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Dynamic Traffic Model With Optimal Gateways Placement in IP Cloud Heterogeneous CRAN

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ABSTRACT In this paper, topology design, optimal routing, and gateways placement selection algorithms are proposed in Heterogeneous Cloud Radio Access Network (C-RAN) with exploiting Free Space Optical (FSO) communication. The proposed network consists of two tiers; the lower tier concerns with clustering Remote Radio Heads (RRHs) based on traffic demands. The upper tier consists of transceivers along with the Cluster Heads (CHs) and gateways. Algorithms are proposed to achieve the lowest number of edges and the highest possible throughput based on the presented optimization problem. Moreover, route optimization and gateway selection problems have been considered in two different traffic scenarios; static (maximum occupancy) or dynamic (Partial occupancy). Furthermore, a disaster recovery algorithm is proposed in case of failure of one of the nodes or edges to maintain the continuous connectivity of the network at the expense of the traffic. Our simulation results show that the number of gateways in a dynamic traffic operation is reduced by 33% in node size of 25, 36, and 42. Also, this reduction is increased to 41% if the node size increased to 49.

INDEX TERMS Centralized radio access networks, free-space optical communication, gateway deployment, link reliability, optimal placement.

I. INTRODUCTION

In the Cloud Radio Access Networks (C-RAN), the cellular fronthaul networks provide connectivity between Remote Radio Heads (RRHs) and Base Band Processing Units (BBUs). C-RAN is a cloud computing-based for Radio Access Network (RAN) that can enable the large-scale deployment. As a result, it eases the collaboration of radio resources and provides real-time virtualization capabilities. BBU is the traditional processing unit for all baseband radio functions, and it is connected to RRHs transceivers via optical links. An essential requirement in 5G fronthaul networks is to be able to forward massive traffic to/from a large number of devices in the district of RRHs into the BBU for processing purposes [1].

On the other hand, fiber optics technology succeeded in matching all expectations for increasing capacity and traffic, as It can provide links with fast data rates, low-latency, high reliability, and high-security degrees. Fiber optic links are not deployed in many countries due to the insufficient fiber infrastructure in using large-sized networks. Therefore, Free space optics (FSO) is a technology that could replace fiber optics and provide a cost-effective solution with high-bandwidth communication links. It has high immunity against interference and more secure due to a point-to-point (PTP) connection. However, FSO links suffer from a degradation in the performance by atmospheric turbulence, obstacles, and beam misalignment [2]. Additionally, the RRHs in the traditional C-RAN are connected PTP to BBUs using CPRI protocol, which is not supported by FSO links. In the next generation C-RAN, RRHs are expected to be connected using IP channel where the data is routed to the destination through multi hops (see Figure 1).

Many works addressed the topology control of FSO links for maximizing the network throughput in wireless networks. For example, Shang *et al.*, [3] and Grossglauser and Tse [4] have discussed the capacity of multi-hop wireless networks on two networks. A localized Delaunay triangulation (LDT)

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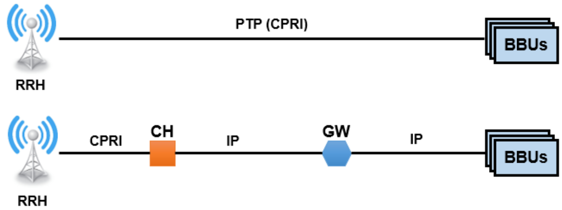

FIGURE 1. **Traditional C-RAN and a next generation C-RAN.**

algorithm is used in Shang *et al.*. It works in the upper tier of a wireless mesh network, where the placement of the gateways is realized. Grossglauser *et al.* investigated the mobility of users in the ad-hoc network, where the connectivity between the nodes is calculated. Moreover, Xin and Wang [5] have discussed three scenarios in selecting gateways location in a multi-hop wireless mesh network that are Fixed-distribution, Random-distribution, and Grid-based distribution. These three scenarios have considered in the optimization problem to maximize the overall network throughput.

Other works considered techniques that can satisfy the increase of the network traffic needs; one method is developing a joint optimization of routing and link scheduling to get the optimal routes within a convenient schedule. Hoffmann & Medina [6] and Hong & Pang [7] implemented a graph-based model of interference and link scheduling system, where the links between nodes and placement of the gateways are optimized with the traffic constraints. Li *et al.* [8] are concerned with finding the optimal route of data from mesh nodes to gateways with maximizing the network throughput. Joint routing and scheduling transmissions are addressed in Tang & Brandt-Pearce [9] and Kodialam & Nandagopal [10] to achieve the required rate in single and multi-hop wireless networks. Alicherry *et al.*, [11] and Li *et al.*, [12] implemented an optimization problem for multi-path routing, link scheduling, and static channel assignment with a constraint of maximizing the network throughput. Liu *et al.* [13] proposed a bootstrap algorithm of FSO networks that aims to form a spanning tree in a short time. A fragment selection and merging (FSM) algorithm is proposed by Son *et al.* [14], and this technique works as the fragments iteratively combine until spanning-tree forms in a mesh network. The initial configuring algorithm with a minimum spanning tree (MST) is proposed in Zhou *et al.* [15], which has a better connectivity and edge weight than other techniques.

In general, the literature focused on improving the throughput in multi-hop wireless mesh networks with a consideration of the permanent placement of gateways. However, the best placement of the gateways is not defined for the optimal route and traffic. Moreover, it also lacks dynamic traffic system models and its performance in different atmospheric conditions for evaluation of the proposed topologies. Furthermore, the disaster recovery approach is not considered in dual-tier networks in the literature. In addition, minimizing the edges and gateways will reduce the cost of the computation and physical systems of the removed gateways. Therefore, topology design, optimal routing, and gateways placement selection algorithms are realized in this work with FSO technology to achieve the demand needs. The proposed topology design for C-RAN architecture is illustrated in the form of the tree graph (see Figure 2). The architecture is based on dual-tier C-RAN, where several RRHs are connected to the adjacent cluster head (CH) that acts as a router, and some of these CHs are considered gateways that can transfer the data to BBUs.

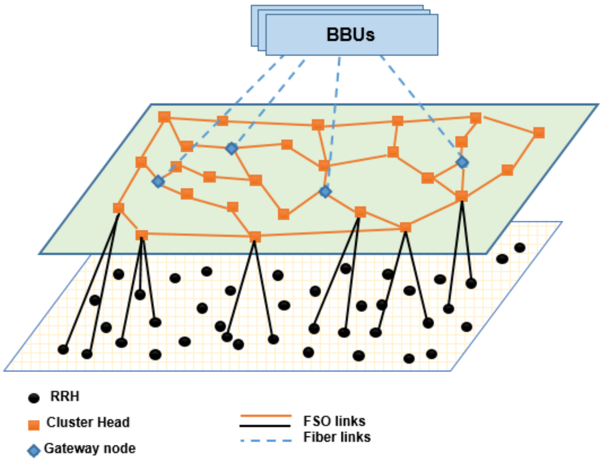

FIGURE 2. **Tree graph of the proposed dual-tier C-RAN.**

In this paper, we investigate the best placement of the gateways and routing paths in RAN to achieve optimal throughput. The Delaunay triangulation (DT) algorithm is used to generate the network topology with predefined cluster head locations. Then a traffic generation and gateways placement algorithms are proposed to show the traffic over the optimal place and routes with static (maximum occupancy) and Dynamic (partial occupancy). The simulation of the algorithms considered several conditions of network capacity and weather conditions. Also, the disaster-recovery technique is proposed with the consideration of static and dynamic traffic scenarios. The rest of this paper is organized as follows; Section 2 introduces the network model and states the problem. Section 3 analyses the traffic generation, gateways placement, and disaster recovery algorithms. Section 4 discusses and justifies the simulated results. Finally, Section 5 concludes the work and points out for future work.

II. SYSTEM MODEL AND PROBLEM STATEMENT

A. NETWORK MODEL

The network model consists of dual tiers; lower and upper layers (see Figure 2). The lower-tier consists of N RRHs, which serves users, while the upper-tier consists of M- CHs connected to several gateways via FSO links. The work assumes that every RRH covers individual districts and provides mobile services to the allocated users in this area. Each RRH is directly connected to the adjacent CH, forming a

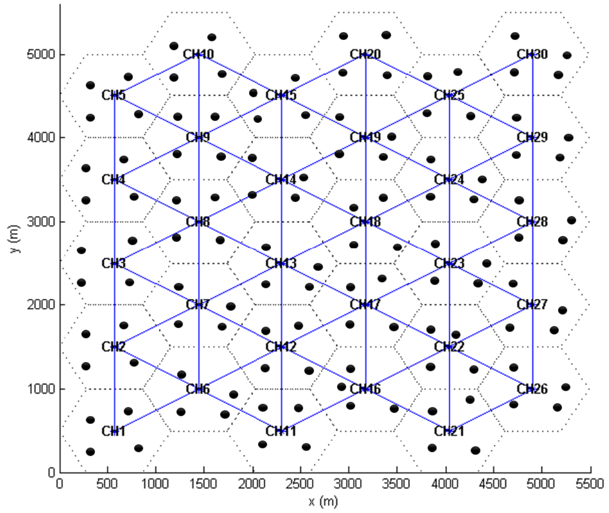

FIGURE 3. **Delaunay triangulation of 120 RRHs and 30 cluster heads (CHs).**

connected network. A small selected fraction of CHs are acting as gateways with a connection to the BBUs. The traffic to/from the RRHs relays through multi-hop routes until reaching one of the gateways and then to BBUs. The DT algorithm generates the distribution of RRHs and CHs in the form of clustered districts (see Figure 3). The model is inspired by constraints of distance and edge degrees at each node. Every RRH has a traffic demand that needs to be routed to one of the gateways via CHs.

DT is a planar graph of triangle-shaped of bounded regions, which is used in this work to construct the network topology and placement of CHs. It is the starting point of our network model with the minimum angles of all triangles that can mitigate the degradation of the atmospheric effects. Moreover, it has high redundancy as it is one of the most planar graphs with the maximum number of edges. Furthermore, most of the edges are short as the incident nodes are near to each other. This leads to short FSO links and better performance consequently. Graph theory is a mathematical structure used to model the relations between the nodes in the network. It uses a pair of sets of vertices and edges $G(V, E)$, where $V = v_1, v_2, \ldots, v_n$ is the set of vertices and $E = e_1, e_2, \ldots, e_m$ is the set of edges.

MST calculates all graph vertices in the network and chooses the minimum sum of the weight of all edges. The weight of the edges is calculated based on Euclidean distance between every two nodes. Saravanan an Madheswaran [16] used the MSTs computational complexity in a simple stochastic network model in a similar constrained edge graph model to be nearly exact O(L log L) for metric graphs, where L is the number of iterations. MST is known as the optimal routing tree of least cost edge-weighted diagram for data aggregation in such a similar problem in ad-hoc networks, according to Khan *et al.*, [17]. Conventionally, running time, delay, remaining energy, and data transmission between computing nodes are the key efficiency factors in mesh networks. MST is usually used to consider these factors with the objective function [18], [19]. The low computational complexity of the MST algorithm motivates us to use it in our model.

The DT algorithm generates the distribution of the RRHs and the cluster heads in the form of cluster areas (see Figure. 3). The model is inspired by the constraints of distance and edge degrees of each cluster. Every RRH has a traffic demand that needs to be routed to one of the gateways via the cluster heads. This work aims to maximize the total throughput of the network, whereas distinct minimum traffic from each RRH should be satisfied.

B. FSO LINK RELIABILITY

FSO suffers from some practical challenges affecting the optical signal when propagating through the atmosphere. These factors include; atmospheric turbulence-induced fading, atmospheric attenuation, and Line-of-sights (LoS) errors. These factors degrade the performance and reliability of the FSO links among nodes. Several irradiance distributions have been used for modeling a light beam propagating through a turbulent channel. The log-normal and Gamma-Gamma distributions are shown to be highly accurate for weak and moderate weather turbulence. For example, the reliability of an FSO link under log-normal fading can be computed as [11]:

$$\Re_{ij} = pr(I \geq I_{th}) = \frac{1}{2}\left[1 - erf\,\frac{ln(I_{th}) - ln(I_0)}{2\sqrt{2\sigma_x^2}}\right] \qquad (1)$$

where I_{th} is the threshold of received signal intensity, I_0 is the average received intensity, and σ_x^2 is the variance of the log-intensity fluctuation. Furthermore, the reliability of an FSO link under Gamma-Gamma distribution is given by:

$$\Re_{ij} = 1 - \frac{1}{\Gamma(\alpha)\Gamma(\beta)}\; G^{2,1}_{1,3}\left(\alpha\beta\frac{I_{th}}{I_0}\,\middle|\,\begin{matrix}1\\ \alpha,\beta,0\end{matrix}\right) \qquad (2)$$

where $\Gamma(.)$ is the gamma function, α, and β are the effective number of large-scale and small-scale cells of the scattering process in the atmosphere, respectively.

If the nominal capacity for all FSO links is C_{nom}, the effective capacity of an FSO link (i, j) for all $i \neq j$ is $Cij = \omega_{ij} C_{\text{nom}}$, ω_{ij} is the weight of an FSO link which is define as

$$\omega_{ij} = \begin{cases} \Re_{ij} & \Re_{ij} \geq \Re_{th} \\ 0 & otherwise \end{cases} \qquad (3)$$

$\Re_{th}$ is the minimum link reliability where the system can perform.

C. PROBLEM STATEMENT

The problem is to find the optimal number of gateways and their location for dynamic traffic in IP-cloud C-RAN. We split the solution of this problem into four steps: (1) Construction of the dual-tier network, (2) Generation and routing of RRHs to maximize the network throughput within two traffic scenarios, number of gateways and number of edges, (3) Finding the optimal number of edges, gateways and their location using graph theory, (4) Investigates a disaster recovery procedures to maintain connectivity in case of link failure or traffic blockage. The details of these solutions are described as follows;

1) **Construction of Dual-tier Network**: Construction of the dual-tier network is maintained using graph theory and DT algorithm for building the topology with predefined locations of the CHs. The structure is classified into a grid-based network where each grid represents a district with some sure RRHS to serve.
2) **Generation and routing of Dynamic Traffic**: It investigates a novel algorithm of routing based on dynamic (maximum occupancy) traffic. The routing is solved based on an optimization problem with edges and traffic constraints. The route of CHs occurs based on the generated traffic with maximizing throughput and minimum edges constraint.
3) **Designing a customized number of edges with optimal locations of gateways**: It designs a tiered network model where the lower tier consists of N RRHs, while the upper-tier consists of M cluster heads connected to several gateways through FSO links. The cluster heads (CH) are modeled using a simple graph theory of $G(V, E)$ with edge weight of link reliability with traffic and edge constraints to achieve maximum throughput and connectivity. Also, a robustness network is considered to resist atmospheric turbulence and immediate obstacles.
4) **Disaster Recovery Algorithm**: It investigates the routing of the dynamic traffic in case of disaster (failure) in one of the grids. The algorithm follows a procedure to recover the disaster and loss of data in the failed grid.

There are other challenges and issues have been considered in the literature in this matter, such as:

- **Fog computing RAN (F-RAN) or Visualised RAN (V-RAN)**: Implementing Edge computing or network function visualization (NFV) to the network is one of the research challenges in the literature, whereas; some of the processing can be conducted at the RRHs. The challenges are to find the optimal visualization and functional split that can be processed at each layer. It is essential to mention that ETSI has announced a couple of functional splits in this matter. This can lead to ease of the management, the flexibility of operation, and reduce the transmission bandwidth between the two layers (known as midhaul).
- **Implementing F-RAN or V-RAN** will relax the midhaul bandwidth but at the expense of the power consumption as the processing will be conducted at several places and there are some consumption for the processing unit even if it is not operating/working. Hence, power consumption and Energy efficiency can be optimized in this matter.
- **Heterogeneous RAN (H-RAN)** is another research challenge, whereas the network may suffer from interoperability issues between the devices in the network. It is worth mentioning that some energy efficiency challenges can be considered in H-RAN, where some BBUs and RRHs can sleep in a low demand period, which can relax the consumption.

III. GATEWAYS PLACEMENT ALGORITHMS

In this section, Traffic Generation, gateways placement, and Disaster recovery algorithms are proposed. The point of the traffic generating is to test the effect of different traffic scenarios on the gateways placement and disaster recovery algorithms. The gateways placement algorithm finds the best placement for CHs and connects it to the adjacent RRHs with the realization of maximum throughput. It examines the Algorithm over static (maximum occupancy) and arbitrary dynamic (partial occupancy) traffic. In the case of dynamic traffic, the Algorithm generates random traffic on the (edges) between CHs and RRHs based on CPRI protocol options and the number of antennas that RRHs may have. Further, in the case of a disaster of one of the edges or nodes, the network may suffer from link failure or traffic blockage. Therefore a disaster recovery algorithm is realized with consideration of the two-different traffic scenarios.

A. DISTANCE CLUSTERING AND TRAFFIC GENERATION ALGORITHM

Distance Clustering and Traffic Generation (DCTG) algorithm are used to generate random traffic between RRH and attached CH. Each CH contains a group of RRHs with total traffic that does not exceed FSO link capacity (see Algorithm 1). In each cluster, a CH node is elected based on the largest residual energy and distance from the gateways. The CH is in charge of aggregating data from RRHs in each cluster to gateways. The Algorithm 1 is used to maximize the overall traffic carried by the network by increasing the number of antennas per RHHs to support the MIMO technique. In the first nine lines in the Algorithm, the network assigns one RRH to each CH as an initial procedure of a minimum number of RRHs based on distance from the adjacent CH. Then, the network randomly assigns other RRHs to each CH with the constraint of the Maximum number of RRHs per CH. Random generation of the number of antennas (1: to Maximum numbers of antennas) in each RRHs. Then the network calculates the maximum traffic in each CH as `Number-Of-Connected-Antennas x Minimum-Traffic-Constant`. Each Cluster assigns RRHs m with the constraint of maximum traffic at each node $F^{th}_{\max,\mathrm{RRH}}$ where M is the number of clusters, N_a is the number of RRHs in cluster a and $F_{\max,\mathrm{RRH}_{ij}}$ is the random selected traffic at node RRH_{ij}.

$$\begin{aligned}&\sum_{a=1}^{M}\sum_{1}^{N_a} RRH_{ij}\\&S.t.:F_{\max,\mathrm{RRH}} \le F^{th}_{\max,\mathrm{RRH}}\end{aligned} \tag{4}$$

Algorithm 1 Distance Clustering and Traffic Generation (DCTG)

```
Require: Distance Clustering and Traffic Generation
Ensure: Maintain G(V,l) with Traffic and Edge Constraints
Initialize edge variables and assign initially one edge of each RRH
for i: 1 to V) do
    for (j: 1 to l) do
        if ($F_{\max,\text{Node}} \leq F^{th}_{\max,\text{Node}}$)
            Estimate $F(j) = C_{\text{node}} \times$ (Random selection of ($N_{Ant}$))
            Estimate $F_{\max,\text{Node}}(i) = \sum_{i \in V} \sum_{j \in l} F(j)$
        end if
    end for
end for
return G(V, l)
```

TABLE 1. System parameters.

Notation	Description
l_{ij}	A link directly connected of node i and node j
K	The number of gateways
K_{GW}	Optimal number of gateways
F_{ij}	Traffic between node i and node j
$F_{max,node}$	Maximum traffic per node
R_{max}	Maximum date rate per link
L_R	Link reliability
L_{max}	Maximum number of edges
C_{node}	Minimum traffic per node
N_{Ant}	Number of antennas per node

Several parameters affect the generation of the maximum traffic scenario, which are; max number of edges L_{max}, max number of gateways K, max traffic per node C_ij, and maximum data rate per link R_{max} (see Table 1).

$$
\begin{aligned}
&Maximise \sum_{i,j \in L} F_{ij} \\
&S.t.: l_{ij} \leq L_{\max} \quad i \neq j \\
&\quad : F_{ij} \leq R_{\max} L_R \\
&\quad : K_{GW} \leq K \\
&\quad : C_{ij} \leq \omega_{ij} \times C_{\text{nom}} \\
&\quad : \Re_{ij} \geq \Re_{th}
\end{aligned} \tag{5}
$$

B. GATEWAYS PLACEMENT

After clustering the network, it is essential in the matter of cost to minimize the number of intermediaries between CHs and BBU. Thus, an optimization problem is introduced to reduce the number of gateways and edges and find the best placement of the gateways with the maximum achievable traffic. Euclidean distance rule is used in determining the best route of data (see Algorithm 2). Moreover, the optimization problem keeps checking and reconfigures the routing alternatives over a multi-level grid until system constraints are satisfied. We emphasized the proposed model on two traffic scenarios; static and dynamic (see Equation 6).

$$
\begin{aligned}
&Minimise : K_{GW} \\
&S.t.: l_{ij} \leq L_{\max} \quad i \neq j \\
&\quad : F_{ij} \leq R_{\max} L_R \\
&\quad : K_{GW} \leq K \\
&\quad : C_{ij} \leq \omega_{ij} \times C_{\text{nom}}
\end{aligned} \tag{6}
$$

Gateway locations Algorithm (GLA) discusses solving the optimization problem on the network (see Algorithm 2). In Algorithm 2, the first two lines aim to make sure that the network is fully satisfied with the number of edges constraint and that all CHs are connected in the network. Each CH represents a cluster area (a district), and it is represented by in the form of a grid. The size of the grid is considered a cube of (2 × 2 cell radius). The placement of the gateways is selected based on the Euclidean distance rule of the connected edges in the DT algorithm.

C. DISASTER RECOVERY ALGORITHM

The backup scenario investigates an alternative route to recover the data in the failed grid to maintain high transmission and connectivity of the data. In Algorithm 3, the network model degrades the traffic of the neighboring terminal CHs to the minimum traffic to recover the failed grid and maintain the connectivity with lower rates. Then, dispatching the failed gateway and call for Genetic Algorithm Minimum Spanning Tree (GA-MST).

IV. SIMULATION AND RESULTS

In this section, we evaluate the performance of the proposed network model on two traffic scenarios; static and dynamic. The dynamic traffic is generated randomly based on the DCTG algorithm. Moreover, the optimal number of gateways and edges are selected from the optimization problem with the maximization of the throughput. The network model is validated and implemented on several RRH sizes of 25, 30, 36, 42, and 49 in both traffic scenarios. Then, GLA finds the optimal placement of CHs to be gateways, considering graph theory parameters (see Table 2) and traffic constraints.

Algorithm 2 Gateway Locations Algorithm (GLA)

Require: graph the cells according to their parameters (cell length, Number of nodes)
Ensure: Ensure Max. Routing of both Scenarios of traffic and provide backup route in case of disasters upon procedures

```
Identify the Grid boundaries
  $GridNumbOfRows = \lceil \frac{DTY_{\text{length}}}{2\times\text{Cellraduis}} \rceil$,
  $GridNumbOfColoumns = \lceil \frac{\text{NumbOfCells}}{\text{NumbOfRows}\times(\text{MaxNumbOfEdgesPerCell}+1)} \rceil$
for i: 0 to (GridNumbOfRows × GridNumbOfColoumns) do
while (NumberOfGridMembers(i) $< MaxNumberOfEdgesperCell$) do
  if (the location of RRH($n$) within grid($i$))
    Grid Members Location = Node location
    Grid Members = Node number
  end if
end if
end if
for i: 0 to (GridNumbOfRows × GridNumbOfColoumns) do
  for i: 0 to (NumbOfGridMembers) do
  OptimalGatewaylocationOfGrid($i$) (= $\sqrt{(x_k - x(k+1))^2 + (y_k - y(k+1))^2}$)
  end if
end if
if (mode == “ Maximum Traffic ″)
  Call Genetic Algorithm Minimum Spanning Tree (GA-MST) with (TotalTraffic < MaxTrafficPerEdge) and
  (TotalEdges < MaxNumbOfEdgesperCell) with regard to OptimalGatewaylocation(i)
  elseif (mode == “ Dynamic Traffic ″)
    Call Distance Clustering and Traffic Generation (DCTG)
    Call Genetic Algorithm Minimum Spanning Tree (GA-MST) with (TotalTraffic < MaxTrafficPerEdge) and
  (TotalEdges < MaxNumbOfEdgesperCell) with regard to OptimalGatewaylocation(i)
  end if
```

Algorithm 3 Disaster Recover Algorithm (DRA)

Require: graph of the network in grid based (cell length, Number of nodes, Gateways placement, edges)
Ensure: Provides backup route in case of disasters upon procedures

```
if (Disaster Recovery happens)
  Degrade the traffic of the terminal edges to MinTraffic
  Dispatch the failed gateway
  Call Genetic Algorithm Minimum Spanning Tree (GA-MST) with (TotalTraffic < MaxTrafficPerEdge) and
  (TotalEdges < MaxNumbOfEdgesperCell) with regard to OptimalGatewaylocation(i)
  end if
```

TABLE 2. Simulation parameters.

Parameter	Value
Number of CHs	25, 30, 36, 42 and 49
Cell radius	1km
Max. edge length	1.5 × Cell radius
Max. number of edges per CH	6
Number of RRHs in cell	1 - 8
Total number of RRHs	90
Number of antennas per RRH	1 - 2
Max. number of edges	4
Link reliability $\Re_{th}$	0.5

The optimal number of gateways and their placement of gateways in static (maximum occupancy) and dynamic (partial occupancy) scenarios are discussed based on Algorithms 1 and 2. There is a trade-off between the number of gateways and dynamic traffic scenarios. As high as the dynamically generated traffic gets, the Algorithm will not reduce the number of gateways. The results obtained are average throughput and the number of gateways within 10^3 iterations in the two traffic scenarios.

After 10^3 iterations, we generated the connectivity matrix by using the DT algorithm and then applied Algorithm 1. As it can be seen in Figures 4 and 5 that CHs in the network with static (maximum occupancy) traffic are used to be routed with sizes of 30 and 42, respectively. The routing of the system's network model is solved in a grid-based model and then iteratively re-configures itself under the edges and traffic constraints until it is satisfied with the best performance.

In Figures 6 and 7, the results obtained from algorithm 2. This algorithm reconfigures the routing of the network model

TABLE 3. Simulation results and comparison.

	25	30	36	42	49
Grid size	3 × 2	3 × 2	3 × 3	3 × 3	4 × 3
Normal no. of gateways	6	6	9	9	12
Optimal no. of gateways (Max. Traffic)	5	6	8	9	10
Average throughput (Max. Traffic)	62.5	75	90	105	122.5
Optimal no. of gateways (Dyn. Traffic)	4	4	6	6	7
Average throughput (Dyn. Traffic)	43	46	50	52	65

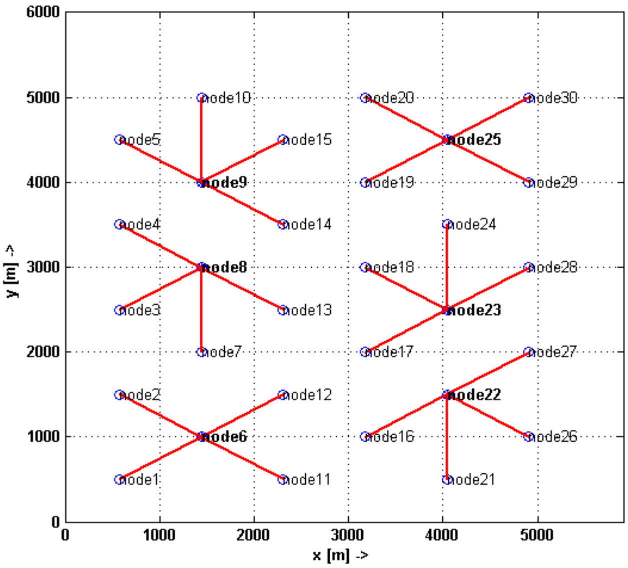

FIGURE 4. Network with maximum traffic of 30 nodes.

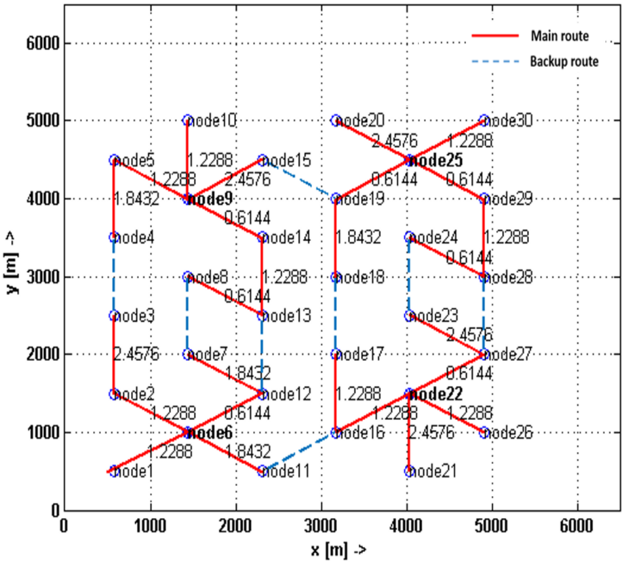

FIGURE 6. Network with dynamic traffic of 30 nodes.

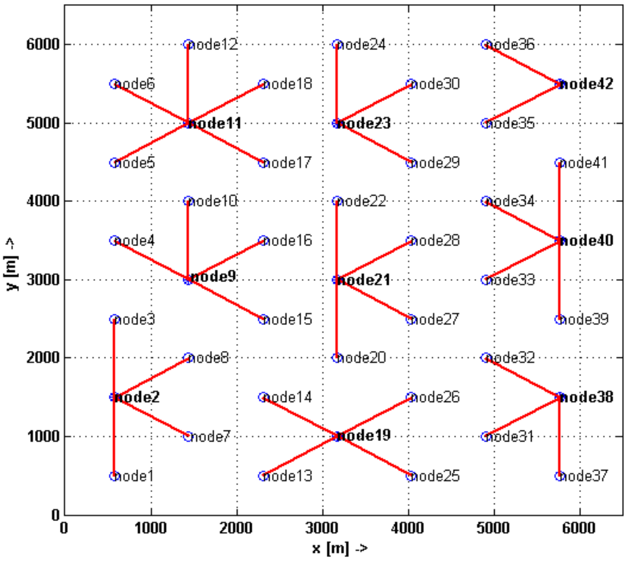

FIGURE 5. Network with maximum traffic of 42 nodes.

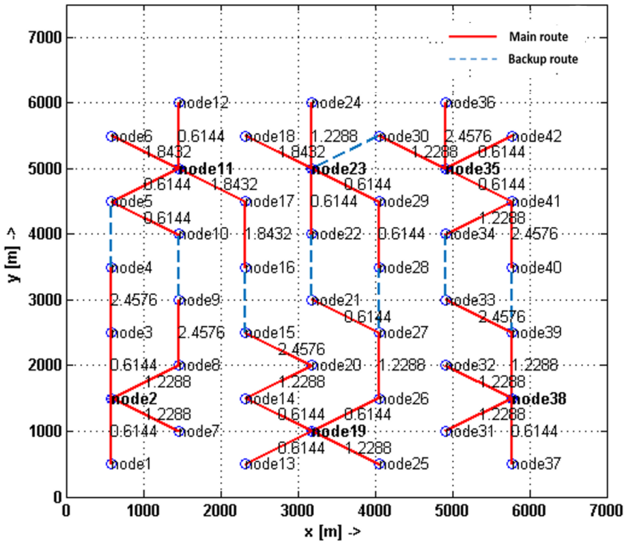

FIGURE 7. Network with dynamic traffic of 42 nodes.

of 30 and 42 CHs of the system based on the random dynamic traffic in grid-based.

In the dynamic traffic scenario, the network model routes differently based on the traffic of all edges in the network. Throughout, the given constraints of traffic and edges, the optimal number of gateways is examined where the best routing path is identified. Moreover, an alternative route is also considered in case of a disaster in CH or edge. Hence, the network will be able to maintain connectivity of most working RRHs at the expense of the neighbor terminal CHs, as Algorithm 3 degrades the traffic of the neighbor edge CHs to the minimum to route the CHs connected to the failed CHs.

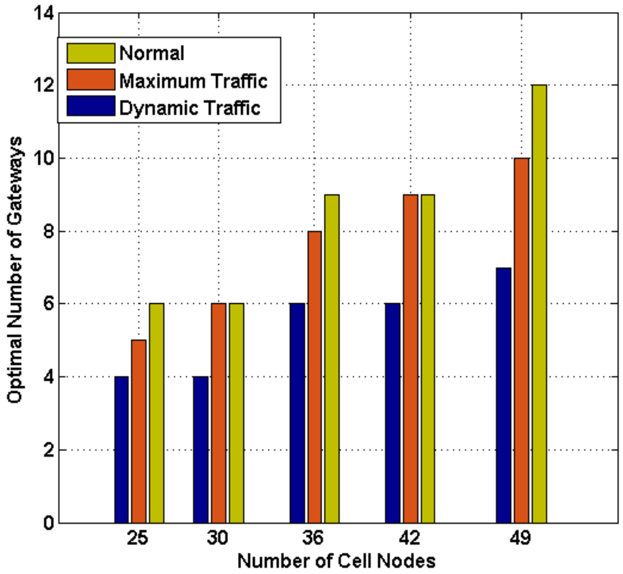

FIGURE 8. Bar chart of optimal number of gateways and number of cell nodes.

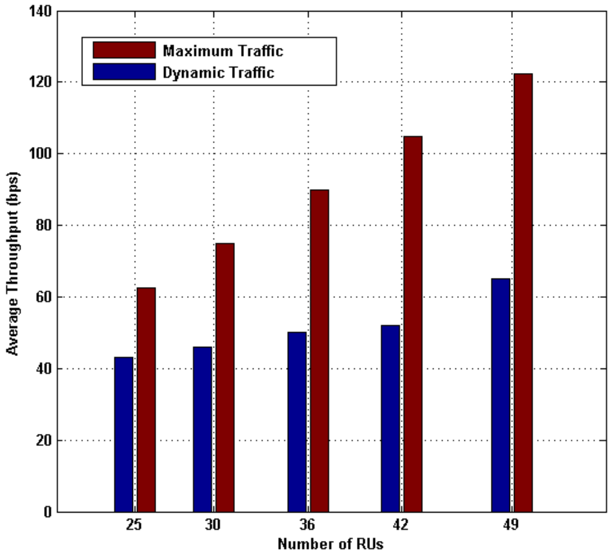

FIGURE 9. Bar chart of average throughput and number of nodes.

Figures 8 and 9 illustrate a bar chart of the optimal number gateways and average throughput with different number of nodes in maximum and dynamic traffic scenarios. In Figure 8, the number of gateways in a dynamic traffic operation is reduced by 33% in node size of 25, 36 and 42. Furthermore, this reduction is increased to 41% if the node size increased to 49. Figure 9 shows the behaviour of the throughput increasing in the cases of dynamic and maximum traffic.

V. CONCLUSION AND REMARK

In this paper, a topology design algorithm is proposed to find the best route of the data and the optimal number of gateways within traffic constraints. The traffic constraints considered in this paper are static, providing the maximum traffic according to CPRI protocols and dynamically generated randomly. An optimization problem is introduced to find the optimal number of gateways in both traffic scenarios with maximizing the overall network throughput with respect to CPRI transmission rates. Moreover, several CH sizes are examined in the optimization problem with the two traffic scenarios to describe the entire network. Furthermore, a disaster recovery algorithm and procedures are proposed as well in case of failure to maintain continuous connectivity of most of the nodes within the same traffic scenario. Alternative paths are implemented in the network once a disaster is realized. The network model automatically degrades the neighbor terminal CHs traffic to the minimum to maintain connectivity and flow of data in most of the nodes in the case of disaster.

The simulation results demonstrated that our algorithms achieved fewer gateways to 5, 6, 8, 9, and 10 instead of 6, 6, 9, 9, and 12 for 25, 30, 36, 42, and 49 CHs sizes, respectively. The optimization problem is applied to 25, 30, 36, 42, and 49 nodes system, and their average throughput are varied from $62.5 - 122.5$ bps and $43 - 65$ bps for static and dynamic traffic, respectively.

It is essential to point out the limitations of the proposed work that the CH selection process depends on the most considerable residual energy and the distance from them to the gateways. This can be enhanced by making the nodes rely on the polling technologies periodically. In the case of disaster recovery, the transmitted data will be lost in case of the unavailability of nearby nodes. Further, the Disaster recovery algorithm does not consider what kind of data should be dropped in the nearby nodes while relaying the data. These limitations can be considered as a future work along with the challenges and issues mentioned in Section II.

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