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RESEARCH ARTICLE

TFACR: A Novel Topology Control Algorithm for Improving 5G-Based MANET Performance by Flexibly Adjusting the Coverage Radius

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ABSTRACT Topology control in next-generation wireless networks has recently attracted the interest of several researchers. The network performance is significantly affected by the topology. Therefore, creating an optimal topology is essential, particularly in fifth-generation (5G) networks, where latency, throughput, energy efficiency, and other performance metrics are highly stringent. In this study, we investigated topology control algorithms in 5G-based mobile ad-hoc networks (MANET). A novel algorithm, namely Topological control by Flexibly Adjusting the Coverage Radius (TFACR) was proposed to improve network performance. The main idea of the TFACR algorithm is to adjust the communication range flexibly to obtain the desired degree of nodes. The degree constraint of the neighboring nodes is considered each time a node adjusts the communication area to ensure node degree balancing throughout the network topology. The TFACR algorithm is implemented in the OMNET++ and INET frameworks using the Reinforcement Learning-based routing protocol (RLRP), Ad-hoc On-demand Distance Vector (AODV) and Destination Sequenced Distance Vector (DSDV) routing protocols to evaluate its performance. The simulation results proved that the proposed algorithm outperformed well-known topology control algorithms in terms of the average node degree, quality of transmission, and energy consumption. This is suitable for 5G-based MANET.

INDEX TERMS 5G-based MANET, topology control algorithm, TFACR, next generation wireless network.

I. INTRODUCTION

Wireless communication technology is rapidly evolving and plays an increasingly important role in data communication networks. Among wireless network models, mobile ad-hoc networks (MANET) are increasingly being applied in many fields such as smart cities, smart agriculture, smart traffic, and IoT ecosystems [1]. A MANET operates as a peer-to-peer network without central control. Because the nodes move frequently, the topology also changes. Consequently, the routing table at each node must be updated regularly in response to topology changes [2]. Figure 1 shows an example of a wireless ad-hoc network in which the topology and routing tables are updated owing to the node movement. Consider the case shown in Figure 1a. According to the wireless ad-hoc network principle, if two nodes are within their coverage range, they are connected via a wireless link. Consequently, a topology comprising seven nodes and eight wireless links is formed. Assuming that a count hop-based routing algorithm (such as Dynamic Source Routing (DSR) [10], Destination Sequenced Distance Vector (AODV) [11], or others) is used, the route from A to G is A → B → D → G based on the information stored in the routing table of the nodes. After a certain period, node G moves to a new location (Figure 1b). The wireless links between D and G ware disconnected because the distance between them was greater than the coverage radius. Because of the topology change, the routing table at the nodes must also be updated. Therefore, the route from A to G changes along to A → C → E → F → G.

Recently, 5G-based MANET have been researched and deployed to broaden the application scope of MANET in

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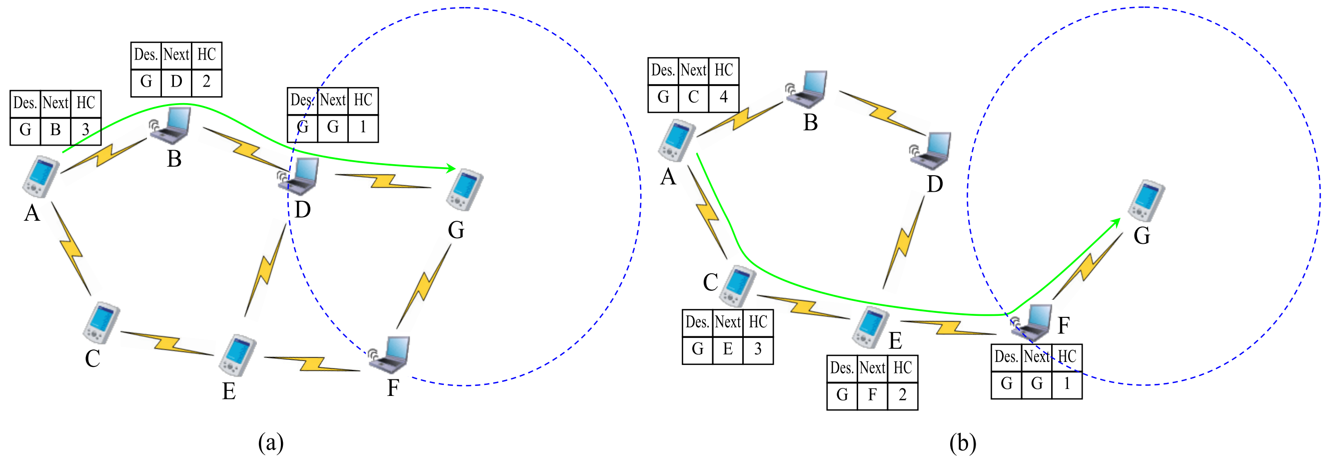


FIGURE 1. An example of topology and routing table which are updated in 5G-based MANET.

the context of growing 5G network technology [1], [3], [4], [5], [6], [7], [8], [9]. An outstanding characteristic of 5G network technology is the use of broadband transmission channels. This allows for improved throughput and reduced end-to-end delay in 5G-based MANET. However, because the traffic demand in 5G-based MANET is high, network nodes are frequently subjected to heavy traffic loads. This is a significant challenge for 5G-based MANET in terms of ensuring quality of service (QoS). Therefore, improving the performance of 5G-based MANET has recently attracted the attention of several research groups. Some of the more common topics that have been deployed include routing protocols [12], [13], [14], [15], [16], [17], [18], network topology control [19], [20], [21], [22], [23], [24], [25], [26], [27], mobility models [28], [29], [30], and network performance evaluation [31], [32], [33]. Among these topics, topology control is the most interesting. This NP-hard problem cannot be solved using conventional algorithms. Therefore, approximate optimization methods are often used to solve this problem. Some methods have recently been implemented such as local approximation methodologies [34], fuzzy logic [27], and machine learning algorithms [23], [35], [36]. In this study, we propose an optimal algorithm to solve the topology control problem for 5G-based MANET, called Topological control by Flexibly Adjusting the Coverage Radius (TFACR). The main contributions of this study are as follows.

(i) We propose TFACR, a novel topology control algorithm for 5G-based MANET, to improve its performance. The main goal of the TFACR algorithm is to build a topology for 5G-based MANET with the degree of each node being close to the desired degree. This is achieved by flexibly adjusting the communication range of each node under the degree constraints of its neighbors.

(ii) We implement the TFACR and some other topology control algorithms in conjunction with the Reinforcement Learning-based routing protocol (RLRP), Destination Sequenced Distance Vector (DSDV) and AODV routing protocols on a 5G-based MANET using the OMNeT++ and INET framework to evaluate the performance of the topology control algorithms.

There are two major distinctions between the proposed method and the earlier approaches. First, when a node adjusts the communication area to change its degree, the degree constraint of its neighbors is considered. This is done to avoid a single node from being disconnected from the network and to equalize the degree of all nodes in the network. Second, the proposed topology control algorithm in this work is considered for 5G-based MANET, in which there is a combined operation of MANET nodes and 5G network nodes.

The remainder of this paper is organized as follows. Section II investigates published works. Section III describes the topology control problem in 5G-based MANET. Section IV presents the proposed algorithm. The experimental results and discussion are presented in Section V. Finally, concluding remarks and promising future study topics are provided in Section VI.

II. RELATED WORKS

In MANET, if nodes are within the coverage range of each other, a wireless link connects them by default. As a result, there are some cases where the network topology has many wireless links, especially in the case of 5G-based MANET with dense node density. A topology with many wireless links has both advantages and disadvantages. The advantage is that the greater the number of wireless links, the greater the network connectivity. The disadvantage is that the higher the number of links, the higher the degree of each node, resulting in the nodes spending more energy to maintain the link. Another major disadvantage of wireless multi-link network topology is that cross-channel interference significantly affects the quality of service. Therefore, it is necessary to control the topology such that the degree of each node or the number of wireless links in the network is moderate and suitable for the configuration and traffic

TABLE 1. The notations used for the paper.

Notation	Description
n	Number of nodes in 5G-based MANET
U	Set of nodes in 5G-based MANET network
$G(U,E)$	Graph representing network topology
$d_{i,j}$	Distance from node i to node j $(i,j \in U)$
r_i	Coverage radius of node i
$N_i = \{j \mid \forall j \in U, d_{i,j} \leq r_i\}$	Set of neighbours of node i
$\alpha_{i,j}$	The variable that it indicates nodes *i* and *j* are neighbors or not
E	Set of links in 5G-based MANET network
δ_i	Degree of node i
k	Desired node degree
k_{max}	Maximum node degree
$G(U_k, E_k)$	Graph representing topology with degree k
$c_{i,j}$	Coverage of node i for node j
$C_i = \{c_{i,j} \mid \forall j \in N_i\}$	Set of coverage of node i for its neighbours
$c_{low}^{(a)}$	Lower bound of radius area which can be adjusted
$c_{up}^{(a)}$	Upper bound of radius area which can be adjusted
$c_i^{(a)}$	Adjusted coverage radius by node i
$c_i^{(a,m)}$	Maximum coverage radius that can be adjusted by node i
$c_i^{(a,p)}$	Proposed coverage radius for adjustment by node i

load in the network. However, because topology control is an NP-hard problem, it cannot be solved using conventional algorithms. Determining the most efficient topology control algorithm is a significant challenge. Consequently, approximate optimization methods are frequently used to solve this problem. This method has recently been used by several research groups.

The authors of [23] proposed an energy efficient topology control algorithm, namely Reinforcement Learning-based Communication Range Control (RL-CRC). The RL-CRC algorithm uses reinforcement learning to adaptively adjust the communication range of each in wireless sensor network. According to the simulation results, the RL-CRC consumes significantly less energy than traditional methods while retaining the same average communication range and node degree. In [25], the authors proposed a topology control algorithm for ad-hoc networks, namely Local Tree-based Reliable Topology (LTRT). It has been theoretically demonstrated that the LTRT algorithm ensures k-edge connection while maintaining the properties of the local minimal spanning tree. The efficiency of LTRT and its superiority over other localized algorithms were demonstrated by simulation results. In [26], a topology control algorithm called the Fault-tolerant Local Spanning Subgraph (FLSS) was proposed for wireless ad-hoc networks. The FLSS algorithm minimizes the maximum transmission power used in the network. According to the simulation results, FLSS not only has better power efficiency than existing fault-tolerant topology control algorithms but also leads to a higher network capacity. In [37], the authors proposed a topology control algorithm for wireless sensor networks based on a minimum spanning tree (MST). Compared with existing algorithms, the proposed algorithm can generate an optimal topology in less time.

Topology control using fuzzy logic has recently also been implemented by several research groups. In [27], a novel Fuzzy logic-based Topology Control (FTC) algorithm was proposed with the main objective of improving network connectivity. The FTC algorithm adaptively changed the communication range to achieve the desired average node degree. The performance of the FTC algorithm was compared with other well-known algorithms by using a simulation method. In [40], the authors proposed a balanced network topology control method based on the fuzzy analytic hierarchy process (FAHP). The network topology was constructed using four criteria: residual energy, node degree, node depth, and transmission power. Experiments demonstrated that the proposed method can ensure robust link quality, effectively improve data throughput, and reduce power consumption.

Recently, software-defined networks (SDN) have been used to solve topology control problems [38], [39]. For this method, the authors of [38] proposed an energy-efficient hierarchical topology control (EEHTC) algorithm for wireless sensor networks. The proposed EEHTC algorithm is divided into two parts: lower-layer topology control (LTC) for common sensor nodes (CSNs) and upper-layer topology control (UTC) for software-defined sensor nodes (SSNs). The simulation results show that, compared to other algorithms, the EEHTC algorithm can effectively extend the network lifetime and reduce node energy consumption.

Topology control is critical for improving network performance. This problem can be resolved in several ways. In this study, we proposed TFACR, a new and efficient

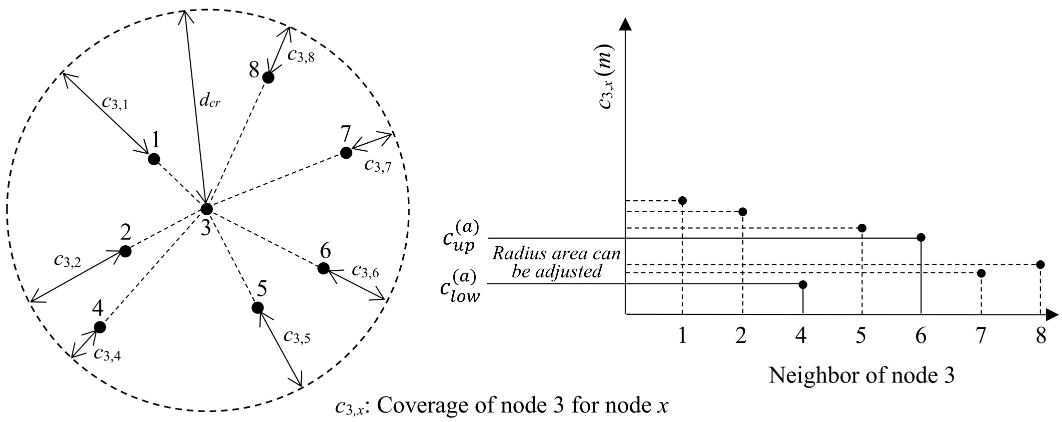


FIGURE 2. **An example of determining the coverage radius to be adjusted for a node.**

topology control algorithm for 5G-based MANET. The TFACR algorithm dynamically adjusts the coverage radius of the nodes while considering that their degree of neighbors maintains the node degree balance and achieves the desired node degree. Details of the proposed algorithm and related content are presented in the following sections.

III. TOPOLOGY CONTROL PROBLEM

In this section, we discuss the topological control problem in 5G-based MANET. First, several relevant concepts and metrics are introduced. Subsequently, the topology control problem is presented. Table 1 describes the notations used in the following sections.

A. CONCEPTS AND METRICS

1) NEIGHBOR NODE

Nodes I and J are considered neighbors of each other if and only if they are within the coverage radius of each other. Let $\alpha_{i,j}$ be a variable indicating whether nodes I and J are neighbors of each other, return to 1 if I and J are neighbors, and return to 0 otherwise. Then, $\alpha_{i,j}$ is determined by

$$\alpha_{i,j} = \begin{cases} 1 & \text{if } d_{i,j} \leq Max(r_i, r_j) \\ 0 & otherwise \end{cases} \tag{1}$$

where r_i and r_j are the coverage radius of the nodes I and J, respectively. $d_{i,j}$ is the distance between nodes i and j, calculated by

$$d_{i,j} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{2}$$

where pairs (x_i, y_i) and (x_j, y_j) are the coordinates of nodes i and j, respectively.

2) NODE DEGREE

The degree of a node is defined as the number of neighbors of that node [25]. Let δ_i be the degree of node I, then δ_i is calculated as

$$\delta_i = \sum_{j=1}^{N} \alpha_{i,j} \tag{3}$$

where $\alpha_{i,j}$ is a variable that indicates whether nodes I and J are neighbors, determined according to (1).

B. TOPOLOGY CONTROL PROBLEM

Consider a 5G-based MANET with n nodes represented by the set $N = \{i|i = 1..n\}$, including x nodes of the 5G network and n - x MANET nodes. In addition, the network system has 5G base stations, as illustrated in Figure 3. We use the assumption as in [25] that each node can control its transmit power to change the coverage radius to reduce energy consumption. Let r_i be the coverage radius of node $i, 0 < r_i \leq r_{max}$, where r_{max} is the maximum coverage radius of the nodes. For each pair of nodes $i, j \in N$, if they are neighbors, that is, $\alpha_{i,j} = 1$ according to (1), a wireless link is established between them. MANET nodes connect to 5G nodes to access the multimedia services of 5G networks. 5G nodes act as gateways for MANET nodes connected to 5G network base stations. The combination of all the nodes and wireless links forms the network topology.

Topology control is defined as the control of technical parameters of a network system to achieve an optimal topology. The optimal objective of the topology depends on the requirements of the network system. For 5G-based MANET, the main objectives are to improve throughput, energy efficiency and reduce latency. These objectives were considered in this study.

In a 5G-based MANET, the topology depends mainly on the coverage radius and location of the nodes. Thus, topology control can be achieved by adjusting technical parameters. In this study, a method for flexible adjustment of the coverage radius was used in the proposed algorithm. Details are provided in the following sections.

IV. PROPOSED ALGORITHM

In this section, we present our proposed TFACR algorithm. To obtain an optimal topology, the nodes must adjust the coverage radius such that its degree is close to the desired value. In a 5G-based MANET, it is difficult to choose a suitable coverage radius value for adjustment because when

TABLE 2. Simulation parameters.

Parameter	Setting
Network area	$1000 \times 1000\ [m^2]$
Maximum communication range	$250\ [m]$
Number of nodes	50:5:100
Desired node degree	3:1:5
Coefficien α	0:0.05:1
Topology control algorithms	NONE, LTRT, FLSS, TFACR
Number of runs of a scenario	50
Routing protocols	AODV, DSDV, RLRP
Traffic pattern	CBR
Transport protocol	UDP
Energy consumption model	StateBasedEpEnergy
Carrier frequency	2.4 [GHz]
Mobility model	Random Waypoint
Mobility speed of nodes	From 5 to 20 [m/s]
Pause time	from 30 to 150 [s]

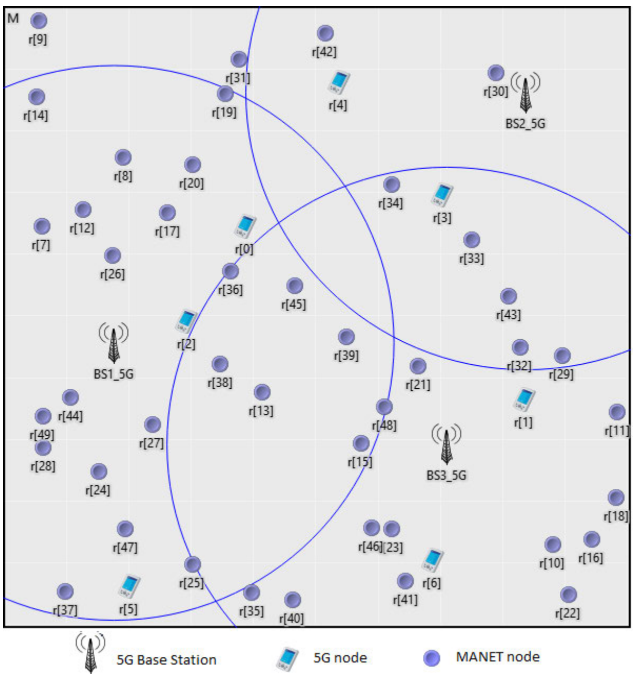


FIGURE 3. Snapshot of a 5G-based MANET simulation topology using OMNET++.

the coverage radius of a node changes, it can affect the degree of neighboring nodes. For the proposed TFACR algorithm, the coverage radius of each node was reduced to an optimal value if the degree of that node is greater than the given desired node degree. Let k be the desired node degree, δ_i be the degree of the node i. In the case that $\delta_i \neq k$, the coverage radius of node i is adjusted by value $c_i^{(a)}$, calculated by

$$c_i^{(a)} = \alpha c_{up}^{(a)} + (1-\alpha) c_{low}^{(a)}; \qquad (4)$$

Algorithm 1 Adjust the Coverage Radius at Node u Using the TFACR Algorithm

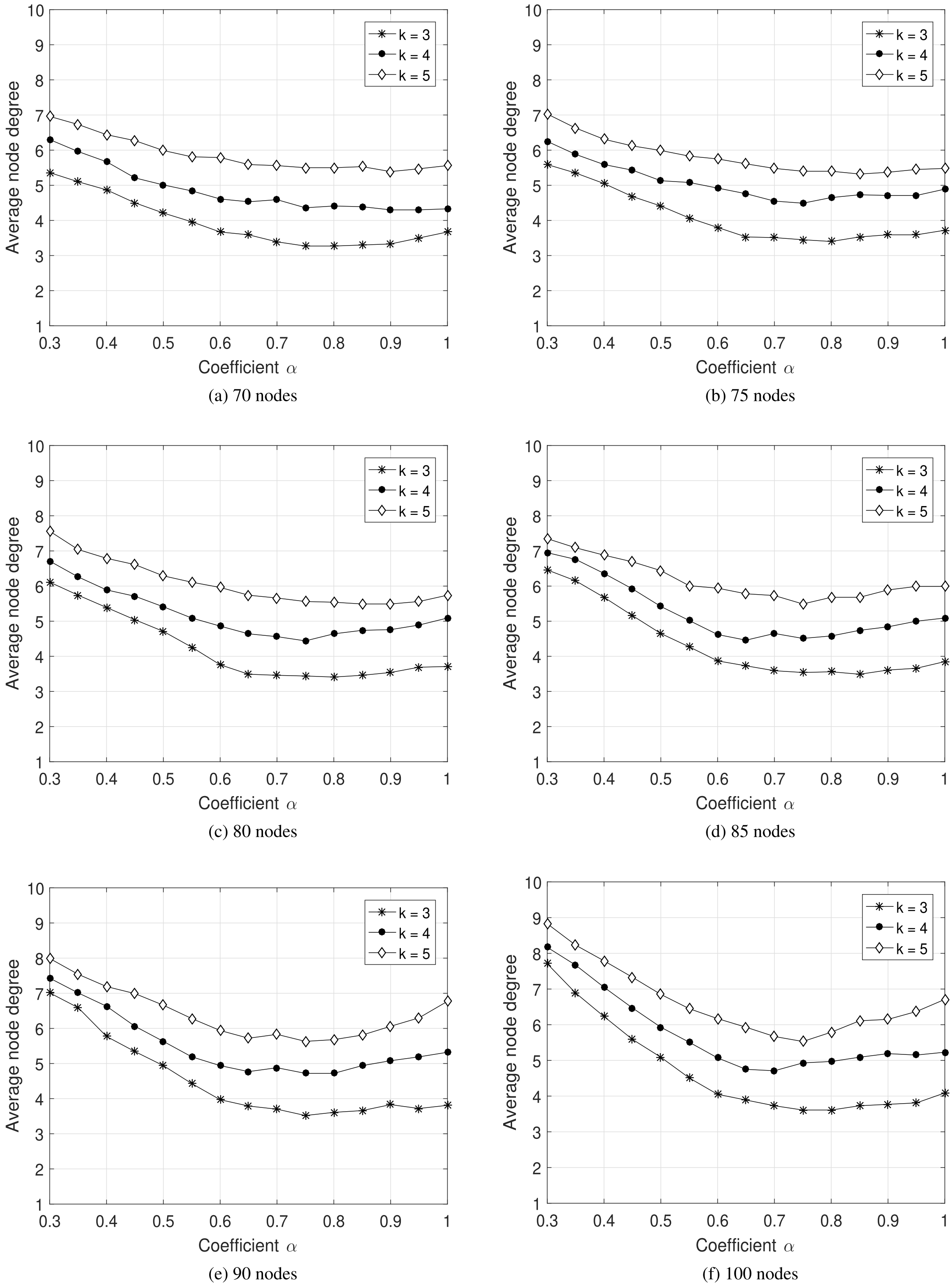
Input: $G(U, E)$, k, k_{max}, α, hello packets coming from all neighbors of i

Output: The adjusted coverage radius of node i (c_i)

Method:

```
for (each received hello packet from neighbor j of i) do
    Read information of r_j and δ_j;
end for
Compute δ_i based on r_j, ∀j ∈ N_i and r_i;
if (δ_i > k) then
    C_i ← ∅;
    c_i^(a,m) ← c_max;
    c_i^(a) ← 0;
    for (each j ∈ N_i) do
        c_{i,j} ← r_i − d_{i,j};
        C_i ← C_i ∪ {c_{i,j}};
        if (δ_j < k) then
            if (c_i^(a,m) > c_{i,j}) then
                c_i^(a,m) ← c_{i,j};
            end if
        end if
        if (δ_j >= k_max) then
            if (c_i^(a,p) < c_{i,j}) then
                c_i^(a,p) ← c_{i,j};
            end if
        end if
    end for
    Sort C_i in descending order;
    c_up^(a) ← C_i[k + 1];
    c_low^(a) ← C_i[δ_i];
    Determine coverage radius to adjust (c_i^(a)) using (4);
    if (c_i^(a) > c_i^(a,m)) then
        c_i^(a) ← c_i^(a,m);
    else
        if (c_i^(a) < c_i^(a,p)) and (c_i^(a,p) < c_i^(a,m)) then
            c_i^(a) ← c_i^(a,p);
        end if
    end if
    Adjust coverage radius of i (r_i) with a value of c_i^(a);
else
    Keep the value of r_i;
end if
```

where $c_{low}^{(a)}$ and $c_{up}^{(a)}$ are the lower and upper bounds of the adjustable radius, respectively. This radius area ranges from the lowest to the highest coverage of the δ_i - k neighbors of node i. α is a coefficient in the range [0, 1] representing the



(a) 70 nodes (b) 75 nodes (c) 80 nodes (d) 85 nodes (e) 90 nodes (f) 100 nodes

FIGURE 4. Effect of the coefficient α on the degree of node.

weight in the reduced radius area $[c_{low}^{(a)}, c_{up}^{(a)}]$. The larger α is, the closer $c_i^{(a)}$ gets to $c_{up}^{(a)}$ and vice versa. In addition, to avoid the case in which a node is disconnected from the network (i.e. its degree is zero), the adjusted coverage radius, $c_i^{(a)}$, must satisfy constraint (5).

$$c_i^{(a)} \leq \underset{\forall j \in N_i, \delta_j < k}{Min} c_{i,j} \tag{5}$$

TABLE 3. Effect of coefficient α on the node degree in case of topology 90 nodes.

α	$k=3$		$k=4$		$k=5$	
	MND(*)	DMD(**)	MND	DMD	MND	DMD
0.00	13.66	10.66	13.66	9.66	13.57	8.57
0.05	10.79	7.79	11.01	7.01	11.17	6.17
0.10	9.90	6.90	10.17	6.17	10.50	5.50
0.15	8.99	5.99	9.43	5.43	9.83	4.83
0.20	8.14	5.14	8.74	4.74	9.21	4.21
0.25	7.41	4.41	7.97	3.97	8.57	3.57
0.30	7.01	4.01	7.43	3.43	7.99	2.99
0.35	6.59	3.59	7.01	3.01	7.54	2.54
0.40	5.77	2.77	6.63	2.63	7.19	2.19
0.45	5.34	2.34	6.06	2.06	6.99	1.99
0.50	4.94	1.94	5.63	1.63	6.66	1.66
0.55	4.43	1.43	5.19	1.19	6.28	1.28
0.60	3.97	0.97	4.94	0.94	5.94	0.94
0.65	3.79	0.79	4.77	0.77	5.72	0.72
0.70	3.70	0.70	4.88	0.88	5.83	0.83
0.75	3.52	0.52	4.72	0.72	5.63	0.63
0.80	3.61	0.61	4.72	0.72	5.68	0.68
0.85	3.66	0.66	4.94	0.94	5.81	0.81
0.90	3.83	0.83	5.08	1.08	6.06	1.06
0.95	3.72	0.72	5.19	1.19	6.30	1.30
1.00	3.81	0.81	5.32	1.32	6.77	1.77

(*)MND: Mean Node Degree
(**)DMD: Difference between Mean and Desired degree

where N_i is the set of neighbors of node i, δ_j is the degree of node j, and $c_{i,j}$ is the coverage of node i for node j. When node i adjusts the coverage radius with a value of $c_i^{(a)}$ that satisfies constraint (5), the degree of a neighbor node j will not change if its current degree is less than k.

To clearly determine the coverage radius to be adjusted, we consider an example, as shown in Figure 2, where node 3 performs the coverage radius adjustment. We assume that the desired node degree is three. At the moment of consideration, the degree of node 3 was 7. Thus, node 3 must reduce the coverage radius to reduce its degree. When node 3 reduces the coverage radius, the degree of the neighboring nodes is also affected. Therefore, the reduced coverage radius must be selected as the optimal value. In this case, the reduced coverage radius value ($c_3^{(a)}$) is selected in the four lowest overlapping areas from $c_{3,4}$ (lower bound) to $c_{3,6}$ (upper bound), $c_3^{(a)}$ is calculated using (4). Algorithm 1 shows the pseudo-code of the TFACR algorithm implemented at each node to adjust its coverage radius. To minimize the case in which the degree of a neighbor node is less than the desired degree (k value), the constraint on the maximum coverage radius that a node can adjust, $c_i^{(a,m)}$, is considered in the TFACR algorithm. The value of $c_i^{(a,m)}$ is determined using steps from (12) to (16). This value is used as the constraint on the adjusted coverage radius, $c_i^{(a)}$, in steps (27) and (28). In addition, the proposed coverage radius for adjustment by each node, $c_i^{(a,p)}$, is also used with the goal that the algorithm can converge quickly. The value of $c_i^{(a,p)}$ is calculated in steps from (17) to (19) and used for the adjusted coverage radius in steps (30) and (31).

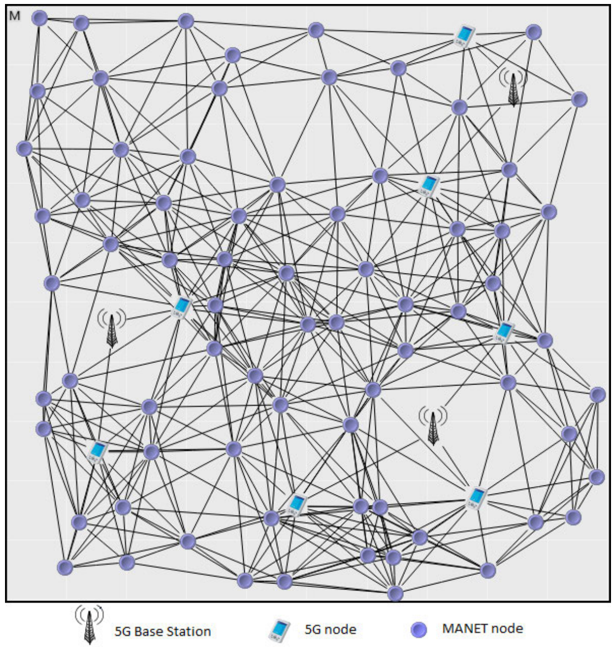


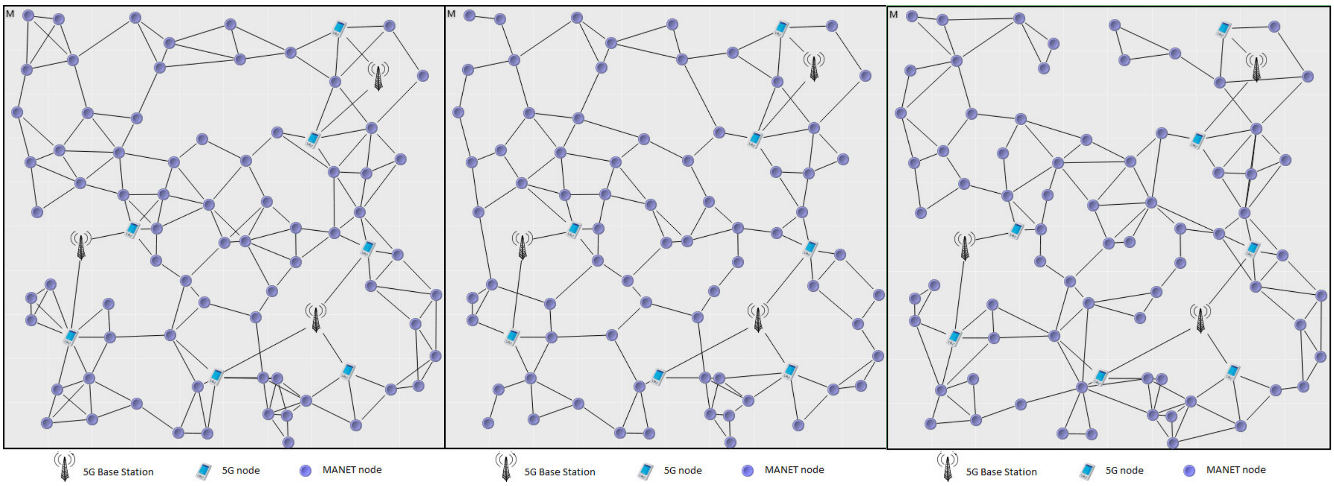
FIGURE 5. Topology in the case of not using topological control algorithm.

One issue to consider when implementing Algorithm 1 at nodes is its computational complexity. The step with the highest complexity in this algorithm is (23), which sorts the array C_i. The size of this array is $|C_i|$, which is the number of neighbors of node i. As a result, the computational complexity of Algorithm 1 is $O(|C_i|^2)$, where $|C_i| \leq n-1$ and n is the number of nodes in the 5G-based MANET. Compared to well-known topology control algorithms, the complexity of the TFACR algorithm is acceptable. It is greater than the complexity of the LTRT algorithm [25], but less than that of the FLSS algorithm [26]. Specifically, the complexity of the RTLT algorithm is $O(k(m+n\log(n)))$, where k, m and n are the connectivity of the resulting topology, number of neighboring nodes and number of edges, respectively. $O(n(m+n))$ is the complexity of the FLSS algorithm, where m and n are the number of nodes and edges, respectively. LTRT and FLSS are two typical topology control algorithms that are used to compare the performance in the next section.

V. PERFORMANCE EVALUATION

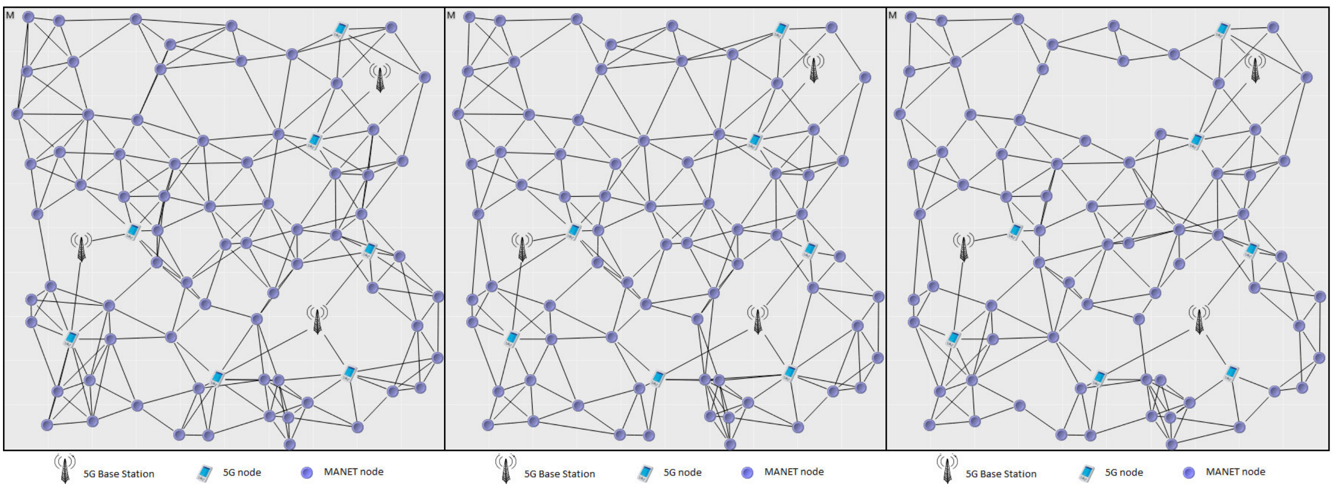
A. SIMULATION SCENARIO

The performance of the proposed TFACR algorithm is evaluated using simulations. The TFACR algorithm is compared with the algorithms of LTRT [25], FLSS [26] and the case without topology control (denoted by NONE) in



(a) LTRT (b) FLSS (c) TFACR

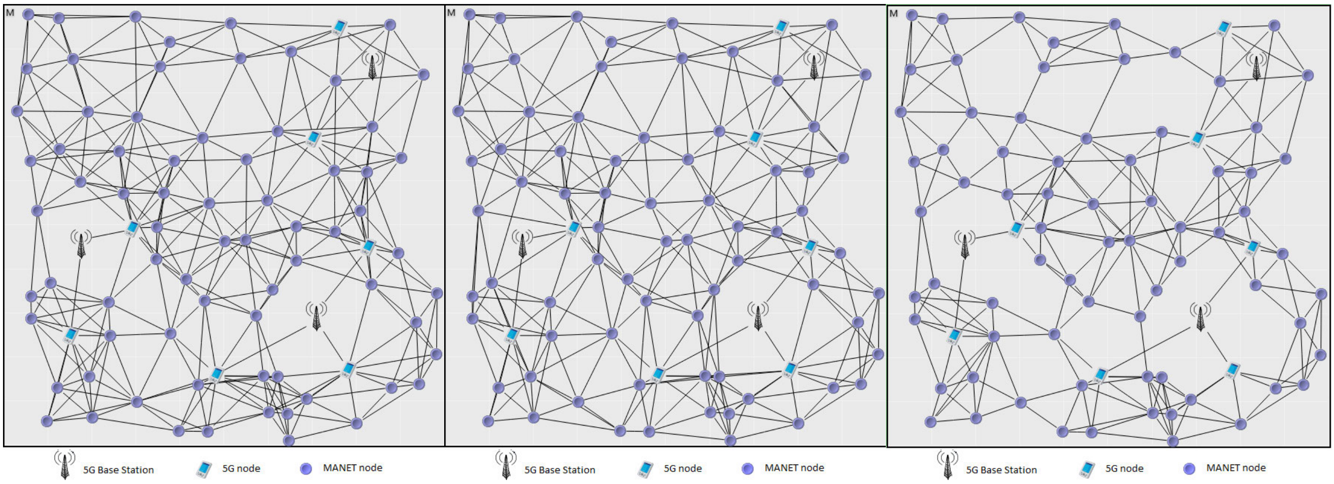
FIGURE 6. Compare the topologies obtained by algorithms LTRT, FLSS and TFACR in case of $k = 2$.



(a) LTRT (b) FLSS (c) TFACR

FIGURE 7. Compare the topologies obtained by algorithms LTRT, FLSS and TFACR in case of $k = 3$.

terms of the average degree of nodes, energy expended ratio, and path loss. For the NONE algorithm, each node always uses the maximum communication range. Consequently, it creates a topology with the highest number of wireless links. For the LTRT algorithm [25], the k desired degree topology is constructed by performing a local spanning tree algorithm k times. Consider a wireless network represented by graph $G(V, E)$, where V and E are the set of nodes and the set of wireless links, respectively. The LTRT algorithm first calculates one of its spanning trees, $T_1(V, \hat{E}_1)$, from $G(V, E)$. Next, it continues to calculate one of its spanning trees, $T_2(V, \hat{E}_2)$, from $G(V, E \backslash \hat{E}_1)$. After k times, the resulting topology is formed by combining all spanning trees, $T_1(V, \hat{E}_1), T_2(V, \hat{E}_2), \ldots, T_k(V, \hat{E}_k)$, that is $G(V, \hat{E}_1 \cup \hat{E}_2 \cup \ldots \cup \hat{E}_k)$. In the FLSS algorithm [26], each node first operates at its maximum communication range to collect information from its neighbors. Then, it sorts all the links in ascending order of weight based on the collected information. For each link (u_0, v_0) in order, it is only chosen for the resulting topology if u_0 is not k-connected to v_0. The simulation assumptions are presented in Table 2. We used a typical application scenario of a 5G-based MANET, which is similar to that in [44]. The simulation was performed in a square region with the area of 1000×1000 [m^2]. The number of nodes ranged from 50 to 100, including 5G and MANET nodes. Additionally, several 5G base stations provide multimedia services. All the nodes were randomly distributed in the simulation area. MANET nodes connect to 5G nodes to access the multimedia services of the 5G networks. 5G nodes can be routers, access points, mobile devices, etc., and operate as gateways for MANET nodes connected to the base stations of the 5G network. The maximum



(a) LTRT (b) FLSS (c) TFACR

FIGURE 8. Compare the topologies obtained by algorithms LTRT, FLSS and TFACR in case of $k = 4$.

communication range for each node was 250 [m]. The routing protocols used for data transmission were AODV, DSDV and Reinforcement Learning-based Routing Protocol (RLRP). The energy consumption model used is a stated-based EP energy consumer, which is already installed in the INET framework [42], and it provides a radio power consumer model for the IEEE 802.11 standard using the default values of CC3220 transceiver. The power consumption is determined by the radio mode, transmitter state and receiver state, using constant parameters. We employed 660 different simulation scenarios, each of which was run 50 times. The results were calculated by averaging all the times. The simulation was executed using OMNeT++ 6.0 [41] and the INET Framework 4.0 [42]. Figure 3 shows a snapshot of the simulation scenario with three 5G base stations, seven 5G nodes, and 43 MANET nodes.

B. SIMULATION RESULTS

1) EFFECT OF COEFFICIENT α

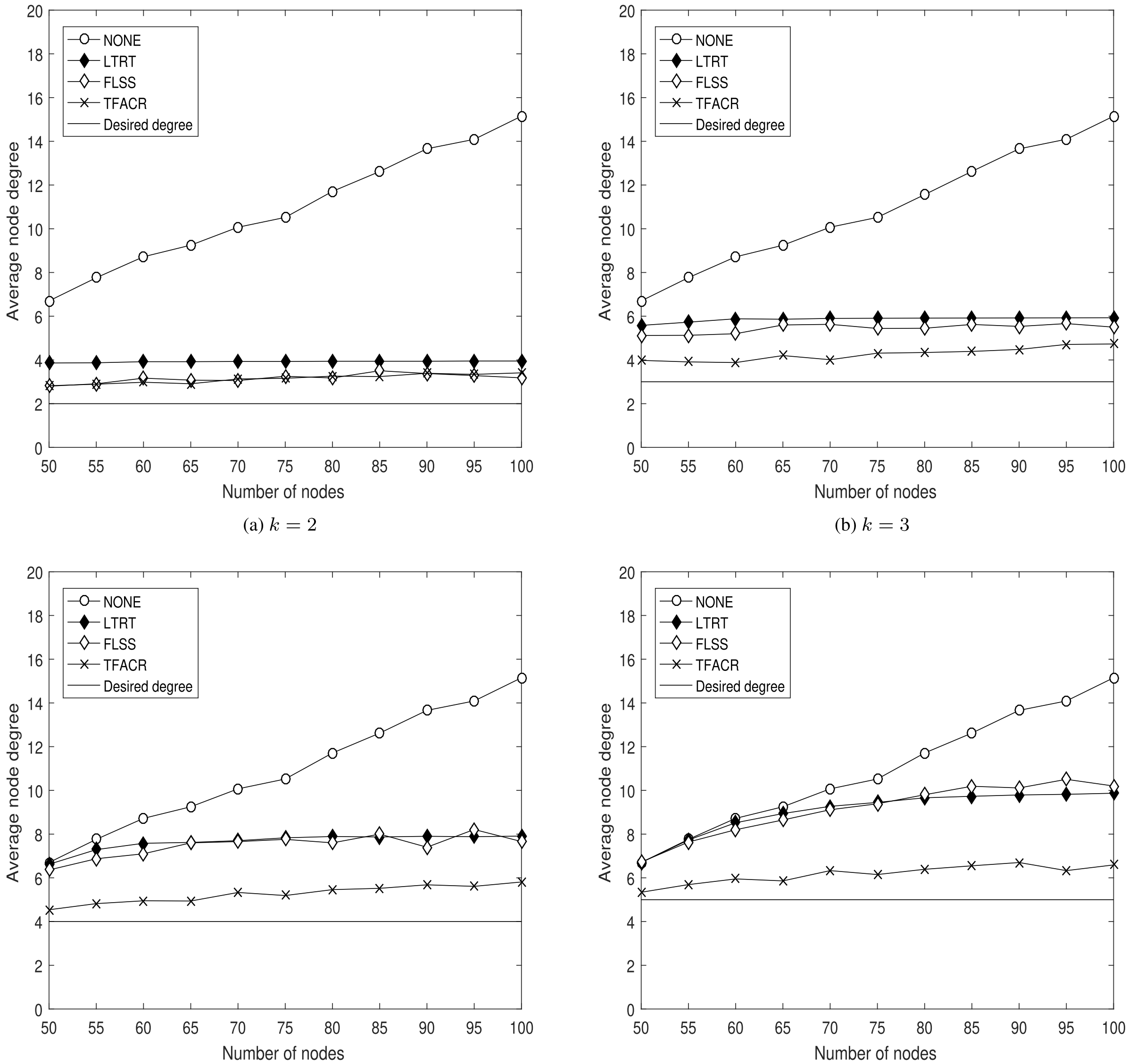
First, we investigate the impact of coefficient α on the performance of the proposed algorithm. As described in Section IV, the coverage radius to be adjusted for each node by the TFACR algorithm depends on factor α in (4). The purpose of the simulation scenarios in this section is to select the value of α such that the performance of the TFACR algorithm is the highest. The results obtained in Figure 4 show the influence of the factor α on the average node degree in the network topology. The main goal of the topology control algorithms is to ensure that the average node degree is closest to the desired node degree. Figure 4 shows that when α increased from 0 to 0.75, the mean degree of the node decreased to the desired degree. When α was greater than 0.8, the mean degree increased again. Thus, To find the mean degree that is closest to the desired degree, a value of α between 0.75 and 0.8 is most appropriate. This is more evident from the data in Table 3, where we analyze the case of a 90 nodes network topology. We can observe that the mean degree is the closest to the desired degree when $\alpha = 0.75$ or 0.80 for all three cases $k = 3$, 4 and 5. The result is exactly the same for the network topology cases where the number of nodes is 70, 80, or 100. Based on the analysis results of the influence of coefficient α on the performance of the TFACR algorithm in this section, we choose α equal to 0.75 for the next simulation scenarios.

2) TOPOLOGICAL ANALYSIS

Figures 5, 6, 7 and 8 show the network topology obtained using the LTRT, FLSS, and TFACR algorithms, and the case without topology control for a 5G-based MANET with 80 nodes. We can observe that, in the absence of the topology control algorithm (Figure 5), the topology has many wireless links between nodes. This leads to some disadvantages, such as nodes consuming a lot of energy to maintain wireless links and crosstalk can occur owing to the denseness of the wireless links. For cases where the topology control algorithm is used, the number of wireless links is reduced depending on the desired node degree (k value). Comparing the LTRT, FLSS and TFACR algorithms, the TFACR algorithm provides the most optimal topology because the mean degree of the nodes is closer to the desired degree. A detailed comparison of the node degrees of the topology control algorithms is presented in the following subsection.

3) NODE DEGREE ANALYSIS

Next, we analyze the degree of the nodes. This is an important metric in the network topology design problem and is defined as the number of neighbors of a node. The results obtained in Figure 9 show the difference in the average node degree for the TFACR, LTRT, and FLSS algorithms, and without topology control. We can observe that in the absence of the topology control algorithm (legend 'NONE'), the average node degree is very large and increases as the total number of



(a) $k = 2$ (b) $k = 3$

(c) $k = 4$ (d) $k = 5$

FIGURE 9. **Compare node degree of different topology control algorithms.**

nodes increases. For the LTRT, FLSS and TFACR algorithms, the average node degree decreased significantly and was close to the desired node degree. Comparing the LTRT, FLSS and TFACR algorithms, TFACR returns the average node degree closest to the desired degree. Specifically, considering the case where the desired degree is three (Figure 9b), the average degrees of the LTRT and FLSS algorithms range from 5.58 to 5.93 and from 5.12 to 5.63, respectively. Meanwhile, this value of proposed algorithm, TFACR, is from 3.88 to 4.73. Similarly for the case where the desired degree is 4 (Figure 9b), the average degree of the LTRT, FLSS and TFACR algorithms ranged from 6.62 to 7.91, from 6.36 to 8.21 and from 4.54 to 5.81, respectively. For the case of the desired degree of 5 (Figures 9c), the mean degree of the TFACR algorithm is also always closer to the desired degree than the other algorithms.

For instances in which the nodes moved, we investigated the average node degree with the results obtained in Figure 10. These findings were obtained for a simulated scenario with 50 nodes, a desired node degree of 4, and node movement ranging from 5 to 20 m/s. We can observe that the TFACR algorithm returns the average node degree closest to the desired node degree. For example, considering the case where the nodes move at an average speed of 10 m/s, the average node degrees of algorithms LTRT and FLSS are 5.59 with standard deviations (SD) of 0.79 and 5.32 with SD of 0.74, respectively. This value is 4.15 with an SD of 0.56 if the TFACR algorithm is used. The results are also similar for the cases in which the nodes move at average speeds of 5, 15, and 20 [m/s]. The influence of the pause time parameter on node degree was also investigated. The simulation results are shown in Figure 11. We can observe that the LTRT algorithm

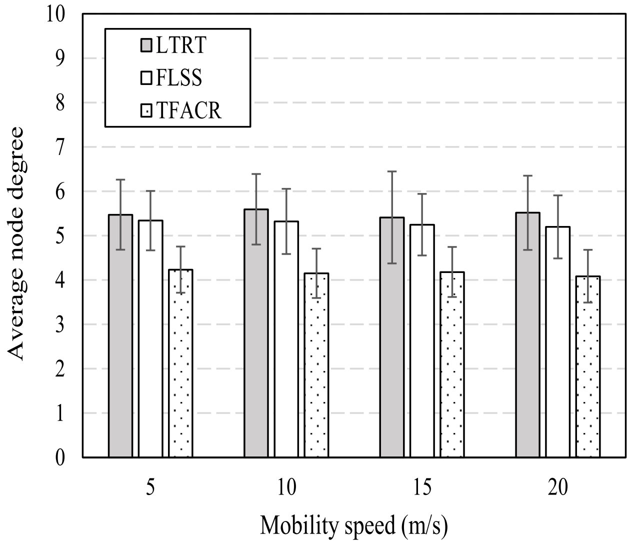
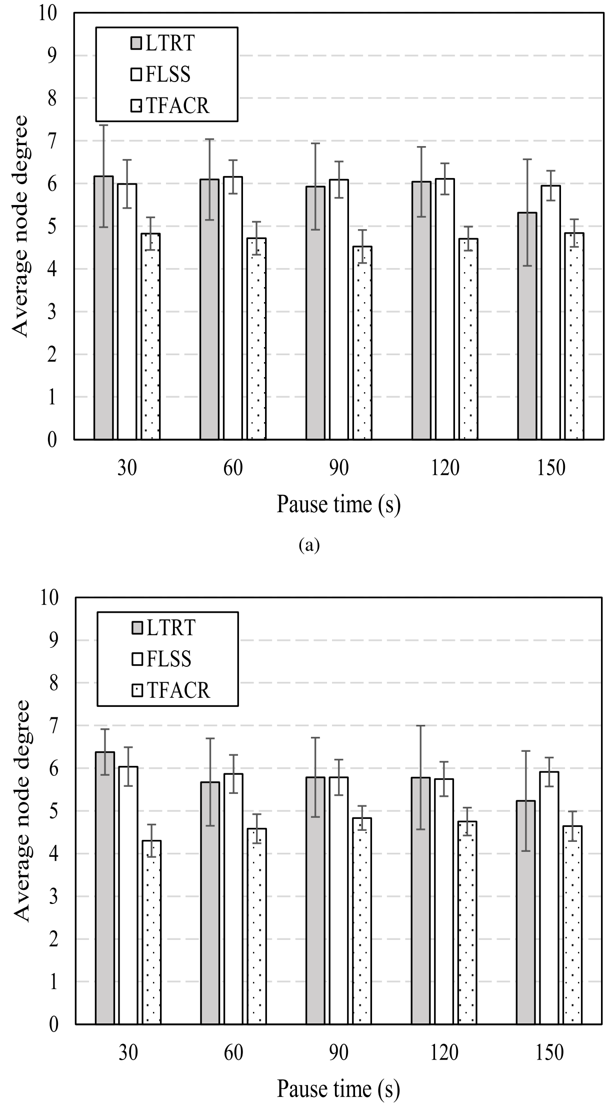


FIGURE 10. Compare the performance of the LTRT, FLSS, and TFACR algorithms in terms of average node degree versus the mobility speed of nodes.



(a)

(b)

FIGURE 11. Compare the performance of the LTRT, FLSS, and TFACR algorithms in terms of average node degree versus pause time for the cases that the average mobility speed of nodes is (a) 5 mps and (b) 10 mps.

is most influenced by the pause time. The FLSS and TFACR algorithms are less affected by this parameter. Comparing the three algorithms LTRL, FLSS, and TFACR, the TFACR algorithm gives the average node degree closest to the desired degree in all cases of pause time. Considering a particular case with a pause time of 90 [s], the average node degree of the LTRT, FLSS, and TFACR algorithms was 5.93 with an SD of 1.01, 6.09 with an SD of 0.42 and 4.52 with an SD of 0.39, respectively. In this simulation scenario, the desired degree is 4. Thus, the TFACR algorithm provided the best node degree.

Based on the results of carefully examining the node order above, we can conclude that the proposed TFACR algorithm outperforms the LTRT and FLSS algorithms in terms of node degree.

4) PATH LOSS ANALYSIS

In this section, we analyze path loss in the entire network. This is an important performance metric in 5G-based MANET, and it significantly affects the quality of the transmission signals. In the context of this study, a free space transmission medium is considered for a 5G-based MANET, and the *PL* is defined as follows [43]:

$$PL\ (dB) = 10log_{10}\left[\left(\frac{4\pi f_c d}{c}\right)^2\right] \quad (6)$$

where f_c is the carrier frequency, c is the speed of light ($\simeq 3 \times 10^8 m/s$) and d is the distance between transmitter and receiver. Figures 12a and 12b compare the average loss of the LTRT, TFACR algorithms, and without topology control. We can observe that the largest loss path occurs in the case without topological control. Comparing the LTRT and TFACR algorithms, the average loss path of the tFaCR algorithm is smaller than that of the LTRT algorithm for both cases with desired degrees of 3 and 4. Thus, the TFACR algorithm outperforms the LTRT algorithm in terms of path loss.

5) ENERGY CONSUMPTION EVALUATION

In this section, we evaluate the energy consumption at all nodes in the network for cases where the topology control algorithms of TFACR, LTRT, and FLSS are used. Ten UDP traffic streams were randomly generated between the pairs of source and destination nodes. To ensure objectivity of the results, we used different routing protocols for the simulation scenarios, including the AODV and DSDV protocols. These are typical protocols in the group of flooding-based routing protocols in MANET [45]. Recently, advanced routing protocols have been proposed for MANET, which typically

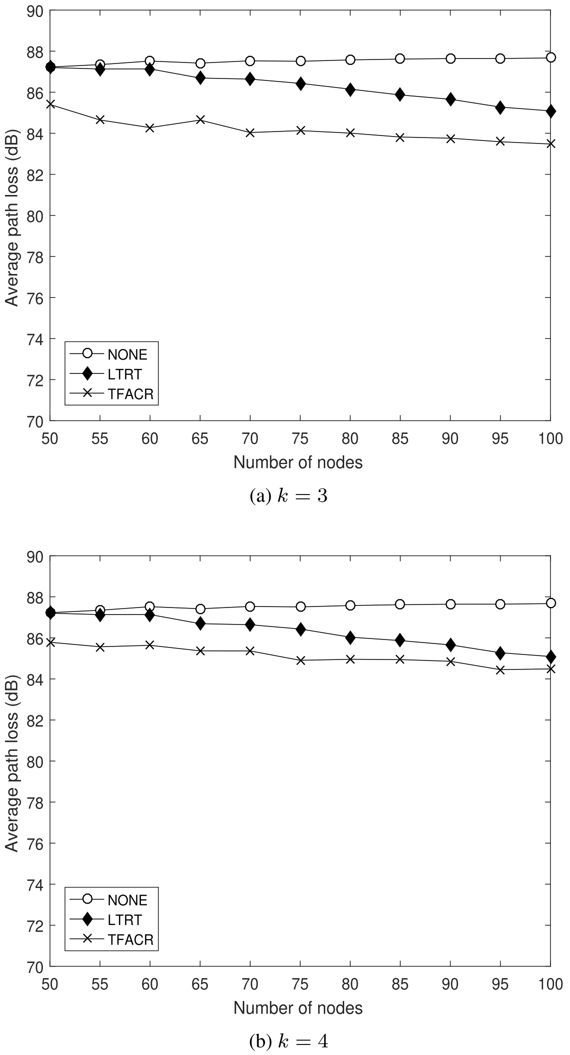


FIGURE 12. Compare the performance of algorithms TFACR, LTRT and without topology control in term of path loss.

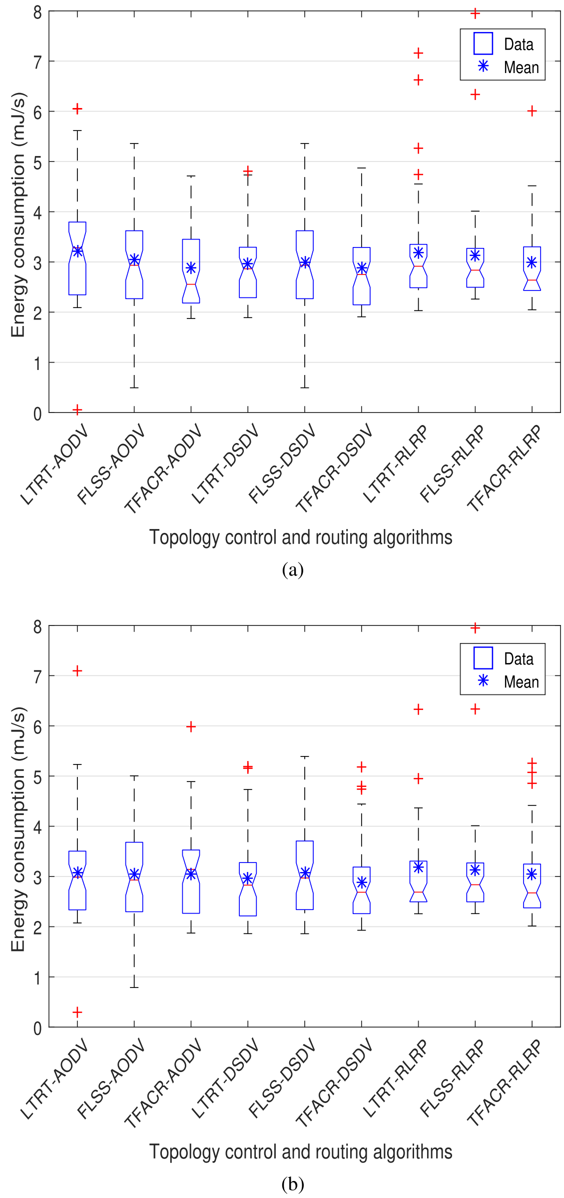


FIGURE 13. Compare the performance of the algorithms LTRT, FLSS and TFACR in term of energy consumption when (a) $k = 3$ and (b) $k = 4$.

reinforcement learning-based routing [46], [47], Distributed Hash Table (DHT)-based routing [48]. In this study, we use a reinforcement learning-based routing protocol (RLRP), which represents advanced routing protocols because it is suitable for 5G-based MANET.

The results obtained in Figure 13 clearly show the energy consumed at the nodes. It can be observed that when using the proposed topology control algorithm, TFACR, nodes consume less energy than the LTRT and FLSS algorithms in cases where AODV, DSDV, and RLRP routing algorithms are used. For example, consider the case where the desired node degree is 3 (Figure 13a) and the AODV routing protocol is used, the maximum, minimum and average values of energy consumed at the nodes for the LTRT, FLSS and TFACR algorithms are 6.1, 1.9 and 3.2 [mJ/s], 5.3, 1.4 and 3.04 [mJ/s] and 4.7, 1.8 and 2.9 [mJ/s], respectively. When using RLPR, both the median and average value of the energy consumed by the TFACR algorithm are smaller than that of the LTRT and FLSS algorithms. The results are also exactly the same for the cases where the desired node degree is 4 (Figure 13b). The energy consumed at the nodes was highly dependent on the traffic load in the network. We also examined this scenario and obtained the results shown in Figure 14. We can observe that the more the traffic load increases, the more power is consumed by the nodes for all algorithms. However, the TFACR algorithm always consumes less energy than the LTRT and FLSS algorithms.

In the case of moving nodes, the energy efficiency of the TFACR algorithm was better than that of the LTRT and FLSS algorithms. This is more evident in Figure 15, where we examined the energy consumption versus time simulation. The results were obtained using a simulation scenario with

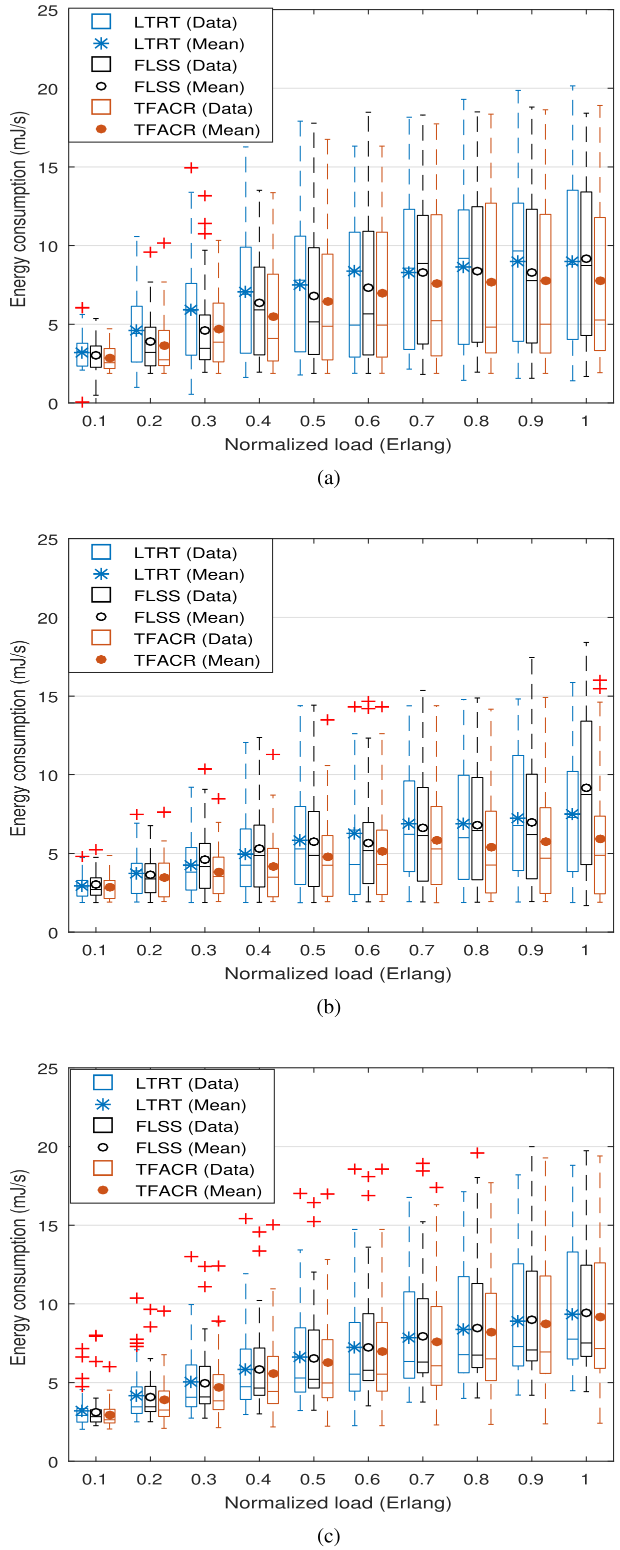


FIGURE 14. Compare the performance of the algorithms LTRT, FLSS and TFACR in term of Energy consumption versus traffic load when using (a) AODV, (b) DSDV and (c) RLRP.

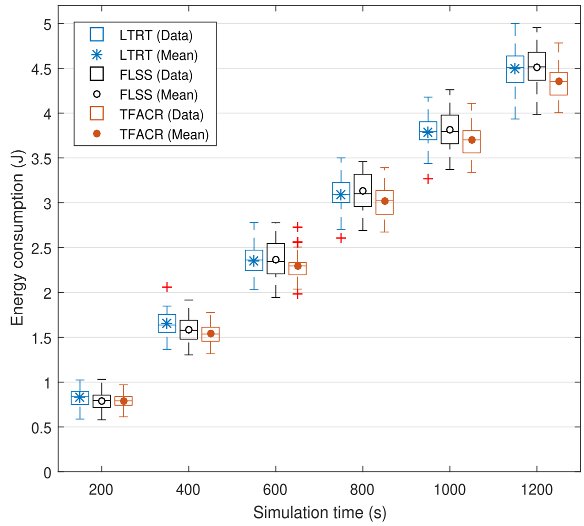


FIGURE 15. Compare the performance of the algorithms LTRT, FLSS and TFACR in term of Energy consumption versus simulation time.

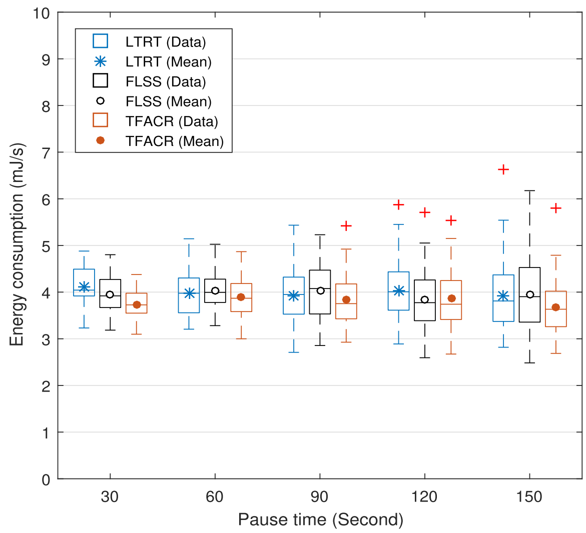


FIGURE 16. Compare the performance of the algorithms LTRT, FLSS and TFACR in term of Energy consumption versus pause time.

50 nodes, an average node moving speed of 10 m/s, a pause time of 30s, and an AODV routing protocol. The energy consumption at the nodes increases with the simulation time for all three algorithms, with the TFACR algorithm always consumes the least amount of energy. Considering a time of 1200 [s], the median - average values of energy consumption at the nodes of the LTRT, FLSS and TFACR algorithms were 4.509 [J] - 4.502 [J], 4.515 [J] - 4.509 [J] and 4.354 [J] - 4.353 [J], respectively. Thus, the TFACR algorithm saved about 0.16 J compared to the LTRT and FLSS algorithms. Another parameter of the migration script that affects the power consumption is the pause time. We investigated the effect of this parameter on the results obtained, as shown in Figure 16. The box charts in this Figure illustrate that the proposed algorithm, TFACR, always delivers the best power consumption in most pause time scenarios.

Based on the simulation results in the previous sections, we can conclude that the proposed algorithm, TFACR, provides better network performance than the LTRT and FLSS algorithms. However, when applying the TFACR algorithm, the traffic load in the network increases due to the overhead used for nodes to update their neighbor information. The traffic overhead of the TFACR algorithm is equivalent to that of the LTRT and FLSS algorithms. Specifically, the information exchange with neighboring nodes in LTRT and FLSS algorithms is performed by broadcasting hello packets containing its node id and position [25], [26]. In TFACR algorithm, we also use hello packets to exchange information between nodes. The hello packet is added two fields namely *nodeDegree* and *location* with the size of 1 byte and 4 bytes, respectively. With a large channel bandwidth such as 5G-based MANET, the increase of 5 bytes of the hello packet has a negligible effect on network performance.

VI. CONCLUSION

Many research groups have recently expressed interest in topology control in 5G-based MANET. The more optimized a network system topology, the better is the network performance. To improve network performance, we propose an efficient topology control algorithm for 5G-based MANET. The main idea of the proposed algorithm is to dynamically adjust the coverage radius to achieve the expected degree of the nodes. Each time a node adjusts the communication area, the degree constraint of the neighbor nodes is considered to ensure node degree balancing throughout the network topology. Simulation results on the OMNeT++ and INET frameworks show that the proposed algorithm outperforms well-known topology control algorithms in terms of the average node degree, path loss, and energy consumption.

In future work, we will continue to develop the algorithm by considering additional constraints on the quality of transmission, such as cross-channel interference, signal-to-noise ratio, and bit error ratio to further improve the network performance.

REFERENCES

[1] K. Q. Vu, V. K. Solanki, and A. N. Le, *A Saving Energy MANET Routing Protocol in 5G*. Cham, Switzerland: Springer, 2022, pp. 213–220, doi: 10.1007/978-3-030-79766-9_13.

[2] S. K. Sarkar, T. G. Basavaraju, and C. Puttamadappa, *Ad Hoc Mobile Wireless Networks—Principles, Protocols, and Applications*. Milton Park, U.K.: Taylor & Francis Group, 2008.

[3] P. Yan, S. Choudhury, F. Al-Turjman, and I. Al-Oqily, "An energy-efficient topology control algorithm for optimizing the lifetime of wireless ad-hoc IoT networks in 5G and B5G," *Comput. Commun.*, vol. 159, pp. 83–96, Jun. 2020, doi: 10.1016/j.comcom.2020.05.010.

[4] R. M. Alaez, E. Chirivella-Perez, J. M. A. Calero, and Q. Wang, "New topology management scheme in LTE and 5G networks," in *Proc. IEEE 87th Veh. Technol. Conf. (VTC Spring)*, Porto, Portugal, Jun. 2018, pp. 1–5, doi: 10.1109/VTCSpring.2018.8417677.

[5] R. Bharathy, T. Manikandan, P. Keerthivasan, P. M. Fayaz, A. M. S. Zafer, and K. M. Krishnan, "Typical MANET design for 5G communication network," in *Ambient Communications and Computer Systems*, Y.-C. Hu, S. Tiwari, M. C. Trivedi, and K. K. Mishra, Eds. Singapore: Springer Nature, 2022, pp. 383–390.

[6] M. F. Khan, K.-L.-A. Yau, M. H. Ling, M. A. Imran, and Y.-W. Chong, "An intelligent cluster-based routing scheme in 5G flying ad hoc networks," *Appl. Sci.*, vol. 12, no. 7, p. 3665, Apr. 2022, doi: 10.3390/app12073665.

[7] V. K. Quy, N. T. Ban, and N. D. Han, "An advanced energy efficient and high performance routing protocol for MANET in 5G," *J. Commun.*, vol. 13, pp. 743–749, Jun. 2018, doi: 10.12720/jcm.13.12.743-749.

[8] M. F. Khan and K. A. Yau, "Route selection in 5G-based flying ad-hoc networks using reinforcement learning," in *Proc. 10th IEEE Int. Conf. Control Syst., Comput. Eng. (ICCSCE)*, Aug. 2020, pp. 23–28, doi: 10.1109/ICCSCE50387.2020.9204944.

[9] R. Nithya, K. Amudha, A. S. Musthafa, D. K. Sharma, E. H. Ramirez-Asis, P. Velayutham, V. Subramaniyaswamy, and S. Sengan, "An optimized fuzzy based ant colony algorithm for 5G-MANET," *Comput., Mater. Continua*, vol. 70, no. 1, pp. 1069–1087, 2022, doi: 10.32604/cmc.2022.019221.

[10] D. Johnson, Y. Hu, and D. Maltz, *The Dynamic Source Routing Protocol (DSR) for Mobile Ad Hoc Networks for IPv4*, document RFC4728. [Online]. Available: http://www.rfc-editor.org/rfc/rfc4728.txt

[11] C. Perkins, E. B. Royer, and S. Das, *Ad hoc On-Demand Distance Vector (AODV) Routing*, document RFC 3561. [Online]. Available: https://www.ietf.org/rfc/rfc3561.txt

[12] T. T. Duong and L. H. Binh, "IRSML: An intelligent routing algorithm based on machine learning in software defined wireless networking," *ETRI J.*, vol. 44, no. 5, pp. 733–745, Oct. 2022, doi: 10.4218/etrij.2021-0212.

[13] N. Li, J. Yan, Z. Zhang, J.-F. Martínez-Ortega, and X. Yuan, "Geographical and topology control-based opportunistic routing for ad hoc networks," *IEEE Sensors J.*, vol. 21, no. 6, pp. 8691–8704, Mar. 2021, doi: 10.1109/JSEN.2021.3049519.

[14] L. H. Binh and V. T. Tu, "QTA-AODV: An improved routing algorithm to guarantee quality of transmission for mobile ad hoc networks using cross-layer model," *J. Commun.*, vol. 13, no. 7, pp. 338–349, 2018, doi: 10.12720/jcm.13.7.338-349.

[15] U. Zeb, W. U. Khan, S. Irfanullah, and A. Salam, "The impact of transmission range on performance of mobile ad-hoc network routing protocols," in *Proc. 3rd Int. Conf. Comput., Math. Eng. Technol. (iCoMET)*, Jan. 2020, pp. 1–4, doi: 10.1109/iCoMET48670.2020.9074090.

[16] L. H. Binh and T. T. Duong, "Load balancing routing under constraints of quality of transmission in mesh wireless network based on software defined networking," *J. Commun. Netw.*, vol. 23, no. 1, pp. 12–22, Feb. 2021, doi: 10.23919/JCN.2021.000004.

[17] A. Bhardwaj and H. El-Ocla, "Multipath routing protocol using genetic algorithm in mobile ad hoc networks," *IEEE Access*, vol. 8, pp. 177534–177548, 2020, doi: 10.1109/ACCESS.2020.3027043.

[18] T.-V. T. Duong, L. H. Binh, and V. M. Ngo, "Reinforcement learning for QoS-guaranteed intelligent routing in wireless mesh networks with heavy traffic load," *ICT Exp.*, vol. 8, no. 1, pp. 18–22, 2022, doi: 10.1016/j.icte.2022.01.017.

[19] B. Devika and P. N. Sudha, "Power optimization in MANET using topology management," *Eng. Sci. Technol., Int. J.*, vol. 23, no. 3, pp. 565–575, Jun. 2020.

[20] Q. Guan, F. R. Yu, S. Jiang, V. C. M. Leung, and H. Mehrvar, "Topology control in mobile ad hoc networks with cooperative communications," *IEEE Wireless Commun.*, vol. 19, no. 2, pp. 74–79, Apr. 2012, doi: 10.1109/MWC.2012.6189416.

[21] K. Genda, "Topology control method adopting optimal topology with minimum cumulative energy consumption over update interval in MANETs," in *Proc. IEEE 17th Annu. Consum. Commun. Netw. Conf. (CCNC)*, Jan. 2020, pp. 1–6, doi: 10.1109/CCNC46108.2020.9045688.

[22] H. Nishiyama, T. Ngo, N. Ansari, and N. Kato, "On minimizing the impact of mobility on topology control in mobile ad hoc networks," *IEEE Trans. Wireless Commun.*, vol. 11, no. 3, pp. 1158–1166, Mar. 2012, doi: 10.1109/TWC.2012.010312.110783.

[23] T. T. T. Le and S. Moh, "An energy-efficient topology control algorithm based on reinforcement learning for wireless sensor networks," *Int. J. Control Autom.*, vol. 10, no. 5, pp. 233–244, May 2017, doi: 10.14257/ijca.2017.10.5.22.

[24] L. H. Binh and T. K. Truong, "An efficient method for solving router placement problem in wireless mesh networks using multi-verse optimizer algorithm," *Sensors*, vol. 22, no. 15, p. 5494, Jul. 2022, doi: 10.3390/s22155494.

[25] K. Miyao, H. Nakayama, N. Ansari, and N. Kato, "LTRT: An efficient and reliable topology control algorithm for ad-hoc networks," *IEEE Trans. Wireless Commun.*, vol. 8, no. 12, pp. 6050–6058, Dec. 2009, doi: 10.1109/TWC.2009.12.090073.

[26] N. Li and J. C. Hou, "Localized fault-tolerant topology control in wireless ad hoc networks," *IEEE Trans. Parallel Distrib. Syst.*, vol. 17, no. 4, pp. 307–320, Apr. 2006, doi: 10.1109/TPDS.2006.51.

[27] Y. Huang, J.-F. Martínez, V. Díaz, and J. Sendra, "A novel topology control approach to maintain the node degree in dynamic wireless sensor networks," *Sensors*, vol. 14, no. 3, pp. 4672–4688, Mar. 2014, doi: 10.3390/s140304672.

[28] O. S. Younes and U. A. Albalawi, "Analysis of route stability in mobile multihop networks under random waypoint mobility," *IEEE Access*, vol. 8, pp. 168121–168136, 2020, doi: 10.1109/ACCESS.2020.3023142.

[29] A. A. Agashe and S. K. Bodhe, "Performance evaluation of mobility models for wireless ad hoc networks," in *Proc. 1st Int. Conf. Emerg. Trends Eng. Technol.*, 2008, pp. 172–175, doi: 10.1109/ICETET.2008.156.

[30] K. C. K. Naik, C. Balaswamy, and P. R. Reddy, "Performance analysis of OLSR protocol for MANETs under realistic mobility model," in *Proc. IEEE Int. Conf. Electr., Comput. Commun. Technol. (ICECCT)*, Feb. 2019, pp. 1–5, doi: 10.1109/ICECCT.2019.8869406.

[31] J. Farooq, L. Bro, R. T. Karstensen, and J. Soler, "Performance evaluation of a multi-radio, multi-hop ad-hoc radio communication network for communications-based train control (CBTC)," *IEEE Trans. Veh. Technol.*, vol. 67, no. 1, pp. 56–71, Jan. 2018, doi: 10.1109/TVT.2017.2777874.

[32] L. The Dung, B. An, N.-S. Kim, and D.-H. Kim, "An analytical model for performance evaluation of multi-hop paths in mobile ad-hoc wireless networks," in *Proc. 4th Int. Conf. Ubiquitous Future Netw. (ICUFN)*, Jul. 2012, pp. 58–62, doi: 10.1109/ICUFN.2012.6261664.

[33] D. E. M. Ahmed, O. O. Khalifa, A. H. A. Hashim, and M. Yagoub, "Performance evaluation of ad hoc on-demand distance vector routing protocol under video streaming," in *Proc. 7th Int. Conf. Comput. Commun. Eng. (ICCCE)*, Sep. 2018, pp. 338–342, doi: 10.1109/ICCCE.2018.8539278.

[34] M. Damian, S. Pandit, and S. Pemmaraju, "Local approximation schemes for topology control," in *Proc. 25th Annu. ACM Symp. Princ. Distrib. Comput.*, Jul. 2006, doi: 10.1145/1146381.1146413.

[35] X. Meng, H. Inaltekin, and B. Krongold, "Deep reinforcement learning-based topology optimization for self-organized wireless sensor networks," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Dec. 2019, pp. 1–6, doi: 10.1109/GLOBECOM38437.2019.9014179.

[36] E. Testi, E. Favarelli, L. Pucci, and A. Giorgetti, "Machine learning for wireless network topology inference," in *Proc. 13th Int. Conf. Signal Process. Commun. Syst. (ICSPCS)*, 2019, pp. 1–7.

[37] G. Wang, H. Wang, X. Cao, X. Li, and H. Luo, "A topology control algorithm based on minimum spanning tree for wireless sensor network," in *Proc. China Autom. Congr. (CAC)*, 2021, pp. 1057–1062, doi: 10.1109/CAC53003.2021.9728118.

[38] Z. Geng, W. Xia, W. Cao, T. Wu, F. Yan, L. Shen, and J. Pang, "An energy-efficient hierarchical topology control algorithm in software-defined wireless sensor network," in *Proc. 13th Int. Conf. Wireless Commun. Signal Process. (WCSP)*, Oct. 2021, pp. 1–6, doi: 10.1109/WCSP52459.2021.9613497.

[39] R. Huang, Y. Dong, G. Bao, Y. Liu, M. Wei, J. Lu, and Y. Huo, "A new topology control algorithm in software defined wireless rechargeable sensor networks," *IEEE Access*, vol. 9, pp. 101003–101012, 2021, doi: 10.1109/ACCESS.2021.3096793.

[40] Y. Huang, B. Tang, L. Deng, and C. Zhao, "Fuzzy analytic hierarchy process-based balanced topology control of wireless sensor networks for machine vibration monitoring," *IEEE Sensors J.*, vol. 20, no. 15, pp. 8256–8264, Aug. 2020, doi: 10.1109/JSEN.2020.2966049.

[41] A. Varga, "OMNeT++ simulation manual," Version 6.x, OpenSim Ltd. Accessed: Aug. 2022. [Online]. Available: https://omnetpp.org/

[42] *INET Framework User's Guide, Release 4.4.0*. Accessed: Aug. 2022. [Online]. Available: https://inet.omnetpp.org/docs/developers-guide/index.html

[43] D. P. Agrawal and Q. A. Zeng, *Introduction to Wireless and Mobile Systems*, 4th ed. Boston, MA, USA: Cengage Learning, 2016.

[44] S. A. Alghamdi, "Stable zone-based 5G clustered MANET using interest-region-based routing and gateway selection," *Peer Peer Netw. Appl.*, vol. 14, no. 6, pp. 3559–3577, Nov. 2021, doi: 10.1007/s12083-021-01113-6.

[45] H.-H. Choi and J.-R. Lee, "Local flooding-based on-demand routing protocol for mobile ad hoc networks," *IEEE Access*, vol. 7, pp. 85937–85948, 2019, doi: 10.1109/ACCESS.2019.2923837.

[46] T.-N. Tran, T.-V. Nguyen, K. Shim, D. B. da Costa, and B. An, "A deep reinforcement learning-based QoS routing protocol exploiting cross-layer design in cognitive radio mobile ad hoc networks," *IEEE Trans. Veh. Technol.*, vol. 71, no. 12, pp. 13165–13181, Dec. 2022, doi: 10.1109/TVT.2022.3196046.

[47] L. H. Binh and T.-V.-T. Duong, "An improved method of AODV routing protocol using reinforcement learning for ensuring QoS in 5G-based mobile ad-hoc networks," *ICT Exp.*, Jul. 2023, doi: 10.1016/j.icte.2023.07.002.

[48] A. Tahir, S. A. Abid, and N. Shah, "Logical clusters in a DHT-paradigm for scalable routing in MANETs," *Comput. Netw.*, vol. 128, pp. 142–153, Dec. 2017, doi: 10.1016/j.comnet.2017.05.033.

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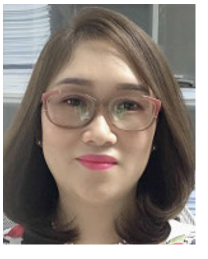

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