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Energy Efficiency and Throughput Optimization in 5G Heterogeneous Networks

Rabia Arshad [1,2], Muhammad Farooq-i-Azam [1,*], Raheel Muzzammel [3], Arfan Ghani [4] and Chan Hwang See [5]

1 Department of Electrical and Computer Engineering, COMSATS University Islamabad, Lahore Campus, Lahore 54600, Pakistan
2 Department of Computer Science, University of Central Punjab, Lahore 54000, Pakistan
3 Department of Electrical Engineering, University of Lahore, Lahore 54000, Pakistan
4 Department of Computer Science and Engineering, School of Engineering, American University of Ras Al Khaimah, Ras Al Khaimah 10021, United Arab Emirates; arfan.ghani@aurak.ac.ae
5 School of Computing, Engineering and the Built Environment, Edinburgh Napier University, Edinburgh EH10 5DT, UK
* Correspondence: fazam@cuilahore.edu.pk

Abstract: Device-to-device communication offers a promising technology for the 5G network that aims to enhance the data rate, reduce latency and cost, improve energy efficiency, and provide other desired features. The 5G heterogeneous network (5GHN) with a decoupled association strategy of downlink (DL) and uplink (UL) is a promising solution for the challenges faced in the 4G heterogeneous network (4GHN). The research presented in this paper evaluates the performance of the 4GHN as well as a DL-and-UL-coupled (DU-CP) access scheme in comparison with the 5GHN with a DL-and-UL-decoupled (DU-DCP) access scheme in terms of the energy efficiency and network throughput in four-tier heterogeneous networks. The energy and throughput are optimized for both scenarios, i.e., DU-CP and DU-DCP, and the results are compared. Detailed performance analyses of the DU-CP and DU-DCP access schemes were conducted with the help of comparisons of the results achieved by implementing a genetic algorithm (GA) and particle swarm optimization (PSO). Both of these algorithms are suited for the non-linear problem under investigation in which the search space is large. The simulation results have shown that the DU-DCP access scheme gives a better performance than the DU-CP scheme in a four-tier heterogeneous network in terms of network throughput and energy efficiency. The PSO achieves an energy efficiency of 12 Mbits/joule for the DU-CP and 42 Mbits/joule for the DU-DCP, whereas the GA yields an energy efficiency of 28 Mbits/joule for the DU-CP and 55 Mbits/joule for the DU-DCP. The performance of the proposed method is compared with those of three other schemes. The results show that the DU-DCP scheme using the GA outperforms the compared methods.

Keywords: cellular networks; D2D communication; energy efficiency; heterogeneous networks; resource allocation; uplink and downlink

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1. Introduction

Device-to-device (D2D) communication is an important part of newer generations of cellular networks due to its low latency and other advantages. It permits user equipment (UE) in close proximity to communicate via a direct link instead of routing communication through the network. In D2D communication, devices can transmit or receive data without assistance from the base station (BS); thus, the overloading of the BS is reduced, and the system throughput is increased. D2D communication underlays the existing cellular network and shares resources of users, which can induce co-channel interference. Reducing this co-channel interference is one of the important challenging tasks in D2D communication. For this reason, many research investigations in the communication world have presented various schemes from different perspectives, e.g., radio networks based on a cloud, energy-aware communications, and dense heterogeneous networks via a wireless channel [1,2]. Among all of the proposed schemes, dense heterogeneous networks (HNs) that are based on Long-Term Evolution-Advanced (LTE-A) may be particularly useful because aggregation can result in better energy efficiency [3] and greater bandwidth. Especially with 5G, small cells (SCs), which include pico cells and femto cells, can be deployed with ease to enhance the capacity of 5G via the off-loading of macro-cell (MC) traffic to the SCs.

One of the major problems in D2D communication is interference management in resource allocation. Resource sharing with cellular users causes interference, which affects the performance of the network. In [4], the authors proposed a strategy for interference management using orthogonality between D2D links and cellular links. On the other hand, direct D2D communication is not possible if the distance between the devices is increased. Thus, a relay must be inserted between the devices, and it can become a two-hop communication. In [5], the authors proposed an algorithm for two-hop D2D communication based on a relay to increase the performance of the network. In a 5G network, the number of D2D users can be more than the number of cellular users in some scenarios, and this condition is considered to be an ultra-dense D2D network. For this scenario, another approach needs to be followed for efficient resource allocation. Network resources will be allocated first to D2D pairs and then to cellular users. The authors in [6] proposed an alternate resource allocation algorithm for an ultra-dense cellular network.

The deployment of 5G meets various requirements of D2D applications, such as ensuring availability, increasing reliability, and minimizing latency. Moreover, it also provides an opportunity to increase energy efficiency and enhances security. The primary enabling technologies that 5G can provide include advanced coding methods, congestion-reducing techniques, and support for heterogeneous networks (HN) as well as software-defined networks. A simplified HN is shown in Figure 1, and a D2D model is illustrated in Figure 2.

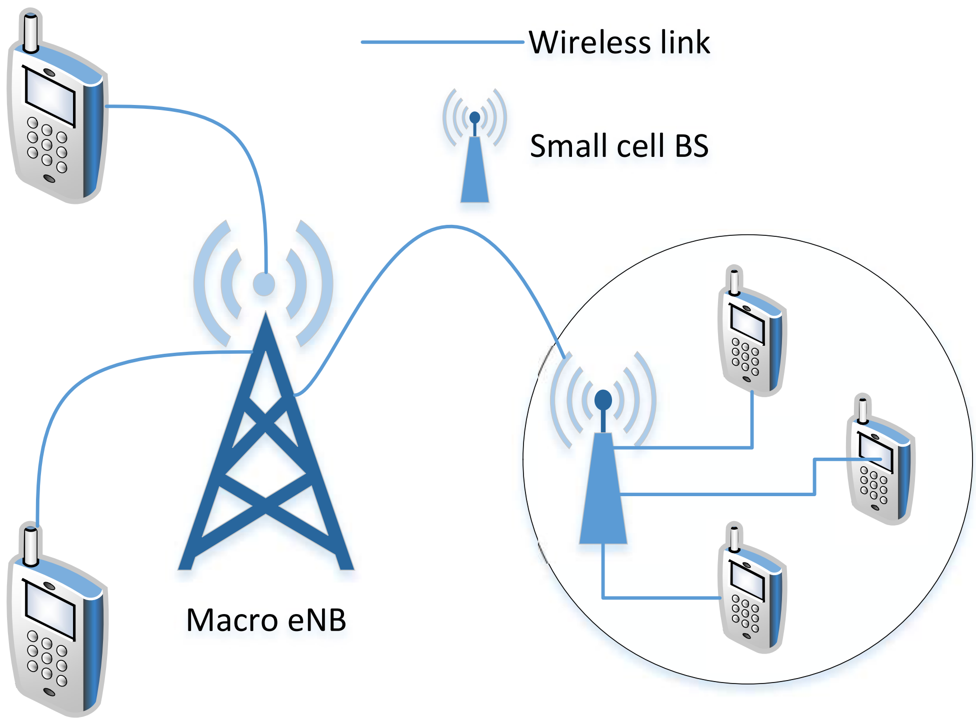

Figure 1. Heterogeneous network.

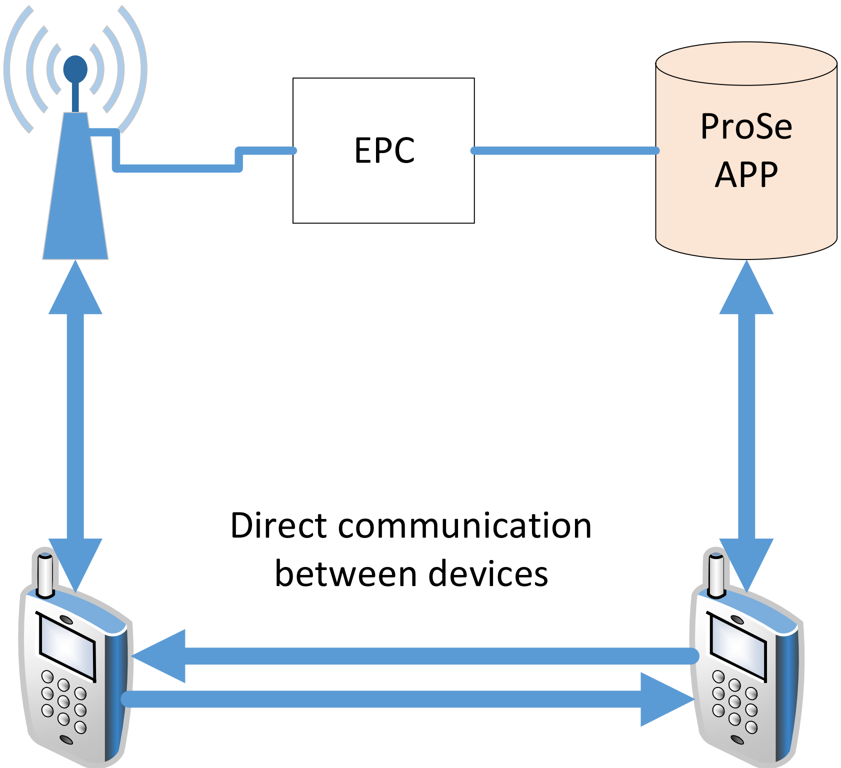

Figure 2. D2D model based on architecture in 3GPP.

Wireless devices and mobile phones with applications such as live gaming, video streaming, and social networking have induced rapid growth in mobile traffic. After a deep analysis of these trends, it has been predicted that almost 71% of IP traffic will be utilized by wireless devices by the year 2022 [7]. Industry and academic organizations have initiated research into new areas [8–11], e.g., massive multiple-input–multiple-output (MIMO), moving toward the millimeter wave (mmWave) spectrum, and deep densification for handling flooded mobile traffic that has been predicted in advance. Deployment of small BSs in the existing 3G network with a macro BS has led to the achievement of extreme densification among all of these methods. By achieving this task, it was possible to bring end users closers to the radio access nodes [12]. BSs in femto cells and micro cells have a small size, reduced cost, and low power consumption. Therefore, extreme densification has achieved targets such as enhanced coverage, improvement in capacity for cell users, and traffic off-loading in the 4GHN [13–16]. The 4GHN makes use of the DU-CP scheme in which the MS is associated in UL and DL with the same BS. The DU-CP is based on the strong signal-to-interference-and-noise ratio (SINR) in DL offered from the macro BS and many small BSs. A low-powered micro BS indicates that the MS might be associated in UL and DL with controlling a macro BS with a higher SINR. Therefore, an MS that is associated with a macro BS will have greater interference during UL in closely located BSs. For this reason, the DU-CP access method causes performance degradation in the 4GHN. In this context, an improved cell association scheme was given by many authors in [17–19] in which an MS can associate with a different BS or the same BS in UL and DL in an HN. This improved scheme is known as the DL-and-UL-decoupling (DU-DCP) access scheme. This scheme has represented the gains of sum rates in dense HNs by an order of 200–300% [19].

Recently, energy efficiency has been considered an important aspect of wireless heterogeneous networks. Many energy efficiency techniques for wireless networks have been proposed in the literature, and some of these techniques have been investigated specifically for the energy efficiency of a base station (BS) [20–22]. In [23], the authors made a classification system for the energy efficiency techniques consisting of five types. Table 1 provides a summary of these classifications.

Table 1. Summary of energy efficiency techniques.

Technique	Classification
Network planning and deployment	• Optimization of BS density • HN deployment
Optimizing radio transmission processes	• Beam forming • Resource allocation
Energy harvesting	• From natural environment • With the help of RF
Hardware-based solution	• RF chain designing • Cloud-based technique

Heuristic algorithms have been designed to tackle different problems in 5G HNs, and many research investigations have been conducted related to these in order to improve the performance of the network. The genetic algorithm (GA) and particle swarm optimization (PSO) are among the well-known optimization algorithms that may be used for this purpose [24]. Whereas the GA is based on various biological techniques, such as inheritance, selection, crossover, and mutation, the PSO uses the swarming behavior of certain living organisms.

In both the PSO and GA [25], a collection of solutions is generated randomly as the starting point, and each solution is termed a population, which is represented by a series of values. The GA helps evolve the population by several generations, during which the most important point is the mutation, as it produces a pseudorandom change. However, in the PSO, each solution moves inside the design space. In each step, the position of each candidate solution changes according to its current speed. Each algorithm has unique characteristics, and the performance of either of the two algorithms depends on the nature of the problem. Whereas the PSO may be good at solving unconstrained optimization problems with continuous variables, the GA is better suited to constrained problems with discrete variables. The GA is also able to handle the complex problems commonly encountered in engineering systems with ease due to its parallel nature [26]. Table 2 compares both of these algorithms and lists the prominent features of the GA and PSO [25–29].

Table 2. Comparison of GA and PSO.

Algorithm	Pros	Cons	Applications
GA	User can explore search space without any loss of partial solutions. Many parts of solution space can be explored simultaneously.	Large computation time, difficult looping structure, higher complexity, sometimes not suitable for reaching decisions.	Data clustering, traveling salesman problem, wireless sensor networks, neural networks, vehicle routing problem.
PSO	Short time interval for computation as there are a few parameters only. Efficiency is good.	It may be difficult to define initial parameters. May not be suitable for non-coordinated system.	Load prognostication, ideal power flow, volatile power management.

The GA and PSO have previously been used in 5GHNs for various purposes, including energy efficiency and throughput maximization. In [30], the authors propose a GA-based energy efficiency scheme for 5GHNs called ESGA-5G. The GA-based scheme performs better than the PSO and achieves a higher percentage of energy efficiency compared to the PSO. In another work [31], energy optimization is investigated in energy-harvesting-enabled mmWave unmanned aerial vehicle (UAV) HNs. The results show that the performance of the GA and that of the PSO achieve comparable network energy efficiencies. The GA and PSO, along with other algorithms, are used for energy efficiency and throughput maximization in mmWave- and microwave-based 5GHNs in [32]. This work compares many algorithms for the optimization of energy and throughput. The results show that the GA performs better than many other algorithms, including the PSO, for both energy efficiency and throughput maximization.

In our work, we leverage the PSO and GA to investigate and compare the DU-CP and DU-DCP cell association strategies. Previously, the DU-CP and DU-DCP schemes were studied only in the context of two-tier and three-tier HNs. In this work, we investigate these schemes for cell association in four-tier HNs in terms of energy efficiency and network throughput. The main contributions of this paper are as follows:

- The performances of the DU-CP and DU-DCP access schemes are evaluated and compared in four-tier HNs. The previous work considered only two-tier or three-tier HNs.
- To optimize the results of the two schemes, a maximization problem is formulated.
- We use the GA and PSO for the comparison of both schemes in terms of network throughput and energy efficiency.

Simulation experiments are conducted for a performance evaluation of the two strategies. The results reveal that the DU-DCP cell association strategy performs better than the DU-CP method in terms of both throughput and energy efficiency. Furthermore, the GA produces better results compared to those of the PSO for the two metrics using either the DU-CP or DU-DCP cell association strategy. The performance of the DU-DCP with the GA is also compared with three other methods. The results show that our proposed strategy has a significant performance advantage over the compared methods.

2. Related Work

In an HN, cell association is an important factor that ensures energy efficiency by load balancing and interference management. Furthermore, it is also leveraged for throughput maximization. Cell association can be defined as the procedure that searches for a suitable BS for user equipment according to a given set of parameters [33]. Several cell association methods have been discussed in the literature for various sets of metrics [34–36].

Yang et al. [37] considered the received signal power and path losses to formulate cell association methods in inter-frequency and intra-frequency conditions. Singh et al. [38] proposed an algorithm based on cell association to enhance the sum rate and load balancing between a small BS and a macro BS. For the rate coverage probabilities in DL and UL among a decoupled association, Elshaer et al. [39] proposed an expression using stochastic geometric tools. Celik et al. [40] considered some objectives, for example, the maximum and minimum fairnesses, to investigate the resource allocation for non-orthogonal multiple access strategies for a decoupled HN. Elshaer et al. [41] formulated a strategy using a trail network of small cells that considers some constraints, e.g., the cell load and backhaul capacity.

Smiljkovikj et al. [42] formulated an expression representing the associated probability for devices in a decoupled HN and also described its effect on the overall throughput gain in an HN using stochastic geometry. Shi et al. [43] investigated the user association in a small cell (typically sub-6GHz) as well as in an mmWave small cell using the DL-and-UL-decoupling access strategy. Jia et al. [44] explored and evaluated the dual connection for all possible DL-and-UL-decoupled access types. After simplifying the conditions of the association, he derived the association and the UL coverage probabilities by using stochastic geometric tools. An optimally distributed dynamic scheme based on time-division multiplexing (TDM) was proposed by Razlighi et al. [45] by investigating the throughput maximization and cell association in a DU-DCP HN.

Cell association strategies were explored by Sekander et al. [46] using game theory, and the authors represented the efficacies of the proposed models in terms of key performance indicators (KPIs), e.g., decoupled and coupled associations, user rates, and the number of non-associated users in UL and DL in the DU-DCP HN network. A frequency reuse method was proposed by Zheng et al. [47] to explore cell association for the mitigation of interference in the DU-DCP HN environment. Ali et al. [48] solved many problems, including cell association and power control, by keeping in mind the maximization of the overall data rate via the use of the outer approximation algorithm (OAA).

Efficient resource allocation and utilization were studied by Elshaer et al. [49] via the formulation of the association of cells method in a DU-DCP HN. Chen et al. [50] formulated a spectrum allocation and load-balancing technique using machine learning to maximize the sum rate in the DU-DCP system. A trade-off between the energy and spectral efficiencies during UL transmission in a three-tier HN with macro cells and pico cells associated with D-D communication was examined by Pervaiz et al. [51]. Resource-sharing techniques with energy-efficient maximization for a DL transmission in an HN were studied by Naqvi et al. [52]. Omar et al. [53] explored energy efficiency and spectral efficiency using a sub-6 GHz mmWave small cell during downlink transmission for a multi-tier HN. A summary of the reviewed work is provided in Table 3.

Table 3. Summary of related work.

Reference	Description	Objective	Tier
[37]	Path loss and received signal power were considered	Maximize data rate	2-tier
[38]	Hungarian algorithm is implemented in order to balance traffic load	Maximize data rate	2-tier
[39]	Rate coverage for mmWave HN is analyzed using stochastic geometry	Rate and coverage probabilities	2-tier
[40]	Resource allocation is investigated for max–min fairness problem	Maximize data rate	2-tier
[41]	Small-cell network of Vodafone is used for cell association strategy	Throughput maximization	2-tier
[42]	Impact of association probability on network throughput in DU-DCP HN using stochastic geometry	Throughput gain and association	2-tier
[43]	Stochastic geometry is used to derive the general expressions of association and coverage probability	Throughput maximization	3-tier
[44]	Cross-tier dual-connectivity DC and decoupled uplink and downlink association are integrated	Association and coverage probabilities	3-tier
[45]	Dynamic time-division duplex scheme is proposed	Throughput maximization	2-tier
[46]	Game theory is used to explore cell association	Rate maximization	2-tier
[47]	Interference mitigation using novel frequency reuse scheme based on sectorization	Maximize data rate	3-tier
[48]	Joint user association, admission control, and power allocation problem is considered	Throughput maximization	2-tier
[49]	Efficient resource utilization and mitigation of interference is analyzed	Minimize interference	3-tier
[50]	Spectrum allocation techniques using machine learning	Maximize data rate	3-tier
[51]	Trade off between energy and spectral efficiency in UL transmission	Rate maximization	3-tier
[52]	Resource sharing for energy efficient maximization in downlink	Rate maximization	2-tier

Table 3. *Cont.*

Reference	Description	Objective	Tier
[53]	Downlink performance of an HN is investigated using stochastic geometry	Coverage probability and rate maximization	3-tier
This	Performance of 4-tier HN is investigated using PSO and GA	Rate maximization and energy efficiency	4-tier

After a detailed review of research work from the past, it is concluded that the DU-CP scheme in the 4GHN provides a sub-optimal solution for increasing heterogeneity as well as a significant transmission power among low-powered small BSs and high-powered macro BSs. The following gaps remained untouched by researchers in previous works:

- The DU-DCP access scheme is analyzed by the researchers studying only two-tier and three-tier HNs.
- The performance analysis of the DU-CP scheme versus the DU-DCP scheme in a four-tier HN is an open research area as not much research has been conducted regarding this aspect.
- The existing research does not consider mobile data traffic from the user point that is associated with UL and DL in a four-tier HN.

Hence, after reviewing the research conducted in the past and considering the gaps, this research work takes into account the performance analyses of the DU-CP access in comparison with those of the DU-DCP access for cell association, energy efficiency, and maximization of the sum rate in a four-tier HN. The research work presented in this paper compares the DU-CP access and the DU-DCP scheme using heuristic algorithms in a four-tier HN. Another unique aspect of our work is the exploitation of the GA and PSO for the performance comparison of the DU-CP and DU-DCP access schemes in a four-tier HN.

3. System Model

In one-tier HN [54,55], the network carrier has direct connections with the UEs, which are used to deliver data. In a two-tier HN, micro cells are deployed in addition to macro cells. Therefore, some UEs are served through the micro cells, which are, in turn, served by the macro cells. In a three-tier HN, femto and pico cells are deployed with the macro cells. In a four-tier HN additional communication paradigm, such as ours, D2D communication is also possible.

In four-tier HN communication, wireless signals are transmitted to and from different tiers with different levels of power. It can be a source of interference for a BS if the neighboring BSs have high transmission powers. Therefore, the transmission power is allocated such that interference is avoided. Hence, the number of mobile users that a BS can serve is dependent on its coverage resulting from the transmission power. Therefore, in four-tier communication, multiple BSs can serve a large number of users by using the cell associations of different tiers [56–58]. However, this added benefit is at the cost of additional complexity. It is easier to implement and optimize, for example, a one-tier network since the number of variables to be optimized is small. However, in a four-tier network, the number of variables to be optimized is large due to the different tiers. Hence, the implementation and optimization of a four-tier HN are relatively complex compared to lower-tier HNs.

According to [56], the DU-CP and DU-DCP access schemes, in terms of cell association, have been explored in a four-tier HN. Two scenarios of communication in the traditional DU-CP access, as well as the innovative DU-DCP access, related to cell association in a four-tier HN, are shown in Figures 3 and 4, respectively. These scenarios are also described as follows:

- **DU-CP HN:** In this scenario, the MS m is associated with the same BS, e.g., a small eNB, macro eNB, WiFi, and D2D, in the UL and DL methods based on the DU-CP access scheme, as given in Figure 3. Here, all MSs that are associated with a macro eNB during UL and DL near the cell edge create interference with a small eNB while transmitting in UL using the DU-CP HN, which is shown by the red dotted lines in Figure 3.

- **DU-DCP HN:** In this scenario, the MS m can be associated with a different or the same BS, e.g., a small eNB, macro eNB, WiFi, and D2D, in UL and DL based on the DU-DCP access scheme, as shown in Figure 4. In this type, all MSs near the cell edge are associated with different BSs in UL and DL, and performance losses are avoided in the DU-DCP HN due to interference during UL in the DU-CP.

A four-tier HN, as described in [56], consisting of a small eNB, macro eNB, D2D, and WiFi, is considered in this paper in which all base stations and mobile stations (MS) are distributed uniformly within the network. The four-tier HN nodes try to avoid inter-tier interference by operating at different frequencies. A small eNB, D2D, and WiFi serve as the traffic off-loader by operating at a lower power. Let there be M number of MSs so as to form the set $\mathcal{M} = \{1, 2, 3, \cdots, M\}$. The BS b, where $b \in \mathcal{B}$, and $\mathcal{B} = \{eNB, WiFi, D2D\}$, serves the mobile station m in UL and DL for the DU-CP HN. However, the MS m aims to be served by a different or the same BS in UL and DL in the DU-DCP HN, with a link $l \in \mathcal{L}$, where $\mathcal{L} = \{dl, ul\}$.

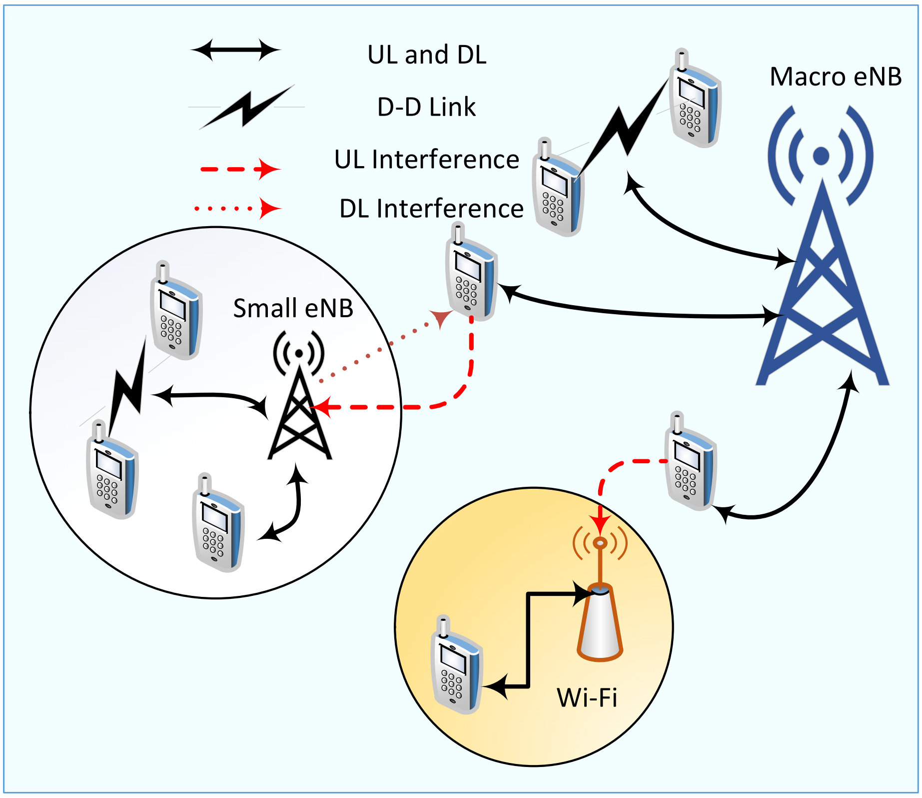

Figure 3. Four-tier DU-CP heterogeneous network.

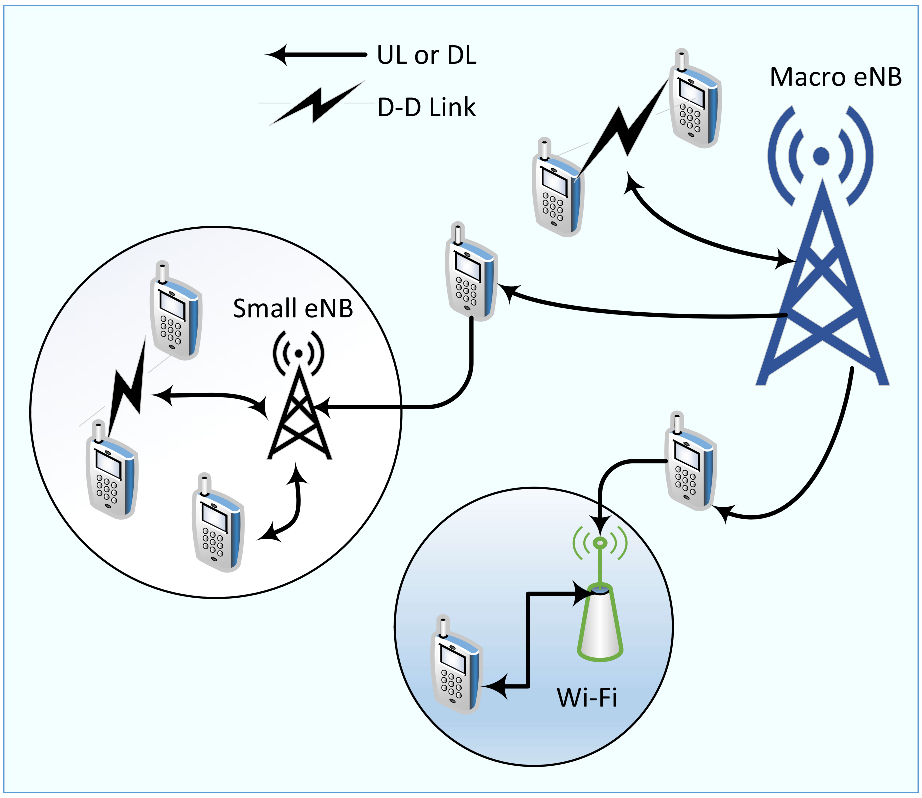

Figure 4. Four-tier DU-DCP heterogeneous network.

Let the variables u_{ulm} and u_{dlm} represent that MS $m \in \mathcal{M}$ is admitted for communication in UL or DL, respectively, as follows

$$u_{ulm} = \begin{cases} 1 & \text{MS } m \text{ is admitted in UL,} \\ 0 & \text{MS } m \text{ is not admitted in UL.} \end{cases}$$

$$u_{dlm} = \begin{cases} 1 & \text{MS } m \text{ is admitted in DL,} \\ 0 & \text{MS } m \text{ is not admitted in DL.} \end{cases}$$

Similarly, let the variables $w_{ulm,b}$ and $w_{dlm,b}$ represent that the MS m is associated with the BS b for communication in UL and DL, respectively, as follows:

$$w_{ulm,b} = \begin{cases} 1 & \text{MS } m \text{ is associated with } b \text{ in UL,} \\ 0 & \text{MS } m \text{ is not associated with } b \text{ in UL.} \end{cases}$$

$$w_{dlm,b} = \begin{cases} 1 & \text{MS } m \text{ is associated with } b \text{ in DL,} \\ 0 & \text{MS } m \text{ is not associated with } b \text{ in DL.} \end{cases}$$

The channel gain g_{mb} in the case that the MS m is associated with the BS b is given by:

$$g_{mb} = \overline{g_m} \zeta G_o \left(\frac{dt_o}{dt} \right)^{\alpha}, \quad (1)$$

where g_m represents the Rayleigh random variable, G_o is the antenna gain, ζ is the zero-mean Gaussian random variable, dt is the distance between the MS m and the BS b, α is the path-loss exponent. The path loss is given by:

$$PL[dB] = L_{pa}(dt_o) + 10\alpha \log \left(\frac{dt}{dt_o} \right) + \zeta, \quad (2)$$

where $L_{pa}(dt_o)$ is the average path loss at a reference distance dt_o. The channel capacities of the MS m, which is associated with the BS b in DL and UL, are given by:

$$C_{dlm,b} = log_2(1 + \gamma_{dlm,b}), \quad (3)$$

$$C_{ulm,b} = log_2(1 + \gamma_{ulm,b}), \quad (4)$$

where $\gamma_{ulm,b}$ and $\gamma_{dlm,b}$ are the signal-to-interference-and-noise ratios in UL and DL, respectively. As discussed in [56], two types of SINRs are experienced both in UL and DL when the MS m associates with the BS b.

- **DL-DL Interference:** Let us consider an MS m that is associated with a BS b to receive data from it in DL. A neighboring base station b', which is also transmitting in DL to another MS m', will cause interference in the communication between the BS b and MS m. This interference is termed DL-DL interference, and the SINR γ_{dd} at the MS m with interference from the neighboring base stations b' is as follows:

$$\gamma_{dd} = \frac{P_b g_{bm}}{\sum_{b'} P_{b'} g_{b'm} + N_o}, \quad (5)$$

  where P_b and $P_{b'}$ are the transmission powers of the base stations b and b', respectively, in DL; g_{bm} and $g_{b'm}$ are the channel gains from the respective base stations b and b' to m; and N_o is the noise power.
- **UL-DL Interference:** When an MS m is associated with a BS b to receive data from it in DL, then a neighboring MS m' will cause interference in the communication between the MS m and the BS b during transmission to a base station b' in UL. In this case, the SINR γ_{ud} at the MS m with interference from m' is as follows:

$$\gamma_{ud} = \frac{P_b g_{bm}}{\sum_{m'} P_{m'} g_{m'm} + N_o}, \quad (6)$$

  where $P_{m'}$ is the transmission power of m' in the uplink, and $g_{m'm}$ is the gain of the channel from m' to m.
- **UL-UL Interference:** If an MS m transmits data to an associated BS b in UL, then the communication in UL between another MS m' with its associated BS b' will be a source of interference for the former communication link in UL, and this is referred to as UL-UL interference. In this case, the SINR γ_{uu} at the BS b with interference from m' is as follows:

$$\gamma_{uu} = \frac{P_m g_{mb}}{\sum_{m'} P_{m'} g_{m'b} + N_o}, \quad (7)$$

  where P_m is the transmission power of m in the uplink, and g_{mb} and $g_{m'b}$ are the channel gains from the respective mobile stations m and m' to b.
- **DL-UL Interference:** Let us consider an MS m transmitting data to an associated BS b in UL. A BS b' transmitting to another MS m' in DL will cause interference to the UL communication between the MS m and the BS b. In this case, the SINR γ_{du} at the BS b with interference from b' is as follows:

$$\gamma_{du} = \frac{P_m g_{mb}}{\sum_{b'} P_{b'} g_{b'b} + N_o}, \quad (8)$$

  where $g_{b'b}$ is the channel gain from b' to b.

The energy efficiency of the system is obtained by considering the ratio of the obtained data rate and the transmitted power. Considering a W bandwidth, this is given by:

$$\epsilon = W\left[\left(\frac{u_{dlm}}{P_b}\log_2(1+\gamma_{dlm,b})\right) + \left(\frac{u_{ulm}}{P_m}\log_2(1+\gamma_{ulm,b})\right)\right], \quad (9)$$

where

$$\gamma_{dlm,b} = \frac{P_b g_{bm}}{\sum_{b'} P_{b'} g_{b'm} + \sum_{m'} P_{m'} g_{m'm} + N_o}, \quad (10)$$

$$\gamma_{ulm,b} = \frac{P_m g_{mb}}{\sum_{m'} P_{m'} g_{m'b} + \sum_{b'} P_{b'} g_{b'b} + N_o}. \quad (11)$$

This paper describes cell association and sum-rate maximization using a traditional DU-CP method and innovative DU-DCP access methods in the HN. Table 4 gives a summary of the notations and symbols used in this paper.

Table 4. Symbols and notations.

M	Total number of mobile stations
B	Total number of base stations
g_{xy}	Channel gain from x to y
N_o	White Gaussian noise
dt	Distance between m and b
dt_o	Reference distance according to antenna
ϵ	Energy efficiency
W	Bandwidth
α	Path-loss factor
ζ	Gaussian random variable
$\overline{g_m}$	Rayleigh variable
P_m	Transmission power of m in UL
P'_m	Transmission power of m' in UL
P_b	Transmission power of b in DL
P'_b	Transmission power of b' in DL
$P^{dl}_{m,b}$	Received power by m associated with b in DL
$P^{ul}_{m,b}$	Received power by b associated with m in UL
γ_{dd}	SINR at the MS m in the case of DL-DL interference
γ_{ud}	SINR at the MS m in the case of UL-DL interference
γ_{uu}	SINR at the BS b in the case of UL-UL interference
γ_{du}	SINR at the BS b in the case of DL-UL interference
$\gamma_{dlm,b}$	SINR in DL
$\gamma_{ulm,b}$	SINR in UL
u_{dlm}	Binary variable to represent m is admitted in DL
u_{ulm}	Binary variable to represent m is admitted in UL
u_{lm}	Binary variable to represent m is using link l
$w_{ulm,b}$	Binary variable to show m is associated with b in UL
$w_{dlm,b}$	Binary variable to show m is associated with b in DL
w_{bml}	Binary variable to show m is associated with b using link l
R_{lm}	Minimum data rate required for m using link l
$C_{dlm,b}$	Data rate obtained by m in DL with b
$C_{ulm,b}$	Data rate obtained by m in UL with b

Table 4. *Cont.*

C_{bml}	Data rate obtained by m with b using link l
$H_{dlm,b}$	DL channel matrix
$H_{ulm,b}$	UL channel matrix
$\Gamma_{dlm,b}$	DL SINR matrix
$\Gamma_{ulm,b}$	UL SINR matrix

4. Rate Maximization

The main aim of this work is to focus on energy efficiency and throughput maximization, for which we consider a single cell consisting of cellular users and D2D pairs. Our objective is to maximize the sum rate using the DU-CP and DU-DCP access methods in an HN while ensuring the QoS requirements of the MS. The optimization problem for the DU-CP access scheme can be formulated as follows:

$$\max_{P_b, w_{bml}} \sum_b \sum_m \sum_l w_{bml} C_{bml}, \tag{12a}$$

Subject to

$$\sum_b w_{bml} \leq 1, \tag{12b}$$

$$\sum_b P^{dl}_{m,b} \leq u_{dlm} P_b, \tag{12c}$$

$$P^{ul}_{m,b} \leq u_{ulm} P_m, \tag{12d}$$

$$C_{bml} \geq u_{lm} R_{lm}, \tag{12e}$$

$$\sum_b w_{bml} - u_{lm} = 0, \tag{12f}$$

$$\sum_b w_{dlm,b} - w_{ulm,b} = 0. \tag{12g}$$

The objective function aims to maximize the sum rate using optimum associations in an energy-efficient manner subject to a number of constraints. Constraint (12b) ensures that an MS is associated with at most one BS. According to constraint (12c), the received power of an MS in DL is always less than the maximum power of the associated base station. There is no received power when the MS is not admitted in DL. Similarly, the power received by a BS from an associated MS is less than the transmission power of the MS, and this is possible only in UL. This is ensured by the constraint (12d). Constraint (12e) provides a quality of service (QoS) guarantee and ensures that the data rate obtained by m with b using link l is always greater than the minimum rate requirement. To confirm that an MS m admitted in DL is associated with the BS b in DL and that an MS m admitted in UL is associated with the BS b in UL, constraint (12f) is introduced. Constraint (12g) is for DU-CP access, ensuring that an MS m is associated with the same BS b in DL and UL. The optimization problem for the DU-DCP access method is the same as (12) after removing constraint (12g) i.e., (12a)–(12f) constitute the DU-DCP access optimization problem.

Two communication scenarios using the DU-CP and DU-DCP access methods are considered. In the DU-CP scenario, the MS m is associated with the same BS in UL and DL, as given in Figure 3. This is described in Algorithm 1. The channel and SINR matrices are determined first. Next, the BS with the maximum SINR with m in DL is determined. Based upon the DU-CP access scheme, the MS m is associated with the BS with the maximum SINR in DL. In the DU-DCP access scheme, depicted in Figure 4, an MS m can be associated with a different or the same BS in UL and DL depending upon the SINR. This is achieved as described in Algorithm 2. As in the case of the DU-CP scheme, the channel matrix for the channel between the MS and the BS is generated in the first step. However, the SINR matrices for both DL and UL are established. The BS with the strongest SINR in DL is associated with the MS in DL, and the BS with the strongest SINR in UL is associated with the BS in UL.

Algorithm 1 DU-CP Algorithm.

M $\leftarrow$ Number of MS;
B $\leftarrow$ Number of BS;
Channel matrix of DL $H_{dlm,b} \leftarrow M \times B$;
Channel matrix of UL $H_{ulm,b} \leftarrow M \times B$;
Calculate SINR matrix $\Gamma_{dlm,b}$ using (5) and (6);
for ($m \in \mathcal{M}$) **do**;
    for ($b \in \mathcal{B}$) **do**;
        Find BS b^* with max SINR with m in DL;
    end for;
end for;
for ($m \in M$) **do**;
    m is associated with BS b^* in DL;
    m is associated with BS b^* in UL;
end for.

Algorithm 2 DU-DCP Algorithm.

M $\leftarrow$ Number of MS;
B $\leftarrow$ Number of BS;
Channel matrix of DL $H_{dlm,b} \leftarrow M \times B$;
Channel matrix of UL $H_{ulm,b} \leftarrow M \times B$;
Calculate SINR matrix $\Gamma_{dlm,b}$ using (5) and (6);
Calculate SINR matrix $\Gamma_{ulm,b}$ using (7) and (8);
repeat;
    for ($m \in \mathcal{M}$) **do**;
        for ($b \in \mathcal{B}$) **do**;
            Find b^* with max data rate in DL;
            Find b^+ with max data rate in UL;
        end for
    end for
    for ($m \in \mathcal{M}$) **do**
        m is associated with BS b^* in DL;
        m is associated with BS b^+ in UL;
        Calculate $C_{dlm,b}$ using (3);
        Calculate $C_{ulm,b}$ using (4);
        if ($C_{dlm,b} < R_{lm}$) **then**;
            Disassociate m from b^*;
        end if;
        if ($C_{ulm,b} < R_{lm}$) **then**;
            Disassociate m from b^+;
        end if;
    end for;
until $m \in \mathcal{M}$ is associated.

5. Simulation Results

The performance of the DU-CP access method is compared with that of the DU-DCP in a four-tier HN using the genetic algorithm (GA) and particle swarm optimization (PSO). We use MATLAB R2020b with its Communications, LTE, and 5G Toolboxes to implement a heterogeneous network. The Global Optimization Toolbox is used for the optimization using the PSO and GA. Several simulation experiments are performed for the evaluation of the two cell association strategies. The parameter settings used in the simulations are given in Table 5. The results are plotted for the illustration of the performance comparison of the two schemes.

Table 5. Simulation parameters.

Parameter	Value
Cell radius	500 m
Carrier frequency	700 MHz
D2D average distance	100 m
Maximum MS	50
Base stations	5
Macro eNB transmission power	40–50 dBm
Pico cell transmission power	20–30 dBm
Femto cell transmission power	10–20 dBm
D2D transmission power	10–25 dBm
MS transmission power	10–30 dBm
WiFi transmission power	10–25 dBm

Figure 5 represents the throughput of the network for the DU-CP and DU-DCP schemes using the PSO. It can be seen that if more devices are connected using a D2D link, then the throughput of the network is higher for the DU-DCP method than for the DU-CP scheme. Similarly, in Figure 6, the throughput of network is given using the GA for the DU-DCP and DU-CP methods. Comparing Figures 5 and 6, it can be seen that the GA gives better results in terms of throughput for the DU-DCP method. Compared to the PSO, the GA provides a 10% better throughput on average for the DU-DCP method. Figure 7 shows a quantitative comparison of the network throughputs achieved by the DU-DCP and DU-CP schemes using the PSO and GA. It further confirms that the GA gives better results for the DU-DCP method than for the PSO algorithm.

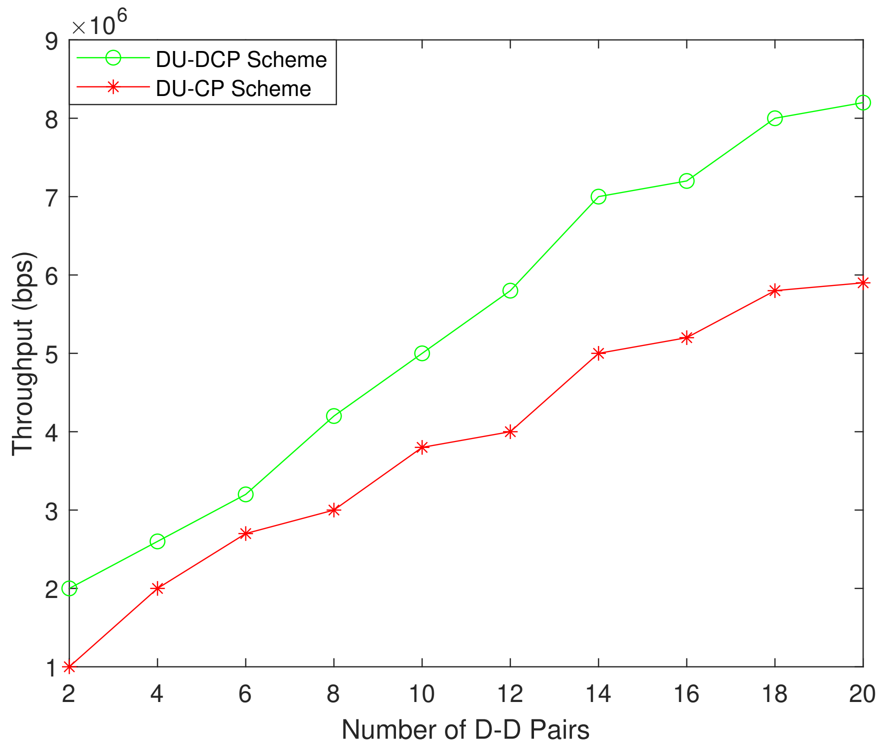

Figure 5. Network throughput using PSO.

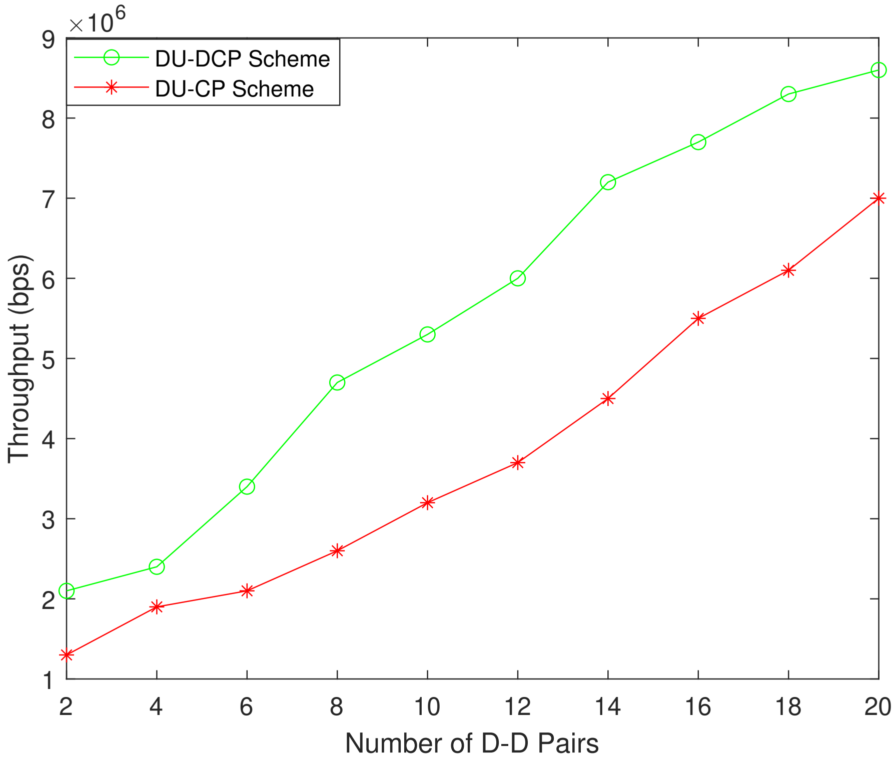

Figure 6. Network throughput using GA.

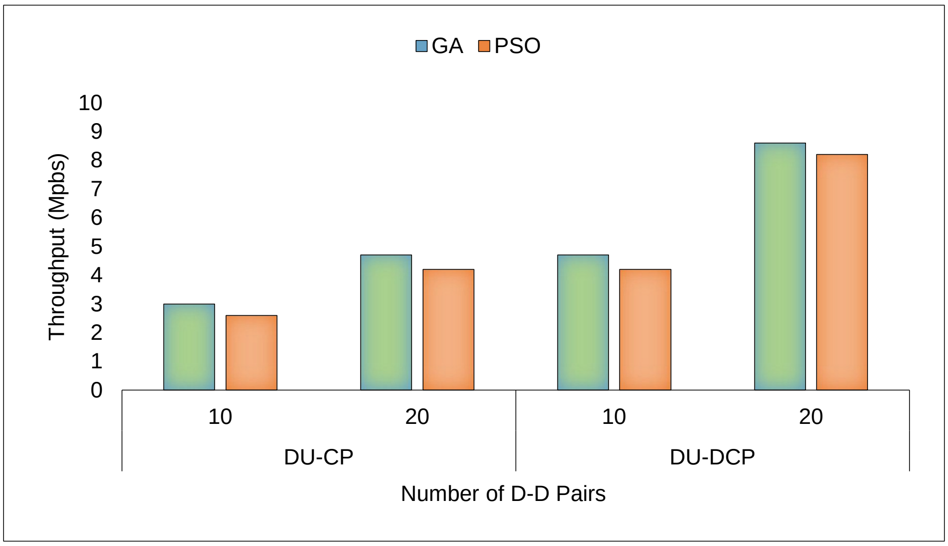

Figure 7. Comparison of network throughput for DU-DCP and DU-CP using PSO and GA.

Figures 8 and 9 represent the energy efficiency of the DU-CP and DU-DCP schemes using the PSO and GA, respectively. From Figure 8, it can be seen that the DU-DCP scheme gives a better performance than the DU-CP method using the PSO. Similarly, in Figure 9, again, it can be seen that the DU-DCP performs better than the DU-CP method using the GA as well. Figure 10 provides a quantitative comparison of the energy efficiencies of both schemes using the PSO and GA. It can be observed that the energy efficiency using the PSO for the DU-DCP method is 30% better than the DU-CP method. It is also seen that the GA gives almost a 27% better energy efficiency for the DU-DCP method on average than the DU-CP method. Moreover, the DU-DCP scheme shows an overall better energy efficiency in comparison to that of the DU-CP scheme using both the GA and PSO. It can be further noted that energy efficiency reduces as the number of devices increases. This can be explained by considering the fact that a higher number of D2D transmitters causes an increase in the interference, and, thus, the transmission rate is degraded, which in return reduces energy efficiency. In a 5GHN system, in the case of a large number of users, the energy efficiency for an HN can reduce due to inter-cell interference. To alleviate this and to reduce inter-cell interference, coordination techniques may be used.

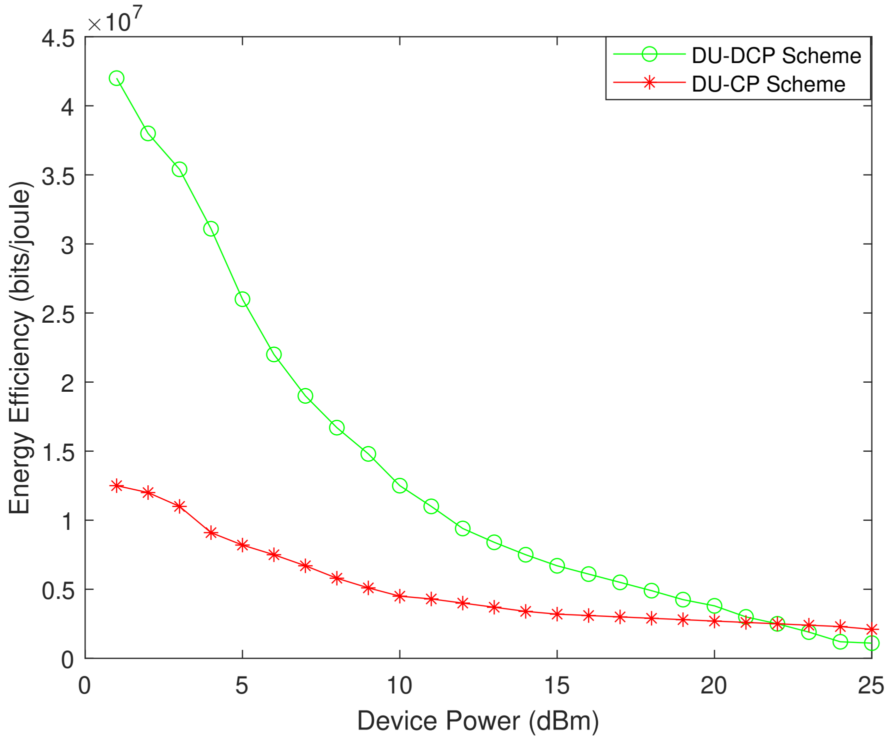

Figure 8. Energy efficiency using PSO.

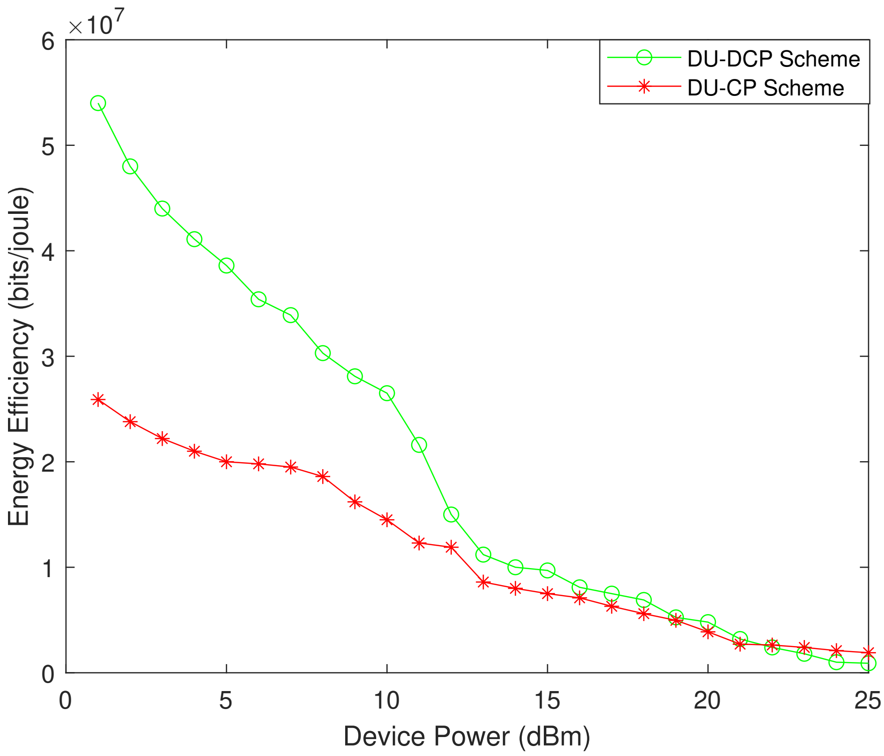

Figure 9. Energy efficiency using GA.

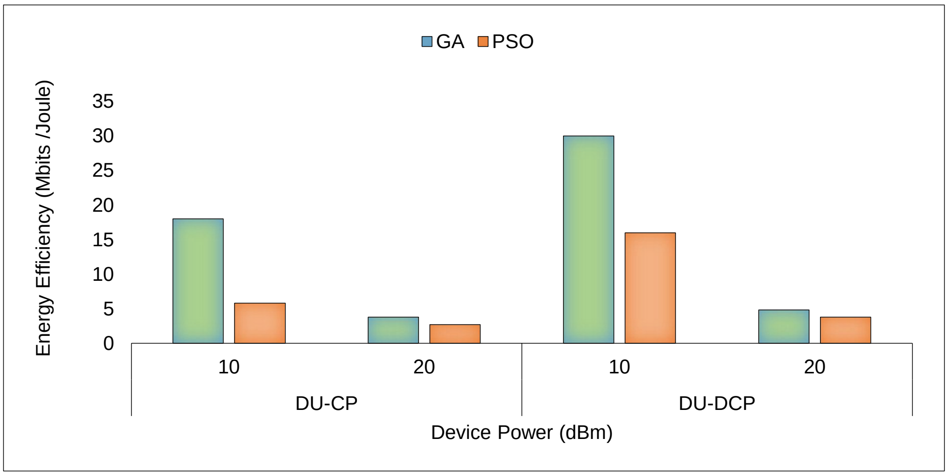

Figure 10. Comparison of energy efficiency for DU-DCP and DU-CP using PSO and GA.

From the results, it is evident that the GA performs better than the PSO in the cases of both the DU-CP and DU-DCP. This is due to the fact that the discrete and parallel nature of the GA is better suited to the DU-CP and DU-DCP problems than the PSO. The main operations in the GA are selection, crossover, and mutation, which help it achieve a better performance. These results are in agreement with the results obtained in other similar works reviewed in Section 3. For example, the GA-based energy efficiency scheme ESGA-5G, proposed in [30], achieves better results than the PSO, as is the case in our work. Likewise, in [32], the performance of the GA is reported to be better than the PSO.

We compare the performance of our proposed method with the schemes proposed by Elshaer et al. in [39], Smiljkovikj et al. in [42], and Ali et al. in [48]. For the purpose of comparison with these methods, we use our DU-DCP scheme with the GA since it has been observed from the previous results that the GA gives better results for the proposed model than the PSO. Figure 11 shows a comparison of the throughput of the proposed system and the models presented in [39,42], which use the stochastic geometry approach, and the model in [48], which uses outer approximation. From Figure 11, it is evident that the proposed model outperforms the compared models given by [39,42,48] in terms of network throughput. The DU-DCP scheme gives approximately a 29% higher throughput using the GA as compared to the network model in [39]. Similarly, the proposed scheme achieves almost a 14% and 7% higher throughput as compared to the models presented in [42,48], respectively. It is also observed from Figure 11 that, initially, the model in [42] gives a slightly better throughput than the model in [48]. However, as the number of connected devices increases, the throughput using [48] increases more rapidly as compared to [42].

Figure 12 shows a comparison of the energy efficiencies of the proposed model and the models in [39,42,48]. It is observed from Figure 12 that the DU-DCP scheme with the GA presented in this work gives an overall better and more energy-efficient performance on average than the compared methods. It is also observed from Figure 12 that, initially, the models in [42,48] give better energy efficiency than the model in [39]. However, as the device power increases, the energy efficiency of [42,48] decreases more rapidly as compared to [39]. Moreover, from Figure 12, it can also be seen that the DU-DCP with the GA gives an approximately 18% higher energy efficiency than the model in [48]. Therefore, it can be concluded from Figure 12 that, on average, the proposed DU-DCP scheme using the GA outperforms the compared schemes in terms of energy efficiency. All of the schemes give similar performances when the device power is high. Hence, from the results in Figures 11 and 12, it is evident that better results in terms of both energy efficiency and network throughput can be obtained using the proposed optimization strategy than the stochastic geometry and outer approximation approaches, as used in [39,42,48].

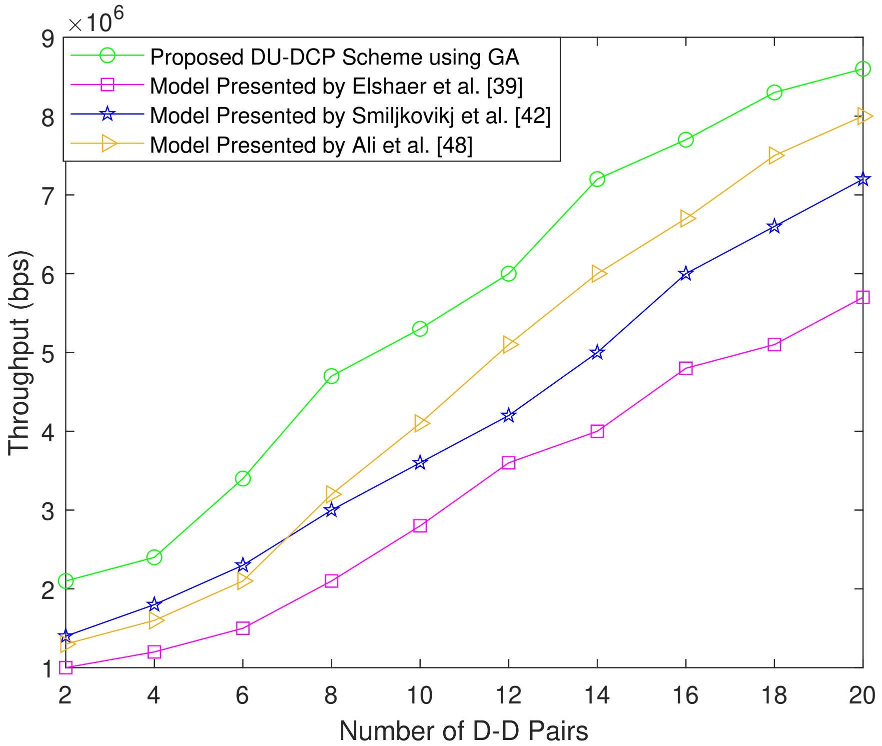

Figure 11. Comparison of network throughput.

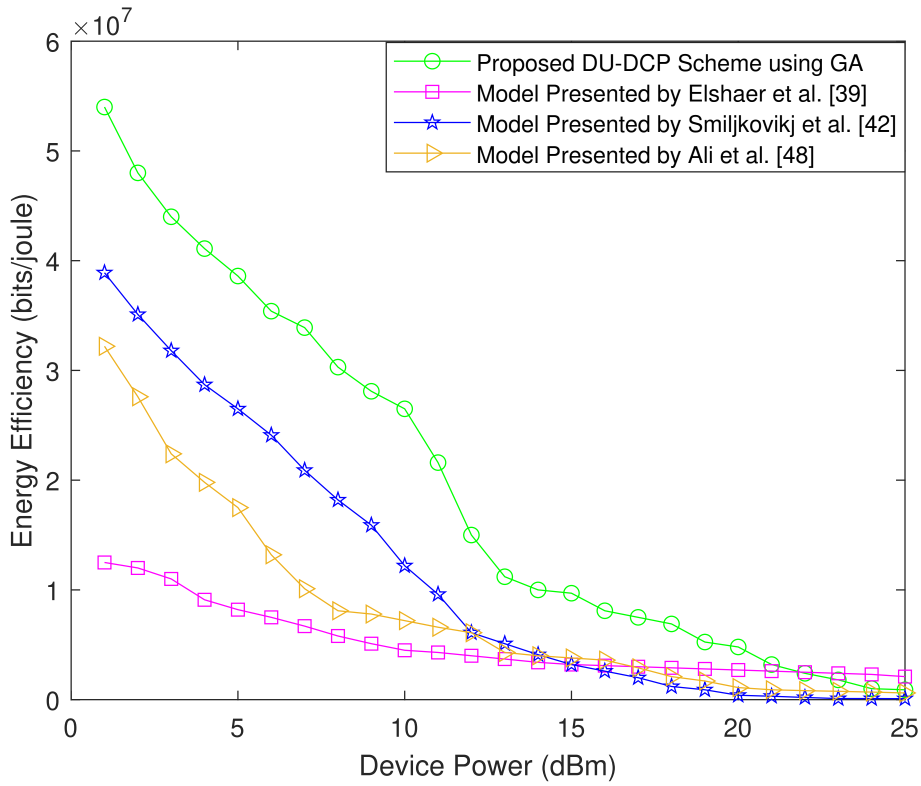

Figure 12. Comparison of energy efficiency.

6. Conclusions

Energy efficiency is one of the major requirements in D2D communication systems. This research work evaluates and analyzes the performance of the DU-CP and DU-DCP schemes proposed for the HN underlying the 5G network in terms of energy efficiency and network throughput. The formulated scheme is solved by employing the PSO and GA to reach a near-optimal solution. It has been shown that the DU-DCP access scheme in the HN outperforms the DU-CP access scheme in terms of network throughput. Furthermore, from the results carried out using the PSO and GA, it can be seen that the DU-DCP scheme is more energy efficient than the DU-CP method. Moreover, it is observed that the GA proves superior to the PSO for optimizing the energy efficiency and network throughput. The GA provides better results for the DU-DCP method than the PSO with an almost 13% higher energy efficiency. The proposed method is compared with three other schemes with respect to throughput and energy efficiency. The results show that the DU-DCP strategy with the GA performs significantly better than the compared methods. Future work will include a hybrid model of both the DU-DCP and DU-CP schemes. Moreover, learning algorithms can also be used for better performance.

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Abbreviations

The following abbreviations are used in this manuscript:

4G	Fourth generation
4GHN	Fourth-generation heterogeneous network
5G	Fifth generation
5GHN	Fifth-generation heterogeneous network
BS	Base station
D2D	Device-to-device
DL	Downlink
DU-CP	Downlink–uplink coupled
DU-DCP	Downlink–uplink decoupled
GA	Genetic algorithm
HN	Heterogeneous network
LTE	Long-term evolution
MC	Macro cell
MS	Mobile station
PSO	Particle swarm optimization
QoS	Quality of service
SC	Small cell
SINR	Signal-to-interference-and-noise ratio
TDM	Time-division multiplexing
UE	User equipment
UL	Uplink

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