

%pool= Cap1+Cap2+Cap3;               %total pool of resources

%call arrival
%new calls;
%An1=1:1:12;
%le=length(An1);
An1= [5 5 5 5 5 5 5 5 5 5 5 5]; %arrival rate
An1=transpose(An1);
%An1=(0.2).*An1;
%An2= 1:1:12;
An2=An1;
%An2=transpose(An2);
%An2=(0.2).*An2;
%An3= 1:1:12;
An3=An1;
%An3=transpose(An3);
%An3=(0.2).*An3;
%un1=0.2:0.2:2.4;                %mean holding time
un1=[1 1 1 1 1 1 1 1 1 1 1 1 1]';
%un1=transpose(un1);

%le=length(un1);
```

```
un2=un1;
un3=un1;
%un2=0.5+c;
%un3=0.5+c;

%handoff calls
c=.5;                         %handoff rate
Ah1=(c.*An1)./0.5;
Ah2=(c.*An2)./0.5;
Ah3=(c.*An3)./0.5;
uh1=un1;
uh2=un1;
uh3=un1;
%uh2=0.5+c;
%uh3=0.5+c;


% initialize normalisation constants
G1=zeros(12,1);
G2=zeros(12,1);
G3=zeros(12,1);
Gn1=zeros(12,1);
Gn2=zeros(12,1);
Gn3=zeros(12,1);
Gh1=zeros(12,1);
Gh2=zeros(12,1);
Gh3=zeros(12,1);
%initialize traffic intesity
%feMBB slice
tn1=zeros(12,1);
th1=zeros(12,1);
%euRLLC slice
tn2=zeros(12,1);
th2=zeros(12,1);
%umMTC slice
tn3=zeros(12,1);
th3=zeros(12,1);

%initialize state probabilities
```

```
%feMBB slice
Pn1=zeros(12,1);
Ph1=zeros(12,1);
%euRLLC slice
Pn2=zeros(12,1);
Ph2=zeros(12,1);
%umMTC slice
Pn3=zeros(12,1);
Ph3=zeros(12,1);

%initialize new call blocking probabilities
Nbp1=zeros(12,1);
Nbp2=zeros(12,1);
Nbp3=zeros(12,1);

%initialize handoff call dropping probabilities
Hdp1=zeros(12,1);
Hdp2=zeros(12,1);
Hdp3=zeros(12,1);

for i=1:le
    Cap1=Cap11(i);
    Cap2=Cap22(i);
    Cap3=Cap33(i);
    %loads at each slice from new calls
    ln1=(Cap1/Cap1).*An1;
    ln2=(Cap2/Cap2).*An2;
    ln3=(Cap3/Cap3).*An3;

    %loads at each slice from handoff calls
    lh1=(Cap1/Cap1).*Ah1;
    lh2=(Cap2/Cap2).*Ah2;
    lh3=(Cap3/Cap3).*Ah3;
    %admissible state
    %new calls
    Sn1=fix(T1(i)/b1(i))+1;
    Sn2=fix(T2(i)/b2(i))+1;
    Sn3=fix(T3(i)/b3(i))+1;
    %handoff calls
```

```
Sh1=fix(Cap1/b1(i))+1;
Sh2=fix(Cap2/b2(i))+1;
Sh3=fix(Cap3/b3(i))+1;
%traffic intensity at each slice due to new calls
tn1(i)=ln1(i)/un1(i);
tn2(i)=ln2(i)/un2(i);
tn3(i)=ln3(i)/un3(i);
%traffic intesnity at each slice due to handoff calls
th1(i)=lh1(i)/uh1(i);
th2(i)=lh2(i)/uh2(i);
th3(i)=lh3(i)/uh3(i);
%add calls to admissible state
for n1=0:Sn1
    for h1=0:Sh1
        for n2=0:Sn2
            for h2=0:Sh2
                for n3=0:Sn3
                    for h3=0:Sh3
                        if ((b1(i)*(n1+h1)<=Cap1)&&(b1(i)*(n1)<=T1(i))&
                            %compute state probabilities
                            %meMBB slice
                            Pn1(i)=(tn1(i)^(n1))/(factorial(n1));
                            Ph1(i)=(th1(i)^(h1))/(factorial(h1));
                            %euRLLC slice
                            Pn2(i)=(tn2(i)^(n2))/(factorial(n2));
                            Ph2(i)=(th2(i)^(h2))/(factorial(h2));
                            %umMTC slice
                            Pn3(i)=(tn3(i)^(n3))/(factorial(n3));
                            Ph3(i)=(th3(i)^(h3))/(factorial(h3));
                            n11=n1;
                            n22=n2;
                            n33=n3;
                            h11=h1;
                            h22=h2;
                            h33=h3;
                            %G(i)= G(i)+Pn1(i)+Pn2(i)+Pn3(i)+Ph1(i)+Ph
                            G1(i)= G1(i)+Pn1(i)*Ph1(i);
                            G2(i)= G2(i)+Pn2(i)*Ph2(i);
                            G3(i)= G3(i)+Pn3(i)*Ph3(i);
```

```
                    %if()
                    %Arrival of new call
                    if ((((b1(i)+b1(i)*(n1+h1))>Cap1)||(b1(i)+
                        %reject new call in feMBB, then calcu
                        Gn1(i)= Gn1(i)+Pn1(i)*Ph1(i);%+Pn2(i)*
                        %Gn1(i)= Gn1(i)+Pn1(i)+Pn2(i)+Pn3(i)+
                    end
                    if ((((b2(i)+b2(i)*(n2+h2))>Cap2)||(b2(i)+
                        %reject new call in euRLLC, then calc
                        %Gn2(i)= Gn2(i)+Pn1(i)+Pn2(i)+Pn3(i)+
                        Gn2(i)= Gn2(i)+Pn2(i)*Ph2(i);%+Pn3(i)*
                    end
                    if ((((b3(i)+b3(i)*(n3+h3))>Cap3)||(b3(i)+
                        %reject new call in umMTC slice, then
                        %Gn3(i)= Gn3(i)+Pn1(i)+Pn2(i)+Pn3(i)+
                        Gn3(i)= Gn3(i)+Pn3(i)*Ph3(i);
                    end
                    if ((b1(i)+b1(i)*(n1+h1))>Cap1)
                        %reject handoff call in feMBB slice,
                        %Gh1(i)= Gh1(i)+Pn1(i)+Pn2(i)+Pn3(i)+
                        Gh1(i)= Gh1(i)+Pn1(i)*Ph1(i);%+Pn2(i)*
                    end
                    if  ((b2(i)+b2(i)*(n2+h2))>Cap2)
                        %reject handoff call in euRLLC slice,
                        %Gh2(i)= Gh2(i)+Pn1(i)+Pn2(i)+Pn3(i)+
                        Gh2(i)= Gh2(i)+Pn2(i)*Ph2(i);%+Pn3(i)*
                    end
                    if ((b3(i)+b3(i)*(n3+h3))>Cap3)
                        %reject handoff call in umMTC slice,
                        %Gh3(i)= Gh3(i)+Pn1(i)+Pn2(i)+Pn3(i)+
                        Gh3(i)= Gh3(i)+Pn3(i)*Ph3(i);
                    end
                    nn1=n1;
                    nn2=n2;
                    nn3=n3;
                end
            end
        end
    end
```

```
            end
        end
    end
    %Compute blocking and dropping probability for each slice
    Nbp1(i)=Gn1(i)/G1(i);
    Nbp2(i)=Gn2(i)/G2(i);
    Nbp3(i)=Gn3(i)/G3(i);
    Hdp1(i)=Gh1(i)/G1(i);
    Hdp2(i)=Gh2(i)/G2(i);
    Hdp3(i)=Gh3(i)/G3(i);
    %compute respective slice utilisation
    U1(i)=(b1(i)*(n11+h11))/Cap1;
    U2(i)=(b2(i)*(n22+h22))/Cap2;
    U3(i)=(b3(i)*(n33+h33))/Cap3;
    %Compute Bandwidth utilisatio of the network
    U(i)=(U1(i)+U2(i)+U3(i))/3;
end
```