**JIMMA UNIVERSITY**

**JIMMA INSTITUTE OF TECHNOLOGY**

**SCHOOL OF GRADUATE STUDIES**

**FACULTY OF ELECTRICAL AND COMPUTER ENGINEERING**


# Performance Analysis of D2D Based WiFi Offloading for 5G Cellular Network


By

Zebenay Anley


This thesis is submitted to School of Graduate Studies of Jimma University in partial fulfilment of the requirements for the degree of

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Zebenay Anley

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Submission Date: January, 2020

# Declaration

I, the undersigned, declare that this thesis work is my original work, has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been fully acknowledged.

The research paper submitted by

Zebenay Anley ____________ ____________

SIGNATURE DATE

APPROVED BY ADVISORS:

ADVISOR: ____________ ____________

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SIGNATURE DATE

Approved by faculty of Electrical and Computer Engineering research proposal examination members

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# Abstract

Cellular traffics are increased from time to time.This traffic increase will be difficult for the cellular network to handle everything on its own. To handle this traffic 5G uses millimeter wave technology which have frequency range 30Ghz- 300Ghz.But there is a problem with this millimeter wave in using it in 5G is that waves at these wavelength(1-10mm) gets easily attenuated by the surrounding and they cannot penetrate from a thick wall as well. Configuration of many small cells may solve this problem, which is expensive. This work studies a routing scheme for offloaded 5G cellular data where the data at a user's telephone set will be first collect in WiFi queue to offload over WiFi and if the WiFi connection is inactive in the user's telephone set then the data will wait in the queue for a given deadline and while it waits in the WiFi queue, the user's telephone set will try to set up a device to device (D2D) connection with a neighboring telephone set with an active WiFi connection. When the deadline will reach for the data in the WiFi queue, the user data will be directed to the neighboring telephone set which has an active WiFi connection and which will permit the user's data to be offloaded through it, else, if no telephone set with an active WiFi connection is found in the environment, after the deadline the data will be sent to the BTS through several small cells.

This routing technique increases the probability of getting the wifi server for the user. The Matlab simulation shows transmission delay can be reduced by increasing the deadline rate and also it shows for the same time interval D2D (situation 2)offloading has better utilization factor from delayed wifi offloading (situation 1) and D2D offloading has less average queue length than a WiFi offloading. This shows that D2D offloading has better transmission rate. The result analyzes the effect of increasing number of servers on utilization factor. The simulation result shows that D2D based wifi offloading is 20% more efficient than delayed wifi offloading interms of utilization factor.

*Keyword:**5G, Cellular Network, D2D, Transmission Delay, WiFi Offloading, Utilization factor***

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First and foremost, I would like to give special thanks and glory to the Omnipotent, Omnipresent, and the Omniscient Almighty God who is the wonderful source of my strength to come this far, and for giving me the grace, wisdom, good health and for guiding me all the way to this phase of my life.

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# Abbreviations

| | |
|---|---|
| **1G** | **F**rist **G**eneration |
| **2G** | **S**econd **G**eneration |
| **3G** | **T**hird **G**eneration |
| **3GPP** | **T**hird **G**eneration **P**artnership **P**roject |
| **4G** | **F**ourth **G**eneration |
| **5G** | **F**ive **G**eneration |
| **AMPS** | **A**dvanced **M**obile **P**hone **S**ystem |
| **AP** | **A**ccess **P**oint |
| **AUC** | **AU**thentication **C**enter |
| **BS** | **B**ase **S**tation |
| **BSC** | **B**ase **S**tation **C**ontroller |
| **BTS** | **B**ase **T**ransceiver **S**tation |
| **CAGR** | **C**ompound **A**nnual **G**rowth **R**ate |
| **CDMA** | **C**ode **D**ivision **M**ultiple **A**ccess |
| **D2D** | **D**evice to **D**evice |
| **EDGE** | **E**nhanced **D**ata Rate for **G**SM **E**volution |
| **EIR** | **E**quipment **I**dentity **R**egister |
| **FDMA** | **F**requency **D**ivision **M**ultiple **A**ccess |
| **FIFO** | **F**irst **I**n **F**irst **O**ut |
| **GPRS** | **G**eneral **P**acket **R**adio **S**ervice |
| **HLR** | **H**ome **L**ocation **R**egistor |
| **IEEE** | **I**nstitute of **E**lectrical and **E**lectronics **E**ngineers |
| **IP** | **I**nternet **P**rotocol |
| **LTE** | **L**ong **T**erm **E**volution |

| | |
|---|---|
| **MO** | **M**obile **O**perator |
| **MS** | **M**obile **S**tation |
| **MSC** | **M**obile **S**witching **C**enter |
| **MTS** | **M**obile **T**elephone **S**ystem |
| **MU** | **M**obile **U**ser |
| **PSTN** | **P**ublic **S**witched **T**elephone **N**etwork |
| **PTT** | **P**ush **T**o **T**alk |
| **QoS** | **Q**uality **o**f **S**ervice |
| **UMTS** | **U**niversal **M**obile **T**elecommunication **S**ystem |
| **VLR** | **V**isitor **L**ocation **R**egister |
| **WCETT** | **W**eighted **C**umulative **E**xpected **T**ransmission **T**ime |
| **WiFi** | **Wi**reless **Fi**delity |

# Chapter 1

# Introduction

## 1.1 Motivation

Rapid growth of user end applications has led in an exponential increase in data traffic generation resulting in a massive overload of cellular networks. The exponential growth of mobile data traffic and a limited number of spectrum resources being a big challenge for cellular network providers and thus traffic offloading has become one of the most critical issues, especially in 5G Various applications [1].

The rise in data traffic on cellular networks has caused an immediate requirement for offloading traffic for best performance of both voice and data services. The majority of mobile data terminals such as smartphones are WiFi enabled, making WiFi an obvious choice for providing additional capacity where traffic demand is high [2].

The increase in mobile data traffic results from both increased smartphone subscription and a continued increase in average data volume per subscription [3]. 3G/4G mobile networks are currently overloaded, due to the increasing popularity of various applications for smartphones [2].

Recent years have witnessed a massive growth in the volume of 3G/4G/5G cellular network traffic. It costs a lot for service providers to solve this problem by simply increasing the deployment of infrastructure. Thus, many offloading methods have been proposed for shifting traffic from 3G/4G/5G cellular networks, which use licensed spectrum resources, to 802.11x WiFi networks, which use un-licensed spectrum resources. In contrast with using licensed spectrum, i.e., the one used in 3G/3.5G/4G cellular network, unlicensed spectrum is less expensive. Furthermore, 802.11x WiFi network may have better throughput and consume less power than 3G/3.5G/4G/5G cellular network [4].

WiFi is essentially useful as it operates in the unlicensed spectrum and its deployment is cost-efficient. Offloading data over active WiFi connection in Handsets may reduce the dependency on small cells in data transfer, decreases the traffic at the Base Transceiver Station (BTS) and decreases the cost of setting up 5G infrastructure.

Due to the diversification of its purposes and the increase in the number of mobile devices accessing mobile networks, demand for mobile data communication has increasing. Users experience degradation of the quality of communication due to congestion of the mobile network [5].

For delayed offloading, the data transfer has a clear cut-off date (deadline). If the cut-off time is high, the consumer is more likely to offload more traffic through the complementary area [6].

Due to the proliferation of smart handheld devices and bandwidth hungry applications, cellular networks face severe traffic overloads. Offloading cellular data via WiFi is a cost-effective and practical solution. Recent theoretical and experimental studies show that a system, known as delayed WiFi offloading, can save cellular power substantially by delaying user data and exploiting mobility and thus increasing chance of meeting WiFi APs (Access Points). Despite the enormous potential of WiFi offloading to alleviate the explosion of mobile data, its success largely depends on the economic incentives given to users and network providers to deploy and use delayed offloading [7].

## 1.2 Statement of the Problem

Cisco predicts that more than 11.6 billion mobile connected devices and traffic will reach an annual rate of 30.6 exabytes per month by 2020 (8 or 106 terabytes). This large amount of traffic on mobile devices will be difficult for the cellular network to handle everything on its own. 5G technology uses millimeter wave which have a frequency range (30-300)Ghz to handle those traffics . These millimeter waves have short ranges, i.e. they are unable to travel a long distance and are very easily attenuated in space. Such waves need to be heavily dispersed in the area to help the millimeter wave move through many small cells until it hits the Base Transceiver Station (BTS) in order to make them travel long distance. Such small cells were deployed contributing to expenses or requires costs this affects the economy of network operators and users.

## 1.3 Objectives of the Thesis

### 1.3.1 General Objective

The main objective of this thesis is to analyze the performance of D2D Based WiFi Offloading for 5G traffic.

### 1.3.2 Specific Objectives

- To analyze the transmission delay for offloading over WiFi through D2D.
- To model a Simulink of the routing scheme using SimEvents library.
- To compare utilization factors for each route.
- To compare Average Queue Length of WiFi and D2D.
- To analyze the waiting line time for one and two server system.

## 1.4 Methodologies

Since there is distance limitation in 5G wireless access technology D2D based WiFi offloading can solve this limitation by extending the routing scheme. Since D2D communication have better coverage than 5G technology. But in 5G to transmit data from transmitter to receiver requires building of many small cells, hence it is costy. D2D based WiFi is the best solution for 5G traffic cost requirement. The mat lab simulation shows how to route a user to the server (D2D server) and analyzes the utilization factor for the three servers (WiFi ,D2D and cellular) and average queue length of them. The methods used to achieve the desired objectives of this thesis were as follows. First, related literature about traffic reduction techniques from cellular networks have been reviewed. Finally, provide using MATLAB simulation results shows the reduction of transmision delay by using this work .

## 1.5 Scope of the Thesis

The tasks performed in this thesis work are as follows. The first task is to analyze the transmission delay by varring the deadline rate the second task is to compare the utilization factor and waiting times for wifi, D2D and cellular server. The third task is to analyze the impact of number of servers on utilization factor.

## 1.6 Significance of the Study

The significance of this thesis work is to reduce the transmission delay by increasing the deadline rate which extends the routing scheme from delayed WiFi offloading scenario to D2D offloading scenario. This extending scheme is used to provide the users chance to get a free WiFi server.

Secondly it is to analyze the average queue length and the utilization factor of D2D based WiFi traffic offloading ,WiFi offloading and cellular offloading for 5G traffic reduction that decrease the cost of buying small cells for data transfer from a transmitter to a receiver for 5G, since 5G is distance limited wireless access technology.

## 1.7 Thesis Organization

This thesis work contains six chapters. The first chapter is the introduction part which contains motivational overview, statement of the problem, objective, methodology, scope and significance of the thesis. The second chapter deals with technical background containing literature review and background of WiFi offloading.

Chapter three generally discuss about D2D based WiFi offloading. Chapter four discusses about the proposed model for D2D based WiFi offloading. Chapter five is about simulation results and discussions; while the last chapter contains conclusion and recommendation for future works.

# Chapter 2

# Technical Background of the Study

## 2.1 Introduction

Mobile networking and wireless networks are the hottest developing fields with proof that new mobile and wireless communication technologies are rising significantly. Wireless communication networks need either additional spectrum or other techniques to further exploit the existing available frequency bands in order to meet the increasing demand for data rate and higher throughput.

Mobile communications technology has evolved rapidly due to increasing demands for higher data rates and high-quality mobile communications services, and much has been written about the need for mobile network operators to meet the growing demand for data services, especially for smartphone users.

The amount of mobile data traffic transmitted via cellular networks is growing exponentially, which is a great opportunity for the mobile communications industry and a major challenge. The expanded use of many popular social networking sites opens the door for millions of Terabytes of data to mobile networks. Due to the increasing prevalence of numerous smartphone apps, 3G/4 G mobile networks are currently overloaded [8].

Due to the enormous amount of mobile data traffic generated, mobile cellular networks are now often heavily loaded [9]. On the other hand, mobile cellular network capacity is increasing at a much slower pace, so that mobile traffic demand in the short to medium term is likely to exceed network capacity. As a result, mobile operators (MOs) around the world desperately need to expand network capacity in a cost-effective and timely manner. An effective way to ease cellular congestion is to use complementary technologies, such as Wi-Fi, to discharge traffic originally targeted at the cellular network.

Juniper Research reported that in 2017, just 40% of global mobile data traffic will enter the cellular network, as most traffic is likely to be offloaded using Wi-Fi [9].

There are two main methods to initiating the offloading of WiFi, namely the offloading initiated by the user and the operator. The mobile user (MU) is responsible for selecting the network technologies it intends to use in the user initiated offloading.

However, the operator profile stored in the mobile device prompts the connection manager to start the offloading procedure in the operator-initiated offloading. The MOs would prefer the offloading initiated by the operator, as it gives them better control over the choice of network users. Nevertheless, as the offloading initiated by the operator requires complicated network control between the MOs and the MUs, further standardization and improvement is still ongoing. Because of its simplicity in implementing, the user-initiated offloading is currently the most popular option [9].

There is a huge increase in the number of mobile users around the globe today. Internet traffic is increasing exponentially and demand for video streaming and other multimedia is expected to see huge demand in the years to come.

There are actually two main wireless networks providing mobile users with connectivity; these are cellular and WiFi networks. Nonetheless, cellular networks may not provide adequate coverage to users due to the increase in the number of mobile users. The only alternative is to offload the users to WiFi networks to reduce the load at the cell sites. Hence, WiFi offloading has gained a lot of attention from researchers. The offloading of mobile users to available networks is an opportunity, but there must assure the same Quality of Service (QoS) be maintained at those networks. Generally, QoS management refers to the allocation of radio resources to requested users by providing minimum guaranteed service. QoS is usually measured in terms of some parameters such as access delay, transmission delay, throughput, jitter and packet loss rate [10].

Although there are several benefits to WiFi offloading, it should also provide incoming users with the necessary value. The WiFi offloading process allows consumers and network operators to use the current WiFi infrastructure without needing additional investment. These benefits can be fulfilled only by providing and maintaining the required quality of service to users. The delay introduced during the offloading process leads to a reduction of throughput among the users, and due to lack of available access points the user may lose the connection. Another key parameter which influences the QoS metric is residence time (the time taken for users in a given network). It is the time consumed by the individual in staying network [10].

Cellular networks are currently facing the challenges of mobile data explosion [11], [12]. Due to the diversification of its uses and the increase in the number of mobile devices accessing mobile networks, the demand for mobile data connectivity has grown. Because of the congestion of the mobile network, users experience loss in service efficiency. It is therefore important to improve the efficiency of the bandwidth utilization of cellular networks [5].

Cellular networks are facing severe traffic overloads due to the proliferation of smart handheld devices and traffic hungry applications [7].

Most smartphone users desire mobile data services. Smartphones offer mobile users Web experience. Increased smartphone use has changed the behavior of consumers because it has enabled and promoted their need to be linked all the time.

In 2015, average smartphone usage increased by 43 percent and smartphones will cross four-fifths of mobile data traffic generated by 2020 [13], [14]. At the same time, WiFi use is booming as more mobile devices are allowed for WiFi, the number of public hotspots is growing and consumer adoption is increasing [2].

Offloading data traffic refers to traffic over WiFi networks from dual mode device ( i.e promoting cellular and WiFi connectivity). It also refers to the use of WiFi network for mobile network delivery.

According to [15], WiFi offloading occurs when mobile data enabled devices use WiFi instead of a cellular connection to transmit and receive mobile data.

The increase in data traffic on cellular networks has caused an immediate need for offloading traffic for optimum performance of both voice and data services [16]. The majority of mobile data terminals such as smartphones are WiFi enabled, making Wi-Fi an obvious choice for providing additional capacity where traffic demand is high [2], [17], [18].

Recent years have witnessed a massive growth in the volume of 3G/4G/5G cellular network traffic. It costs a lot for service providers to solve this problem by simply increasing the deployment infrastructure. Thus, many offloading methods have been proposed for shifting traffic from 3G/4G/5G cellular networks, which use licensed spectrum resources, to 802.11x WiFi networks, which use un-licensed spectrum resources. In contrast with using licensed spectrum, i.e., the one used in 3G/3.5G/4G cellular network, unlicensed spectrum is less expensive.

Let the signal coverage of the WiFi network be inside the signal coverage of 3G/4G/5G cellular. A mobile node can switch from the 3G/4G/5G cellular network to the WiFi network when the mobile node is inside Wi-Fi's signal coverage. WiFi offloading can have the corresponding mobile nodes to release the 3G/4G/5G cellular network to improve spectrum efficiency and may also result in better throughput and consuming less power than using the 3G/4G/5G cellular network ; additionally, WiFi offloading can have lower or even free cost because using WiFi network is normally free [4].

Over the last few years, an increasing number of wireless devices occur in the market, such as smartphones, tablets and laptops. People often use these various intelligent terminals to access the Internet for entertainment and resource consuming services, which is one of the primary contributors to global mobile traffic growth. According to Cisco Visual Network Index, global mobile data traffic grew 63% in 2016, reaching 7.2 exabytes per month at the end of 2016; up from 4.4 exabytes per month at the end of 2015 (One exabyte is equivalent to one billion gigabytes, and one thousand petabytes). Additionally, Cisco also forecasts that mobile data traffic will grow at a compound annual growth rate (CAGR) of 47% from 2016 to 2021, and reach 49.0 exabytes per month by 2021 [16]. Up to now, there already exist several major Concerns to alleviate congestion and make network more efficient. Apparently, the most straightforward one is to install more base stations per area, so that the capacity of networks is increased. As it is known to all, upgrading the cellular network to the next-generation is another promising way such as 5G but it requires investment [16].

## 2.2 Evolution of Wireless Access Networks (From 1G to 5G)

There has been a vast advancement in mobile wireless communication since the last few decades. This innovation consists of a number of generations and is still going on. The journey of mobile wireless communication began with 1G followed by 2G,3G,4G,and under research upcoming generations 5G as shown in Figure 2.4.

In the last few decades, Mobile Wireless Communication networks have experienced a remarkable change. The mobile wireless Generation (G) generally refers to a change in the nature of the system, speed, technology, frequency, data capacity, latency etc. Each generation have some standards, different capacities, new techniques and new features which differentiate it from the previous one. The first generation (1G) mobile wireless communication network was analog used for voice calls only. The second generation (2G) is a digital technology and supports text messaging. The third generation (3G) mobile technology provided higher data transmission rate, increased capacity and provide multimedia support. The fourth generation (4G) integrates 3G with fixed internet to support wireless mobile internet, which is an evolution to mobile technology and it overcome the limitations of 3G. It also increases the bandwidth and reduces the cost of resources. 5G stands for 5th Generation Mobile technology and is going to be a new revolution in mobile market which has changed the means to use cell phones within very high bandwidth. User never experienced ever before such high value technology which includes all type of advance features and 5G technology will be most powerful and in huge demand in near future. Mobile communication has become more popular in last few years due to fast reform from 1G to 5G in mobile technology. This reform is due to requirement of service compatible transmission technology and very high increase in telecoms customers. Generation refers change in nature of service compatible transmission technology and new frequency bands. In 1980 the mobile cellular era had started, and since then mobile communications have undergone considerable changes and experienced massive growth.

### 2.2.1 First Generation, 1G

These phones were the first mobile phones to be used, which was introduced in 1982 and completed in early 1990. It was used for voice services and was based on technology called as Advanced Mobile Phone System (AMPS) in Figure 2.1. The AMPS system was frequency modulated and used frequency division multiple access (FDMA) with a channel capacity of 30 KHz and frequency band of 824-894MHzIts.

Basic features are:

- Speed 2.4 kbps
- Allows voice calls in 1 country

- Use analog signal.
- Poor voice quality
- Poor battery life
- Large phone size
- Limited capacity
- Poor handoff reliability
- Poor security
- Offered very low level of spectrum efficienc

It introduces mobile technologies such as Mobile Telephone System (MTS), Advanced Mobile Telephone System (AMTS), Improved Mobile Telephone Service (IMTS), and Push to Talk (PTT). It has low capacity, unreliable handoff, poor voice links, and no security at all since voice calls were played back in radio towers, making these calls susceptible to unwanted eavesdropping by third parties.

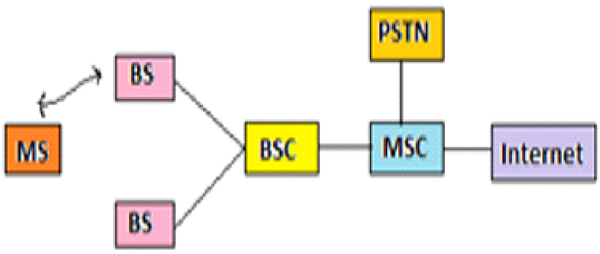


FIGURE 2.1: Architecture of Advance Mobile Phone System [19]

### 2.2.2 Second Generation (2G)

2G refers to the second generation based on GSM and was emerged in late 1980s. It uses digital signals for voice transmission. Main focus of this technology was on digital signals and provides services to deliver text and picture message at low speed (in kbps). It use the bandwidth of 30 to 200 KHz. Next to 2G, 2.5G system uses packet switched and circuit switched domain and provide data rate up to 144 kbps. e.g. GPRS, CDMA and EDGE.

The main features of 2G Second generation:

- Data speed was up to 64kbps
- Use digital signals
- Enables services such as text messages, picture messages and MMS(Multimedia message)
- Provides better quality and capacity
- Unable to handle complex data such as videos.
- Required strong digital signals to help mobile phones work. If there is no network coverage in any specific area, digital signals would weak.

### 2.2.3 2.5 Generation (2.5 G) :

The GSM in Figure 2.2 technology was continuously improved to provide better services which led to development of advanced Technology between 2g and 3g .

- Provides phone calls
- Send/receive e-mail messages
- Web browsing
- Speed 64-144 kbps
- Camera phones
- Take a time of 6-9 mins. to download a 3 mins. MP3 song

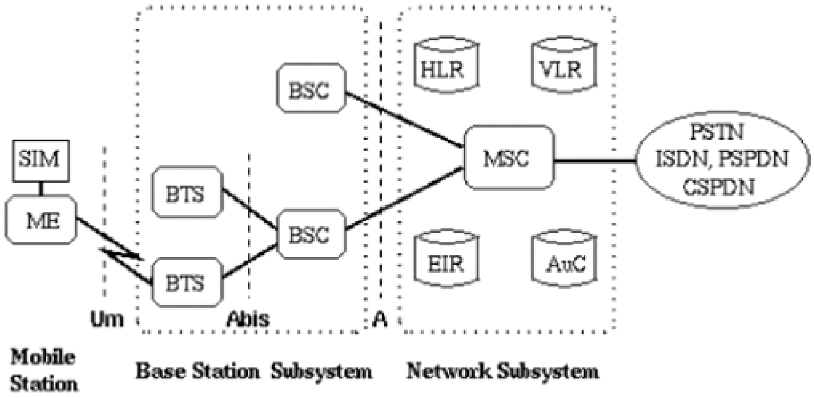


FIGURE 2.2: GSM System Architecture [19]

### 2.2.4 Third Generation (3G)

3G is based on GSM and was launched in 2000. The aim of this technology was to offer high speed data. The original technology was improved to allow data up to 14 Mbps and more using packet switching. It uses Wide Band Wireless Network with which clarity is increased. It also offers data services, access to television/video, new services like Global Roaming. It operates at a range of 2100MHz and has a bandwidth of 15-20MHz used for High-speed internet service, video chatting.

The main features of 3G are:

- Speed 2 Mbps
- Typically called smart phones
- Increased bandwidth and data transfer rates to accommodate web-based applications and audio and video files.
- Provides faster communication
- Send/receive large email messages
- High speed web/more security/video conferencing/3D gaming
- Large capacities and broadband capabilities
- TV streaming/mobile TV/Phone calls

- To download a 3 minute MP3 song only 11 sec-1.5 mins time required.
- Expensive fees for 3G licenses services
- It was challenge to build the infrastructure for 3G
- High bandwidth requirement
- Expensive 3G phones
- Large cell phones 3G mobile system was called as UMTS(Universal Mobile Telecommunication System) in Europe, while CDMA2000 is the name of American 3G.

### 2.2.5 Fourth Generation (4G)

4G offers a downloading speed of 100Mbps. 4G provides same feature as 3G and additional services like Multi-Media Newspapers, to watch T.V programs with more clarity and send Data much faster than previous generations [20]. LTE (Long Term Evolution) is considered as 4G technology. 4G is being developed to accommodate the QoS and rate requirements set by forthcoming applications like wireless broadband access, Multimedia Messaging Service (MMS), video chat, mobile TV, HDTV content, Digital Video Broadcasting, minimal services like voice and data, and other services that utilize bandwidth as indicated in Figure 2.3. The main features of 4G are

- Capable of provide 10Mbps-1Gbps speed
- High quality streaming video
- Combination of WiFi and Wi-Max
- High security
- Provide any kind of service at any time as per user requirements anywhere
- Expanded multimedia services

- Low cost per-bit
- Battery uses is more
- Hard to implement
- Need complicated hardware
- Expensive equipment required to implement next generation network

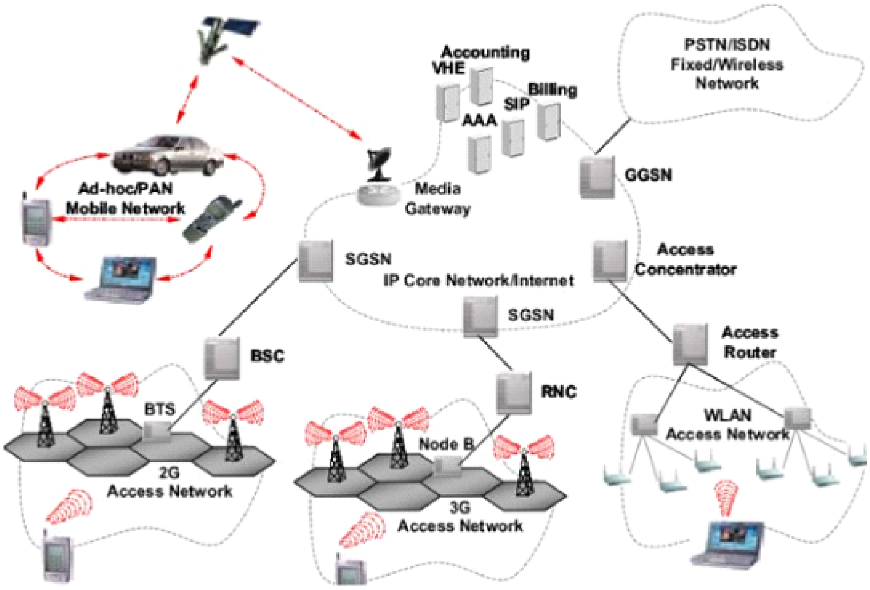


FIGURE 2.3: 4G Network Architecture [19]

### 2.2.6 Fifth Generation (5G)

5G refer to Fifth Generation which was started from late 2010s. Facilities that might be seen with 5G technology includes far better levels of connectivity and coverage. It is a complete wireless communication with distance limitations.

The main features of 5G are:

- It is highly supportable to WWWW (wireless World Wide Web)
- High speed, high capacity
- Provides large broadcasting of data in Gbps.

- Multi-media newspapers, watch TV programs with the clarity(HD Clarity)
- Faster data transmission that of the previous generation
- Large phone memory, dialing speed, clarity in audio/video
- Support interactive multimedia, voice, streaming video, internet and other
- More effective and attractive [21].

| Technology | 1G | 2G | 3G | 4G | 5G |
|---|---|---|---|---|---|
| Start/Deployment | 1970-80 | 1990-2004 | 2004-10 | Now | Soon (probably by 2020) |
| Data Bandwidth | 2Kbps | 64 Kbps | 2 Mbps | 1 Gbps | Higher than 1 Gbps |
| Technology | Analog | Digital | CDMA 2000, UMTS,EDGE | Wi-Max, Wi-Fi, LTE | WWWW |
| Core Network | PSTN | PSTN | Packet N/W | Internet | Internet |
| Multiplexing | FDMA | TDMA/CDMA | CDMA | CDMA | CDMA |
| Switching | Circuit | Circuit,Packet | Packet | All Packet | All Packet |
| Primary Service | Analog Phone Calls | Digital Phone Calls and Messaging | Phone calls, Messaging, Data | All-IP Service (including Voice Messages) | High speed, High capacity and provide large broadcasting of data in Gbps |
| Key differentiator | Mobility | Secure, Mass adoption | Better Internet experience | Faster Broadband Internet, Lower Latency | Better coverage and no droped calls, much lower latency, Better performance |
| Weakness | Poor spectral efficiency, major security issue | Limited data rates, difficult to support demand for internet and e-mail | Real performance fail to match type, failure of WAP for internet access | Battery use is more, Required complicated and expensive hardware | ? |

FIGURE 2.4: 4G Network Architecture [19], [22], [23]

The first four generations were completely dependent upon the base station (BS), thus called network centric. But 5G is heading towards device-centric approach, i.e. network setup and managed by the devices themselves. Device-to-Device (D2D) Communication is being considered as an essential component of the 5G networks. It is expected to result in an enhanced system capacity, increased spectral efficiency, better throughput and reduced latency [24].

## 2.3 Traffic Impact of 4G and 5G

In 2017, 4G already carried 72 percent of the total mobile traffic and represented the largest share of mobile data traffic by network type. It will continue to grow faster than other networks, however the percentage share will go down slightly to 71 percent of all mobile data traffic by 2022 (Figure 2.5). By 2022, 5G will support 12 percent of mobile traffic. 5G connectivity with its very high bandwidth (100 Mbps) and ultra-low latency (1 millisecond) is expected to drive very high traffic volumes.

Currently, a 4G connection generates about three times more traffic than a 3G connection. There are two reasons for the higher usage per device on 4G. The first is that many 4G connections today are for high-end devices, which have a higher average usage. The second is that higher speeds encourage the adoption and usage of high- bandwidth applications, such that a smartphone on a 4G network is likely to generate significantly more traffic than the same model smartphone on a 3G or 3.5G network. By 2022, a 4G connection will still generate nearly two times more traffic than a 3G connection.

By 2022, the average 5G connections will generate nearly 3 times more traffic than the average 4G connection.

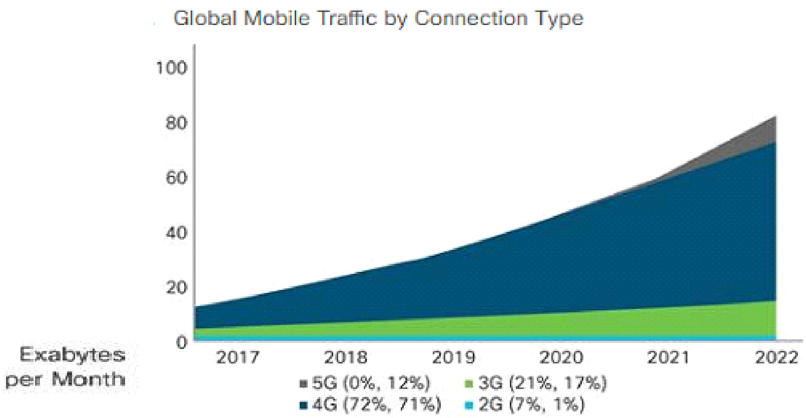


FIGURE 2.5: Source: Cisco VNI Mobile, 2019 [25]

## 2.4 Cellular Network Traffic Reduction

As we know the rapid growth in mobile broadband demand is stretching network capacity and in order to realize the need for traffic offloading, best technology to start with is LTE since it is the most advanced and widely used unifying macro wireless access network technology. Cisco estimates that traffic in 2011 will grow 131 percent, reflecting a slight decrease in growth rates. The evolving device mix and the migration of traffic from the fixed network to the mobile network have the potential to bring the growth rate higher, while flat pricing and traffic offload may reduce this effect. Projection released data from Cisco VNI [26–32], shows that without offloading, the combined amount of tablet and Smartphones traffic would be 2.7 Exabytes per month in 2015, up 54-fold from 2010. With offloading, Smartphones and tablet traffic will amount to 1.9 Exabytes per month in 2015, up 52-fold from 2010 [26]. Over 800 million terabytes of mobile data traffic will be offloaded in 2015. As it is depicted the total offload for Smartphones and tablets will be 39 percent in 2015, up from 31 percent in 2010 [8].

The main driving forces behind this overwhelming increase in mobile data traffic are:

- Incredible growth of new mobile services and improved connected device capabilities.
- Deployment of high bandwidth cellular data networks, for example LTE
- Flat-rate mobile data pricing (flattish fixed market)
- Ever increasing array of diverse data applications driving more and more traffic on the cellular network.
- Internet services mainly online advertising and web surfing to more bandwidth demanding services, for example mobile TV or Video on demand, large file download, VoIP, YouTube, online game play etc [8].

The overwhelming growth of the mobile data traffic has an effect on both the provider's network operator, and the end-user experience. This means that the data traffic can create high pressure on network resources, and as mobile devices increase in number networks will become more congested on the radio access during peak hours. As a result of this, network congestion may prevent cellular voice users from accessing the network, who are still the largest contributors to the revenue growth of operators. Network congestion is going to worsen in coming years and adversely affect the revenue growth of operators. Therefore, network congestion is becoming a major problem for operators, which needs an immediate attention. On top of this, due to network congestion the end-user would also experience a harsh drop of effective throughput rate in the network [8].

## 2.5 The Role of Wireless Local Area Network (WLAN)

WLAN is widely accepted and popular because it doesn't require a licensed spectrum. It's cheap equipment and very large number of compatible devices for the flexible deployment of wireless access through various hotspots into airports, any small office, home, hotels, universities, and the cities where ubiquitous wireless is becoming a reality is also another reason for its popularity. It gives users the mobility to move around within a local coverage area and still be connected to the network. Both WLANs and 4G are capable of providing higher-speed wireless connections that cannot be offered by earlier cellular technologies like 2G. WLANs can cover only a small area and allow limited mobility, but provide higher data rates. Therefore, WLANs are well suited to hotspot coverage where there is a high density of demand for high-data-rate wireless services requiring limited mobility. WLAN is also in a number of 3G/4G devices (i.e., Smartphones, laptops, and netbooks) that typically consume a large portion of resources, a mechanism that offloads data traffic from 3G/4G to WiFi is very interesting to mobile network operators that want to balance the data cost and make better use of network. The basic idea behind WiFi offloading is whenever a WLAN access point is available, some or all of the traffic is routed through the WLAN access point, thus offloading the cellular access network. The offloading should be a 3GPP operator controlled, i.e. mobile network operators should be able to control which traffic is routed over WLAN and which one is kept on cellular network [8].

## 2.6 Mobile Data Offloading

WiFi provides an invaluable complement to cellular in the delivery of high-quality broadband services to smartphone users, particularly indoors. Cellular networks offer high performance, wide area blanket coverage but do not always cover indoor locations well ,WiFi fills these gaps. WiFi traffic from both mobile devices and Wi-Fi-only devices together will account for more than half of total IP traffic by 2022 [33]. Mobile data offloading or simply data offloading refers to the use of complementary network technologies and innovative techniques for delivery of data originally targeted for mobile/ cellular networks to alleviate congestion and making better use of available network resources. By offloading users from the 3G/4G /5G networks to WiFi networks, mobile operators can add more capacity in an affordable and flexible way. WiFi offloading demands that carriers thoroughly test it to ensure a transparent, high-quality experience for customers. This includes providing a transparent high quality experience for users that is sustained even as user and application demands grow [33], [34].

Internet traffic is increasing exponentially every year and will increase more by the year 2022, Mobile and offload from mobile devices together will account for 48 percent of total IP traffic by 2022, a testament to the significant growth and impact of mobile devices and lifestyles on overall traffic. WiFi traffic from both mobile devices and Wi-Fi-only devices together will account for more than half (51 percent) of total IP traffic by 2022, up from 43 percent in 2017 [33]. In 2017, wired devices accounted for the majority of IP traffic. And a significant portion of this traffic will be due to wireless. As a result, cellular networks are becoming heavily congested. Nearly three-fifths of traffic (59 percent) will be offloaded from cellular networks (on to Wi-Fi) by 2022 [33].

This unprecedented growth of data traffic can be attributed to several factors, like: the introduction of high-end devices such as smart-phones, tablets, laptops, handheld gaming consoles, etc. that can multiply traffic, also the growth in mobile network connection speeds and the rise of mobile video content that increase the average traffic per device. Mobile video traffic has already surpassed 50% of total mobile data traffic and continues to increase. The availability of mobile broadband services at prices and speeds comparable to those of fixed broadband is also an important factor for the unprecedented growth of data traffic [33].

Mobile data offloading or simply data offloading refers to the use of complementary network technologies and innovative techniques for delivery of data originally targeted for mobile/ cellular networks to alleviate congestion and making better use of available network resources as in Figure 2.6 bellow. The objective is to maintain Quality-of-Service (QoS) for customers, while also reducing the cost and impact of carrying capacity hungry services on the mobile network [4]. Most mobile operators worldwide have already started to implement an offloading solution [33].

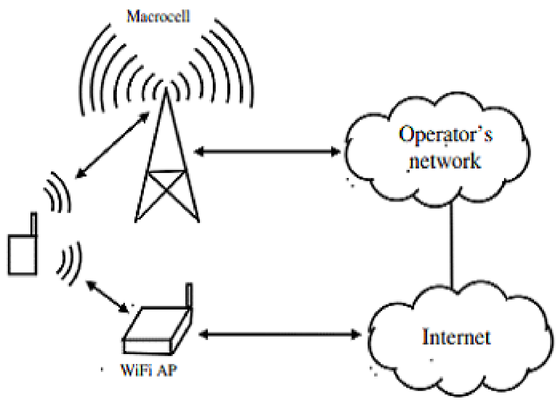


Figure 2.6: Mobile Data Offloading via WiFi Aps [33]

Mobile data offloading (WiFi offloading) is considered as the use of a complementary wireless technology to transfer data formerly targeted to flow through the cellular network, in order to improve some key performance indicators.

To accommodate the explosive growth in mobile data traffic, both mobile cellular operators and mobile user s are increasingly interested in offloading the traffic from cellular networks to WiFi networks. However, previously proposed offloading schemes mainly focus on reducing the cellular data usage, without paying too much attention on the quality of service (QoS) requirements of the applications [9]. These papers study the WiFi offloading problem with delay-tolerant applications under usage-based pricing. The aim is to achieve a good tradeoff between the user's payment and its QoS characterized by the file transfer deadline [9].

Generally, the cellular bands have issues related to the available cellular bands and networks are used to manage the load. In this case, the traffic is diverted to unlicensed WiFi spectrum or other network technologies, which helps to reduce the load on the existing cellular bands. Users from 3G, 4G, or 5G networks can utilize data offloading schemes in an affordable and flexible manner, thereby building a heterogeneous network by integrating WiFi with radio networks for 4G/5G users. The advantage of data offloading is unleashing better resource and spectrum utilization. One popular approach for data offloading is device-to-device (D2D) communication.

Simply when an accessible WiFi connection is available, the sessions will be transferred to WiFi saving cost and energy (during low-throughput data transfer) to the user. The WiFi offloading is classified as infrastructure based, access point (AP) based, terminal to terminal (T2T) based, based on the type of deployment and as delayed offloading, non-delayed offloading based on the type of delay.

Currently there exist two types of WiFi offloading according to their requirements in terms of content delivery guarantees. The usual way of offloading is on-the-spot offloading: when there is WiFi available, all traffic is sent over the WiFi network; otherwise, all traffic is sent over the cellular interface.

More recently, "delayed" offloading has been proposed: if there is currently no WiFi availability, (some) traffic can be delayed instead of being sent/received immediately over the cellular interface. In the simplest case, traffic is delayed until WiFi connectivity becomes available.

This is already the case with current smartphones, where the user can select to send synchronization or backup traffic only over WiFi. A more interesting case is when the user can choose a deadline (e.g., per application, per file, etc.). If up to that point no AP is detected, the data are transmitted over the cellular network.

Delayed WiFi offloading: delay a data transfer until the user enters a WiFi servers. It can significantly save the cellular capacity by delaying users' data and exploiting mobility and thus increasing chance of meeting WiFi APs (Access Points).

Delayed offloading offers additional flexibility and promises potential performance gains to both the operator and user compare to on the spot offloading [26].

### 2.6.1 On-the-spot Offloading

When there is WiFi available, all traffic is sent over the WiFi network; otherwise, all traffic is sent over the cellular interface.

On-the-spot offloading is to use spontaneous connectivity to WiFi and transfer data on the spot; when users move out of the WiFi coverage, they discontinue the offloading and all the unfinished transfers are transmitted through cellular networks. Most of the smart-phones which give priority to WiFi over the cellular interface in data transmissions can be expected to currently achieve on-the-spot offloading [33].

### 2.6.2 Delayed WiFi Offloading

Cellular networks are facing severe traffic overloads due to the proliferation of smart handheld devices and traffic hungry applications. A cost-effective and practical solution is to offload cellular data through WiFi. Recent theoretical and experimental studies show that a scheme, referred to as delayed WiFi offloading, can significantly save the cellular capacity by delaying users' data and exploiting mobility and thus increasing chance of meeting WiFi APs (Access Points).

## 2.7 Literature Review

The existing mobile data offloading literature focuses on either economics or technology issues. Related to network economics, paper [35] considered a 3G cellular network, where the MO uses discount coupons to incentivize MUs to use delayed data offloading. The problem was formulated as a reverse auction with one buyer and multiple sellers, where the MO is the buyer, and the MUs are the sellers. According to [36] the user adoption of supplementary technology (e.g., WiFi or femtocell) for cellular traffic offloading. The utility function of each user is related to its valuation of the technology, the congestion level, and the flat pricing of the service provider. The studies in [7], [21] considered an offloading market, where the MOs pay the third-party deployed APs for data offloading. The study in [7] describes the sub game perfect equilibrium in a data offloading game, where the base stations (BSs) propose the market prices, and the APs determine the volume of data traffic that they are willing to offload. The study in [21] proposed an iterative and incentive compatible double auction that maximizes the social welfare. The study in [7] studied the economic aspects of WiFi offloading in a monopolistic market with multiple MUs and one MO. Each MU is characterized by its willingness to pay, traffic demand, delay profile, and WiFi contact probability based on [9].

Related to the mobile data offloading technology, the study in [11] evaluated the costs and benefits of WiFi offloading in metropolitan area with real mobility traces. They characterized the number of WiFi access points (APs) required for the support of a given QoS requirement. Study [37] studied the sub band selection, power allocation, and scheduling problem of a small cell base station, which can transmit with both the cellular and WiFi interfaces. The base stations can self-organize and adjust their transmission strategies using reinforcement learning. There are a number of recent research results on the study of delayed WiFi offloading policy. Paper [38] conducted a measurement study on WiFi availability for moving vehicles. They proposed the Wiffler system for data offloading based on the prediction for future WiFi availability using past mobility history. In [39] Performed another measurement study on WiFi offloading with pedestrians. They conducted trace-driven simulations to study the impact of various parameters on the offloading efficiency. According to in [40] considered energy-efficient offloading for delay-tolerant applications. They showed that the proposed offloading algorithms can offload a significant amount of traffic from the cellular network and extend the battery lifetime. Paper in [41] considered the cost-throughput-delay tradeoff in user-initiated WiFi offloading. Given the predicted future usage and the availability of Wi-Fi, the proposed system decides on the application that should offload its traffic to WiFi at a given time, while taking into account the cellular budget constraint of the MU. In fact, similar to this paper with a detailed user's decision model, the works related to data offloading algorithm design in [38–41] focus on the single-user offloading problem. On the other hand, the works related to data offloading economics in [7], [21],[35], [36], considered simplified models on users' decisions, and they mainly focus on the multi-user offloading problem [9].

Over the years, a lot of work is proposed and carried out in the field. The existing mobile data offloading literature focuses on either economics or technology issues. Related to network economics, paper [35] considered a 3G cellular network, where the MO uses discount coupons to incentivize MUs to use delayed data offloading. The problem was formulated as a reverse auction with one buyer and multiple sellers of data offloading considering few prominent works. Donguen Suh through "Efficiency analysis of WiFi Offloading Techniques" proposed consideration of two types of WiFi offloading techniques entitled as opportunistic WiFi offloading, where opportunistically meeting Wifi access points (APs) and mobile node tend to be the only condition for data offloading. Also delayed WiFi offloading, where with the expectation of future AP contacts data transfer is delayed. They also formulated analytical models on WiFi offloading efficiency as the ratio of the amount of offloaded data to the total amount of data [42]. Insook Kim through "Probabilistic Offload Scheme in Integrated Cellular WiFi Systems" proposed WiFi offloading problem in an integrated cellular WiFi system consisting of mobile base station (MBS) and WiFi access point (AP). They propose a probabilistic offloading scheme, where cellular packets that arrive at the queue of MBS are offloaded to the queue of WiFi AP with an offload probability. The offload probability is determined to minimize the average delay experienced by the cellular packets while guaranteeing stability of both cellular and WiFi system. This paper Studied two priority disciplines: First-In-First-Out (FIFO) and Non-Preemptive Priority Rule (NPPR). Considered the congestion in network, penalty switching and pricing of network in congestion-aware network selection problem in data offloading. The offload probability p is determined to minimize the average delay experienced by cellular packets while guaranteeing stability of both systems (cellular and Wi-Fi) [3].

# Chapter 3

# D2D Based WiFi Offloading for 5G Traffic Reduction

## 3.1 Introduction

Traffic offloading is an attractive solution for the operators to increase the system radio capacity in the future cellular networks. Device to Device (D2D) technology helps achieve this goal by allowing direct communication between closely located user devices. However, as D2D devices transmit on the cellular network uplink bandwidth, the communication mode selection should be properly studied in order to limit mutual interference between D2D and cellular links [43].

## 3.2 D2D Communication

D2D communication is defined as direct communication between two mobile users in cellular networks without crossing the base station (BS) or core network. It has advantages such as increased spectral efficiency and reduced communication delay.

It is generally non-transparent to the cellular network and it can occur on the cellular spectrum (i.e., inband) or unlicensed spectrum (i.e., outband). In a traditional cellular network, all communications must go through the BS even if both communicating parties are in range for D2D communication.

Mobile users in today's cellular networks use high data rate services (e.g., video sharing, gaming, proximity aware social networking) in which they could potentially be in range for direct communications (i.e., D2D). Hence, D2D communications in such scenarios can highly increase the spectral efficiency of the network. Nevertheless, the advantages of D2D communications are not only limited to enhance spectral efficiency. In addition to improving spectral efficiency, D2D communications can potentially improve throughput, energy efficiency, delay, and fairness. Figure 3.1 bellow shows the general classification of D2D communication.

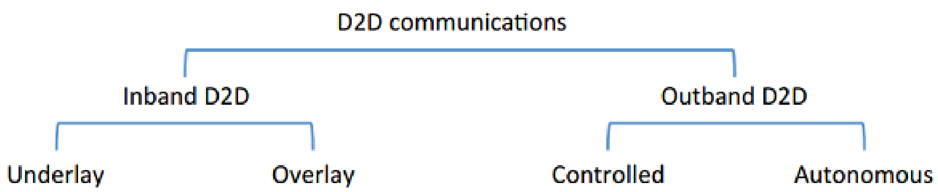


FIGURE 3.1: Classifications of D2D Communications [43].

## 3.3 Inband D2D Communication

D2D communication can operate in the cellular spectrum, called the inband or can use unlicensed spectrum, called the out band. The interference in unlicensed band is higher compared to that in the licensed band.

Inband D2D communication is further divided into underlay mode and overlay mode of operation based on how the spectrum resources are shared for D2D communication. In underlay mode, both the cellular user and D2D user use the same resources maintaining the interference level as low as possible. The spectrum efficiency is increased to a great extent with underlay mode .The overlay mode D2D communication uses dedicated cellular resources for operation. This implies that there exists no interference between cellular and D2D user. But since the precious resources are dedicated for D2D operation, in case of absence of users in proximity, these resources will be wasted. The main challenge in inband D2D is the interference between D2D users and cellular communications. To mitigate the interference, high complexity resource allocation methods are introduced, which increase the computational overhead of the BS or D2D users.

### 3.3.1 Underlay D2D Communication

Underlay D2D achieves better spectral efficiency, power efficiency, QoS, fairness, reliability and cellular coverage. Existing research work focuses on the importance of inband underlay D2D communication in increasing spectrum efficiency and methods for resource allocation. Underlay mode is shown to have the advantage of spectral efficiency and better QoS with efficient interference management in [44]. The uplink performance metrics for inband underlay D2D are discussed in [45] which emphasizes on the effect of interference from adjacent D2D user. In [46], [47], the authors use a network science approach for D2D communication for energy efficiency (30% improvement) and delay (15% improvement). In [48] , a joint spectrum and power allocation framework is proposed based on pricing with QoS guarantee. The interference between cellular users and D2D users is controlled by the base station by setting a price for each D2D channel used. In order to achieve this, a game-theoretic approach is used where the D2D pairs compete for the spectrum until a Nash equilibrium is achieved. The system performance and the speed of convergence of the proposed algorithms are shown in simulation results of [48]. In [49], a fair resource allocation problem for D2D communications in OFDMA based wireless cellular networks is discussed. They propose waveforms that can be used for D2D communication which can improve delay and achieve maximum rate.

### 3.3.2 Overlay D2D Communication

In overlay mode, the absence of D2D users makes the spectrum underutilized but simplifies the resource allocation as the cellular user interference does not exist. However, overlay mode can achieve better throughput performance [50]. In [51], [52], the work analyses overlay D2D coexisting with OFDM network. In [53], a scheme is proposed to mitigate interference between the D2D users in overlay mode reusing the resources. Another interesting area in D2D communication is mode selection between cellular mode and D2D mode. Mode selection is discussed in detail in [54]. The authors in [10], discuss the mobility impact on mode selection using an analytical approach.

## 3.4 Outband D2D Communication

In outband D2D communication, the D2D links exploit unlicensed spectrum. The interference between cellular and D2D users is absent in outband. The outband D2D communication is further divided into controlled and autonomous mode of operation. Using the unlicensed spectrum would require an extra interface and also, usually adopts other technologies like WiFi direct or bluetooth. In[55], the work suggests control of interference to cellular network i.e., controlled outband D2D communication. In contrast to this the cellular communications can be controlled and D2D communication can be left to users. Outband D2D communication may suffer from the uncontrolled nature of the unlicensed spectrum. It should be noted that only the devices which have two wireless interfaces (e.g., WiFi and LTE) can use outband D2D. Therefore, the users can have D2D communication and cellular communication simultaneously [3], [56], [57]. This paper uses controlled out band D2D communication.

# Chapter 4

# Proposed System Models

## 4.1 Introduction

D2D based wifi offloading is important technology for 5G cellular network. It is used for reducing traffics from 5G , increases the probability of getting free wifi access points by increasing the deadline rate for users and reduces the transmision delay in data transfer. This chapter deals about the mathimatical model and graphical design of the proposed thesis work.

## 4.2 Queuing Theory

Queuing theory is explicitly used to analyze and design any kind of system that involves waiting in lines for a service, such as restaurants, banks, mobile data etc. The queues can be formed at the receiving end only or the transmission end only or at both ends. They act as data buffers and also protect data packets from crashing into one another. However queues can be a wasteful downtime.

Queuing models are usually denoted by A commonly used shorthand notation, called Kendall notation: A/B/c/K, where A denotes the distribution of the inter-arrival time, B denotes the distribution of the service time, c denotes the number of servers, and K denotes the capacity of the queue. If K is omitted, it is assumed that $K = \infty$. The inter-arrival time is the amount of time between the arrival of one customer and the arrival of the next customer. It is calculated for each customer after the first and is often averaged to get the mean inter-arrival time, represented by lambda. Service time is defined as the time required to serve a customer. There are lots of different queuing models and single server models have been discussed below:

## 4.3 M/M/1

M stands for Markov and is commonly used for the exponential or Poisson distribution. Hence an M/M/1 queue is one in which there is one server (and one channel) and both the inter-arrival time and service time are exponentially distributed [58]. The important equations for M/M/1 models by using LITTLE's law are:

$$\begin{aligned} L &= \sum_{n=0}^{n=\infty} n(1-\rho)\rho^n = \frac{\lambda}{\mu-\lambda} \\ &= \frac{\lambda}{\mu-\lambda} = \frac{\rho}{1-\rho} \end{aligned} \tag{4.1}$$

$$\begin{aligned} L_q &= \sum_{n=1}^{n=\infty} (n-1)P_n = \frac{\lambda^2}{\mu(\mu-\lambda)} = \rho L \\ &= \frac{\rho^2}{1-\rho} \end{aligned} \tag{4.2}$$

$$W = \frac{1}{\mu-\lambda} \tag{4.3}$$

$$W_q = \frac{\lambda}{\mu(\mu-\lambda)} = \rho W \tag{4.4}$$

$$\rho = \frac{\lambda}{\mu} \tag{4.5}$$

Where, $\rho$ denotes utilization factor , $L$ denotes expected no. of customers in system, $L_q$ denotes expected queue length, $W$ denotes the waiting time in system ,$W_q$ denotes the waiting time in queue, $\mu$ denotes servicing rate and represents arrival rate.

## 4.4 Routing Scheme

It is expected that the 5th generation of mobile systems (5G) will be provided by the telecommunication companies to the general public in the year 2020. But currently, there is enough technology to implement 5G so why the telecommunication companies are not providing 5G network. Millimeter-waves with high frequencies, 30Ghz to 300Ghz, need to be used to fronthaul 5G traffic as most of the good range of radio frequencies. These millimeter-waves have short ranges i.e. they cannot travel a long distance and they get attenuated in space very easily. So to make these waves travel long distance small-cell need to be densely deployed in the environment to help the millimeter-wave to travel through many small-cell until it reaches the Base Transceiver Station (BTS). Hence to make the 5G cellular network infrastructure less depended on small-cell, scientists and engineers are trying to develop ways to offload traffic without the assistance of small cells.

This thesis can be considered as an extended work of [42] where the traffic is offloaded over WiFi is available. Otherwise, if unavailable, the traffic is delayed to offload via cellular network until a deadline is reached.

Delayed offloading; if no WiFi connection is available, (some) traffic can be delayed up to a given deadline, or until WiFi becomes available.

The proposed routing scheme is as follows in Figure 4.1 below;
**Situation 1:** User's cell phone will check WiFi's availability. If WiFi is available, it will send its data to WLAN as WiFi offloading offers much higher data rate, less power consumption and avoid traffic overload at base stations.
**Situation 2:** If WiFi is not available data traffic will wait till its deadline is

reached. While the data is waiting in the queue to reach the deadline time, it will run another process where it will do Device 2 Device (D2D) communication with its neighboring cell phones to check whether they have a WiFi connection or not. If they have, then the user's cell phone will establish a D2D connection with one of the neighboring cell phones which are running WiFi and offload all the data to the neighboring device which in turn will offload these data over WiFi.

**Situation 3:** if the user's cell phone cannot find any neighboring device with an active WiFi connection then it will do the typical cellular communication with the base station to offload its data.

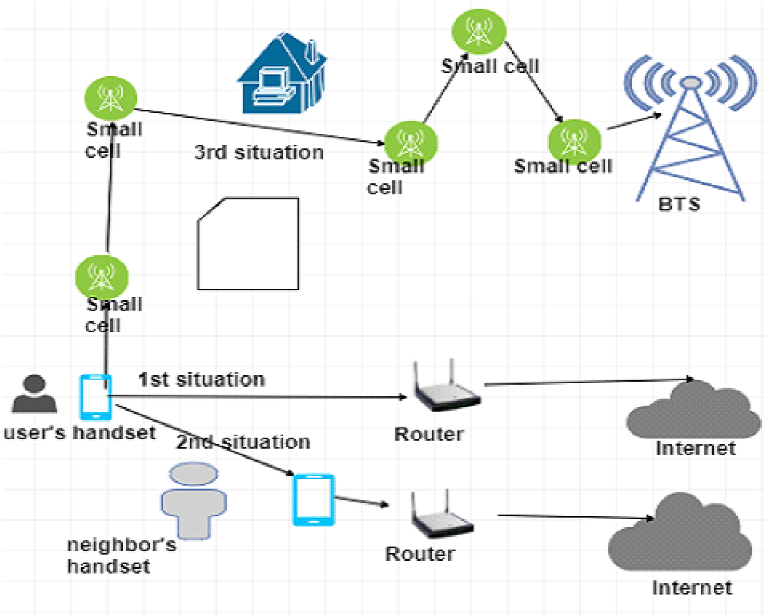


FIGURE 4.1: 5G Cellular Data Offloading Using Different Techniques

## 4.5 Markov's Chain

Paper [42] modeled their WiFi queue with a 2D Markov chain. This work extended their model by considering D2D in the Markov chain in Figure 4.2 States with WiFi connectivity are denoted with i, Wi-Fi, states with only cellular connectivity i, Cellular and states with D2D connectivity i, D2D. Here, i represent the number of customers in the system (service + queue). While in the WiFi states, the system empties at the rate of $\mu$ and in both D2D state and cellular at a rate of

$i\xi$. The rate $i\xi$ represents the rate of offloading the files that abandoned the WiFi queue as there was no WiFi and now after the expiration of the deadline; these files are either being offloaded by the cellular state or by the D2D state. Here $\mu$ represents servicig rate and $\xi$ represents deadline rate. Unlike [42], this paper made no attempt to derive the total transmission delay of the proposed model from the above extended Markov chain instead modeled the proposed model by taking equations or models for delay in each of the three states from existing published paper as this equation for total transmission delay more appropriate. The total transmission delay of this model will be discussed in the later section of this paper.

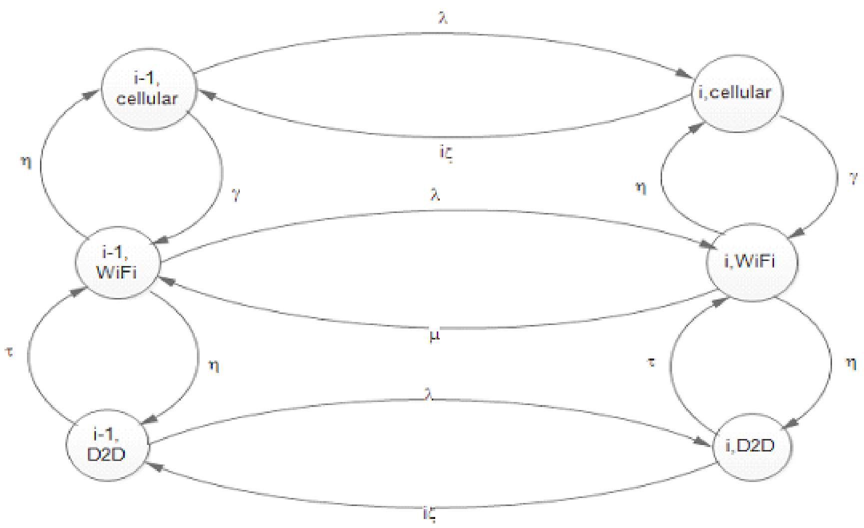


FIGURE 4.2: The 2D Markov Chain for the WiFi Queue in Delayed Offloading with Consideration to D2D WiFi Queue

The growth in internet traffic from mobile phone is exponential. The limited capacity of core data network has become a problem also 5G will demand cellular networks with ultra-low delay, high throughput and low congestion at the core network. This huge amount of mobile device traffic will be tough for the cellular network to handle all on its own. One solution to this problem is to deploy a huge number of small cells in the environment. But telecommunication companies are feeling reluctant on bearing the huge cost of buying, installing and maintenance of these small cells. To date, WiFi offloading seems to be an easy and inexpensive solution to the problem. WiFi AP is already found at the customer's end: WiFi routers installed at homes and work. By sending the user's traffic over Wi-Fi, telecommunication companies will need to install fewer amounts of small cells in the environment and it will also cause less traffic at the BTS.

Paper [42] mentions two types of WiFi offloading: on-the-spot offloading and delayed offloading. This paper uses the latter; delayed offloading. In delayed offloading all the user's traffic will be sent over WiFi when there is an active WiFi connection in the user's handset; otherwise, all traffic is sent over cellular interface after the traffic has waited for a deadline in the queue for the WiFi to come back. This work extended this routing scheme and made it better and less depended on small cells by including D2D in the routing scheme.

At times someone find him/herself within the coverage of a WiFi network but fail to establish a WiFi connection in him/her mobile handset due to not knowing the password of the WiFi access point (AP). Delayed offloading can be made handy in those situations by making the user's handset search its environment for any neighboring handset with an active WiFi connection with the AP while the user's traffic is waiting in the WiFi queue to reach the deadline. WiFi access points have already become densely deployed in the environment: shopping mall, universities, schools, offices, and restaurants. Most of the time there have been fail to use these APs because of not knowing the security password of the access points. In such places, there is a high chance that someone in the environment knows the security password and he/she has already an active WiFi connection in his/her handset. By making user's traffic offload through the WiFi connection of someone else's handset after the deadline is reached, 5G data offloading can be made less depended on small cells.

This thesis assumed that the data will offload according to First Come First Served (FCFS) queuing discipline and at all times the cellular network will be available. Whenever the WiFi connection gets lost, the packets in the WiFi queue will be given a deadline. The deadline time will be set in an increasing manner to the queued packets from the first to the last that is the 2nd packet waiting in the queue will be given a slightly longer deadline than the 1st packet in the queue. If the WiFi connection does not come within the deadline the packets will offload either by neighboring handset through D2D or by cellular network again offload according to First Come First Served (FCFS) queuing discipline. Also, if D2D connection is possible with WiFi activated neighboring handset, the packets that will collect in the WiFi queue of the neighbor's handset will offload by First Come First Served (FCFS) queuing discipline.

## 4.6 Performance of WiFi Queue

All files arriving to the system are by default sent to the WiFi interface with a deadline assigned (drawn from an exponential distribution). Files are queued (in FCFS order) if there is another file already in service (i.e. being transmitted) or if there is no WiFi connectivity at the moment, until their deadline expires. If the deadline for a file expires (either while queued or while at the head of the queue, but waiting for Wi-Fi), the file abandons the WiFi queue and is transmitted through the cellular network. These kind of systems are known as queuing systems with impatient customers [42] or with reneging [59].

## 4.7 One-hop Device to Device (D2D) Communication

D2D communication is another promising solution in minimizing the cost of implementing 5G cellular infrastructures and reducing traffic at the BTS. D2D communication in cellular network refers to the direct communication between the mobile users without the involvement of Base Station (BS) or the core network elements. Many papers have shown procedures for neighbor discovery and data offloading using D2D communication. In this routing scheme, there is a restriction to one-hop D2D communication which involves the transmission of data by a single hop. The reason for restricting to only one-hop D2D is because current technology is only just enough to do one-hop D2D and proves to be unreliable for multi-hop D2D as studied from many papers.

D2D is of two types: Network-centric and Device centric. Network-centric means communication between mobile users depends on the network infrastructure. This means that the user of a particular network, for example, Airtel, will only be able to do D2D. Whereas, device-centric means network setup is managed by the proximate device. This means that the user of a particular mobile handset, for example, Samsung, will only be able to do D2D will each other. So, users of the same mobile network operator or same banded handsets can allow each other to offload their data.

[60] Measured the average round-trip delay of 6.71ms for one-hop D2D where 20 ping packets were sent from a transmitting device to a 70m far apart receiving device. The maximum discovery distance and transmission rate for D2D communication are 354m and 50Mbps respectively which is greater than Wi-Fi, 35m and 11Mbps (IEEE 802.11b) respectively [48]. The radio frequency for wireless communication can use any frequency band: licensed or unlicensed band. Millimeter wave of high frequency can deliver high speed for short distances between the two devices.

In this routing scheme, the user's handset will search to find any handset in its environment with an active WiFi connection to a WLAN. After the discovery of such handset, user's handset will then try to set up a reliable connection with the neighbor's handset by assigning an IP address as proposed in [52]. The algorithm using Abstract Protocol Notation (APN) for the user's handset to discover neighboring handset with active WiFi connection is given in Figure 4.3 below:

The user's handset broadcasts a request to find WiFi active handsets in its surroundings. As soon as the broadcast message is sent a timer is turned on. The timer will count time up to the deadline time of packets in the WiFi queue of the user's handset to get replies from other handsets in its surroundings. If any affirmative reply of WiFi available handset comes then the user's handset will send

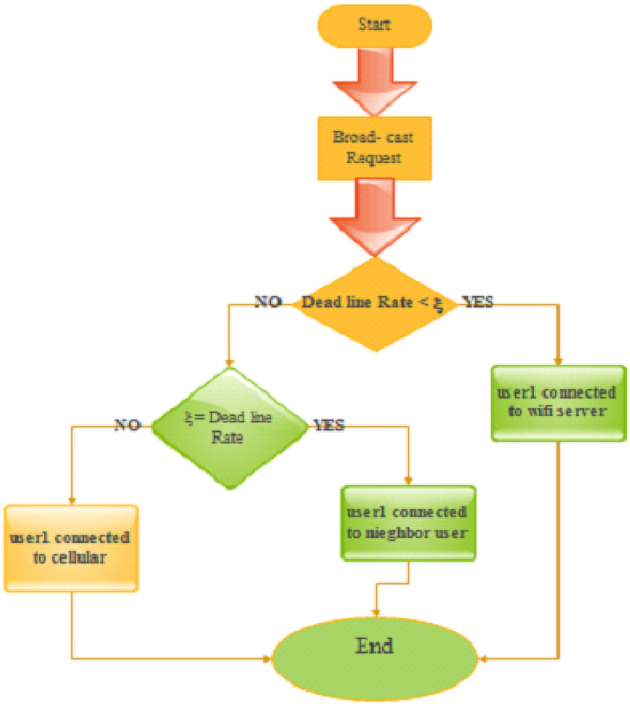


FIGURE 4.3: A Routing Scheme for D2D Based WiFi Offloading

another request to establish D2D connection with the WiFi activated neighboring handset. Otherwise, if no WiFi active neighboring handset is found then the packets in the user's handset will offload over the cellular network.

## 4.8 Total Expected Delay

In order to send a packet from source to destination a packet experiences delay at every stage along its transmission. The total delay experienced by a packet is the accumulation of the delays: nodal processing delay, queuing delay, transmission delay and propagation delay. This model assume that the traffic arrives as a Poisson process with rate $\lambda$, the WiFi available period as an exponential distribution with rate $\mu$, the WiFi unavailable period as an exponential distribution with rate $\eta$, the deadline as an exponential distribution with rate $\xi$, and the file sizes are exponentially distributed.

The WiFi queue is based on the Markov chains which are shown in Figure 4.2 above. The total expected delay for this system is given below:

$$E[D] = \rho 1 DWiFi + \rho 11 DD2D - WiFi + \rho 111 DCELLULAR \tag{4.6}$$

Where $\rho 1$ is the probability that WiFi is available in user's handset, $DWiFi$ stands for total end to end delay associated to offloading through Wi-Fi, $\rho 11$ represents the probability that WiFi is available in the neighbor's handset with condition that WiFi is unavailable in the user's handset, $DD2D - WiFi$ denotes total end to end delay associated to offloading by WiFi through one-hop D2D communication with the neighboring handset, $\rho 111$ indicates the probability that the WiFi and D2D communication are unavailable with condition that cellular network is always available, and $DCELLULAR$ means the total end to end delay associated to offloading through cellular network. To calculate the end to end delay for situation-2 where user' WiFi is unavailable but D2D communication is possible with the neighbor's handset, the delays: the delay occurred due to waiting till the deadline in the WiFi queue, the delay incurred to perform D2D communication and finally the delay accumulated to transmit data over the neighbor's Wi-Fi; need to be accounted each individually. The paper [51] gives WCETT which is the Weighted Cumulative Expected Transmission Time to offload to BTS through multi-hop D2D communication. The WCETT from [51] is given as:

$$WCETT = (1 - \beta) * \sum_{i=1}^{n} ETT_i + \beta * maxX_j \tag{4.7}$$

Where $X_j = \sum_i ETT_i$ and $ETT = ETX * \dfrac{S}{B}$ ETX stands for the number of expected retransmission before a packet is successfully transmitted and S is the size of the packet and B is the bandwidth of the link. According to [51], the first term of WCETT expression, that multiplied $1 - \beta$, quantifies the resources consumption in the whole considered route, whatever the channels used and the second term, weighted by $\beta$, represents the channel diversity. From equation 4.7 we compute the delay equation for one–hop D2D as follows:

For one-hop

$$X_J = \sum_i ETT_i \tag{4.8}$$

$$X1 = \sum ETT1 \tag{4.9}$$

$$X = ETX * \frac{S}{B} \tag{4.10}$$

Thus

$$\begin{aligned} WCETT &= (1-\beta)\sum_{i=1}^{n} ETT_i + \beta * maxX_j \\ &= (1-\beta)ETX * \frac{S}{B} + \beta * ETX * \frac{S}{B} \end{aligned} \tag{4.11}$$

$$\begin{aligned} Done-hopD2D = WCETT &= (1-\beta)ETX * \frac{S}{B} + \beta * ETX * \frac{S}{B} \\ &= ETX * \frac{S}{B} - \beta ETX * \frac{S}{B} + \beta ETX * \frac{S}{B} \\ &= ETX * \frac{S}{B}(1-\beta+\beta) \\ Done-hopD2D &= ETX * \frac{S}{B} \end{aligned} \tag{4.12}$$

From paper [42], we get the delay model associated with calculating delay expe-

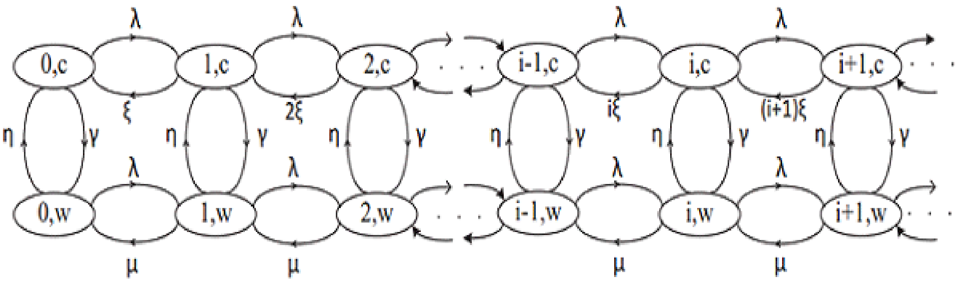


FIGURE 4.4: The 2D Markov Chain for the WiFi Queue in Delayed Offloading [42]

rienced by a packet while it is being offloaded over WiFi. The delay model for offloading over WiFi from [42] is given below:

$$E(T) = \frac{1}{\lambda}\left(\left(1+\frac{\gamma}{\eta}\right)\frac{\lambda-\mu(\Pi\omega-\Pi0,\omega}{\xi} + \frac{(\lambda-\mu)\Pi\omega+\mu\Pi0,\omega}{\eta}\right) = D_{WiFi} \tag{4.13}$$

The end to end delay where the data is offloaded through D2D over WiFi is as follows.

$$E[D] = \rho 1 D_{WiFi} + \rho 11 D_{D2D} - WiFi + \rho 111 D_{CELLULAR} \tag{4.14}$$

$$E[D] = 0 + \rho 11 D_{D2D} - WiFi + 0 \tag{4.15}$$

$$E[D] = \rho 11 D_{D2D} - WiFi \tag{4.16}$$

Where, $D_{D2D} - WiFi = D_{Deadline} + D_{D2D} + D_{WiFi}$

$$\begin{aligned} D_{D2D} - WiFi &= D_{Deadline} + ETX * \frac{S}{B} \\ &+ \frac{1}{\lambda}\left(\left(1 + \frac{\gamma}{\eta}\right)\frac{\lambda - \mu(\pi\omega - \pi 0, \omega)}{\xi} + \frac{(\lambda - \mu)\pi\omega + \mu\pi 0, \omega}{\eta}\right) \end{aligned} \tag{4.17}$$

$$\begin{aligned} E[D] &= \rho 11 D_{D2D} - WiFi = \rho 11 \left(D_{Deadline} + ETX * \frac{S}{B}\right. \\ &+ \left.\frac{1}{\lambda}\left(\left(1 + \frac{\gamma}{\eta}\right)\frac{\lambda - \mu(\pi\omega - \pi 0, \omega)}{\xi} + \frac{(\lambda - \mu)\pi\omega + \mu\pi 0, \omega}{\eta}\right)\right) \end{aligned} \tag{4.18}$$

Since $\rho 1 + \rho 11 + \rho 111 = 1; use \rho 11 = 1 (\rho 1 = \rho 111 = 0)$

$$\begin{aligned} E[D] &= D_{D2D} - WiFi = D_{Deadline} + ETX * \frac{S}{B} \\ &+ \frac{1}{\lambda}\left(\left(1 + \frac{\gamma}{\eta}\right)\frac{\lambda - \mu(\pi\omega - \pi 0, \omega)}{\xi} + \frac{(\lambda - \mu)\pi\omega + \mu\pi 0, \omega}{\eta}\right) \end{aligned} \tag{4.19}$$

## 4.9 Impacts of Number of Server on Utilization Factor

The more the number of servers in a system gets more and better performance. As the number of server increase the utilization factor decreases, a system can serve more number of users than the single server .Or if number of server increases the waiting time taken for a user decreases and a transmission delay decreases and

Waiting times are the main source of dissatisfaction. By LITTLE's law Utilization factor for k servers can be calculated as

$$\rho = \frac{\lambda}{k\mu} \tag{4.20}$$

# Chapter 5

# Result and Discussion

## 5.1 SimEvents Model

The SimEvents library was heavily used for model design. First a FIFO (first in first out) queuing scheme was built and then an entity generator is used to replicate data packets.

The proposed routing scheme has been modeled and tested using the simulation software MATLAB/Simulink. The simevents library of Simulink has been used cleverly to replicate this data offloading scheme and the results and explanation of the simulation is given in the subtopics below.

Characteristics have been provided to the entities using the blocks of attributes to set the amount of time that the entities (or data packages) must wait in queue and then timers have been set to mimic how a mobile device will search for a fixed period of time for WiFi network and then move to another path.The template M / M/1 was used. There is only one server and both the inter-arrival time and service time have been set to exponential distribution to ensure that the model flows the model M / M/1.

The Simulink model is shown below in Figure 5.1 The results of the simulation of the proposed routing model over a simulation time of 500 units are shown in the

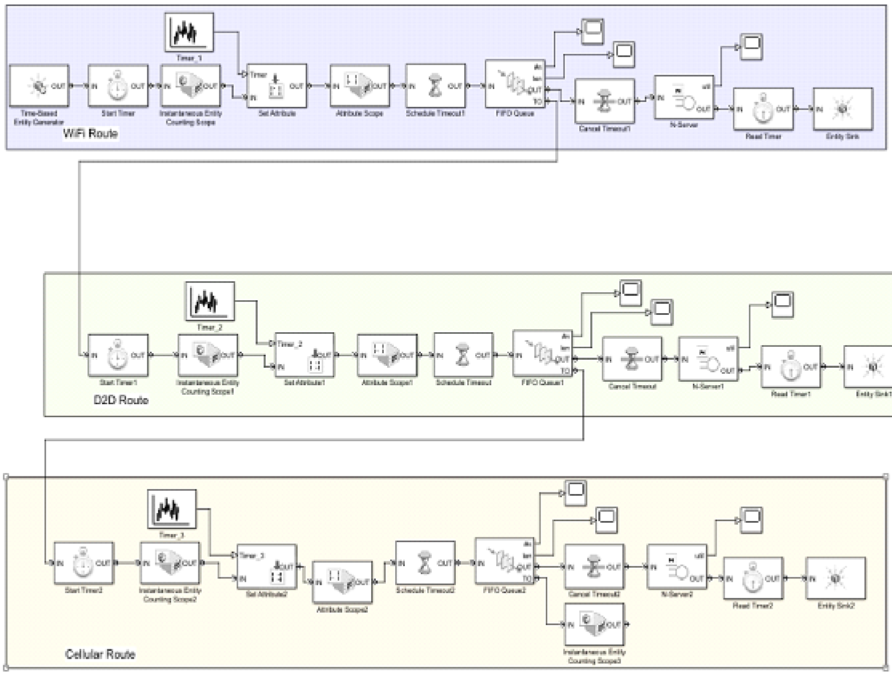


FIGURE 5.1: Simulink Model of the Proposed Routing Scheme using SimEvents Library

figures below. The utilization factors of each server (WiFi, D2D and Cellular) are shown in Figure 5.2, Figure 5.3, Figure 5.4 respectively. The graphs of average queue length of WiFi route and D2D route are shown in Figure 5.5 and Figure 5.6 respectively, The utilization factor shows what percent of the server is busy and the average queue length shows how many entities or data packets are in the queue of a certain server at a certain time.

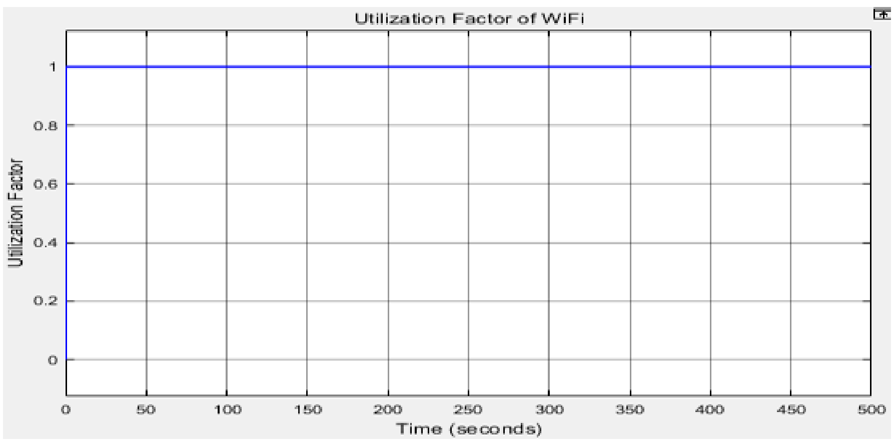


FIGURE 5.2: Utilization Factor of WiFi Route

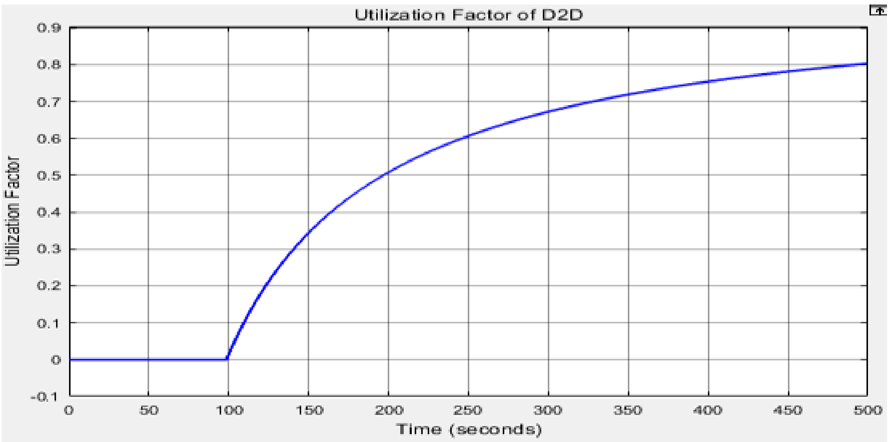


FIGURE 5.3: Utilization Factor of Device to Device Route

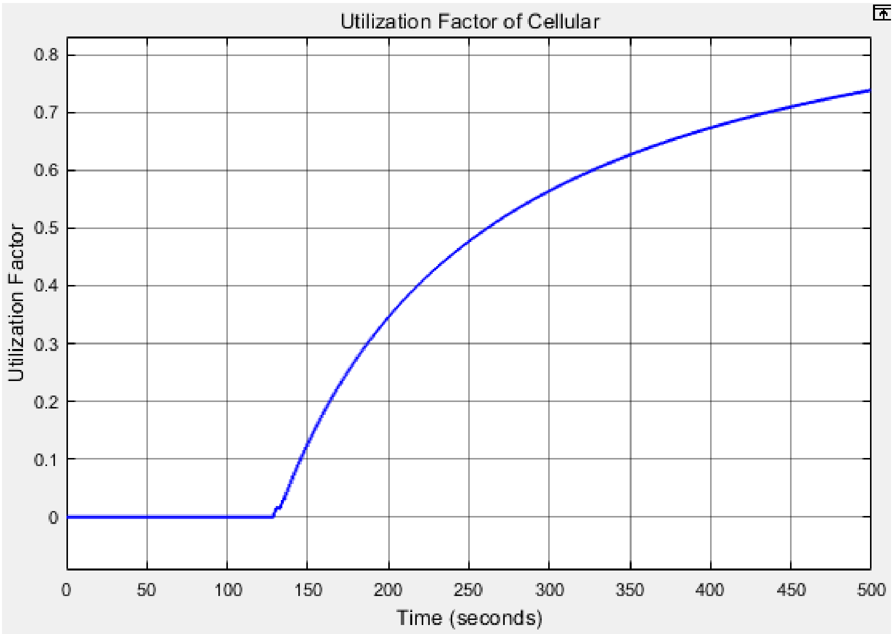


FIGURE 5.4: Utilization Factor of Cellular Network

From the simulation result we can conclude that the utilization factor of WiFi route is larger (approximately =1) means that this wifi server is busy (un available). As a result a user packet need to offload to D2D because this D2D server have utilization value between 0 and 0.8 meaning that this server is available for the user (the server is free). Utilization factor of cellular network is less than from these two servers (WiFi and D2D server) (between 0 and 0.75). This indicates that cellular server is always available. If wifi and D2D servers are unavailable the packet (traffic )must be offloaded to cellular servers.

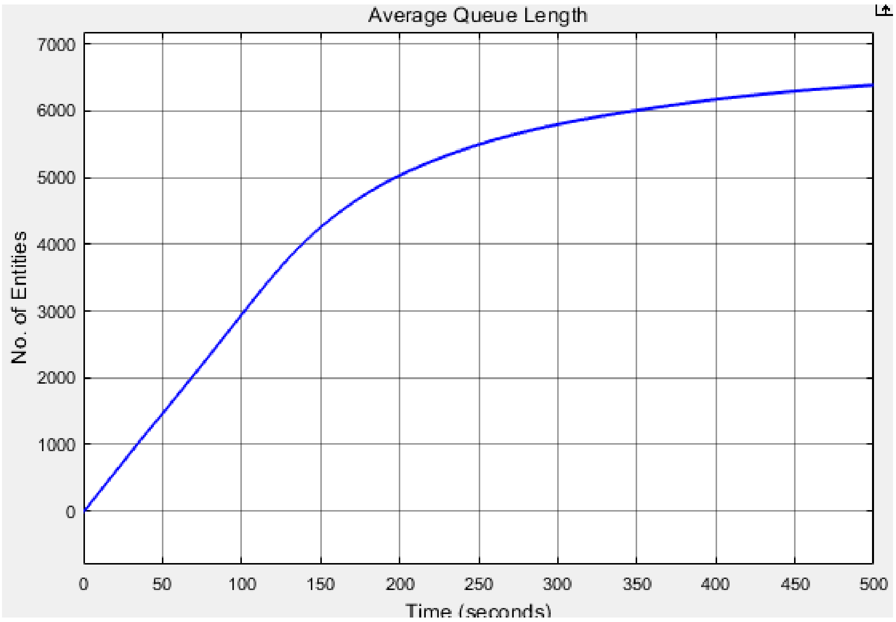


FIGURE 5.5: Average Queue Length of WiFi Route

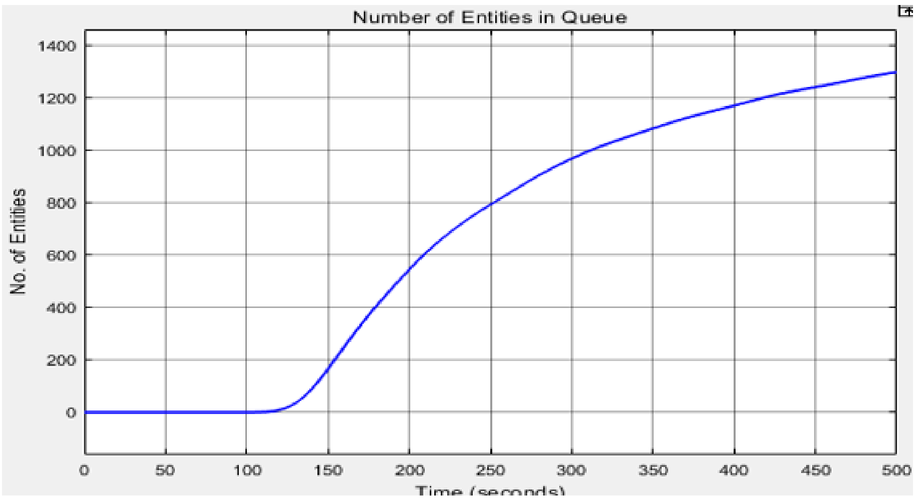


FIGURE 5.6: Average Queue Length of D2D Route

The simulation result shows that there are more queues in the WiFi server than the D2D server for the same time unit (interval (500 units)) .This indicates that the wifi server is much busy or there are more entities in the wifi queue than in D2D queue. The waiting time taken for the entities or subscribers is more for WiFi server than D2D server. Which means there is much delay in wifi server than D2D server. This paper describes the importance of D2D communication over traffic offloading, which reduces the transmission delay between source and destination and reduces the cost required to transmit data from source to destination in 5G (next generation wireless technology). As we have seen in queuing theory queue length depends on servicing rate, as servicing rate increases the queue length decreases .Meaning that the server gives a service if it is free, or there is less queue in the server(less entities are found in the server).

## 5.2 Transmission Delay versus Packet Arrival Rate

Here the simulation results are used to analyses the advantage of D2D communication over wifi offloading for traffic reduction of cellular networks (5G) .This shows that the end to end transmission delay depends on many parameters like packet arrival rate, deadline rate , service rate, WiFi exiting rate ,cellular exiting rate .

TABLE 5.1: Parameters Used in the Simulation Result

| | |
|---|---|
| Arrival rate ($\lambda$) | 0 up to 1.5 |
| The rate of leaving the cellular state ($\gamma$) | 0.003 |
| The rate of leaving the wifi state ($\eta$) | 0.6 |
| Wifi Servicing rate ($\mu$) | 0.003 |
| Probability of finding the system under WiFi coverage ($\pi\omega$) | 0.2 |
| Stationary probability of finding 0 files in WiFi state ($\pi 0, \omega$) | 0.1 |
| $D_{Deadline} + ETX * \frac{S}{B}$ | 0.0035 |
| Deadline rate ($\xi$) | 0.05,0.9,2,20 |
| size of the packet (S) | 6 GHz |
| bandwidth of the link (B) | 7.5 Mbyte |

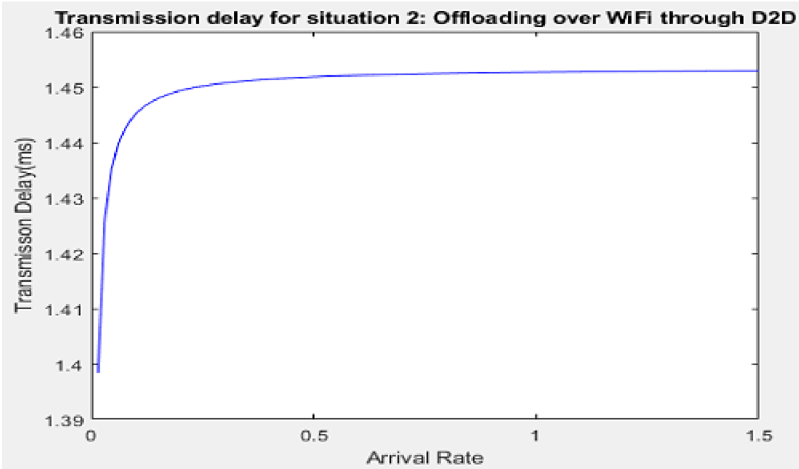


FIGURE 5.7: The Average Delay of Offloading over Wifi through D2D for A Packet of Size 7.5Mbyte($\xi = 0.9$)

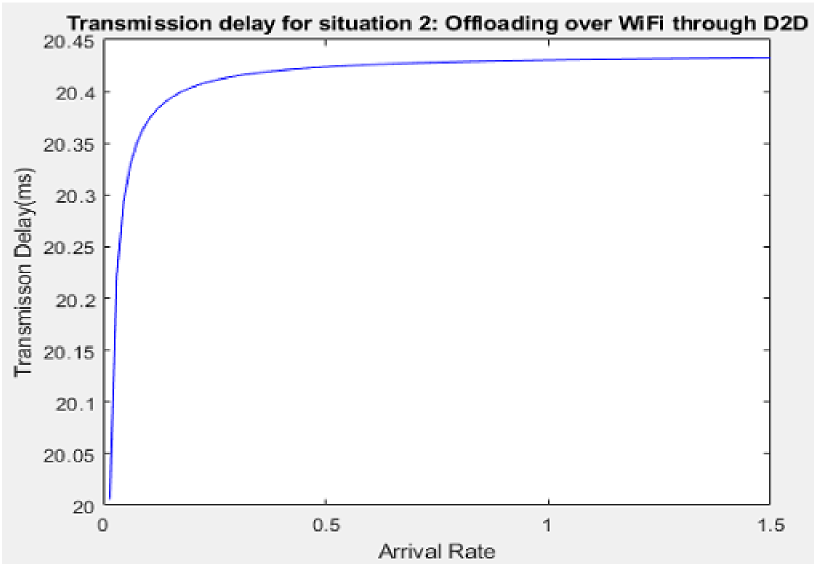


FIGURE 5.8: The Average Delay of Offloading over WiFi through D2D for A Packet of Size 7.5Mbyte ($\xi$=0.05)

The above simulation result shows that by increasing the deadline rate we can reduce the transmission delay of the transmitting data or if we increase the deadline rate there is a chance to get a WiFi availability or offloading to cellular server will reduce this results the reduction of building many small cells to transmit data for a long range distance. As we know 5G networks have distance limitation proqblem to transmit data from source to destination is difficult it needs the construction of many small cells this construction requires cost this proposed system (D2D based wifi offloading) is used to reduce the need of many small cells by increasing the

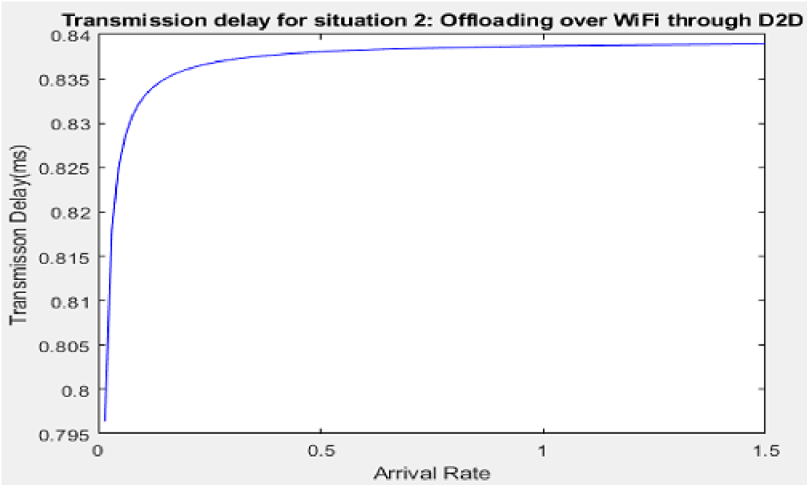


FIGURE 5.9: The Average Delay of Offloading over Wifi through D2D for A Packet of Size 7.5Mbyte ($\xi$=2)

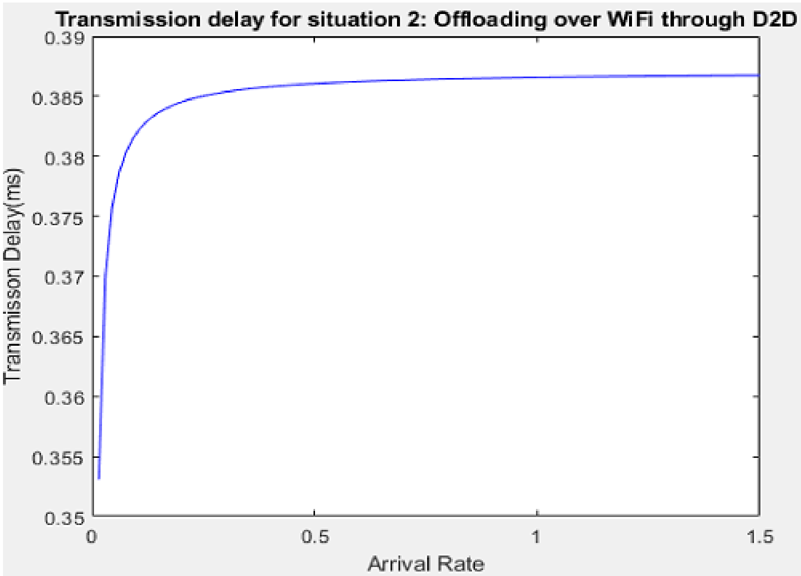


FIGURE 5.10: The Average Delay of Offloading over WiFi through D2D for A Packet of Size 7.5Mbyte ($\xi$=20)

deadline rate for the same other parameters it reduces the chance of offloading traffics to cellular network. Generally, for a 10 fold increase in zeta the gain in delay is a little greater than 2 times.

## 5.3 Effects of Number of Servers on Utilization Factor

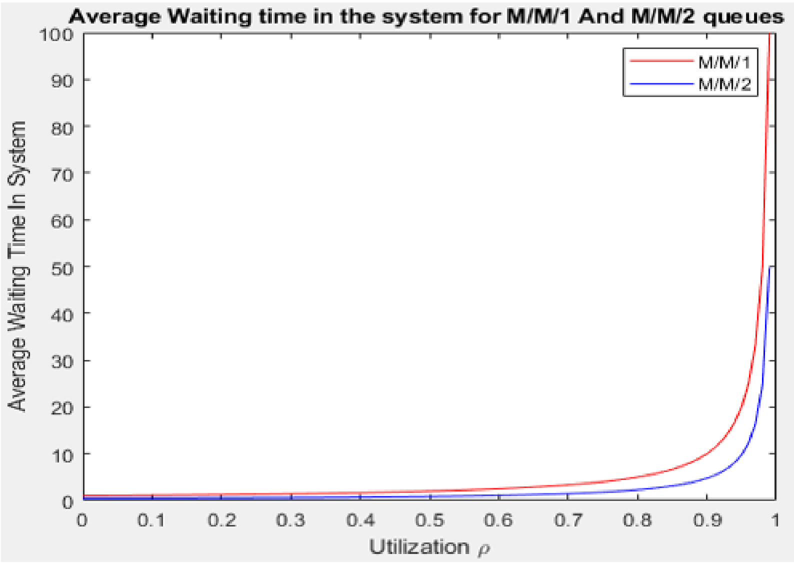


FIGURE 5.11: Average Waiting Time versus Utilization Factor for One Server and Two Servers

The above result in Figure 5.11 shows for the same amount of arrival rate ($\lambda$=(0-0.99)) and servicing rate ($\mu$ =1) a two servers system have less waiting time than the single server. As k increases utilization factor decreases and waiting lines for a user decreases.

# Chapter 6

# Conclusion and Recommendation

## 6.1 Conclusions

Generally the aim of this paper is to analysis some performance parameters of D2D based WiFi offloading for 5G traffic reduction. From year to year cellular traffics are very huge as a result it is difficult to fulfill users requirement for cellular networks as they require cost .To fulfill users requirement there are some technologies to be used from those cellular traffic offloading to WiFi is studied in previous researchers .Since WiFi is unlicensed it is profitable technology. But in this paper performance of D2D based WiFi offloading is studied this is because of D2D based WiFi offloading increases the probability of getting WiFi access points for users by increasing the deadline rate. This reduces the total transmission delay for data transfer. The Matlab simulation shows that some routing parameters like utilization factor, average queue length and transmission delay. These parameters are used to analysis the performance of the offloading technology that is explained in this paper. And this thesis work studied about effect of number of servers on utilization factor.

## 6.2 Recommendations

The following few promising future work is recommended by this thesis work.

- And this work is done on static devices it is interesting thing that what happened when the devices are dynamic.

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# Appendix

## Important Terminology

**A.** *SimEvents:* SimEvents provides a discrete-event simulation engine and element library for analyzing event-driven system models and optimizing performance characteristics like latency, throughput, and packet loss. Queues, servers, switches, and different predefined blocks permits for the modelling of routing, process delays, and prioritization for planning and communication. With SimEvents, it's doable to check the results of task temporal order and resource usage on the performance of distributed management systems, package and hardware architectures, and communication networks. Operational analysis may also be conducted for choices associated with statement, capability designing, and supply-chain management. For simulation the previous library had to be known as victimization simeventslibwithin the command window of MATLAB

**B.** *Markov Chain:* This mathematical system is called after its creator: Andrev Markov. A Markov process could be a random model depiction a succession of conceivable occasions within which the chance of each occasion depends simply on the state accomplished within the past occasion. once a selected condition is met, the systems that moves from one state to a different. Markov process is predicated on memorylessness .In different word, future state of the method solely depends on the past state and not the sequence of states. This basic presumption makes the calculation of probability straightforward and permits this calculation to be connected in range of eventualities.