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QoS-Aware and Energy-Efficient Network Design for Green Wireless Communication

Duda Sudhakar[1*], Dhiraj Sunehra[2]
[1]Research Scholar, JNTU Hyderabad, Hyderabad, Telangana, India. Email addresses: dsudhakar_ece@mgit.ac.in
[2]Professor, ECE, JNTUH University College of Engineering, Sircilla, Telangana, India.

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Abstract:

With the sharp rise in the number of devices and high data rate demand, the concepts of cell splitting and frequency reuse have become integral to cellular communication. However, these strategies increase the number of base stations, which in turn raises radiation levels and energy consumption. Consequently, green network design has become an important aspect of cellular communication. GREEN NETWORK stands for Globally Resource Optimized Energy Efficient Network; this research focuses on optimal resource allocation for creating an energy-efficient cellular network with improved performance. By switching-off some base stations during non-peak hours, significant energy efficiency can be achieved. We developed an adaptive base station switch-off algorithm that selects a low traffic, medium traffic, or high traffic switch-off method based on current traffic conditions. During low and medium traffic conditions, switching-off some of the existing base stations significantly saves power without affecting quality of service (QoS).

Keywords: Green Networks, Energy Optimization, Traffic Distribution, Adaptive Mobile Networks, QoS of Adaptive Networks.

1. Introduction

Due to technological advancements, mobile communication has become integral to our daily lives [1][2]. The number of mobile users and the demand for higher data rates are increasing rapidly [3][4]. To accommodate these growing numbers and demands, cell splitting and frequency reuse are promising solutions [5][6]. However, these methods lead to an increase in the number of base stations, which in turn raises energy consumption [6][7][8], contributes to global warming, and escalates CO2 emissions [5][9][10]. Additionally, to achieve higher bandwidth, 5G and 6G technologies are moving towards GHz frequency bands [11][12]. Higher frequency signals attenuate more than lower frequency signals, resulting in increased radiation power in a given area due to cell splitting and the shift to higher frequency bands [11][13]. This increased radiation power not only poses potential harm to human health but also raises operational expenditure (OPEX) [14]. Therefore, energy efficiency and green communication have become prominent demands in 5G and 6G communications [15][16].

Traffic conditions in the network are not constant; they vary with time and location [5]. During low traffic hours, switching-off some of the base stations in the network is a promising solution for enhancing energy efficiency and green communication network design [17][18][19]. We have developed and are proposing methods for switching-off base stations during low traffic hours. Traffic is modeled using a Poisson distribution, and based on the traffic conditions; one of the switch-off methods is selected. The various base station switch-off methods are explained in Section 3, and the results are presented and discussed in Section 4.

2. Objectives

W. Ur Rehman et al. examined a Heterogeneous Cellular Network (HCN) consisting of Macro Base Stations (MBSs) and Small Base Stations (SBSs), with each MBS surrounded by four SBSs. Some of these SBSs are powered by renewable energy sources like solar or wind power, while the remaining MBSs and SBSs rely on conventional on-grid power. During high traffic hours, all MBSs and SBSs are active. During low traffic hours, only the SBSs powered by conventional on-grid power are switched-off or put into sleep mode to conserve energy. In this work, only SBSs powered by conventional on-grid power are considered for switching-off [6].

M. Feng et al. developed a base station switch-off algorithm for a two-tier massive MIMO network. This network includes macro base stations (MBSs) and small base stations (SBSs), with each MBS supporting multiple SBSs. MBSs are always kept in the ON state, while SBSs are switched ON or-off depending on traffic conditions [5].

F. H. Panahi et al. proposed a two-tier (femto-macro) HetNet. This network comprises macro base stations and femto base stations, with each macro base station potentially containing several femto base stations. Based on traffic conditions, some macro and femto base stations are switched on or off. Since femto base stations have limited coverage, switching-off those results in minimal power savings, whereas switching-off macro base stations can significantly affect coverage area [9].

P. H. Huang et al. developed a base station switch-off method for a network with an arbitrary deployment of base stations. During high traffic conditions, all base stations remain active, whereas during low traffic conditions, a base station is switched-off, and its coverage area is managed by adjacent base stations using a cell zooming concept. This network structure may be more suitable for rural areas and less effective in urban areas with a high density of base stations [20].

In this work, we have developed methods for switching-off base stations during low traffic hours. To select which base stations to switch-off and to manage the traffic of the switched-off base stations, we followed specific criteria to ensure the quality of service (QoS) for the mobile devices connected to these base stations.

3. Methods

To minimize energy consumption during low traffic hours, we propose an adaptive base station switch-off algorithm. In this algorithm, based on the traffic conditions, one of several base station switch-off methods is selected, and some of the existing base stations are turned-off. To implement these methods, we consider a cluster of 49 base stations arranged in a row and column configuration, as illustrated in matrix equation (1). The bolded base stations are referred to as inner matrix base stations, and all of these inner matrix base stations have adjacent base stations in all directions.

$$\text{BSs}=\begin{bmatrix} BS01 & BS02 & BS03 & BS04 & BS05 & BS06 & BS07 \\ BS08 & \boldsymbol{BS09} & \boldsymbol{BS10} & \boldsymbol{BS11} & \boldsymbol{BS12} & \boldsymbol{BS13} & BS14 \\ BS15 & \boldsymbol{BS16} & \boldsymbol{BS17} & \boldsymbol{BS18} & \boldsymbol{BS19} & \boldsymbol{BS20} & BS21 \\ BS22 & \boldsymbol{BS23} & \boldsymbol{BS24} & \boldsymbol{BS25} & \boldsymbol{BS26} & \boldsymbol{BS27} & BS28 \\ BS29 & \boldsymbol{BS30} & \boldsymbol{BS31} & \boldsymbol{BS32} & \boldsymbol{BS33} & \boldsymbol{BS34} & BS35 \\ BS36 & \boldsymbol{BS37} & \boldsymbol{BS38} & \boldsymbol{BS39} & \boldsymbol{BS40} & \boldsymbol{BS41} & BS42 \\ BS43 & BS44 & BS45 & BS46 & BS47 & BS48 & BS49 \end{bmatrix} \ldots (1)$$

Based on network traffic, the algorithm selects one of three switching methods—low traffic, static, or dynamic—whichever is capable of switching-off the greatest number of base stations. To illustrate this method, we generate an example traffic distribution matrix for base stations (BSs) and mobile devices (MDs), as shown in Equations (2), (3), and (4). These matrices indicate the number of MDs connected to each BS at a particular instant of time. For each BS, the number of MDs connected or communicating at a given instant is randomly generated using the 'rand' function (Equations (2), (3), and (4)). Based on the traffic conditions in the network, the traffic distribution is categorized into three cases: **Case 1**: Low Traffic Distribution, **Case 2**: Medium Traffic Distribution, and **Case 3**: High Traffic Distribution. These cases are represented in Equations (2), (3), and (4).

Case 1: Low Traffic Distribution

$$\text{BSsMDs}=\begin{bmatrix} 3 & 2 & 3 & 11 & 0 & 3 & 2 \\ 5 & 6 & 9 & 4 & 8 & 1 & 3 \\ 9 & 6 & 4 & 5 & 1 & 6 & 8 \\ 5 & 9 & 5 & 1 & 11 & 6 & 3 \\ 0 & 6 & 3 & 2 & 7 & 11 & 3 \\ 10 & 6 & 6 & 2 & 11 & 4 & 0 \\ 6 & 3 & 0 & 4 & 10 & 5 & 1 \end{bmatrix} \ldots (2)$$

Case 2: Medium Traffic Distribution

$$\text{BSsMDs}=\begin{bmatrix} 104 & 53 & 39 & 51 & 10 & 95 & 92 \\ 49 & 58 & 2 & 39 & 52 & 23 & 87 \\ 49 & 57 & 120 & 100 & 101 & 110 & 32 \\ 1 & 105 & 56 & 104 & 98 & 105 & 101 \\ 63 & 109 & 106 & 63 & 1 & 74 & 56 \\ 64 & 5 & 90 & 36 & 40 & 76 & 53 \\ 4 & 97 & 102 & 104 & 40 & 89 & 73 \end{bmatrix} \ldots (3)$$

Case 3: High Traffic Distribution

$$\text{BSsMDs}=\begin{bmatrix} 124 & 148 & 122 & 145 & 133 & 109 & 113 \\ 129 & 117 & 125 & 134 & 129 & 136 & 127 \\ 123 & 132 & 130 & 144 & 124 & 149 & 148 \\ 109 & 115 & 132 & 146 & 121 & 137 & 136 \\ 139 & 126 & 128 & 142 & 107 & 103 & 125 \\ 149 & 117 & 122 & 140 & 145 & 126 & 117 \\ 136 & 123 & 134 & 149 & 137 & 114 & 131 \end{bmatrix} \ldots (4)$$

3.1 Switch-off Methodology for Low Traffic Distribution (i.e. for Case 1)

In this case, the traffic distribution in the network is very low, as shown in Equation (2). If the combined traffic of all nine adjacent base stations is less than 150, then, according to Equation (1), the base stations BS9, BS11, BS13, BS23, BS25, BS27, BS37, BS39, and BS4 are kept in active state and remaining base stations are switched-off. The power levels of active base stations are doubled

If the power received by the mobile devices (MDs) of switching-off base stations from adjacent active base stations exceeds the threshold value, then all mobile devices (MDs) of the switching-off base stations are reallocated to the adjacent active base stations, as shown in Equation (6).

$$\text{Switch ON BSs}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{1} & 0 & \mathbf{1} & 0 & \mathbf{1} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{1} & 0 & \mathbf{1} & 0 & \mathbf{1} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{1} & 0 & \mathbf{1} & 0 & \mathbf{1} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(5)$$

$$\text{BSsMDs after switch-off}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{47} & 0 & \mathbf{29} & 0 & \mathbf{23} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{28} & 0 & \mathbf{21} & 0 & \mathbf{23} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{31} & 0 & \mathbf{27} & 0 & \mathbf{10} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(6)$$

3.2 Switch-off Methodology for Medium Traffic Distribution (i.e., Case-2)

If the traffic of a base station is below a threshold (i.e., less than 70) and the sum of the traffic for the cluster of 9-base stations exceeds 150, the algorithm employs Case-2. The steps involved in this case are explained below:

STEP-I: Criteria for Selecting a Base Station to Switch-off

Adjacent base stations are referred to as cooperative base stations. For example, as shown in Figure.1, the cooperative base stations for BS5 include BS1, BS2, BS3, BS4, BS6, BS7, BS8, and BS9.

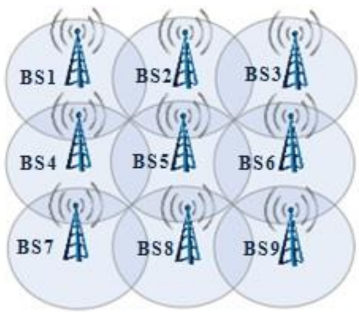

Fig. 1:BS5 Cooperative base stations

A base station can be selected for switching-off only if it has adjacent cooperative base stations and its traffic is below the threshold (i.e., the number of mobile devices connected to the base station).

In our algorithm, a base station is considered for switching-off if the number of mobile devices connected to it is below the threshold value and it has adjacent cooperative base stations. For our simulation, the threshold for the number of mobile devices is set to 70.

STEP-II: Procedure to Generate the Possible Switch-off Base Stations Matrix

$$\text{BSsMDs}=\begin{bmatrix} 104 & 53 & 39 & 51 & 10 & 95 & 92 \\ 49 & \mathbf{58} & \mathbf{2} & \mathbf{39} & \mathbf{52} & \mathbf{23} & 87 \\ 49 & \mathbf{57} & 120 & 100 & 101 & 110 & 32 \\ 1 & 105 & \mathbf{56} & 104 & 98 & 105 & 101 \\ 63 & 109 & 106 & \mathbf{63} & \mathbf{1} & 74 & 56 \\ 64 & \mathbf{5} & 90 & \mathbf{36} & \mathbf{40} & 76 & 53 \\ 4 & 97 & 102 & 104 & 40 & 89 & 73 \end{bmatrix} \ldots(7)$$

In the BSsMDs inner matrix, if the number of mobile devices connected to a base station falls below the threshold value of 70 MDs, the base station is considered for switching-off. The algorithm verifies all base stations in the BSsMDs inner matrix, ensuring that each has cooperative base stations, and generates a possible switch-off matrix. From the BSsMDs inner matrix shown in Equation (7), the current traffic for base stations BS09, BS10, BS11, BS12, BS13, BS16, BS24, BS32, BS33, BS37, BS39, and BS40 is below the threshold of 70 MDs. Based on Equation (7), the possible switch-off matrix is presented in Equation (8).

$$\text{Possible Switch-off BSs}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & 0 \\ 0 & \mathbf{1} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \mathbf{1} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \mathbf{1} & \mathbf{1} & 0 & 0 \\ 0 & \mathbf{1} & 0 & \mathbf{1} & \mathbf{1} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(8)$$

STEP-III: Static Switch-off Base Stations Matrix Generation

Using the 'Possible Switch-off BSs' matrix, the algorithm generates the 'Static Switch-off BSs' matrix. In the 'Static Switch-off BSs' matrix, an element marked as '1' indicates a base station selected for static switch-off, and this method is referred to as the "Static Switch-off Method."

To identify base stations for static switch-off, the algorithm scans the 'Possible Switch-off BSs' matrix from the beginning. Whenever it encounters a '1' (indicating a potential switch-off base station), it designates this base station as a static switch-off base station. Subsequently, all adjacent base stations are removed from consideration by setting all adjacent elements of the chosen base station to '0' in the 'Possible Switch-off BSs' matrix. The algorithm continues this process until all elements in the 'Possible Switch-off BSs' matrix are examined. It then generates the 'Static Switch-off BSs' matrix. Using matrix Equation (8), the generated 'Static Switch-off BSs' matrix is shown in Equation (9).

$$\text{Static Switch-off BSs}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{1} & 0 & \mathbf{1} & 0 & \mathbf{1} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \mathbf{1} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \mathbf{1} & 0 & 0 \\ 0 & \mathbf{1} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(9)$$

STEP-IV: Dynamic Switch-off Base Stations Matrix Generation

From the 'Possible Switch-off BSs' matrix, the algorithm identifies the base station with the lowest traffic and selects it for dynamic switch-off. All adjacent base stations are then excluded from consideration by setting their corresponding elements to '0' in the 'Possible Switch-off BSs' matrix.

The algorithm repeats this process, continuously identifying and selecting base stations with the lowest traffic for dynamic switch-off and updating the 'Dynamic Switch-off BSs' matrix accordingly. In the 'Dynamic Switch-off BSs' matrix, an element marked as '1' denotes a base station selected for dynamic switch-off. This method is referred to as the 'Dynamic Switch-off Method. Using matrix Equation (8), the generated 'Dynamic Switch-off BSs' matrix is shown in Equation (10).

$$\text{Dynamic Switch-off BSs}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \mathbf{1} & 0 & 0 & \mathbf{1} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \mathbf{1} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \mathbf{1} & 0 & 0 \\ 0 & \mathbf{1} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(10)$$

If base stations are switched-off using the ‘Dynamic Switch-off BSs’ matrix, fewer mobile devices will need to be handed over during the process. This is because the matrix prioritizes base stations with lower traffic for switch-off, reducing the impact on mobile devices.

STEP-V: Procedure for Handover of Mobile Devices from Switched-off Base Stations to Adjacent BSs

In the ‘Static or Dynamic Switch-off BSs’ matrix, an element marked as '1' indicates that the corresponding base station has fewer mobile devices (MDs) than the threshold value and can be switched-off. The MDs from these base stations are then handed over to adjacent base stations.

When allocating mobile devices from a deactivated base station to adjacent active base stations, the following factors are considered:

1. The received power (Pr_max) from neighbouring base stations.
2. The current number of MDs connected to these neighbouring base stations.

The received power (Pr) of an MD with respect to neighbouring base stations is calculated as shown in Equation (11).

$$\mathrm{Pr(m)} = \mathrm{e(i)} * \mathrm{Pt(i)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

The attenuation factor (e) is randomly generated to range from -∞ to -53 dBm and depends on various factors such as the distance between the base station (BS) and the mobile device (MD), environmental conditions, and obstacles like buildings and trees. As the distance between the mobile device (MD) and the base station increases, the signal path loss or attenuation also increases. The algorithm calculates the received power Pr(m) from all adjacent base stations and selects the base station that provides the maximum received power, denoted as Pr_max. Here, Pr(m) represents the received power of the m-th mobile device from the i-th cooperative base station, while Pt(i) and e(i) are the transmitted power and attenuation factor of the i-th base station, respectively. As distance increases, attenuation also increases, causing the mobile device (MD) to receive maximum transmitted power from a base station when it is closer to the base station. Conversely, if the MD is very far from the base station, it cannot receive significant power. The attenuation factors e are randomly generated between -∞ and -53 dBm.

When allocating switching-off base station MDs to cooperative base stations, the algorithm considers an upper limit, referred to as the maximum allocating limit (MAL), which is set to 100. This limit denotes the maximum number of MDs that can be allocated to a cooperative base station. The algorithm ensures that the workload of adjacent base stations does not exceed this MAL. Depending on the network operating area and traffic distribution, an appropriate value for MAL must be assigned. Without this criterion, all MDs from switching-off base stations might be allocated to a single base station, potentially causing that base station to be unable to serve new requests from its own MDs due to the maximum service MD limit. In this study, the maximum service MD limit is set to 150 for each base station. If both conditions are met (i.e., the maximum received power from neighboring base stations and the allocation limit MAL), the MDs from the switched-off base stations are allocated, and the modified load is calculated using Equation (12).

$$\left.\begin{aligned} MDs\ of\ BS(r,c) = MDs\ of\ BS(r,c) + 1 \\ MDs\ of\ BS(p,q) = MDs\ of\ BS(p,q) - 1 \end{aligned}\right\}$$

$$if\ MDs\ of\ BS(r,c) < \mathrm{BS.MaxAllocatLim}\ \&\&\ \mathrm{Pr}\ \_max > Pr\_th \ldots (12)$$

Where BS(r,c) is the neighboring BS, BS(p,q) is the BS being switched-off, r, p = row, c, q = column and Pr_threshold power chosen as -50 dBm.

This procedure is repeated until all MDs from the selected switched-off base stations are handed over and all switched-off base stations in the Switch-off BSs matrix are processed.

STEP-VI: Cell Zooming

If any mobile devices (MDs) from switching-off base stations cannot be handed over due to insufficient received signal power, the power levels of neighboring (cooperative) base stations can be increased to expand their coverage area. This technique is known as "cell zooming."

If any MDs are not allocated due to insufficient received signal strength from the neighboring base stations, the power levels of the relevant adjacent base stations are increased i.e. doubled. The remaining (unallocated) MDs from the switched-off base stations are then allocated to these base stations.

STEP-VII: Procedure to Calculate Power Consumed by the Network

The power consumed by the network is determined using the following equation (13):

$$P_{\_consumption} = \eta * Pt + Pc + LPl \dots\dots\dots (13)$$

where $P_{consumption}$ is the total power consumed by the network, η is the transmission power efficiency, Pt is the base station (BS) transmission signal power, Pc is the constant operational power, L is the number of radio links in the network (which is equal to the number of mobile devices, with each device allocated one radio link), and Pl is the radio link serving power.

In this context:

- η*Pt and Pc represent constant power components.
- L·Pl represents the variable power component, as the number of radio links (or mobile devices) is dynamic and changes with time and location.

TABLE I. SIMULATION PARAMETERS

S.No.	Parameter	Value
1.	Constant operational power (Pc)	130W
2.	Transmission power efficiency (η)	0.32
3.	BS transmission signal power (Pt)	46 dBm / 39.8 W
4.	Radio link serving power (Pl)	250mW
5.	Pr threshold	-50dBm / 0.00001mW
6.	Cooperative BS Maximum Allocating Limit	100 MDs
7.	MDs limit to switch-off BSs in low traffic distribution	150
8.	Lower limit to switch-off a BS	70 MDs
9.	Maximum MDs Limit in each BS	150 MDs

3.3 Methodology for Case 3: High Traffic Distribution

$$\text{BSsMDs}=\begin{bmatrix} 124 & 148 & 122 & 145 & 133 & 109 & 113 \\ 129 & 117 & 125 & 134 & 129 & 136 & 127 \\ 123 & 132 & 130 & 144 & 124 & 149 & 148 \\ 109 & 115 & 132 & 146 & 121 & 137 & 136 \\ 139 & 126 & 128 & 142 & 107 & 103 & 125 \\ 149 & 117 & 122 & 140 & 145 & 126 & 117 \\ 136 & 123 & 134 & 149 & 137 & 114 & 131 \end{bmatrix} \dots(5)$$

In this case, the traffic distribution in the network is high, with each base station handling traffic levels exceeding the threshold value of 70. As a result, no base stations are switched-off, and no handovers occur due to base station shutdowns. All base stations remain in an active state.

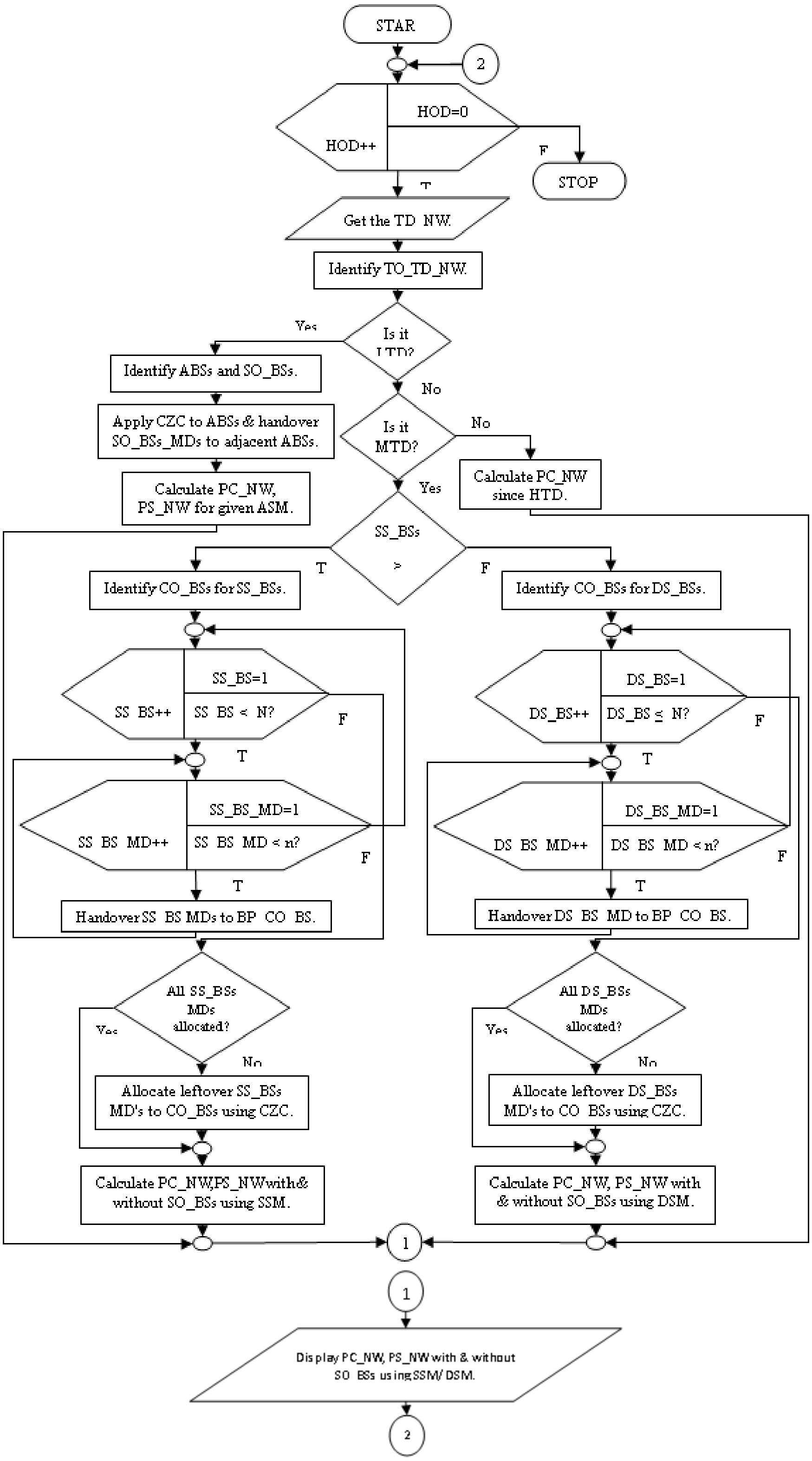

Fig2: Adaptive Base Station Switch-off Algorithm flow chart.

HOD: Hour of the Day;

TO_TD_NW: Type of Traffic Distribution in the Network;

LTD: Low Traffic Distribution;

MTD: Medium Traffic Distribution; HTD:High Traffic Distribution;

HTD: High Traffic Distribution;

ABS: Active Base Stations;

DSM: Dynamic Switch_-off Method;

SSM: Static Switch_-off Method;

PS_BS: Possible Switch_-off Base Station;

SS_BS: Static Switch_-off Base Station;

DS_BS: Dynamic Switch_-off Base Station;

TD_NW: Traffic Distribution in the Network;

CO_BS: Co-Operative Base Station;

SO_BS: Switch_-off Base Station;

CZC: Cell Zooming Concept;

PC_NW: Power Consumed in the Network;

PS_NW: Power Saved in the Network;

BP_CO_BS: Best Possible CO_Operative Base station;

SS_BS_MD: Static Switch_-off Base Station Mobile Device;

SO_BSs_MDs:Switch_-off Base Stations_Mobile Devices;

3.4 Steps in the Adaptive Switch-off Method:

1. The algorithm generates the BSs-MDs network traffic distribution matrix, as shown in matrix equations (2, 3, and 4).
2. If the traffic distribution in the network is low, as described in CASE-1, the algorithm allocates traffic to the adjacent active base stations BS9, BS11, BS13, BS23, BS25, BS27, BS37, BS39, and BS41, as detailed in “Methodology for Case-1.”
3. If the traffic distribution in the network is medium, as described in CASE-2, the algorithm follows the steps outlined in “Methodology for Case-2” and allocates the network traffic distribution accordingly.

3.1 Using the methodology described in CASE-2, STEPs I and II, the algorithm generates the ‘Possible Switch-off BSs’ matrix, as shown in matrix equation (8).

3.2 From the ‘Possible Switch-off BSs’ matrix, STEPs III and IV generate the ‘Static Switch-off BSs’ and ‘Dynamic Switch-off BSs’ matrices, respectively, as shown in matrix equations (9) and (10).

3.3 The algorithm then compares the ‘Static Switch-off BSs’ and ‘Dynamic Switch-off BSs’ matrices:

3.4 If the number of switching-off base stations in the ‘Static Switch-off BSs’ matrix is greater than in the ‘Dynamic Switch-off BSs’ matrix, the ‘Static Switch-off BSs’ matrix is chosen for switching-off the base stations.

3.5 If the number of base stations in the ‘Static Switch-off BSs’ matrix is fewer than in the ‘Dynamic Switch-off BSs’ matrix or number of base stations in both matrices is equal, the ‘Dynamic Switch-off BSs’ matrix is selected as it typically results in fewer mobile handovers.

3.6 Mobile devices from the chosen ‘Static Switch-off BSs’ or ‘Dynamic Switch-off BSs’ matrix are handed over (reallocated) to adjacent (cooperative) base stations, as described in STEP-V.

3.7 If mobile devices cannot be handed over due to insufficient signal strength, the cell zooming concept is used to transfer these devices to adjacent base stations with increased power levels, as explained in STEP-VI. If, after applying the cell zooming concept, some mobile devices are still not successfully allocated due to low signal strength, small cells, such as Femto Base Stations, are employed to service the remaining devices.

3.8 After the handover process, using STEP-VII and Table I, the algorithm calculates the power consumed by the network with and without base station switch-offs, displays the generated matrices, and presents the results.

4. If all base stations have traffic exceeding the threshold value of 70 as described in CASE-3, none of the base stations are switched-off, and no handovers occur due to base station shutdowns. All base stations remain active.

4. Results and Discussion

4.1 Results and Discussion for Low Traffic Distribution (Case 1)

In this case, the traffic distribution in the network is very low, as illustrated in equation (14) below.

$$\text{BSsMDs}=\begin{bmatrix} 3 & 2 & 3 & 11 & 0 & 3 & 2 \\ 5 & \mathbf{6} & 9 & \mathbf{4} & 8 & \mathbf{1} & 3 \\ 9 & 6 & 4 & 5 & 1 & 6 & 8 \\ 5 & \mathbf{9} & 5 & \mathbf{1} & 11 & \mathbf{6} & 3 \\ 0 & 6 & 3 & 2 & 7 & 11 & 3 \\ 10 & \mathbf{6} & 6 & \mathbf{2} & 11 & \mathbf{4} & 0 \\ 6 & 3 & 0 & 4 & 10 & 5 & 1 \end{bmatrix} \ldots(14)$$

When the traffic distribution in the network is very low, only a few base stations (in this case, 9 out of a total number) are switched on, while the others are switched-off. To cover the switched-off base stations, the power levels of the switched-on (active) base stations are increased. The matrix equation (15) illustrates the status of the base stations, where a ‘1’ in the 'Switch ON BSs' matrix indicates a switched-on base station and a ‘0’ indicates a switched-off base station. The power levels of the switched-on base stations (BS9, BS11, BS13, BS23, BS25, BS27, BS37, BS39, and BS41) are doubled, and the traffic from adjacent switched-off base stations is allocated to these switched-on base stations, as shown in equation (16).

$$\text{Switch ON BSs}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{1} & 0 & \mathbf{1} & 0 & \mathbf{1} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{1} & 0 & \mathbf{1} & 0 & \mathbf{1} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{1} & 0 & \mathbf{1} & 0 & \mathbf{1} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(15)$$

$$\text{BSsMDs after switch-off}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{47} & 0 & \mathbf{29} & 0 & \mathbf{23} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{28} & 0 & \mathbf{21} & 0 & \mathbf{23} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{31} & 0 & \mathbf{27} & 0 & \mathbf{10} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(16)$$

4.2 Results and Discussion for Medium Traffic Distribution (i.e., CASE-2)

When the traffic distribution is medium, some base stations where the number of mobile devices is less than the threshold value of 70 are switched-off. The traffic from these switched-off base stations is allocated to adjacent base stations. According to equation (17), the BSsMDs inner matrix shows that the current traffic associated with base stations BS09, BS10, BS11, BS12, BS13, BS16, BS24, BS32, BS33, BS37, BS39, and BS40 is below the threshold value of 70 mobile devices. Using the BSsMDs matrix from equation (17), the algorithm generates a possible switch-off matrix, which is shown in matrix equation (18).

$$\text{BSsMDs}=\begin{bmatrix} 104 & 53 & 39 & 51 & 10 & 95 & 92 \\ 49 & \mathbf{58} & \mathbf{2} & \mathbf{39} & \mathbf{52} & \mathbf{23} & 87 \\ 49 & \mathbf{57} & 120 & 100 & 101 & 110 & 32 \\ 1 & 105 & \mathbf{56} & 104 & 98 & 105 & 101 \\ 63 & 109 & 106 & \mathbf{63} & \mathbf{1} & 74 & 56 \\ 64 & \mathbf{5} & 90 & \mathbf{36} & \mathbf{40} & 76 & 53 \\ 4 & 97 & 102 & 104 & 40 & 89 & 73 \end{bmatrix} \ldots(17)$$

$$\text{Possible Switch-off BSs}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & 0 \\ 0 & \mathbf{1} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \mathbf{1} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \mathbf{1} & \mathbf{1} & 0 & 0 \\ 0 & \mathbf{1} & 0 & \mathbf{1} & \mathbf{1} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(18)$$

Using the Possible Switch-off Matrix from equation (18) and applying Steps III and IV of the "Medium Traffic Distribution Methodology," the generated static switch-off matrix and dynamic switch-off matrix are shown in equations (19) and (20), respectively.

$$\text{Static Switch-off BSs}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(19)$$

$$\text{Dynamic Switch-off BSs}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(20)$$

For the given traffic condition as shown in equation (17), the algorithm is able to switch-off 6 base stations using the static switch-off method and 5 base stations using the dynamic switch-off method. To save more power under the given traffic conditions, the algorithm selects the static switch-off method. Using "Medium Traffic Distribution Methodology Step-V," the mobile devices from the switched-off base stations are handed over to cooperative/adjacent base stations.The cooperative base stations for BS9 and for all 6 static switch-off base stations are shown in matrix equations (21) and (22), respectively.

$$\text{COP BSs for Static Switch-off base station\_1}=\begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(21)$$

$$\text{COP\_SET for Static Switch-off base stations} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 2 & 1 & 3 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 4 & 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 5 & 1 & 0 \\ 1 & 6 & 1 & 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(22)$$

Matrix equation (23) shows the traffic reallocation from the first switched-off base station (BS9) to neighboring base stations. The cooperative base stations for BS9 are BS1, BS2, BS3, BS8, BS10, BS15, BS16, and BS17, with current associated traffic levels of 104, 53, 39, 49, 2, 49, 57, and 120, respectively. Base stations BS1 and BS17 already have traffic exceeding the Maximum Allocation Limit (MAL = 100), so no mobile devices are allocated to these two base stations.

Out of the 58 mobile devices from the switched-off base station BS9, based on received signal strength and the available capacity, 6, 12, 7, 12, 10, and 11 mobile devices are reallocated to the cooperative base stations BS2, BS3, BS8, BS10, BS15, and BS16, respectively.

$$\text{Switch-off base station1 MDs allocation to adjacent BSs}=\begin{bmatrix} 0 & \mathbf{6} & \mathbf{12} & 0 & 0 & 0 & 0 \\ \mathbf{7} & \mathbf{58} & \mathbf{12} & 0 & 0 & 0 & 0 \\ \mathbf{10} & \mathbf{11} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(23)$$

Similarly, for the remaining 5 switched-off base stations along with BS9, the handover/allocation of mobile devices before cell zooming is shown in Matrix equation (24). With the exception of the 4th switched-off base station (BS24), traffic and mobile devices from all other switched-off base stations are successfully handed over to their adjacent/cooperative base stations.

Before applying cell zooming, out of 56 mobile devices from BS24, 54 are allocated to cooperative base stations. Due to the Maximum Allocation Limit (MAL = 100) and the received signal strength, the 3rd and 32nd mobile devices from BS24 are not allocated to any of its adjacent base stations. The attenuation factors for cooperative base stations relevant to these mobile devices are detailed in equations (24) and (25) to calculate the receiving power for the 3rd and 32nd mobile devices from BS24.

Base station BS24's cooperative base stations are BS16, BS17, BS18, BS23, BS25, BS30, BS31, and BS32, with their associated traffic levels being 57, 120, 100, 105, 104, 109, 106, and 63, respectively. Base stations BS17, BS18, BS23, BS25, BS30, and BS31 have traffic levels exceeding the maximum allocation limit. According to matrix equations (24) and (25), the attenuation factors for BS16 and BS32 are very low, resulting in low received signal strength for the 3rd and 32nd mobile devices from BS24. Consequently, these mobile devices cannot be allocated to these cooperative base stations.

However, since BS16 and BS32 have traffic levels below the maximum allocation limit, the power levels of these base stations can be increased using cell zooming. This allows the unallocated mobile devices from BS24, specifically the 3rd and 32nd devices, to be allocated to BS32 and BS16, respectively, as shown in matrix equation (27).

$$\text{Allocation\_MatrixWithoutZooming}=\begin{bmatrix} 0 & \mathbf{6} & \mathbf{10} & \mathbf{5} & \mathbf{17} & \mathbf{5} & \mathbf{5} \\ \mathbf{7} & \mathbf{58} & \mathbf{18} & \mathbf{39} & \mathbf{12} & \mathbf{23} & \mathbf{3} \\ \mathbf{10} & \mathbf{39} & 0 & 0 & 0 & 0 & \mathbf{2} \\ 0 & 0 & \mathbf{54} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \mathbf{26} & \mathbf{1} & \mathbf{1} & 0 \\ \mathbf{4} & \mathbf{5} & \mathbf{2} & 0 & 0 & 0 & 0 \\ \mathbf{1} & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(24)$$

Switching-off BS4 3^{rd} MD Attenuation factor (e)

$$=1.0e\text{-}08 * \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{0.002} & \mathbf{0.235} & \mathbf{0.285} & 0 & 0 & 0 \\ 0 & \mathbf{0.255} & 0 & \mathbf{0.225} & 0 & 0 & 0 \\ 0 & \mathbf{0.105} & \mathbf{0.080} & \mathbf{0.045} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(25)$$

Switching-off BS4 32nd MD Attenuation factor (e)

$$=1.0e\text{-}08 * \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{0.055} & \mathbf{0.26} & \mathbf{0.105} & 0 & 0 & 0 \\ 0 & \mathbf{0.005} & 0 & \mathbf{0.03} & 0 & 0 & 0 \\ 0 & \mathbf{0.335} & \mathbf{0.285} & \mathbf{0.065} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(26)$$

$$\text{Allocation\_MatrixWithZooming}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{1} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \mathbf{2} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \mathbf{1} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \ldots(27)$$

Matrix equations (28) and (29) illustrate the traffic distribution in the network both before and after the application of the cell zooming concept.

$$\text{BSsMDs\_Post\_AllocationBeforeZooming}=\begin{bmatrix} 104 & 59 & 58 & 56 & 27 & 100 & 97 \\ 56 & \mathbf{0} & 20 & \mathbf{0} & 64 & \mathbf{0} & 90 \\ 59 & \mathbf{96} & 120 & 100 & 101 & 110 & 34 \\ 1 & 105 & \mathbf{2} & 104 & 98 & 105 & 101 \\ 63 & 109 & 106 & \mathbf{89} & \mathbf{0} & 75 & 56 \\ 66 & \mathbf{0} & 92 & 36 & 40 & 76 & 53 \\ 5 & 97 & 102 & 104 & 40 & 89 & 73 \end{bmatrix} \ldots(28)$$

$$\text{BSsMDs\_Post\_AllocationAfterZooming}=\begin{bmatrix} 104 & 59 & 58 & 56 & 27 & 100 & 97 \\ 56 & \mathbf{0} & 20 & \mathbf{0} & 64 & \mathbf{0} & 90 \\ 59 & \mathbf{97} & 120 & 100 & 101 & 110 & 34 \\ 1 & 105 & \mathbf{0} & 104 & 98 & 105 & 101 \\ 63 & 109 & 106 & \mathbf{90} & \mathbf{0} & 75 & 56 \\ 66 & \mathbf{0} & 92 & 36 & 40 & 76 & 53 \\ 5 & 97 & 102 & 104 & 40 & 89 & 73 \end{bmatrix} \ldots(29)$$

4.3 Results and Discussion for Case-3: High Traffic Distribution

$$BSsMDs=\begin{bmatrix} 124 & 148 & 122 & 145 & 133 & 109 & 113 \\ 129 & 117 & 125 & 134 & 129 & 136 & 127 \\ 123 & 132 & 130 & 144 & 124 & 149 & 148 \\ 109 & 115 & 132 & 146 & 121 & 137 & 136 \\ 139 & 126 & 128 & 142 & 107 & 103 & 125 \\ 149 & 117 & 122 & 140 & 145 & 126 & 117 \\ 136 & 123 & 134 & 149 & 137 & 114 & 131 \end{bmatrix} \ldots(30)$$

In this case, the traffic distribution in the network is high, so none of the base stations are switched-off. Consequently, there is no need for handover due to base station switch-off. All base stations remain in an active state.

Table II. Simulation results

S.No.	**Parameter**	**Case-I** (Low Traffic Distribution)	**Case-II** (Medium Traffic Distribution)	**Case-III** (High Traffic Distribution)
	Number of BSs in network.	49	49	49
1.	Number of MDs in network.	239	3238	6347
2.	Possible switch-off BSs.	40	12	0
3.	Switch-off Base Stations	40	6	0
4.	Handover Mobile Devices (MDs)	200	182	0
5.	Left over MDs before cell zooming.	-	2	0-(No BS is Switched-off)
6.	Handover MDs with cell zooming	200	2	0-(No BS is Switched-off)
7.	Power consumed by the network without switch-off BSs.	7.054 KW	7.804KW	8.581KW
8.	Power consumed by the network with Adaptive Switch-off BSs.	1.459KW	6.973KW	8.581KW
9.	Power saved by the network with switch-off BSs.	5.595KW	831W	0 KW (No BS is Switched-off)

Table II shows the simulation results for all three cases: Low, Medium, and High Traffic Distribution.

CASE-1: In this case, the traffic distribution in the network is very low, with a total of 239 mobile devices and very low traffic at each base station, as shown in equation (14). To cover the entire network area, the power levels of only 9 base stations are increased, while 40 base stations are switched-off. The 200 mobile devices from the switched-off base stations are handed over to adjacent 'Switched ON' base stations, as detailed in equation (16). After switching-off 40 base stations, the power consumed by the network is reduced to 1.459 kW, resulting in a power saving of 5.595 kW.

CASE-2: In this case, the traffic distribution is medium, with a total of 3,238 mobile devices in the network, as shown in equation (17). Using the static switch-off method, 6 base stations with traffic less than 70 mobile devices are switched-off. The 182 mobile devices from these 6 switched-off base stations are handed over to cooperative base stations. After switching-off these 6 base stations, the power consumed by the network is reduced to 6.973 kW, achieving a power saving of 831 W.

CASE-3: In this case, the traffic in the network is very high, with traffic at each base station exceeding 70, as shown in equation (30). Consequently, no base stations are switched-off. All base stations remain active, resulting in no power savings from switching-off base stations.

4.4 Traffic generation using 'Poisson Distribution':

In real-world scenarios, traffic distribution in the network is not constant; it varies with time and location. Therefore, in the simulation, traffic is generated using a Poisson distribution function. Figure 2 illustrates the traffic variation in the network. It shows that as time and iteration numbers increase, traffic levels also rise, reaching a maximum during peak hours and decreasing again during non-peak hours.

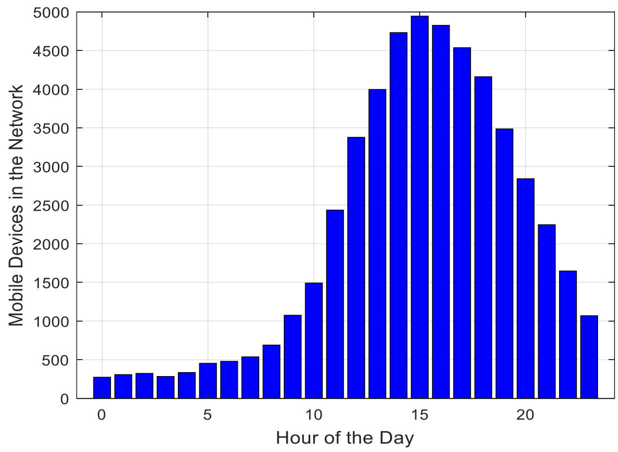

Fig. 2: Distribution of mobile devices in the network over a given day.

During non-peak hours, when traffic is low, some base stations can be switched-off. The generated traffic is applied to the adaptive switching-off algorithm. Based on the traffic distribution in the network when traffic is low, the algorithm selects one of its switching-off methods—Low Traffic Switching-off, Static, or Dynamic Switching-off.

For each iteration, Figures 3 and 4 show the number of switched-off and switched-on base stations in the network, respectively. When traffic is very low, a greater number of base stations are switched-off. When the traffic distribution is medium, base stations with traffic below the threshold are switched-off using either the static or dynamic switching-off method.

From Figures 2, 3, and 4, during hours 0 to 4, traffic in the network is very low, resulting in only 9 base stations being switched-on and 40 base stations being switched-off. During hours 14 to 16, traffic is very high, and no base stations are switched-off. In the remaining iterations, with medium traffic distribution, base stations are switched-off using the static and dynamic switching-off algorithms.

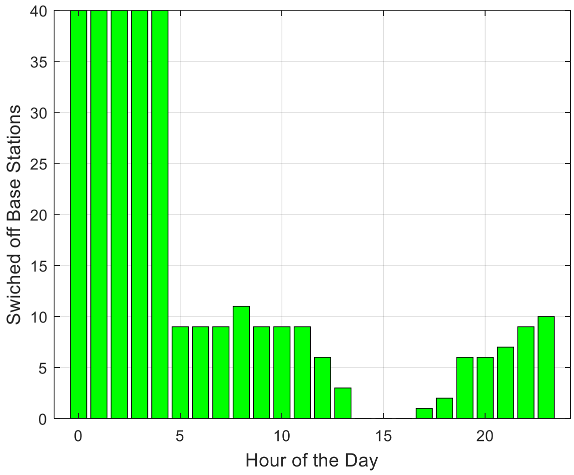

Fig. 3: Number of base stations switched-off in the network.

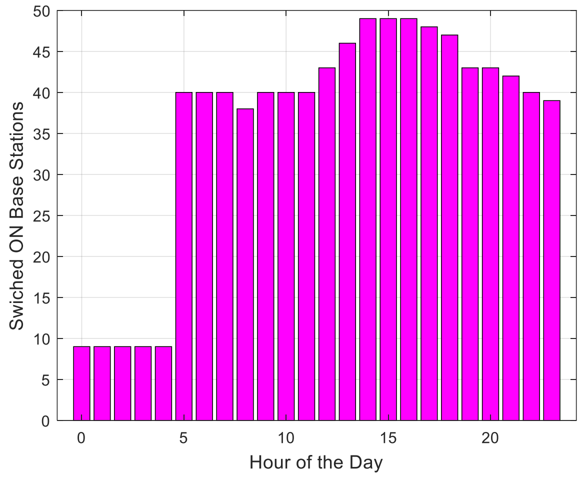

Fig. 4: Number of active base stations in the network.

To switch-off any base station, its associated traffic must be handed over to adjacent switched-on base stations. **Figure 5** shows the number of mobile devices that need to be handed over, while **Figure 6** displays the actual handover of these mobile devices. From Figures 5 and 6, it can be seen that all mobile devices from the switched-off base stations are successfully handed over to the adjacent base stations.

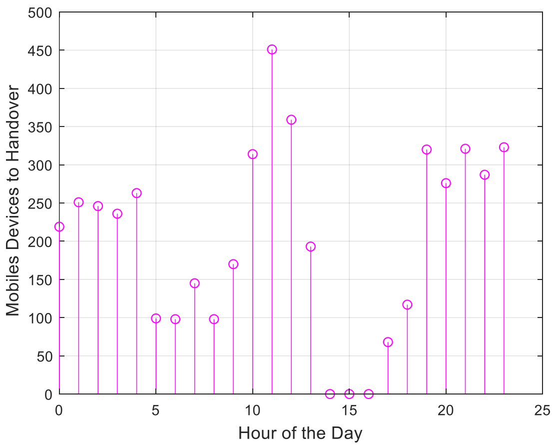

Fig. 5: Distribution of mobile devices to be handed over in the network.

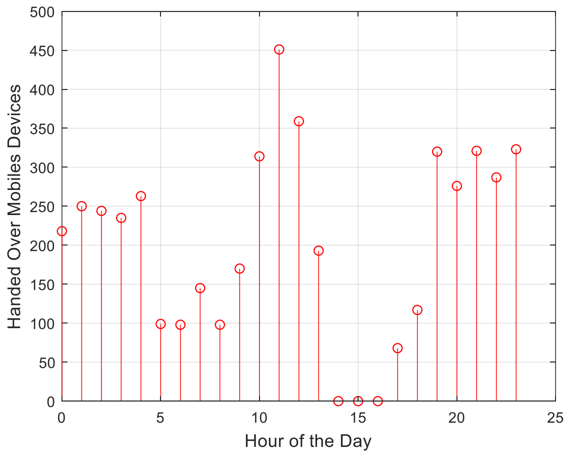

Fig. 6: Number of mobile devices handed over during base station switch-off.

Figure 7 illustrates that power consumption remains very high even during low traffic conditions.

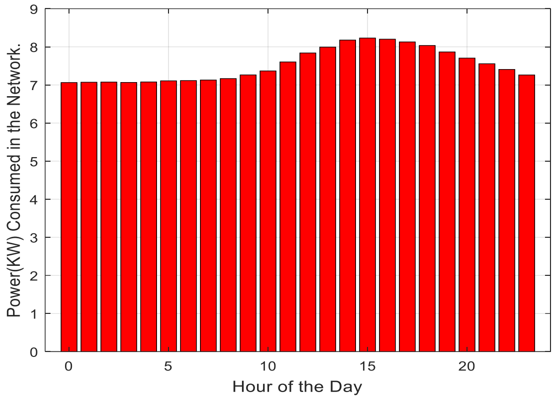

Fig. 7: Power consumption in the network when no base stations are switched-off.

Figure 8 shows the power consumed in the network, while **Figure 9** shows the power saved in the network using the adaptive switch-off method. When traffic is very low, i.e., during the 0th to 4th hours, only 9 out of 49 base stations are kept in the switch-on mode while 40 base stations are switched-off, resulting in significant power savings. During the 14th to 16th iterations, when traffic distribution is very high, no base stations are switched-off, and thus no power is saved. In the remaining hours, where traffic distribution is medium, a few base stations are switched-off using static and dynamic methods, leading to power savings, as shown in Figures 8 and 9.

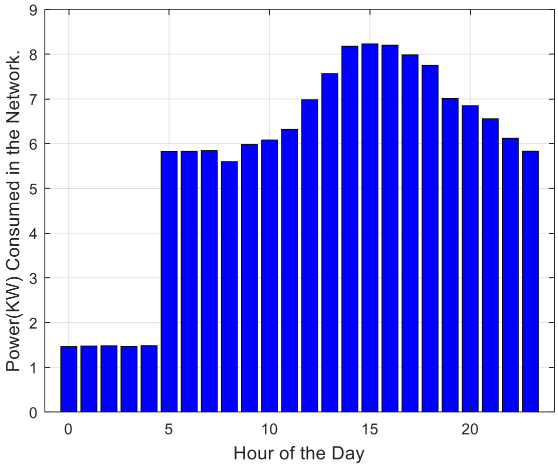

Fig. 8: Power consumption in the network after switching-off the base stations.

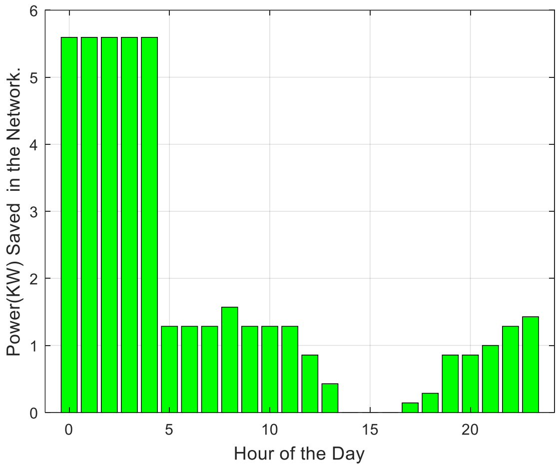

Fig. 9: Power saved per hour in the network by applying the proposed Adaptive base station switch-off method.

5. Conclusion

In this work, we developed methods for switching-off base stations based on network traffic conditions, categorizing traffic distribution into three types: Low, Medium, and High. Traffic was generated using a Poisson distribution in the simulation, and the algorithm selected the appropriate switching-off method based on the traffic condition—whether low, medium, or high.

During low traffic conditions, a greater number of base stations are switched-off. In a cluster of 9 base stations, only the middle base station is kept on by increasing its power level, while all adjacent base stations are switched-off. In cases of medium traffic distribution, some low-traffic base stations are switched-off using either static or dynamic methods. For high traffic distribution, all base stations remain active to provide service to all mobile devices and achieve higher data rates.

Results for these three cases are presented in the results section. Whether during low or medium traffic conditions, all associated traffic and coverage areas of switched-off base stations are redistributed to adjacent base stations to maintain the quality of service (QoS) for mobile devices.

During low traffic distribution, the network's power consumption without and with base stations switched-off is 7.054 kW and 1.459 kW, respectively, resulting in a power saving of 5.595 kW by switching-off 40 out of 49 base stations in the cluster. During medium traffic distribution, power consumption without and with base stations switched-off is 7.804 kW and 6.973 kW, respectively, leading to a power saving of 831 watts by switching-off 6 base stations. In high traffic distribution, no base stations are switched-off, and the power consumption in the network is 8.581 kW.

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Mr.D. SUDHAKAR is working as Assistant Professor at Mahatma Gandhi Institute of Technology, Hyderabad. He has obtained Bachelor’s Degree in Electronics and Communication Engineering (ECE) from Sree Kavitha Engineering College, Khammam (S.K.E.C), in 2007, Master’s Degree (M.Tech) in Embedded Systems from CMR College of Engineering and Technology, Hyderabad (C.M.R.C.E.T), in 2011. Currently, He is working towards the Ph.D.degree in Electronics and Communication Engineering (Green Wireless Communications) from Jawaharlal Nehru Technological University, Hyderabad.

Dr. Dhiraj Sunehra is Professor in the Dept. of ECE at JNTUH Univ. College of Engg. Sircilla, Telangana, India. He is a member of SMIEEE, MACM, MIETE, MISTE. He has obtained Bachelor’s Degree in Electronics and Communication Engineering (ECE) from Chaitanya Bharathi Institute of Technology (C.B.I.T.), Hyderabad in 1997, Master’s Degree in Digital Systems & Computer Electronics from Jawaharlal Nehru Technological University Hyderabad (JNTUH) in 2001, and Doctoral Degree in ECE from Osmania University, Hyderabad, India in 2012.