Base Station Sleep Modes to Trade-off Energy Saving and Performance in 5G Networks.

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Preface

The work presented in this thesis report is essentially for the completion of the Master degree in Communications and Computer Networks Engineering. This is the research based thesis report which I carried in Department of Electronics and Telecommunications, Politecnico di Torino. The work is performed under the supervision of Prof. Michela Meo and I would like to thank her for guiding me and reflecting positive energies that I always felt in every meeting and discussion with her. I would also like to thank my co-supervisor, Dr. Daniela Renga as she kept her door open for me and always encouraged and guided me throughout this time period. I learnt a lot under the supervision of both of them and this is the most memorable time during my master degree. Also, I want to thank my lab mates for making this research learning a bit easier through their motivation.

Further, I want to thank my family. My parents, who are always there for me and without their support I would never be able to reach here. My sister and brothers who lifted me up with their motivation and love. I would also like to thank my friends in Italy and in Pakistan for boosting me up whenever i felt weak.

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Abstract

With the dynamic growth in ICT industry from recent years, energy demand is increasing with the demand of high data rates in mobile cellular communication. Base Stations(BSs) contribute to 80% of energy consumption of overall mobile cellular radio network. Efforts are reinforced for energy efficient system design for cellular networks concerning worldwide increase in energy costs and CO2 emissions impacting ecological balance. Under the energy efficiency incorporation studies for BSs, Sleep Modes(SMs) are discussed widely to save energy consumption by radio resources by turning them off in low utilization periods.

In this thesis, a simulation study is carried out by using Advance Sleep Modes (ASMs)[1] for 5G network New Radio (NR) signaling and other Internet of Things(IOTs) applications. Sleep modes are composed of different duration and have specific switching time. Hence, according to arrival rates and service time, BS can benefit from SMs by achieving lower energy consumption with respect to standard setting where BS is always active. Consequently, a reactivation delay adds in the system. As 5G networks are thought to be ultra-responsive with low latency, we need to achieve energy saving considering the constraint to ensure reliability and QOS guarantees. Therefore, additional delays due to ASMs are investigated and reasoned after reactivation time required for arrivals happened during BS is in sleep mode. We considered a formulation of sleep mode strategy where proper settings of the duration of each SM allows to trade-off additional latency due to reactivation and energy saving. Under this study we find that by configuring parameters properly for SMs, we can reduce reactivation delays upto 90% with a negligible increase in power consumption.

To better look at realistic traffic scenarios, we consider traffic traces of weekdays and weekend arrival patterns for both Residential and Metropolitan areas. The

system behaviour under these traffic patters is investigated deeply by simulating BS under ASMs and useful findings are achieved regarding overall energy consumption during the day. Our results reflect that we can set a threshold according to the traffic load as on higher load BS cannot take much advantage from SMs. Whereas, the effect of error in traffic prediction is also discussed by looking at delays and energy savings using the same parameter settings. In the end, a detailed overview is presented which includes the analysis of efficient ways of using SMs for limiting energy costs for Mobile Operators as well as keeping service level constraints regarding 5G mobile radio network into consideration.

Contents

Terminology

Abbreviation	Explanation
BS	Base Station
SM	Sleep Mode
ASM	Advanved Sleep Mode
NR	New Radio
DL	DownLink
UL	UpLink
ICT	Information & Communication Technology
IOTs	Internet of Things
DTX	Discontinuous Transmission
DRX	Discontinuous Reception
UE	User Equipment
PC	Power Consumption
MNOs	Mobile Network Operators

1 Introduction

With the tremendous growth in ICT industry and its overall impact on world ecological and economic health, has raised serious global concerns. According to a statistical analysis, Information and Communication Technology is responsible for about 2% of global CO_2 emissions [2] and this figure is even comparable with carbon footprint caused by aviation industry. The idea of Green Communication emerged as a whole to research and develop measures for controlling CO_2 emissions in environment caused by the increase in the energy consumption due to exponential increase of mobile users and demand of wireless services. This surge in demand of high-data rates and consequent up-gradation in mobile cellular technology is leading mobile operators and service providers towards installation of more base stations and data centers and other network equipment. Therefore, a growing complexity in mobile cellular networks has led Mobile Network Operators(MNOs) to bear increased operational expenditures and energy costs. Analyzing the consumption of energy from these network elements, BSs alone consume around 80% of energy in a cellular network. This breakdown of energy consumption in cellular network is clearly defined in Fig. 1.

The global rise in energy prices and sustainability requirements, has encouraged researchers to work under this concept of green communications and find useful solutions for reducing energy consumption and environment controls. Under the feasibility study of mobile network architecture, the idea of turning off few components of BSs with constraint of providing network coverage seemed possible. Many different studies under this research area suggested that as BSs are designed to serve at peak load conditions, hence a lot of resources get wasted under non-peak traffic hours. Therefore, by selectively turning off components in hours when traffic is minimal, a lot of energy consumption could be saved. In cellular networks, sleep modes refer to switching On and off BSs components or

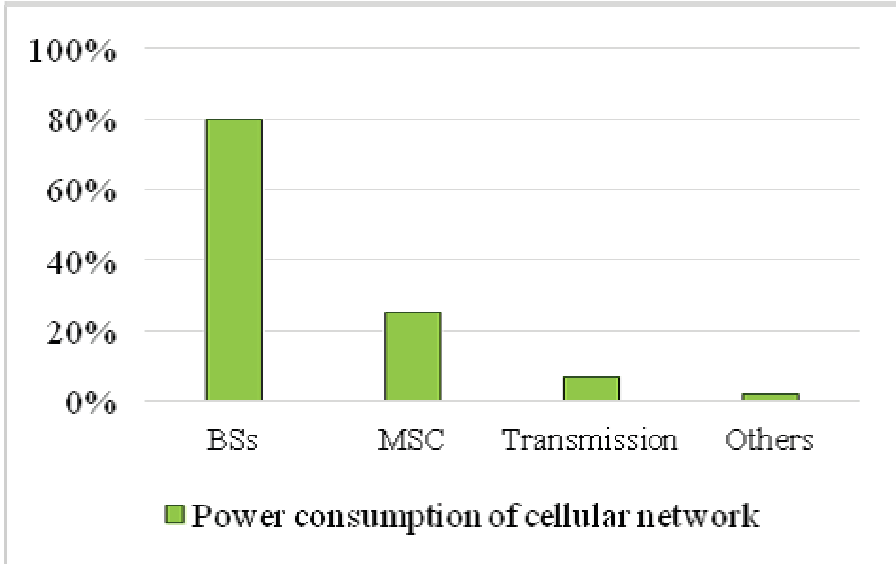

Figure 1: Breakdown of Power Consumption in Cellular Network[3]

entire BSs under a traffic prediction mechanism and it proves to be an efficient energy saving technique specially under low load conditions.

In this thesis work we further investigated the research done by[1] regarding implementation of Advanced Sleep Modes (ASMs) for signaling of 5G New Radio architecture. They suggested a buffering technique for the connections generated by users while the BS is in sleep mode with varying signaling periodicity. The sleep mode process is performed by gradually moving towards deeper sleep levels consequently achieving higher energy gains. We formulate a simulation environment according to ASMs and investigate the trade-off between power consumption and latency added at the service level in the system. Furthermore, we consider several scenarios such as fixed rate input signal periodicity (5G signaling) and exponentially distributed arrival rates (IOTs applications) on overall energy saving by both systems within the simulation environment.

In our research we focus mainly on the delays added due to BS operation in sleep mode and defined strategies that can be used to minimize these delays without affecting a lot on overall energy saving. Furthermore, as traffic prediction plays vital role to operate a BS using sleep modes, already predicted traffic patterns were analyzed in terms of latency using ASMs and an insight on effect of error in prediction on decision of sleep modes and overall percentage energy saving is also analyzed and discussed.

1.1 Motivations

Under the study of green communication for mobile networks, among many techniques to address the growing energy expenses and carbon footprint, sleep mode techniques are widely discussed and their implementation is proven to be easier as no hardware replacement is required. We adopted this in our research to understand the basic operation of 5G base stations under sleep modes with a simulation environment and analyze the effect of different parameters towards achieving our energy efficiency goal. It is suggested in [4] and shown below in Fig. 2 that even in quiet high load conditions still the BS has free slots in which it is consuming full power, although no user data is being transferred. This leads to employ a mechanism such as sleep modes, that can prevent this wastage of mobile network resources and help manage the energy expenditures for mobile operators.

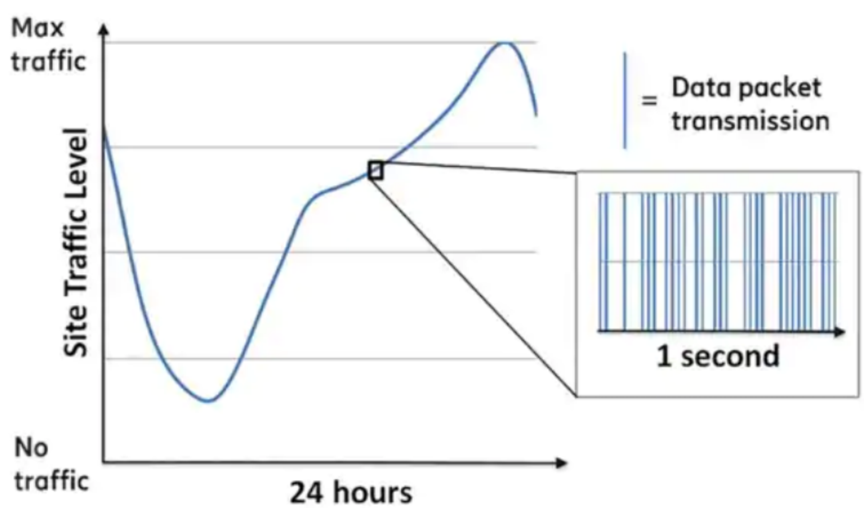

Figure 2: Variation in Traffic load during a day [4]

Therefore, the proposed scheme for BS utilizing sleep modes define a technique to prevent losses for those arrivals that come when BS is in sleep mode[**1**] i.e. buffer management technique. In this technique users are buffered for the duration required by BS to get back in active mode from SM. Consequently reactivation delays are experienced by the arrivals while BS is in any of energy saving state(SM). This idea seems authentic to us and we further enhanced our research in the same direction by observing those parameters that are involved in reactivation delays through multiple simulation experiments. Our research defines a way forward to minimize this latency while still managing to achieve a lot in terms of energy savings. We considered both 5G signaling and IOTs applications by setting parameters according to network requirement.

Furthermore, traffic prediction is a necessary element for implementation of sleep modes in order to effectively achieve energy savings in mobile cellular networks. So we analyze some traces for weekdays and weekend traffic patterns by making those as input traffic for BS under sleep mode operation and observed the overall delays for 24 hours simulation. Also the effect of prediction error on power consumption was carefully investigated with process simulation.

As 5G communication has strict delay constraints, we focus more towards minimizing the reactivation delays by formulating strategies for sleep mode durations in order to target 5G network architecture incorporated features in 5G White Paper-NGMN Alliance [5].

1.2 Related Work

Sleep modes techniques have emerged as the one of the key concepts for energy efficient system design for mobile cellular networks hence, its incorporation in the 5G and future technologies is considered elementary.

Among the initial works presented in this area of study Marsan et al. [6] introduced the concept of switching on and off base station under different traffic conditions. They do a comparative study of multiple fixed switching techniques with different traffic profiles and concluded that there is no single optimal configuration for all traffic profiles. Hence switching on and off cells must be tailored according to the traffic rate. In another research work presented by the same group they convince that switching off BSs in one fixed period of time after analysis of daily traffic patterns is quite equivalent to multiple sleep periods for shorter durations [7]. They argue that increase in complexity of cellular networks by using multiple sleep periods for shorter duration cannot be underestimated. Hence, only a marginal gain from the fixed switching off scheme is overall systematically sub optimal. Therefore energy saving must be achieved under the constraint of manageable network function.

Since the idea of green communication emerged and the ongoing research for energy saving in cellular networks has developed, many directions are considered for achieving better performance with comprehensive use of resources. Two generic models for sleep modes in cellular networks are discussed by [8]. In dynamic framework BS is put into sleep periods instantaneously according to the rate of traffic, while in semi-static under the low load conditions BS is put into sleep mode for minutes or hours. The result describes that both techniques are considerable for low traffic rates while the dynamic one is better for high variation in traffic. Authors in [9] analyze the real traffic traces of Manchester United, England, and presented a dynamic switch off technique for BSs under low traffic rates.

As data rate requirement has increased, Mobile cellular technology has also been enhanced to accomplish networking goals. Authors in [3] propose an algorithm, Message Passing with Load balancing (MPLA), in which base station can go into a sleep mode after handovering its user to nearby BSs. They suggest a message passing technique in which the BSs communicate with each other and take the decision to turn off BS through cooperation. In this way, BS can decide to switch off its resources as well as not to burden a neighboring cell, While the handover will be managed by balancing load among neighboring cells. Therefore, service quality could be maintained while achieving high percentage of energy saving.

For 4G mobile cellular technology, efficient ways of energy utilization are studied by considering DTX(Discontinuous Transmission) and DRX(Discontinuous Reception) schemes. DRX and DTX work in upload and download directions respectively for UE's power and transmissions. In the case of downlink, DTX directly relates with energy consumption from BS. Therefore, frameworks to periodically switch components of BS and UE into sleep modes under low traffic conditions are considered by [10]. Frenger et al. [11] further suggest that if we transmit only the most important synchronization signals in radio sub-frames under the idle periods we would be able to turn off the radio transmitter, hence achieving prominent energy saving in 4G cellular networks.

In [12], authors perform analysis on a queuing model and discussed that BS experience different outcome of arrivals while it is in sleep mode. Basic parameters like setup time and sleep period length could affect the strategies of detection of arrivals and bring about a variation in the overall energy saving. They argued that it may not be necessary that a complex sleeping mode strategy proves to be better than the simple one while considering the switching cost and other cost functions into account.

Energy efficiency is one of key requirements in 5G networks. In [13] authors show that as data rates are going to be higher in 5G cellular networks, it is mandatory to make the system more energy efficient in order to balance power consumption. They suggest that due to increase in BSs densities and bandwidth, access network consumes major share of network energy. Hence, unnecessary resource usage at non-peak hours with low load conditions must be reduced by switching off components of BSs.

Considering traffic prediction an important factor that influences the decision of using sleep modes effectively, [14] propose a multi-view ensemble learning model to predict traffic load in network. Authors use a machine learning approach to analyze network traffic with spatial, temporal and event driven view and then suggest sleep mode strategy accordingly for energy efficient cellular communication.

With all this background knowledge related to our research area we propose to adopt a strategy that deals with the latency constraint of 5G networks. Keeping in consideration sleep modes technique that helps the overall system to behave better in terms of consuming network's energy, our formulation insures that we can make the additional delays due to SMs smaller, still achieving a good percentage of saving with respect to 5G network energy consumption goals.

2 Research Objectives

2.1 Objectives

In 5G mobile cellular network, capacity is increased by large factor thereby providing huge date rates to users and connected devices. Therefore, technology will be shifted towards denser networks consisting of smaller cells, resulting in increasing energy requirements. Considering this, sleep modes are incorporated in 5G standardization to make the overall network energy efficient and to reduce the operational costs of mobile cellular networks. Indeed, sleep modes allow to modulate the network energy consumption over time, in order to make it more proportional to the dynamic variations of user demand.

Our main objective in this research work is to study the BS operation using sleep modes and analyze different factors and their impact on performance. In our research we mainly focus on reactivation delays that are added in the system due to sleep modes. Furthermore, we analyze the parameter settings that control these reactivation delays and find ways to minimize this latency with negligible impact on power consumption. Our study leads to achieve energy savings with better performance in terms of reactivation delays. To prove this statement we considered in our simulation different scenarios such as 5G signaling, massive IOTs and some real traffic traces and come altogether with very practical results for coming up cellular technologies.

2.2 Methods

Each SM has a standard duration before getting into deeper sleep mode. Under different arrival rates this factor impacts on additional average reactivation delays. We analyze these delays with various signaling periodicity for 5G networks as well as different arrival rates in case of massive IOTs scenario. Further, we investigate SM duration to trade-off these delays with energy saving.

Apart from signaling and IOTs, where the burst conveys only useful data and are of shorter duration, we do not neglect the real traffic scenarios where the user could demand a longer service duration and each connection duration is of comparatively longer time. Therefore, we perform simulation on real traffic traces considering varying load at different time of the day. By setting a threshold on required energy saving under a given load, we analyze that we can still manage to reduce the reactivation delays through modification of our SM parameters. Also we find that using these modified settings, even if there is an error in traffic prediction, the delays will still be lower with respect to those we achieve using standard settings.

2.3 Structure

In Chapter 4 we discuss the theoretical implementation of Advanced Sleep Modes, the buffer management technique and useful computational formulae for Power Consumption, Load and Latency for BS incorporated with SMs. Furthermore, all the useful states such as ON, Idle, Deactivation and Reactivation are clearly explained. In Chapter 5, Simulation setup is explained by representing the simulator's key features using flowchart diagrams. Also scenarios are presented which we considered for our experimentation and analysis. A logical insight of simulator design is explained presenting the algorithm that is run to operate the system. For each state in SM the BS is consuming different power, hence we clearly present those values to have a more clear idea of power consumption at any level in SM.

In Chapter 6, useful results from the simulation are discussed regarding each mentioned scenarios such as a comparison and trade-off between latency and energy saving for 5G signalling with varying periodicity of input signals. Also, the impact of real traffic patterns is analyzed using same parameter settings with comparatively larger service times. All the simulated findings are clearly presented and explained. In the end conclusion remarks and further suggestions to enhance this work are mentioned in Chapter 7.

3 Advanced Sleep Modes for Energy Efficient Base Station

3.1 Introduction

Rapid increase in the number of connected devices and consequent traffic increment demand a proportional increase in energy efficiency in mobile cellular networks. Sleep Modes thus refer to save energy by dynamically turning some of components from BSs when no data need to be transmitted. In this way an effective utilization of mobile network resources could be managed within the threshold of QOS requirements. When there are no data to be transmitted, some BS components are deactivated and the BS enters the first SM level, with a specific power consumption. After a predefined period, if there is still no traffic demand, additional components are deactivated, entering the second SM level, with even lower power consumption, and so on so forth. In case some data need to be transmitted at some point during this progressive deactivation process, the BS is reactivated and the data can be transmitted.

Advanced Sleep Modes are quantified under the same idea where four different sleep modes are introduced according to the power consumption of BS and its components. Transition times for each sleep mode refer to activation and reactivation durations and they are similar to the switching time of respective component in BS.

In table 1, four Advanced Sleep Modes are described with their reactivation and deactivation time durations along with representation of respective slots in a Resource Block. During each SM, components that are disabled in BS to achieve energy saving are also mentioned. Under our simulation study, we purposely not consider SM4 due to its high transition time duration which is non compatible with the delay constraint of 5G cellular network [15].

Table 1: Advanced Sleep Modes definition

Sleep Modes	**Resource Block element**	**Transition Time**	**Disabled BS hardware components**
SM1	OFDM symbol	71us	Power Amplifier & processing Components
SM2	Subframe /TTI	1ms	More components
SM3	frame	10ms	Most components
SM4	Standby mode	1s	BS out of Operation

3.2 Implementation Strategy

ASMs are gradually implemented if the BS is found idle, such as when no arrivals are to be served or no signaling burst is to be sent by BS. Each SM is categorized into a Deactivation slope, which is the time required to disable specific BS components and is generally half of transition time of that SM, followed by the Sleep length which is the minimum time duration required to be in that SM before transitioning into the next SM and is equal to transition duration of SM. If the arrival occurs while BS is in SM, time needed by BS to be in active state is half the total transition time and is referred to as the Reactivation slope. Fig. 3 describes this ASM implementation strategy.

3.3 Buffering Approach

While BS is in sleep mode it can still listen to the incoming requests and if a request occurs during this phase it is kept in buffer until the base station completes its respective transition time require to reactivate the disabled components. There could be three possible conditions that a request may encounter

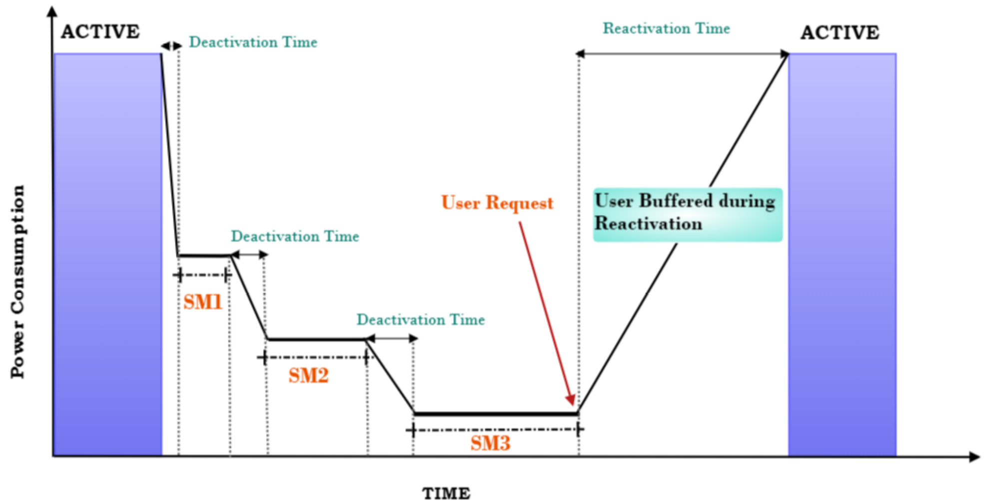

Figure 3: Implementation Strategy of Advanced Sleep Modes

upon its arrival:

- If the BS is in any of deactivation phase between one SM to another, then it has to wait for the completion of remaining time for deactivation slope followed by the time for reactivation slope to be back in active condition (Fig. 4). During this period the request must be put in buffer and the delay it experiences is termed as reactivation delay.
- If the BS is in any sleep mode i.e SM1, SM2 or SM3, then the reactivation process starts immediately and the request will be put in buffer for the reactivation time required from that SM Fig. 5. And the latency falls under reactivation delay.
- If the BS is already serving a request and another request is made which need to wait in the queue for completion of ongoing service, it's the queueing delay inside the server. But usually BSs are designed to have a high capacity to meet QoS, hence in our simulation we neglected queueing delays.

ASMs are designed in such a way that BS gradually enter from one sleep mode to another during the idle periods. Hence if the user request occurs in a deeper sleep mode the buffering duration will be greater and consequently reactivation delay experienced by the user will be larger. Also if more than one request is made during SM operation, BS will serve them in round robin fashion once it is activated from SM.

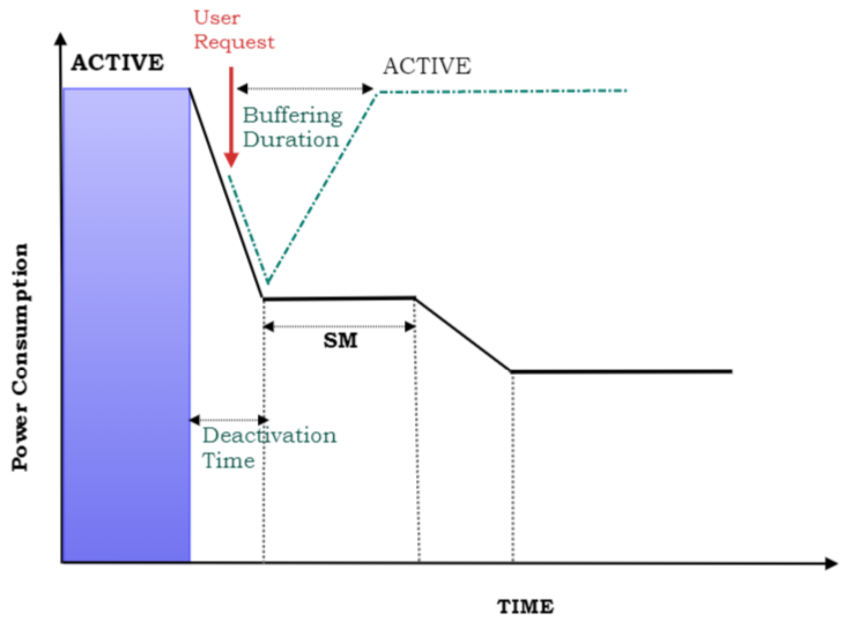

Figure 4: Buffering Approach during Transition mode

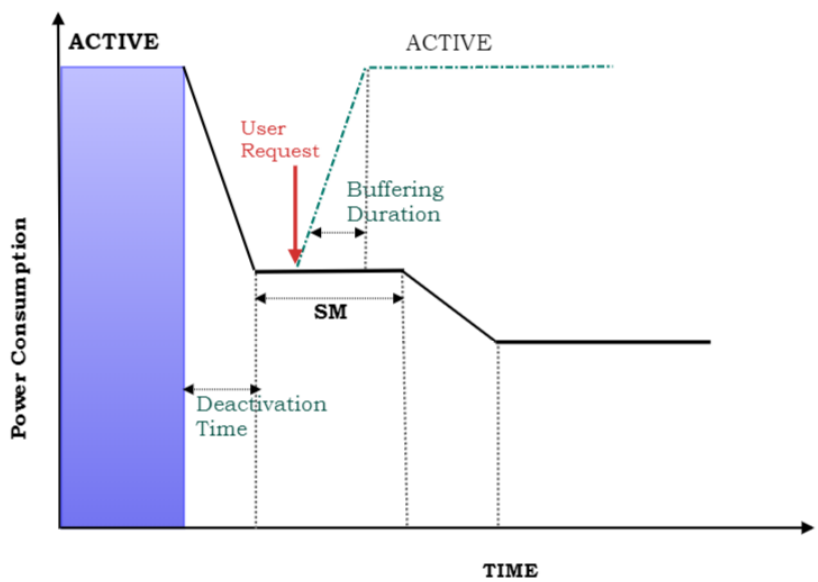

Figure 5: Buffering Approach during sleep mode

3.4 Energy Consumption Computation

We consider the same energy consumption model as presented in [1]. Considering BS with following parameters:

- N_e : represents the number of events corresponding to any change that occurs such as a request from a user, its departure or activation of Sleep Modes.
- τ_i: represents the duration between two successive events i and i-1.
- P_i: power consumption of BS in τ_i and is computed using iMEC power tool [16]. P_i depends on state of BS denoted by S_i and μ_i which is the load and L_{τ_i}, sleep level during τ_i.

EC for BS is computed as follows:

$$E = \sum_{i=1}^{N_e} \tau_i P_i(S_i, \mu_i, L_{\tau_i}, L_{\tau_i - 1}) \tag{1}$$

Under this energy consumption model in eq(1), BS could possibly be in any of following four different states:

- **Idle**: In this state ($S_i = 0$), if BS is activated its power consumption P_i depends on sleep level during τ_i. As there are no users in this state so load ($\mu_i = 0$).
- **ON**: In this state ($S_i = 1$), PC depends on load which is ($\mu_i = 1$) if there is a user available to be served by the BS.
- **Reactivating**: In this state ($S_i = 2$), BS is activating from any level of sleep mode to serve a buffered user or a signaling burst. Here, PC depends on respective sleep level from which BS is reactivating.
- **Deactivating**: In this state ($S_i = 3$), BS is entering a sleep mode hence its PC depends on the previous level from which it is transitioning to next sleep level.

3.5 Load Computation

With the simulation study of BS under sleep modes , we computed load as the fraction of total time period BS is in active mode.

$$\rho_k = \frac{1}{T}\sum_{j=1}^{N_e} \tau_j 1_{\{x_e(\tau_j)=1\}} \tag{2}$$

Where T is the total simulation period and $x_e(\tau_j)$ is equal to one if load is one and otherwise zero.

3.6 Latency Computation

With latency, we only refer to buffering delays encountered by request for service generated when the BS is in Sleep Mode. The time between the user request while BS is in sleep mode and when user starts getting service is referred to as latency experienced by the user. It is actually the reactivation time needed by BS to be back in active state from sleep state and serve the buffered users. To be clear, we are not considering the delays in the network due to queues while computing the latency.

$$\Delta_{Latency,i} = T_{serve,i} - T_{req,i} \tag{3}$$

where $T_{serve,i}$ is the time when user starts getting service and $T_{req,i}$ is the time user requested a service.

3.7 Power consumption at different States

Base Station consumes different power when it is operating at full load or it is active for signaling. Similarly, it consumes a specific power when it is in idle state. Therefore it is obvious that when the BS will go from one sleep mode to a deeper level, the value of power consumption should change accordingly. In our simulation study we used power values specified in [1] and we present them in table 2.

Table 2: Base Station Power Consumption at different states

Active		Idle (0% load)	ASM			
Full load	Signaling		1	2	3	4
750W	490W	328W	157W	42.9W	28.5W	24.3W

4 Base Station SMs Simulation Setup

4.1 Introduction to Setup

For simulation of BS using the SMs that we have discussed before, we code a simulation environment using SimPy library in python. We define the same parameters as mention in table 1, however we avoid to use SM4 as it has transition time latency higher than 5G network latency constraints.

Fig 6 represents a flowchart of overall process simulation of BS, it is clearly presented that SM process will start when there are no arrivals. Arrivals could possibly be a service request from an incoming user or a regular periodic signaling burst necessary to perform synchronization and other control functions.

If the the base station is idle, it will start a sequential transitioning from one sleep level to deeper sleep level unless process is interrupted due to an incoming arrival. In this case request will be buffered for the time period required by the BS to reactivate from SM and once BS is reactivated it will serve all the requests waiting in the buffer. After successfully completing all the requests, base station again will look for the idle periods to start transitioning again from active state to SM1 and then higher sleep levels. However, if the BS went into deeper level, such as SM3 it will remain in SM3 until an arrival wakes up the base station. Therefore, significant saving could be achieved in deeper SM specially for low arrival rates.

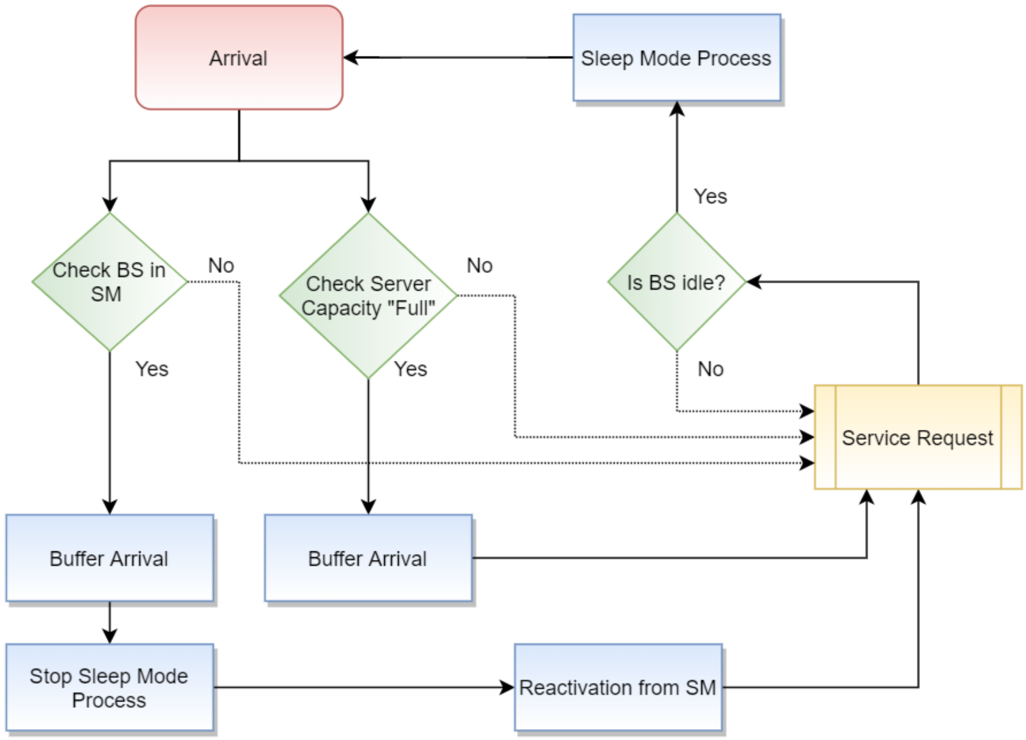

Figure 6: Flowchart BS Sleep Mode Simulation

Transitioning from sleep mode i to $i+1$ are more clearly presented in flowchart diagram in Fig 7. At every transition state BS keeps hearing the incoming requests and if a request occurs during a deactivation phase from one SM to next, it calculates the remaining transition time to enter next state followed by a reactivation duration to the active or serving state. Conversely, if request interrupts during any sleep mode, BS will directly start reactivation to move back to active state.

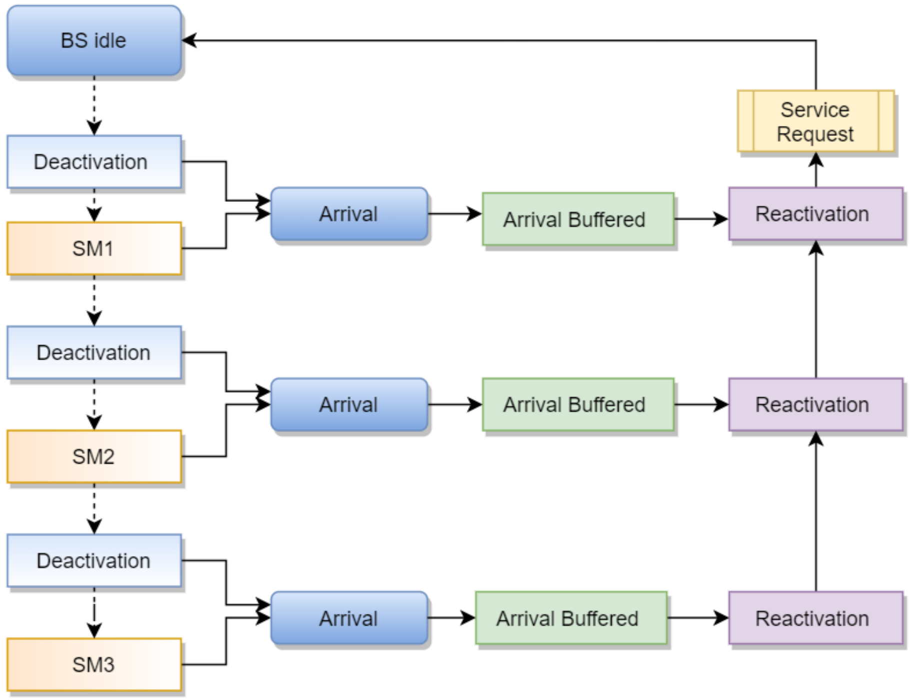

Figure 7: Flowchart representation of ASMs levels

4.2 Simulator

Below we report simulation environment using Python, and all the experimental calculations and statistics were obtained with the following structural approach to the problem.

Algorithm 1: Pseudo code for BS sleep Modes simulator

```
initialize the simulator environment;
initialize the buffer for incoming user requests;
initialize a traffic generator;
initialize a BS with sleep modes;
initialize the process for a given simulation time;
repeat
if buffer is empty then
    while no user request do
        deactivate and enter SM1;
        wait for SM1 duration;
        deactivate and enter SM2;
        wait for SM2 duration;
        deactivate and enter SM3;
        wait until a request comes.;
    end
else
    calculate reactivation time from SM;
    put user in buffer for reactivation time;
    elapse for reactivation time;
    serve all the requests in buffer;
end
Function Generator()
    Generate user requests;
    put them in buffer;
```

4.3 Simulation Scenarios

5G networks are emerging with features such as high data rates with less delays and more network densification. From the past it has been clear that to increase the capacity of overall network and service requirements, operators must meet the expense of network expansion. With consequent increase in the number of BSs, more resources are required to fulfill the energy requirements. Therefore, base stations contribute a major share in overall operating costs by consuming most of the network's energy. 5G base stations are thus designed to be energy efficient to decrease overall expenditure with a motivation to reduce environmental effects as well.

In our simulation study, we develop three scenarios and analyze them in depth to understand the ways to modify our BS sleep mode parameters in order to contribute to deploy energy efficient networks with delay constraints or the delay sensitive IOTs applications. Our aim is to study and minimize delays due to reactivation under various traffic patterns and input conditions with a negligible impact on overall energy saving. Below we report the three scenarios that we consider in this research activity.

4.3.1 5G Signaling with fixed periodicity

Here, we consider fixed periodic signaling for 5G and see the impact by varying the periodicity. In this scenario we chose 1ms exponential service time duration as signaling bursts could be of different length depending on its type. All the other parameters are considered as standard, such as SM duration and power values for each phase. We studied the impact of changing the SM duration to trade-off latency versus energy consumption. Our main purpose of this trade-off in this scenario is to find those parameter settings that result in minimum delays so that if the signaling is delayed, it should not impact on connectivity or other important features such as handover.

4.3.2 Massive IOTs with varying arrival rates

Under this section, we consider varying arrival rate with exponentially distributed inter-arrival time between successive arrivals. This scenario is designed to focus on massive IOTs related applications, therefore we chose service time duration as 10ms and is exponentially distributed. IOTs applications require low power consumption while the delays are subjective to particular application. Hence, we analyze both reactivation delays and power consumption and have a trade-off analysis that could be used according to the application specifications.

4.3.3 Multi Server with Real Traffic traces

In this scenario, we took real mobile traffic traces representing weekdays and weekend traffic patterns for metropolitan and residential areas. Firstly, we perform a multi server simulation analysis of base station using SMs by considering a higher service time duration such as 30s for a varying arrival rate. All the necessary data, for example average load, delays and power consumption is analyzed and then those real traffic traces are used as input rate for simulating a BS with sleep modes. This helps us to better understand the average power consumption at different day times in a realistic scenario. Further, we analyze the reduction in latency by configuring different SM durations from standard settings. In the end, we quantify the effect of error in traffic prediction and find that even with an error in prediction, we can still achieve minimal delays using modified settings as compare to standard.

Adapting SMs to traffic Mobile network BS traffic vary under influence of many factors such as time of the day and area. Furthermore, weekdays and weekends also impact on total load of the system. SMs effective utilization can only be achieved if BS adapt with the traffic. Therefore traffic prediction helps in deciding sleep mode settings according to traffic load in network.

4.4 Sleep Mode settings

With the standard settings it is known that each SM has some fixed duration and BS elapse that duration before transitioning into next sleep mode. The duration for each SM is already defined in table 1. With the simulation analysis we find that SM duration directly impacts the reactivation delays for varying arrival rate. Such as, for given arrival rate if we increase SM2 duration, there is high probability that user will arrive when BS is in SM2. Similarly, as reactivation time from SM2 to active state is less, user will experience less delay and buffering time will decrease. Therefore in our scenarios we simulated with different minimum duration for each sleep mode according to the given arrival rate to reduce the reactivation delays. These SM settings vary with the traffic load and are implemented under a traffic prediction mechanism and application's delay sensitivity requirements.

To summarize, this chapter includes BS simulation setup with SMs. With the help of flowchart diagrams we explained the BS operation, transitioning from one SM to another and conditions that effect the process, such as an incoming user request or a fixed signal for 5G mobile network communication. All the simulation scenarios that we analyzed and whose results will be mentioned in next chapter are described here. furthermore, we define SM settings that we considered while simulation of these scenarios.

5 Simulation Results

In this chapter we will discuss about the most significant results from our thesis research. Our study lies under the umbrella of energy saving using SMs for 5G NR architecture. To understand its various features, we develop a simulation environment and our main objective is to highlight the reactivation delays due to ASMs mentioned by [1]. Further we look for the solution to minimize these additional delays with a negligible effect on overall energy saving. Below, we present the findings of all the strategies that are described in section 5.3.

5.1 5G Signaling and Massive IOTs

Two scenarios, 5G signaling with fixed signaling periodicity and massive IOTs with varying arrival rate are considered in this section. Different simulation results are plotted to understand important features of both scenarios as well as a comparison is performed to highlight key differences between the two.

5.1.1 Reactivation Delays

In Fig 8 and Fig 9, we observe the reactivation delays for the two scenarios, fixed signaling for 5G base stations and exponential arrival rates for IOTs applications. We consider these two scenarios together as they both depict shorter service time durations, such as 1ms for varying signaling periodicity of 5G and 10ms for varying arrival rates in massive IOTs. The figures clearly represent that reactivation delays are almost 5.5ms for both scenarios.

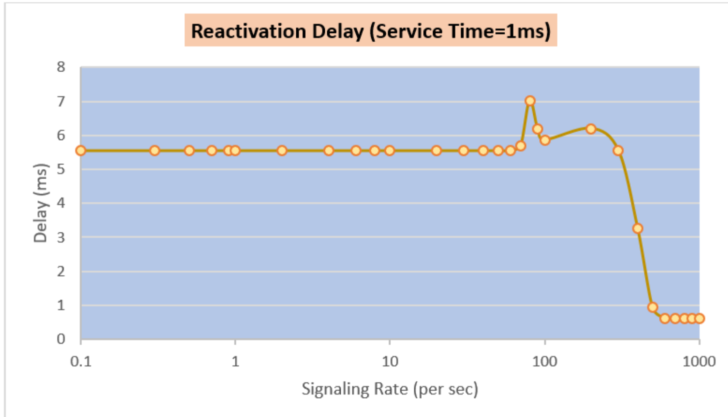

Figure 8: 5G Signaling: Reactivation Delays

For fixed 5G signaling, at signaling rate 500 per second, reactivation delay rapidly decrease as BS is in active state for most of the time due to high signaling rate and consequently it is not going into SMs. We can also analyze that at rate 80 per second, the delay abnormally increase to around 7ms. The reason for this abnormality is that every time BS enters into SM3 it has to reactivate due to next signaling burst arrival at fixed rate of 80 per second.

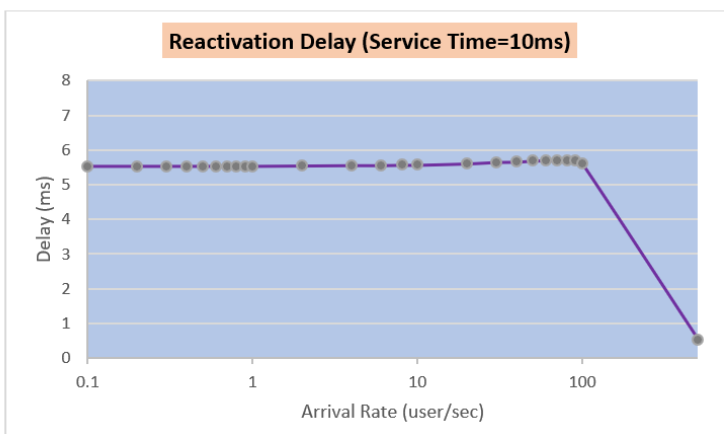

Figure 9: Massive IOTs: Reactivation Delays

While if we observe at massive IOTS scenario in Fig 9 , at arrival rate 100 per second, reactivation delay starts decreasing as BS shift towards active state with only few times going into sleep state. If we compare both scenarios we can clearly find that as service time duration of massive IOTs is larger than Fixed signaling therefore, BS tends to move towards active state at lower arrival rates and reactivation delays start decreasing earlier in massive IOTs scenario.

5.1.2 Energy Saving

Sleep Modes in BSs are incorporated to achieve energy saving and to limit the use of resources in low or idle traffic conditions. Fig 10 and Fig 11, represents the percentage energy saving in fixed signaling for 5G scenario and massive IOTs scenario. For achieving these results, in our simulation we used power consumption values as mentioned in table 2. To better approximate energy consumption for fixed signaling case we took as reference 490W which is the power value consumed by BS during signaling period.

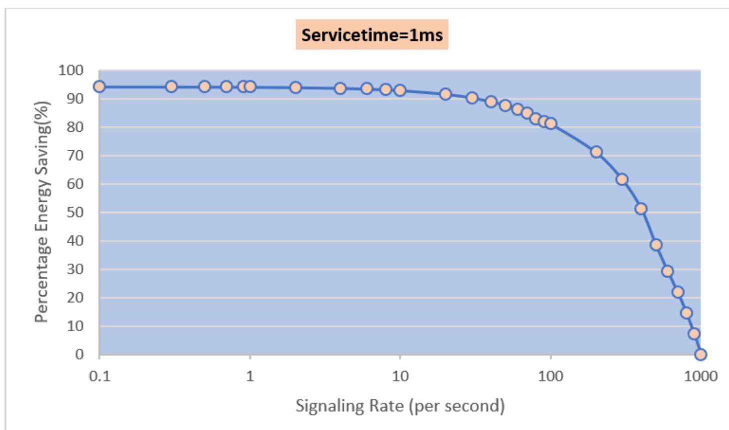

Figure 10: 5G Signaling: Percentage Energy saving

In Fig 10 we can analyze that percentage energy saving is higher in low periodicity values as BS spend most of the time in deeper sleep state. More than 90% saving could be achieved for signaling rates less that 50 per second. As the periodicity starts increasing from 50 to 200 signals per second, percentage saving slowly starts dropping and reaches to 70%. Further increase in periodicity results in rapid drop in energy saving as BS continues to be in active state for most of time. For fixed signaling we can see that at a rate 1000 per second with 1ms service time duration, SMs contribute in 0% energy saving.

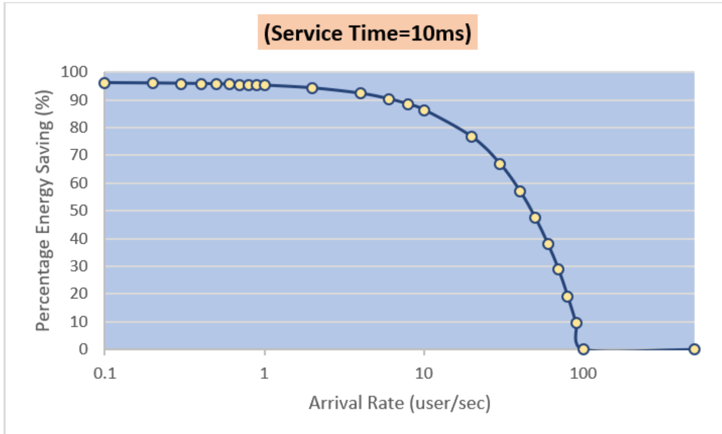

Figure 11: Massive IOTs: Percentage Energy saving

On the contrary, in massive IOTs scenario we have considered exponential arrivals with a varying rate. Therefore we consider the arrivals as user requests and computed the percentage energy saving with reference to BS power value in active full load condition, i.e. 750W. In this scenario, we analyze the same as for fixed signaling, that for lower rates we can achieve more than 90% energy saving. Afterwards, around an arrival rate of 10 users per second, percentage energy saving starts decreasing in steep manner and reaches to 0% at 100 users per second.

If we compare the two scenarios, we can analyze that in massive IOTs scenario as service time duration is larger, hence at comparatively lower rates, users have to wait for an ongoing request and therefore BS experiences larger queues. This phenomenon results in more active time and less energy saving with respect to fixed signaling scenario.

5.1.3 Energy Saving during SMs

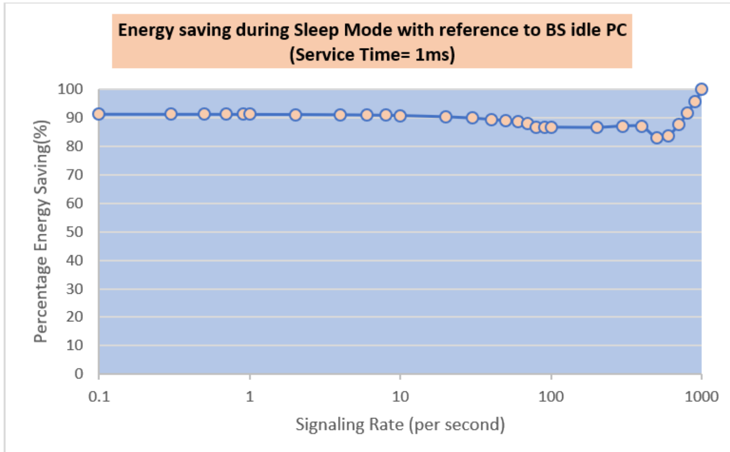

Figure 12: 5G Signaling: Percentage Energy saving in SMs

In Fig 12 and Fig 13, we can analyze the energy saving for the time BS is in sleep modes. For the computation of percentage saving in SMs we use value of power that BS consume at idle state (0% load) as a reference, i.e. 328W. Therefore, when there are idle periods at a given arrival rate BS will consume at-least 328W. We calculated the the amount of energy consumption in SMs and compare it with idle power consumption.

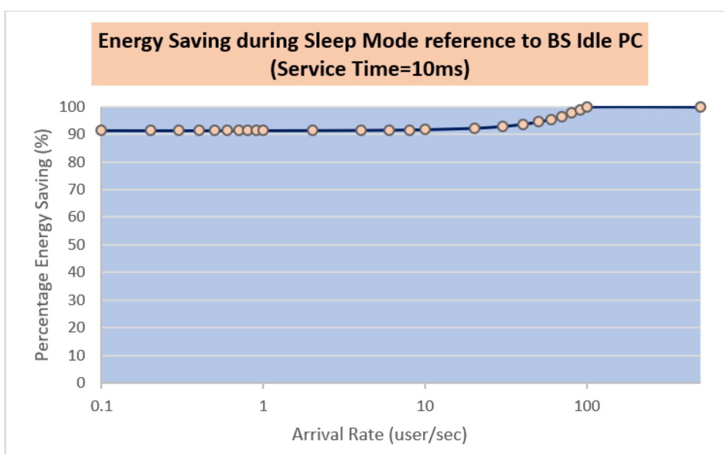

Figure 13: Massive IOTs: Percentage Energy saving in SMs

Both the scenarios, 5G signaling and massive IOTs, depict that BS can save up to 90% energy consumption using SMs rather than consuming idle power consumption without SMs. For the fixed signaling in Fig 12, we can analyze that around rate 500 per second, BS shift to full load active condition. Therefore, power consumed in SM is almost 0 as the total time duration that BS spent in SMs is nearly 0. Similarly for massive IOTs scenario in Fig 13, at an arrival rate 100(user/sec) BS shift to active state from idle state. Hence no more utilization of SMs could be possible.

5.1.4 Load analysis with varying input rate

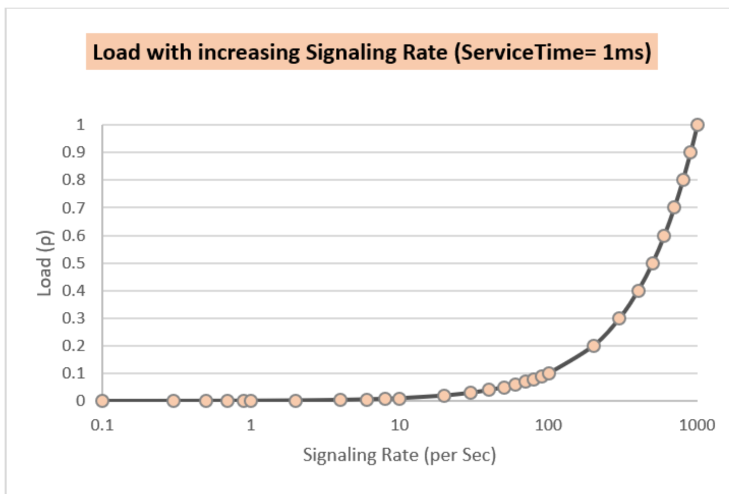

Figure 14: 5G Signaling: Load Analysis

Fig 14 and Fig 15 describe the load in the system at a given rate. To compute this, we have used equation 2 in chapter 4 according to which load is the proportion of simulation time period when BS is active. In case of fixed signaling in 5G mobile networks presented in Fig 14, it is observed that from rate 0.1 to 100 per second, average load in BS is less than 0.1. While as the rate increases from 100 to 1000 per second there is an exponential rise in load, which represents that BS is in active state for most of the simulation time period.

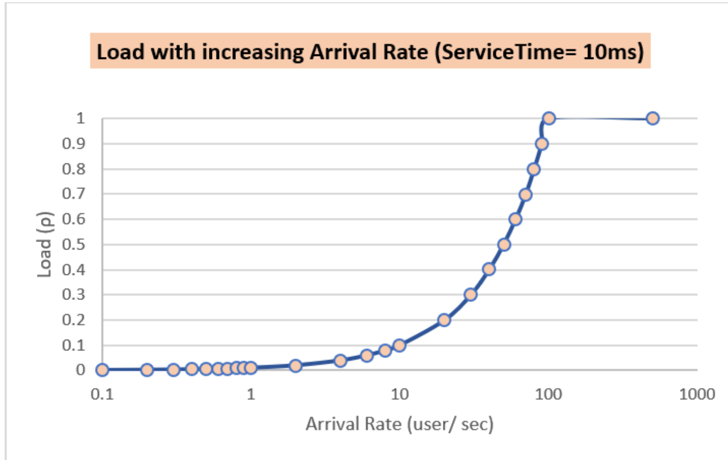

Figure 15: Massive IOTs: Load Analysis

For the massive IOTs scenario, we already know that at an arrival rate of 100 per second BS is active for 100% simulation time period. Therefore we can predict and also see in Fig 15 that load is equal to 1 at this rate. In comparison to previous scenario we analyze that in this case load starts increasing rapidly from rate 10 to 100 per second. The main reason for this difference in both cases is the comparatively larger service time duration of massive IOTs scenario that keeps the system active for more time period.

5.1.5 Proportion of Simulation Time spent in different modes

Figures 16 and 17 describe the time spent by BS in each of sleep mode i.e. $time\_S1$, $time\_S2$, $time\_S3$ and time spent in active state i.e. $activetime$. BS is simulated for a total time period of 6000 seconds with varying input rate depending upon fixed signaling or massive IOTs scenarios. BS spends different proportion of time period in each phase according to the input arrival rate.

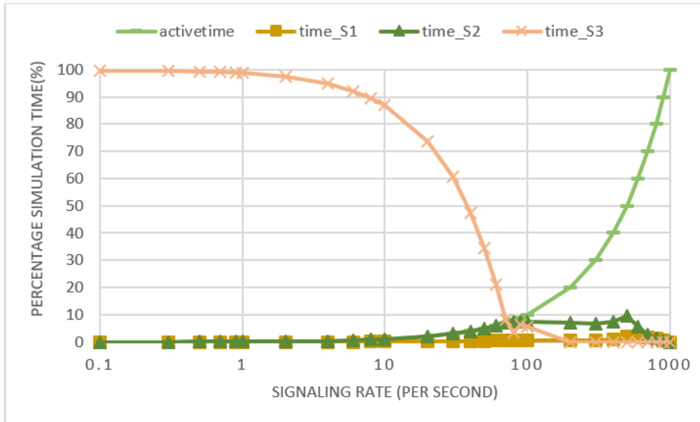

Figure 16: 5G Signaling: Time spent in each SM & when BS is active

For fixed signaling scenario reported in Fig 16, it is visible that for low rates most of the simulation time period is spent in SM3($time\_S3$). As the signaling rate increases we can see that $time\_S3$ starts decreasing and $activetime$ starts increasing. However, if we observe at rate 80 per second we can analyze that BS is spending most of simulation time period in neither of these four mentioned states. For a better understanding of this behaviour if we review Fig 8 in which reactivation delays are reported, we can see a spike that rose to 7ms at the same rate. Therefore, BS instead spends most of time in transition duration i.e. reactivating from sleep modes.

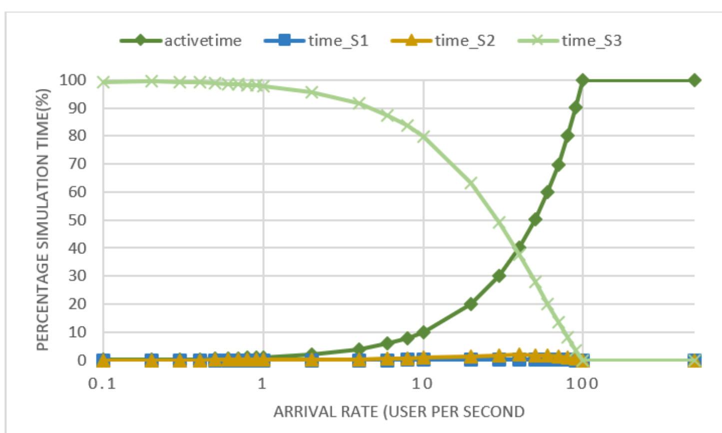

Figure 17: Massive IOTs: Time spent in each SM & when BS is active

Refer to Fig 17 where massive IOTs scenario is reported, similar trend is observed for lower arrival rate but as the rate increases we can see a comparatively smooth transition from SMs to active state. For both the scenarios it is prominent that as rate increases, chances of BS to be waken up from SM2 and SM1 increases. Therefore, we can see a small rise in time periods of both SMs at higher rates.

5.1.6 Probability of arriving in each SM

In this section we discuss about the probability of arrival while BS is in any of SMs i.e. SM1, SM2, SM3. For those arrivals that occur during the deactivation from SM(i) to SM(i+1) will be considered as a part of SM(i+1). Our main interest is to find the probability of BS in each SM when an arrival occurs considering a varying arrival rate.

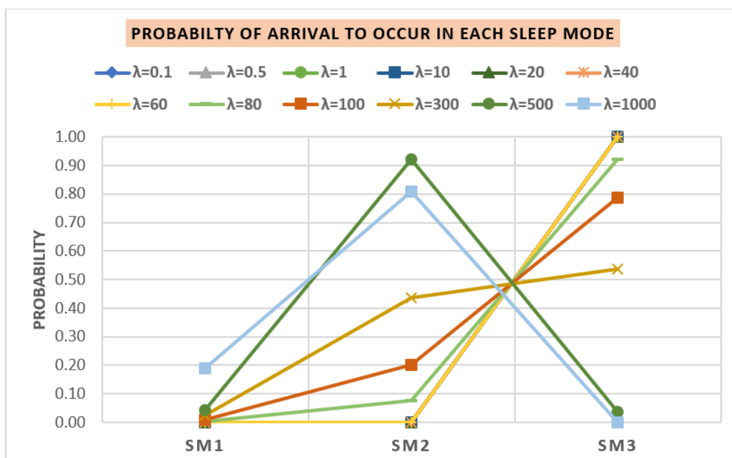

Figure 18: 5G Signaling: Probability of arrival in various SMs

In case of simulation of BS with fixed rate signaling reported in Fig 18, we can analyze at lower rates probability of an arrival to occur while BS is in SM1 and SM2 is negligible. Therefore it is highly probable that an incoming signal or arrival find the BS in SM3. Consequently as the rate increases, probability for SM1 and SM2 increases while SM3 decreases significantly. As the duration of SM1 is $71\mu s$ which is very small, we can observe that even at higher rates it is more probable that BS transit from SM1 to SM2.

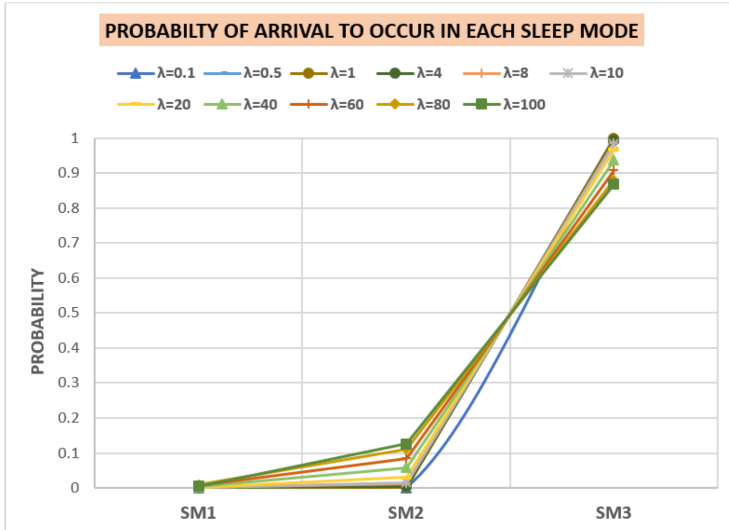

Figure 19: Massive IOTs: Probability of arrival in various SMs

For massive IOTs scenario we have comparatively larger service time duration, also the arrivals are exponentially distributed. Therefore in Fig 19 for lower rates, probability of BS to be in SM3 is almost 1 while in other states is nearly 0. As the value of lambda reaches to 100, the probability of SM3 and SM2 is effected by one decimal point in decreasing and increasing manner respectively. While probability of SM1 does not vary.

If we compare scenarios we can analyze that as the signaling or arrival rate reaches 100 per second, probability of being in SM2 increases, SM3 decreases and SM1 stays the same for both scenarios. However for further increase in arrival rate, in fixed signaling scenario there is a significant rise in probability of SM2 with a consequent drop in SM3 probability, also a comparative increase in probability of SM1 is observed. While for massive IOTs beyond the rate 100 per second BS goes to active state with no or very less chances to go in sleep modes.

5.1.7 Trade-off Analysis with modified settings

In this section, we highlight the results for our main research objective considering fixed signaling scenario for 5G and massive IOTs scenario. As mentioned before in our research objectives in chapter 3, our aim is to minimize the reactivation delays added in the system due to sleep modes with a negligible impact on power consumption(PC). Therefore in following results highlighted in Fig 20 and Fig 21, we present a trade off analysis between power consumption and reactivation delays that we achieved by modifying parameter settings while simulating.

In fixed signaling scenario, we vary the signaling periodicity therefore simulation is performed considering BS signaling power consumption, i.e. 490W. While in massive IOTs scenario we consider full load active power consumption as our reference, i.e. 750W.

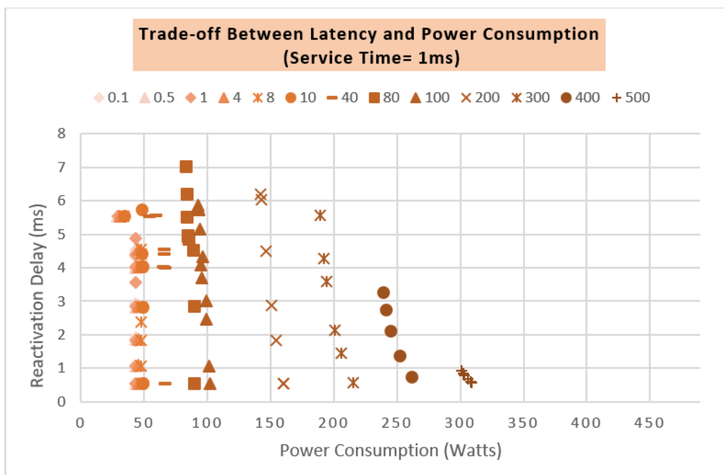

Figure 20: 5G Signaling: Trade-off with modified settings

In Fig 20 we can analyze the trade-off performance with fixed signaling periodicity. By changing the SM duration from the standard parameter settings we could minimize the reactivation delays from more than 5ms to less than 0.6ms. More than 90% reduction could be achieved. However, if we observe the effect on power consumption, it is significantly less. For higher signaling rate, reactivation delays are already small as system does not allow to utilize SMs a lot.

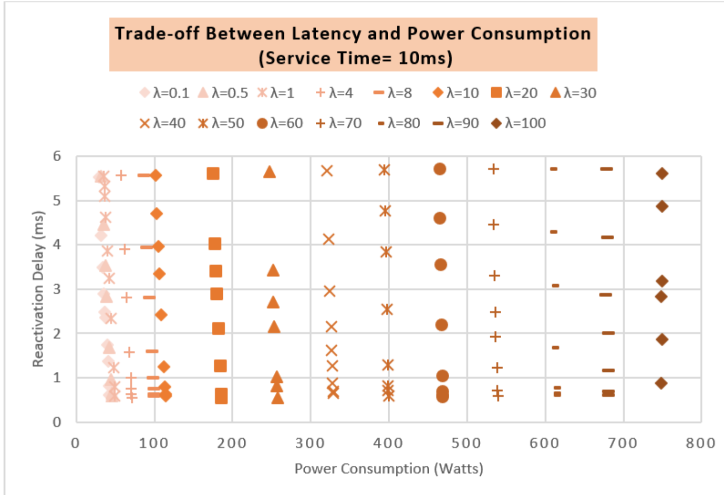

Figure 21: Massive IOTs: Trade-off with modified settings

Fig 21 describes the results of simulation for massive IOTs. Here we can observe that even at an arrival rate of 100 per second, where the power consumption is already above 700W, meaning that BS is active for most of time period, we can still significantly reduce reactivation delays with negligible impact on PC in base station.

Therefore, we can say that modified parameter settings may perform better than standard settings under different arrival conditions.

5.2 Multi-server Base Station simulation

In the previous scenarios we assumed signaling or arrivals that require few burst of milliseconds to be transmitted. Therefore we cannot predict the behaviour of BS operating with SMs under a real traffic scenario. Practically, user may request a service for a longer duration or there could be a stream of packets for the same connections. In this simulation, we analyze a simple case where each request is subjected to an exponentially distributed service time duration of 30s. Our aim is to obtain results somehow closer to what we can perceive in the real traffic scenario. Also in multi-server simulation scenario we suppose a large BS capacity. Therefore delays will only be the one due to buffering of users for reactivation of BS from SMs. In subsections we will discuss about the important findings from multi-server BS simulation.

5.2.1 Reactivation Delays and Energy Savings

Fig 22 describes the reactivation delays experienced at various arrival rate. We started with a very low arrival frequency i.e. 1 user per 1000 seconds, to a much higher arrival rate of 1 user per 2 seconds. However, we can observe that the reactivation delay stays almost constant to 5.5ms irrespective to the arrival rate.

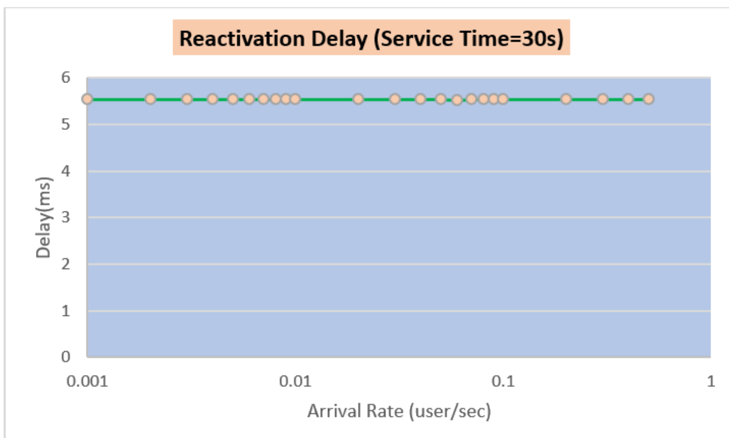

Figure 22: Multi-server BS: Reactivation Delays

This is because every time a BS is idle and it can go in sleep mode, it will transit from each SM to reach SM3. Total time required to reach SM3 is 6.06ms which is still very less than our maximum inter-arrival time of 2 seconds, therefore the probability of a user arrival is maximum when BS is in SM3. Reactivation time required from SM3 is 5.535ms and we analyze the same constant value in our simulation.

Fig 23 presents the percentage energy saving with a simulation of multi-server BS using sleep modes. For overall energy saving including both active time and sleep time, full load active power consumption is taken as a reference. We can analyze in pink curve that percentage energy saving drops rapidly till it reaches the rate 0.1 user per second. Thereafter, we cannot achieve much saving as BS stays in active state. Regarding the percentage saving in idle state using sleep mode, idle power consumption is taken as a reference and more than 90% saving is achieved till arrival rate 0.1 user per second and later BS does not find idle periods.

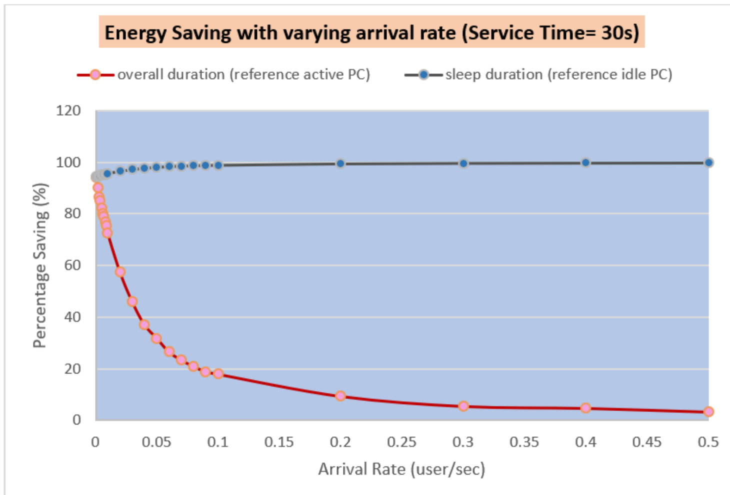

Figure 23: Multi-server BS: Percentage Energy Saving

5.2.2 Load Analysis and Time spent in different modes

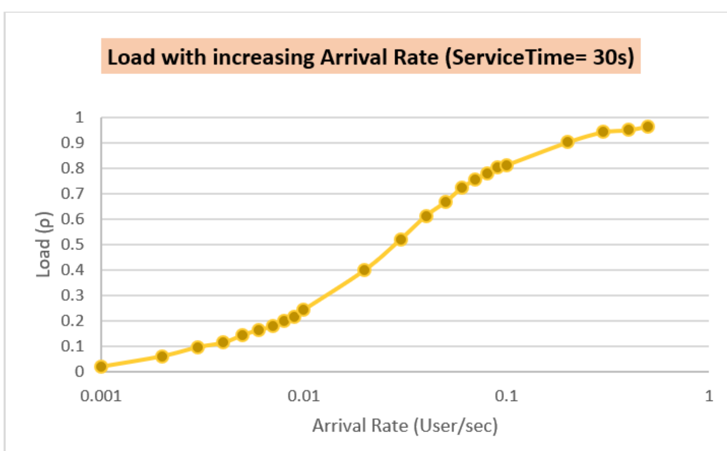

Figure 24: Multi-server BS: Load Analysis

Fig 24 describes load at varying arrival rate. We can observe that load is almost linear to rate of user arrivals per second. Once the arrival rate reaches 0.1, value of load is above 0.8 which is considered to be almost equal to full load condition. We know that service time duration directly impact the value of load by changing the state of BS. Larger service time duration will result in more active time even if the arrival rate is comparatively low.

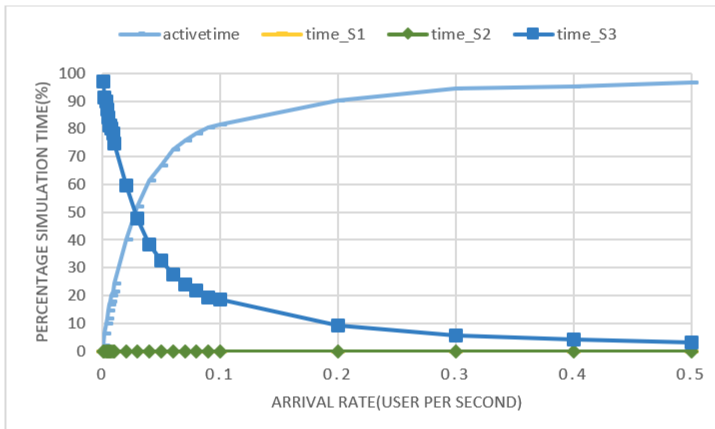

Figure 25: Multi-server BS: Time spent in each SM & when BS is active

Fig 25 expose the time duration BS spent in each state during one complete simulation cycle. We vary the arrival rate and simulated for total simulation time period to understand the behavior of BS under sleep mode operation. We can observe that for low arrival rate, BS spends most time in SM3($time_S3$) while $activetime$ is negligible. Further, there is rapid shift of BS operation from SM3 ($time_S3$) to active state($activetime$) within the range of arrival rates 0 to 0.1(user/sec). Also we can analyze that time spent in SM1 and SM2 is only accountable for transitioning towards SM3 i.e. deactivation time, therefore it is negligible.

5.2.3 Trade-off Analysis: Reactivation delays and Power Consumption

In multi-server scenario, service time duration and arrival rates are set to represent more closely BS operation in real traffic situation. With the simulation of previous results we already analyzed that under varying arrival rate and service time duration of 30s, BS tends to go into SM3 during idle periods. Therefore reactivation delays are almost 5.5ms. Considering our research main objective to minimize these delays in system and impact on power consumption we perform a trade-off analysis with multi-server simulation.

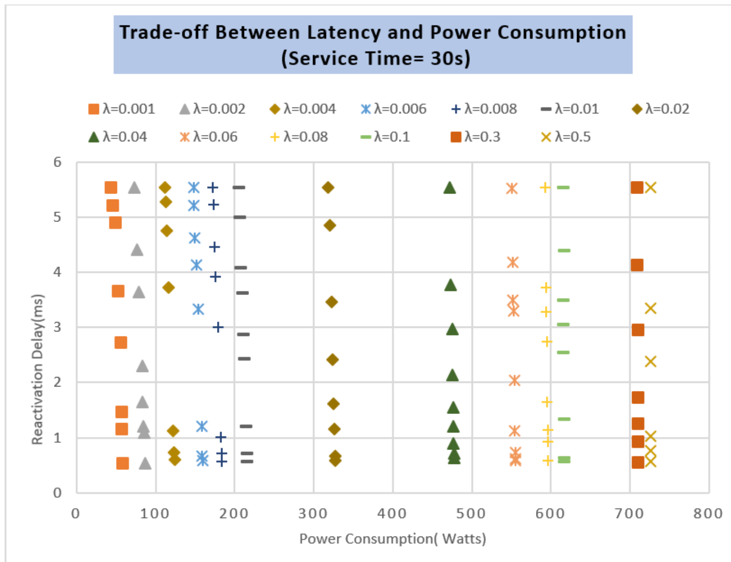

Figure 26: Multi-server BS: Trade-off Analysis

Fig 26 represents the finding of our simulation result. We can clearly understand by looking at the figure that by changing the SM duration from standard values we can perform better in terms of reactivation delays by reducing them up to 90%. However, if we focus on power consumption for each value of arrival rate, there is a marginal increase using modified settings. Therefore, we can reduce the additional delays with negligible impact on overall power consumption with a realistic traffic scenario simulation.

5.3 Traffic Patterns Simulation

BS can effectively utilize sleep modes if there is a strong prediction mechanism for incoming traffic. A lot of work has been done in this specific area and many techniques and algorithms are proposed by researchers to predict the traffic. Among those sophisticated ideas, day and night traffic patterns or weekdays and weekend traffic patterns are analyzed and used to predict load at different times of the day.

In our simulation, we used real traffic patterns of weekdays and weekend from metropolitan and residential areas. For simulation purpose, traffic values are normalized from 0 to 0.9. Furthermore, with the multi-server simulation analysis, it is known that BS remains in active state beyond an arrival rate of 0.5, therefore for the duration in which normalized values are more than or equal to 0.5, we consider BS in active state with full-load power consumption. Normalized traffic pattern is shown in Fig 27.

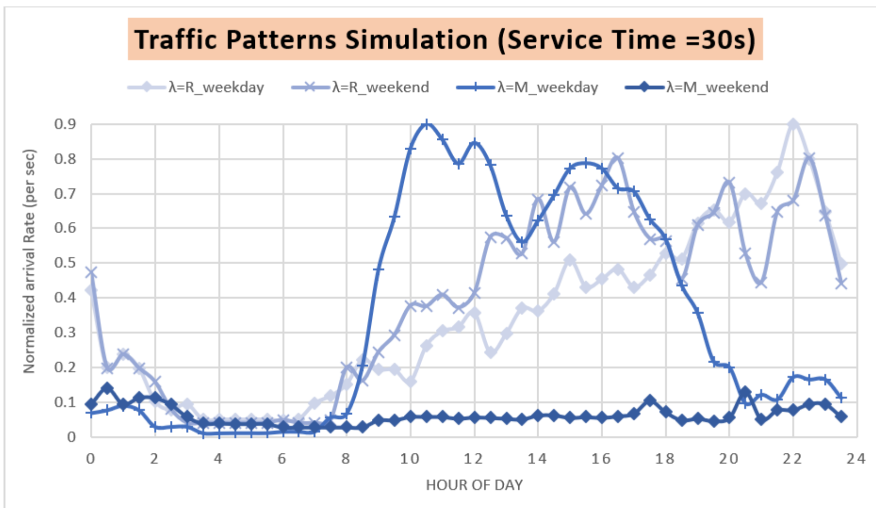

Figure 27: Weekday and Weekend Traffic pattern for Residential and Metropolitan area

5.3.1 Energy Saving

In Fig 28 simulation results for percentage energy saving for week day and weekend traffic pattern are described. For simulation purpose we consider service time duration of 30s as in multi-server scenario. While for arrival rate we use normalized value that we describe in Fig 27. At 0.5 user per second and afterwards, BS is supposed to be in active state, therefore BS is consuming 750W active high load power with percentage energy saving equal to zero. For rates smaller than 0.5(user/sec), we simulated with respect to changing traffic pattern for each residential and metropolitan area.

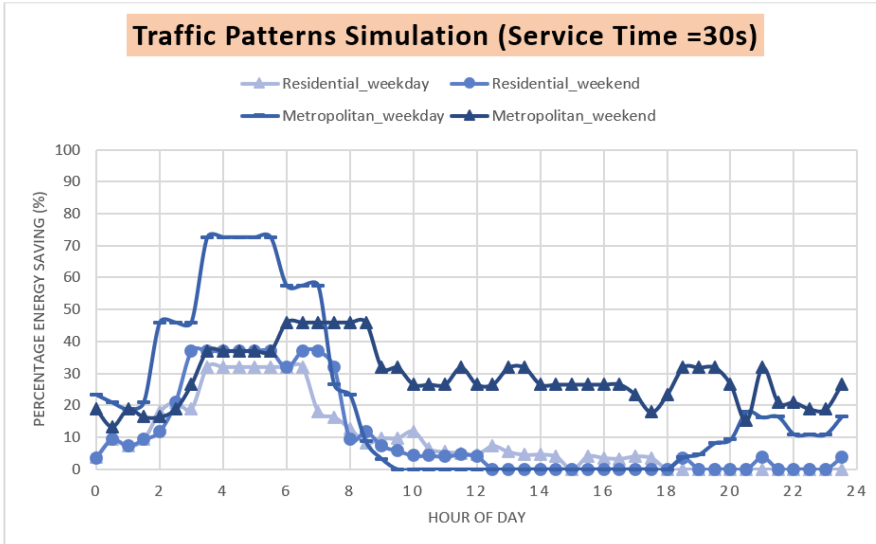

Figure 28: Weekday and Weekend Traffic pattern for Residential and Metropolitan area

If we observe in Fig 27 that during hours 2 to 8, traffic load is quiet low therefore a comparatively high percentage saving is attainable. Fig 28 shows that during this time duration in metropolitan weekdays we can save more than 70% power consumption. Where else, in other three cases saving is near to 40% during this time. In metropolitan weekend, traffic is reasonably low throughout the day hence, on average percentage saving is around 35%. If we observe both patterns of residential areas, traffic rate is high for most time of day therefore we can only see energy saving from 2a.m in night to 12p.m in morning.

We also study the impact of error in traffic prediction on power consumption and reactivation delays. As traffic pattern is influenced by many factors such as mobility, particular time, place etc., Therefore even with high accuracy rate traffic load prediction algorithms in mobile networks, a margin of error is still possible. To understand this behaviour we calculated the standard deviation in power consumption considering 5%, 10% and 15% error in prediction. A random(5%, 10% and 15%) error is added in the arrival rate for all traffic patterns and BS is simulated to observe effect on power consumption. Table 3 represents the standard deviation of power consumption for different traffic patterns due to a certain percentage error.

Table 3: Standard deviation in Power consumption of real Traffic traces

Error Percentage	Standard Deviation: Power consumption for sleep mode BS			
	Residential Weekday	Residential Weekend	Metropolitan Weekday	Metropolitan Weekend
5%	1.11	1.08	0.61	0.173
10%	1.4	2.64	1.11	0.25
15%	1.85	5.37	1.63	0.62

5.3.2 Reactivation Delays with standard and modified settings

In this section simulation results for reactivation delays considering traffic traces are described and analyzed. In each figure below, there is a reactivation delay using standard settings and another one with modified settings. For modified settings we consider a threshold on total power consumption according to which sleep duration in each mode is adjusted in manner that it does not increase power consumption by more than 1%. We find that under this strict constraint, still we are able to considerably reduce the delays. Also we mention the impact of error in prediction on reactivation delays if BS is working with modified parameter settings.

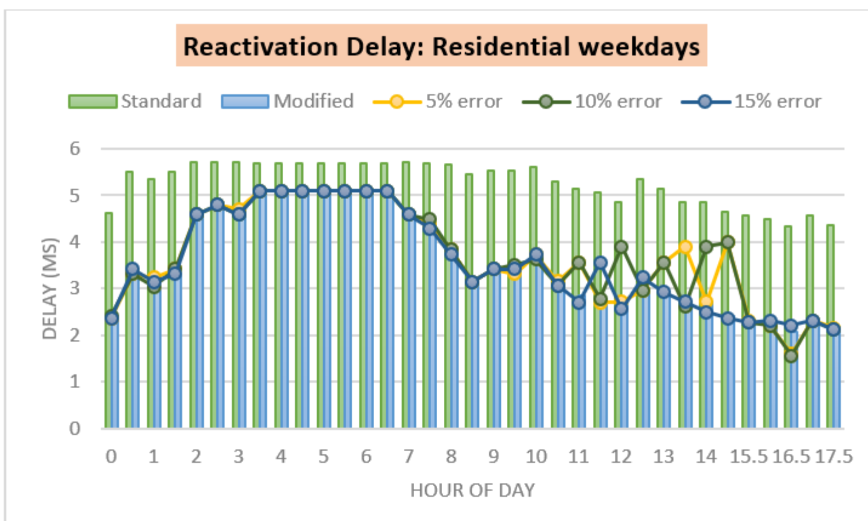

Figure 29: Residential Weekday: Trading off Latency with 1% increment in power consumption & Effect of error

In Fig 29, residential weekday traffic pattern is considered and reactivation delays are plotted according to simulation results. As mentioned before in previous section, we do not consider those hours in simulation where the traffic rate is above 0.5 per second. Green bars represents the reactivation delay with standard settings while the blue bars show the reduced reactivation delay due to modified parameter settings. We can observe that at different time of the day under varying traffic rate, the amount of reduction in delays is different. Overall under the strict constraint of maximum 1% increase in power consumption, we can increase the system performance by reducing delays. This could be very effective for 5G mobile communication.

In the same figure, impact on reactivation delay with error in prediction are shown by lines. 5%, 10% and 15% error is considered and we can clearly analyze that even with an error in traffic rate prediction, our reactivation delays are still less using the modified parameter settings with respect to standard settings.

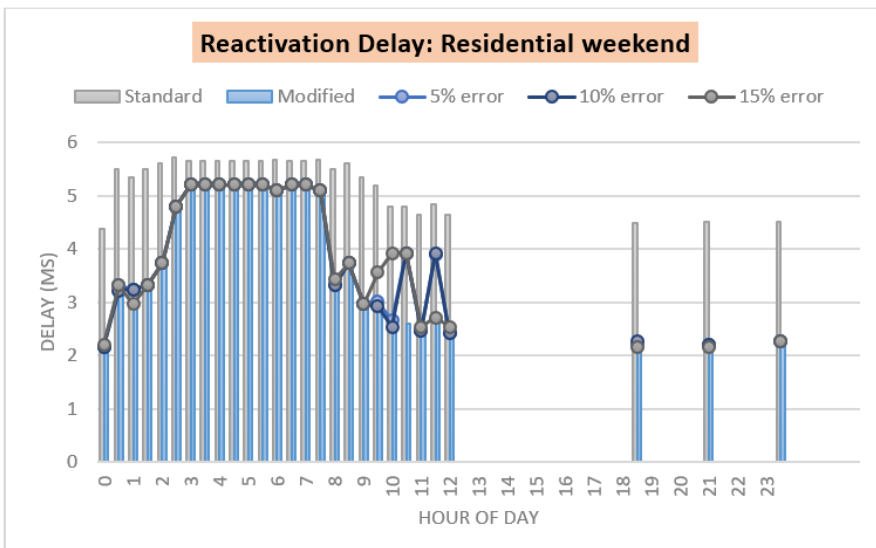

Figure 30: Residential Weekend: Trading off Latency with 1% increment in power consumption & Effect of error

Fig 30 shows the reactivation delay for residential weekends. Blank spaces between the plot are because of traffic rate more than 0.5(user/sec) and in this period BS remains active with full load active power consumption of 750W. Gray bars represent the delays with standard settings while the blue bars with modified parameters. It is observed that during hours 10 to 12, reactivation delays increase due to error in prediction, still it never crosses the value with standard settings. Therefore we can say under all conditions modified settings will reduce the reactivation time duration thereby reducing respective delays and even with an error in prediction modified settings give better performance in terms of reactivation delays.

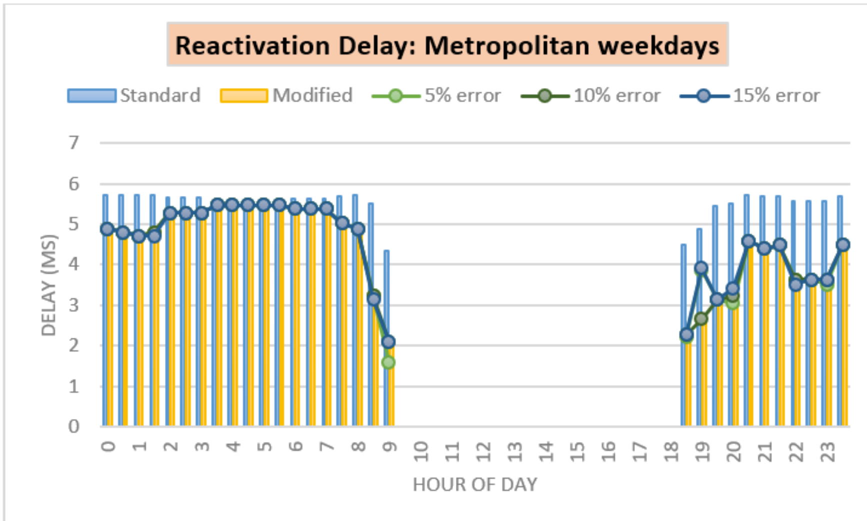

Figure 31: Metropolitan Weekday: Trading off Latency with 1% increment in power consumption & Effect of error

Per hour reactivation delays of metropolitan weekdays are shown in Fig 31. The results show that as we put the restriction of 1% maximum increment in power consumption using modified settings, therefore for very low arrival rates in hours 2 to 8 reactivation delays with modified settings are still high. This is because in low load periods BS goes to deeper sleep modes and reactivation delays from respective mode is higher.

In Fig 32 metropolitan weekend reactivation delays are shown. It is clear that as the traffic rate is low, therefore BS experience almost 5.7ms delay throughout the day with standard settings. However, with modified settings under the constraint, we are able to reduce these delays to about 12%. In this traffic pattern scenario, we can also analyze that as rate of arrival is low, therefore even 15% error in prediction does not effect much on BS performance.

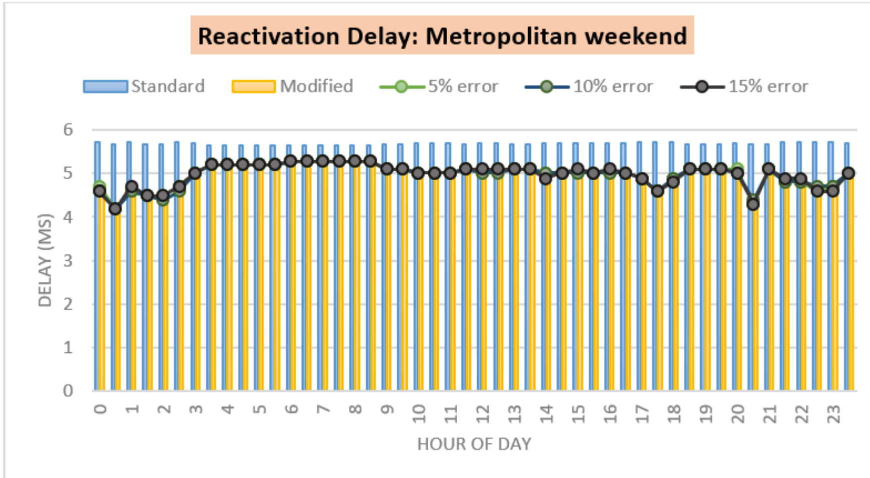

Figure 32: Metropolitan Weekend: Trading off Latency with 1% increment in power consumption & Effect of error

Table 4: Average Reactivation Delays for Traffic traces with standard and modified settings

Parameters	Average Reactivation Delays during BS in sleep mode			
	Residential Weekday	Residential Weekend	Metropolitan Weekday	Metropolitan Weekend
Standard	5.27	5.27	5.52	5.68
Modified	3.55	3.73	4.47	5.01
% decrease	32.68%	29.22%	19.02%	11.89%

Table 4 show the average reactivation delay for each traffic pattern and also present the amount of reduction we can achieve using the modified settings with respect to standard settings under the constraint on power consumption.

In this chapter we presented some useful simulation results that define a clear working of BS with SMs in a simulation environment. Many different scenarios are presented to give reader an insight of variables that are key performance metrics in BS operation such as power consumption, reactivation delays, load and average time spent by BS in each state with varying arrival rate. A trade-off analysis for each scenario is presented so to open the design possibilities and effective utilization of SMs for an energy efficient 5G mobile network within the performance level constraint.

6 Conclusion

Growing number of devices and increase in data rate requirement is leading mobile cellular networks towards deploying efficient technology such as 5G cellular communication. However this requires more energy resources which impact on infrastructure and network operation cost functions for Mobile Network Operators. Base stations consume most of the mobile network energy resources therefore a concept of Advanced Sleep Modes technique to minimize the usage of resources in low peak traffic hours in cellular networks is presented by [1]. In this thesis research, we investigated that using ASMs, reactivation delay adds into the system and may impact 5G delay constraint communication requirement. We therefore, developed a simulation environment to deeply analyze parameters that control these additional delay and suggest that through a proper adjustment in each sleep mode duration, we can trade-off reactivation delays with the overall BS power consumption. We simulated several scenarios including fixed signaling periodicity, massive IOTS and real mobile traffic traces and our results show that around 90% reduction in reactivation delay is possible with negligible impact on power consumption. We propose a strategy to chose each SM duration in such a way to reduce reactivation time while not losing more than a given amount of saving. Furthermore, these strategies should be made according to different performance requirements and use cases, to effectively utilize the network resources. With more delay constraint applications we can chose to increase SM2 duration to restrict BS going into deeper sleep mode thereby limiting the reactivation delays. While, with less delay sensitive applications, deeper sleep levels are more appropriate to achieve more in terms of energy saving.

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