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Fog Node-Based Clustering Algorithms For Enhancement Of Throughput Of 5G Network

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***Abstract*— In this research, development of cluster algorithm for 5G network device-to-device (D2D) communication cluster head selection is presented. The research addressed the challenge of interference arising from lack of coordination among the small cells in 5Gnetwork D2D communication. Specifically, a fog computing–based Edge Location Assisted Water-Filling (ELA-WF) clustering algorithm was developed and used for the determination or selection of fog nodes among many small cells and for clustering of other small cells to the fog nodes in 5G network . The ELA-WF clustering algorithm aims to maximize the throughput by increasing the total communication rate based on a Water-Filling algorithm, while ensuring stable queuing delays in the 5G network. The performance of ELA-WF clustering algorithm was compared with that of the classical Voronoi tessellation model based on simulations conducted using ANYLOGIC software. The comparison is made with respect to data rate for normalized bandwidth or spectral efficiency (SE) with the assumption that there are 125 SCs that are normally distributed over an area of which gap statistics analysis was used to determine the optimal number of cluster heads or in this case of fog nodes as 5. The results showed that there is a significant advantage of ELA-WF algorithm compared to Voronoi tessellation model; notably, more than a 2 dB advantage is observed for the spectral efficiency of 1 bits/s/Hz. This result is quite important and useful in the design of next generation wireless networks that will have fog or edge computing units.**

Key words: Fog node, 5G network, clustering algorithms, interference, throughput maximization, network

1. Introduction

The interference among small cells in 5G network can undermine the core advantage of increasing throughput with the network architecture [1,2,3,4,5]. This lack of coordination among the small cells results in one of the greatest challenges faced by the network. However, this can be overcome by fog networking which can control and coordinate the small cells to ensure better interference mitigations [6,7,8]. This paper adapts the principles of fog computing by upgrading some small cells to fog nodes to solve the performance challenges in network.

Particularly, the determination, or selection, of the fog nodes among many small cells and the connection of other small cells to the fog nodes are pertinent issues to be considered in this paper. Hence, a method that can be used in to tackle this problem is the Voronoi tessellation approach [9].

Notably, the higher the data rate the smaller the transmission delay and the smaller the queuing delay, since the service rate of the queues is directly proportional to the data rate, which, consequently, can ensure more stable queues in the small cells. Hence, this paper seeks to increase the overall data rate (the throughput) by proposing a novel clustering algorithm to meet the various requirements in 5G that can be employed for both downlink and uplink.

In this paper, the details of the solution approach based on Edge Location Assisted Water-Filling algorithm (ELA-WF) is presented and compared with the solution based on the classical Voronoi tessellation approach [9,10]. The two solution approaches are simulated using some experimental setups in ANYLOGIC software [11]. The spectral efficiencies and end-to-end latency are the two major metrics used in comparing the performance of the two solution approaches.

2. Methodology

This paper presents an approach to overcome the challenge of interference rising from lack of coordination among the small cells in 5G network by deploying fog networking, which is used to control and coordinate the small cells to ensure better interference mitigation. The network model for the 5G network is first presented and then used to describe the solution approach.

In the network model, fog nodes are used as cluster heads to serve small cells (SCs) and each of the small cell can access many fog nodes. The small cell (SC) location are fixed. Also, based on the channel quality, a small cell can be selected and upgraded to a fog node to serve as cluster head. The locations of such small cells to be upgraded to fog nodes are determined. As such, the fog nodes location changes as channel realization changes. So, the major issue for the network model is to dynamically determine the locations of fog nodes that will be upgraded from small cells for a quasi-static fading channel and then specify which small cells can be upgraded to fog node and which of the prior existing fog node will the newly elected fog node take over control. This problem is addressed using Edge Location Assisted Water-Filling (ELA-WF) clustering algorithm.

ELA-WF) clustering algorithm operate by first determining the location of the SCs which it will upgraded to become fog nodes among many other SCs that a found within a given area; it is assumed that the location of the SCs are known and they are static. After the selection of the SCs and upgrading them to fog nodes, the remaining SCs are then clustered around these selected fog nodes. The clustering of the SCs in done in a probabilistic way in such a way that each each of the SC is connected to all the upgraded fog nodes with a certain probability, where the probability value depends on the channel quality of the SC. The ELA-WF algorithm details are presented in Procedure I.

Importantly, the ELA-WF algorithm requires the values of K (which is the number of fog nodes in the network) and N (which is the number of small cells in the network). While N is known, the value of optimal value of k need to be determine. The ELA-WF algorithm does not have a means of determining the optimal number of cluster heads, K required. In this paper, the gap statistics is used to determine the value of K. The value of N and the obtained value of k from the gap statisctis are then used in the ELA-WF algorithm.

Procedure I**: Edge Location Assisted Water-Filling (ELA-WF)**

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1.) Initialize $K$ and $N$// K is the number of fog nodes while N is the number of small cells in the network.
2.) Let K 1 = N;  $N = N + K$ and $K = K1$.
3.) Form the $(N + K) \times (N + K)$ channel matrix $H$ where all diagonal terms of $H$ are set to zero.
4.) Initialize $\gamma_{nk}^{0} = 0$ for $k = 1, 2, \dots, K$ and $n = 1, 2, \dots, N$ for each entry in $H$. Hence, matrix $\Gamma = 0$ where $\Gamma$ is the
    $(N + K) \times (N + K)$matrix
5.) Iterate starting from $l = 1$
        a.) Initialize $n = 1$
        b.) Select $\omega_{nk}^{l}$ that satisfies the model in 14 $\forall k$ except $k = n$.
        c.) Find $\sigma_{kj}^{l}$ for $\gamma_{nk}^{l-1}$ using 21 $\forall k$ except $k = n$.
        d.) Apply ELA-WF algorithm to find $\gamma_{nk}^{l}$ using Equation 22 $\forall k$ except $k = n$.
        e.) Update $\gamma_{nk}^{l} = {}^{1}/_{K} * \gamma_{nk}^{l} + \left(1 - {}^{1}/_{K}\right) * \gamma_{nk}^{l-1}$ $\forall k$ except $k = n$ to ensure the convergence as usually done in
        ELA-WF as presented in Equation 15 and Equation 16
        f.) Set $\gamma_{nk}^{l} = 0$ for $k = n$
        g.) Repeat steps $b$ to $f$ for $n = 2, \dots, N$.
        h.) Continue iterations until $\gamma_{nk}^{l} - \gamma_{nk}^{l-1} < \epsilon, \forall k \text{ and } \forall n$
6.) Find the expected value of $\gamma_{nk}$ with respect to $n$ for $k = 1, 2, \dots, K$ as $v = \left[E[\gamma_{n1}]E[\gamma_{n2}] \dots E[\gamma_{nk}]\right]$.
7.) Reset $N$ and $K$ to the initial values which are given as a priori information.
8.) Determine the index of the highest $K$ values in v. Note that these indices give the locations of the fog nodes that will be
        upgraded from small cells.
9.) Remove the $K$ rows that correspond to the indices of the $K$ highest values in $v$. This reduces the dimension of matrix $\Gamma$ to
        $N \times (N + K)$.
10.) Remove the $N$ columns of $\Gamma$ that correspond to the indices of the lower $N$ locations in $v$, which produces a $N \times K$ matrix
        of $\Gamma$.
11.) Normalize the sum of the entries of $\gamma_{nk}$to 1 in each row for $k = 1, 2, \dots, K$, which shows the connection probability of
each small cell to the $K$ number of fog nodes.
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3.0 Results and Discussion

The Voronoi tessellation model which corresponds to the connection of a small cell with the fog that has the strongest signal for average values of channels is compared to the proposed ELA-WF soft clustering algorithm. The two solution approaches are simulated using some experimental setups in ANYLOGIC software. The comparison is made with respect to data rate for normalized bandwidth or spectral efficiency (SE) with the assumption that there are 125 SCs that are normally distributed over an area of which gap statistics analysis was used to determine the optimal number of cluster heads or in this case of fog nodes as 5. The results for the gap analysis is summarized in Table 1 and Figure 1.

The ELA-WF algorithm is used to probabilistically connect each of the small cell to all selected 5 fog nodes depending on the channel conditions without any concern on the distance. On the other hand, Voronoi tessellation considers the smallest distance as the only criterion to determine to which of the 5 fog nodes it assigns each of the small cell without considering the channel quality. The results of the spectra efficiency versus carrier to noise ratio, C//N (dB) for the two approaches are presented in Table 2 and Figure 2. As shown in the results, ELA-WF algorithm has better spectral efficiency than the Voronoi tessellation approach.

The experiment is conducted again by increasing the number of fog units from $K = 5$ to $K = 10$ for 125 SCs. It should be noted that the performance of both ELA-WF and Voronoi tessellation model decrease in this case as depicted in Table 3 and Figure 3. In all, the ELA-WF algorithm had better spectral efficiency than the Voronoi tessellation approach and the gap statistics gave optimal number of cluster head

Table 1 The results for the gap analysis for determination of the number of cluster head, K required in the ELA-WF algorithm

Number of clusters, K with N = 125 SCs	Gap
1	0.17
2	0.24
3	0.26
4	0.28
5	0.327
6	0.25
7	0.24
8	0.245
9	0.245
10	0.252

Figure 1 The graph for the gap analysis for determination of the number of cluster head, K required in the ELA-WF algorithm

Carrier to noise ratio, C//N (dB)	Spectral efficiency (in bits/Hz) for ELA-WF Clustering Algorithm	Spectral efficiency (in bits/Hz) for Voronoi Tessellation Method
0	0.850817	0
1	1.083657	0.23284
2	1.304777	0.45396
3	1.514177	0.66336
4	1.711857	0.86104
5	1.897817	1.047
6	2.072057	1.22124
7	2.234577	1.38376
8	2.385377	1.53456
9	2.524457	1.67364
10	2.651817	1.801

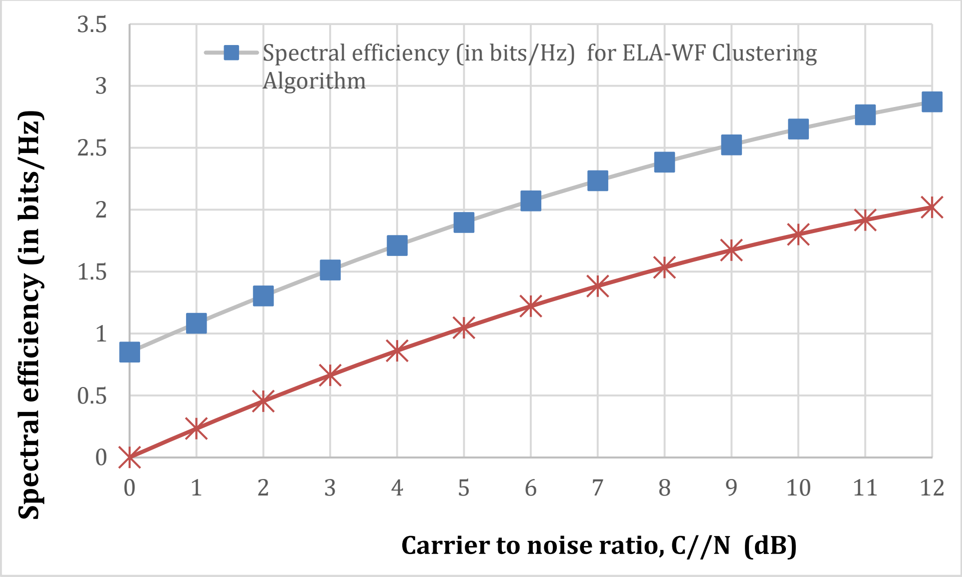

Figure 2: Comparison of the spectral efficiency of ELA-WF algorithm compared to Voronoi tessellation for $K = 5$ and N =125

Carrier to noise ratio, C//N (dB)	Spectral efficiency (in bits/Hz) for ELA-WF Clustering Algorithm	Spectral efficiency (in bits/Hz) for Voronoi Tessellation Method
0	0.5162	0
1	0.6391	0.1229
2	0.7588	0.2426
3	0.8753	0.3591
4	0.9886	0.4724
5	1.0987	0.5825
6	1.2056	0.6894
7	1.3093	0.7931
8	1.4098	0.8936
9	1.5071	0.9909
10	1.6012	1.085
11	1.6921	1.1759
12	1.7798	1.2636

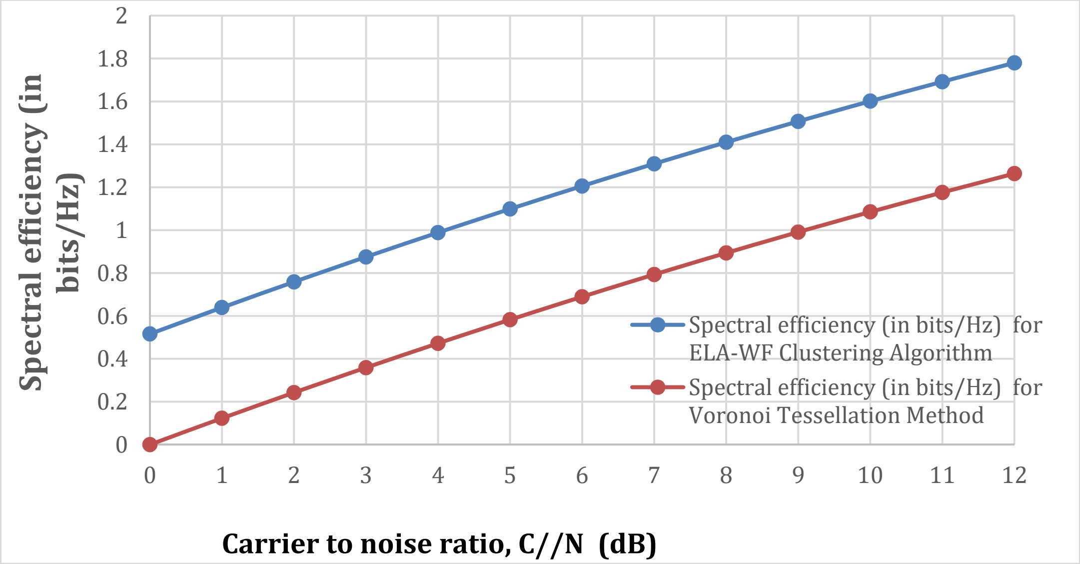

Figure 3: Comparison of the spectral efficiency of ELA-WF algorithm and red to Voronoi tessellation for $K = 10$ and N =125

4. Conclusion

Development of fog node-based cluster algorithm for 5G network is presented. The cluster algorithm is for both device to device communication and cluster head selection by specifying the connection of small cells with many possible fog nodes by the clustering algorithms, which aim to maximize the throughput by increasing the total communication rate based on a Water-Filling algorithm (ELA-WF). Gap statistics analysis was used to determine the optimal number of cluster heads or in this case of fog nodes. Comparison of ELA-WF with the state-of-the-art Voronoi tessellation model, which does not guarantee a stable queuing delay, but it has clearly demonstrated the superiority of the ELA-WF clustering algorithm in terms of substantially increasing the throughput, or spectral efficiency in parallel with reducing latency. In all, the advantage of the proposed ELA-WF clustering algorithm grows over the classically used model in terms of the spectral efficiency and latency when the number of fog nodes is increased. This result is quite important and useful in the design of next generation wireless networks that will have fog or edge computing units.

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