

A High Capacity Energy Efficient Approach for Traffic Transmission in Cellular Networks

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Abstract—The efficiency of cellular networks can be improved in various aspects such as energy consumption, network capacity and interference between neighboring cells. This paper proposes a high capacity energy efficient scheme (HCEE) for data transmission in cellular networks in a country area. In this paper, the authors obtain a new equation to characterize the minimal required output power for traffic transmission between a base station (BS) and a mobile user (MU) based on the MU distance from the BS. Also, the cells boundaries (the boundary of overlapping areas of neighboring cells) by two static and dynamic approaches are specified. This work helps for better frequency allocation to MUs and allows increasing network capacity. In this paper, the analytical modeling in order to formulate the HCEE algorithm and evaluate its performance is used. The performance evaluation results show the simplicity of the HCEE algorithm and its effect on energy consumption decline, network capacity enhancement and the interference reduction.

Keywords—cellular networks, energy efficiency, frequency assignment, interference avoidance, transmission power control.

1. Introduction

In the last decade, the number of subscribers and the traffic in cellular networks has significantly increased. The mobile traffic volume is expected to be almost 26 times in 2015 rather than in 2010. Such a growth in cellular industry has pushed the limits of capacity and energy consumption in mobile networks because mobile equipments are fully working in all days of a year [1].

Information and communication technology (ICT) represents around 30% of total energy consumption in the world. Around 57% of this value is related to MUs, mobile devices and wireless networks. The Global e-Sustainability Initiative (GeSI) research estimates an increase of 72% in ICT energy consumption in 2020. In addition, around 2 to 2.5% of total carbon emissions are related to the ICT industry and it is expected to be nearly doubled by 2020 [2]. Such a value of emission has exceeded the CO₂ output of the entire aviation industry [3]. Moreover, a significant portion of network operator's costs is dependent on energy costs. Therefore, the operators of mobile

networks try to provide the capacity and required coverage for users, and to reduce the consumed energy of these networks.

By designing energy aware components in BSs and energy aware network deployment strategies, the idle capacity of BSs can be minimized, and the energy wastage will be reduced [4].

There are many strategies designed for reducing the energy consumption of various elements of mobile networks. A known strategy is the sleeping technique in idle times. The various systems may exploit the idleness at various levels. For example, the Catnap system introduced in [5] saves energy by combining the small gaps between packets by delaying the transmission of them and converting these gaps into significant sleep intervals. In other words, the user's mobile terminal can be switched to the low power consuming states in these sleep intervals. The key design component of the Catnap system is a new scheduler with the goal of increasing the sleep interval for a certain transmission without great effect on the total transmission time. The other method introduced in [6] is based on this reality that the coverage quality of cellular networks is not the same everywhere. In some areas, a signal is strong and in others it is weak. The signal strength has a direct effect on the energy consumption because of two major reasons: increasing the energy consumption and reducing the data rate in unit of time when the signal is weak. Therefore, it is possible to employ the variation of the signal strength for energy saving. To accomplish this, the future signal strength must be predicted based on the location and history. Then, some algorithms use the predicted signal strength to efficiently schedule communications. Therefore, energy can be saved by deferring the communications until a mobile device moves to the area with better signal strength or conversely by prefetching data before the signal decreases.

As discussed in [7], new mobile devices have several radio interfaces (such as Wi-Fi and 3G) for data transmission. Since these interfaces have different features (i.e., the nominal data rate and the achievable data rate are different in these radio interfaces), the consumed energy can be different for transmitting the same amount of data. In addition, the availability of these types of networks is different. The coverage of cellular network is more

than Wi-Fi. In general term, transmitting big data units via a Wi-Fi network can achieve more energy efficiency rather than a cellular network, whereas Wi-Fi may be not available every time. Since some applications (such as video capture application on a smartphone that can capture video clips and then automatically upload them to a server) are delay tolerant, therefore it is possible to defer data transmission until a low energy Wi-Fi connection becomes available. Hence, the major point is designing an algorithm for establishing a tradeoff between energy and delay.

The cell zooming technique [8] relies on turning equipments off in idle times. In a cellular network, the cell size is usually defined as the area in which users can receive control signals from a BS. Hence, cell size and capacity are fixed based on the estimation of peak traffic load. Because of users' movements and bursty nature of many applications, network traffic load has temporary fluctuations. If the size and the capacity of each cell are designed based on the maximum traffic load, some of the cells are usually under low traffic load and some others are under heavy traffic load. In this case, the static cell design and deployment for traffic load fluctuations is not optimal. Under cell zooming, the cell size is continuously adjusted according to the traffic load conditions. In this technique, traffic load is concentrated in few cells in order to minimize the number of active cells in the network. In other words, the cells with low traffic load are set to the sleep mode. In this case, neighboring cells are either spread in order to ensure full network coverage or they can cooperate in order to serve the users within the inactive cells.

The switch off scheme is another method for solving the problem of energy aware management in access cellular networks [3]. This method tries to specify the amount of energy that can be saved by reducing the number of active cells in the network when traffic load is low. The reduction of the traffic in a cellular network is due to the combination of two elements: the day-night behavior of users and the daily movement of users between the residential areas and the office regions. Thereupon, the need for capacity is high during the peak time in both areas, but this need is reduced during the period in which those areas are light-populated (e.g., residential areas during day period and office regions during night period). Therefore, some cells can be switched off and radio coverage can be guaranteed by the active cells, with the small increase in the transmission power. Indeed, the main goal in this method is to optimize the saving energy. In other words, it is important to find a suitable number of cells in order to switch them off. Although turning off many cells can lead to significant savings, the traffic pattern shows that this case is possible only for a short period of time. Therefore, turning off a few cells during long period times can cause more energy saving.

Since the current mobile networks are not very energy efficient, in [9] and [10], the mechanisms to improve the efficiency of BSs have been proposed. In [9], a method for

dynamic management of BSs has been explored in order to understand the scope for energy saving. The main objective of [10] is to create a suitable radio structure that can save power by reducing the power consumption of various elements of BS such as radio transceivers, power amplifiers, and transmit antennas.

It is difficult for network operators to maintain the capacity growth, utilize bandwidth, decrease delay, and limit the energy consumption at the same time. Therefore, the framework for Green Radio – a wireless architecture in [11] consists of four fundamental efficiency tradeoffs:

- deployment-energy tradeoff to balance the deployment cost, throughput and energy consumption in the whole network,
- spectrum-energy tradeoff in order to balance the accessible rate and the energy consumption of the system,
- bandwidth-power tradeoff to balance the bandwidth utilized and the required power for the transmission,
- delay-power tradeoff to balance the average end-to-end delay and the average consumed power in the transmission.

By using these tradeoffs in different research aspects, such as network planning, resource management and physical layer transmission design, the performance parameters of the network such as power consumption, delay and so on can be achieved simultaneously.

A link adaptive transmission scheme has been proposed in [12] that improves the energy efficiency by adapting both transmission power according to the channel states and the consumed power. Relaying [13] is another way to improve the energy saving in wireless networks. By choosing some nodes as relay nodes, more connections can be established between a source-destination pair. Therefore, data can be delivered through several links. It is clear that one of these links is the shortest path and hence, the required time to transmit a fixed amount of data and thereupon the consumed energy is reduced.

Turning off some elements of data centers such as CPUs, disks and memories when they are in idle state is another effective method for avoiding from unnecessary energy consumption [14]. In addition, cooling of data centers improves the energy efficiency. It is presented in [15] that separating hot air and cold air plays the main role in the cooling energy efficiency. This efficiency is not achievable without designing a HVAC system. It is measured that around 50% of the energy consumption in BSs is related to power amplifiers (PA) [16]. It is presented in [17] that to achieve PA efficiency and energy efficiency in whole network, the BS structure must be changed. In a technique called envelope tracking, the PA power voltage is changed dynamically with ensuring that the output power of transistors remains in a suitable level. This technique achieves high energy efficiency.

It is predicted that mobile applications and services will generate 26 times more traffic load in 2015 than that in 2010. Therefore, they must be able to work based on dynamic users' demands and wireless links. The work in [18] introduces an adaptive approach to reduce energy consumption of multimedia transmissions that it works based on the selecting proper source compression and coding. A method for designing energy efficient applications has been introduced in [19] that works based on the prediction of application activities by learning historical patterns. This approach dynamically limits and adjusts low-layer functions of mobile devices for saving energy.

Another strategy for reducing energy consumption is the control of radio equipment transmission power by focusing on the lowering of transmission power of BSs and MUs. Since interference between cells causes unnecessary energy loss, the work in [20] considers a two layer cellular network in which one frequency channel is used in both layers. The interference between macro cells and femto cells is controlled, and the energy consumption declines by adjusting the transmission power via self-configuration and self-optimization techniques. In self-configuration, a femto cell BS measures the average received pilot powers from neighboring BSs. Then, the femto cell BS adjusts its transmission power based on the strongest pilot power to achieve initial cell coverage. Next, the femto cell BS performs a self-optimization and adjusts the transmission power continuously so that the femto cell coverage does not leak to the outdoor areas while the indoor area coverage of femto cell is provided.

The previous works have some restrictions. For example, the research from [5], [6] and [7] are based on deferring information transmission, thus increasing transmission delay. The paper [6] is applicable only for special applications because all applications do not tend to defer their information transmission. The proposed algorithms in [8] and [14] increase blocking probability of users because it is likely that sufficient bandwidth does not exist when a new user enters to the network and therefore the user is blocked. In [20], femto cells are used for increasing the network capacity, but at the expense of increasing the network equipment costs. Therefore, it is so important to find a method without these restrictions.

The objective of this paper is to design a new method for energy consumption reduction, increasing the capacity, and interference avoidance in cellular networks. The HCEE algorithm is proposed for data transmission in cellular networks in a country area that adjusts the amount of transmission power based on a specific distance from BS in order to reduce the energy consumption and interference probability.

The author's contribution in this paper is to develop a new transmission technique that adjusts the amount of transmission power between a BS and MUs. In addition, the boundaries of neighboring cells overlapping area are specified in order to use all available frequencies for serving those users located outside of the overlapping areas.

2. Network Model

In this paper, a cellular network in a country area is considered, where houses are mostly flat and usually far from each other. This network consists of N cells, each with radius R . Each cell is surrounded by another m overlapping cells. In cellular networks, the used frequencies in each cell must be different from its neighboring cells because of interference. In order to coordinate the assigned frequencies, the cells are clustered. Inside a cluster with C neighboring cells, each cell must have different frequencies from the other cells within the cluster. Let the total number of network frequencies be F . With clustering, each cell can only use the $1/C$ of these frequencies, i.e., the number of assigned frequencies to each cell is $\lfloor F/C \rfloor$. Figure 1 shows the structure of the network model under study, where the cells are modeled as hexagon. However, in reality, they are overlapping cells in which the interference of frequencies may occur. In this figure, the green (gray) cells show an instance cluster with three cells (the least number of cells for building a cluster), where different frequencies are used in each cell. A BS with h directional antennas is located in the center of each cell. Using directional antenna can lead to reduce transmission power and interference. Therefore, the energy efficiency can be improved [21].

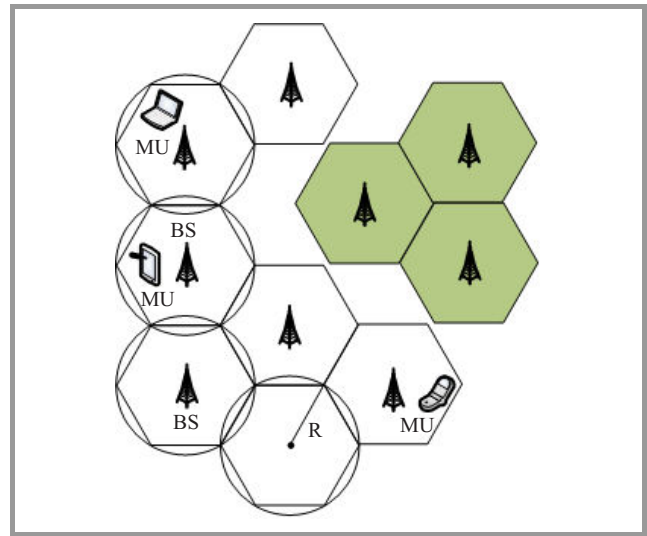


Fig. 1. The network model.

Let the maximum number of active users in each cell be N_a , where each user is equipped with an omnidirectional antenna and located in a random place within the cell.

3. The HCEE Algorithm

The interference phenomenon between neighboring cells is an important issue in a cellular network that not only reduces the network throughput, but also causes the unnecessary energy consumption. The used frequencies in each cell should be different from the other neighboring cells.

The amount of transmission power between the BS and an MU is proportional to the BS range specification and the amount of energy consumption. In other words, whatever transmission power is reduced, the less energy is consumed. Also whereas the transmitted signal cannot leak in the areas far from the location of the MU, the interference phenomenon can be avoided. The minimum amount of power for traffic transmission between the BS and MU_i is given by

$$P_t(\text{dBm}) = S_r(\text{dBm}) + L_p^i(\text{dB}), \quad (1)$$

where P_t is the BS transmission power (in dBm) and S_r is the receiver sensitivity of MU_i . Parameter L_p^i is the amount of path loss which is dependent on various factors such as the distance between MU_i and the BS.

Note that in rural or countryside areas, the buildings are low and they are far from each other, therefore the effect of these snags on the transmitted signal power downfall is low. Thus, it is assumed in Eq. (1) that the transmission power downfall occurs only because of path loss.

The amount of path loss is obtained from Eq. (2) known as the "Friis transmission equation":

$$L_p^i(\text{dB}) = 10 \log \frac{(4\pi d_i)^2}{G_t G_r \lambda^2}, \quad (2)$$

where d_i is the distance between MU_i and BS, G_t is the antenna gain of transmitter and G_r refers to the receiver antenna gain. The antenna gain refers to the directionality of an antenna given by:

$$G = \frac{4\pi A_e}{\lambda^2}, \quad (3)$$

where A_e refers to the effective area of an antenna dependent on its shape.

Since P_t in Eq. (1) is the minimum power required between the BS and MU_i , P_t is different for each user. Reducing the amount of P_t could have two advantages:

- The network energy consumption is reduced;
- Since the transmission power for the users located in non-overlapping areas does not leak to other areas, it is possible to use all F available frequencies in a cellular network to service the users. In other words, in the outside of overlapping areas, all cells can equally use all F frequencies because the interference does not occur in these areas, thus enhancing the network capacity.

To achieve the latter advantage, the boundary of overlapping areas of cells must be specified (see Fig. 2). In other words, the goal is to find the value of r (where $r < R$) so that all frequencies can be used for the users located within the circle with radius r . For serving the users located in distances from the BS in between $(R - r)$ and R , different frequencies must be used. In this paper, it is considered that all users exactly located on the boundary of the overlapping

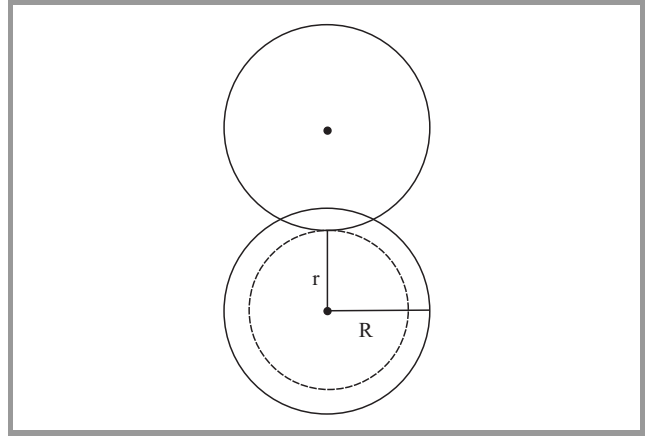


Fig. 2. Specification of radius r .

area are as those users that located inside the overlapping area in order to avoid the interference.

Using different values of P_t for each user and updating them when a user moves is difficult and also consumes more energy. Therefore, in this paper, the amount of transmission power is equal for all the users allocated within the circle with radius r . This amount of transmission power is obtained from Eqs. (1) and (2), where the value of d_i in Eq. (2) for all users in this area is equal to r . On the other hand, for all users allocated in the overlapping area, the value of d_i is equal to R .

To find r , the two methods as static and dynamic in the following are proposed.

3.1. Static Method

In this method, a constant value for r is obtained so that interference avoidance can be guaranteed. According to Fig. 3:

$$r + 2\alpha = R. \quad (4)$$

On the other side, considering the triangle ABC and trigonometric formulas:

$$r + \alpha = R \cos 30^\circ. \quad (5)$$

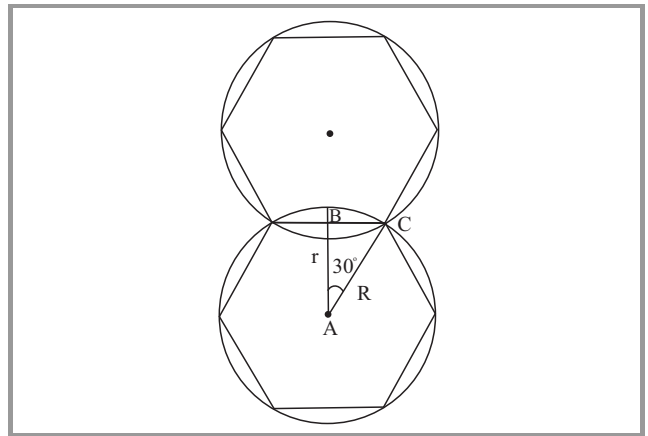


Fig. 3. Static method for finding r .

With solving Eqs. (4) and (5) in an equation system, one can find:

$$r = 0.732R. \quad (6)$$

$$\alpha = 0.134R. \quad (7)$$

3.2. Dynamic Method

In this method, the value of r within cell k is updated based on the received power from neighboring BSs at MUs located within cell k . Indeed, each MU within cell k periodically informs its base station (BS_k) about the amount of received power from neighboring BSs. Then, BS_k can choose the smallest of the received powers as the maximum range of neighboring BS, i.e., the boundary of overlapping area with cell k .

Define an interval with length τ for periodic updates. Let the amount of received power from a neighbor BS at MU_i within cell k at time T in interval τ be $P_{i,T}$. During this interval, MU_i informs its BS_k about the amount of $P_{i,T}$. Note that the amount of received power at MU_i can be variable within the interval because of the MU movement. This is because, for each MU, the average received power must be calculated within interval τ . The BS_k calculates the average value of \bar{P}_i among $P_{i,T}$ values for MU_i in interval τ by:

$$\bar{P}_i = \frac{\sum_{T=1}^{\tau} P_{i,T}}{\tau}. \quad (8)$$

Define U_{NC} to be the set of MUs within cell k that receive power from neighboring BSs during interval τ . Clearly, there could be some MUs that hear nothing from neighboring BSs. Note that the amount of \bar{P}_i for these users is unequal to zero.

Now BS_k chooses the minimum of \bar{P}_i values among all MUs in U_{NC} :

$$P_{\min} = \text{Min}\{\bar{P}_i | i \in \{U_{NC}\}\}. \quad (9)$$

Let MU_j has the smallest power, i.e. $P_{\min} = \bar{P}_j$. Then, r is equal to the distance of MU_j from BS_k , i.e.

$$r = \{d_j | \bar{P}_j = P_{\min}\}, \quad (10)$$

where d_j is the distance between MU_j and BS_k .

Since the value of r in this method is periodically updated based on the actual received power from neighboring BSs, the dynamic method may work better than the static method in terms of network throughput.

4. Performance Evaluation

In this section, the performance of HCEE algorithm is evaluated by proprietary program written in C++. All calculations are performed for cell k surrounded by six neighboring cells, where users are randomly located within each

cell. Then, the locations of users are randomly changed within each cell at different time snapshots, where each time snapshot is called iteration in the following scenarios. The simulation results show that the percentage of allocated users within the circle with radius r under the static method are between 78.9% and 81.08% with 95% confidence interval, regardless of the number of active users located inside cell k or at radius of cell k (see Fig. 4). In Fig. 4, the horizontal axis shows the number of iterations of the HCEE algorithm during time. The allocated users within the circle with radius of r under the dynamic method are between 77.19–90.46% of total users with 95% confidence interval at various times because of path loss variation that depends on the channel state and weather conditions. Therefore, the value of r and percentage of allocated users within the circle with radius r are different at various times. Figure 5 shows the number of allocated users within the circle with radius r under the dynamic method and Fig. 6 shows the variation of r at various times in both static and dynamic methods for $R = 5000$ m. According to Fig. 6, the value

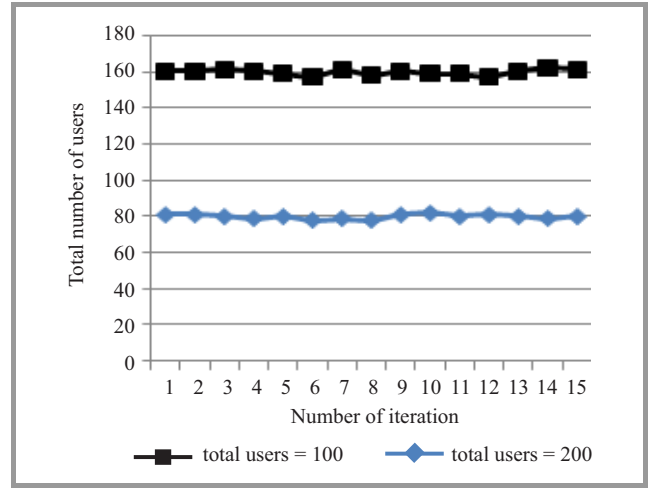


Fig. 4. Number of allocated users within the circle with radius r under the static method.

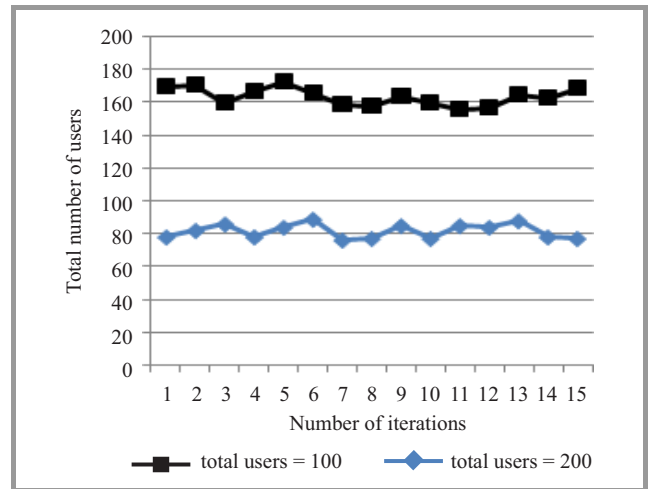


Fig. 5. Number of allocated users within the circle with radius r under the dynamic method.

of r is constant in the static method, but variable under the dynamic method because the value of r in the static method is obtained from Eq. (6) that only depends on R , but in the dynamic method the value of r is obtained based on the received control signal power from neighboring BSs at MUs. Since the amount of received control signal power depends on the weather conditions and path loss, it will be different at various times.

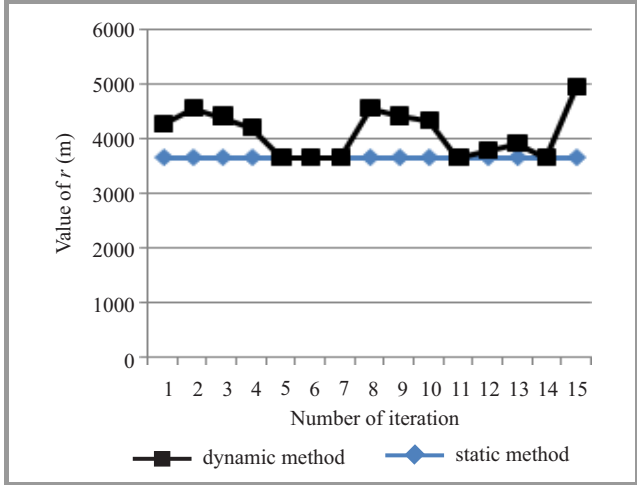


Fig. 6. The value of r in static and dynamic methods.

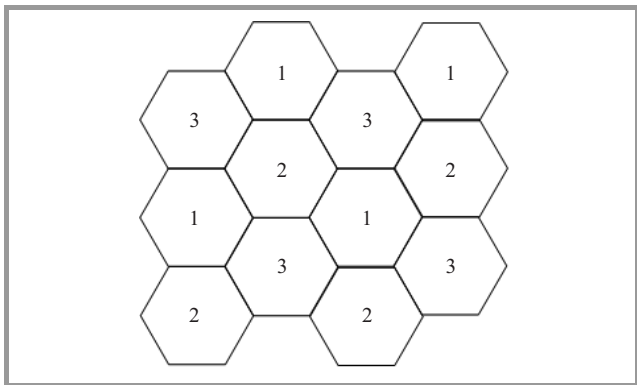


Fig. 7. The network clustering and frequency assignment.

Figure 7 shows the network clustering, so that the same frequencies are assigned to the cells with the same number. According to the Fig. 7 and under conventional clustering, if the cells within ternary clusters is clustered, the number of assigned frequencies to the users of cell k becomes only $F/3$. On the other hand, using HCEE, the number of assigned frequencies to the users within cell k will become F . In other words, the network capacity will be increased three-fold under the static method. However, under the dynamic method, the network capacity will be increased around three-fold up to four-fold.

As stated in Sections 2 and 3, the amount of energy consumption in the network can be reduced by replacing omnidirectional antennas with directional versions and adjusting the amount of transmission power of BSs, i.e., by replacing

the conventional method with the HCEE algorithm. Define the level of power saving as:

$$Power\ saving = 1 - \frac{E_x}{E_y}, \quad (11)$$

where E_x is efficient power consumption and E_y is inefficient power consumption. The inefficient power consumption is the consumed power under conventional network structure without using the HCEE algorithm, while the efficient power consumption is defined as the consumed power under using the HCEE algorithm, i.e., using directional antennas and adjusting transmission power using Eq. (1).

Figures 8 and 9 show the effect of replacing omnidirectional versions with directional antennas and adjusting the transmission power, i.e., using the HCEE algorithm, on the energy consumption under dynamic and static methods, respectively, for various radiuses for cell k . This value of power is calculated when maximum number of active users is $N_a = 100$.

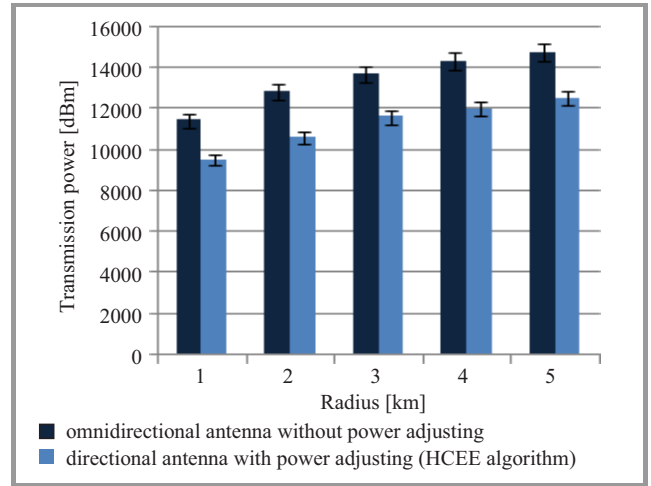


Fig. 8. The effect of using HCEE algorithm on the power consumption under dynamic method.

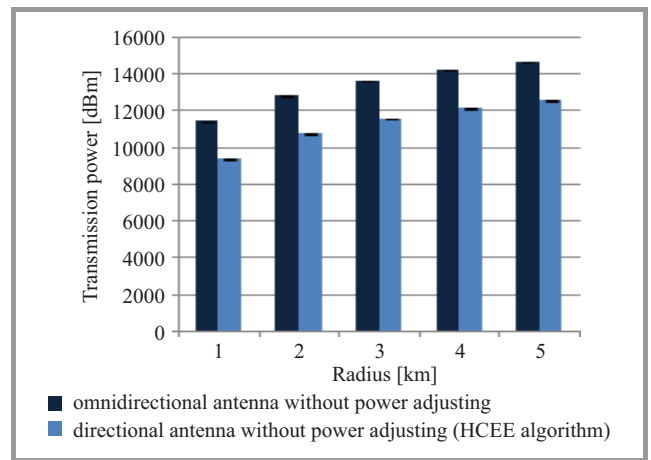


Fig. 9. The effect of using HCEE algorithm on the power consumption under static method.

As it is shown in Figs. 8 and 9, the amount of transmission power goes up with increasing the radius of cell because the transmission power has a direct correlation with the square of value of r that increases with increasing the cell size.

As shown in Figs. 8 and 9 (the inefficient power consumption and efficient power consumption under the HCEE algorithm) and according to Eq. (11), the amount of power saving is around 0.2, i.e., the consumed energy in cell k can be reduced by almost 20% using the HCEE algorithm under both static and dynamic methods rather than the conventional method. Although the amount of transmission power under the dynamic method is different at various iterations because of difference in value of r , but the average of this amount is almost equal to the static method.

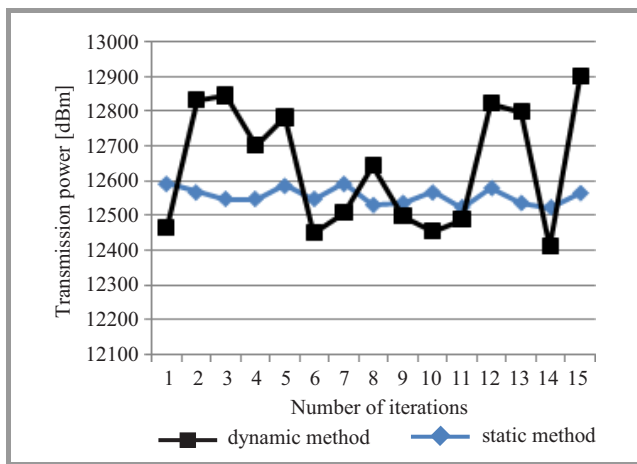


Fig. 10. The variation of transmission power in static and dynamic methods.

In Fig. 10, the variation of transmission power in both static and dynamic methods at various iterations is shown at $R = 5000$ m. As stated earlier, the horizontal axis shows the number of runs of the algorithm.

Figures 11 and 12 show the number of interfered users within cell k at $N_a = 100$ under both dynamic and static methods, respectively. As shown in these diagrams, the interference is reduced by using the HCEE algorithm because in conventional method the transmission power is adjusted to cover the whole area of a cell even for those users allocated near the BS. However in HCEE, for those users located within the circle with radius r , the amount of transmission power is adjusted to only cover the area of this circle. The difference between the number of interfered users in static and dynamic methods is because of the difference between the calculated values for r , i.e., the boundary of cells, in these methods. With the increase in cell size, the number of interfered users is reduced because the same numbers of users, i.e., N_a , are distributed in the larger space and with more distance from each other.

According to the obtained simulation results, the performance of the dynamic method in capacity improvement is better than the static method, but for other performance parameters, such as the amount of transmission power, the dy-

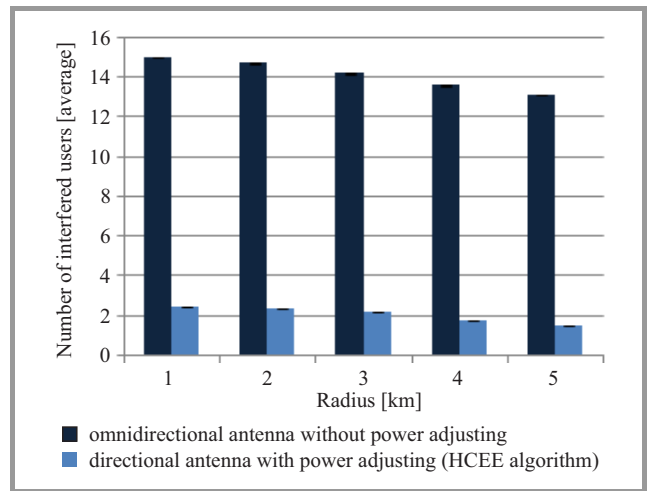


Fig. 11. The number of interfered users under the dynamic method.

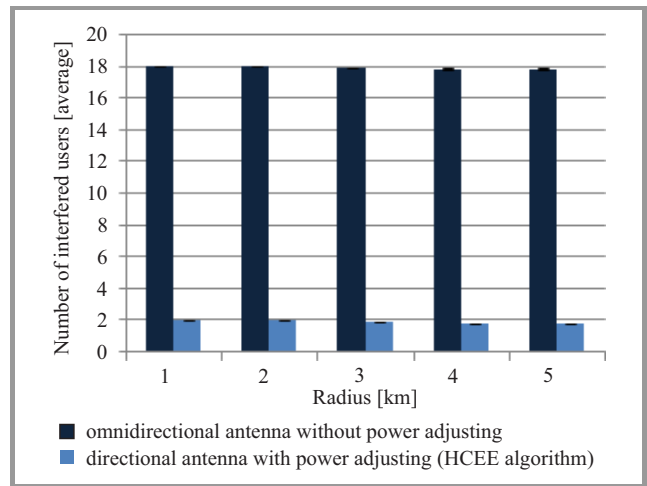


Fig. 12. The number of interfered users under the static method.

amic method is better in some cases than the static method and in some cases is worse than the static method. However, when we consider a time interval and calculate the average of the performance metrics, the results are almost equal in the both static and dynamic methods. Furthermore, the performance of HCEE in terms of energy consumption decline, capacity improvement, and interference avoidance is much better than the conventional method.

5. Conclusion

This paper has proposed a novel efficient scheme for traffic transmission, i.e., the HCEE algorithm that is based on adjusting transmission power and calculating radius r in order to increase the network capacity. An analytic formulation has been provided for the operation of HCEE. Our performance evaluation results show that the HCEE can increase the energy efficiency and capacity of the network compared to the conventional method in which power adjustment and frequency reuse are not addressed inside cells. Further-

more, the HCEE algorithm can decrease the interference probability among neighboring cells. For future work, the authors consider research covering a city with tall and dense buildings and extend the proposed work for those situations.

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