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Alhabo, M, Zhang, L and Nawaz, N (2019) GRA-based Handover for Dense Small Cells Heterogeneous Networks. IET Communications, 13 (13). pp. 1928-1935. ISSN: 1751-8628

https://doi.org/10.1049/iet-com.2018.5938

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IET Communications

Journals
The Institution of Engineering and Technology

GRA-based Handover for Dense Small Cells Heterogeneous Networks

ISSN 1751-8644
doi: 0000000000
www.ietdl.org

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Abstract: Ultra-dense small cell (SC) deployment in future 5G network makes the architecture of the network as heterogeneous networks (HetNets). This is a good solution to boost the capacity of the network and extend its coverage. However, the dense SCs deployment has brought new challenges to the network including interference, frequent unnecessary handovers and handover failures. Therefore, user equipment (UE) will suffer from a degraded quality of service (QoS). In this paper, we propose a Grey Rational Analysis based handover method (GRA-HO) in dense SCs HetNet. The proposed method combines the Analytical Hierarchy Process (AHP) technique to obtain the weight of the handover metrics and the GRA method to rank the available cells for the best handover target. The performance of the proposed method is evaluated and compared with the traditional Multiple Attribute Decision Making (MADM) method including Simple Additive Weighting (SAW) and VIKOR methods. Results show that the GRA-HO method has outperformed the existing methods in terms of reducing the number of frequent handovers and link failures, in addition to enhancing the energy efficiency.

1 Introduction

The rapid growth of the number of mobile devices associated to the cellular network has forced towards a high capacity demand [1]. The existing macrocell (MC) base stations are unable to tackle this demand. The technology of small cells (SCs), which are economic small base stations with lower transmit power and radius coverage compared to the MCs, has been invented to cope with the high capacity and coverage needs. The networks consisting of both MCs and SCs are named as heterogeneous networks (HetNets) [2]. In spite of their extraordinary benefits, the ultra-dense deployment of SCs has brought new challenges such as interference, and frequent unnecessary handovers. Hence, low QoS is delivered to the UE [3]. Thus, such problems must be overcome to gain the benefits from dense SCs deployment. There have been a number of researches targeting the handover (HO) problem in the literature. We proposed a method to reduce the number of target SCs and reduce the unnecessary HOs in HetNet in [4]. The neighbour cell list (NCL) of the SCs is formed by utilizing the distance between the UE and the SC in addition to the angle of movement of the UE. Fast moving UEs are not allowed to HO to the SCs. Results reveal that the NCL has been reduced, in addition to minimizing the unnecessary HOs and enhancing the network throughput. In [5], we also proposed a method to minimize both of the unnecessary HO and HO failure. A predicted time of stay (ToS) is deployed to omit SCs, which could cause unnecessary HO or HO failure, from the target NCL. The UE can perform HO to the SC, which supplies a sufficient signal to interference plus noise ratio (SINR) and has enough capacity to service the UE. Time and the SINR are utilized to achieve a trade-off between the unnecessary HO and HO failures. Results show that both of the unnecessary HO and HO failure have been reduced. An inbound HO method for throughput enhancement and load balancing is presented in [6]. The influence of interference and predicted ToS are utilized to achieve the offloading from congested MC to a light loaded SC. A HO margin according to the serving cell load and interference level is computed to achieve the offloading. Results show that the proposed method has minimized the unnecessary HO and outage probability in addition to improving the throughput for the UE and the network. Authors in [11] proposed an interference coordination method using Nash bargaining game approach. The resource block reuse strategy is changed among SCs in the network aiming to reduce the interference and enhance the QoS and resource block utilization. Results reveal that the network throughput is improved compared to other methods. In [12] [14], authors proposed methods to achieve high resource block efficiency in SCs network by reducing the interference among SCs. Resources are dynamically distributed based on QoS requirements. Results show a reduction in the interference and enhancement in the spectrum efficiency. Authors in [13] proposed an energy efficiency method in dense SCs network. SCs are cooperating based on a coalitional game theoretic approach to get an optimal subframe and power configurations. Simulation results show that this method enhances the energy efficiency while keeping the capacity at maximum level compared to other literature works. In [15], authors proposed a cooperative distributed intercell interference coordination (ICIC) method. A communication is required between two neighbouring base stations to control the power allocation and resource block usage. Essential information about user satisfaction and power allocation are obtained by messages exchange between base stations where the transmission power of each base station is adjusted. Then, according to user QoS requirements the resource blocks are distributed. Results reveal an enhancement in the energy efficiency and throughput.

Multiple attribute decision making (MADM) is one of the largely used techniques that deals with the selection of the best alternatives which are characterised based on multiple attributes. The HO problem can be dealt with by taking into account different criteria [7]. Therefore, the MADM techniques can be a proper solution to model and tackle the HO decision. In this work, we used four HO decision metrics, the downlink SINR, target cell capacity, the UE transmit power with respect to the target cell and the ToS. Choosing the HO metrics is critical for making the HO decision, especially in dense SCs deployment. The highly dense deployment of SCs leads to severe interference in the network. Therefore, we incorporate the downlink SINR as one of the HO metrics. Furthermore, we consider the UE transmit power with respect to the target cell as a HO metric. This will make sure that the UE performs HO to the cell that requires less power in uplink, which in turn will reduce the power consumption and eventually enhance the energy efficiency. Moreover, the cell capacity is also used in HO decision so as to reduce the link failure (HO failure due to lack of resources) and also manage the load balance among cells in the network. High-speed UEs pass the coverage area of a SC and stay for a short time causing an unnecessary HOs which causes a signalling overhead. The proposed GRA-HO method incorporates the predicted time of stay for the UE in the target cell as one of the HO attributes to reduce the probability of unnecessary HOs. In fact, giving unplanned fixed weight value to the HO metrics in MADM techniques is not a proper strategy because this will cause the UE to select a wrong target cell, and hence increasing the unnecessary HO and/or HO failure which leads to reduced throughput and an increase in the signalling overhead. Therefore, in this work, we adopt the AHP technique to assign weights to the HO metrics.

The GRA is an essential part of the grey system theory. Basically, the grey system theory deals with uncertainty in information. If the system information are all known, then the system is named white system. On the other hand, if no information is available about the system, then it called a black system. With partially known information, the system is named grey system [8]. Due to the multiple criteria that can be used in modelling the HO problem in dense SC environment, the GRA is a suitable MADM method that can be deployed to solve the cell selection problem. In order to obtain the grey relationship between HO metrics (attributes), the grey relational coefficients (GRC) need to be computed. Then, the GRC are ranked and the cell index with the highest rank is elected as a possible HO cell. Therefore, the proposed method adopts the combination of AHP and GRA. The AHP technique first assigns the weights for all HO metrics then the GRA selects the target HO cell by ranking the available neighbouring candidate cells. The benefits of deploying the GRA in dense SC HetNet are: the results depend on the original value of the HO metrics obtained during the measurement report by the UE, processing of the calculations is simple and straightforward and it is suitable for multiple complicated relationships between alternatives [9]. In order to ensure fair comparison and dimensional attributes, the normalization is considered as a main process in all MADM techniques. There are many normalization techniques that can be used to achieve the attributes normalization such as square-root, sum, max-min and enhanced max-min techniques [10]. Ranking abnormality is the phenomena of reversal ranking which means that the ranking of the alternatives changes when omitting any of the lowest ranked alternative [8]. This phenomena can lead to high number of unnecessary HOs. To limit this problem, the enhanced max-min normalization technique is used in our proposed GRA-HO method.

Many research studies have been conducted by using MADM techniques in network selection. However, most of them do not consider the proper weighting assignment and energy efficiency. Also, most of these works do not consider the UE mobility, which means that the HO metrics values are not really the actual values measured during the UE movement, when using MADM techniques in network selection with dense SC deployment. In fact, dense SC scenarios is rarely considered in MADM literature works. To this extent, our contributions can be drawn as:

- The selection of multiple HO metrics including SINR, UE transmit power, cell capacity and UE ToS in the target cell.
- Using the AHP technique to obtain the weights of the HO metrics prior to cell selection.
- Deploying the GRA method to rank the available cells for HO purpose and select the cell with the highest rank as HO target.
- Adopting the enhanced max-min normalization technique in which the benefit and cost attributes are dealt with differently so as to minimize the effect of the probability of ranking abnormality on the proposed method, and hence, reducing the unnecessary HOs.
- Integrating the AHP and GRA in a (GRA-HO) method for dense SCs HetNet scenario.
- Implement, evaluate and compare the GRA-HO method with the traditional MADM methods including SAW and VIKOR where the results show that the proposed GRA-HO method outperformed the other two methods in terms of reducing the unnecessary HO and link failure, in addition to enhancing the energy efficiency.

In this paper, upper-case boldface letters are used to represent matrices and lower-case boldface are used to represent vectors. The rest of the paper is organized as follows. Section 2 presents the related work. The system model is given in section 3. The proposed method procedures are illustrated in section 4. The performance and results analysis are given in section 5. Finally, the conclusion is drawn in section 6.

2 Related Works

Multiple criteria decision problems are gaining high attention recently. The principle of network selection is one of these problems. In general, MADM technique have been widely used to deal with the complicated decision making including the network selection problem. One of the simplest MADM methods is the simple additive weighting (SAW). In [16], authors proposed a SAW method for HO decision. The serving cell is in charge of performing the process of alternative selection aiming to extend the lifetime of the UE battery. The HO metrics used in their work are bandwidth and cost. However, one of the disadvantages of SAW method is that a low value of one HO metric can negatively be affected by high value metric, e.g., when an alternative has low throughput with an affordable cost, it can be chosen over a slightly costly alternative with a much better throughput gain. Another MADM method is the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) which is based on the concept of selecting the alternative which is close to the positive ideal solution and far from the negative ideal solution [17]. Authors in [18] used the TOPSIS method to model the HO problem considering different metrics including bandwidth, cost, delay, jitter, and packet loss. Authors argued that TOPSIS is very sensitive to the values of the UE related HO metrics. In [19], the authors used TOPSIS with AHP in alternative ranking. The AHP is used to obtain the attribute weights and TOPSIS is then applied to rank the alternatives. Multiple attributes used in their work include packet delay, bandwidth, jitter, packet loss, cost, and security. In [20], the authors proposed a HO method for load balancing HetNets. The impact of interference is considered to offload the user from the congested cells. The proposed method uses a modified A3 HO initiation event considering the cell load and the interference. The results show a good performance in load balancing and throughput improvement. Authors in [21] compared the performance of four MADM method for a network selection. TOPSIS, SAW, GRA and multiplicative exponential weighted (MEW) methods are adopted. The attributes used in their comparison include delay, jitter, bit error rate, and bandwidth. They also used four traffic classes in their comparison including conversational, streaming, interactive, and background traffic class. The authors concluded that all of the methods have identical performance for conversational and streaming classes. While for interactive and background traffic classes, the performances of SAW, MEW and TOPSIS are the same. On the other hand, the GRA method produces higher bandwidth and less delay for the interactive and background traffic. Authors in [22] proposed two modified weighted TOPSIS methods for the purpose of handover management. The first method considers the entropy weighting technique for HO metrics weighting. The second method utilizes a standard deviation weighting technique for HO metrics weighting. Results show that the proposed methods have reduced the number of unnecessary handovers and radio link failures probability, in addition to improving the mean user throughput.

3 System Model

The system model in this work takes into account the two-tier heterogeneous network which consists of dense number of SCs, N_{sc}, deployed under the coverage area of a single MC base station of 500m radius, since the problem of interest is in dense SC deployment, as depicted in Fig.1. The SCs are deployed randomly

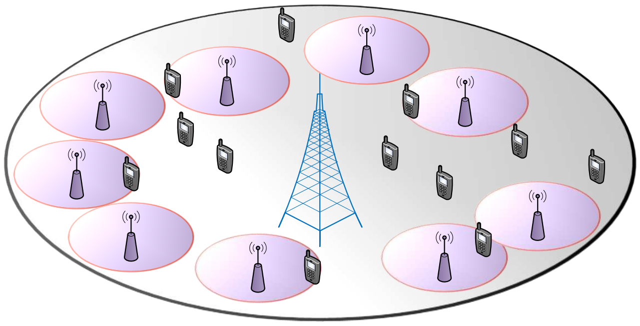

Fig. 1: HetNet System Model

according to a uniform distribution and each one covers a radius of 100m. Both cell tiers operate in the same frequency band. The minimum distance constraint is taken into consideration to ensure the overlapping between SCs. The minimum distance between MC site and SC sites is set to 75m and the SC to SC site distance is set to 40m [2]. UEs are uniformly distributed and their mobility can be defined using two parameters: UE velocity, V_{ue_k}, and UE direction, θ_k. These two parameters can be defined as Gaussian distribution and are updated accordingly using the following equations [23]

$$V_{ue_k} = \mathcal{N}(v_m, v_{std}), \tag{1}$$

$$\theta_k = \mathcal{N}(\theta_m, 2\pi - \theta_m \tan(\frac{\sqrt{V_{ue_k}}}{2})\Delta t), \tag{2}$$

where v_m represents the mean velocity of the UE, v_{std} denotes the standard deviation of the UE velocity, θ_m is the previous direction of the UE, Δt is the period between two updates of the mobility model, and $\mathcal{N}(x, y)$ is a Gaussian distribution with mean x and standard deviation y. The Gauss mobility model is a widely used model to represent the mobile user movement, particularly for medium to high speeds (e.g., vehicular speed) [24].

Let N_{bs} be the set of all cells in the network, $N_{bs} = \{0, 1, 2, \cdots, N_{sc}\}$, where 0 represents the MC base station, and U_i is the set of UEs served by cell i.

In order to maintain service continuity for UE k, it should receive a minimum signal strength of $RSRP_{th}$ and to maintain the ongoing service quality, it should have a minimum SINR of γ_{th}^{up}.

In the following subsections we illustrate the HO metrics used in the proposed method including the downlink SINR of target cell, the UE transmit power with respect to the target cell, the capacity of target cell and the ToS.

3.1 *Downlink SINR Criterion*

The downlink reference signal received power (RSRP) of cell i in dBm can be expressed as

$$P^r_{bs_i \to ue_k} = P^t_{bs_i} \cdot h_{bs_i \to ue_k}, \tag{3}$$

where $P^r_{bs_i \to ue_k}$ is the downlink RSRP of cell i received at UE k, $P^t_{bs_i}$ is the transmission power of cell i and $h_{bs_i \to ue_k}$ is the channel gain between the UE and cell i considering the path loss and shadowing effects [25], the propagation model between the MC and the user is defined as

$$\delta_{m \to ue_k} = 128.1 + 37.6\ \log_{10}(d_{m \to ue_k}) + \xi, \tag{4}$$

where $d_{m \to ue_k}$ is the distance between the user and the MC base station in kilometres, and ξ is a Gaussian distribution random variable with zero mean and 12 dB standard deviation [26].

For SC, the path loss is defined as

$$\delta_{sc_i \to ue_k} = 38 + 30\ \log_{10}(d_{sc_i \to ue_k}) + \xi, \tag{5}$$

where $d_{sc_i \to ue_k}$ is the distance between the user and SC i in metres.

The downlink SINR must be taken into account to incorporate the influence of interference in HO decision. The downlink SINR for cell i received at UE k in dBm can be computed as

$$\gamma^r_{bs_i \to ue_k} = \frac{P^r_{bs_i \to ue_k}}{\sum_{bs \in N_{bs}, bs \neq bs_i} P^t_{bs} \cdot h_{bs \to ue_k} + \sigma^2}, \tag{6}$$

where σ^2 is the noise power and the term $\left(\sum_{bs \in N_{bs}, bs \neq bs_i} P^t_{bs} \cdot h_{bs \to ue_k}\right)$ represents the summation of the downlink power from the neighbouring cells except cell i i.e., the interferer cells.

3.2 *User Transmit Power Criterion*

The mean UE transmit power can be estimated for a candidate cell by performing the standard measurement. Assuming that the channel gain is symmetric, i.e., $h_{bs_i \to ue_k} = h_{ue_k \to bs_i}$, and using (3), the uplink RSRP of UE k for the target cell i, $P^r_{ue_k \to bs_i}$ in dBm, can be given as

$$P^r_{ue_k \to bs_i} = \frac{P^t_{ue_k} P^r_{bs_i \to ue_k}}{P^t_{bs_i}}, \tag{7}$$

where $P^t_{ue_k}$ is the UE mean transmit power for cell i. Thus, the uplink SINR can be written as

$$\gamma^r_{ue_k \to bs_i} = \frac{P^r_{ue_k \to bs_i}}{I_{ue_k \to bs_i}}, \tag{8}$$

where $I_{ue_k \to bs_i}$ is the interference caused by UEs in the same cell i and the interference caused by UEs in the neighbouring cells plus noise,

$$\begin{aligned} I_{ue_k \to bs_i} = &\sum\nolimits_{ue \in U_i, ue \neq ue_k} P^t_{ue} \cdot h_{ue \to bs_i} + \\ &\sum\nolimits_{bs \in N_{bs}, bs \neq bs_i} \sum\nolimits_{ue \in U_i} P^t_{ue} \cdot h_{ue \to bs} + \sigma^2, \end{aligned} \tag{9}$$

where the first line of (9) represents the interference from the UEs in the same cell and the second line represents the interference from the UEs in the neighbouring cells plus noise power.

Given the minimum requirement for maintaining quality performance γ_{th}^{up} and based on (7) and (8), we can measure an estimate of the UE transmit power with respect to cell i as shown in (10)

$$P^t_{ue_k} = \frac{I_{ue_k \to bs_i} \cdot P^t_{bs_i} \cdot \gamma^{up}_{th}}{P^r_{bs_i \to ue_k}}. \tag{10}$$

Equation (10) can be utilized to predict the power consumption of UE k, if we consider the UE transmit power as a main source to the UE power consumption. Therefore, we can use this criterion to minimize the UE transmit power by performing the HO to the cell that requires a lower power requirement.

3.3 *Cell Capacity Criterion*

The cell capacity plays an important role in HO decision making as it can limit the HO failure, and hence, improving the QoS delivered to the UE in terms of throughput satisfaction. The cell capacity can be defined as [27]

$$CP_i = BW \cdot (1 - R^i_{ue}) \cdot \log_2(1 + \gamma^r_{bs_i \to ue_k}), \tag{11}$$

where BW is the system bandwidth and R^i_{ue} is the total ratio of resources assigned to all active UEs in cell i compared to the cell's

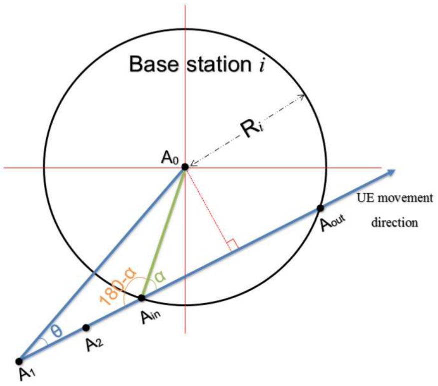

Fig. 2: Time of stay measurement inside a base station

total resources, R^i_{total}, which can be expressed as

$$R^i_{ue} = \frac{\sum\limits_{\forall j} R_{uej}}{R^i_{total}}, \tag{12}$$

where R_{uej} is the resource allocated to user j from cell i, thus the term $\sum\limits_{\forall j} R_{uej}$ represents the summation of all resources allocated to all active users in cell i.

3.4 *Predicted ToS Criterion*

As depicted in Fig.2, the ToS, ToS_{ue_k}, can be measured as

$$\begin{aligned} ToS_{ue_k} &= \frac{\mid \overrightarrow{A_{in}A_{out}} \mid}{V_{ue_k}} \\ &= \frac{2R_i \cos(\alpha)}{V_{ue_k}}, \end{aligned} \tag{13}$$

where A_{in}, and A_{out} are respectively the entry and the exit points of the UE to and from base station i and R_i is the base station radius. We can get the following from Fig.2

$$\frac{\mid A_1 A_0 \mid}{\sin(180-\alpha)} = \frac{R_i}{\sin(\theta)}, \tag{14}$$

where A_0 and A_1 are respectively the location of base station i and the previous location of the UE. Equation (14) can be rewritten as

$$\sin(\alpha) = \frac{\mid A_1 A_0 \mid \sin(\theta)}{R_i}. \tag{15}$$

Therefore

$$\cos(\alpha) = \sqrt{1 - \frac{\big(\mid A_1 A_0 \mid \sin(\theta)\big)^2}{R_i^2}}. \tag{16}$$

The angle between the UE trajectory and the base station i, θ, can also be calculated as

$$\theta = \arccos\left(\frac{\overrightarrow{A_1A_0} \cdot \overrightarrow{A_1A_2}}{\mid \overrightarrow{A_1A_0} \mid \times \mid \overrightarrow{A_1A_2} \mid}\right), \tag{17}$$

where A_2 is the current location of the UE. Finally, we substitute (16) and (17) in (13) to get the time of stay as

$$ToS_{ue_k} = \frac{2R_i\sqrt{1 - \frac{\left(|\overrightarrow{A_1A_0}| \cdot \sin\left(\arccos\left(\frac{\overrightarrow{A_1A_0}\cdot\overrightarrow{A_1A_2}}{|\overrightarrow{A_1A_0}|\times|\overrightarrow{A_1A_2}|}\right)\right)\right)^2}{R_i^2}}}{V_{ue_k}}. \tag{18}$$

4 Proposed Grey Relational Analysis Based Handover (GRA-HO) Method

The proposed GRA-HO method combines the AHP and GRA principles in a HO decision method for dense SC HetNets. The attributes (i.e. HO metrics) used for cell ranking are: the downlink SINR ($\gamma^r_{bs_i \rightarrow ue_k}$), the UE transmit power ($P^t_{ue_k}$), cell capacity (CP_i) and ToS. The HO decision is based on choosing a proper alternative (i.e. base station) among the available set of alternatives. Henceforth the base station(s) will be named alternative(s) and the HO decision metric(s) will be named attribute(s). The whole procedures of the proposed method can be divided into three parts. In the first part, the attributes of all cells that satisfy the condition of sustaining service continuity (cells with $RSRP \geq RSRP_{th}$), are obtained. The second part is to obtain the weighting vector $\mathbf{w}$ which will be detailed in section 4.1. While the third part involves applying the GRA to rank the available alternatives so as to obtain the best alternative for HO as explained in section 4.2.

4.1 *Weighting of HO Metrics*

We deploy the Analytical Hierarchy Process (AHP) technique [28] to obtain the weights of the attributes prior to the process of GRA-HO. The AHP uses the Saaty scale table 1 [28] to grant the importance of each attribute in a range of 1 to 9 to construct the pairwise comparison matrix. Note that the intermediate values in table 1 are used for uncertainty states e.g. when the decision maker is not sure whether to choose "strong importance 5" or "very strong importance 7", the alternative solution is to choose the intermediate value 6. Generally, the importance of each attribute is different from others. Therefore, the first step is to derive a comparison matrix for the relative importance of each attributes according to the numerical importance scale in table 1. The pairwise comparison matrix is a square matrix with size (n*n). In our proposed method, we have n=4 i.e., we have 4 attributes, therefore the size of the pairwise comparison matrix is (4*4).

Table 1 Saaty Scale Table [28]

Importance Intensity	Definition
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate Values

Let the pairwise comparison matrix, denoted as $\mathbf{P}$, defined as

$$\mathbf{P} = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{24} \\ p_{31} & p_{32} & p_{33} & p_{34} \\ p_{41} & p_{42} & p_{43} & p_{44} \end{bmatrix}, \tag{19}$$

$$\text{subject to } p_{ii} = 1, \text{ and } p_{ij} = \frac{1}{p_{ji}}, \tag{20}$$

where p_{ij} is constructed from table 1. The elements in $\mathbf{P}$ are weighted against each other e.g., SINR versus ToS. Therefore, the values of the diagonal of matrix $\mathbf{P}$ is equal to 1 because the relative importance of a certain attribute with respect to itself produces a value of 1.

After obtaining the pairwise comparison matrix, we need to construct the normalized Eigen vector of the matrix $\mathbf{P}$. First, each element in the matrix is normalized by dividing it by the correspondent column sum producing the normalized matrix $\mathbf{P^n}$ with p^n_{ij} elements as given in (21), where the sum of each column must yield

1.

$$\mathbf{P^n} = \begin{bmatrix} \frac{p_{11}}{\sum_{i=1}^{n} p_{i1}} & \frac{p_{12}}{\sum_{i=1}^{n} p_{i2}} & \frac{p_{13}}{\sum_{i=1}^{n} p_{i3}} & \frac{p_{14}}{\sum_{i=1}^{n} p_{i4}} \\ \frac{p_{21}}{\sum_{i=1}^{n} p_{i1}} & \frac{p_{22}}{\sum_{i=1}^{n} p_{i2}} & \frac{p_{23}}{\sum_{i=1}^{n} p_{i3}} & \frac{p_{24}}{\sum_{i=1}^{n} p_{i4}} \\ \frac{p_{31}}{\sum_{i=1}^{n} p_{i1}} & \frac{p_{32}}{\sum_{i=1}^{n} p_{i2}} & \frac{p_{33}}{\sum_{i=1}^{n} p_{i3}} & \frac{p_{34}}{\sum_{i=1}^{n} p_{i4}} \\ \frac{p_{41}}{\sum_{i=1}^{n} p_{i1}} & \frac{p_{42}}{\sum_{i=1}^{n} p_{i2}} & \frac{p_{43}}{\sum_{i=1}^{n} p_{i3}} & \frac{p_{44}}{\sum_{i=1}^{n} p_{i4}} \end{bmatrix}. \tag{21}$$

The normalized Eigen vector $\mathbf{w}$, of size (n*1), is then obtained by averaging across the rows [29], that is

$$w_j = \frac{\sum\limits_{j=1}^{n} p_{ij}^{n}}{n}, \tag{22}$$

where the sum of $\mathbf{w}$ vector is 1 because it is a normalized vector.

The Eigen vector is considered as the weighing vector providing that it is consistent. Consistency means to check whether the pairwise matrix $\mathbf{P}$ entries are consistent or not. Generally, inconsistency is allowed in AHP for some extent. A maximum of 10% inconsistency is tolerable by the AHP technique [30] [31]. The measure of consistency is called the consistency ratio (CR) where the smaller the CR the better the consistency and 10% is the highest acceptable ratio for CR. The procedures of finding CR can be summarized as:

- First step is to define the random index (RI) according to Saaty table 2 [28]. It has been proven that RI depends on the number of attributes. In our proposed GRA-HO method, we have 4 attributes, hence, RI = 0.9.

Table 2 Random Index [28]

Number of Attributes	1	2	3	4	5
RI	0	0	0.58	0.9	1.12

- Second step is to find the consistency index (CI) based on

$$CI = \frac{\lambda_{max} - n}{n-1}, \tag{23}$$

where λ_{max} is the largest principle value that can be obtained from the summation of products between each element of vector $\mathbf{w}$ and the sum of each column in the pairwise matrix $\mathbf{P}$.

$$\lambda_{max} = \sum_{j=1}^{n} \Big(\sum_{i=1}^{n} p_{ij} \Big) \cdot w_j. \tag{24}$$

- Finally, the CR is computed as

$$CR = \frac{CI}{RI}. \tag{25}$$

When the consistency ratio (CR) is 10% or less, then the judgement is proper and the weighing vector $\mathbf{w}$ is acceptable to be used in GRA-HO. Otherwise the AHP procedures must be repeated to attain the consistency.

4.2 Cell Ranking Using Grey Relational Analysis (GRA)

The UE has a m number of target alternatives, n number of attributes for each alternative and attributes weighting vector $\mathbf{w}$. We can present the procedures of GRA method as follows:

Procedure 1: The decision matrix, $\mathbf{D}$, is built by mapping the alternatives against the attributes as given below

$$\mathbf{D} = \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} \\ x_{21} & x_{22} & x_{23} & x_{24} \\ x_{31} & x_{32} & x_{33} & x_{34} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & x_{m3} & x_{m4} \end{bmatrix}, \tag{26}$$

where the rows correspond to the alternatives, and the columns represent their correspondent attributes, $n = 1, \cdots, 4$, $m = 0, 1, \cdots, N_{sc}$, x_{ij} represents the value of the j^{th} attribute for the i^{th} alternative. Thus, x_{i1} = SINR, x_{i2} = $P_{ue_k}^{t}$, x_{i3} = CP_i and x_{i4} = ToS. Where

$$\mathbf{D} = \begin{array}{c|cccc} & SINR & P_{ue_k}^{t} & CP_i & ToS \\ \hline A_1 & \gamma_{bs_1 \to ue_k}^{r} & P_{ue_1}^{t} & CP_1 & ToS_{ue_1} \\ A_2 & \gamma_{bs_2 \to ue_k}^{r} & P_{ue_2}^{t} & CP_2 & ToS_{ue_2} \\ A_n & \gamma_{bs_n \to ue_k}^{r} & P_{ue_n}^{t} & CP_n & ToS_{ue_n} \end{array}$$

Procedure 2: The decision matrix is then normalized so as to make the attributes dimensionless in the range of [0,1] for comparability. We used the enhanced max-min normalization technique which accounts for both cost attributes (the smaller the better) and the benefit attributes (the larger the better). In our proposed method, we have four attributes, one of which is a cost attribute ($P_{ue_k}^{t}$) and the other three are benefit attributes (SINR, CP_i and ToS). For cost attribute, the normalization of the j^{th} attribute for the i^{th} alternative is computed as

$$x_{ij}^{n} = \frac{\max\limits_{\forall i}\{x_{ij}\} - x_{ij}}{\max\limits_{\forall i}\{x_{ij}\} - \min\limits_{\forall i}\{x_{ij}\}}. \tag{27}$$

While for the benefit attributes, the normalization is expressed as

$$x_{ij}^{n} = \frac{x_{ij} - \min\limits_{\forall i}\{x_{ij}\}}{\max\limits_{\forall i}\{x_{ij}\} - \min\limits_{\forall i}\{x_{ij}\}}. \tag{28}$$

Procedure 3: In this step, the definition of the ideal reference sequence, whose sequence is close to the best alternative. Generally, for an attribute j^{th} of an alternative i^{th}, if the value of x_{ij}^{n} is equal or close to 1, then the performance of this alternative for this attribute is the best one compared to others. Therefore, preferred value of the j^{th} attribute for the i^{th} alternative is 1, hence, we define the ideal reference sequence as x_j^{*}=1 $\forall j = 1, 2, 3, 4$, i.e., the ideal alternative vector can be defined as [1 1 1 1].

Procedure 4: This step calculates the Grey Relational Coefficient (GRC) which is used as a measure for how much is the j^{th} attribute for the i^{th} alternative, i.e., x_{ij}^{n}, close to the ideal sequence x_j^{*}. The formula for calculating the GRC is given as

$$GRC(x_{ij}^{n}, x_j^{*}) = \frac{\min\limits_{\forall i, \forall j}\{\delta ij\} + \Psi \max\limits_{\forall i, \forall j}\{\delta ij\}}{\delta_{ij} + \Psi \max\limits_{\forall i, \forall j}\{\delta ij\}}, \tag{29}$$

where δ_{ij} = $\mid x_j^{*} - x_{ij} \mid$ and Ψ is the distinguishing coefficient $\in$ [0,1].

Procedure 5: The ranking of the grey relational coefficients, denoted as GRA_i, is finally obtained as

$$GRA_i = \sum_{j=1}^{n} w_j \; GRC(x_{ij}^{n}, x_j^{*}), \tag{30}$$

$$\text{subject to} \sum_{j \in n} w_j = 1, \tag{31}$$

where w_j is the j^{th} attribute weight.

Procedure 6: The largest grey relational coefficient grade is the HO target cell.

$$\text{HO}_{\text{target}} = \arg\max GRA_i. \tag{32}$$

The procedures of the GRA-HO method is depicted in Algorithm (1).

Algorithm 1 GRA-HO Method

```
1: Start procedures
2: Obtain HO metrics, $\gamma^{r}_{bs_i \to ue_k}$, $P^{t}_{ue_k}$, $CP_i$ and ToS for all cells
   with $RSRP \geq RSRP_{th}$
3: Built the pairwise comparison matrix P
4: Obtain the weighting vector w using AHP
5: Check the consistency
6: if CR $\leq 10\%$ then
7:     Go to step 10
8: else
9:     Go to step 3
10: end if
11: Generate the decision matrix D according to the values
    obtained in step 2
12: Apply the GRA steps on the decision matrix D
13: Rank the alternatives obtained from step 12
14: Perform HO to the alternative with the highest rank
15: End procedures
```

5 Performance and Results Analysis

The performance of the GRA-HO method is evaluated in terms of computational complexity, number of HOs, radio link failure and mean UE energy efficiency and compared against other two methods, the conventional SAW method and the conventional VIKOR method. Simulation parameters are listed in table 3 [22].

Table 3 Simulation Parameters [9][22][23][32]

Simulation time	1200 sec
Bandwidth (BW)	20 MHz
Carrier Frequency (F_c)	2.5 GHz
Macrocell Transmit power	43 dBm
Macrocell Radius	500 m
Small Cell Radius	100 m
Number of Small Cell	50
Number of UEs	100
Maximum Small cell Transmit power	30 dBm
Minimum required signal for service continuity ($RSRP_{th}$)	-70 dBm
Uplink SINR threshold (γ^{up}_{th})	3 dB
UE transmit power	23 dBm
Mean velocity of the UE (v_m)	{1,20,40, 60,80,100} km/h
Standard deviation for UE velocity (v_{std}) [23]	1 km/h
Period between two updates of the mobility model (Δt) [23]	1 sec
Distinguishing coefficient (Ψ) [9]	0.5

In SAW method, each attribute is assigned a weight, and the sum of all given weights is equal to 1. The weighted sum of all alternatives is used to select the alternative. The overall score is expressed as [10]:

$$SAW^{*} = \arg\max_{i \in m} \sum_{j=1}^{n} w_j p^{n}_{ij}. \tag{33}$$

The alternative with the highest rank is selected as the best one as given in (33).

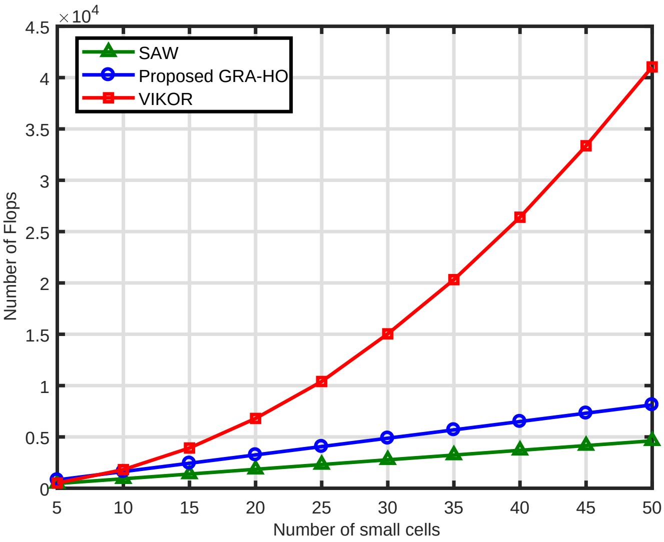

Fig. 3: Complexity Analysis (Number of Flops vs. the number of small cells)

In VIKOR [33], the alternatives are ranked according to their closeness to the ideal positive solution (ideal solution is the solution that has the best values for all attributes compared to the other solutions, i.e., alternatives).

5.1 Complexity Analysis

Fig.3 depicts the computational complexity of the proposed GRA-HO method compared to SAW and VIKOR methods. This is done by evaluating the three algorithms in terms of the number of floating point operations (flops) with different sizes of the decision matrix (i.e., different densities of SCs). We used the Matlab function defined in [34] which scans and parses each line of the simulation code and counts the number of flops. As can be noticed from Fig.3, the computational complexity increases with the increase in the size of the decision matrix for all method. The VIKOR method has extremely high complexity operations compared to SAW and GRA-HO. The proposed GRA-HO has slightly higher number of flops compared to SAW method owing to the operations of the AHP for consistent weight calculations. However, this slight difference well justified the accurate cell selection of the proposed GRA-HO method. Unlike the VIKOR method, the curve of the proposed method is linearly increasing due to the slight increase in the number of SCs.

5.2 Number of Handovers

The number of HOs is depicted in Fig.4. The SAW method has the higher increase in the number of HOs compared to VIKOR and GRA-HO. The proposed GRA-HO method has the lowest number of HOs especially for low and medium speed UEs. This reduction can be owed to the use of ToS metric and the enhanced max-min in attribute normalization which helps in unnecessary HO reduction. Unlike the SAW and VIKOR method, which give a fixed weight for the attributes leading to a higher number of HOs, the GRA-HO method assigns consistent weights to the attributes leading to the minimization of unnecessary HOs.

5.3 Radio Link Failure

A radio link failure is declared if the HO is initiated to the target cell but the downlink SINR of that cell drops below a predefined threshold γ_{th} for a period of time window T310, which is 1 second, as defined in [32]. Fig.5 illustrates the radio link failure. The higher the velocity the higher the radio link failure for all methods. The SAW method yields higher failure compared to VIKOR due to its

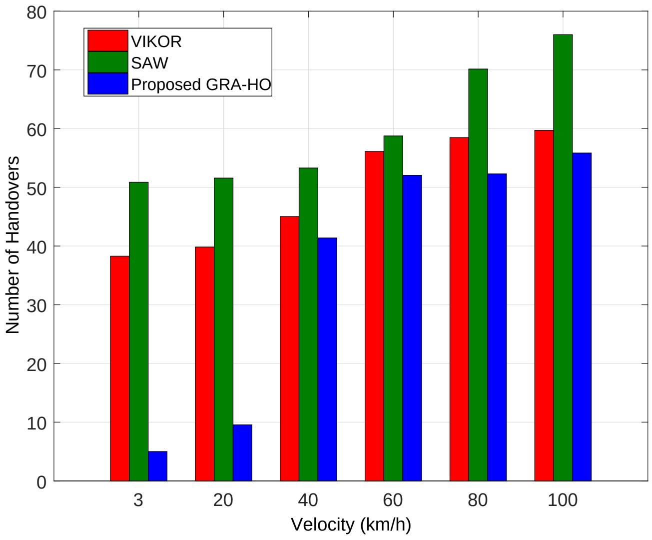

Fig. 4: Number of handovers vs. different user velocities

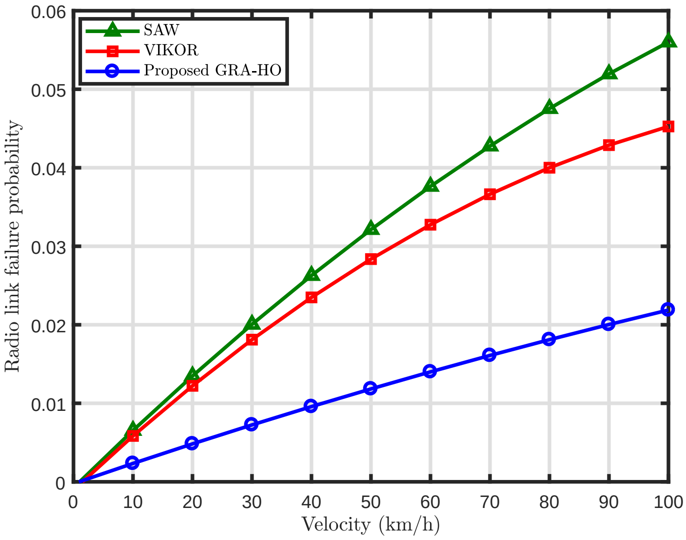

Fig. 5: Radio link failure probability vs. different user velocities

straight forward computational prior to HO, and hence, higher link failure. On the other hand, the proposed GRA-HO method has the lowest radio link failure due to the early HO to the correct target cell with a sufficient available capacity. For instance, when the velocity is 40km/h, the proposed GRA-HO method has 56% and 61% reduction in radio link failure compared to VIKOR and SAW methods respectively. The low radio link failure in the GRA-HO method emphasizes the consistency of weighting calculation of the attributes which leads to an accurate cell selection compared to the other two methods.

5.4 *Energy Efficiency*

In this subsection, we evaluate the performance of the three algorithms in terms of mean UE energy efficiency taking into account the UE transmit power consumption needed to associate to the target cells. We make use of the energy metrics defined in [35] to measure the energy efficiency (EE)

$$EE = \frac{Channel\ capacity\ (bits/sec)}{Transmit\ power\ (watt)}. \tag{34}$$

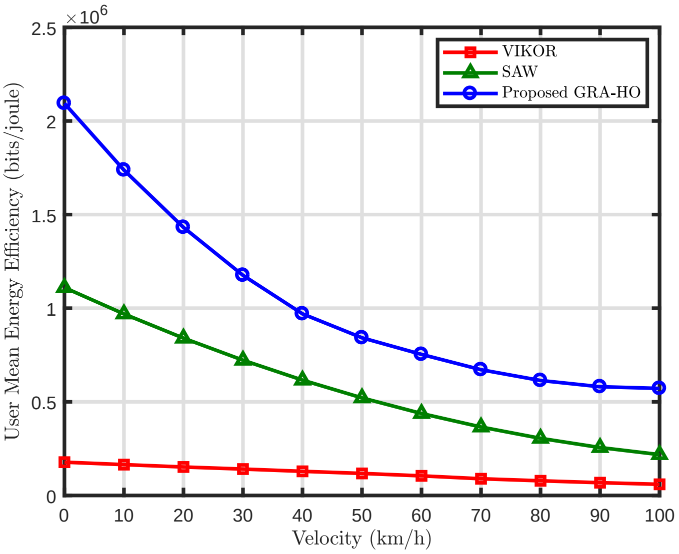

Fig. 6: User energy efficiency vs. different user velocities

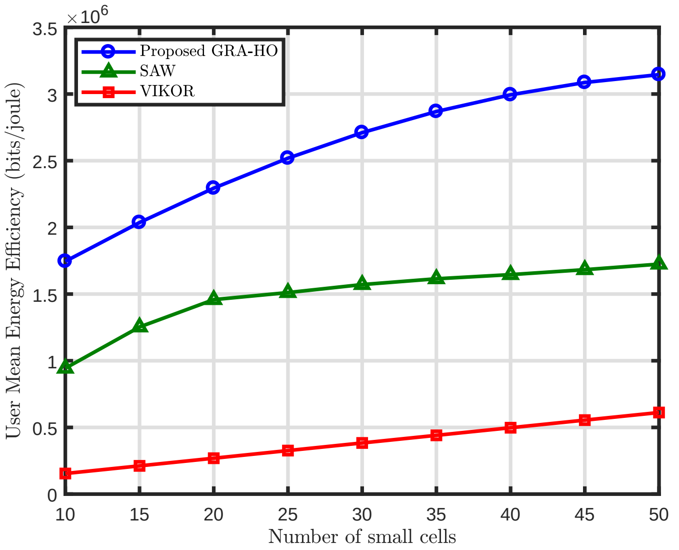

Fig. 7: User energy efficiency vs. the number of small cells

Which means how many bits is carried per joule energy i.e., how much energy is utilized to transmit that amount of bits. The mean UE energy efficiency is depicted in Fig.6. The energy efficiency is inversely proportional to the velocity in all methods because the higher the velocity the lower the ToS, and hence, the lower throughput which yields a lower energy efficiency. Generally, the VIKOR has the lowest energy efficiency compared to SAW and GRA-HO method due to its complicated computational complexity.

Fig. 7 shows the energy efficiency against variable densities of SCs when the mean velocity of the UE is fixed at 3km/h. Basically, the higher the number of SCs the better the performance in terms of mean UE energy efficiency. This is because the traffic load generated by the UEs will be distributed among the SCs, and hence, reduce the interference caused by other UEs. Which means that the UE mean throughput will be enhanced resulting in an improved energy efficiency. The proposed GRA-HO method has outperformed the other two methods owing to the AHP consistent weight assignment to the UE transmit power criterion.

6 Conclusion

We proposed a GRA-HO HO method for dense SCs HetNet which jointly accounts for influence of interference, cell capacity, energy consumption and predicted time of stay. The proposed method uses the AHP technique to assign weights to the attributes then the GRA MADM method is applied to rank the alternative and select the best one for HO. Enhanced max-min normalization is used to normalize the attributes during GRA process to reduce the ranking abnormality of the GRA and hence reduce the unnecessary HO. Simulation results show a good performance for the GRA-HO method in terms of computational complexity. Results also show that the proposed GRA-HO method can minimize the frequency of HOs and reduce the radio link failure in addition to enhance the energy efficiency compared to the classical SAW and VIKOR methods.

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