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# Interference management based on clustering in RIS-aided ultra dense network under multicell scenario

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**ABSTRACT**

Ultra dense network (UDN) and reconfigurable intelligent surface (RIS) are two latest technologies in encountering the increasing demands for network capacity and quality of service in wireless cellular networks. UDN is created by densely deploying femtocells in macrocells area. It causes complex interferences because distances among femtocells are likely very close. RIS provides solution in regulating the reflection of the signal emitted from the transmitter to the receiver to resolve the obstacles. However, RIS reflects the interference signals as well causing more complex interference problems. This paper proposes a solution using clustering method as interference management in RIS-aided UDN network. By clustering method, nearby femtocells are grouped and allocated different frequency channels among femtocells in a cluster. The performance of two systems–the baseline system and the one employing a clustering method–is evaluated based on signal to interference plus noise ratio (SINR), throughput, and bit error rate (BER). Simulation results indicate that SINR and throughput improved by 1.57% and 1.73%, respectively. Meanwhile, the BER for the baseline system is $5.78\times10^{-8}$ and decreased when applying the proposed method system with a value of $2.26\times10^{-8}$. The proposed clustering method is promising to confront the interference problems.



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## 1. INTRODUCTION

By the continuous advancement and popularity of wireless communication networks, the number of mobile users exponentially increases, so that the need for good signal quality and large capacity in mobile networks is always be challenging in the world of telecommunications, markedly in wireless communications [1]-[3]. Ultra dense network (UDN) is one of the efficient technologies to improve resource utilization efficiency and throughput and meet the challenges in 5G and beyond networks. By the application of network densification, it can increase the density of access points (APs) or base stations (BSs) and hence meet the needs of higher network capacity demands [4]-[6]. In wireless cellular communication networks, UDN is created by deploying densely small cells i.e., femtocells into larger cells such as macrocells or microcells. The densely distributed femtocells that form UDNs have the goal of reducing the distance between the BS and the users, so that signal attenuations will be reduced and ensure that the quality of communication in the network will be guaranteed [7]. However, due to the dense deployment of small BSs and sharing the co-channel frequencies among adjacent neighboring cells either femtocells or macrocells, it causes interferences and deteriorate the quality of desired received signal power, therefore efforts are needed to increase the quality of desired signal power and reduce the effects of interferences that occur with the aim of increasing network capacity and quality [8]. On the other hand, reconfigurable intelligent surface (RIS) is an emerging technology that provides a solution in mitigating the blocked signals by reflecting and forwarding signals that are obstructed by obstacles to the desired receiver [9]. RIS has component elements that can reflect incoming signals towards the intended receiver. However, due to its nature property the RIS elements also reflect interference signals towards the intended receiver [10].

Some literatures discuss about RIS-assisted wireless networks by using channel estimation algorithm focusing to optimize the value of signal to interference plus noise ratio (SINR) with respect to the BS transmit power vector and RIS settings [11]. A multi-band multi-cell system with the help of RIS, based on the phase shift model, BS is applied using different frequencies and considering the interaction among the signals [12]. Cai *et al.* [12] evaluated the system performances through a simulation experiment. Based on their simulation, the results that are applying the proposed model achieved a significant performance improvement in the optimization of the RIS-assisted multicell multiband system [12].

To overcome the problem of interferences, one of researches proposes interference management technique through clustering method [13]. They analyze the optimal number of clusters to achieve the maximum capacity of user devices/equipment (UE) in a joint distribution network (UDN) environment. It is found that with an increase in the number of clusters, there is an increase in frequency reuse and user capacity. Altering a parameter, such as the center frequency, has a significant impact on determining the optimal number of clusters and leads to a reduction in both the received power at the BS and the interference from other clusters. Hence, the effect of frequency (path loss) has the greatest impact on the optimal number of clusters [13].

In another research, a dynamic frequency plan with user clustering for a joint distribution network (UDN) is proposed [14]. The proposed method aims to improve system throughput and user performance at the cell edge while considering the complexity level by involving weight design, graph building, and spectral clustering [14]. Coordinated multi-point technology (CoMP)-based users are randomly distributed. Their results show that the proposed method is able to improve user's spectral efficiency (SE) and system throughput, especially for users at the cell edge [14].

Another research investigated the user centric clustering and BS model for solving the interference problems in UDN [15]. The proposed algorithm increases linearly with the network size. It is very suitable for UDNs and outperforms the maximized SINR algorithm significantly, which focuses on the placement of clustering and BS [15].

There are also studies that use RIS assistance and applying clustering for downlink RIS assisted nonorthogonal multiple access (NOMA) system with the purpose of maximizing energy efficiency [16]. User clustering is solved with matching algorithm, and its result is that the downlink RIS-assisted NOMA system improves the energy efficiency compared without RIS [16]. However, to the best of authors' knowledge, the major literatures that suggest to implement the use of clustering on a dynamic frequency plan with user clustering for a joint distribution network, the number of clusters and the placement of clustering, none of them addresses the use of clustering in UDN multicell scenarios for downlink transmission considering the distance among the femtocells.

This paper introduces a distance-based clustering approach to address the interference issues arising from the dense deployment of femtocells within macrocells in UDNs, where both femtocells and macrocells operate on the same frequency band. The proposed clustering technique assigns different frequency bands to femtocells within a cluster to minimize interference among nearby femtocells. This frequency allocation pattern is then reused across other clusters. The method is expected to mitigate interference among femtocells and enhance the overall performance of the UDN network. Compared to the previous research [17], we also generally have discussed a clustering technique to reduce interference in UDN networks. However, our approach in [17] has not involved RIS technology, whereas this research focuses on the integration of two technologies namely RIS and clustering technology to minimize the occurrence of interferences.

The remaining of this paper is arranged as follow. Following this introduction section, section 2 presents the research method adopted. The design of considered network scenarios is discussed as well as its assumptions and the analysis of performance parameters to be taken into account. These performance parameters are the SINR, throughput, and bit error rate (BER) values. Section 3 presents the results and discusses it. Section 4 concludes this paper.

## 2. METHOD

The main research method in this paper is modeling and simulation. This section describes in details system model, its assumptions, performance metrics that are analyzed, for the system, and simulation parameters.

### 2.1. System model

The focus of this paper is to mitigate the effects of interference in UDN network. This paper considers a cellular communication network with access mode in downlink transmission by utilizing orthogonal frequency division multiple access (OFDMA). This paper proposes two simulation scenarios. In the first scenario, a network configuration with three macrocells is established, using a frequency reuse factor (FRF) of 3, which allocates one-third of the total system bandwidth to each macrocell. As depicted in Figure 1, a RIS is placed at the boundary of these three macrocells. A number of femtocells, denoted as *N*, are densely distributed within each macrocell according to a uniform distribution for downlink transmissions. Each femtocell is assigned one-third of the total bandwidth randomly, in line with the FRF of 3, depending on its position within the macrocell. All femtocells are presumed to be actively transmitting signals from their BSs (Home E Node B/HeNB) to the femtocell user equipment (FUE). This setup, known as the baseline system, serves as the starting point for analyzing interference issues arising from the dense deployment of femtocells within the coverage area of the three macrocells. Additional information about this scenario is presented in Figure 1.

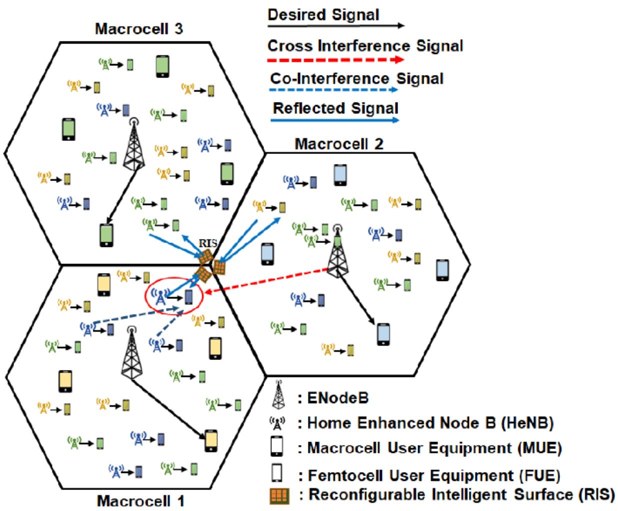


Figure 1. Baseline system of first scenario

The second scenario is applying clustering method in the first scenario in which involves grouping adjacent femtocells to use different channel frequencies and form a group or a cluster, hence the grouping is based on the distance of neighboring femtocells. The goal is to reduce interference among femtocells by increasing the distance between those assigned the same channel frequency band, thereby minimizing co-channel interference.

In summary, two simulation scenarios of heterogeneous cellular networks, comprising femtocells and macrocells, are created. The first scenario, called as the baseline system, aims to analyze interference problems arising from the dense deployment of femtocells across three macrocells. The second scenario proposes a clustering technique for femtocells to address and to reduce these interference issues.

#### 2.1.1. Comparison between baseline system and proposed clustering method

The configuration based on first scenario is shown in Figure 1. Since two types of cells occur in the scenario, overall network is also referred to as heterogeneous or two-tier networks. Two-tier refers to femtocell and macrocell tiers. Co-tier (between same tier) and cross-tier (between different tier) interferences can be observed in the femtocell under study i.e., the observed femtocell (drawn as red circle in Figure 1). Each macrocell and femtocell is assigned a unique sub-bandwidth according to an FRF of 3, creating three distinct sub-bandwidths. These are labeled as channels 1, 2, and 3. In the first scenario, shown in Figure 1, macrocells 1, 2, and 3 are each allocated channel 1, 2, and 3, respectively. Femtocells follow the same channel assignments and are color-coded–yellow, blue, and green–to indicate sub-bandwidths corresponding to channels 1, 2, and 3.

Since both macrocells and femtocells apply FRF of 3, that is mentioned earlier, for femtocell's channel allocation it is randomly assigned based on their appearance on each macrocell. In addition, femtocells and macrocells share same total system bandwidth. Therefore, it is likely creating large number of interferences to femtocells of the same sub-bandwidth frequencies which are close to each other, since the femtocells are densely deployed. Figure 1 illustrates the interferences observed when examining a femtocell within macrocell

1 during downlink transmission for both macrocells and femtocells. Figure 1 uses blue dashed lines to illustrate co-tier interference and red dashed lines to depict cross-tier interference.

Figure 2 shows when it applies the proposed clustering method. The distances among the femtocells sharing the same frequency channels become wider and it reduces the interference of femtocells that share the same frequency channels. The clustering method approach combines three adjacent femtocells into one group and assigns different channel to each femtocell belonging to the same group. Subsequently, the same clustering pattern is repeated to form additional clusters. This process continues until the last group is formed within a given macrocell area. This is described according to the application following of this clustering technique remains consistent with the setup visually illustrated in Figure 2.

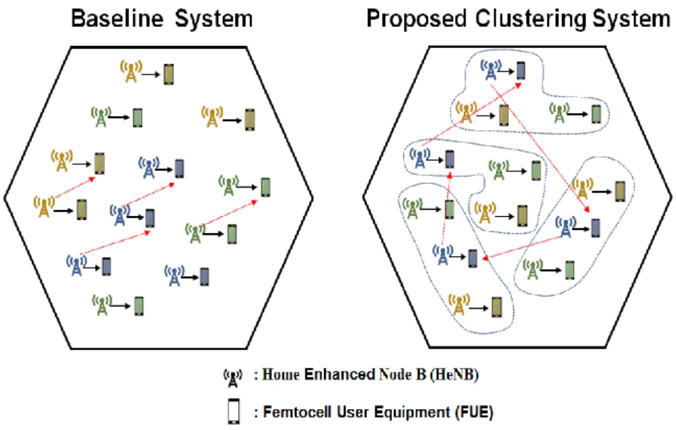


Figure 2. Illustration of comparison between baseline system and proposed clustering method

Figure 3 depicts second scenario that is considered when the proposed clustering method is applied. In Figure 3, a number of femtocells, *N*, is distributed densely according to uniform distribution in each area of macrocells. The clustering process operates as follows: the femtocell nearest to the macrocell base station (eNB) is selected as the reference to start the first cluster construction. This reference femtocell then measures its distances to the surrounding femtocells and selects the two closest ones to create a cluster consisting of three femtocells. These three femtocells are then removed from the pool of femtocells available for future clustering. To determine the next reference femtocell, the third closest femtocell to the original reference is chosen. The two nearest femtocells to this new reference form the second cluster. This process repeats iteratively until all femtocells within a macrocell are grouped into clusters. By applying this method, the distance between femtocells sharing the same channel is increased, which is expected to reduce co-channel interference. The pseudocode for this proposed clustering algorithm is shown in Figure 4.

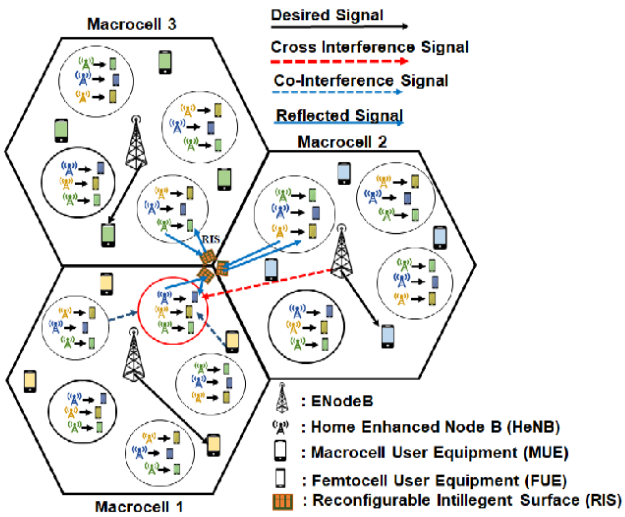


Figure 3. Clustering method at RIS aided muticell scenario

```
Input:
    femtocells_list ← list of all femtocells with their coordinates
    macrocell_bs ← coordinates of macrocell base station (eNB)
Initialize:
    clusters ← empty list to store clusters
    used_femtocells ← empty list
While number of used_femtocells < total femtocells in femtocells_list:
    If clusters are empty:
        // Step 1: Find first reference femtocell (closest to macrocell BS)
        reference ← femtocell in femtocells_list not in used_femtocells
                     with minimum distance to macrocell_bs
    Else:
        // Step 2: Find new reference femtocell
        previous_reference ← reference of the last formed cluster
        reference ← 3rd closest femtocell to previous_reference
                    that is not in used_femtocells
    // Step 3: Find 2 closest femtocells to the reference
    cluster_members ← list of 2 femtocells closest to reference
                      from femtocells_list that are not in used_femtocells
    // Step 4: Form cluster
    current_cluster ← [reference] + cluster_members
    Add current_cluster to clusters
    // Step 5: Mark femtocells as used
    Add all femtocells in current_cluster to used_femtocells
Output:
    clusters // list of clusters, each containing 3 femtocells
```

Figure 4. Pseudocode of proposed clustering method

## 2.2. Performance analysis

The simulation carried out in this paper obtains the values of three parameters to be collected for performance analysis. These three parameters are SINR, throughput, and BER values. Calculation analysis of these three parameters is described in the following sub-sections.

### 2.2.1. Signal to interference plus noise ratio

Based on the scenario shown in Figure 1, different frequency allocations are applied to the three macrocells. It is assumed that each femtocell has one active FUE and uses same channel as its co-channel. Observations are made on one of the femtocells during downlink transmission, concurrently with the eNBs downlink transmission to its macrocell user equipment (MUE). When a femtocell in a macrocell area is observed, interference occurs at the observed FUE caused by other HeNBs that use same frequency chancel as well as caused by the macrocell uses same frequency channel. In this paper, the signal quality at the observed FUE is remarked by calculating the SINR value. There are two interferences that are being observed in this paper i.e., co-tier interference which this interference arises from other femtocells using the same frequency and cross-tier interference which occurs while the femtocell being observed using the same frequency as the macrocell. The SINR value at the observed FUE can be calculated by using (1) based on [18].

$$SINR_{FUE} = \frac{P_{FUE}}{\sum_{k=1}^{i} I_{crt}(k) + \sum_{l=1}^{j} I_{cot}(l) + P_N} \quad (1)$$

Here, $P_{FUE}$ represents the desired signal power at the observed FUE (in mW), $I_{crt}(k)$ denotes the *k*-th cross-tier interference power (in mW), $I_{cot}(l)$ represents the *l*-th co-tier interference power (in mW), *i* and *j* indicate the total number of cross-tier and co-tier interference sources, respectively, and $P_N$ refers to the total system noise power (in mW). The expected signal power $P_{FUE}$ at the observed FUE is calculated using (2).

$$P_{FUE} = \frac{P_{HeNB}}{L} \quad (2)$$

where $P_{HeNB}$ is the transmit power of HeNB (mW) and $L$ is the propagation path loss. In (2) in logarithmic scale or decibel (dB) unit can be stated in (3).

$$P_{FUE}(dBm) = P_{HeNB}\ (dBm) - L\ (dB) \quad (3)$$

In urban area, the channel model is based on standard of ref. [19] stated in (4). The standard channel model used for femtocells in urban area is based on [20]. It can be expressed in (5).
Channel model for macrocell system:

$$L_{macro}(dB) = 15.3 + 37.6\ log_{10}(r) + L_{oth} \quad (4)$$

Channel model for femtocell system:

$$L_{Femto}(dB) = 127 + 30\ log_{10}\left(\frac{r}{1000}\right) \quad (5)$$

Here, $r$ represents the distance between the eNB or HeNB and the receiving MUE or FUE, while $L_{oth}$ (in dB) denotes the penetration loss due to walls along the transmission path between the transmitter and receiver.

For the system with RIS, the RIS channel model adopted is two-ray channel model which is based on ref. [21]. The received power at the receiver can be calculated as shown in (6) [21].

$$P_r = (Z+1)^2 . P_t . \frac{\lambda}{4\pi d} \quad (6)$$

where $P_r$ is received power (mWatt), $P_t$ is transmit power (mWatt), $Z$ is total of RIS elements, $\lambda$ is wavelength of transmitted signal in meter, and $d$ is the distance between transmitter and receiver (meter).

### 2.2.2. Throughput

Throughput is actual amount of success data received per time unit that measure how much data is received successfully, based on the maximum data rate transmitted over a network or communication system in a period of time. Throughput can be calculated based on the Shannon capacity using (7) [22].

$$T = B \times log_2(1 + SINR) \quad (7)$$

where $T$ is the system throughput (Mbps) and $B$ is the total system bandwidth (MHz) and $SINR$ is the measured SINR.

### 2.2.3. Bit error rate

BER is the total bit error received on a data set through a communication link that has changed due to noise, interference, or synchronization bit mismatch. The details of BER calculation are explained in (8) [23].

$$BER_{FUE} = \frac{3}{4} Q\left(\sqrt{\frac{4}{5} \text{ x } \frac{\gamma_{FUE}}{log_2(M)}}\right) \quad (8)$$

Here, $Q(.)$ denotes the $Q$-function of the value within the brackets, and $\frac{\gamma_{FUE}}{log_2(M)}$ represents the normalized SINR per bit, which depends on the modulation scheme used.

### 2.2.4. Outage probability

Outage probability is the likelihood of the certain performance parameter dropping below a threshold value of $\beta$ (a certain value associated with performance parameters), indicating that the receiver is out of the ENodeB range in the context of cellular communication. Outage probability can be denoted using cumulative distribution function (CDF) and complementary cumulative distribution function (CCDF). CDF is a method used to estimate the probability distribution, where the CDF is employed to calculate the cumulative probability of scalar continuous distribution values. Moreover, the CDF is also applied to determine the distribution of random multivariable variables. The calculations to assess the SINR and throughput values using the CDF are described in (9) for SINR, along with the CDF of throughput computation using the CDF outlined in (10).

$$CDF(SINR) = P[SINR \leq \beta] \quad (9)$$

$$CDF(T) = P[(B * log_2(1 + SINR)) \leq \beta] \quad (10)$$

CCDF is a function that yields values inversely related to the CDF. Typically, this function is utilized to calculate the failure rate or BER. The following steps outline the calculations to determine the BER value using the CCDF function, interpreted through (11) as described in the research [24].

$$CCDF(BER) = P\ [BER > \beta\ ] \quad (11)$$

### 2.3. Simulation parameters

As stated previously, in this paper it is considered a multicellular system consisting of three macrocells. The number of femtocells is randomly deployed with a uniform distribution having 210 femtocells for each macrocell. The ENodeB at the macrocell has a power of 46 dBm, while the power at the HeNB is 23 dBm. Three macrocells are applied FRF of 3, where each macrocell is assigned a different frequency channel. Macrocell has a radius of 1,000 meters and the radius for the femtocells is 30 meters. RIS with 3 by 3 elements placed in the center between the border of three macrocells. To simplify analyzing system performance, it is assumed based on the initial scenario that the HeNBs serves one FUEs and there is other HeNBs using the same frequency channel as well as another eNB. The distance between FUE and each HeNB is set at 10 meters. Simulations are conducted for 10,000 iterations, with each iteration producing an average value of the three predefined performance parameters, namely SINR, throughput, and BER. Testing is carried out based on increasing the number of femtocells until it reached 210 femtocells. After that, the CDF value for SINR and throughput performance parameters and CCDF for BER performance parameter are calculated. The simulation experiments are repeated for 10,000 iterations, and each performance parameter is collected for each number of femtocells and then they are each averaged, except for CDF and CCDF they are measured for the number of femtocells is 210. We chose an iteration time of 10,000, because based on the results obtained, a high number of iterations will produce a narrower output distribution so that the resulting graph becomes smoother. Running 10,000 iterations is necessary to provide a value that is close to expectation, from the faithful average result of the iterations, so that this can reduce the occurrence of momentary fluctuations in the results obtained in the trial. The computation process was carried out as many as 10,000 iterations with a processing time of 2 hours using a laptop device that has a read access memory (RAM) capacity of 8 GB for running the proposed method algorithm. Table 1 summarizes the simulation parameters used for simulation experiment.

Table 1. Simulation parameters

| No. | Parameter | Value |
|---|---|---|
| 1. | Quantity of macrocells | 3 |
| 2. | FRF for microcells and femtocells | 3 |
| 3. | Macrocell radius [18] | 1,000 meters |
| 4 | Femtocell radius [18] | 30 meters |
| 5. | Number of HeNBs | 210 |
| 6. | Number of MUEs | 210 |
| 7. | HeNB transmission power | 23 dBm |
| 8. | Macrocell eNB transmission power | 46 dBm |
| 9. | Overall system bandwidth | 10 MHz |
| 10. | Modulation type | 16-QAM |
| 11. | Duration of simulation | 10,000 iterations |
| 12. | Noise power spectral density | -174 dBm/Hz |
| 13. | Number of RISs | 1 |

## 3. RESULTS AND DISCUSSION

Extensive simulation experiment has been carried out for two systems according to Figures 1 and 3. Figure 1 shows a scenario applied in this paper which is a scenario as a baseline system that RIS is applied in the system. Figure 3 depicts a scenario of proposed system by applying the clustering method. The simulation results that are shown in this section are the baseline system simulation results which are labelled as UDN RIS aided and the system with proposed method is written as UDN clustering RIS aided. The simulation results are shown in Figure 5 for the SINR measurement. As illustrated in Figure 5, the SINR value declines with the increasing number of HeNBs. At 210 HeNBs, the UDN RIS-Aided system records an SINR of 21.67 dB, whereas the system employing the clustering method attains a slightly higher SINR of 22.04 dB. Comparing the two systems, after clustering method applied in the system, SINR value of system increases by 1.57%.

Figure 6 presents the simulation results of the SINR CDF, corresponding to the SINR values shown in Figure 3 when there are 210 femtocells. At an SINR value of 24 dB, the baseline system achieves a CDF of 61.75%, while the system using the clustering method attains a CDF of 56.82%. These findings from Figures 5 and 6 suggest that the proposed clustering method is effective in increasing the distance between femtocells assigned the same frequency channels, ensuring that neighboring femtocells do not share identical channels and thereby reducing interference levels.

Figure 7 displays the simulation outcomes, highlighting the throughput comparison between the baseline system and the system enhanced with the proposed approach. The trend closely aligns with the SINR results, confirming their consistency. When there are 210 femtocells, the baseline system achieves a throughput of 72.07 Mbps, while the system with clustering reaches 73.32 Mbps, reflecting a 1.73% increase. Figure 8 displays the throughput CDF corresponding to the values in Figure 7. At a throughput of 80 Mbps, the baseline system and the proposed method have CDF values of 62.86% and 57.95%, respectively. Overall, the proposed clustering method enables the system to deliver higher throughput or data rates.

Figure 9 shows the BER performance as a function of the number of HeNBs. From the graph, when there are 210 femtocells, the BER for the baseline system is $5.78\times10^{-8}$, while the clustering method achieves a lower BER of $2.26\times10^{-8}$. Figure 10 presents the CCDF of BER. When the BER reaches 0.2, the CCDF values are 10.32% for the baseline system and only 1.43% for the proposed clustering method. This indicates that the proposed method significantly lowers the CCDF of BER as the BER increases. The reduction in interference achieved through clustering contributes to the improved BER performance. Overall, the simulation results clearly show that the proposed approach outperforms the baseline system.

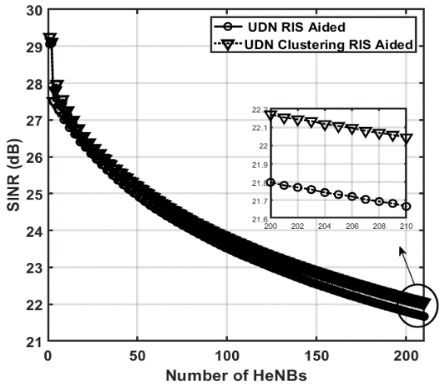


Figure 5. The results for SINR to the quantity of HeNBs

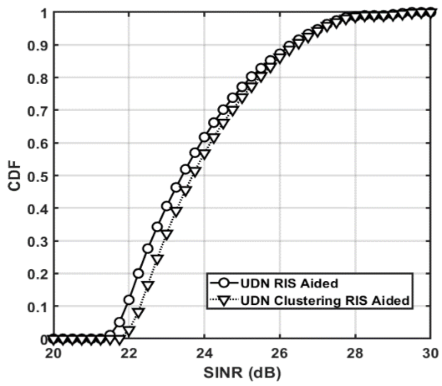


Figure 6. The CDF of SINR

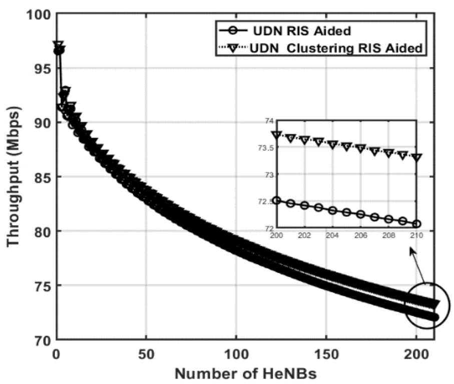


Figure 7. The results for throughput to the quantity of HeNBs

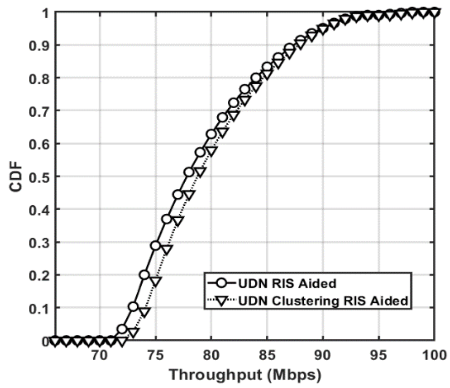


Figure 8. The CDF of throughput

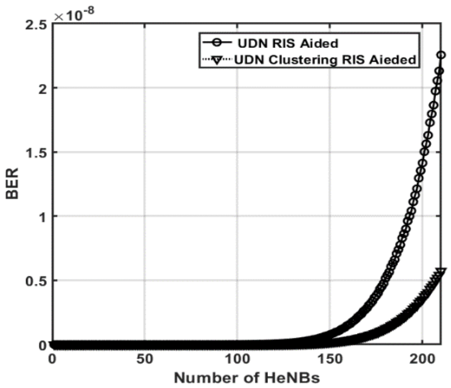


Figure 9. The results for BER to the quantity of HeNBs

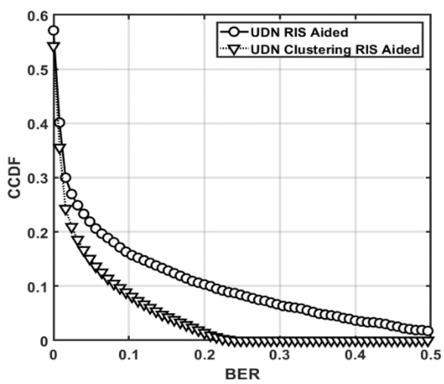


Figure 10. The CCDF of BER

In order to realize the relationship of this paper to other research works, it is surveyed the most related works available in the literatures. Table 2 presents the results of others studies and researches related to the topic in this paper. The research in this paper discusses simulation for multicell scenario in downlink transmission that focuses on the calculation of femtocell analysis based on the performance parameters tested. By applying the proposed clustering method based on distance can increase the SINR value by 1.57% in addition to two other performance parameters.

Table 2. The comparisons of this paper to the previous research results

| No | Method | Results |
|---|---|---|
| 1. | User clustering, passive beamforming, and power allocation jointly optimized for downlink RIS [16]. | The proposed method can improve the energy efficiency by 7.8%-23.1%. |
| 2. | Analyze the optimal number of clusters in UDN network [13]. | The influence of the frequency band is the biggest factor affecting the optimal number of clusters. |
| 3. | Dynamic user clustering as proposed [14]. | The proposed method is able to improve user SE and system throughput especially for user located at the cell edge. |
| 4. | A cluster-based energy-efficient resource management (CEERM) [25]. | The proposed method obtained the outage value while the number of cells equal to 24 with network throughput value $12 \times 10^8$ bit/s and network energy efficiency $3.02 \times 10^8$ bit/Joule. |
| 5. | Clustering and CDSA model [26]. | The SINR value and throughput value reached 5dB and 4.67%, respectively. |
| 6. | Distributed user-centric clustering [15]. | By applying the proposed method, performance loss value under 5.75%. |
| 7. | This paper. | The improvements in terms of SINR reached 1.57% and the throughput value reached 1.73% by applying the proposed method. |

We have conducted significance tests using paired *t*-test, based on the results obtained, the proposed method provides a statistically significant improvement in SINR performance over baseline system. This is evidenced by *p*-values <0.05 in most experiments and the deviation standards for this statistical test is shown in Figure 11.

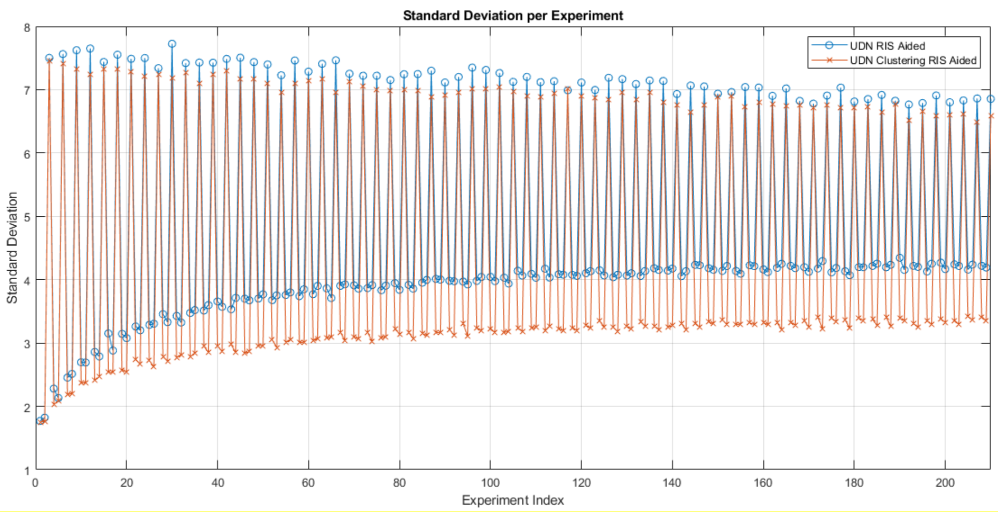


Figure 11. The standard deviation of simulation

## 4. CONCLUSION

Dense femtocells in cellular networks or it is referred to as UDN, are able to cope with increased traffic demands. RIS-aided in network system can also increase the signal power, but will increase the interference that will be received by intended receiver or FUEs. UDNs also experience interference due to frequency reuse among neighboring femtocells. Accordingly, this paper presents a clustering approach intended to minimize interference by spacing out femtocells that use the same frequency channel. A comprehensive simulation is conducted to evaluate three performance metrics as the number of femtocells increases up to 210 users. The proposed method shows that the SINR value has increased by 1.57%, the throughput value has increased by 1.73%. Meanwhile, the BER value for the baseline system is $5.78\times10^{-8}$ and decreased when applying the proposed clustering method system with a value of $2.26\times10^{-8}$. It implies that the proposed clustering method is promising to support the increasing demands of user traffics in UDN. These findings confirm that the clustering method enhances communication quality in dense femtocell environments.

As future work, the clustering strategy can be extended by incorporating machine learning techniques to dynamically adapt to real-time traffic and interference patterns. Machine learning can be utilized to dynamically form clusters based on real-time traffic patterns and channel conditions. This enables the system to continuously learn and adapt to changing network environments. However, it needs to be paid attention to apply machine learning that the problems to be tackled are suitable to be solved by algorithms of machine learning and hence the benefits offered machine learning algorithms are optimum.

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## AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
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R : **R**esources
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O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

## CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

## INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

## DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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