



Enabling sustainable green communication in three-tier 5G ultra dense HetNet with sleep cycle modulated energy harvesting

Arijeet Ghosh¹ · Iti Saha Misra¹

Accepted: 3 May 2024

© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2024

Abstract

The recent upsurge of data-demanding applications has necessitated a paradigm shift in deployment scenario in the direction of Multi-tier Ultra-Dense Heterogeneous networks (UDHN), which involve the dense deployment of more than one tier of small cells under-laying traditional macro cellular networks. However, higher data rates and the dense deployment of Small cell eNodeBs (SeNBs) elicit a possible escalation of network energy consumption which stirs up the mobile operators' operating expenditure. To deal with this, primarily, in this work, we present the Strategic Sleeping Policy of the SeNBs based on M/M/1 queuing theory and investigate its impact in reducing the power consumption of the proposed three-tier UDHN which consists of one tier of Macro eNodeB and two tiers of SeNBs based on performance metrics like Energy Efficiency and Area Energy Consumption Ratio. Further, we also introduce a novel Sleep Cycle Modulated Energy Harvesting Technique for SeNBs to ensure proper utilization of energy resources. An analytical model based on Continuous Time Markov Chain is also developed to evaluate the Energy Utilization of the proposed SCMEH method. The comprehensive performance analysis reveals that the implementation of integrated SCMEH enabled SeNBs under HetNet can not only guarantee QoS requirements under concurrent time-varying urban tele-traffic conditions but also ensure Sustainable Green Communication by radically controlling the estimated power consumption per hour basis throughout a day.

Keywords Ultra dense heterogeneous network · Non homogeneous poisson point process · Matérn cluster process · K-means clustering · Energy efficiency

1 Introduction

With the unprecedented growth of Information and Communication Technologies (ICT) and the abundance of mobile devices like tablets, smartphones, and Internet of Things (IoT) devices facilitating multiple applications like smart sensing indoor environment, live video streaming, conferencing, web browsing and image/video transfer spawns humongous amount of data traffic all around the world [1]. According to the CISCO Annual Report 2018–2023 almost two-thirds of the global population which means 5.3 billion total users (i.e. 66% of the global population) will possess

internet access by 2023. The report also claims that there will be 3.6 networked devices per capita by 2023 making the total number of networked devices climb up to 29.3 billion [2]. India being the second-largest telecommunication market has the second-highest number of internet users in the world. The population of internet users in the country has increased at a 13.38% of compounded annual growth rate (CAGR) from 391.5 million in 2016 to 834.3 million in 2021 [3]. The extent of internet users in the country is anticipated to stretch up even more to 900 million by 2025. India is projected to have 330 million 5G users by 2026 [3].

Network densification of traditional Macro eNodeBs (MeNB) has potentially reached its theoretical limit [5] while dealing with the enormous amount of data demand with guaranteed QoS [6]. Hence, this has opened a new frontier before the network service providers by compelling them to bring a monumental change in their network deployment strategies from prudently deployed hefty tower-mounted MeNBs to irregularly distributed heterogeneous arrangements that often additionally comprise smaller micro/pico

✉ Arijeet Ghosh
arijeet259@gmail.com

Iti Saha Misra
itisahamisra@yahoo.co.in

¹ Department of Electronics and Telecommunication Engineering, Jadavpur University, Kolkata, West Bengal 700032, India

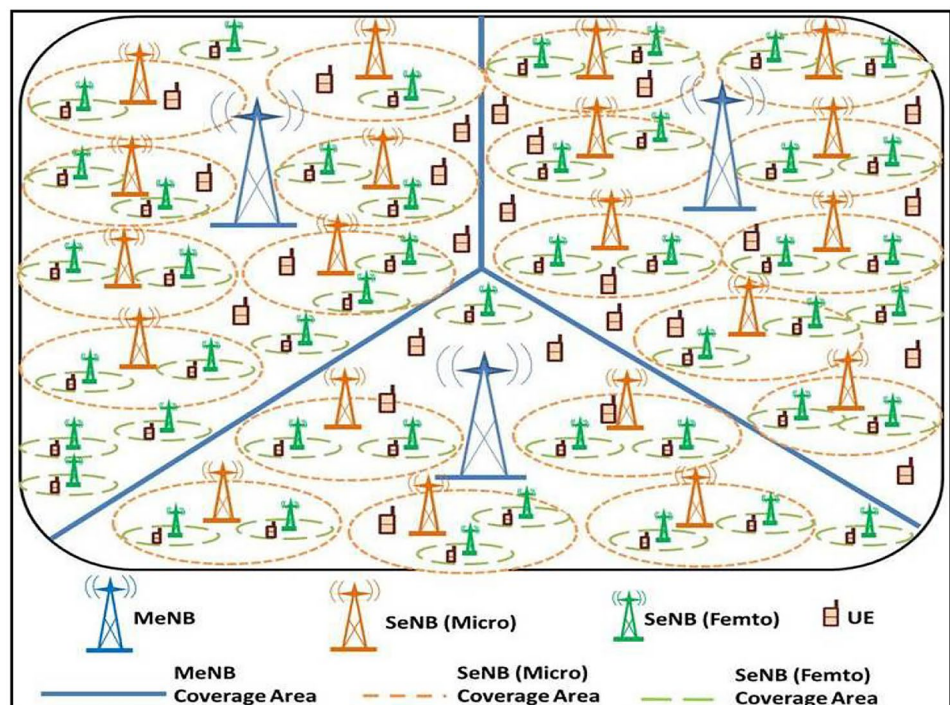
cells [7]. These small cells which are served by SeNBs using the same, different, or partially different channels with the MeNBs, termed as co-channel, dedicated, or partially shared channel deployments, often differ in terms of operational power, transmit power, coverage regions, user admission capability, persistent spectral efficiency, path loss models and their spatial distribution [8]. Due to the dense deployment of multiple tiers of low-power SeNBs with the conventional MeNBs the resulting network architecture is often denoted as multi-tier Ultra Dense Het-Net (UDHN). Figure 1 shows the conjectural illustration of a three-tier UDHN [5].

United Nations too in its ‘Agenda 2030’ for sustainable development goals (SDG) has set some specific frameworks for future ICT to contribute in a significant way to the various sectors of society including a greener future [9]. The ICT sector in general and more precisely the mobile communications sector have a close connection with the UN SDG framework [9]. Facilitating people’s lives for a better sustainable future, modern communication network often comes with increased energy consumption as evident in the recent 5G network [10]. In fact, it is speculated that the price paid for this enormous growth of energy consumption will arise even further if no energy-efficient method is deployed along with. Several recent surveys estimated that the contribution of global CO₂ emission is nearly 4% and projected to surpass the assessed figure with the further progress of 5G and beyond [9, 10]. However, ‘UN SDG 13: Climate action which targets net zero emission by 2050’ expects the mobile industry to be

the first to make positive efforts in this regard. In another recent study [11], it is observed that some global key players like Vodafone, and Orange in this industry have made significant endeavour to reduce their CO₂ emissions by up to 50% within a span of 14 years between 2006 and 2020.

It is expected that the deployment of additional infrastructure to handle increased data demand will increase the daily power consumption of any such UDHN. Evidently, the network energy consumption will also bear an additional price tag for mobile service providers. According to [10], energy price has been projected to be about 10%–15% of the total network Operating Expenses (OPEX) in mature markets that can further amount to 50% of the Operating Expenditure in developing markets [12, 13]. India is the fastest-growing telecommunication market globally and one of the key contributors to the CAGR of internet users in Asia Pacific [2, 3]. Consequently, most of the urban areas in India create immense opportunities to design deployment scenarios for sustainable green network architectures for seamless penetration of 5G technology which is expected to be commercially rolled out in the final quarter of 2022 [11]. To date, the majority of the research in mobile network deployment has revolved around QoS based performance metrics like throughput, and spectral efficiency. Nevertheless, their recent trends show an increased interest among academia and industry professionals toward sustainable green communication (SGC) [14] by maintaining its QoS performance intact.

Fig. 1 A typical three-tier HetNet consisting one tier of MeNB and two-tiers of SeNBs



2 Related work and motivation

After about a decade of in-depth research towards the improvement of QoS standards through designing innovative deployment scenarios like Het-Net, many researchers have recently shown keen interest in improving the energy efficiency of such complex future networks to achieve SGC to foster future technological advancements [14, 15]. From the implementation viewpoint, naive models are desirable as for composite systems large amounts of parameters are convolved for simulation and analysis. Thus, designing a docile model for such complex and sustainably green UDHN is a tedious task and requires standard assumptions such as terrain-specific hour-wise user distribution patterns and operational specifications of different categories of eNBs. In this regard, various distinguished researches have already been observed in recent literature. From a deployment designing perspective, Poisson Point Process (PPP) in its pure or modified form aided by teledensity dependent clustering technique is found to be the most discussed method to design complex multi-tier UDHN for Urban scenarios. As one of the key aspects of 5G, clustered UDHN is a promising deployment model to cope with ever-increasing numbers of mobile User Equipments (UE) with guaranteed QoS demands. Clustered UDHN can enhance the Signal-to-Interference-plus-Noise Ratio (SINR) by deploying more SeNBs to bring the network nearer to UEs [16]. Unfortunately, deployment of UDHN comes at an additional cost. In reality, it generates a massive challenge for the wireless communication sector in terms of better management of network energy consumption [17]. Some serious efforts have been made in recent years to cope with this most critical issue of the modern era of telecommunication. A number of notable energy-saving methodologies like strategic/dynamic sleep mode policy and/or energy harvesting techniques have been found as the most promising solutions to make those complex UDHNs energy efficient to achieve SGC [14–19]. In this subsection, a few of the contemporary related research works are deliberated that encouraged us to explore even further. SGC techniques can be summarized under two broad categories.

- Strategic Sleep mode policies
- Energy Harvesting and Scheduling

Dense deployment of eNBs imposes a major impact on network power consumption as investigated by Tiankui Zhang et. al [19]. The minimum achievable data rate and throughput in terms of the traffic load in each tier are derived. The closed-form EE equation with respect to the BS deployment is also obtained. The simulation

validates that EE maximization can be achieved by the optimized BS deployment. In [20], Jiaqi Lei et.al. developed an analytical framework for estimating the average link SE, average throughput, and EE in a two-tier ultra-dense Heterogeneous Cellular Network, as well as providing guidelines for practical deployments. In [16], the authors designed Het-Net based on the Poisson Point Process and derived the coverage probability to evaluate the area spectral efficiency and energy efficiency of the network in view of three Fractional Power Control (FPC) strategies. The numerical results and Monte Carlo simulation results shown in the work reveal that optimum power control can alleviate the interference by balancing out performances of UEs. Authors have also investigated the effect of eNB sleeping strategies on the performance of the network when it is moderately burdened.

In [21, 22], the authors have modelled coverage probability, average achievable rate, and EE in multi-tier Het-Net with different sleep strategies for small cells centered around the stochastic geometry-based Het-Net model. The authors [21] then tried to maximize EE under random and strategic sleeping policies with restrictions on both coverage probability and wake-up times, whereas in [22], precisely, the impact of dynamic sleep mode policies on the power consumption and on the EE is inspected and demonstrated that the performance improvements rest on the level of background noise. In another work [23], the authors studied the design and the trade-offs of EE cellular networks through the deployment of sleeping strategies and small cells and derived the success probability and EE in homogeneous macrocell (single-tier) and heterogeneous k-tier wireless networks under different sleeping policies. In addition, the authors have also framed the energy EE maximization problems and defined the optimal operating conditions for macrocell base stations. A unique dynamic cluster-based method for maximizing the EE of wireless small cell networks is proposed by Sumudu Samarakoon et. al. in [24, 25] which allows intra-cluster synchronization among the SeNBs for improving the downlink performance by means of load balancing while fulfilling QoS demands of UEs. In [26], the clusters-based approach creates a path for the implementation of opportunistic SeNBs sleep-wake swapping method to maintain stability between delay and energy consumption. In [27], a coordination mechanism between SeNBs is proposed to minimize a cost function, which invokes the trade-offs between EE and flow level performance. GiaKhanh Tran et. al. in [28] have designed a proactive cell activation/deactivation technique jointly with user association methodologies to maximize the network's EE entrusted upon traffic model based on realistic measurement data in metropolitan Tokyo.

The urgency to reduce CO₂ emission and energy costs associated with it has given birth to a novel SGC technique labeled as Energy Harvesting (EH) and/or Wireless Power

Transfer (WPT). Works testified over the last few years on this method are mentioned herewith. In [29], Yuyi Mao et. al. have performed a complete investigation of EH in SeNB-based networks regarding the feasibility analysis of powering SeNBs with renewable energy sources like solar. The work performed some case studies and proclaimed that among potential EH sources, the blend of solar and wind energy sources could turn out to be a good candidate to empower SeNBs. In addition, the authors have also performed trade-offs between the network performance, SeNB density, and grid power consumption. Some other noted works also discuss the use of renewable sources of energy to be the right candidates for EH solutions but these sources may not be sustainable as a long-term solution [1]. In order to guarantee the QoS demands of UEs in this age of UDHN environment, network elements especially low-powered SeNBs are prone to consume more power and drain their batteries even faster. Due to the limited energy sources of SeNBs, simultaneous wireless information and power transfer (SWIPT) has been projected as a milestone solution to serve as a long-lasting energy source for SeNBs, hence improving the QoS demands. In SWIPT networks, SeNBs are able to refill their energy repositories through RF which can be used to charge their inbuilt batteries. An elaborated explanation of SWIPT is presented in [30]. In [31] a scalable deployment model of k-tier SWIPT based Het-Net is formulated for its critical performance evaluation. Additionally, the EE performance evaluation of SWIPT networks is investigated in [32]. In [33] TiejunLv et. al. have exhibited that Het-Nets with EH can improve the EE only when the density of the SeNBs is high in a Het-Net. However, the works cited above have little clarity on channelizing the harvested energy whether from natural sources or by SWIPT. A key challenge for EH-enabled network deployment is to maneuver a network seamlessly regardless of the stochastic nature of traffic and energy arrivals [34]. Lakshmikanth Guntupalli et.al. in [34] proposed one such on-demand energy request technique to boost the performance of an EH-enabled IoT network.

3 Our approach and contributions

To this extent, it is well understood that all the distinguished works discussed above made significant contributions to reduce power consumption in modern wireless network scenarios. However, co-implementation of strategic sleeping policies for Energy harvesting (EH) enabled SeNBs inside a HetNet through scalable network planning and deployment under real-time urban traffic scenario is certainly an aspect that can be investigated even further to attain tractable solution for attaining SGC for future networks. It is also perceived that the popularity of mobile internet users in countries like India, the world's 2nd largest telecommunication

market, real-time traffic scenario corresponding to urban terrain need to be deliberated as a key consideration in designing SGC models. So, taking into consideration India's Urban tele-traffic scenarios on an hourly basis (for the city of Kolkata), this research work proposes to model a three-tier UDHN in which low powered SeNBs are deployed with integrated Strategic Sleeping Policy (SSP) and sleep cycle modulated Energy harvesting policy with an ultimate goal of a significant reduction in hourly power consumption. The organisation of this research paper is as follows:

3.1 Modelling the customer arrival process in an Indian urban scenario

This work aims to model the customer arrival process in a typical Indian Urban condition (considering the population and subsequent teledensity for the city of Kolkata) as an One dimensional Poisson arrival process within a total time span of 12 h (typically busy office hours from 10 am in the morning to 9 pm in the late evening) with a step size of one hour each in subsection 4.1.

3.2 Modelling three tier UDHN as different SPP

A generalized multitier composite UDHN architecture is sculpted in subsection 4.2. Each entity of Three Tier UDHN, namely, Urban Macros (UMa) Urban Micro cells deployed in the street canyons (UMi-SC) and Indoor Hotspots (InH) along with User Equipment (UE) are scattered in a particular two dimensional (2D) plane following different spatial distribution. UMa and UMi-SCs are distributed by HPPP and Clustered NHPPP respectively whereas the InHs are modelled as a special case of the Poisson Cluster process (PCP) i.e. Matérn Cluster Process (MCP).

3.3 Distribution of SINR at random user location

One of the key facets of this paper (as depicted in Sect. 6) is to derive the expression for SINR with the aid of transmit power and path loss only which is quite lucid and mathematically compliant contrasted to the derivation of SINR in other works. The expression of the path loss model for Macro cell and Small cell environment for urban scenario is considered from 3GPP TR 38.901 Release 16 as mentioned in Sect. 5.

3.4 Sustainable green communication (SGC) techniques

As discussed earlier that SGC is and will be the most debated topic in the upcoming days as more and more countries (especially populous countries like India) will commercially adopt 5G technology. Some significant efforts have

been made in this work to reduce the power consumption of the proposed UDHN deployment model. Initially in subsection 7.1, the power consumption scenario of each network element has been modelled. Then a novel SSP based on M/M/1 queuing theory for the SeNBs is proposed in subsection 7.2. In addition, this work also introduces a novel Sleep Cycle Modulated Energy Harvesting (SCM-EH) policy in subsection 7.3. Further, an analytical model based on CTMC is developed in Sect. 8 for designing SGC metrics for further performance evaluation.

3.5 Designing the SGC performance parameters

The performance of the proposed HetNet model under an urban traffic arrival scenario is then evaluated based on SGC metrics like Energy Efficiency (EE), Area Energy Conservation Ratio (AECR), and Energy Utilization (EU) in Sect. 9.

3.6 Performance analysis of proposed SGC technique

Simulation results in Sect. 10 critically evaluate the performance of proposed SGC techniques under three-tier UDHN under time-varying urban teletraffic condition to ensure QoS requirements and co-implementation of SSP and EH techniques (i.e. SCM-EH policy) on both tiers of SeNBs can substantially reduce the power consumption on an hourly basis throughout a day.

4 Methodology

4.1 Modeling hourly user arrival in urban scenario

Firstly in this paper, the User Equipment (UE) arrival process within a certain coverage region is modelled as a one dimensional (1D) PAP [35] following certain assumptions.

1. The number of UEs which arrive within an interval $(m, n]$ has an expected value equivalent to the duration of the interval:

$$\mathbb{E}[N(m, n)] = \mu(n - m) \tag{1}$$

where, $\mu > 0$ is the rate of the UE arrival process.

2. UE arrivals in disjoint time intervals are independent i.e. if $m_1 < n_1 < m_2 < n_2 \dots \dots \dots m_r < n_r$, then random variables $N(m_1, n_1], \dots \dots, N(m_r, n_r]$ are independent.
3. The probability of two or more UE arrivals in an infinitesimal time interval is given as:

$$\mathbb{P}[N(m, m + t) \geq 2] = 0(t), t \downarrow 0. \tag{2}$$

Based on the above considerations, it leads that the number of UEs arriving within a time interval should trail a Poisson distribution:

$$N(m, n) \sim \text{Poisson}(\mu(n - m)) \tag{3}$$

where, $\text{Poisson}(\alpha)$ implies the Poisson distribution with mean $\alpha = \mu(n - m)$, is hereby defined as

$$\mathbb{P}[N = \eta] = \frac{e^{-\alpha} \cdot \alpha^\eta}{\eta!}, \eta = 1, 2, 3, \dots \tag{4}$$

Figure 2 depicts the hourly arrival of UEs in the region of Kolkata (Indian urban scenario) bearing the Tele traffic of 143.66% [36], and population density of 24,760/ km² (as of January 2023) [37]. The sampling instants in the x-axis purely indicate time stamps in a day in 24 h format.

4.2 Modeling a three tier UDHN

The huge amount of teletraffic loads especially in urban regions of the country necessitates the deployment of adding another tier in the networks deployment architecture and analysis for sustainable improvement in QoS demand. Also, the idea of UDHN is estimated to meet concerns regarding the propagation losses in 5G networks by indulging the end users to get closer to the access nodes [5]. This realization is accomplished by the co-deployment of both indoor and outdoor small cells in an urban terrain where massive traffic is generated under the footprint of macrocells [4–6]. Urban small cells are typically of two types, namely, Urban Microcell or UMi-SC deployed in the street canyons (SC) and Indoor Hotspots or InH [38]. Fig. 4.7 depicts a hypothetical demonstration of a

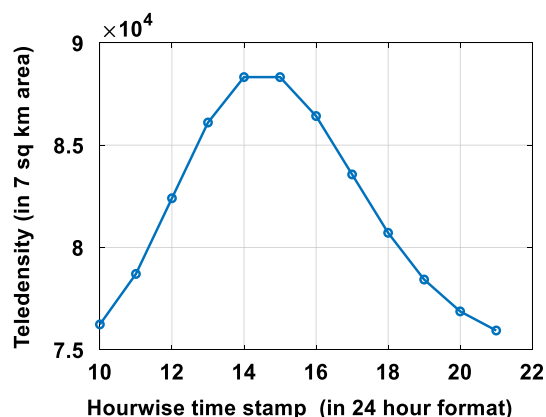


Fig. 2 Modelling Hourly User Arrival profile in Indian urban Scenario using PAP

three-tier UDHN. The modelling of three-tier network is sectioned into two segments. Primarily, a two-tier HetNet consisting of UMa underlaid with UMi-SC is modelled using NHPPP followed by optimizing the location of UMi-SCs using K means Clustering. After that, the third tier of access nodes i.e. InH are distributed as a Matérn cluster point process [39], which is a type of cluster point process where randomly located points tend to form random clusters. In this subsection, at first, a three-tier UDHN is demonstrated where individual tier represents the eNBs of a specific type in a two-dimensional finite region $A \subset \mathbb{R}^2$.

4.2.1 Distribution of UMa BY HPPP

MeNBs are spatially distributed as independent HPPP (as shown in Fig. 3), Ψ_{UMa} of density, λ_{UMa} . The number of MeNBs in any finite region $A \subset \mathbb{R}^2$ denoted as $N_{UMa}(A)$, is a random variable with the Poisson distribution [6],

$$\mathbb{P}[N_{UMa}(A) = \eta_{UMa}] = \frac{e^{-\mu_{UMa}(A)} \cdot \mu_{UMa}(A)^\eta}{\eta_{UMa}!}, \eta_{UMa} = 1, 2, 3 \dots$$

With mean (rate function)

$$\mu_{UMa}(A) = \lambda_{UMa} \times A \tag{5}$$

4.2.2 Distribution of UMi

UMi usually deployed in the street canyons are spatially distributed as independent NHPPP, Ψ_{UMi} of density, λ_{UMi} . The points of the NHPPP associated with each UMi eNBs in the 2nd tier in any finite region $A \subset \mathbb{R}^2$ are symbolized

as $N_{UMi}(A)$, is a random variable with the Poisson distribution [40],

$$\mathbb{P}[N_{UMi}(A) = \eta_{UMi}] = \frac{e^{-\mu_{UMi}(A)} \cdot \mu_{UMi}(A)^\eta}{\eta_{UMi}!}, \eta_{UMi} = 1, 2, 3 \dots$$

With mean (intensity function)

$$\mu_{UMi}(A) = \iint_A \lambda(x, y) dx dy \tag{6}$$

Note that the UEs are also spatially distributed as independent HPPP, Ψ_{UE} of density, λ_{UE} . Considering each UE that belongs to Ψ_{UE} as the data points and the positions each UMi in Ψ_{UMi} as initial positions of the cluster centres, this work implements the k-means clustering algorithm on the top of NHPPP Ψ_{UMi} to form two-tier HetNet using clustered NHPPP. K means clustering algorithm is an unsupervised data clustering algorithm that can segregate NHPPP distributed UEs into ‘K’ Voronoi cells or clusters [41] as demonstrated in Algorithm 1. Subsequently, K means can also optimize the centroid locations of each of the clusters in an iterative manner so that the average distance between the centroids (SeNB positions) and all the cluster members (UEs) will be minimized. The centroid locations can be seen as the optimum location of SeNBs [42]. The implementation of k means clustering algorithms on the top of NHPPP leads to another spatial point process termed in this research work as Clustered NHPPPP.

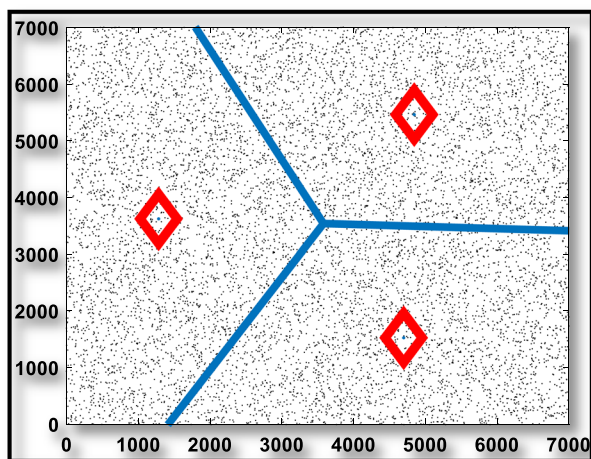


Fig. 3 Distribution of UMa BY HPPP; UMa; UMa coverage area

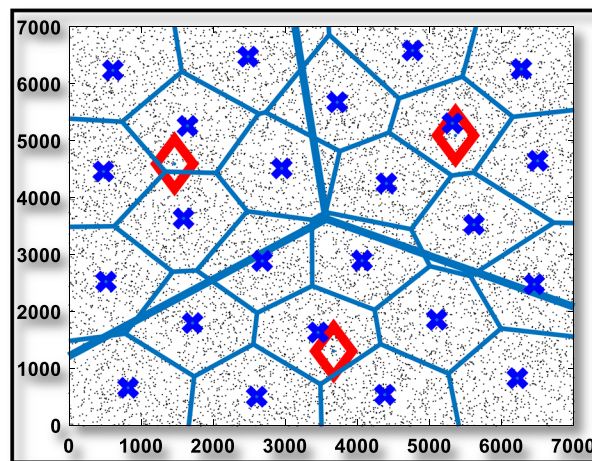


Fig. 4 Distribution of two-tier HetNet by clustered NHPPP; UMa; UMa coverage area UMi-SC; UMi-SC coverage area

Algorithm 1 Finding optimum location of the SeNBs using K means Clustering

-
- Step 1: Preliminary SeNB locations (distributed as NHPPP $\Psi_k|k = 2$) will be treated as the primary centroids (or initial locations of the SeNBs) for each cluster.
 - Step 2: Allocate every UE from Ψ_{UE} to its nearest centroid (temporary positions of the SeNB) according to the minimum Euclidean distance function. Let assume there are q clusters and C_q cluster centers.
 - Step 3: For each cluster, $q = 1 \dots Q$, and for each centroid, C_q recalculate the locations of the centroids by taking mean of all the UEs those are assigned to a particular SeNB or centroid.
 - Step 4: Repeat step 3 until convergence.
-

Finally, this algorithm aims at minimizing a cost function; in this case, a squared distance function by iterative methods, then reconfigures the cluster association in an iterative fashion to acquire an improved shape. The convergence criterion of such an objective function is a

well-known topic and has been discussed in several notable studies [43, 44].

$$\text{Minimize } Z = \sum_{q=1}^Q \sum_{i=1}^n \|\chi^i - C_q\|^2 \tag{7}$$

Fig. 5 Schematic concept of the formation of clusters in MCP

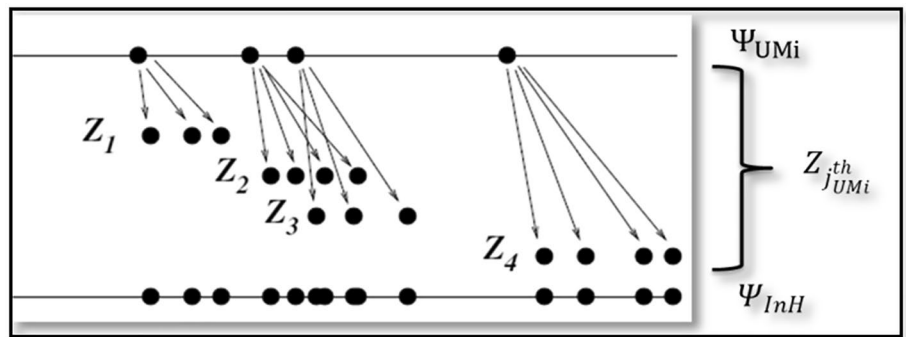
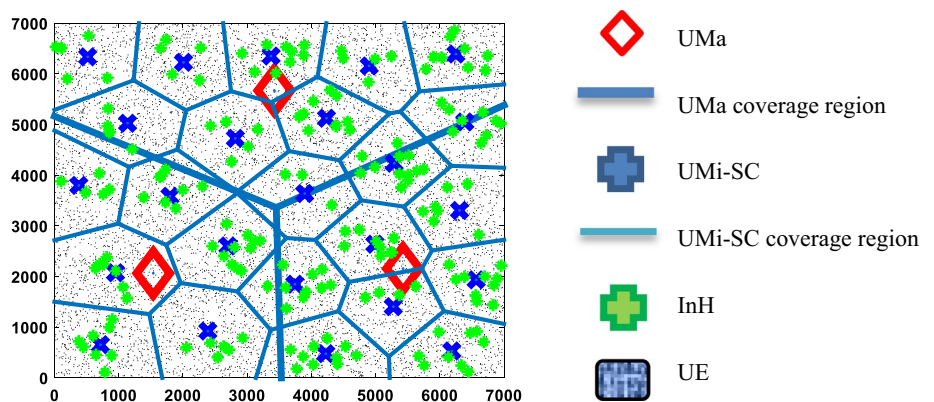


Fig. 6 Distribution of three-tier UDHN by different SPP



where, $\|\chi^i - C_q\|$ is a chosen distance measure between a data point χ^i and the cluster center C_q , is an indicator of the distance of the i data points from their respective cluster centers. In Fig. 4a, the SeNBs and UEs are generated as disjoint sets of NHPPP. The resulting two-tier HetNet is depicted in Fig. 4.

4.2.3 Distribution of InH

The distribution of InH in the hotspot region in an urban environment can be collectively perceived as a cell free distributed antenna system (DAS) [45] around each UMi eNBs belonging to Ψ_{UMi} . They are also considered as point process Ψ_{InH} in the same finite region $A \subset \mathbb{R}^2$ and are distributed as Matérn cluster process (MCP) [39] a special case of Poisson Cluster Process (PCP) because they trace a correlation with elements of Ψ_{UMi} . For generating a Poisson cluster process consider each $j_{UMi}^{th} \in \Psi_{UMi}$ is associated with some random but finite set of points $Z_{j_{UMi}^{th}}$ which are denoted as the offsprings of each parent $j_{UMi}^{th} \in \Psi_{UMi}$ as depicted in Fig. 5. The superposition of all such clusters of daughter points yields the cluster point process $\Psi_{InH} = \bigcup_{j_{UMi}^{th} \in \Psi_{UMi}} Z_{j_{UMi}^{th}}$. Notably in our work, the parent process Ψ_{UMi} is a uniformly distributed PPP in the finite region $A \subset \mathbb{R}^2$ and each cluster $Z_{j_{UMi}^{th}}$ consists of a random number of points $z_{InH} \in Z_{j_{UMi}^{th}}$, where $z_{InH} \sim Poisson(\mu_{UMi}(A))$, is independently and uniformly distributed in the disk $\Phi(j_{UMi}^{th} \in \Psi_{UMi}, r_{j_{UMi}^{th}})$ of radius $r_{j_{UMi}^{th}}$ centered on $j_{UMi}^{th} \in \Psi_{UMi}$.

Thus the locations of the first tier UMa follow HPPP, Ψ_{UMa} with rate $\mu_{UMa}(A)$, locations of the second tier UMi follow K means clustered NHPPP, Ψ_{UMi} with intensity, $\mu_{UMi}(A) = \iint_A \lambda(x, y) dx dy$, and the locations of the third tier InHs (Ψ_{InH}) follows MCPP with density $\mu_{UMi}(A) \times \overline{\lambda_{InH}}$ whose parent point process is Ψ_{UMi} . The demonstration of three-tier UDHN is depicted in Fig. 6. For notational simplicity we denote $k \in \{UMa, UMi, InH\}$ as the index of the tier with which a typical user is associated.

The actual hourly scenarios of two-tier UDHN are portrayed in Fig. 7. The main focus of the previous chapter is to find out the optimal density of SeNBs within a two-tier HetNet in the presence of real time hourly user arrival scenario and finally analyse the proposed model in terms of ASE. However, In this chapter, we not only extended the modelling of the network to generate a three-tier UDHN but also present a detailed Energy Efficiency analysis of the said model to evaluate its sustainability in terms of greener communication.

5 Pathloss models

The technical report issued by 3GPP TR 38.901 version 16.1.0 Release 16 has broadly standardized path loss models for frequencies from 0.5 to 100 GHz under diverse deployment scenarios [38]. The path loss propagation models for various scenarios considered in this work are abridged in Table 1. The definition of distance is demonstrated in Fig. 8. The shadow fading (SF) standard deviations for different deployment aspects are considered to be log-normal (given in Table 1).

6 Distribution of SINR at random user location

In this subsection, the main focus is engaged to calculate downlink SINR at any random location for a given scenario. To start with, it is considered that a random user is located at a distance Δ_0 from the serving eNodeB (S-eNB) from which it receives maximum power. All other eNBs belonging to that network will be orchestrated as non-serving eNodeB (NS-eNB) and will eventually be treated as a source of interference to that particular user. Now to derive the expression of SINR, it must be noted that it primarily depends upon two parameters i.e. transmit power (P_k^{tx}) and path loss of the link. Here, in this work, the 3GPP path loss models for Macro Cell and Small cells are considered [38].

Without the loss of generality, the amount of path loss measured at any arbitrary i^{th} user for $n \in N$ (where, N is the total no of users) located at (x, y) from any of its serving j^{th} eNB of k^{th} tier is considered as

$$PL_k(x, y)_i^j = 32.4 + 20 \log_{10}(f_c^{j \in k}) + B^{j \in k} \log_{10}(d_{3D,n}^{j \in k}) \quad (8)$$

where,

$B^{j \in k}$ = pathloss exponent of the logarithmic distance term corresponding to MeNB, SeNB type of network infrastructure.

The resultant received power at any arbitrary i^{th} user from j^{th} eNB of k^{th} tier is given as

$$P_k^{rx}(x, y)_i^j = P_k^{tx} - PL_k(x, y)_i^j \quad (9)$$

Simultaneously, the downlink SNR of the link between a typical j^{th} eNB and an i^{th} UE located at $(x, y)_i^j$ is given as,

$$SNR_k(x, y)_i^j = P_k^{rx}(x, y)_i^j - \Theta \quad (10)$$

where, Θ is the downlink Noise Figure [55] in dB.

Hence, the cumulative SINR at any arbitrary n^{th} user from i^{th} eNB of k^{th} tier can be calculated as,

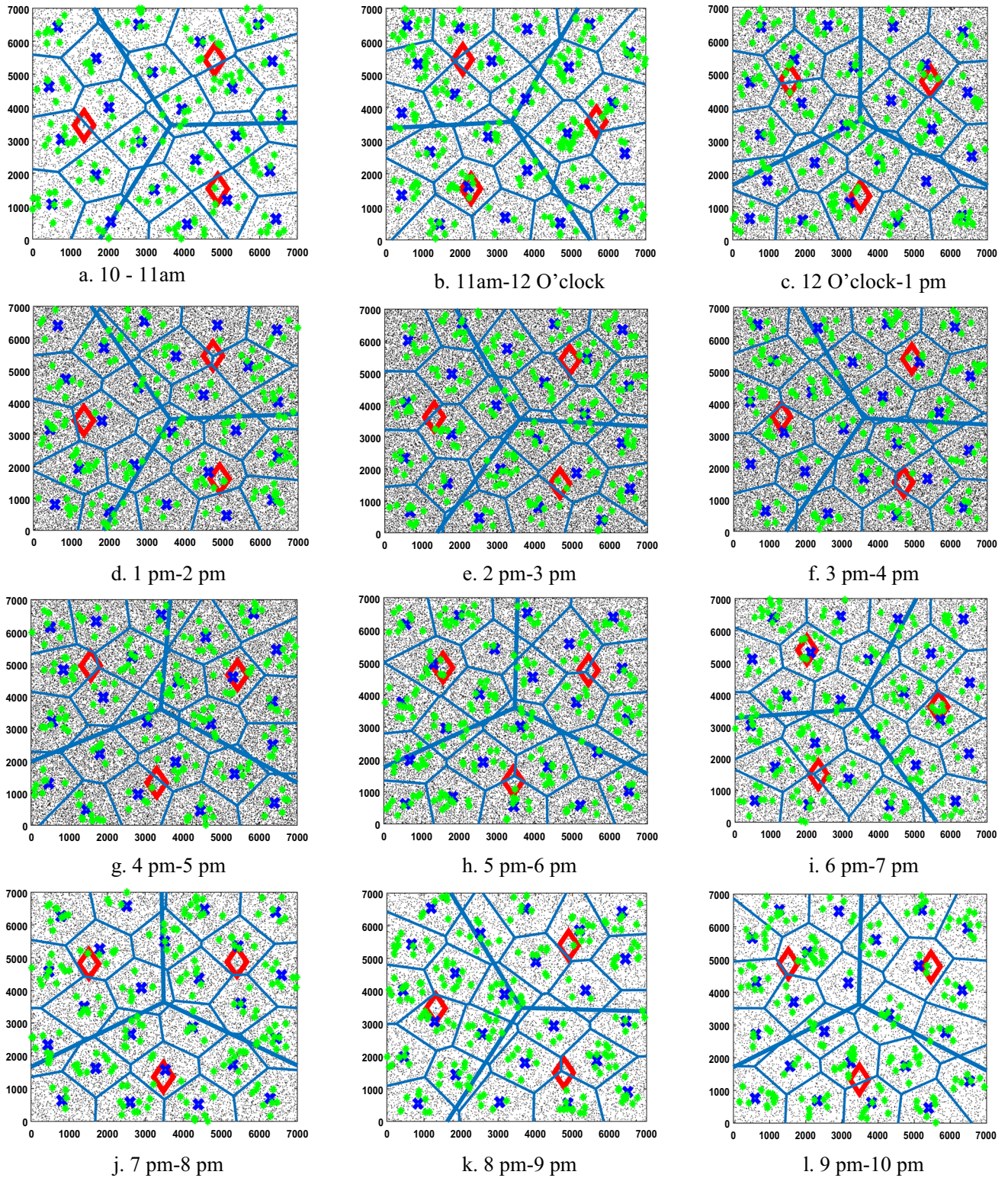


Fig. 7 Estimated hourly modeling of a Indian Urban Scenario (Kolkata) as Three-tier UDHN modeled by HPPP, NHSCPPP and MCP in a 7000 sq. m geographical area with UE density ~ 143.38%

Table 1 Pathloss model for different scenarios [38]

Scenario	Pathloss propagation models [center frequency, $f_c^{j \in k}$ in GHz, distance, d_{3D} in meters] σ_{SF} = shadow fading std. [db]
Urban Macro Cell nLoS served by MeNB	$32.4 + 20 \log_{10}(f_c^{UMa}) + 30 \log_{10}(d_{3D}), \sigma_{SF} = 7.8$
Urban Micro Cell nLoS served by SeNB	$32.4 + 20 \log_{10}(f_c^{UMi}) + 31.9 \log_{10}(d_{3D}), \sigma_{SF} = 8.2$
Indoor Hotspot (InH)	$32.4 + 20 \log_{10}(f_c^{InH}) + 17.3 \log_{10}(d_{3D}) \sigma_{SF} = 3$, Note that, in case of InH O2I is not applicable assuming that InH will generally operate in LoS condition

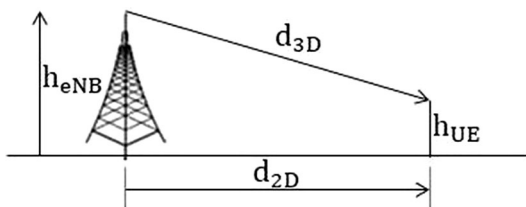


Fig. 8 Distance definition i.e. $d_{3D} = \sqrt{(d_{2D})^2 + (h_{eNB} - h_{UE})^2}$ [38]

$$\gamma_k(x, y)_i^j = \frac{SNR_k(x, y)_i^j}{\left\{ \sum_{k \in K} \sum_{l=1}^{j-1} SNR_k(x, y)_i^l \right\} + 1} \quad (11)$$

Note that, UE will be served by its strongest eNB i.e. the UE will be connected to the eNB which offers the best SINR. So, a random i^{th} UE located at $(x, y)_i$ served by any j^{th} eNB belonging to Ψ_k is considered to be in coverage if:

$$\max_{(x,y)_i \in \Psi_k} \gamma_k(x, y)_i^j > \gamma_k^{th} \quad (12)$$

7 Sustainable green communication techniques

Urban HetNets (the precursor of UDHN) in general, have been planned aiming to optimize coverage, capacity, spectral efficiency or throughput. Clearly, it is not necessarily expected to deal with anything about energy efficiency. Also, traditional deployment strategies were mostly intended to withstand peak load and extreme conditions. Thus at times they encounter redundancy or provide extra capacity which makes the system underutilized during non-peak hours at the cost of energy

drainage. This opens up a new opportunity for investigating possible energy saving techniques which make SGC an interesting and technically challenging research field. Therefore, a new deployment paradigm is immediately desirable so that current set-ups will uphold the same level of QoS while decreasing the aggregate energy consumption in the future [17].

7.1 Power consumption model of UDHN

Before exploring the methods to make the urban UDHNs energy efficient, we design power consumption models considering all network components. 5G base stations popularly mentioned as eNodeB (eNB) can be classified into two main groups, depending on transmission power and coverage range.

- Urban Macro (UMa): with a transmission power of about 40W for devices with a channel bandwidth of 20 MHz and 80W for LTE-A devices with channel bandwidth of 40 MHz [46]. MeNBs typically range up to a few kilometers.
- Urban Micro (UMi): with transmission power ranging between 0.05W and 6W, SeNBs can be further categorized into UMa-SCs and InHs. UMa-SCs target small to medium zones typically spanning from a few hundred meters up to one kilometer with opaque traffic (hotspots) such as shopping malls, office places, stadiums, or train stations, whereas InHs typically ranging within a few meters are designed to serve smaller areas such as private homes or indoor spaces. UMa-SCs in general can be mounted lampposts or traffic lights for outdoor scenarios because of their small form factor [46].

The power usage at full system load of the different types of eNBs can range from about 6W for an UMi to 1 kW for an

Table 2 Load dependencies of different types of eNBs [46]

eNB type (j = 1,2,3 for j ∈ k)	P_0^j (in Watt)	P_{max}^j (in Watt)	α^j	P_{sleep}^j (in Watt)
UMa eNB (j = 1)	130	40	4.7	75
UMi eNB (j = 2)	56	6.3	2.6	39
InH (j = 3)	4.8	0.05	8.0	2.9

UMa [14]. Typically, this power consumption is exhibited as the sum of a static value and a dynamic and load-dependent value [46]:

$$P_c^j = \begin{cases} N_{TRX}^j(P_0^j + \alpha^j P_{out}^j) & 0 < P_{out}^j < P_{max}^j \\ N_{TRX}^j \cdot P_{sleep}^j & P_{out}^j = 0 \end{cases} \quad (13)$$

where $j = 1, 2, 3$ represents the UMa, UMi-SC or InH respectively.

N_{TRX}^j = number of transmit/receive channels.

P_0^j = eNB power consumption at zero Radio Frequency (RF) output power.

α^j = slope of the load dependent power consumption curve.

P_{out}^j = load-dependent part of the RF output power.

P_{max}^j = value of P_{out}^j at maximum load.

P_{sleep}^j = eNB power consumption at no load.

Table 2 specifies the load dependencies of the different eNB types. The power consumed by an UMa eNB raises more steeply with the increasing traffic load than that of a UMi eNB due to the more powerful power amplifier that UMa eNBs use to cover widespread zones, whereas SeNBs need an amplifier designed for much lower coverage and, as a result, reside lower in energy consumption. Remarkably, P_0^j represents a significant part of the total energy consumed by any eNB and, due to this reason, in this work, the use of sleep modes have been scrutinized in front of varying traffic arrival scenario throughout the whole day.

7.2 Introduction to strategic sleeping policy

Based on the power consumption model, we adopt power saving modes for UMi-SCs and InHs. Let us consider the UMi-SCs (outdoor small cells) and InHs as a subset of SeNB. We consider two modes of operation. During ‘Always on’ mode the SeNB is in full operation and consuming maximum power. On the other hand, during sleep mode when the SeNB is in the idle state having no or minimal traffic, only the power supply, backend connection, and generic CPU core will be on. Instead of randomly selecting these sleeping periods this work presents a planned sleeping strategy based on M/M/1 Queuing theory [47] to reduce the unnecessary energy drainage during no traffic hours.

Strategic Sleeping policy (SSP) for SeNBs:

Consider any eNB from of UMi-SCs or any InH as a single server system in which UEs arrive following a Poisson process with rate λ so that the inter-arrival times are i.i.d. exponential random variable with mean $1/\lambda$. Assume that the service times are i.i.d exponential random variable with mean $1/\mu$ and that inter-arrival times and service times are independent of each other [47].

Let $N_s(t)$ be the number of customers that are being served at time t and let τ denote the service time. Now if we designate the set of servers to be the system then the Little’s formula becomes [47]

$$E[N_s(t)] = \lambda(t)E[\tau] \quad (14)$$

where, $E[N_s(t)]$ =Estimated number Busy server in the system.

For a single server system $N_s(t)$ can only be 0 or 1, so $E[N_s(t)]$ represents the proportion of the time that the server is busy [47]. If $p_0 = P[N_s(t) = 0]$ denotes the steady state probability that the system is empty then we can write $1 - p_0 = \rho = E[N_s(t)] = \lambda(t)E[\tau]$, i.e., the proportion of the time that the server is busy or in other words proportion of the time a SeNB is in the active state [47]. Consequently, $(1 - \rho)$ gives the proportion of the time one SeNB is in the idle state [47]. Note that Arrival rate = $\lambda(t) < \mu(t)$ = Service rate, i.e., $\rho < 1$. Applying SSP, (13) for SeNBs can be rewritten as

$$P_c^{j=2,3} = \begin{cases} T_{TRX}^{j=2,3} \cdot \rho^{j=2,3} \cdot (P_0^{j=2,3} + \alpha^{j=2,3} P_{out}^{j=2,3}) & 0 < P_{out}^{j=2,3} \\ < P_{max}^{j=2,3} T_{TRX}^{j=2,3} \cdot (1 - \rho^{j=2,3}) \cdot P_{sleep}^{j=2,3} & P_{out}^{j=2,3} = 0 \end{cases} \quad (15)$$

Eventually the total power consumption (P_{tot}^j) can be derived as

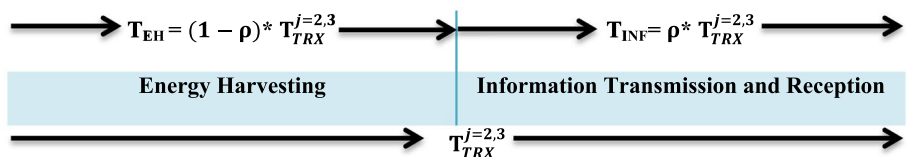
$$P_{tot}^j = T_{TRX}^{j=1} \cdot \rho^{j=1} \cdot (P_0^{j=1} + \alpha^{j=1} P_{out}^{j=1}) + T_{TRX}^{j=2,3} \cdot \rho^{j=2,3} \cdot (P_0^{j=2,3} + \alpha^{j=2,3} P_{out}^{j=2,3}) + T_{TRX}^{j=2,3} \cdot (1 - \rho^{j=2,3}) \cdot P_{sleep}^{j=2,3} \quad (16)$$

where, $T_{TRX}^{j=2,3}$ = total operational period for UMi-SCs or InHs.

7.3 Energy harvesting methodologies

Energy harvesting models play key roles in improving energy efficiency of modern day wireless networks [32, 33]. In this work, we mainly focus on designing a novel energy harvesting model for UMi-Sc and InH, namely, Sleep Cycle

Fig. 9 Time slot allocation of Serving Small cell eNBs



Frame 1							Frame 2						
T_{EH}	T_{INF}	T_{INF}	T_{EH}	T_{INF}	T_{INF}	T_{INF}	T_{EH}	T_{EH}	T_{INF}	T_{INF}	T_{INF}	T_{EH}	T_{INF}

Fig. 10 The protocol of energy harvesting for one SeNB

Modulated Energy Harvesting (SCM-EH) which enables user admission into the network.

In the SCM-EH model the necessary energy required to endure data transmission is harvested during the time when any UMi-Sc or InH is in sleep mode such that the harvesting mechanism doesn't affect data transmission cycle. The SCM-EH model of the three-tier UDHN will be analysed in this section. The working period of the any eNB from two small cell tiers is assumed as $T_{TRX}^{j=2,3}$. The working period is divided into two parts, which are energy harvesting (T_{EH}), information transmission reception (T_{INF}). Considering the eNB as a single server system, it is well elaborate in the previous section that ρ is the proportion of the time that the server is busy or in other words proportion of the time a SeNB is in the active state [47]. Consequently, $(1 - \rho)$ gives the proportion of the time one SeNB is in the idle state [47]. Hence, the proportion of the energy harvesting time in whole period is $(1 - \rho)$. During the period of energy harvesting, the serving UMi-SC eNB or InH harvest energy from the electromagnetic wave transmitted by UMa eNB. The generalised notion of the time slot allocation is demonstrated in Fig. 9.

The energy harvested by the serving node in the energy harvesting time can be expressed as follows:

$$E_{EH}^{j=2,3} = P_k^{rx}(x,y)^{j=2,3} \times (1 - \rho^{j=2,3}) * T_{TRX}^{j=2,3} \quad (17)$$

where,

$\rho^{j=2,3}$ is the proportion of the time that the UMi-SCs or InHs are busy.

$T_{TRX}^{j=2,3}$ = total operational period for UMi-SCs or InHs

$$P_k^{rx}(x,y)^{(j=2,3 \rightarrow j=1| \in k)} = P_k^{rx}(x,y)^{(j=1| \in k)} - PL_k(x,y)^{(j=2,3 \rightarrow j=1| \in k)}$$

$$PL_k(x,y)^{(j=2,3 \rightarrow j=1| \in k)} = 32.4 + 20 \log_{10}(f_c^{UMa}) + 30 \log_{10}\left(d_{3D}^{(j=2,3 \rightarrow j=1| \in k)}\right)$$

Figure 10 represents protocol of energy harvesting for one serving eNB of two consecutive time slots. The entire operation period is subdivided into n numbers of time frames. Here each time frame consists of seven time slots. The distribution of T_{EH} and T_{INF} within a time slot is not deterministic rather they depend upon the value of $(1 - \rho)$ and ρ respectively with in a frame. The serving eNB chooses the time slot for energy harvesting when it is in idle mode and transmits information in the other time slots when it is in active mode.

Algorithm 2 Connection Allocation through SCM-EH Technique for SeNBs

function = *SCM-EH* (E_{tot})

Initialize,

M =No of UMa eNBs

S_{UMi-SC} =No of UMi-SC eNBs

S_{mH} =No of InHs

E_{tot} =total available Energy

\Allocation of Energy Blocks to UMa eNB and SeNBs.\

$AVL_EN_{\Phi_{j=1}} = (\frac{E_{tot}}{2})/M$ *\ Initially Available energy at UMa eNBs *\

$AVL_EN_int_{\Phi_{j=2}} = (P_c^{j=2}|T_{TRX}^{j=2} = 1 \text{ hour})$ *\ Initially Available energy at UMi-SC eNBs*\

$AVL_EN_int_{\Phi_{j=3}} = (P_c^{j=3}|T_{TRX}^{j=3} = 1 \text{ hour})$ *\ Initially Available energy at InHs *\

$AVL_EN_{\Phi_{j=2}} = (AVL_EN_int_{\Phi_{j=2}} + E_{EH}^{j=2})$ *\ Actual energy at UMi-SC eNBs after EH*\

$AVL_EN_{\Phi_{j=3}} = (AVL_EN_int_{\Phi_{j=3}} + E_{EH}^{j=3})$ *\ Actual Available energy at InHs after EH*\

Where, $1 \leq m \leq M$ *\No of UMa eNBs*\

Where, $1 \leq s_{\Phi_{j=2}} \leq S_{UMi-SC}$ *\No of UMi-SC eNBs *

Where, $1 \leq s_{\Phi_{j=3}} \leq S_{mH}$ *\No of InHs*\

for $i = 1$ to maximim no of users

for each MeNB ' m '

Initiate energy request for connection ' i ' (E_{REQ}^i)

Calculate $SINR_{\Phi_{j=1}}^{th}, SINR_{\Phi_{j=1}}^{im}$ & Check whether $SINR_{\Phi_{j=1}}^{um} > SINR_{\Phi_{j=1}}^{th}$

If **true** then check whether $AVL_EN_{\Phi_{j=1}} \geq E_{REQ}^i$ & allow Connection ' i '

such that $AVL_EN_{\Phi_{j=1}} = AVL_EN_{\Phi_{j=1}} - E_{REQ}^i$

else

for each UMi-SC eNBs ' $s_{\Phi_{j=2}}$ '

Calculate $SINR_{\Phi_{j=2}}^{th}, SINR_{\Phi_{j=2}}^{is}$ & Check whether $SINR_{\Phi_{j=2}}^{is} > SINR_{\Phi_{j=2}}^{th}$

If **true** then check whether $AVL_EN_{\Phi_{j=2}} \geq E_{REQ}^i$ & allow Connection ' i '

such that $AVL_EN_{\Phi_{j=2}} = AVL_EN_{\Phi_{j=2}} - E_{REQ}^i$

else

for each InHs ' $s_{\Phi_{j=3}}$ '

```

Calculate  $SINR_{\Phi_{j=3}}^{th}, SINR_{\Phi_{j=3}}^i$  & Check whether  $SINR_{\Phi_{j=3}}^i > SINR_{\Phi_{j=3}}^{th}$ 

If true then check whether  $AVL\_EN_{\Phi_{j=3}} \geq E_{REQ}^i$  & allow Connection 'i'

such that  $AVL\_EN_{\Phi_{j=3}} = AVL\_EN_{\Phi_{j=3}} - E_{REQ}^i$ 

else

    reject connection 'i'

endif

end of for

endif

end of for

end if

end of for

end of for

end function
    
```

The time complexity of the proposed SCMEH algorithms can be realised by estimating the loops of the algorithm. However, in our research, the time complexity is calculated for best and worst case scenario. The best case time complexity of our proposed SCMEH algorithm will be $O(N_{UE}(A) \times 1) = O(N_{UE}(A))$, considering the best case scenario where all the UEs are accommodated in one urban macro base station. Note that The number of UEs in any finite region $A \subset \mathbb{R}^2$ denoted as $N_{UE}(A)$, is a random variable with the Poisson distribution [6],

$$[N_{UE}(A) = \eta_{UE}] = \frac{e^{-\mu_{UE}(A)} \cdot \mu_{UE}(A)^\eta}{\eta_{UMa}!}, \eta_{UE} = 1, 2, 3 \dots$$

With mean (rate function)

$$\mu_{UE}(A) = \lambda_{UE} \times A \tag{18}$$

However, the worst case time complexity of our proposed SCMEH algorithm will be $O(N_{UE}(A) \times N_{UMa}(A) \times N_{UMi}(A) \times N_{InH}(A))$ where

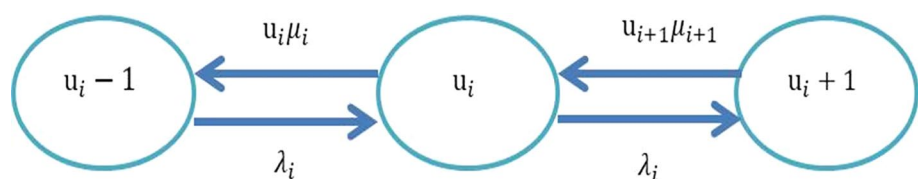
$N_{UMa}(A), N_{UMi}(A), N_{InH}(A)$ are the random variable representing the numbers of Urban Macros, Urban Micros and Indoor Hotspots respectively in any finite region $A \subset \mathbb{R}^2$.

8 Analytical model for performance evaluation

In this section, a Continuous time Markov Chain [48] based analytical model is developed to evaluate the readiness of the performance metrics. The Markov model is chosen here as it establishes the probability of being in a given state at a given point of time, as well as the expected number of transitions between states upon the admission or rejection of a connection 'i'. Note that an eNB either admits or rejects one connection at a certain instant in time.

Figure 11 reveals the general notion of the Markov Chain. In this work, the states of each eNB are modelled as a separate one dimensional Markov Chain. State $s = (u_i)$ represents that the BS has currently admitted u_i number of connections under one per eNB. The BS will be in a

Fig. 11 Generalized State Transition Diagram of the Markov chain Model for EH analysis



particular State $s = (u_i)$ until a new connection is admitted into the network or an ongoing connection is terminated. The arrival process of newly originated connection is considered to be Poisson with rates λ_i and the service time of the same is exponentially distributed with mean $1/\mu_i$ respectively.

The state space S for our proposed connection allocation scheme powered by proactive/reactive EH is obtained based on the following equation.

$$S = \{s = (u_i) | (u_i, E_i) \leq E\} \tag{19}$$

From Fig. 11, it is observed that every state $s = (u_i)$ in state space ‘ S ’ is accessible from every other state i.e. each state communicates with other states in the state space ‘ S ’. Therefore, the state space ‘ S ’ forms a bounded set and the Markov chain obtained is irreducible. Let the steady state probability of the state $s = (u_i)$ is represented by $\Pi_{(u_i)}$. The state balance equation of state ‘ s ’ is given as

$$\{\lambda_i \cdot \varphi_{(u_i+1)} + u_i \mu_i \cdot \varphi_{(u_i-1)}\} \cdot \pi_{(u_i)} + (u_i + 1) \cdot \mu_i \cdot \varphi_{(u_i+1)} \pi_{(u_i+1)} = \lambda_i \cdot \varphi_{(u_i-1)} \pi_{(u_i-1)} \tag{20}$$

$$\text{where, } \varphi_{(u_i)} = \begin{cases} 1, & (u_i) \in S \\ 0, & \text{Otherwise} \end{cases} \tag{19}$$

Here, $\varphi_{(u_i)}$ represents the characteristic equation. By using (76), the state balance equations of each state in the state space ‘ S ’ are obtained. Solutions of these equations provide the steady state probabilities of all states in the state space S with the normalized condition imposed by (20).

$$\sum_{s \in S} \Pi_{(u_i)} = 1 \tag{21}$$

9 Performance metrics for SGC

With a motive to analyse the effectiveness of three tier UDHN deployment and their respective energy saving methodologies to achieve SGC, different performance metrics are used in this work. Energy consumption metrics can be broadly written off into two categories [1]: Absolute metrics and Comparative metrics. Energy efficiency, Energy Consumption ratio are some of the familiar absolute metrics in many of the literature.

- Energy efficiency (EE) (in bps/kilo-watt):

EE aims to put a figure on energy savings at the macrocell area in an heterogeneous network as well as small cells as the 2nd tier and is given as [1, 49].

$$EE = \frac{\text{Netowrk Throughput}}{\text{Network Power Consumption}} = \frac{\mathcal{R}}{P_{tot}^j} \text{ (Mbit/Joule)} \tag{22}$$

The Shannon bound constrained Spectral Efficiency (\mathcal{R}) in the following equation can be computed similarly as demonstrated in [6, 16].

$$\mathcal{R} = \mathbb{E}[f(\lambda_m, \lambda_s, \gamma_k^{th})] = (\lambda_M + \lambda_S) \cdot \mathbb{E} \left[\left[\log_2 \left(1 + \max_{(x,y) \in \Psi_k} (\gamma_k(x,y)^j) \right) \right] \bigcup_{k \in K, (x,y)^j \in \Psi_k} \gamma_k(x,y)^j > \gamma_k^{th} \right] \tag{23}$$

- Area energy consumption ratio (AECR) (in kilo-watt/ bps/km2):

AECR is defined as the ratio of the network consumption to the system throughput calculated per square km coverage area (Π) [10]. The metric \mathcal{R} and P_{tot}^j is derived from Eq. (22) and (16) respectively.

$$\begin{aligned} AECR &= \frac{\text{Total Power Consumption}}{\text{Average Rate} * \text{Coverage Area}} \\ &= \frac{P_{tot}^j}{\mathcal{R} * \Pi} \text{ (KWH.BPS}^{-1}.KM^{-2}) \end{aligned} \tag{24}$$

Beside these absolute metrics this work also introduces one important relative metrics for comparative performance analysis.

- Energy utilization (EU): The EU is defined as the ratio of total Energy consumed for successful connection admission to the total available energy of the system [32]. EU can be obtained as follows:

$$EU = \frac{\sum_{s \in S} (u_i, E_i) \pi_{(u_i)}}{E_{tot}} \tag{25}$$

10 Results and discussion

The analytical results direct that lower energy requirement of SeNBs in a three-tier UDHN reduces the energy consumption. However, the proposed Sleep Cycle Modulated Energy Harvesting (SCM-EH) methodology proposed in this work provided a sustainable solution to reduce energy consumption even further while maintaining its QoS specifications intact. In the second part of this section, we basically emphasized upon critically analysing the performance of SCM-EH based SGC solutions based on some absolute and comparative performance metrics as well. Further investigation also shows that modulating EH interval in sync with the

Table 3 Scenario consideration and simulation parameters

Ratio of eNB density between UMa, UMi and InH [38]	1:8:8				
Load dependencies [46]	eNB Type ($j = 1, 2, 3$ for $j \in K$)	P_0^j (in Watt)	P_{max}^j (in Watt)	α^j	P_{sleep}^j (in Watt)
	UMa eNB ($j = 1$)	130	40	4.7	75
	UMi eNB ($j = 2$)	56	6.3	2.6	39
	InH ($j = 3$)	4.8	0.05	8.0	2.9
eNB Height (Meter) [38]	h_{UMa}	25			
	h_{UMa-SC}	10			
	h_{InH}	4			
UE Height (Meter)	h_{UE}	1.70			
Scenario Consideration [3]	UMa	Non line of sight			
	UMi				
	InH	Line of sight			
	UMa operating Freq	3300–3670 MHz			
	UMi operating Freq	24.25–28.50 GHz			
	InH operating Freq				
Pathloss Models [38]	UMa	$32.4 + 20\log_{10}(f_c^{UMa}) + 30\log_{10}(d_{3D}), \sigma_{SF} = 7.8$			
	UMi	$32.4 + 20\log_{10}(f_c^{UMi}) + 31.9\log_{10}(d_{3D}), \sigma_{SF} = 8.2$			
	InH	$32.4 + 20\log_{10}(f_c^{InH}) + 17.3\log_{10}(d_{3D}), \sigma_{SF} = 3$			

sleep cycles of SeNBs (both UMi-SCs, and InHs) produces the best outcome with an aim to accomplish SGC. Table 3 includes 3 Scenario Consideration and Simulation Parameters for further analysis of the proposed SCMEH algorithm.

- Hour-wise comparative performance analysis of proposed SSP to achieve sustainable green communication Technique under Indian Urban context:

In this subsection, we primarily focus upon hour-wise comparative performance analysis between traditional MeNB based scenario, two-tier Het-Net and three-tier UDHN considering urban scenario in terms of aforementioned absolute SGC metrics. Further, the numerical results also examine the impact of employing the proposed SSP on the top of two-tier HetNet and three-tier UDHN. The x-axis level in Figs. 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26 which ranges from 10 to 21 is adopted to represent the time stamp on a particular day at which users arrive into the network in accordance with PAP based user arrival model depicted in Fig. 2.

- Comparative performance analysis with respect to EE (in bps/kilo-watt):

Numerical results shown in Figs. 12, 13, 14, 15, 16 leads us to the fact that the introduction of two-tiers of SeNBs (UMa-SCs and InHs as additional network element)

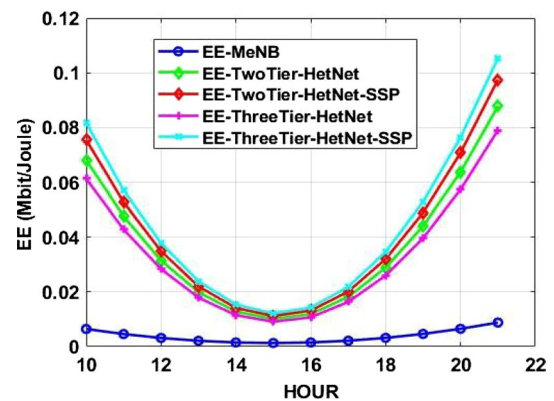


Fig. 12 Comparative EE analysis (hour-wise)

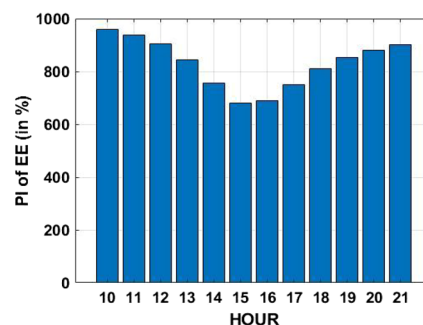


Fig. 13 PI of Het-Net than MeNB w.r.t EE in %

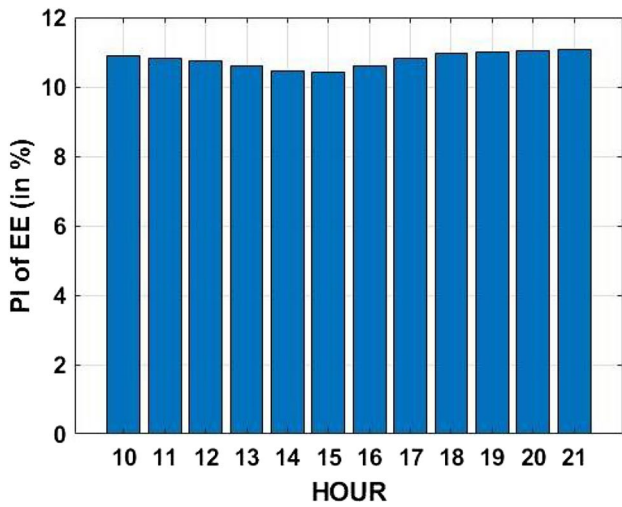


Fig. 14 Performance improvement of Het-Net-SSP than Het-Net w.r.t EE in %

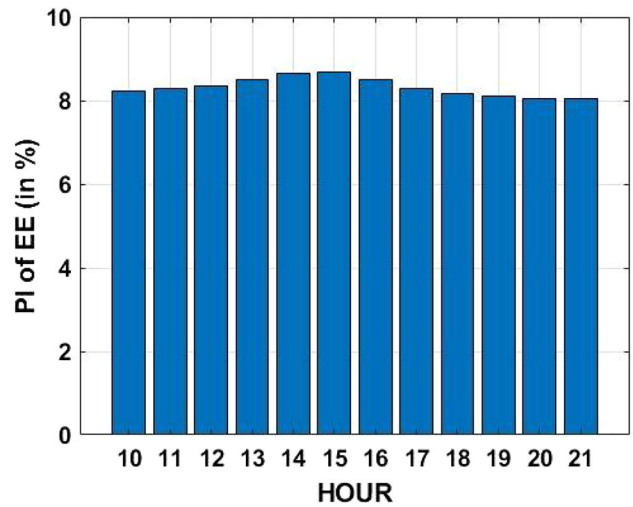


Fig. 16 Performance improvement of three-tier UDHN-SSP than two-tier HetNet-SSP w.r.t EE in %

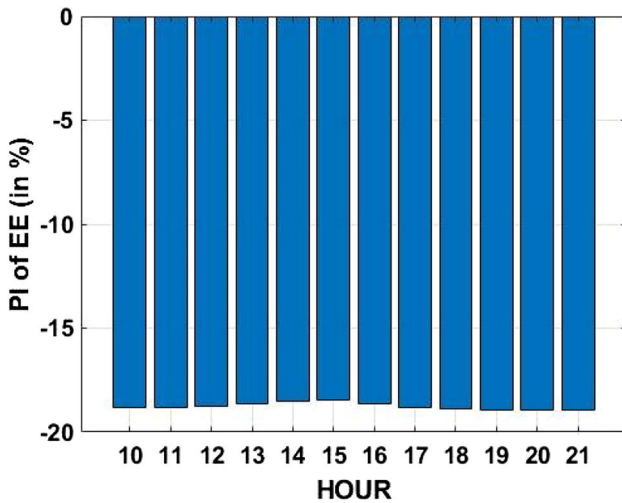


Fig. 15 Performance improvement of two-tier HetNet-SSP than three-tier UDHN w.r.t EE in %

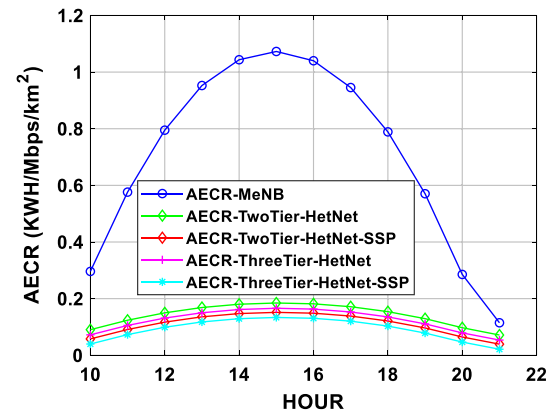


Fig. 17 Comparative AECR analysis (hour-wise)

consumes much less power compared to traditional larger MeNBs by the virtue of less load dependencies (as shown in Table 2). This makes them a better choice to make the network energy efficient as well. Hour-wise performance improvements based on EE metric between traditional MeNB (denoted by blue line plot in Fig. 12) and two-tier HetNet (in %) (denoted by green line plot in Fig. 12) implicate that during peak hours near about 700% improvement in EE is achieved. However, during non-peak hours (viz. 21 pm) the percentage improvement reaches near 900% (see Fig. 13). The proposed SSP of SeNBs in two-tier HetNet deployment addresses this issue and improves the EE to a greater extent as shown by red line plot in Fig. 12. The

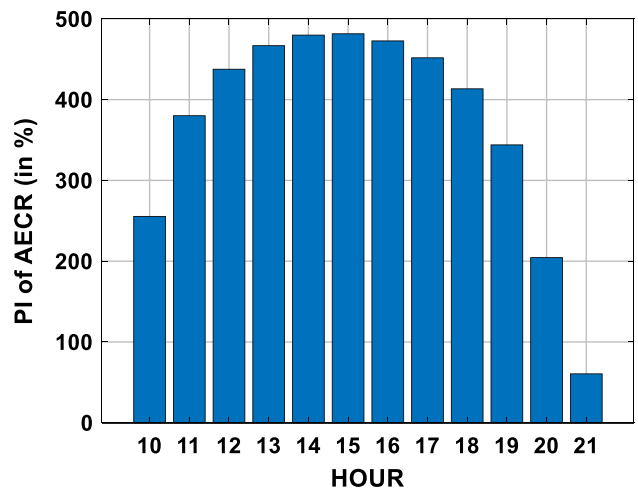


Fig. 18 Performance improvement of Het-Net than MeNB w.r.t AECR in %

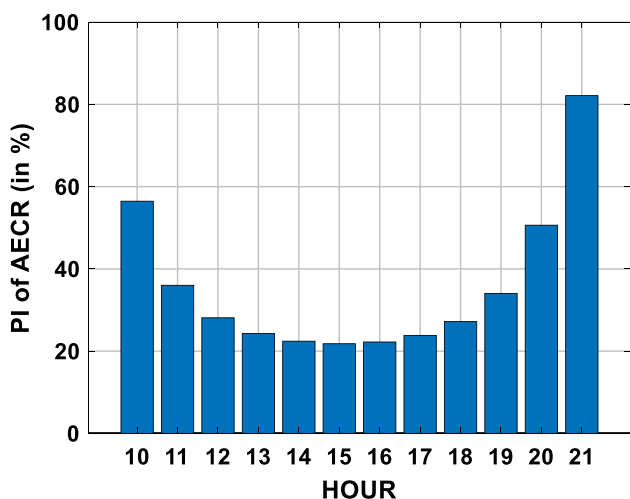


Fig. 19 Performance improvement of Het-Net-SSP than Het-Net w.r.t AECR in %

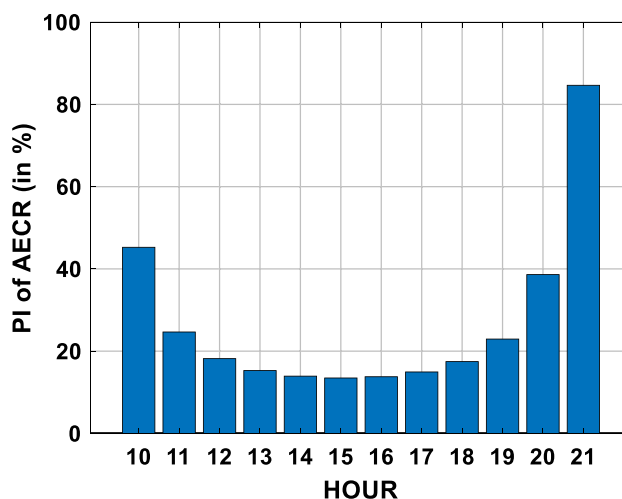


Fig. 21 Performance improvement of three-tier UDHN-SSP than two-tier HetNet-SSP w.r.t AECR in %

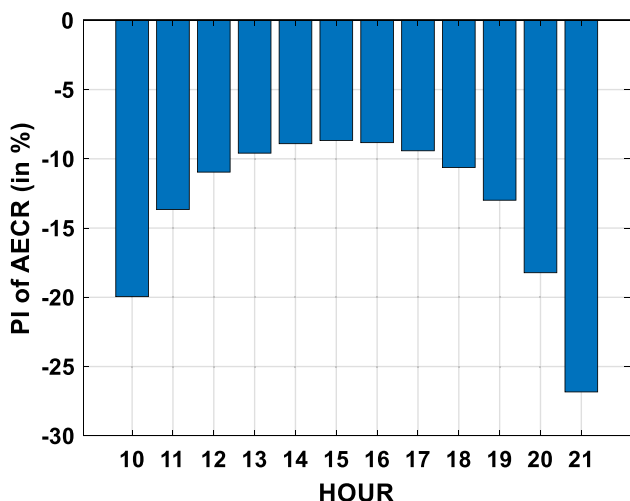


Fig. 20 Performance improvement of two-tier HetNet-SSP than three-tier UDHN w.r.t AECR in %

maximum percentage improvement of Het-Net with SSP than Het-Net without SSP reaches up to approximately 11% during 10 am in the morning and 21 pm in the evening as shown in Fig. 14.

The addition of the third tier of SeNBs i.e. InHs distributed as MCP around each UMi-SC eNBs improves the Spectral Efficiency of the overall network as they bring the network nearer to the user. In addition, implementation of 5G FR2 i.e. (24.5 GHz -28.6 GHz) as operating frequency in InHs paves the way for higher throughput as InH are debarred from the grasp of wall penetration loss (refer to Table 1) by creating LoS links between the end user and itself.

Hence, the inclusion of another tier of eNBs i.e. InHs inevitably increases the overall power consumption leading

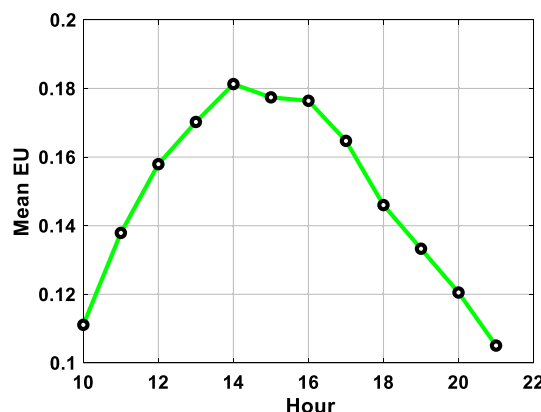


Fig. 22 Hourly Mean EU of Traditional MeNB

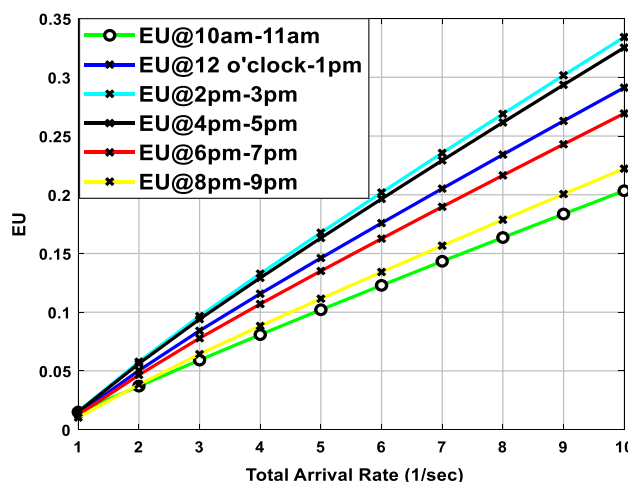


Fig. 23 Two hourly EU variation in Traditional MeNB

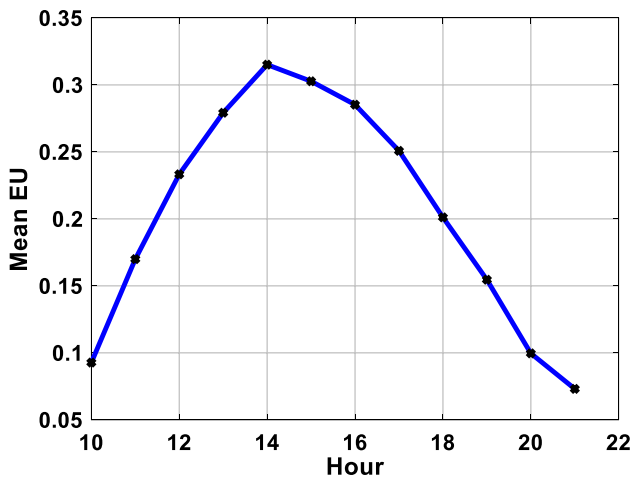


Fig. 24 Hourly Mean EU of three-tier UDHN with deterministic energy allocation (DEA)

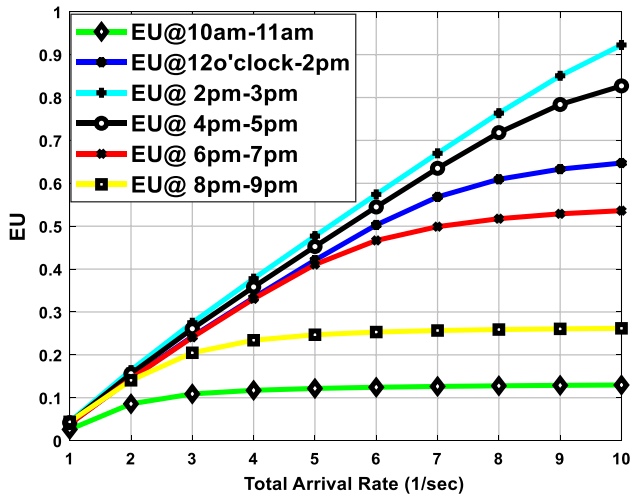


Fig. 25 Two hourly EU variation in three-tier UDHN with DEA

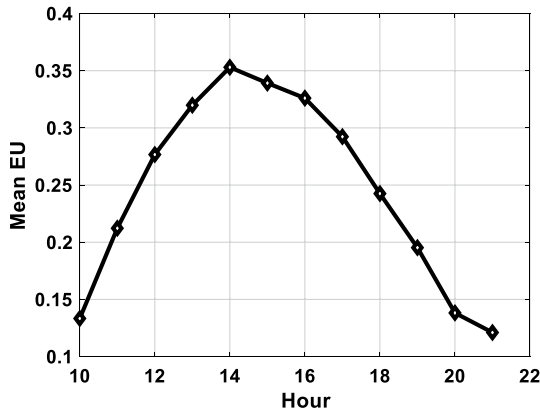


Fig. 26 Hourly Mean EU of three-tier UDHN with SCM-EH

to a subsequent reduction in the EE performance of the three-tier UDHN as shown by the magenta colour line plot in Fig. 12. It is observed from Fig. 15 that implementation of three-tier UDHN leads to 19% reduction in EE performance peak hours and an 18% reduction in non-peak hours as compared with two-tier HetNet with SSP due to continuous signalling overheads as the InHs are considered to be deployed as the so-called cell free coordinated multipoint distributed antenna system. Hence, proper SSP needs to be incorporated in the InH tier also to achieve the best performance in terms of EE. It is observed from Fig. 12 that implementation of SSP in both the small cell tiers i.e. in UMi-SCs and in InHs leads to the most improved EE performance as depicted by Fig. 16. A maximum of 8.5% performance has been observed in three-tier UDHN with SSP during peak hours when compared to two-tier HetNet with SSP.

Comparative performance analysis with respect to AECR (in kilo-watt/bps/km²):

AECR being an inclusive SGC metric containing all three factors viz. bit rate, Energy consumed and total coverage area provides a holistic impression about an emerging SGC solution. Like the previous metric Figs. 17, 18, 19, 20, 21 envisages that the three UDHN with SSP will provide better AECR than the sole MeNB based traditional network. It is perceived that the low power requirement of SeNBs contributes significantly in improving the AECR. Figure 18 displays that during peak hours (at 2 pm) the AECR performance (in %) of two-tier HetNet rallies up to 600% and during non-peak hours (at 21 pm) lowers down to 200%. However, the percentage comparisons between two-tier HetNet with SSP and without SSP (as shown in Fig. 19) foresee that the proposed SSP enabled SeNBs within HetNet improves the AECR with a better success rate reaching up to approximately another 90%, especially during non-peak hours (at 21 h). However, the AECR performance of a three-tier UDHN degrades than that of a two-tier HetNet due to cumulative signalling overhead in a coordinated multipoint deployment pattern of InHs as shown in Fig. 20. Nevertheless, the implementation of SSP in three-tier UDHN is able to attain more than 80% (depicted in Fig. 21) improvement in AECR with its closest competitor i.e. two-tier HetNet with SSP. The numerical results and their subsequent performance analysis in the aforementioned paragraphs clearly implicate that deployment of three-tier UDHN will definitely emerge as a better choice than traditional MeNB based deployment and two-tier HetNet in encountering abundant urban traffic by not only ensuring guaranteed QoS (in terms of SE) but also leading with an adequate margin in accomplishing SGC (in terms of EE and AECR). Further, it is also observed that implementation of SSP on small cell tiers makes the UDHN more competent explicitly during non-peak hours making the network resources utilized in a wiser

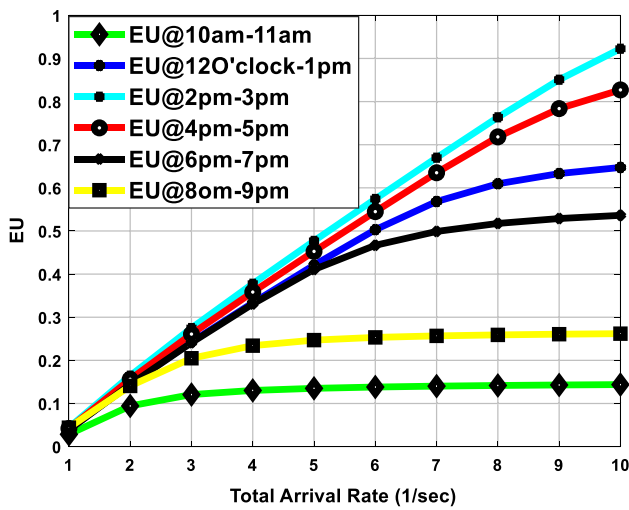


Fig. 27 Two hourly EU variation in three-tier UDHN with SCM-EH

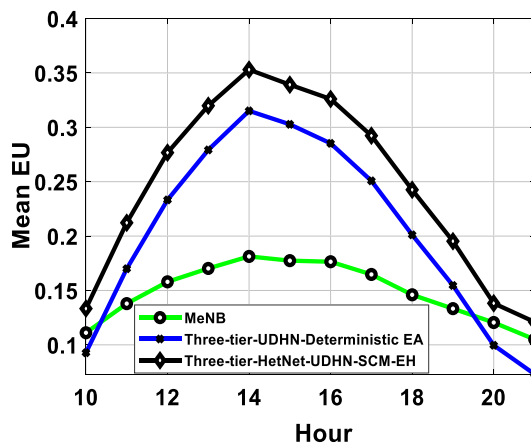


Fig. 28 Comparative analysis of Mean EU

manner which leads us to a stage where analysing the utilization of the proposed three-tier UDHN in terms of relative SGC metrics (i.e. Energy Utilisation) have become inevitable. Additionally, we will also show that implementation of the proposed Sleep Cycle Modulated Energy Harvesting (SCM-EH) technique in accordance with SSP in three-tier UDHN will improve the Energy Utilisation (EU) of the network even further.

- Hour-wise comparative performance analysis of proposed SCMEH technique in three-tier UDHN under Indian Urban context:

Here in this subsection, we demonstrate the numerical performance of three-tier UDHN under the umbrella of proposed EH technique i.e. SCM-EH policy, in which the required energy is harvested by serving SeNBs (UMi-SC,

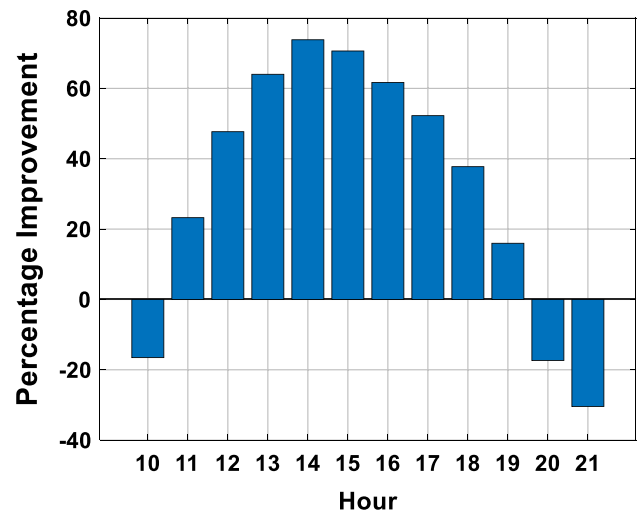


Fig. 29 Performance Improvement (in %) of three-tier UDHN with DEA over MeNB w.r.t Mean EU

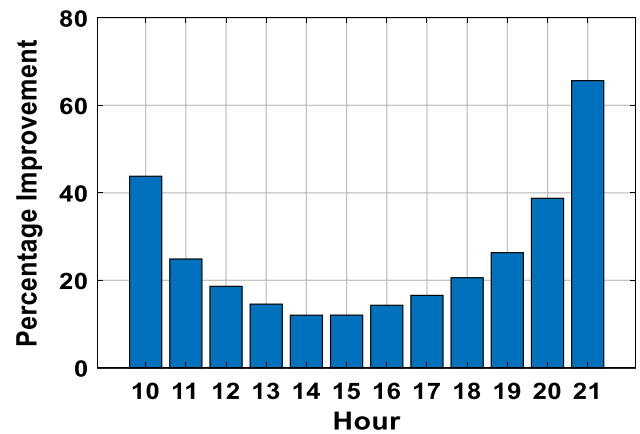


Fig. 30 Performance Improvement (in %) of three-tier UDHN with SCM-EH over three-tier UDHN with DEA w.r.t Mean EU

and/or InH) during sleep cycle of the respective serving nodes. Numerical analysis of traditional MeNB based networks and three-tier UDHN with energy allocation in a predetermined fashion has also been done to realize the comparative performance analysis. Figures 27, 28 and 29 show the hourly EU of Sole MeNB based network, three-tier UDHN with deterministic energy allocation to the two tiers of SeNBs, and three-tier UDHN with proposed SCM-EH policy i.e. integrated SSP and EH respectively. In those figures, the EU plots are demonstrated based on two hours apart to avoid congestion in the visualization. However, Figs. 22, 23, 24 which contain the hourly mean EU for Sole MeNB based network, three-tier UDHN with deterministic energy allocation (DEA) to the two tiers of SeNBs, and three-tier UDHN with proposed SCM-EH policy respectively, establishes the fact that during peak hours (around 2 pm) all the

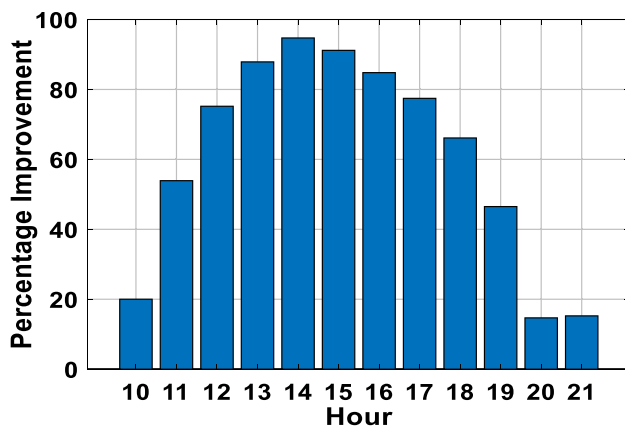


Fig. 31 Performance Improvement (in %) of three-tier UDHN with SCM-EH over MeNB in w.r.t Mean EU

scenarios sustain with better EU and lagging behind during non-peak hours (around 10 am of 9 pm).

However, the comparative analysis (as shown in Fig. 25) among the above scenarios reveals some interesting observations. Figure 30 which presents the percentage improvement of mean EU between sole MeNB based scenario and three-tier UDHN with DEA exhibits that three-tier UDHN with DEA in which the estimated required energy is allocated to the SeNBs well before initiation of user admission in a pre-determined fashion performs fairly well providing a maximum improvement of 73.82% in terms of Mean EU during peak hours (around 2 pm) but falls behind up to approximately 30.43% during non-peak hours (around 9 pm) due to less amount of inward traffic in those time intervals keeping the serving nodes in ‘ON’ or active mode for entire interval of communication. Having realized the significant concern, we propose the EH modulated by the sleeping strategies of the serving SeNBs scheme within the purview of the three-tier UDHN with acts in sync with the strategic sleeping modes of the serving nodes and harvests energy from the RF broadcast signal from UMa eNBs only during the sleeping interval. The process of SCM-EH is demonstrated in subsection 7.3.

Percentage improvements shown in Fig. 26 clearly validate that three-tier UDHN implemented with SCMEH stands superior in utilizing energy ensuring approximately 12.02% improvements in peak hours (around 2 pm) and 65.65% in non-peak hours (around 9 pm) than three-tier UDHN with deterministic energy allocation (DEA). The integration of SSP with EH addresses this issue and thereby brings novelty in ensuring an improved EU with an aim to meet the criteria for SGC. Finally, Fig. 31 visibly validates that the three-tier UDHN driven by SCM-EH policy in small cell tiers ensures superior EU than traditional MeNB based network

throughout the entire time interval irrespective of the variability of peak (94.72% improvement in Mean EU) or non-peak hours (20% improvement in Mean EU).

11 Conclusion

This paper analyses the performance of aforementioned network arrangements in terms of achieving SGC full term based on performance metrics viz. EE and AECR and EU. Simulation results validate that deployment of low powered SeNBs produces significant improvements in both the SGC metrics, especially in the peak hours. However, during non-peak hours due to less or no traffic condition, the proposed deployment scenarios often end up underutilizing available energy resources. To improve the performance even during non-peak hours, implementation of SCM-EH in small cell tiers (i.e. UMi-SCs and InHs) of three-tier UDHN and their integrated execution in the later stage are proposed. Simulation results and performance evaluations shown in Sect. 10 advocate that the implementation of SCM-EH (i.e. Sleep Cycle Modulated Energy harvesting policy) enabled SeNBs (both UMi-SCs and InHs) under three-tier UDHN can not only guarantee QoS requirements under concurrent time varying urban teletraffic condition but also achieves significant improvement EE metrics as well as EU (approximately 94% during peak hours and 20% during non-peak hours) compared to traditional sole MeNB based network architecture, hence ensuring SGC by profoundly regulating the estimated power consumption per hour basis throughout a day.

12 Future work

In forthcoming days, wireless technologies will be nearly as ubiquitous as chips, connecting not only people and their personal devices, but a great many other devices including automobiles and billions of other devices that traditionally have not had wireless connectivity. So, the important question arises that how close are we to reach the fundamental limits of densification, where further densification no longer allows (significant) further spectrum reuse and the accompanying throughput gains? In addition, the primary goal for future mobile networks should not be limited to increase the peak rates, but the rates that can be guaranteed to the majority of the locations in the geographical coverage area.. So as a future scope of this thesis, the user centric cell-free network architecture can be incorporated primarily in the third tier by replacing indoor hotspots to handle the expected avalanche of massive user densification and

to reach the aforementioned goal of future networks with uniformly high data rates to a greater extent. Certainly, the speculated changes will bring respective perturbation to the power consumption profile of the future networks. However, the proposed novel SCMEH policy may still be implemented to that sort of complex future network having ubiquitous deployment user centric cell-free architecture specifically in the indoor scenarios.

Acknowledgements The authors bestow their sincere gratitude to the Department of Electronics and Telecommunication Engineering, Jadavpur University, Kolkata for the pursuance of this research work.

Author contributions Arijeet Ghosh has performed the background study, designed and analyzed the proposed methodology, and written the manuscript. Iti Saha Misra has guided and finalized it.

Funding Not applicable.

Declarations

Conflict of interest Not applicable.

Ethical approval I have taken prior approval from my supervisor and research committee of the Department of Electronics and Telecommunication Engineering at Jadavpur University before submitting this research paper to Telecommunications Systems, Springer.

Consent for publication I sought my co-author's consent before communicating this manuscript to Telecommunications Systems, Springer. I declare that the manuscript is the authors' original work and is not communicated for publication elsewhere.

References

1. Alamu, O., Gbenga-Ilori, A., Adelabu, M., Imoize, A., & Ladipo, O. (2020). Energy efficiency techniques in ultra-dense wireless heterogeneous networks: An overview and outlook. *Engineering Science and Technology, an International Journal*, 23(6), 1308–1326.
2. Cisco, U. (2020). Cisco annual internet report (2018–2023). *White paper*, 10(1), 1–35.
3. IBEF. Telecommunication Report March 2022. tech. rep., Indian Brand Equity Foundation; 2022.
4. Chochliouros, I. P., Kourtis, M. A., Spiliopoulou, A. S., et al. (2021). Energy efficiency concerns and trends in future 5G network infrastructures. *Energies*, 14(17), 5392.
5. Kazi, B. U., & Wainer, G. A. (2019). Next generation wireless cellular networks: Ultra-dense multi-tier and multi-cell cooperation perspective. *Wireless Networks*, 25, 2041–2064.
6. Dhillon, H. S., Ganti, R. K., Baccelli, F., & Andrews, J. G. (2012). Modeling and analysis of K-tier downlink heterogeneous cellular networks. *IEEE Journal on Selected Areas in Communications*, 30(3), 550–560.
7. Saker, L., Micallef, G., Elayoubi, S. E., & Scheck, H. O. (2012). Impact of picocells on the capacity and energy efficiency of mobile networks. *Annals of telecommunications-Annales des télécommunications*, 67(3), 133–146.
8. Sidiq, S., Sheikh, J. A., Mustafa, F., & Malik, B. A. (2022). A new method of hybrid optimization of small cell range development and density for energy efficient ultra-dense networks. *Transactions on Emerging Telecommunications Technologies*, 33(7), e4476.
9. Matinmikko-Blue, M., Yrjölä, S., Ahokangas, P., Ojutkangas, K., & Rossi, E. (2021). 6G and the UN SDGs: Where is the Connection? *Wireless Personal Communications*, 121(2), 1339–1360.
10. Salahdine, F., Opadere, J., Liu, Q., Han, T., Zhang, N., & Wu, S. (2021). A survey on sleep mode techniques for ultra-dense networks in 5G and beyond. *Computer Networks*, 201, 108567.
11. GSMA. 2019 Mobile Industry Impact Report: Sustainable Development Goals. 2019.
12. Srivastava, A., Gupta, M. S., & Kaur, G. (2020). Energy efficient transmission trends towards future green cognitive radio networks (5G): Progress, taxonomy and open challenges. *Journal of Network and Computer Applications*, 168, 102760.
13. Alsharif, M. H., Nordin, R., Abdullah, N. F., & Kelechi, A. H. (2018). How to make key 5G wireless technologies environmental friendly: A review. *Transactions on Emerging Telecommunications Technologies*, 29(1), e3254.
14. Yao, M., Sohul, M. M., Ma, X., Marojevic, V., & Reed, J. H. (2019). Sustainable green networking: Exploiting degrees of freedom towards energy-efficient 5G systems. *Wireless Networks*, 25(3), 951–960.
15. Wu, J., Zhang, Y., Zukerman, M., & Yung, E. K. (2015). Energy-efficient base-stations sleep-mode techniques in green cellular networks: A survey. *IEEE communications surveys & tutorials*, 17(2), 803–826.
16. Liu, Q., & Zhang, Z. (2020). The analysis of coverage probability, ASE and EE in heterogeneous ultra-dense networks with power control. *Digital Communications and Networks*, 6(4), 524–533.
17. López-Pérez, D., De Domenico, A., Piovesan, N., Xinli, G., Bao, H., Qitao, S., & Debbah, M. (2022). A survey on 5G radio access network energy efficiency: massive MIMO, lean carrier design, sleep modes, and machine learning. *IEEE Communications Surveys & Tutorials*, 24(1), 653–697.
18. Zhang, S., Cai, X., Zhou, W., & Wang, Y. (2019). Green 5G enabling technologies: An overview. *IET Communications*, 13(2), 135–143.
19. Zhang, T., Zhao, J., An, L., & Liu, D. (2016). Energy efficiency of base station deployment in ultra dense HetNets: A stochastic geometry analysis. *IEEE Wireless Communications Letters*, 5(2), 184–187.
20. Lei, J., Chen, H., & Zhao, F. (2018). Stochastic geometry analysis of downlink spectral and energy efficiency in ultradense heterogeneous cellular networks. *Mobile Information Systems*, 1, 2018.
21. Liu, C., Natarajan, B., & Xia, H. (2015). Small cell base station sleep strategies for energy efficiency. *IEEE Transactions on Vehicular Technology*, 65(3), 1652–1661.
22. Soh YS, Quek TQ, Kountouris M. Dynamic sleep mode strategies in energy efficient cellular networks. In: 2013 IEEE International Conference on Communications (ICC) 2013 Jun 9 (pp. 3131–3136). IEEE.
23. Soh, Y. S., Quek, T. Q., Kountouris, M., & Shin, H. (2013). Energy efficient heterogeneous cellular networks. *IEEE Journal on selected areas in communications*, 31(5), 840–850.
24. Samarakoon S, Bennis M, Saad W, Latva-Aho M. Dynamic clustering and sleep mode strategies for small cell networks. In: 2014 11th International Symposium on Wireless Communications Systems (ISWCS) 2014 Aug 26 (pp. 934–938). IEEE.

25. Samarakoon, S., Bennis, M., Saad, W., & Latva-Aho, M. (2015). Dynamic clustering and on/off strategies for wireless small cell networks. *IEEE Transactions on Wireless Communications*, 15(3), 2164–2178.
26. Samarakoon S, Bennis M, Saad W, Latva-Aho M. Opportunistic sleep mode strategies in wireless small cell networks. In: 2014 IEEE International Conference on Communications (ICC) 2014 Jun 10 (pp. 2707–2712). IEEE.
27. Tang, J., Shojaeifard, A., So, D. K., Wong, K. K., & Zhao, N. (2018). Energy efficiency optimization for CoMP-SWIPT heterogeneous networks. *IEEE Transactions on Communications*, 66(12), 6368–6383.
28. Tran GK, Shimodaira H, Rezagah RE, Sakaguchi K, Araki K. Practical evaluation of on-demand small cell ON/OFF based on traffic model for 5G cellular networks. In: 2016 IEEE Wireless Communications and Networking Conference 2016 Apr 3 (pp. 1–7). IEEE.
29. Mao, Y., Luo, Y., Zhang, J., & Letaief, K. B. (2015). Energy harvesting small cell networks: Feasibility, deployment, and operation. *IEEE Communications Magazine*, 53(6), 94–101.
30. Perera, T. D., Jayakody, D. N., Sharma, S. K., Chatzinotas, S., & Li, J. (2017). Simultaneous wireless information and power transfer (SWIPT): Recent advances and future challenges. *IEEE Communications Surveys & Tutorials*, 20(1), 264–302.
31. Zheng, Z., Zhang, X., Cai, L. X., Zhang, R., & Shen, X. (2014). Sustainable communication and networking in two-tier green cellular networks. *IEEE Wireless Communications*, 21(4), 47–53.
32. Lv T, Gao H, Shi Z, Su X. Energy efficiency of two-tier heterogeneous networks with energy harvesting. In: 2017 IEEE International Conference on Communications (ICC) 2017 May 21 (pp. 1–6). IEEE.
33. Guntupalli, L., Gidlund, M., & Li, F. Y. (2018). An on-demand energy requesting scheme for wireless energy harvesting powered IoT networks. *IEEE Internet of Things Journal*, 5(4), 2868–2879.
34. Landstrom S, Murai H, Simonsson A. Deployment aspects of LTE pico nodes. In: 2011 IEEE International Conference on Communications Workshops (ICC) 2011 Jun 5 (pp. 1–5). IEEE.
35. Baddeley A, Bárány I, Schneider R. Spatial point processes and their applications. *Stochastic Geometry: Lectures Given at the CIME Summer School Held in Martina Franca, Italy, September 13–18, 2004* 2007: 1–75.
36. DoT . Monthly Telecommunication Report February 2022. tech. rep., Department of Telecommunication, Govt. of India; 2022.
37. KMC . Population Density of Kolkata as on March 2022. tech. rep., Kolkata Municipal Corporation; 2022.
38. 3GPP . Study on channel model for frequencies from 0.5 to 100 GHz (Release 16). tech. rep., 3GPP TR 38.901; 2018.
39. Afshang, M., Saha, C., & Dhillon, H. S. (2017). Nearest-neighbor and contact distance distributions for Matérn cluster process. *IEEE Communications Letters*, 21(12), 2686–2689.
40. Mukherjee S. Analytical modeling of heterogeneous cellular networks. Cambridge University Press; 2014 Jan 23.
41. Liu Y, Li W, Li Y. Network traffic classification using k-means clustering. In: Second international multi-symposiums on computer and computational sciences (IMSCCS 2007) 2007 Aug 13 (pp. 360–365). IEEE.
42. Hartigan, J. A., & Wong, M. A. (1979). Algorithm AS 136: A k-means clustering algorithm. *Journal of the royal statistical society. Series c (applied statistics)*, 28(1), 100–108.
43. Selim, S. Z., & Ismail, M. A. (1984). K-means-type algorithms: A generalized convergence theorem and characterization of local optimality. *IEEE Transactions on pattern analysis and machine intelligence*, 1, 81–87. <https://doi.org/10.1109/TPAMI.1984.4767478>
44. Bottou, L., & Bengio, Y. (1994). Convergence properties of the k-means algorithms. *Advances in neural information processing systems*, 7.
45. Demir ÖT, Björnson E, Sanguinetti L. 2021 Foundations of user-centric cell-free massive MIMO. In: Foundations and Trends® in Signal Processing. 14(3–4):162–472.
46. PiovesanN, G. A. F., Miozzo, M., Rossi, M., & Dini, P. (2018). Energy sustainable paradigms and methods for future mobile networks: A survey. *Computer Communications*, 119, 101–117.
47. Leon-Garcia A. Probability and random processes for electrical engineering. Chapter 12. Pearson Education India; 1994.
48. Ghosh, A., & Misra, I. S. (2017). A joint CAC and dynamic bandwidth allocation technique for capacity and QoS analysis in heterogeneous LTE based BWA network: few case studies. *Wireless Personal Communications*, 97(2), 2833–2857. <https://doi.org/10.1007/s11277-017-4637-x>
49. Galiotto, C., Pratas, N. K., Doyle, L., & Marchetti, N. (2017). Effect of LOS/NLOS propagation on 5G ultra-dense networks. *Computer Networks*, 19(120), 126–140.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.



Arijeet Ghosh completed his Master's in Electronics and Telecommunication Engineering from West Bengal University of Technology (MAKAUT), Kolkata, India in 2012. Presently, he is working as Ph.D. Scholar in the Department of Electronics and Telecommunication Engineering, Jadavpur University, Kolkata, India. Previously he had worked as an Assistant Professor at Bengal College of Engineering and Technology followed as Project Fellow in a UGC-funded project titled "Call Admission Control for the Optimisation of Resource Utilisation" in the UPE Phase II scheme, under Prof. Iti Saha Misra, Department of ETCE, Jadavpur University. Further, he has also worked as a Senior Research Fellow under State Govt. Fellowship Scheme in the Department of ETCE, Jadavpur University. He has authored several international conferences and SCI-indexed journal papers. His current research interests are in the areas of Resource allocation, Energy Management, and network planning in Ultra-dense Heterogeneous BWA Networks.



Itri Saha Misra received her B.Tech. degree in Radio Physics and Electronics from Calcutta University, Kolkata, India in 1989, and M.Tech. degree in Electronics and Telecommunication Engineering from Jadavpur University, India in 1991. After completion of Ph.D. (Engg.) from Jadavpur University in 1997, she is currently a Professor in the same department. She has authored more than 250 research papers in refereed Journals and International Conferences and has filed several patents. She is the author

of a widely acclaimed textbook on “Wireless Communication and Networks: 3G and Beyond” by McGraw Hill. She is the Senior Member of IEEE, ComSoc Chair, Kolkata Chapter, and the founder Chair of Women in Engineering Affinity Group (WIEAG), IEEE Kolkata Section. Under her leadership, WIE AG won the first prize in 2007 and IEEE ComSoc Kolkata Chapter won the 2015 Chapter Achievement

Award. She is also the recipient of the Career Award for Young Teachers by the All India Council for Technical Education (AICTE) for the financial year 2003–2004 and obtained the IETE Gowri Memorial award in 2007 in the best paper category in the general topic of “4G networks: Migration to the Future”. She has been a reviewer of several IEEE and other journals and conferences like IEEE TWC, IEEE TMC, Communication Letters, GLOBECOM, VTC, etc. She was the General Chair for IEEE International 5G Summit and GISFI Meeting in Kolkata, in March 2017. She has handled many projects from Govt. of India including DST FIST, DST PURSE, UGC-UPE, AICTE, etc. Her current research interests are in areas of VoIP, Cognitive Radio Networks, Energy Efficient IoT solutions, Mobility Management, Wireless Body Area Networks, Call Admission control and packet scheduling in cellular and BWA networks, smart antenna systems, etc.