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A FINAL THESIS REPORT

ON

“ANALYSIS OF ENERGY OPTIMIZATION OF BTS OF 5G NETWORK OVER SDN ENVIRONMENT”

SUBMITTED BY

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“Analysis of Energy optimization of BTS of 5G network over SDN environment”

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A Final thesis report submitted for the requirements of Master of Science Degree in Information and Communication Engineering

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DEPARTMENTAL ACCEPTANCE

The thesis entitled “**Analysis of Energy optimization of BTS of 5G network over SDN environment** ", submitted by **Sonu Singh** in fulfillment of the requirement for the award of the degree of “**Master of Science in Information and Communication Engineering**” has been accepted as a genuine record of work independently carried out by her in the department.

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ABSTRACT

Attracting a huge attention towards energy optimization of mobile communication network as it contains the major part of total energy consumption of Information and Communication Technology (ICT). During low traffic load, the energy is wastage as the design of wireless network is made for maximum traffic load, but the maximum traffic occurs only for few hours. A base station transceiver (BTS) consume more energy than any other network devices used in end access network. Most of the resources of BTS are unused during the low traffic load at night time, which results in unnecessary wastage of energy and decreases energy efficiency. Therefore, to increase the energy efficiency of 5G end access network, the energy optimization of BTS is necessary. In this thesis, the concept of Dynamic Transmitter Sleep (DTS) Technique has introduced over Software Defined Network (SDN) platform to reduce the energy consumption of BTS in 5G network with the addition of smart link sleep approach to save more energy by deactivating network links between network elements of end access network during idle state. During low traffic, DTS approach automatically switch the unnecessary transmitter to sleep mode and wakeup only required transmitter when increasing traffic is noticed, without degrading the Quality of Service (QoS) and to achieve more energy efficiency smart link sleep approach has also implemented which is an SDN based energy optimization technique. This technique is performed over SDN environment where data and control planes are separated providing high flexibility, cost effective and energy efficiency. Hence, DTS technique has applied to the 5G BTS which was simulated in SDN environment where Mininet-WiFi emulator used as network simulation testbed and OpenDayLight as SDN controller. After implementation of DTS mode during low traffic, it saved 34.6% of energy in single BTS and 43.79% of network link energy has been reduced by the use of smart link sleep technique. Therefore, this energy saving approach has potential to reduce noticeable amount of energy consumption under the benefits of SDN.

***Keywords**:* 5G, BTS, Energy Consumption, Energy Optimization, SDN, Mininet-WiFi, OpenDayLight

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ABBREVIATIONS AND SYMBOLS

API	Application programming interface
BSs	Base stations
BBU	Baseband unit
BPF	Baseband processing function
BTS	Base Station Transceiver
C-RAN	Centralized radio access network
CSP	Cloud service provider
CU	Cost unit
DC	Data center
DTST	Dynamic transmitter shutdown technique
DTS	Dynamic transmitter sleep
LTE	Long Term Evolution
4G	Fourth Mobile Generation
5G	Fifth Mobile Generation
3GPP	Third Generation Partnership Project
MTC	Machine Type Communication
HTC	Human Type Communication
eMBB	Enhanced Mobile Broadband
mMTC	Massive Machine Type Communication
ITU	International Telecommunication Union
mMIMO	Massive Multiple Input Multiple Output

URLLC	Ultra-Reliable Low Latency Communication
NR	New Radio
NFV	Network function virtualization
ODL	Open Daylight
OF	Open Flow
OVS	Open virtual Switch
RRU	Remote radio unit
SDN	Software-defined networking
SD-RAN	Software-defined Radio Access Network
VN	Virtual network
VNF	Virtual network function

CHAPTER-1
INTRODUCTION

1.1 Background

With the development of Information and communication technology (ICT), energy consumption of communication infrastructures also growing exponentially[1]. Telecommunication communities are giving major focus on energy efficiency of the overall network due to many reasons like requirement of high data rate, environmental impact due to CO_2 emission, effect on climate change caused by using fossil fuels for energy production.[2]. Excess release of CO_2 in the atmosphere will cause excess rise in global temperature affecting climate. Higher spectral efficiency is needed for growing number of smart devices with their bandwidth-hungry mobile application like live video streaming, online video gaming, etc. [3]. The telecom industry has estimated to increase their internet traffic over 1,000 times in year 2020, with more than half of the traffic volume in file sharing[4]. It is necessary to make energy efficiency as a key of concern for the design of next generation 5G networks. Ericsson expected that 1.9 billion mobile users will be connected to 5G network before the completion of year 2024. More than 57% of total network energy consumption takes place within the base stations (BSs)[5].

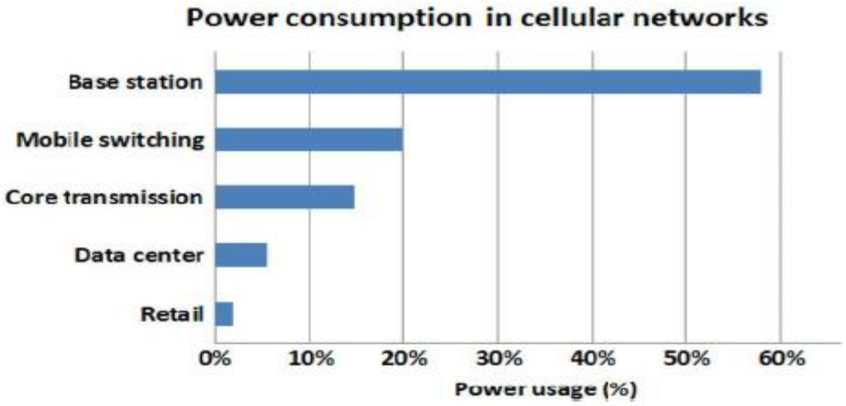

Figure 1.1: Power consumption in mobile networks & base station[5].

According to MTN, a 5G base station consumes twice or more power than a 4G base station. Increasing the energy cost more at higher frequencies due to the need of more antennas and denser layer of small cells. Some leading Chinese operators in the world for 5G deployments gives the warning of more power consumption as the electricity cost were rising fast with 5G [6]. China Mobile has tried using lower cost deployments of MIMO antennas. 5G base stations are carrying five times the traffic as when equipped with only 4G, pushing up power consumption. According to Huawei, compared to 4G the power consumption per unit of traffic (Watt/bit) is greatly decreased, but the power consumption of 5G increases. The proportion of sites with more than five frequency bands will increase from 3% in 2016 to 45% in 2023. As a result, the maximum power consumption of 5G site will be higher than 10 kW as shown in figure 1.2, and will be doubled for the site where more than 10 frequency bands are used.

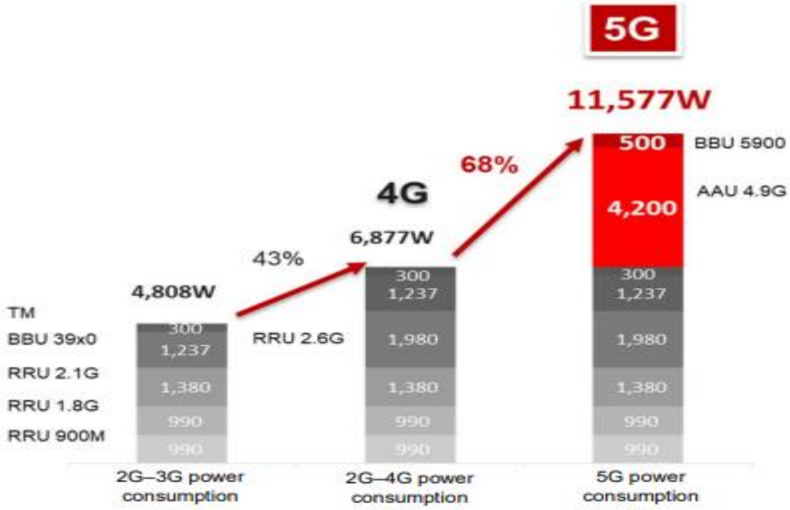

Figure 1.2: Typical maximum power consumption of a 5G site (Source: Huawei)

In the 5G network, both low-frequency and high-frequency bands will be deployed together with a large number of end sites to meet the service requirement of increasing network capacity which ultimately increase the power consumption of the entire network exponentially[7].

According to [8], even in highly loaded network most of the time, the base station resources are unused. 5G can make better use of power optimization techniques in the base station part with great enhancement in energy efficiency of entire network. A major part of energy consumption in mobile networks comes from the radio base station (BTS) sites and that the consumption is stable. Although the base stations are spending most of their time without transmitting user data but still consuming energy all the time because most of the hardware components of BTS remain active to transmit mandatory idle mode signals that are defined in the 4G or 5G standards such as synchronization signals, reference signals, and system information[8]. As shown in figure 1.3, there is significant energy consumption in the base station even at the time when BS is in an idle state i.e. when there is no output power.

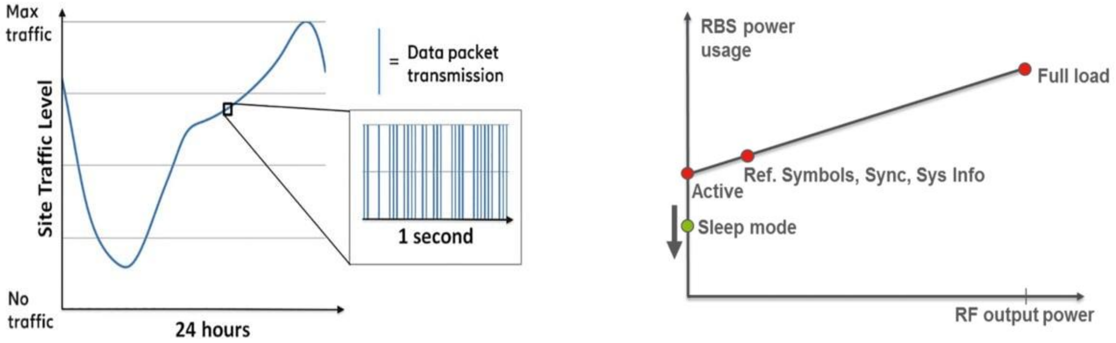

Figure 1.3: Varying network traffic load during the day (a) and Base station power model (b)

The arrival of 5G with a variety of advance features like ultra reliable low latency communication (uRLLC), enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), softwarization and virtualization of network connection[9]. The main purpose of 5G is to improve the user-centric concept rather than the operator-centric concept used under 3G or the service-centric concept used under the 4G network. To fulfill the requirement, the 5G network has extended into a multi-layer network that consist a variety of technical enhancement to broaden the range of wireless services[10]. SDN provides flexibility in network management. This will reduce the complex problems and costs facing the 5G mobile network.

The importance of SDN within 5G wireless networks is its ability to provide new functionality such as network capability and automation of the latest facilities at the rise of virtualized strategies on trusted and secure networks. Also, SDN makes it possible to separate control concepts using specific vendor hardware for original software users and vendors. Therefore, it allows for the improvement of data performance and roadmap for wireless structure into system solutions for all-purpose or in-cloud computing. [9]

The Software Defined Radio Access Network (SDRAN) is defined as a Radio Access Network (RAN) network that can benefit from SDN views. Separating the control plane from the RAN data plane can lead to better spectrum performance or better disruption management within distributed BSs as a core component, such as a CRAN system,the SDRAN system also puts different processing resources together to form a pool. Resources would therefore be managed and allocated powerfully at demand at the pool level. The base station is the equipment needed to communicate with mobile terminals and the main network (CN). [12]

With the increase in traffic, investment in BSs also increases and eventually operating costs increase. As BS consumes about 60% of the total network power, energy consumption and power consumption also increase with the increase in the number of BS. Traffic depends on time and place. With the network set up for high traffic but in real life, the full load is for a few hours a day [15]. Inside a base station, Transceiver (TRX) is the most energy demanding hardware part. Power amplifier is the largest energy consumer inside BS. The energy consumption of single base station can be reduced by shutting down the transceivers according to traffic flow pattern dynamically. This technique saves up to 18.8% of energy in macro base station of 3G Network[11]. Therefore, this energy saving amount is for single basestation and it will give satisfactory results of energy saving for overall network. Hence, this thesis focuses on the enhancement in amount of energy saved by DTST technique and reduce the complexity of network management with the use of SDN for radio access network (RAN) to control the base station of 5G cellular network.

SDN is a smart network that minimizes hardware usage. The value of SDN in 5G wireless networks lies particularly in its ability to bring new capabilities to secure and reliable networks, such as network visibility, automation and the addition of new services in addition to the built-in resources. Also, SDN policies solve the problem of Radio Resource Management on 5G networks with multiple usage cases (interruption management, mobile edge computing, RAN sharing). Therefore, to address all the previous challenges in the 5G mobile network and reduce costs, SDN was proposed to provide the necessary flexibility in the construction of the 5G network. SDN also helps to simplify network management and configuration. It also reduces costs through the flexibility of 5G network operations. This is due to the services rendered by the SDN on the network by separating the data transfer in the network control. In SDN, the controller maintains the integrity of the entire network. On the other hand, the data plane is still distributed on the change and shift of the route responsible for forwarding or moving the route based on the flow inputs generated by the control plane. In the art of SDN architecture, open -flow protocol is used to define data structure, messages, and processes, to define all tangible and intangible objects in the data path and to validate traditional flight control functions, such as packet transfers, table route management, and separate flow management. For 5G mobile networks, the controller will use open-flow protocols to communicate with basic 5G devices, maintain network topologies, set new streams, and collect network statistics to meet QoS requirements.

1.2 Statement of Problem

Base stations consume the largest power in overall mobile network. Many studies conducted on the power optimization of base station. Traffic aware energy scheme has applied to shut down the whole base station during low or no traffic load. Different BS sleeping techniques have been studied to save the energy of BS. BS sleeping approaches saves the satisfying amount of energy consumption according to the strategies applied but it shows degradation in quality of services (QoS)[2] [5] [3] and [12]. To overcome this drawback, the unused hardware resources of base station can be managed during low traffic load or in ideal condition instead of sleeping whole BS. Using dynamic transmitter shutdown technique (DTST), we can save a bit less energy than shutting down whole BS but this technique maintains the QOS of the network [11] where the transmitter of base stations are made dynamically shutdown when there is low traffic flow. This research proved that 18.8% of energy can be saved from single BS of 3G network by applying DTST technique. Till now the DTST technique is applied only on legacy network platform and analysis was done. Now, the research question covered by this thesis is:

1. How much energy would be saved by DTST technique for SDN based 5G networks? Power efficiency can be determined algorithmically or by hardware design in SDN. SDN energy saving methods are divided into Hardware energy saving strategies and software energy saving process. When the software's energy saving method is separated by traffic information, storage system awareness and administration. Traffic aware systems are encouraged by the fact that network components are often misused during low traffic. The main goal is to turn on or off network devices depending on the traffic load. when

traffic load is low this method has the potential to save up to 50% of total energy used[13]. In legacy network, to get the satisfactory result, this technique should be applied to each base station which is difficult to manage and control for large no of BS. SDN will add the flexibility to the network by separating control plane and data plane. Hence, network can be controlled and managed by SDN controller placed distance apart from networks. The important properties of a SDN traffic aware energy efficiency approaches are elasticity, topology awareness, queue engineering, and smart sleep on and off. Here in this thesis the smart sleep on and off technique will be used for the transceivers of base station in 5G network and the corresponding result will be analyzed. Therefore, this thesis focuses the energy optimization of SDN based 5G network using Dynamic transmitter sleep (DTS) technique with the benefits of SDN.

1.3 Objective

- To analyze the energy consumption of BTS in 5G network over SDN environment using Dynamic Transmitter Sleep (DTS) Technique

1.4 Outline of thesis

Here, the clear outlook of the chapters of the thesis are as follows:

- Chapter 2: consists the literature review of 5G cellular network and the optimization techniques used for switching off-on the base stations of cellular access network.
- Chapter 3: provides the 5G network scenario, a system flowchart and explanation of all factors that are necessary to answer the research question. We created a simple 5G cellular network scenarios controlled by SDN controller and DTS technique will be implemented in this scenario to optimize the base stations power and energy.
- Chapter 4: presents the results and discussion. Moreover, we created the 5G network topology and passed the network traffic through the topology and recorded power of BTS without using any optimization technique.
- Chapter 5: this chapter consist of Conclusion section which provide the conclusion of overall experimental outcomes on the basis of observed result.

CHAPTER-2

LITERATURE REVIEW

The 5G network is all-IP based model for wireless and mobile networks. 5G network architecture consist of a user terminal and some different Radio Access Technology (RAT). Compared to other networks, the function and services of 5G will be more efficient and better. The features of 5G offers high speed, low latency, better quality, flexible and software controlled.

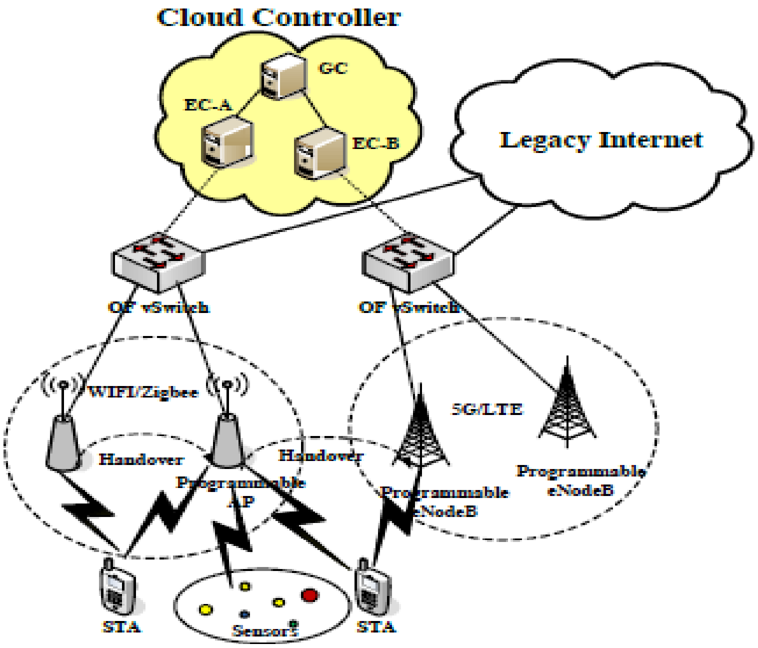

Figure 2.1: SDN based 5G network Architecture[14].

The core 5G network is based on the service to achieve a flexible combination of network functions, fast marketing time, agile usage, and standalone autonomy. 4G network design is based on hardware applications and tightly integrated networks; however, the 5G network has been redefined to separate the functions of the control plane, allowing for flexible integration and independent evolution. SDN and NFV are the most useful technologies for next-generation core network architecture [9]. To add the flexibility to the network, SDN separate the control plane and data plane and uses SDN controller to control the network devices. NFV seperates the hardware and the software, where hardware elements are replaced with virtual applications running on general-purpose hardware platforms [15][16]. SDN improves the network quality and energy efficiency by allowing higher data rates and lower latency which ultimately improves the user experience. The SDN switches act as forwarding devices which results in data and control plane separation. The networks traffic is managed by SDN controller which is logically centralized, results in routers and switches elimination, and also eliminates the conventional table forwarding format. These switches and controllers are linked together using these application programming interfaces (API) which has been preprogrammed. OpenFlow is a commonly used API, with well-known controllers and one of them is OpenDayLight controller. Which is used in this thesis as SDN remote controller.

There are several benefits of SDN. It is one tool for reducing energy waste and maximizing power use during peak hours, resulting in traffic consolidation. The majority of SDN work is focused on traffic, defense, and routing[17]. Because of its inherent strengths, SDN has been used in transport networks, wireless sensor networks, network function virtualization (NFV), cloud radio access networks (C-RAN), the Internet of Things (IoT), and edge computing. Granularity, stability, centralized control, lower operating costs, traffic scan with the help of software, cloud level extraction, and assurance of QoS are some of the other advantages of SDN[18].

5G RAN architecture is divided into central unit (CU) and distributed unit (DU) with open interface to enhance interoperation. Figure 1.2 shows the functionalities of CU and DU and their comparison with 4G RAN.

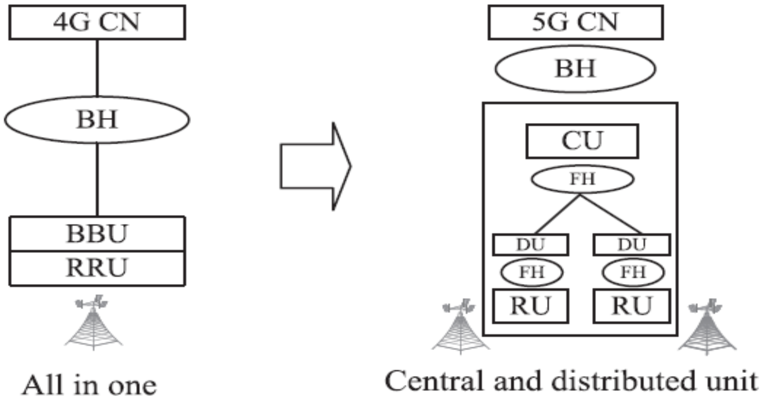

Figure 2.2: 4G and 5G RAN architecture.

The CU is a RAN controller and manages data distribution, capable of using multiple connections, seamless mobility management, and efficient use of spectrum. The CU is needed to be centralized and developed to support multi-leg management. DU is latency-sensitive and consists of L1 with partial L2. CU has ability to serve as a hook to tie up distributed data between multiple DUs, also to reduce backhaul pressure for data distribution between BSs without hook points. CU can tie up 4G and 5G to accelerate data distribution between multi-RATs[19]. A base station of 5G is known as gNodeB (gNB) which is consist of CU, DU, and RRU.

2.1 Software Defined Radio Access Network (SDRAN)

SDRAN system centralizes different baseband processing resources together to constitute a pool. Thus resources could be managed and dynamically allocated on demand on a pool level. The three key technologies in SDRAN are User Flow & Resource Flow, Packets Processing Based on OpenFlow Switches, GNV (Global Network View)[20]. The overview of software-defined RAN architecture is illustrated in Figure 1.6. It consists of three main parts: wireless spectrum resource pool (WSRP), baseband processing unit (BBU) pool and SDN controller.

a) WSRP transmit radio frequency signals to UEs in the downlink. It forward the baseband signals from UEs to OpenFlow switches which equip at BBU pool.

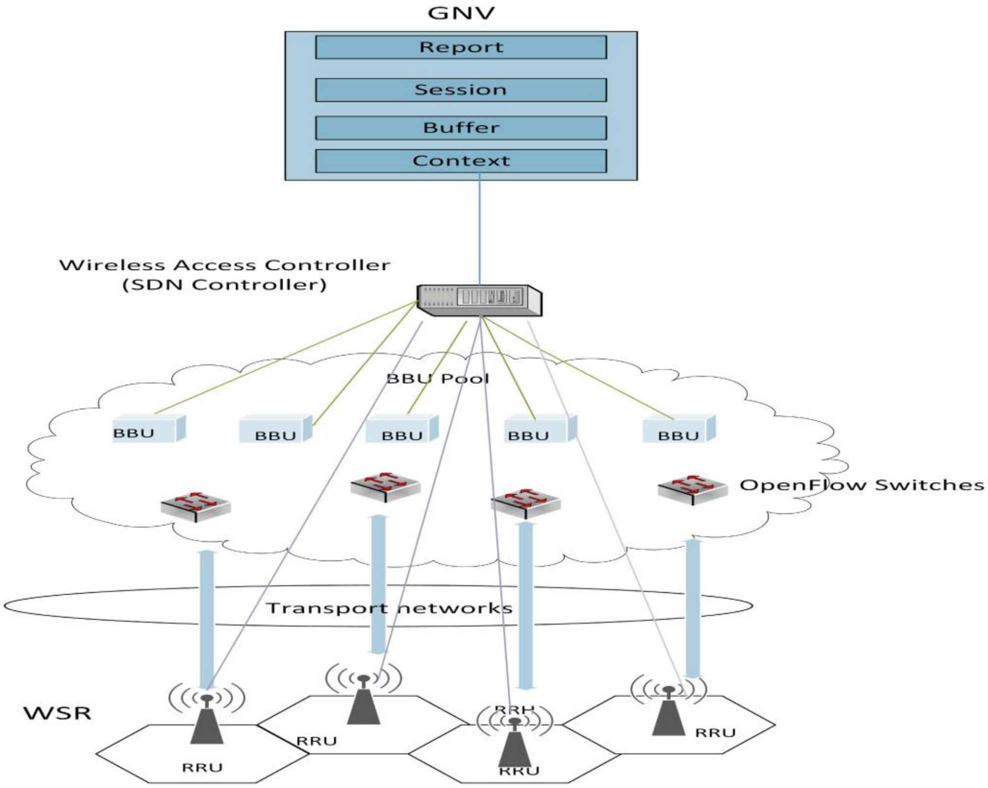

Figure 2.3: SDRAN Architecture[20]

b) BBU pool: The BBU pool consists of a mass of soft BBU notes and OpenFlow switches. A soft BBU is a place where processing resource and capability is dynamically allocated and reconfigured based on real-time conditions. OpenFlow switches transform the baseband signals from UEs or the radio resources into flow tables.
c) SDN controller: It determines the policies of single soft BBU note, and virtual access element contains a SDN agent where communication occurs through SDN protocol with the controller.

2.2 5G Base Station power consumption

In 5G network, the power consumption model is splited into core network power consumption and base station power consumption. In literature [21], Base station power consumption model denotes the power consumed by the resources of Radio Remote Head (RRH) in 5G network. The RRH consists of a radio frequency and power amplifier that scale linearly with the number of antennas and also the necessary voltage suppliers. However, the power module of RRH can be distributed into the following components.

Antenna: Each antenna requires radio frequency and Power Amplifier to provide the necessary required signal operations and amplification.

RF transceiver's: The RF unit handles a number of functions related to the medium frequency and baseband interface, such as voice fluctuations / power reduction, power output, d/a and a/d conversion, less noise amplification and clocks.

Power amplifier (PA): PA is a key factor to consider in PM, as it uses a lot of power in the network, especially in RRH. PA amplifies the electrical signal received from the Optical to Electrical (O/E) converter prior to its transmission to the air connector and vice versa. In rare cases, its efficiency can be as high as 54% when transmitting high power. This low performance comes due to the strong dynamics of the orthogonal frequency division multiplexing signals.

The power consumption of the proposed SDC-RAN can be indicated by the independent load (Pstatic) and the additional power depending on the increasing load in terms of the power slope (Δ), as shown in Figure 2.3, the maximum power supply (Psupply) of RRH, the bandwidth allocation used (B) and the number of radio chains (A). A high-performance PC is achieved with high power transmission (Pout).

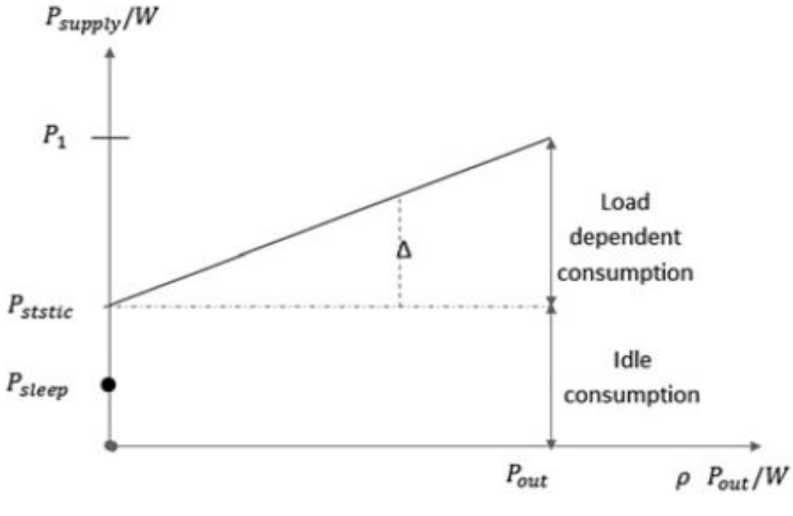

Figure 2.4: Base station load dependent power consumption and idle power consumption

In addition, when RRH does not transmit, it can enter sleep mode with a lower PC (Psleep). Total electrical power was then reduced, to W

$$P_{\text{supply}}(\rho) = \left(\begin{array}{ll} (R)(P_1 + \Delta P_{\text{out}}(\chi - 1)) & \text{if } 0 < \rho \leq 1. \\ (R)P_{\text{sleep}}, & \text{if } \rho = 0. \end{array} \right.$$

P1 = P_{static} + ΔP_{out}; ρ is traffic load parameter. If ρ = 1, the network full traffic load, whereas the network is in idle state when ρ = 0.

Hence, this power model shows that certain fix amount of power consumption takes place by the BS in idle state too.

2.3 Related Research on Energy optimization

To reduce the energy consumption in mobile cellular network, BS switching On-Off is one of the preferable method due to its easy implementation and no change needed in network architecture. Many research has conducted under this popular technique firstly studied in IEEE 802.11b [22]. In this approach when there is low traffic and in some delay tolerant cases, they reduce the consumption of energy by turning off some resources in the cellular network. The complete shutdown of BS for low traffic load to save the energy consumption is termed as binary sleeping mode which means just switch on and off of BS. Most of the research focused on this Binary sleeping mode technique for BS [23][24][25][26]. In [27], the author used stochastic geometric for switching off macro BS under the constraints of converge saving 60%of energy comparing to the status when all the base stations are in active state. The author has used best BS switching on-off method and user connection depends on throughput performance of HetNet in [28] to reduce the energy consumption of base station configured with massive MIMO antennas. In this literature, the author talks about centralize scheme which gives the optimal policy using linear programming. Also some additional techniques are applied with BS shutdown method in literature [3], where the author proposed the switching on/off based energy saving (SWES) algorithm which was practically implemented to turn off the BS one by one with minimal network impact by shifting the additional load increment to its neighboring BS. Also three other heuristic versions of SWES were proposed to reduce the signaling and implementation overhead over the air and backhaul. In [2], To improve the energy efficiency of 5G network the author presented the review on the classification of machine learning implementation in 5G network where the several issues regarding energy efficiency in 5G network were discussed which can be solved using machine learning.

Several levels of sleep models to the same base station gives additional capacity to adjust the base stations with pattern of traffic load and their type which gives better system performance. The author presented the energy optimization model and two sleep algorithm in [29] to analyze the energy consumption of LTE HetNets where the algorithms works as scheduling a single event to make sleep the entire small BSs overlay and later the time instance was defined to sleep each single small BS and finally the optimization model was used to study the performance evaluation. In [12], Four categories of sleep mode was controlled by online reinforcement learning technique SARSA for 5G network BSs resulting considerable energy saving with acceptable packet dropping level. In [30], the author gives the model to increase the energy efficiency of HetNet without change in Quality of service (QoS). Here the author studied about switching small cells to different sleep mode levels without degradation in quality of service. In [31], [32], [5], the author talked about deactivating the components of the base station to optimize the energy of a cellular network following the green touch model. In literature [17], the author shows that the combination of massive MIMO and small cells can greatly improve the total power consumption. The author proved that under QoS constraints, power minimizing spatial multiflow transmission is obtained by convex optimization problem solving technique. In [33], the study is focused on the detailed implementation of sleep cycle algorithm in different simulated scenarios and their impacts on users. In [34], the author studied about an optimization technique used for the special features of 5G traffic and applied it to formulate optiloop: a real time and strategy based on an efficient network management which is simulated under SDN environment. The delay of energy arrangement problem in a BS sleep mode techniques was also studied by author in [35]. Extra user-perceived delay can be seen after switching-off a BS which ultimately results in the amount of energy can be optimized by arranging a some of delays.

The another type of Base station components sleeping scheme is Cell DTX which was introduced in 4G LTE Rel-8 to reduce the energy consumption of BSs [36][37]. In these literatures they applied cell DTX SM techniques where it switches off the transceivers of BS when there is no traffic which gives the better performance than complete BS sleep scheme because Cell DTX sleep mode ensures the fast cell activation upon request. Without the degradation in quality of service (QoS), the author proposed dynamic transmitter shutdown technique (DTST) algorithm switching off the unused transceiver of 3G BS when there is less traffic load[11]. In this approach instead of switching off whole base station, the author has used the dynamic technique to switching-off only transmitter of the base station when there is low traffic load with constant monitoring on quality of service. For this they have choose the time period when there is flow of low traffic load to implement the DTST algorithm. For traffic prediction and forecasting they have used Erlang-B formula and Halt's-Winter forecasting method.

To apply these all optimization technique, we have to follow the traffic pattern of the network and base stations. Generally all the optimization algorithms are implemented during low traffic load [25]. Also, the technical specification of 5G, NR base station has been provided by ETSI in [38]. To perform these optimization techniques in SDN platform can be more energy efficient as SDN itself is an energy optimization technique with reducing hardware implementation cost and saving the power and energy used for cooling agent of base stations and other hardware [39]. In literature [40], the author studied about handover implementation in SDN-based and partially virtualized LTE architecture.

CHAPTER-3

METHODOLOGY

In this chapter, we present the structure of SDN-based 5G cellular network for energy optimization of base station using traffic aware dynamic transmitter sleep technique. This strategy minimizes BS power consumption which ultimately optimize the overall network energy consumption. The traffic flow at daytime is higher than that of night time. The key idea of SDN-based energy saving algorithm is that during low traffic load, power can be saved by shutting down the maximum transmitter into sleep state. To achieve this result first, we have to create a SDN based 5G environment by simulating a 5G cellular network topology inside mininet-wifi emulator as shown in figure 3.1. The topology consists of a SDN controller denoted by *C1*, three openflow switches *S1*, *S2* and *S3* and five base stations namely *AP1*, *AP2*, *AP3*, *AP4* and *AP5*. Each base station connects with five hosts. The design of cellular network is made to handle maximum network traffic. In real time maximum traffic flow only occurs for few hours a day. In this case transmitter sleep mode will help to save energy from the idle TRX. From each transceiver we can use the channels belong to transmitter among total channels of TRX. Also, the quality of service will not be compromised while applying DTS technique. The Transceiver (TRX) can be operated in two modes:

Active mode: In this mode, the TRX work with full function. It transmits and receive signals as usual basis.

Sleep mode: In this mode, the TRX neither receive nor transmit any user traffic. This is the power saving mode where it can only handle the hear request from base station which helps TRX to switch abruptly to active mode.

Hence the use of SDN will make the network flexible and reduce the complexity of the network by separating the data plane and control plane. Here OpenDayLight controller is used as the remote SDN controller to control the switches and routers of the network.

3.1 System Block Diagram

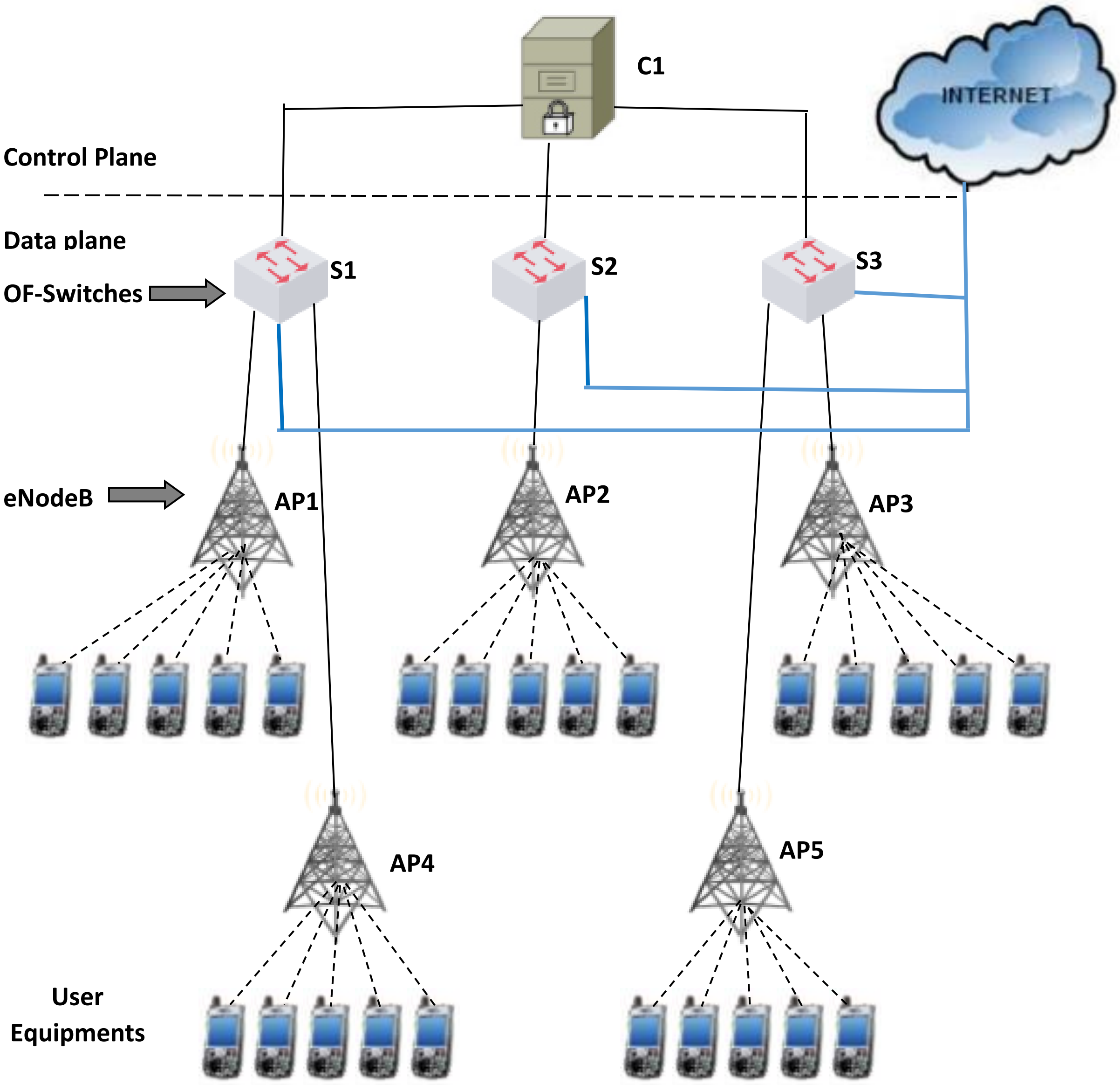

Figure 3.1. Implementation of SDN based architecture for 5G network in Mininet-WiFi.

3.2 System Model and Operation

BTSs are connected to openflow switch (OF-Switch) which control all the BTSs. Therefore, switching off few unused transceivers of base station at the time of low traffic can improve energy efficiency of the system ultimately. In this study we assume a base stations with 8 number of transceivers.

According to the study [41],the high traffic flow occurs from 0.4 and 1 (i.e. $0.4 < \lambda \leq 1$), during 10 a.m. to 11 p.m. (13 hrs). The low traffic flow occurs from 0 and 0.4 (i.e. $0 < \lambda \leq 0.4$), during 11 p.m. and 10 a.m. (11 hrs). Here λ is normalized parameter for traffic load.

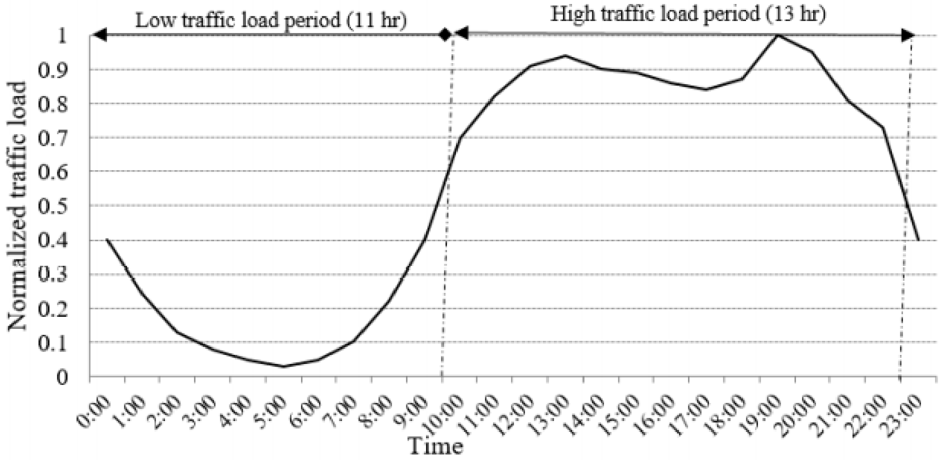

Figure 3.2: Daily traffic load pattern of BS [41].

The above figure 3.2 shows the daily traffic pattern of base station which matches with our sleeping and working pattern. From graph we can notice that there is maximum traffic load during daytime after 10:00 AM and start decreasing after 11:00 PM. Since in this technique we are not going to shut down the whole base station during low traffic load rather we will just put the idle transceivers in sleep mode dynamically. So to apply this technique on the basis of daily traffic load pattern, at night after 11:00 PM to morning 10:00 AM will be appropriate. Here the equation (1) below shows the power consumption of base station depends on the traffic load parameter λ.

$$P(bs) = \begin{cases} P0 + (Pm - P0)\lambda, & 0 \leq \lambda \leq 1 \\ P0, & \lambda = 0 \end{cases} \qquad (1)$$

P0 represents the idle state power of the base station and *Pm* represents maximum power of base station when traffic load is highest.

To built and test the performance of 5G wireless network we have used mininet-wifi emulator as a testbed and OpenDayLight remote controller as SDN Controller which works as a brain of the network. Speed of the communication process between users of 5G network is indicated by Throughput and latency parameters.

3.3 SDN Optimization Technique

Energy efficient approaches for SDN are categorized below in figure 3.4. which is divided in hardware based and software based approach. Software based approach has further classified into three parts traffic aware, end system aware and rule placement[13]. Here the sub-categories of traffic aware approaches are shown among which Smart sleep on and off technique will be applied in this thesis.

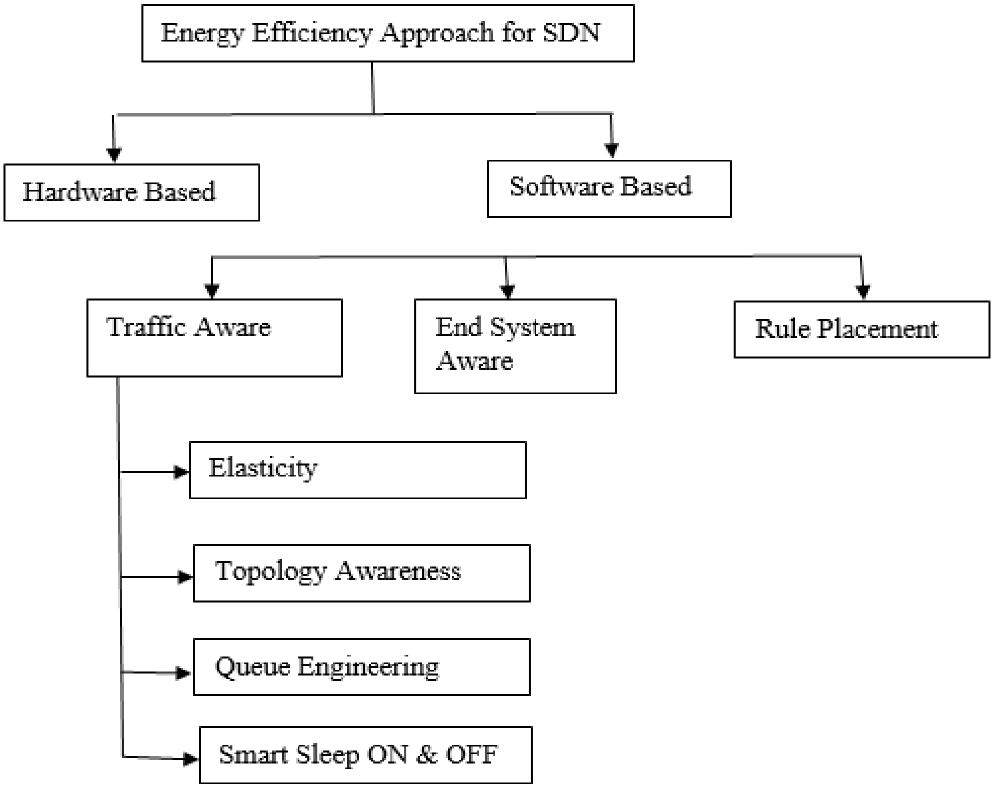

Figure 3.3: SDN based Energy Efficiency Approach

In traffic aware model, $G = (S,L)$ is an undirected weighted graph as network representation where S represents the number of switches and $Si \in S$ belongs to switch i and e$ij \in L$ represents link between *Si* & *Sj*. The weight *Wij* represents the bandwidth of the link connected *Si* & *Sj*. Let *Zi* denote the status of switch *Si* such that

$$Zi = \begin{cases} 1, & if\ switch\ Si\ is\ active \\ 0, & otherwise \end{cases} \qquad (2)$$

PZi and *Pij* are power consumption of switch *Si* and the link *lij* which is measured in W(watt). Traffic in the network is represented by set of flows F is the set of flow which represents the flow of traffic where $f \in F$ is defined as *f*=(*src, dst, λf*). *src* and *dst* $\in S$ are the source and destination switches and *λf* is the rate of flow *f* measured in bytes per second.

$$Fij = \begin{cases} 1, & if\ flow\ f\ passes\ through\ edge\ eij \\ 0, & otherwise \end{cases} \qquad (3)$$

Eq. (4) help to reduce the sum of the energy consumed by switches and the links. The the sum of $Fij * Pij$, gives the total energy consumption of all flows with the help of edge e*ij*. The total power consumed by all active switches is given by second part of equation (4).

$$minimize(\sum_{\forall f} \sum_{\forall lij} Fij * Pij + \sum_{\forall Zi} Zi * PZi) \qquad (4)$$

$$subject\ to \sum_{\forall f} Fij * \lambda f \leq Wij, \forall eij \qquad (5)$$

The constraint in Eq. (5) gives the total rate of flows between two switches which should be less than link capacity.

$$\sum_{\forall f} Fai = \sum_{\forall f} Fib, Si \neq src, dst \in f src, dst, \lambda f \qquad (6)$$

Constraint in Eq. (6) gives the number of flows entering and exiting from switches should be equal.

$$Fmj = Fin, Sm = src, Sn = dst, \forall emj, \exists ein \qquad (7)$$

Constraint on Eq. (7) defines a flow passing from source should reach the destination point.

$$Fij \leq Zj, \forall Sj \in S \tag{8}$$

$$Fij \leq Zi, \forall Si \in S \tag{9}$$

$$Zi \leq \sum_{\forall f} [Fij + Fji], \forall Si \in S \tag{10}$$

The limitations on Eqs. (8) – (10), using switch state and flow-link variables for maintaining the correlation between switches and links. While conditions 8 and 9 state that for inactive switch link, flow should not be use. Condition 10 confirms that if flow is not entering through the given switch links, then switched off the switch.

3.4 Proposed DTS algorithm

In this section we describe the detail operation of the DTS technique which aim to switch off the idle and low traffic TRXs to sleep mode at the duration of less traffic flow. Before applying DTS technique, certain resource allocation to the channels of TRXs should be manages. The use of non-BCCH transceiver channels will be less when the allocation of channels is performed on broadcast control channel (BCCH) TRX. Base station allocates channels on the basis of priorities of TRXs. High priority channels are assigned to User equipment (UE). OF-Switches controls the base stations which is controlled by SDN controller. To make the more transceivers idle controller centralizes busy channels into few TRXs. The handover of low traffic TRX should be done to another carrier. BCCH and packet data channel (PDCH) should not be available while putting TRX in sleep mode. Antenna frequency hopping should be disabled and no packet channel available in sleeping TRXs. Power consumption measurement should be taken before applying DTS technique.

In Figure 3.2, the proposed DTS algorithm is depicted in flowchart. First we have to choose the accurate duration to apply this technique. Generally, the traffic flow is heavy at day time and reduce at night time. So night time after 10 p.m. to next day morning 6 a.m. will be more appropriate. Voice and data traffic measurement will be taken in hourly basis. Halt-Winter (H-W) forecasting technique will be used to forecast the traffic that performs prediction of future values of time series based on properly weighted previous values which include seasonal component(I_t), trend component (b_t) and level component (S_t).

$$S_t = \alpha(Y_t /(I_t - L)) + (1 - \alpha)(S_{t-1} - b_{t-1}) \quad \text{(i)}$$

Where,

$$I_t = \beta(Y_t/S_t) \quad \text{(ii)}$$

$$b_t = \gamma(S_t - S_{t-1}) + (1 - \gamma)b_{t-1} \quad \text{(iii)}$$

A $m-$step ahead Holt-Winter's forecast is computed by following formula

$$F_{t + m} = (S_t - mb_t)I_{t-L+ m} \quad \text{(iv)}$$

α, β, γ are the overall smoothing parameter, seasonal smoothing parameter and trend smoothing parameter respectively. These parameters values are between 0 & 1 and are selected to minimize root mean square error (RMSE) between real and forecasted value. The initial conditions of above equations are:

$$S_t = \sum_{t=1}^{L} Y_t /L \ , \ b_t = 0 \quad \text{(v)}$$

$$I_t = \frac{Y_t}{S_t} \quad \text{for } t = 1 \ldots L \quad \text{(vi)}$$

L is the number of period in one season. To calculate the number of required channels ,the traffic will be predicted in hourly basis by H-W method. The required number of channel will decide how many TRXs should keep in sleep mode. The Earlang B formula will be used to calculate required number of channels and the blocking probability, P_B is given by:

$$P_B = \frac{A^n}{\sum_{k=0}^{n} \frac{A}{k!}} \quad \text{(vii)}$$

Where A is the predicted traffic in erlang and n is the number of channels. Therefore, the Erlang B formula is given by the following equation:

$$P_B(n,A) = \frac{AP_B(n-1,A)}{n+AP_B(n-1,A)} \quad \text{(viii)}$$

After calculating required number of channels, the decision for switching to sleep mode will be done by comparing required channel with the difference of available channel and transmitter channel. If the difference is greater than required channel then transmitter must be switch to sleep mode else it remains active. BBU first allocates channels to the operating TRXs and if the channel is not available then it allocates to sleeping TRX and notify BTS to switch on the TRX. Also to ensure the quality of service the cell availability and channel availability will be continuously monitor to keep 100%, if not then TRX should be switch on from sleep mode to active mode.

Area power consumption(APC) is the energy efficiency matrix which is given by the ratio of total power consumption(P) to the preferred deployment area(S). Mathematically,

$$APC = P/S \qquad \text{(ix)}$$

The regression model will be used to show the effect of traffic load on energy consumption.

$$Y = A + X\beta \qquad \text{(x)}$$

Where, Y = BTS energy consumption

X = traffic load

A = regression coefficient

β = weighted corresponding coefficient

In the above equation (x) of regression model, it takes energy consumption of base station as the function of traffic load.

3.5. Flowchart

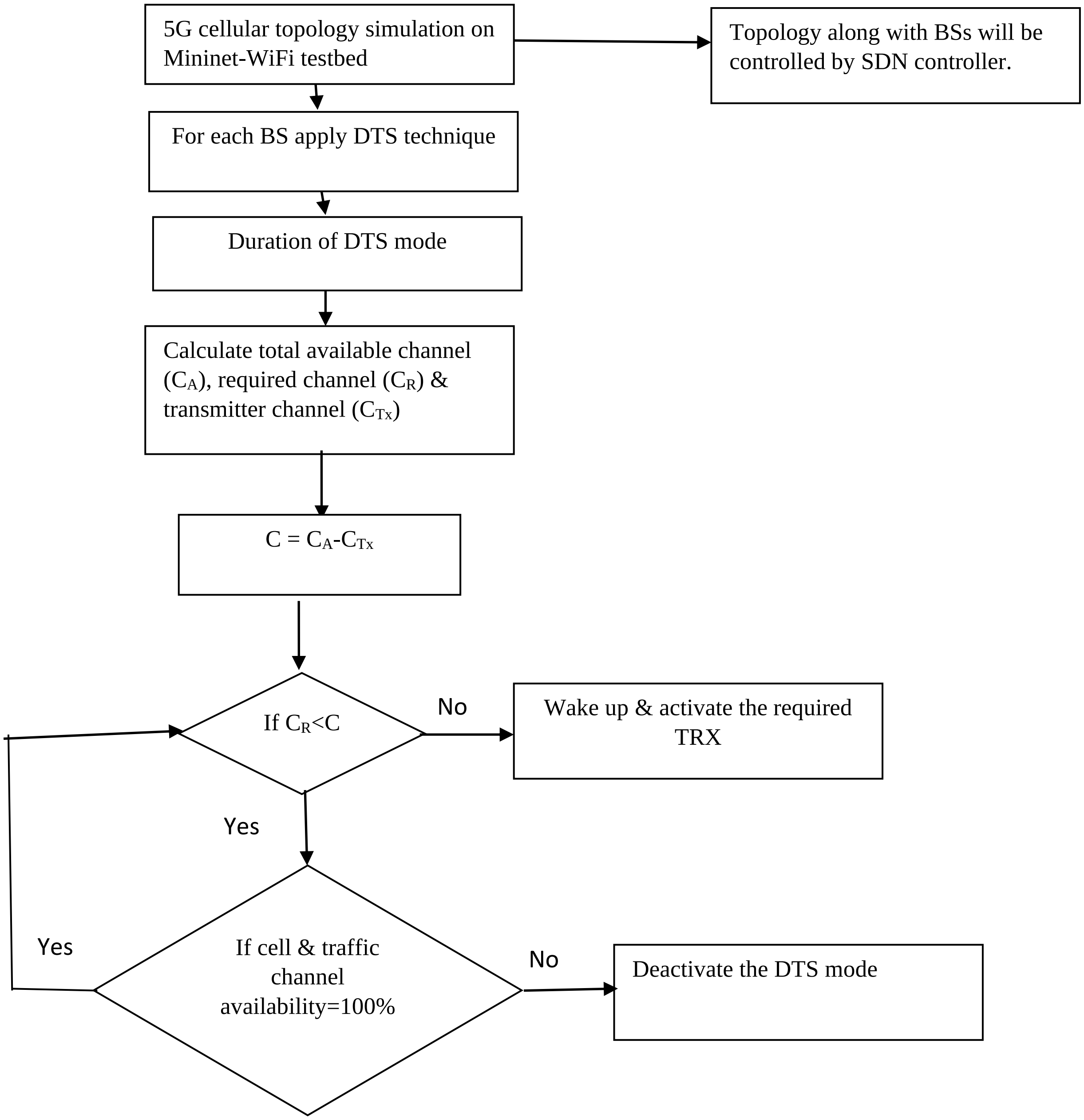

Figure 3.4: overall step Flowchart

3.6. Experimental tools and techniques

3.6.1. Emulator Description

Mininet is a network emulator which creates a network of virtual hosts, switches, controllers, and links. Mininet-WiFi is the extended version of Mininet SDN network emulator with extend in the functionality of Mininet by adding virtualized WiFi stations and access points based on the standard Linux wireless drivers and 80211_hwsim wireless simulation driver. The Mininet-WiFi components are shown in figure 3.3. It provides a simple and inexpensive network testbed for developing OpenFlow applications. It enables complex topology testing, without the need to wire up a physical network. Mininet-WiFi provides an easy way to get correct system behavior and to experiment with topologies. It supports custom topologies. It supports simple and extensible Python API for network creation and testing. The Mininet-WiFi extended the base Mininet code by adding or modifying classes and scripts. So, Mininet-WiFi adds new functionality and still supports all the normal SDN emulation capabilities of the standard Mininet network emulator[42]. This Mininet-Wifi network emulator runs in the Linux Operating System (OS). Here we have used Ubuntu-16 for this emulation.

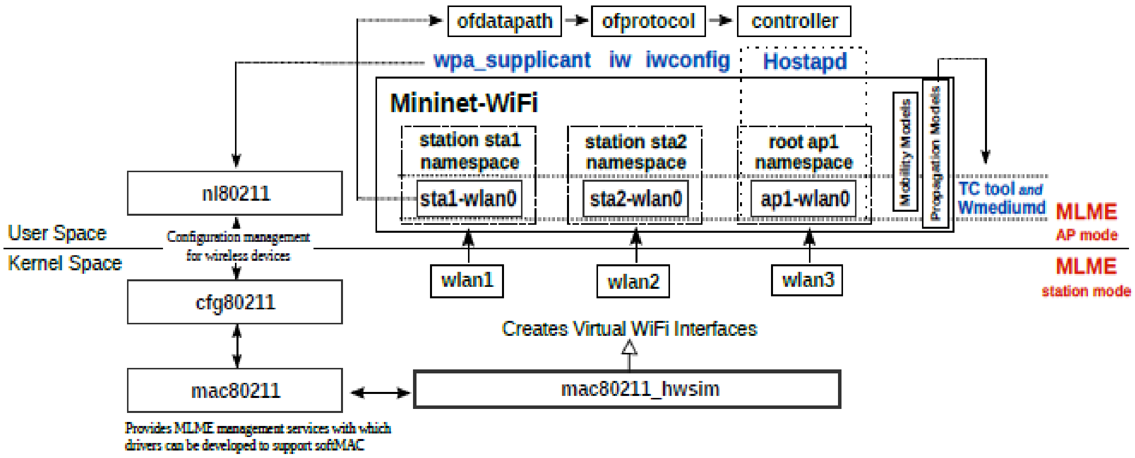

Figure 3.5: Mininet-WiFi Components [42].

According to the component available in the emulator, the topology of Figure 3.1 was built, containing the wireless and wired interfaces as per the requirement. To indicate the 5G network performance, throughput and latency parameters are used. These parameters are the indicator of the speed of communication process between two users.

3.6.2. SDN controllers

A SDN controller is an application in software-defined networking (SDN) that manages flow control to enable intelligent content deliver. A SDN controller is an intelligent part of the network. It is a centralized control point that is responsible for passing information to the network nodes connected to it. It also manages the flow of traffic in the network. The controller executes a specific algorithm and interacts with the network topology as decided by algorithm. In Mininet it is possible to test a set of open-source controllers, considered as remote controllers, since they need to be connected to Mininet through a specific IP address. In addition to the mininet reference controller, the range of open source controllers are available like POX, OpenDayLight, FloodLight and RYU. In this thesis, the OpenDayLight (ODL) controller is used. ODL plans to deliver complex services in the 5G era by optimizing softwarized and virtualized networks to satisfy end-users' rapidly shifting service demands.

3.6.3. Optimization Technique

Dynamic Transmitter Sleep (DTS) Technique: Dynamic Transmitter Sleep Technique (DTS) is an algorithm which dynamically adjusts the transceiver switching system based on the traffic flow scenario without any degradation in Quality of Service (QoS). This energy optimization technique considers the transmitter sleep duration, cell availability and channel availability[11]. Hence, in this research DTST algorithm will be applied to the SDN controlled base stations of 5G network according to their traffic flow.

3.6.4. Data collection and Analysis

Data is collected on the basis of standard specification and features of 5G network devices and equipment.

Data is analyzed in virtual platform of SDN on the basis of traffic flow. Cellular network will design to flow maximum traffic and the analysis will be on the basis of real network. Full load in real network will remain only for few hours per day. Also at the weekend and holidays, the traffic flow will be maximum compare to other days. So the analysis will be done on the basis of daily, weekly.

Data analysis will be based on simulation method for this Mininet emulator will be used.

CHAPTER-4

SIMULATION RESULT AND DISCUSSION

In this section, SDN is implemented on the 5G cellular network using Mininet-WIFI emulator with python API. The program is written in python script and executed in Mininet-WiFi emulator. Table 1, shows the simulation parameters used in our network scenario which has been taken from the latest research papers about 5G base stations [16][43].

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TABLE 1: Simulation Parameter

Parameter	Value
Simulation Time	24 h
Number of stations (CPEs)	25
Number of base stations (BS)	5
Number of switches	3
Number of controller	1
Idle mode power	150 W
Fixed power of BS	750W
Maximum power of BS	1350W
Transmission Power	40 W
Power of transmitter	100W
Power of network link	40W
Delay time between on & sleep	0.00216s
Central Frequency	2 GHz
BS antenna height	25m
No. of Transceiver	8
Maximum capacity of BS	500mbps
Channel Propagation loss	0.5 dB
Data rate per station	5 mbps

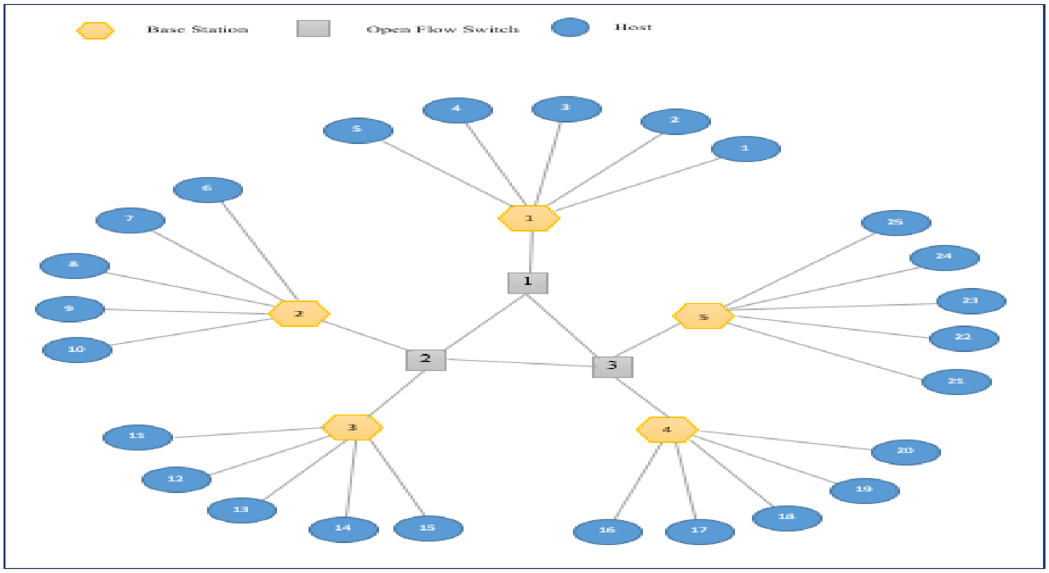
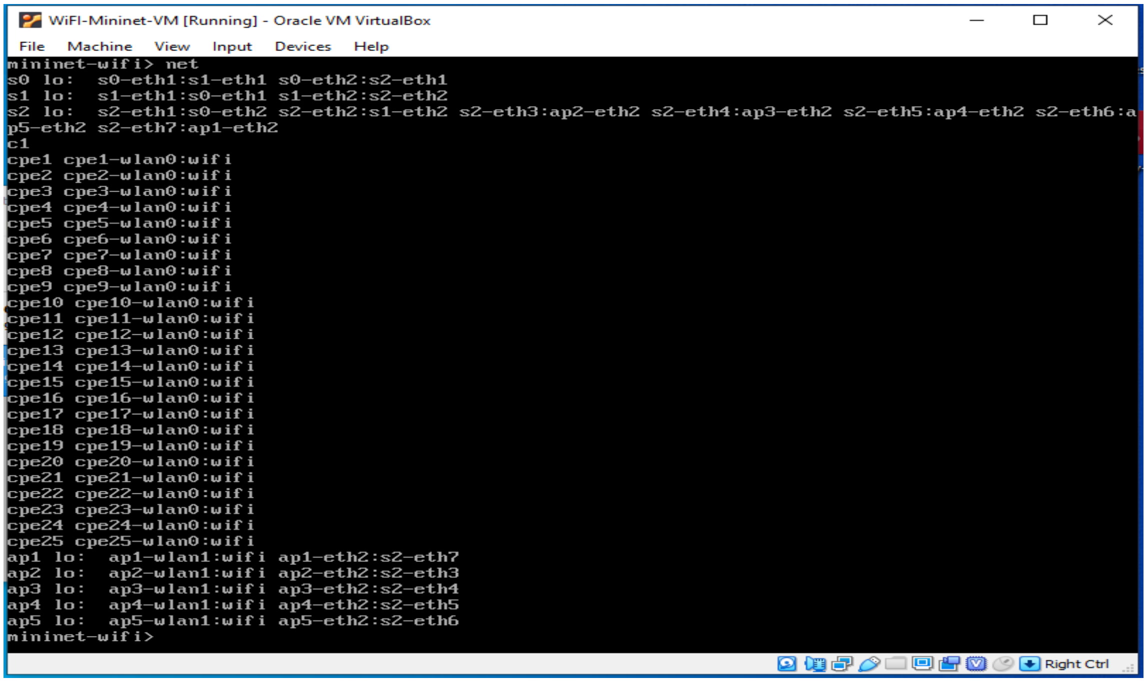


Figure 4.1: Simulated network topology

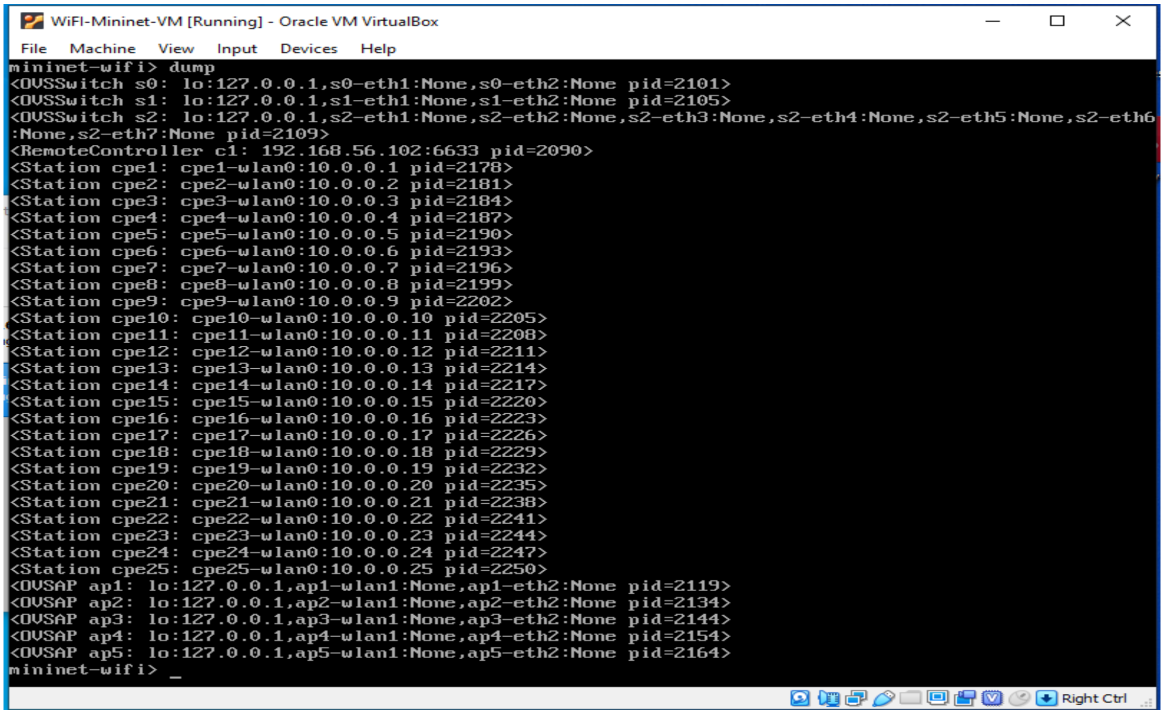
Here, in Figure 4.1 shows the screenshots of diagrammatical representation of network connectivity between 1 remote controller, 3 openflow switches, 5 base stations and 25 users after running the python code to create network topology inside Mininet-WiFi emulator. Similarly figure 4.2 shows how devices are connected to each other to form a network.



```
mininet-wifi> net
s0 lo:  s0-eth1:s1-eth1 s0-eth2:s2-eth1
s1 lo:  s1-eth1:s0-eth1 s1-eth2:s2-eth2
s2 lo:  s2-eth1:s0-eth2 s2-eth2:s1-eth2 s2-eth3:ap2-eth2 s2-eth4:ap3-eth2 s2-eth5:ap4-eth2 s2-eth6:a
p5-eth2 s2-eth7:ap1-eth2
c1
cpe1 cpe1-wlan0:wifi
cpe2 cpe2-wlan0:wifi
cpe3 cpe3-wlan0:wifi
cpe4 cpe4-wlan0:wifi
cpe5 cpe5-wlan0:wifi
cpe6 cpe6-wlan0:wifi
cpe7 cpe7-wlan0:wifi
cpe8 cpe8-wlan0:wifi
cpe9 cpe9-wlan0:wifi
cpe10 cpe10-wlan0:wifi
cpe11 cpe11-wlan0:wifi
cpe12 cpe12-wlan0:wifi
cpe13 cpe13-wlan0:wifi
cpe14 cpe14-wlan0:wifi
cpe15 cpe15-wlan0:wifi
cpe16 cpe16-wlan0:wifi
cpe17 cpe17-wlan0:wifi
cpe18 cpe18-wlan0:wifi
cpe19 cpe19-wlan0:wifi
cpe20 cpe20-wlan0:wifi
cpe21 cpe21-wlan0:wifi
cpe22 cpe22-wlan0:wifi
cpe23 cpe23-wlan0:wifi
cpe24 cpe24-wlan0:wifi
cpe25 cpe25-wlan0:wifi
ap1 lo:  ap1-wlan1:wifi ap1-eth2:s2-eth7
ap2 lo:  ap2-wlan1:wifi ap2-eth2:s2-eth3
ap3 lo:  ap3-wlan1:wifi ap3-eth2:s2-eth4
ap4 lo:  ap4-wlan1:wifi ap4-eth2:s2-eth5
ap5 lo:  ap5-wlan1:wifi ap5-eth2:s2-eth6
mininet-wifi>
```

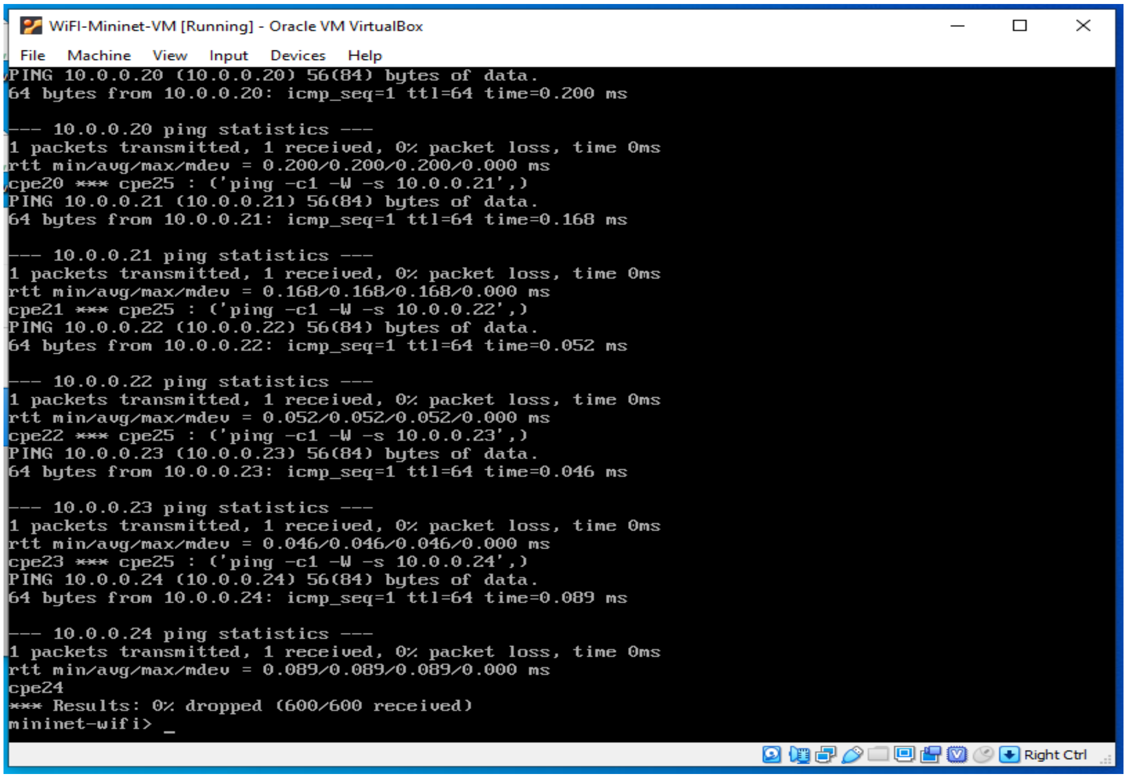
Figure 4.2: network connectivity status for 5G network in Mininet-WiFi emulator.

Figure 4.3 is the screenshots taken while executing *dump* command to show the list of information about connected stations, access points, and controller. And figure 4.4 is the screenshots showing 100% packet received status checked the connection established between each node in the network by using *pingall* command. In this particular network switches acts as OpenFlow switches and it is possible to see their flow table at anytime during the program execution. If there will be no packets exchanged, the flow tables will be empty, otherwise each table present the flow entries corresponding to the rules to be applied to each packet type that passes through the switch. This process can be seen with *dpctl dump-flows* command and it is shown in figure 4.5. this screenshot was taken after establishing the ping beween all nodes.



```
mininet-wifi> dump
<OVSSwitch s0: lo:127.0.0.1,s0-eth1:None,s0-eth2:None pid=2101>
<OVSSwitch s1: lo:127.0.0.1,s1-eth1:None,s1-eth2:None pid=2105>
<OVSSwitch s2: lo:127.0.0.1,s2-eth1:None,s2-eth2:None,s2-eth3:None,s2-eth4:None,s2-eth5:None,s2-eth6
:None,s2-eth7:None pid=2109>
<RemoteController c1: 192.168.56.102:6633 pid=2090>
<Station cpe1: cpe1-wlan0:10.0.0.1 pid=2178>
<Station cpe2: cpe2-wlan0:10.0.0.2 pid=2181>
<Station cpe3: cpe3-wlan0:10.0.0.3 pid=2184>
<Station cpe4: cpe4-wlan0:10.0.0.4 pid=2187>
<Station cpe5: cpe5-wlan0:10.0.0.5 pid=2190>
<Station cpe6: cpe6-wlan0:10.0.0.6 pid=2193>
<Station cpe7: cpe7-wlan0:10.0.0.7 pid=2196>
<Station cpe8: cpe8-wlan0:10.0.0.8 pid=2199>
<Station cpe9: cpe9-wlan0:10.0.0.9 pid=2202>
<Station cpe10: cpe10-wlan0:10.0.0.10 pid=2205>
<Station cpe11: cpe11-wlan0:10.0.0.11 pid=2208>
<Station cpe12: cpe12-wlan0:10.0.0.12 pid=2211>
<Station cpe13: cpe13-wlan0:10.0.0.13 pid=2214>
<Station cpe14: cpe14-wlan0:10.0.0.14 pid=2217>
<Station cpe15: cpe15-wlan0:10.0.0.15 pid=2220>
<Station cpe16: cpe16-wlan0:10.0.0.16 pid=2223>
<Station cpe17: cpe17-wlan0:10.0.0.17 pid=2226>
<Station cpe18: cpe18-wlan0:10.0.0.18 pid=2229>
<Station cpe19: cpe19-wlan0:10.0.0.19 pid=2232>
<Station cpe20: cpe20-wlan0:10.0.0.20 pid=2235>
<Station cpe21: cpe21-wlan0:10.0.0.21 pid=2238>
<Station cpe22: cpe22-wlan0:10.0.0.22 pid=2241>
<Station cpe23: cpe23-wlan0:10.0.0.23 pid=2244>
<Station cpe24: cpe24-wlan0:10.0.0.24 pid=2247>
<Station cpe25: cpe25-wlan0:10.0.0.25 pid=2250>
<OVSAP ap1: lo:127.0.0.1,ap1-wlan1:None,ap1-eth2:None pid=2119>
<OVSAP ap2: lo:127.0.0.1,ap2-wlan1:None,ap2-eth2:None pid=2134>
<OVSAP ap3: lo:127.0.0.1,ap3-wlan1:None,ap3-eth2:None pid=2144>
<OVSAP ap4: lo:127.0.0.1,ap4-wlan1:None,ap4-eth2:None pid=2154>
<OVSAP ap5: lo:127.0.0.1,ap5-wlan1:None,ap5-eth2:None pid=2164>
mininet-wifi> _
```

Figure 4.3: Dump connection status of the implemented network

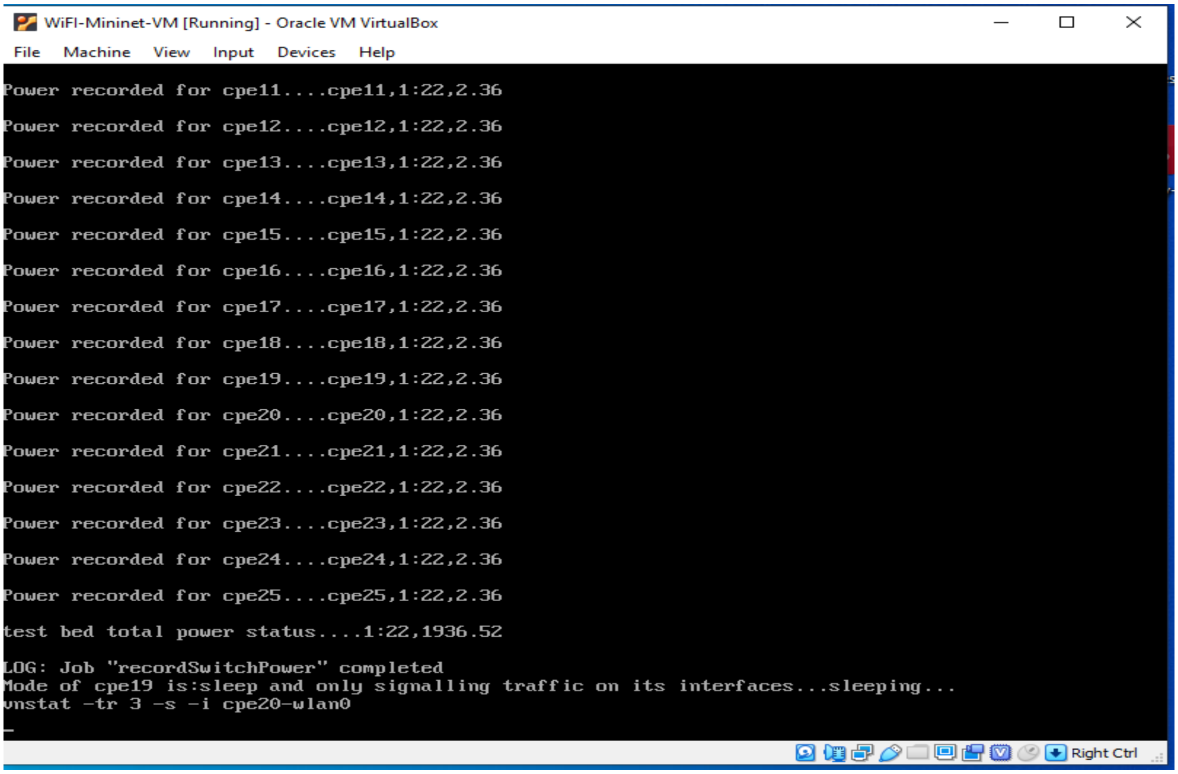


```
PING 10.0.0.20 (10.0.0.20) 56(84) bytes of data.
64 bytes from 10.0.0.20: icmp_seq=1 ttl=64 time=0.200 ms

--- 10.0.0.20 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.200/0.200/0.200/0.000 ms
cpe20 *** cpe25 : ('ping -c1 -W -s 10.0.0.21',)
PING 10.0.0.21 (10.0.0.21) 56(84) bytes of data.
64 bytes from 10.0.0.21: icmp_seq=1 ttl=64 time=0.168 ms

--- 10.0.0.21 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.168/0.168/0.168/0.000 ms
cpe21 *** cpe25 : ('ping -c1 -W -s 10.0.0.22',)
PING 10.0.0.22 (10.0.0.22) 56(84) bytes of data.
64 bytes from 10.0.0.22: icmp_seq=1 ttl=64 time=0.052 ms

--- 10.0.0.22 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.052/0.052/0.052/0.000 ms
cpe22 *** cpe25 : ('ping -c1 -W -s 10.0.0.23',)
PING 10.0.0.23 (10.0.0.23) 56(84) bytes of data.
64 bytes from 10.0.0.23: icmp_seq=1 ttl=64 time=0.046 ms

--- 10.0.0.23 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.046/0.046/0.046/0.000 ms
cpe23 *** cpe25 : ('ping -c1 -W -s 10.0.0.24',)
PING 10.0.0.24 (10.0.0.24) 56(84) bytes of data.
64 bytes from 10.0.0.24: icmp_seq=1 ttl=64 time=0.089 ms

--- 10.0.0.24 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.089/0.089/0.089/0.000 ms
cpe24
*** Results: 0% dropped (600/600 received)
mininet-wifi> _
```

Figure 4.4: Ping established between stations of implemented network.

```
 cookie=0x2b00000000000001, duration=219.613s, table=0, n_packets=55, n_bytes=3910, idle_age=211, pr
iority=2,in_port=2 actions=output:1
 cookie=0x2b00000000000007, duration=223.414s, table=0, n_packets=45, n_bytes=3825, idle_age=3, prio
rity=100,dl_type=0x88cc actions=CONTROLLER:65535
 cookie=0x2b00000000000009, duration=223.414s, table=0, n_packets=42, n_bytes=3178, idle_age=214, pr
iority=0 actions=drop
*** ap3 ------------------------------------------------------------------------
NXST_FLOW reply (xid=0x4):
 cookie=0x2b00000000000003, duration=219.665s, table=0, n_packets=11, n_bytes=790, idle_age=212, pri
ority=2,in_port=1 actions=output:2,CONTROLLER:65535
 cookie=0x2b00000000000002, duration=219.665s, table=0, n_packets=57, n_bytes=4050, idle_age=211, pr
iority=2,in_port=2 actions=output:1
 cookie=0x2b00000000000006, duration=223.452s, table=0, n_packets=45, n_bytes=3825, idle_age=3, prio
rity=100,dl_type=0x88cc actions=CONTROLLER:65535
 cookie=0x2b00000000000006, duration=223.452s, table=0, n_packets=41, n_bytes=3120, idle_age=214, pr
iority=0 actions=drop
*** ap4 ------------------------------------------------------------------------
NXST_FLOW reply (xid=0x4):
 cookie=0x2b00000000000012, duration=219.645s, table=0, n_packets=10, n_bytes=700, idle_age=213, pri
ority=2,in_port=1 actions=output:2,CONTROLLER:65535
 cookie=0x2b00000000000011, duration=219.645s, table=0, n_packets=56, n_bytes=3980, idle_age=211, pr
iority=2,in_port=2 actions=output:1
 cookie=0x2b0000000000000d, duration=223.445s, table=0, n_packets=45, n_bytes=3825, idle_age=3, prio
rity=100,dl_type=0x88cc actions=CONTROLLER:65535
 cookie=0x2b0000000000000d, duration=223.445s, table=0, n_packets=43, n_bytes=3288, idle_age=214, pr
iority=0 actions=drop
*** ap5 ------------------------------------------------------------------------
NXST_FLOW reply (xid=0x4):
 cookie=0x2b0000000000000f, duration=219.664s, table=0, n_packets=10, n_bytes=700, idle_age=212, pri
ority=2,in_port=1 actions=output:2,CONTROLLER:65535
 cookie=0x2b00000000000010, duration=219.659s, table=0, n_packets=56, n_bytes=3980, idle_age=211, pr
iority=2,in_port=2 actions=output:1
 cookie=0x2b0000000000000f, duration=223.456s, table=0, n_packets=45, n_bytes=3825, idle_age=3, prio
rity=100,dl_type=0x88cc actions=CONTROLLER:65535
 cookie=0x2b0000000000000f, duration=223.456s, table=0, n_packets=43, n_bytes=3288, idle_age=214, pr
iority=0 actions=drop
mininet-wifi> _
```

Figure 4.5: Implemented network elements flow table in Mini-WiFi.



```
Power recorded for cpe11....cpe11,1:22,2.36
Power recorded for cpe12....cpe12,1:22,2.36
Power recorded for cpe13....cpe13,1:22,2.36
Power recorded for cpe14....cpe14,1:22,2.36
Power recorded for cpe15....cpe15,1:22,2.36
Power recorded for cpe16....cpe16,1:22,2.36
Power recorded for cpe17....cpe17,1:22,2.36
Power recorded for cpe18....cpe18,1:22,2.36
Power recorded for cpe19....cpe19,1:22,2.36
Power recorded for cpe20....cpe20,1:22,2.36
Power recorded for cpe21....cpe21,1:22,2.36
Power recorded for cpe22....cpe22,1:22,2.36
Power recorded for cpe23....cpe23,1:22,2.36
Power recorded for cpe24....cpe24,1:22,2.36
Power recorded for cpe25....cpe25,1:22,2.36
test bed total power status....1:22,1936.52
LOG: Job "recordSwitchPower" completed
Mode of cpe19 is:sleep and only signalling traffic on its interfaces...sleeping...
vnstat -tr 3 -s -i cpe20-wlan0
_
```

Figure 4.6: Recording Power of the network.

4.1 Observed Output

Figure 4.7 and Figure 4.8 show an analysis of energy consumption according to traffic pattern before and after the implementation of the energy saving strategies for 5G BTSs respectively. As traffic decreases, the amount of energy consumption also decrease with decrease in used resource. Data analysis shows that the difference in base station energy consumption minimum and maximum is 750 Wh and 1350 Wh respectively. we observed that energy consumption reduces after applying the energy optimization technique during low traffic flow at night time.

In figure 4.7, we can observe that the energy consumption during low traffic is not decreased yet fixed amount of energy consumed and fluctuate among idle state power. This is due to the fix amount of power allocated for the certain level of traffic load in normal condition of BTS. The network switch to idle state power when there is no traffic and network link. The fixed amount of power is assigned for traffic load with load parameter (λ) less than or equals to 0.4 and the maximum power for full traffic load is assigned 1350 W (i.e. when $\lambda = 1$). The graph shows dynamic pattern between the traffic load 0.4 and 1. This occurs with the condition applied for allocation of power during network flow. When λ > 0.4 then Power is measured with formula P = 750 + (λ-0.4)P_0. P_0 is the power consumption of BS in idle state when there is no traffic flow and 750 W is the fixed amount of power allocated for traffic flow up to λ = 0.4.

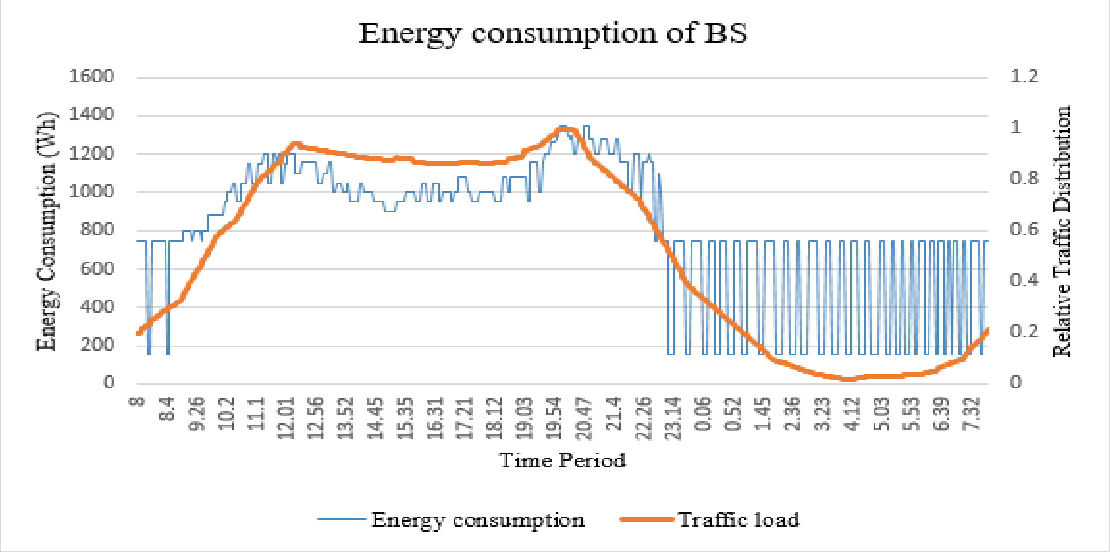


Figure 4.7: Energy consumption of base station before applying energy saving technique

In Figure 4.8, the Dynamic Transmitter Sleep (DTS) Technique was applied as energy saving technique during night period from 11 pm to 8 am. We can observe the difference in graph during low traffic load. Here for simulation of network we have allocated the power of transmitter to 100 W. When transmitter is active at that time it consumes 100 W power. In this simulated network we supposed 8 transceivers per BS among them 2 transceivers use control channels. So for sleeping process we have used only 6 transmitters. Here we can clearly see the sleeping pattern of transmitter during low traffic at night time from 11 pm to 8 am. During low traffic it switch off the transmitter to sleep mode as a result decrease in power consumption.

Figure 4.9 shows the energy consumption pattern of all links used in network after using the link energy saving technique. It saves the satisfied amount of energy by switching of the links between the network devices which was in idle state during the low or no traffic load period and switch on immediately when the network devices get active mode.

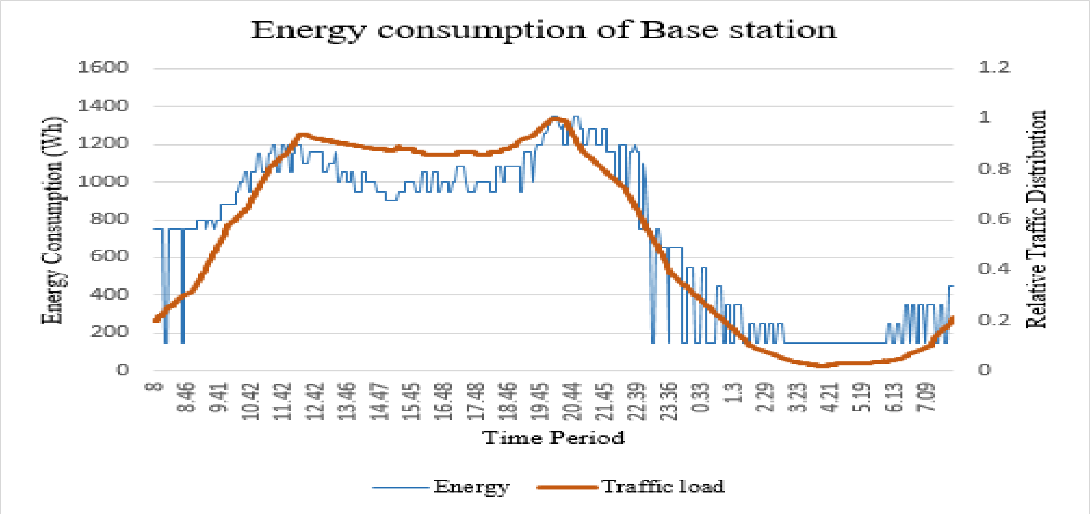


Figure 4.8: Energy consumption of base station after applying energy saving technique

Hence, the fluctuation between switching on and off occurs in very less duration as network device remain idle for very short duration. But during night time when dynamic sleep technique applied, the links are automatically switched to sleep mode as they detect the network devices with idle state. The time when we make BS sleep for three hours from 3 am to 6 am is the time when there is almost zero traffic load.

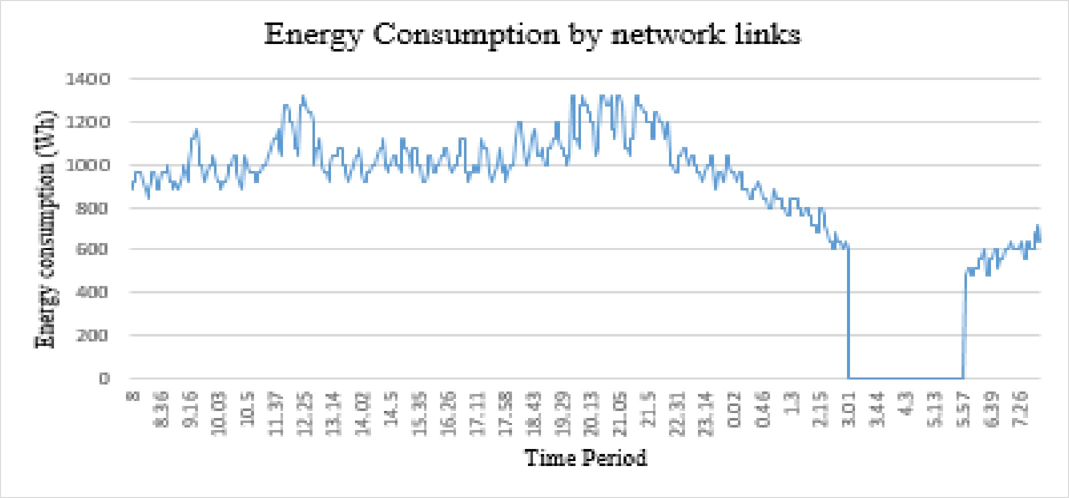


Figure 4.9: Energy consumption of all network links in 24 hrs.

4.2 Energy Consumption Observation

Here the energy consumption of base station has been observed before and after applying the dynamic transmitter sleep technique.

Table 2: Energy consumption of each BS before and after applying DTS mode

Base Station (BS)	Energy consumption from 11 pm to 8 am (kWh)
Before applying DTST	9.874
After applying DTST	6.457

Energy consumption saving = 9.874 – 6.457 = 3.416 kWh

% of energy consumption saving = 3.416/9.874 = 34.6 %

Table 3: Energy consumption of total network links before and after applying DTS mode

Total Network link	Energy consumption (kWh)
Before using energy saving technique	1.32
After using energy saving technique	0.742

Energy consumption saving = 1.32 – 0.742 = 0.578 kWh

% of energy consumption saving = 0.578/1.32 = 43.79 %

34.6% of energy has saved after applying the dynamic transmitter sleep technique to reduce the energy consumption of 5G base station which was simulated in SDN platform using mininet-wifi as testbed and OpenDayLight as SDN controller. Also, the additional 43.79% of energy has been saved by total network by deactivating the links between two idles state network devices. Table 3 shows the energy consumed by a base station before and after applying the DTS energy saving technique at night time during 11:00 pm to 8:00 am. The energy consumed by base station in normal condition is 9.874 kWh and 6.457 kWh after applying DTS technique which results in saving 3.416 kWh energy daily for single base station during low traffic period at night time.

Table 4 shows the energy consumed in 24 hours by total network links used by network devices to connect with each other via wired or wireless connection. In normal condition all network links are active all the time although the network devices remains in idle state. During this period the energy consumed by network link in 24 hours is 1.32 kWh. And after applying the smart link sleep technique, the energy consumed by network links reduced to 0.742 kWh saving 0.578 kWh amount of energy.

4.3 Energy consumption of total network

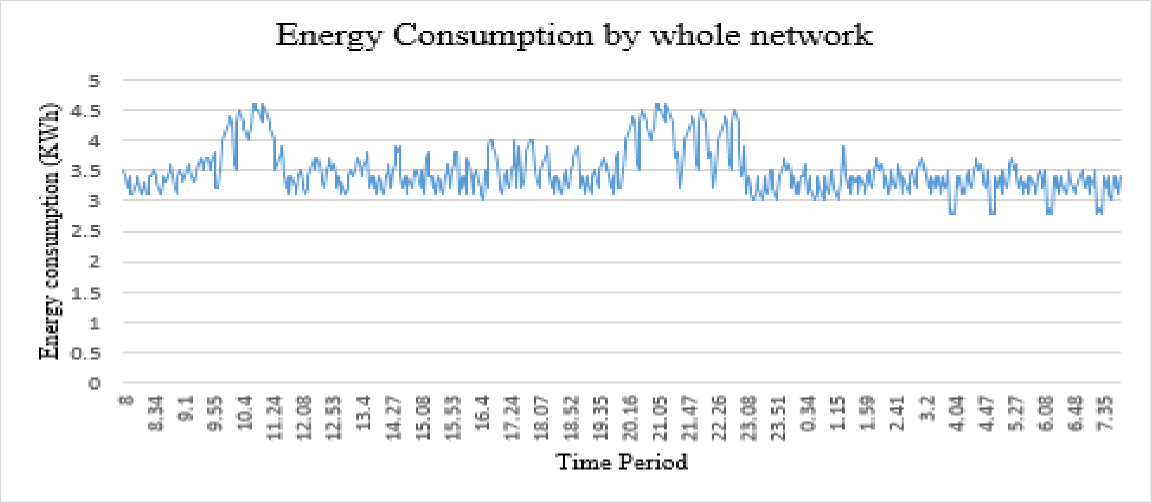


Figure 4.10: Energy consumption of total network in 24 hrs.

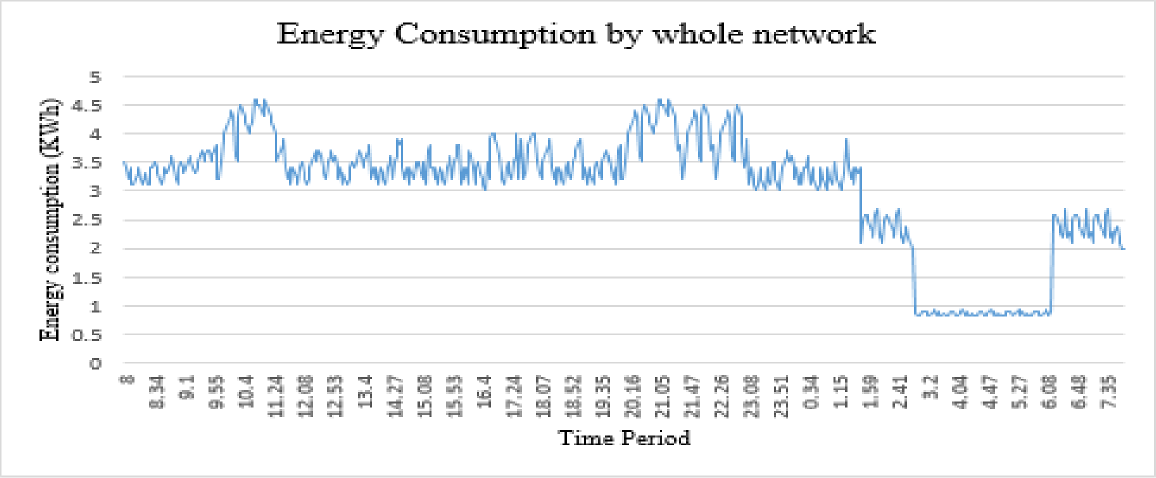


Figure 4.11: Energy consumption of total network in 24 hours after applying DTS mode.

Table 4: Energy consumption of total network before and after applying DTS mode

Total network	Energy Consumption in kWh
Before DTS technique	87.54
After DTS technique	51.04

Energy consumption saving = 87.54 – 51.04 = 36.50 kWh

% of energy consumption saving = 36.50/87.54 = 41.69 %

Here, figure 4.10 & figure 4.11 shows the pattern of energy consumption of overall simulated network before and after applying DTS mode respectively. As mentioned in Table 4, energy consumed by overall network in 24 hours is 87.54 kWh and after applying DTS mode, the energy consumption is 51.04 kWh. Hence, result shows that we can save 36.5 kWh energy i.e. 41.69% of total energy after applying DTS technique to the base stations.

4.4 Energy consumption of BS at different traffic pattern

Energy consumption of base stations before and after applying energy saving technique with different network traffic patterns has been observed which is shown in graphs.

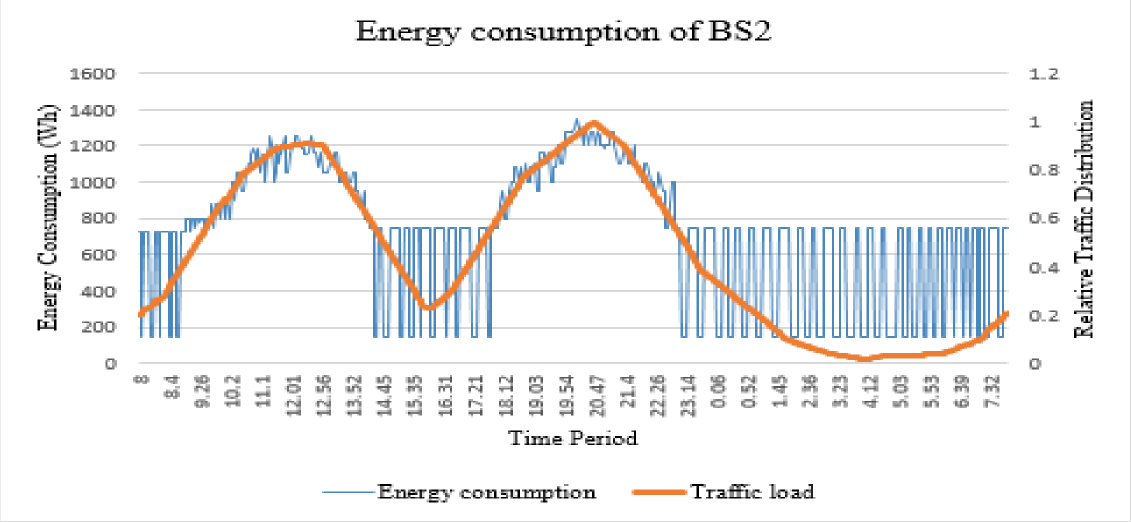


Figure 4.12: Energy consumption of base station before applying energy saving technique

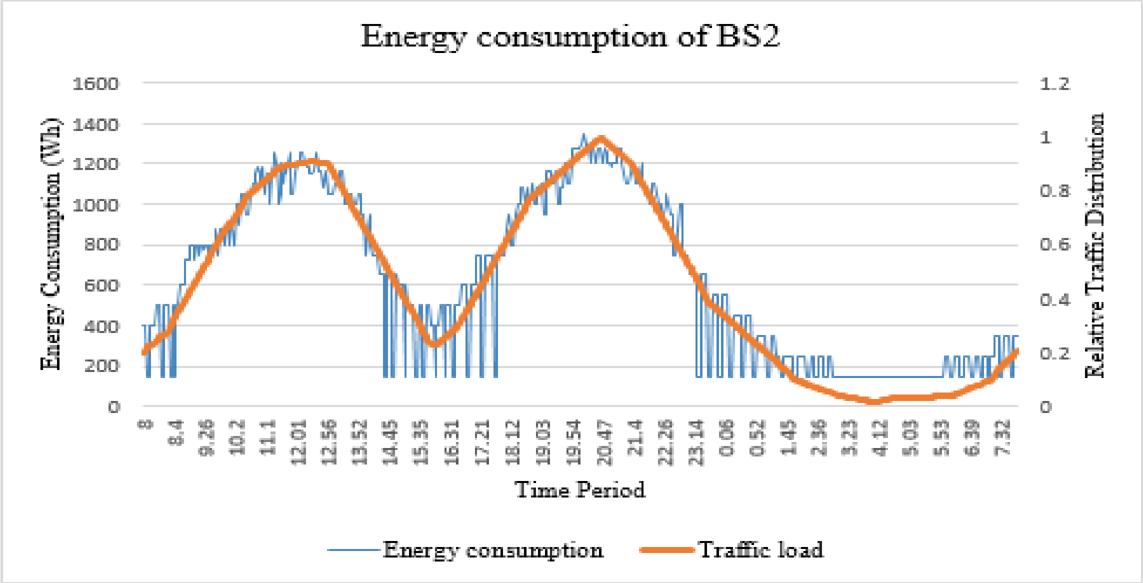


Figure 4.13: Energy consumption of base station after applying energy saving technique

Table 5: Energy consumption of each BS before and after applying DTS mode

Base station BS2	Energy Consumption in KWh
Before DTS technique	12.84
After DTS technique	7.710

Energy consumption saving = 12.84 – 7.710 = 5.13 kWh

% of energy consumption saving = 5.13/12.84 = 39.95 %

Figure 4.12 and figure 4.13 shows the energy consumption a base station BS2 with random traffic pattern before and after applying energy saving technique respectively. Graph clearly shows the energy consumption of BS2 according to traffic pattern which saves 5.13 kWh of energy i.e. 39.95% of total energy consumed by BS2.

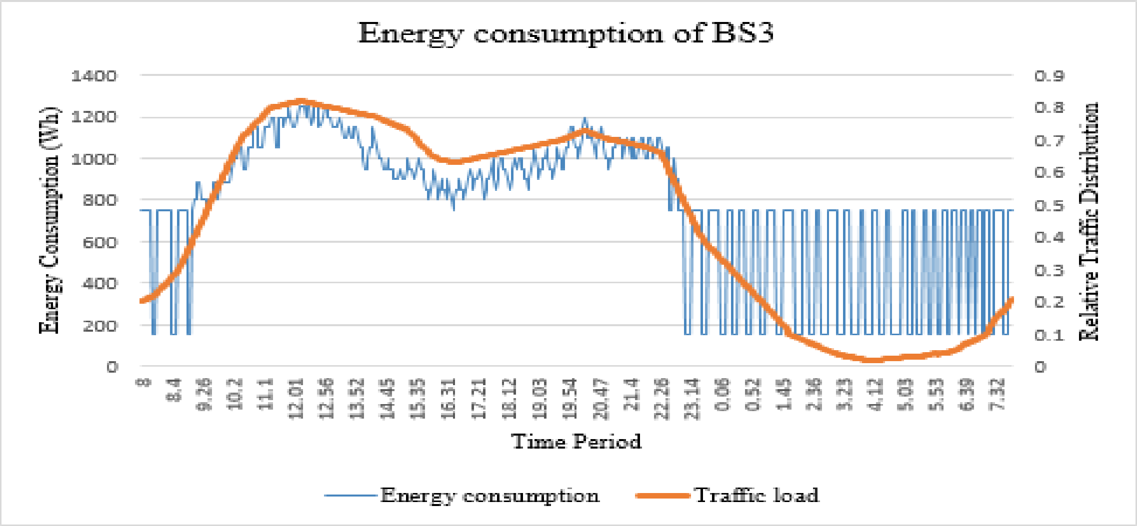


Figure 4.14: Energy consumption of base station before applying energy saving technique

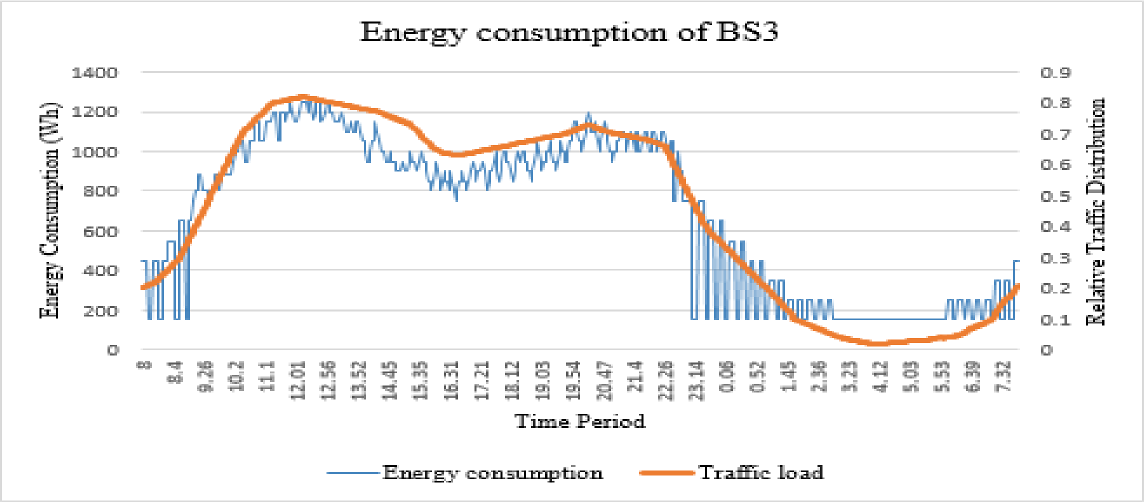


Figure 4.15: Energy consumption of base station after applying energy saving technique

Table 6: Energy consumption of each BS before and after applying DTS mode

Base station BS3	Energy Consumption in KWh
Before DTS technique	9.882
After DTS technique	6.295

Energy consumption saving = 9.882 – 6.295 = 3.587 kWh

% of energy consumption saving = 3.587/9.882 = 36.3 %

Similarly, energy consumed by a base station BS3 with weekend traffic pattern is shown in Figure 4.14 and Figure 4.15 before and after applying energy saving technique respectively. This traffic patterns denotes the weekend traffic flow. Hence, DTS can save up to 3.587 kWh energy which is 36.3% of total energy consumed by a base station BS3 during weekend.

CHAPTER- 5

CONCLUSION

This study has performed the energy saving techniques on the 5G macro base station using SDN simulation environment. Here, we compared the consumptions of energy before applying and after applying energy saving technique of 5G base station using SDN paradigm. Hence, this study concludes that the Dynamic Transmitter Sleep (DTS) Technique saves 34.6% of energy of BS during low traffic period while using over SDN environment and also saves 45.22% of total network link energy after applying SDN energy optimization technique adaptive link rate (ALR) for smart link sleep and wake up of total network links. Also, the total network energy consumption is reduced by 41.69% which shows the clear impact of energy saving approach on total network.

The DTS technique shows its effectiveness with different pattern of traffic flows by reducing the energy consumption according to the flow during low traffic load.

Software defined wireless network works to enhance the DTS technique to reduce more energy as compare with using it without SDN paradigm. DTS technique shows better performance in SDN simulated environment as SDN enhances the energy efficiency by their own features. 5G macro base station has programmable feature and supports openflow protocol to communicate with SDN. This technique will be more effective to small cells of 5G network which works in high frequency range with low latency time.

REFERENCES

[1] A. Abrol and R. K. Jha, “Power Optimization in 5G Networks: A Step Towards GrEEn Communication,” *IEEE Access*, vol. 4, no. c, pp. 1355–1374, 2016, doi: 10.1109/ACCESS.2016.2549641.

[2] A. Mughees, M. Tahir, M. A. Sheikh, and A. Ahad, “Towards Energy Efficient 5G Networks Using Machine Learning: Taxonomy, Research Challenges, and Future Research Directions,” *IEEE Access*, vol. 8, pp. 187498–187522, 2020, doi: 10.1109/access.2020.3029903.

[3] E. Oh, K. Son, and B. Krishnamachari, “Dynamic base station switching-on/off strategies for green cellular networks,” *IEEE Trans. Wirel. Commun.*, vol. 12, no. 5, pp. 2126–2136, 2013, doi: 10.1109/TWC.2013.032013.120494.

[4] I. Chih-Lin, C. Rowell, S. Han, Z. Xu, G. Li, and Z. Pan, “Toward green and soft: A 5G perspective,” *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 66–73, 2014, doi: 10.1109/MCOM.2014.6736745.

[5] M. Masoudi, M. G. Khafagy, E. Soroush, D. Giacomelli, S. Morosi, and C. Cavdar, “Reinforcement learning for traffic-adaptive sleep mode management in 5G networks,” *IEEE Int. Symp. Pers. Indoor Mob. Radio Commun. PIMRC*, vol. 2020-Augus, no. July, 2020, doi: 10.1109/PIMRC48278.2020.9217286.

[6] L. Hardesty, “5G base stations use a lot more energy than 4G base stations: MTN | FierceWireless,” *FIERCE Wireless*. 2020, [Online]. Available: https://www.fiercewireless.com/tech/5g-base-stations-use-a-lot-more-energy-than-4g-base-stations-says-mtn.

[7] Huawei, “5G Power Whitepaper,” 2019, [Online]. Available: https://carrier.huawei.com/~/media/CNBG/Downloads/Spotlight/5g/5G-Power-White-Paper-en.pdf.

[8] P. Frenger and R. Tano, “A technical look at 5G energy consumption and performance - Ericsson,” *Ericsson*. 2019, [Online]. Available: https://www.ericsson.com/en/blog/2019/9/energy-consumption-5g-nr.

[9] A. Sutton, “5G network architecture,” *J. Inst. Telecommun. Prof.*, vol. 12, pp. 8–15, 2018, doi: 10.1016/b978-0-08-102267-2.00001-4.

[10] J. T. J. Penttinen, “5G Network Planning and Optimization,” *5G Explain.*, pp. 255–269, 2019, doi: 10.1002/9781119275695.ch9.

[11] M. S. Dahal, J. N. Shrestha, and S. R. Shakya, “Energy saving technique and measurement in green wireless communication,” *Energy*, vol. 159, pp. 21–31, 2018, doi: 10.1016/j.energy.2018.06.066.

[12] M. Tran and M. Tran, “Energy Consumption Optimizations for 5G networks,” 2019.

[13] B. G. Assefa and Ö. Özkasap, “A survey of energy efficiency in SDN: Software-based methods and optimization models,” *J. Netw. Comput. Appl.*, vol. 137, no. October 2018, pp. 127–143, 2019, doi: 10.1016/j.jnca.2019.04.001.

[14] G. Sun, F. Liu, J. Lai, and G. Liu, “Software defined wireless network architecture for the next generation mobile communication: Proposal and initial prototype,” *J. Commun.*, vol. 9, no. 12, pp. 946–953, 2014, doi: 10.12720/jcm.9.12.946-953.

[15] H. A. Eissa, K. A. Bozed, and H. Younis, “Software Defined Networking,” *19th Int. Conf. Sci. Tech. Autom. Control Comput. Eng. STA 2019*, no. May, pp. 620–625, 2019, doi: 10.1109/STA.2019.8717234.

[16] C. N. Tadros, M. R. M. Rizk, and B. M. Mokhtar, “Software Defined Network-Based Management for Enhanced 5G Network Services,” *IEEE Access*, vol. 8, pp. 53997–54008, 2020, doi: 10.1109/ACCESS.2020.2980392.

[17] K. Vinoth, S. Purushothaman, R. Baskar, and C. Gomathi, “Optimal Energy Efficiency for 5G Wireless Communications,” no. 12, 2018.

[18] J. Manuel and C. Sobral, “Doctoral thesis Energy Efficient Radio Resource Management for Heterogeneous Networks Joaquim Manuel Camões Sobral de Bastos.”

[19] C.-L. I, G. Yu, S. Han, and G. Y. Li, “Green and Soft Network Design,” *Green Software-defined Wirel. Networks*, pp. 61–141, 2019, doi: 10.1017/9781108277389.004.

[20] Y. Lu, X. Su, J. Zeng, L. Rong, C. Yang, and X. Xu, “Software Defined Radio Access Network in 5G Mobile Network,” *Proc. 2015 10th Int. Conf. Commun. Netw. China, CHINACOM 2015*, vol. 1, pp. 132–136, 2016, doi: 10.1109/CHINACOM.2015.7497924.

[21] R. S. Alhumaima and H. S. Al-Raweshidy, “Evaluating the energy efficiency of software defined-based cloud radio access networks,” *IET Commun.*, vol. 10, no. 8, pp. 987–994, 2016, doi: 10.1049/iet-com.2016.0046.

[22] Contributors and IEEE, *IEEE 802.16e-2005 Standard*, vol. 2005, no. February. 2005.

[23] Ł. Budzisz *et al.*, “Dynamic resource provisioning for energy efficiency in wireless access networks: A survey and an outlook,” *IEEE Commun. Surv. Tutorials*, vol. 16, no. 4, pp. 2259–2285, 2014, doi: 10.1109/COMST.2014.2329505.

[24] J. Wu, Y. Zhang, M. Zukerman, and E. K. N. Yung, “Energy-efficient base-stations sleep-mode techniques in green cellular networks: A survey,” *IEEE Commun. Surv. Tutorials*, vol. 17, no. 2, pp. 803–826, 2015, doi: 10.1109/COMST.2015.2403395.

[25] F. Han, S. Zhao, L. Zhang, and J. Wu, “Survey of Strategies for Switching Off Base Stations in Heterogeneous Networks for Greener 5G Systems,” *IEEE Access*, vol. 4, no. c, pp. 4959–4973, 2016, doi: 10.1109/ACCESS.2016.2598813.

[26] a Nswers, “C Ellular W Ireless N Etworks,” no. June, pp. 48–53, 2015.

[27] J. Peng, P. Hong, and K. Xue, “Stochastic analysis of optimal base station energy saving in cellular networks with sleep mode,” *IEEE Commun. Lett.*, vol. 18, no. 4, pp. 612–615, 2014, doi: 10.1109/LCOMM.2014.030114.140241.

[28] M. Feng, S. Mao, and T. Jiang, “BOOST: Base station ON-OFF switching strategy for energy efficient massive MIMO HetNets,” *Proc. - IEEE INFOCOM*, vol. 2016-July, 2016, doi: 10.1109/INFOCOM.2016.7524485.

[29] P. Dini, M. Miozzo, N. Bui, and N. Baldo, “A model to analyze the energy savings of base station sleep mode in LTE HetNets,” *Proc. - 2013 IEEE Int. Conf. Green Comput. Commun. IEEE Internet Things IEEE Cyber, Phys. Soc. Comput. GreenCom-iThings-CPSCom 2013*, no. May 2014, pp. 1375–1380, 2013, doi: 10.1109/GreenCom-iThings-CPSCom.2013.240.

[30] C. Liu, B. Natarajan, and H. Xia, “Small Cell Base Station Sleep Strategies for Energy Efficiency,” *IEEE Trans. Veh. Technol.*, vol. 65, no. 3, pp. 1652–1661, 2016, doi: 10.1109/TVT.2015.2413382.

[31] P. Lahdekorpi, M. Hronec, P. Jolma, and J. Moilanen, “Energy efficiency of 5G mobile networks with base station sleep modes,” *2017 IEEE Conf. Stand. Commun. Networking, CSCN 2017*, pp. 163–168, 2017, doi: 10.1109/CSCN.2017.8088616.

[32] F. E. Salem, A. Gati, Z. Altman, and T. Chahed, “Advanced Sleep Modes and their impact on flow-level performance of 5G networks,” *IEEE Veh. Technol. Conf.*, vol. 2017-Septe, pp. 1–7, 2018, doi: 10.1109/VTCFall.2017.8288125.

[33] X. Liu and N. Deng, *Emerging optical communication technologies for 5G*. Elsevier Inc., 2019.

[34] F. Malandrino, C. Casetti, C. F. Chias Serini, and G. Landi, “Optimization-in-the-Loop for Energy-Efficient 5G,” *19th IEEE Int. Symp. a World Wireless, Mob. Multimed. Networks, WoWMoM 2018*, 2018, doi: 10.1109/WoWMoM.2018.8449758.

[35] X. Guo, Z. Niu, S. Zhou, and P. R. Kumar, “Delay-Constrained Energy-Optimal Base Station Sleeping Control,” *IEEE J. Sel. Areas Commun.*, vol. 34, no. 5, pp. 1073–1085, 2016, doi: 10.1109/JSAC.2016.2520221.

[36] P. Frenger, P. Moberg, J. Malmodin, Y. Jading, and I. Gódor, “Reducing energy consumption in LTE with cell DTX,” *IEEE Veh. Technol. Conf.*, pp. 1–5, 2011, doi: 10.1109/VETECS.2011.5956235.

[37] K. Hiltunen, “Total power consumption of different network densification alternatives,” *IEEE Int. Symp. Pers. Indoor Mob. Radio Commun. PIMRC*, pp. 1401–1405, 2012, doi: 10.1109/PIMRC.2012.6362567.

[38] ETSI, “TS 138 104 - V15.3.0 - 5G; NR; Base Station (BS) radio transmission and reception (3GPP TS 38.104 version 15.3.0 Release 15),” vol. 0, p. 160, 2018.

[39] I. Santos, P. Vieira, R. Borralho, M. P. Queluz, and A. Rodrigues, “Emulating a Software Defined LTE Radio Access Network Towards 5G,” *2018 12th Int. Conf. Commun. COMM 2018 - Proc.*, no. June, pp. 371–376, 2018, doi: 10.1109/ICComm.2018.8430180.

[40] J. Prados-Garzon, O. Adamuz-Hinojosa, P. Ameigeiras, J. J. Ramos-Munoz, P. Andres-Maldonado, and J. M. Lopez-Soler, “Handover implementation in a 5G SDN-based mobile network architecture,” *IEEE Int. Symp. Pers. Indoor Mob. Radio Commun. PIMRC*, vol. 0, no. September, 2016, doi: 10.1109/PIMRC.2016.7794936.

[41] M. H. Alsharif, A. H. Kelechi, J. Kim, and J. H. Kim, “Energy efficiency and coverage trade-off in 5G for eco-friendly and sustainable cellular networks,” *Symmetry (Basel).*, vol. 11, no. 3, 2019, doi: 10.3390/sym11030408.

[42] B. Longxun and Q. Technology, “The User Manual,” pp. 1–85, 2012.

[43] M. Wook Kang and Y. Won Chung, “An efficient energy saving scheme for base stations in 5g networks with separated data and controlplanes using particle swarm optimization,” *Energies*, vol. 10, no. 9, pp. 1–28, 2017, doi: 10.3390/en10091417.