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RESEARCH ARTICLE

Gateway Selection and Clustering in Multi-interface Wireless Mesh Networks considering Network Reliability and Traffic

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ABSTRACT

This work considers the gateway selection and clustering problem in a multi-interface Wireless Mesh Network (WMN). The Evolved Reliability and Traffic-aware Gateway Selection (ERTGS) scheme is here introduced in order to increase the performance in terms of throughput. There are two main phases in the proposed idea, first some Internet Gateway Candidates (IGCs) are selected from the mesh nodes in the network, based on the network traffic. Then in the second step using path-tracing method the best of these candidates are selected as Internet gateways. Moreover, to decrease the network energy consumption a refined ERTGS is also proposed whose effect in simulation is shown. A clustering method is later proposed exploiting Genetic Algorithm (GA) to give the priority to the nodes with the shortest hop to connect to the cluster head. Simulation results demonstrate how our Gateway Selection and Clustering Scheme (GSCS) outperforms two successful approaches in terms of throughput and network energy consumption. Copyright © 2017 John Wiley & Sons, Ltd.

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1. INTRODUCTION

Wireless Mesh Networks (WMNs) are a promising technology which have emerged since early 2000s and have received lots of attention. WMNs have certain merits that make them an economical solution for wireless broadband access. Self-healing, cheap-to-deploy and high scalability are characteristics of WMNs which have made this connectivity type attractive for city projects and lots of application scenarios [1]. Their importance still remains high in the last years; this is noticeable even by looking to the most recent wireless communication and networking systems, e.g., fog computing and networking or 5G wireless communication systems, where WMNs are considered as one of the possible constituent [2].

A mobile client in WMNs can access the Internet in a multi-hop fashion by communicating through a wireless backbone. This multi-hop wireless network is comprised of two types of nodes: Mesh Routers (MRs) and Mesh Clients (MCs) which provide the end users with backhaul access [1]. MRs have minimal mobility and provide wireless connections for MCs. They form the Backbone of the WMNs (BWMNs) and relay each other's packets by multi-hop communicating. MCs, which are stationary or mobile, can associate with one of the MRs and gain access to Internet through Internet Gateways (IGWs). IGWs are MRs in BWMN configured with wired links with bridging functionality between WMNs and the Internet. A typical WMN is illustrated in Figure 1.

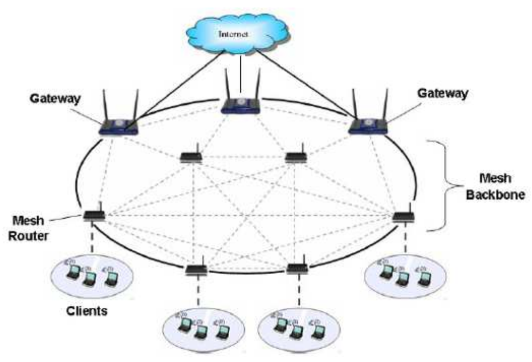

Figure 1. Wireless Mesh Network [3]

One of the most important network performance indicators is throughput [4–6]. Lots of research in WMNs concentrate on improving throughput to guarantee broadband network performance [7–11]. Since all the traffic in the network aggregates in the IGWs, and due to the few IGWs in the network, it is of vital importance to choose an appropriate mesh node as a gateway. At the same time it is not a possible solution that of giving to all MRs the IGW capabilities due to the implementation cost. Thus, a proper IGW selection should be done by trading off between cost and achieving a target throughput and, in general, optimizing network performance.

Network performance is influenced by many factors. In wireless networks a failure may arise because a communication link is disconnected or a network node becomes incapacitated. A node or link failure will deteriorate network performance sharply because fewer neighboring nodes for relaying the packets will be left and packets should traverse longer paths. Moreover, a short down time may cause substantial data loss in which rapid recovery from failure is important [12]. Therefore, networks require high levels of reliability. As far as we are concerned, only one work has considered the impact of reliability of routes for the selection of IGWs. Using a coefficient for each MR in the network and using this coefficient in the path tracing method, the best MRs are selected as gateways.

The amount of traffic flowed through each IGW also affects the performance of the network. IGWs have high capacity and if they are placed in areas with low traffic, it may lead to an unbalanced network. To use the capacity of IGWs properly, it is considerably important to have IGWs deployed in areas with high amount of traffic.

MRs in WMNs have minimal mobility comparing with wireless sensor networks or Adhoc Networks. However, this does not mean that MRs in WMNs have a constant access to electrical source, and energy consumption is not a concern. Moreover, MRs with high speed are increasingly being designed. In [13], the authors took into consideration the design of green routers, which are efficient in energy consumption. Apart from the design of green routers there have been other efforts in the optimization of energy consumption. Due to employment of many MRs in special geographical locations and due to electricity oscillation in some areas, MRs are in need of connection to an uninterrupted power supply. There are some devices that act like a source of energy in these emergency situation. Furthermore, there have been some other research on utilization of solar energy for the routers' main energy source or exploiting rechargeable routers for reduction of constant use of electrical energy in [14] and [15]. As a result, energy consumption is also a concern in WMN.

In this work, as a result, we are interested in trading-off between network throughput maximization and minimization of network energy consumption. To achieve this, the problem of IGW selection, which is of paramount importance in WMN, is addressed. In the proposed ERTGS scheme, the data traffic is assigned to each node in the network according to the nodes' connectivity degree. Moreover, a refined scheme for minimizing the energy consumption is also introduced. A clustering scheme is then introduced exploiting Genetic Algorithms (GA) in which the routers closer to a gateway have the priority to be placed in the same cluster. The main contributions of this paper are as follows:

(i) An optimized IGW selection based on network traffic and link failure in the path between source and destination node for maximizing the overall network throughput.

(ii) An algorithm which sharply reduces network energy consumption.

(iii) Although most of the works in clustering focus on load balancing and reducing the delay, they do not give the priority to the nearest node to the gateway when clustering the mesh nodes. Using GA, we propose a method using a set of criteria to optimize clusters. As it is possible to see in the simulation results, this approach allows to enhance the performance of the network.

The rest of this paper is organized as follows. An overview of related works is shown in Section 2. In Section 3, the preliminaries of underlying network are described. The evolved gateway selection algorithm, ERTGS, and an optimization on it are further presented in Section 4. The clustering idea is later explained in this section. In Section 5, the performance of Gateway Selection and Clustering Scheme (GSCS) is evaluated and compared to other works. Finally, the paper concludes in Section 6.

2. RELATED WORKS

Most of recent research in WMNs has been dedicated to the problem of IGW selection and clustering. In this section, the most important works in the literature in this field are concisely introduced. Many techniques were used for selecting optimized MRs with gateway functionality.

The throughput performance problem was highlighted in [7] and an IGW selection method was proposed to maximize the network throughput. Bottleneck Collision Domain (BCD) is first defined in their work as a range that encloses a set of wireless links to avoid collision. First a random node is selected as tentative gateway. Then it is replaced with a new gateway if there is a node in its collision domain with less total traffic. The authors also calculated an upper bound considering the total traffic in BCD and maximum available transmission throughput on the Media Access Control (MAC) layer. Based on the proposed upper bound they can control the traffic from the node to the gateway to optimize the throughput. However, this algorithm might be problematic in case of high traffic in the network. Selecting gateways in areas with reduced traffic may lead the nodes with high traffic demand to connect to the nearest gateway with multiple hops and, thus, increasing the delay. Furthermore, the redundancy of path from a gateway to MRs in its coverage area was not considered. Similar to the previous work, in [16] first

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the nodes which are heavily loaded are selected and then among them the ones having smallest BCD are selected as gateways.

Authors in [17] proposed a recursive algorithm for IGW selection with the aim of minimizing the number of IGWs and satisfying the Quality of Service (QoS) requirements, i.e., delay, relay load and gateway constraints. They presented a greedy approach in which the adjacency matrix was computed representing connectivity graph of dominating set of the previous iteration. Then the node that covers the greatest number of remaining uncovered nodes is selected iteratively. However, in this work the decision-making step is done greedily and does not produce an optimal result.

In [18], the authors aimed at maximizing the throughput in a grid-based gateway placement scenario to place the gateways in the cross points on the grid. They used different interference models in their work. However, the proposed gateway selection method was trying all the combinations of positions using linear programming and selecting the combination with the highest throughput. Since they used a lot of gateways, their work achieved better throughput, connectivity and coverage. On the other hand, the cost of the equipment by using a lot of gateways increased.

In [19], the problem of gateway placement with the aim of minimizing the number of gateways and guaranteeing bandwidth requirements was addressed. The gateway placement was formulated as a network flow problem and then an algorithm was developed for IGW selection. In the proposed algorithm, an MR can be connected to multiple IGWs through multiple paths without considering path length as an optimization parameter. Therefore, by using this greedy heuristic, long paths may be selected, increasing the delay in the network. Moreover, the traffic effort from MR to IGW cannot be addressed effectively. Hence, the performance cannot be guaranteed.

Due to extremely high computational load to generate an optimal solution, the authors in [20] proposed a new algorithm for IGW selection using a cross-layer throughput optimization taking physical interference model, hop count, and switching overhead into account. However, the network traffic was not considered in their work.

A heuristic algorithm was developed for large-scale networks based on Greedy Dominating Tree Set Partitioning (GDTSP) in [21], namely degree-based GDTSP and weight-based GDTSP. The degree-based IGW selection emphasized the connectivity degree of IGW within the maximal MR-IGW hop while the weight-based IGW selection placed emphasis not only on coverage but also on MR-IGW hop and selects more MRs close to the IGW. In degree-based algorithms, all nodes within R-hop are treated similarly in terms of connectivity while in weight-based methods higher value is given to MRs with fewer hops. To this aim, they have defined a formula for calculating the available bandwidth for each gateway when connecting an MR to it in the cluster phase. However, updating the table for the available bandwidth takes a lot of time.

IGW placement problem was the main focus of [22]. Two sub-algorithms were proposed for clustering with the objectives of minimizing the number of IGWs and minimizing the IGW-MR hops. The proposed method was introduced for preventing zero degree nodes i.e., nodes with zero connection, in the network after clustering. At first, in their IGW selection algorithm the largest degree node will be the IGW. If there is more than one largest-degree node the algorithm looks for the second and, if the same situation exists, the third hop, to find nodes with only one connection. Then the selection of IGW behaves different in the two sub-algorithms, for small (S) and large (L) degree. Zero-degree-(S) opts the node which has the smallest degree node among its neighbors and Zero-degree-(L) selects the node with the largest degree node in its neighbors. But the gateway nodes in Zero-degree-(S) are selected close to each other and in Zero-degree-(L) some IGWs are underused.

A centralized IGW selection method aiming at balancing the load served by IGWs was proposed in [23]. One of the assumptions in this work is that current demand of the nodes is known. However, it is not stated how this information is obtained. Similar to [23], the solutions proposed in [24, 25] also assumed a specific demand for each node, although they are not designed for TCP traffic since no accurate knowledge of the capacity is known.

A cluster-based routing approach is presented in [26] in which a node whose signal strength is higher than the neighboring nodes is selected as cluster head and among those nodes the one that received more messages from the neighboring nodes as a connectivity is selected as the gateway.

Differently from the previous works, [27] defines a rate controller in the source node to decide which gateway should be the recipient of the the flow. At each time slot the gateway whose rate controller, considering delay priority of the flow and length of queue, is the smallest is selected.

A cluster-based hybrid routing is proposed in [28] to improve the QoS in WMNs. The clusters are shaped based on the frequency of the nodes; the frequency is divided in three levels: higher, middle and lower levels. Cluster heads are selected based on the battery power and then a path is established between the cluster head and the nearest adjacent cluster head. However, this work does not provide a precise explanation about the procedure of the division of the nodes into the three levels. Moreover, the way the cluster heads are selected and energy is consumed is not clarified. The selection of cluster head in this work is the closest to our work, however, the goal and the scheme are different.

The authors in [29] proposed a fuzzy-based clustering approach considering three parameters which are bandwidth, number of single-hop neighbors and distance to the gateway. The node whose distance is shorter to the gateway, whose single-hop neighbors are higher and whose link bandwidth is the highest is selected as the cluster head. However, fuzzy logic brings about a high computational complexity to network. Moreover, it is not well-explained how bandwidth is considered in the scenario. Furthermore, all nodes should send a message to their neighboring nodes finding whether they are their single-hop neighbors or not and this brings an additional complexity to the network.

After reviewing the previous works, we came to the conclusion that IGWs selection can be performed more appropriately if IGWs are elected from areas with high traffic. In this case, in a network with high traffic demand we can have a better performance. Moreover, if the selected gateway has many paths to transmit the packet, in case of a link failure the performance will not decrease dramatically. For this reason, ERTGS is introduced taking into consideration the network traffic and the reliability of paths in case of a link failure. We further introduce a clustering method which tries to increase the throughput by prioritizing the single hop nodes to be connected to the nearest gateway. To decrease the computational complexity, we have classified the nodes considering the consumed energy of the nodes. Finally, we compare the performance of our approach with [21] and [22] and show the effectiveness of our new method.

3. PRELIMINARIES AND PROBLEM DEFINITION

3.1. System Model

A WMN can be modeled as an undirected network graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$, in which $\mathcal{V} = \{v_1, \dots, v_i, \dots, v_n\}$ represent the set of n mesh nodes that include MRs and those to be configured as IGWs in the WMN. We assume that every MR v_i has the same transmission range, $R_T(i)$.

Among n mesh nodes, only a limited number, at most m, where $m \leq n$, can be equipped with the gateway functionality and provide the connectivity to the Internet for the WMN. For the sake of simplicity, let $\oplus = \{\phi_1, \dots, \phi_j, \dots, \phi_m\}$ be the set of m gateways and all the other non-gateway nodes $v \in \mathcal{V} - \oplus$ are simply MRs. Each MR v has the functionality of aggregating the traffic from all its MCs and then route them to IGWs in a multi-hop fashion to be forwarded to the Internet. $\mathcal{E} = \{e_1, e_2, \dots, e_l\}$ is instead the set of possible directed communication links. Since, it is not feasible for economic and complexity reasons that there should be many IGW, an IGW selection algorithm should be considered for properly selecting them among the MRs.

3.2. IGW selection problem

Basically, the problem of IGW selection in a network with n mesh nodes is defined as selecting m of the nodes to be given the gateway functionality. These nodes act like an interface between the mesh network and the internet [30]. To select the appropriate nodes as IGWs many parameters have been considered in the literature.

In this section, we formulate the IGW selection problem as an Integer Linear Program (ILP). Given the number of n mesh nodes we aim at selecting m of these nodes as IGWs in the WMN, so that the overall throughput is maximized and the energy consumption in the network is minimized. To express the mathematical formulation, the following Boolean variables are introduced:

- The gateway selection variable,

$$X_i = \begin{cases} 1 & \text{if the } i\text{th node is a gateway} \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

- The gateway assignment variable,

$$U_{\phi_j, v_i}(R) = \begin{cases} 1 & \text{if } \phi_j \text{ is the gateway of } v_i \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

  where R is a threshold for the maximum number of hops between an MR and a gateway.

- The inter-gateway connection variable,

$$U_{\phi_i, \phi_j} = \begin{cases} 1 & \text{if } \phi_i \text{ is connected to } \phi_j \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

- The router connection variable,

$$U_{v_i, v_j} = \begin{cases} 1 & \text{if } v_i \text{ is connected to } v_j \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

The number of packets sent per unit of time from node v_i to v_j is denoted by $A(v_i, v_j)$. Now, we define $\eta(\phi_j)$, the throughput of a gateway node, as:

$$\eta(\phi_j) = \sum_{\substack{k=1 \\ X_k=0}}^{n} \big(A(v_k, \phi_j) \cdot U_{\phi_j, k}(R)\big) + \sum_{\substack{k=1 \\ X_k=1}}^{m} \big(A(\phi_k, \phi_j) \cdot U_{\phi_k, \phi_j}\big) \quad (5)$$

which is the sum of the traffic demand sent from the MRs and gateways connected to the jth gateway. Likewise $\eta(v_i)$, the throughput of an MR v_i, is defined as:

$$\eta(v_i) = \sum_{\substack{k=1 \\ X_k=0}}^{n} A(v_k, v_i) \cdot U_{v_i, v_j} \quad (6)$$

corresponding to the traffic demand received by the ith node from the connected nodes. Now we define the network throughput, η_{Net}, as:

$$\eta_{Net} = \sum_{j=1}^{m} \eta(\phi_j) \quad (7)$$

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On the other hand, the energy consumption for the ith mesh node can be defined as:

$$E^i = E^i_{tr} + E^i_{re} + E^i_{id}$$

in which E^i_{tr} and E^i_{re} are the amount of energy consumed by the i-th mesh node for transmitting or receiving packets, respectively, and E^i_{id} is the average amount of energy consumed by a mesh node per unit of time during its idle time. We have exploited the energy consumption formula in [31] for defining the energy consumption in the i-th node as:

$$E^i = \left(E^i_{tr} \sum_{\substack{k=1 \\ i \neq k}}^{n} A(v_i, v_k) \cdot U_{v_i, v_k} \right) + \left(E^i_{re} \sum_{\substack{k=1 \\ i \neq k}}^{n} A(v_k, v_i) \cdot U_{v_k, v_i} \right) + E^i_{id} \quad (8)$$

Now, let us define the network energy consumption as:

$$E_{Net} = \sum_{i=1}^{n} E^i \quad (9)$$

Based on the above definitions the IGW selection problem as an ILP in graph $\mathcal{G}$ can be formulated as:

$$\begin{cases} \max(\eta_{Net}) = \max \left\{ \sum_{j=1}^{m} \left(\sum_{\substack{k=1 \\ X_k=0}}^{n} A(v_k, \phi_j) \cdot U_{\phi_j, v_k}(R) + \sum_{\substack{k=1 \\ X_k=1}}^{n} A(\phi_k, \phi_j) \cdot U_{\phi_j, \phi_k} \right) \right\} \\ \min(E_{Net}) = \min \left\{ \sum_{i=1}^{n} \left(E^i_{tr} \sum_{\substack{k=1 \\ i \neq k}}^{n} A(v_i, v_k) \cdot U_{v_i, v_k} + E^i_{re} \sum_{\substack{k=1 \\ i \neq k}}^{n} A(v_k, v_i) \cdot U_{v_k, v_i} + E^i_{id} \right) \right\} \end{cases} \quad (10)$$

subject to

$$\sum_{i=1}^{n} X_i = m \quad (11)$$

$$\sum_{j=1}^{m} U_{\phi_j, v_i}(R) = 1 \qquad \forall i \quad (12)$$

$$h(v_i, \phi_j) \leq R \quad (13)$$

$$\eta(v_i) \leq \overline{\eta_i^{RO}} \quad (14)$$

$$\eta(\phi_j) \leq \overline{\eta_j^{GW}} \quad (15)$$

There are two objectives in the formulation which are maximizing the network throughput and minimizing network energy consumption that are respectively shown in (10). Moreover, some constraints are also required for the formulation. Constraint (11) ensures that exactly m gateways will be deployed. The requirement that each node is assigned to only one gateway is shown in constraint (12). Constraint (13) ensures that the distance between a router and a gateway, $h(v_i, \phi_j)$ does not exceed the threshold R. Moreover, each router has a specific throughput which is the local traffic plus the relay traffic from the other nodes. Constraint (14) explains that this throughput, cannot be above the defined maximum threshold $\overline{\eta_i^{RO}}$ of an MR. Likewise, the traffic relays to a gateway cannot exceed $\overline{\eta_j^{GW}}$ defined as the maximum throughput threshold of a gateway, as depicted in constraint (15).

As seen, gateway selection can be written in an ILP which has been proved to be an NP-hard problem [32]. This formulation can be solved in a reasonable computational time with few number of nodes in a small network. Thus, for extending the network we propose a heuristic and a meta-heuristic solution in the following sections.

4. THE PROPOSED IGW SELECTION METHOD

In this section, we introduce the proposed ERTGS. Then, an energy consumption optimization is proposed, as an additional strategy.

4.1. WMN Traffic

The growth in usage of WMNs has increased the demands for supporting more users. Therefore, one of the most important issues in supporting more users is the capacity of the gateways [33]. All mesh gateways in the network have a specific capacity. If they are requested to give a capacity above their limit, they will inevitably fail. On the other hand, if their capacity is not properly used the network quality will deteriorate. Traffic demand of the ith node, corresponds to the amount of traffic the node should manage and it is equal to the generated traffic plus the relay traffic. In this work, traffic is assumed to be unknown for the given network since it is dynamic and can frequently change. In other words, when traffic is constituted by TCP flows, the demand of nodes cannot be assumed to be known and remain the same even after a change in IGW selection [34]. Since the amount of traffic depends on the connectivity degree of a certain node, that is, the higher the connectivity degree of a node, the higher traffic is generated by that node, we can select some IGCs among all MRs in a way that IGCs are selected in areas with high amount of traffic. Therefore, their capacity is well-used. The parameters in our model are summarized in Table I.

The proposed IGC selection method is shown in Algorithm 1. In the algorithm, all traffic in the interference range of all mesh nodes is calculated. In this work, nodes are listed according to the calculated aggregated traffic in their domain. MRs with high amount of traffic

Table I. Parameters in the IGC and IGW selection method

Term	Definition
$\mathcal{V}$	set of all mesh nodes in the network
l	number of links in the interference range of node v
p	number of gateway candidates
Y_n	n^{th} path between two nodes
TD	traffic demand generated in the network
$\mathcal{C}$	set of IGCs
i	a selected node in $\mathcal{V}$ or $\mathcal{C}$
j	all the gateway candidates in $\mathcal{C}$ except i
R	a threshold for number of hops between two nodes
$R_{i,j}$	reliability of path from node i to j using path tracing method
$Sum(i)$	sum of reliability of node i to all the other IGCs
$T(i)$	the aggregate traffic in the interference range of node i
$\mathcal{K}$	a list of nodes

Algorithm 1 IGC Selection algorithm

Input: $\mathcal{V}$
Output: $\mathcal{C}$
for each $i \in \mathcal{V}$ **do**
  $T(i) = \sum_j TD_j$
Sort i in $\mathcal{K}$ according to $T(i)$
Select P of i in $\mathcal{K}$ with high $T(i)$
$\mathcal{C} \leftarrow i$

load in the list are inserted into $\mathcal{C}$ in order to narrow down the amount of calculation for the IGW selection algorithm. The selected nodes are the gateway candidates for transmitting packets from the MRs due to their position in areas with higher traffic.

4.2. Reliability of routes in WMNs

MRs with high number of nodes in their neighborhood and high number of links have a high chance to relay the packets in case of a link or node failure. Redundancy of routes for relaying a packet in case of a node or link failure will reduce the delay. Thus, if IGWs are placed in an area with higher redundancy of links they have a higher chance for transmitting the packets successfully in case of a link failure.

Since in fixed networks the probability of a link failure is far lower than the probability of a node failure, the results from works on network reliability of fixed networks are not generally applicable to wireless networks. This is the reason why links are considered as invulnerable to failure in fixed networks. On the other hand, in wireless networks link failure happens frequently due to the inherent characteristics of the radio channel. Thus, it is natural to model the nodes as invulnerable to failure and only focus only on the link failures in the analysis [35].

In wireless networks, protection schemes, in which recovery routes are preplanned, generally offer better recovery speeds than restoration approaches, which search for new routes dynamically in response to a failure [36]. Therefore, a protection scheme is considered in this work. The path tracing method is used for calculating the reliability of a route among all selected IGCs. To do so, a value for MRs is needed. A coefficient in $[\alpha \;\; \beta]$ range, where α and β are respectively the minimum and maximum reliability values, is allocated to each MR using Poisson distribution function in each run of the simulation and then the number of runs is averaged. By inserting the value in path tracing method, the reliability of routes between two IGCs is calculated as:

$$R_{i,j} = P(Y_1 \cup Y_2 \cup Y_3 \ldots, \cup Y_n) \qquad (16)$$

$R_{i,j}$ is the reliability of routes between i-th and j-th IGCs and Y_n represents a route between the two IGCs having a delay lower than D_{QoS}. D_{QoS} is the delay constraint and it shows the number of hops away from a specific MR. Considering (16) we propose the IGW selection algorithm.

Algorithm 2 IGW Selection algorithm

Input: $\mathcal{C}$
Output: A value for each IGC
for each $i \in \mathcal{C}$ **do**
  for all the paths from i to j **do**
    if $D_{QoS} \leq R$ **then**
      $R_{i,j} = P(Y_1 \cup Y_2 \cup Y_3 \ldots, \cup Y_n)$
      $Sum(i) = \sum R_{i,j}$

According to Algorithm 2, one IGC is chosen from the set $\mathcal{C}$ and then for all the paths between the selected IGC and another IGC with fewer than R hops the reliability of the routes are calculated. Summing the reliability of all paths between the selected IGCs and the other IGCs we allocate the obtained result as a value to that IGC. The same strategy goes for all IGCs and, in the end, all IGCs have a value.

4.3. ERTGS Scheme

Using the proposed algorithms we introduce now our IGW selection algorithm in which m nodes are selected out of n MRs to be equipped with gateway functionality. The IGW selection method is illustrated in Algorithm 3.

According to the proposed Algorithm 3, for each MR in the network the IGCs are selected according to network traffic. Then for all the selected IGCs, stored in $\mathcal{C}$, the second algorithm is called and the reliability of all paths between two IGCs is calculated and a value is allocated to each IGC according to the summation of reliability of all the paths to the other IGCs. In the end, the nodes with the highest amount of $Sum(i)$ will be elected as gateways.

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Algorithm 3 IGW Selection Method: ERTGS

1. **Input:** $\mathcal{V}$
2. **Output:** N IGWs
3. **for** each $i \in \mathcal{V}$ **do**
4. Algorithm 1
5. **for** each $i \in \mathcal{C}$ **do**
6. Algorithm 2
7. Select N of the nodes i having highest $Sum(i)$ as IGWs.

4.4. Optimization of Energy Consumption in ERTGS

Although with the proposed gateway selection algorithm the throughput of the network increases, the energy consumption rises as well. For this reason, we have proposed a scheme in our gateway selection approach to reduce the nodes' energy consumption. The energy consumption optimization is performed as in Algorithm 4.

Algorithm 4 Energy Consumption Optimization

1. Determine the amount of consumed energy in the interference range of all the gateway candidates after a certain amount of iterations
2. Find the node with the lowest consumed energy among all the other nodes in the interference range of all the gateway candidates
3. Set the node as the gateway candidate
4. Repeat steps 2-4

If a node is considered as gateway candidate for all the runs in the simulation, it consumes a lot of energy and, thus, computational complexity of the network will increase. In this idea, which is executed after a certain amount of time, we compute the consumed energy of each node in the interference range of the IGCs in order to find the node with the lowest amount of energy consumed and replace it with the IGC. Now that the IGC has been replaced with a node with lower energy consumption, the network energy consumption will reduce. The impact of the proposed optimization on network energy consumption is demonstrated in Section 5.

4.5. The proposed Clustering Method

A mesh cluster can be defined as a set of nodes $\mathcal{C} \subseteq \mathcal{V}$. All clusters have a cluster head $h \in \mathcal{C}$. The nodes in $\mathcal{C}$ and the arcs between them shape a cluster graph. If the cluster graph is connected, then the mesh cluster is connected. There are three primary QoS constraints in the design of BWMNs: delay, relay load, IGW capacity [17], considered as:

- The delay from any MR to its IGW should not exceed the defined maximum number of hops by delay constraint, D_{QoS}.
- The relay load constraint is the maximum number of MRs that are directly connected to a single MR. Each MR cannot be connected to more than the defined R_{QoS} MRs.
- The IGW capacity constraint can be defined as the maximum number of MRs that an individual IGW can serve, C_{QoS}.

Most of the proposed ideas for clustering have considered some parameters, e.g., load balancing and delay, by aiming at increasing the throughput. The node degree, traffic and the capacity of the gateway have also been taken into consideration for the proposed algorithms. In the algorithm we are going to propose, the priority is given to the nodes with the fewer number of hops from the cluster head to connect to the gateways. By having the gateways using our gateway selection scheme, we propose a clustering algorithm based on GA.

GAs are numerical optimization algorithms inspired by both natural selection and natural genetics. They represent an intelligent exploitation of a random search used to solve optimization problems. GAs exploit historical information to direct the search into the region of better performance within the search space. The basic techniques of the GAs are designed to simulate processes in natural systems necessary for evolution. It has been proven that GAs do not have a high negative impact on energy consumption in wireless networks. For instance, in [37] WSN nodes are shown as chromosomes and a few fitness parameters are defined considering the cluster distance and message transfer energy. Simulation results demonstrate that by using GA, as the number of alive nodes decreases, the energy consumption reduces. As the author put in, GAs successfully reduce the energy consumption for most of the times, a few cases of having a higher energy consumption is also possible due to the inherent of GA. In [38] the authors have proposed a GA-based approach to find a solution to the coverage problem in wireless sensor networks by activating only the necessary number of sensor nodes at any particular time instant which leads to saving the overall system energy. [39] considers GA for the selection of cluster head. In this work, nodes send whether they can be a candidate cluster head to a base station. The base station receives the messages from all nodes, and then it searches for an optimal probability of nodes which can be cluster heads exploiting GA by minimizing the total energy consumption.

A GA algorithm attempts to find the best solution from a set of candidate solutions. A chromosome or solution is composed of several genes or variables and is generated from a genetic mutation and corresponds to a potential solution [40]. By the word routers in the rest of the article, we mean all the mesh nodes except gateways. Our clustering algorithm is depicted in Algorithm 5.

Now we define the deletion criteria exploiting GA.

Chromosome Encoding: There are three common types of expressing individuals: encoding as a real number, an integer and a binary. In this paper, we use binary encoding

Algorithm 5 The Clustering Method

1: Connect all the MRs which can be connected to any IGW with a single hop.
2: Deletion criteria exploiting GA for the nodes connected to more than one IGW.
3: Connect the MRs which are not connected to any IGWs and can be connected to an IGW with two hops.
4: Repeat step 2.
5: Connect the MRs which are not connected to any IGWs and can be connected to an IGW with three hops.
6: Repeat step 2.

to denote a potential solution.

Population Initialization: The initial individuals are generated with P, which is a designated parameter, elements. Each individual is a K-dimensional vector where K is the number of gateways. In our work each path between two nodes is considered an individual or a possible solution.

Fitness Function: In this stage the chromosomes are given a fitness value. The deletion criteria of the path are prioritized as follows:

(A) A path in which the router can connect to another gateway with one hop and not to break the QoS constraints

(B) A path in which the router can connect to another gateway with two hops and not to break the QoS constraints

(C) A path in which the router can connect to another gateway with three hops and not to break the QoS constraints

This means the paths in (A) are given the lowest fitness and the paths in (C) are given the highest fitness to find the optimal solution.

Selection: In this operation, the individuals with better fitness have more chance to be selected for next generation population. We have used roulette-wheel selection for the selection of some of the rest individuals for the next generation. This means some paths are deleted using the information in the fitness function and the rest are selected for next generation.

Crossover: For the first run in our algorithm, which is connecting the MRs to gateways with a single hop, the crossover stage is not active since the length of all the chromosomes is one. However, for the second and the third run, which is connecting the routers to gateways respectively with two and three hops, selected chromosomes are combined in order to make better paths.

Mutation: In the mutation operation, we make some changes to single gene of the parent chromosomes in order to make better paths for next generation. Several individuals with low probability are selected and some of the bits in these selected individuals are flipped. Then these mutated individuals are updated to denote the valid solutions for the proposed clustering idea.

Replacement: If the new created paths, which are children chromosomes, are better solutions than the parent nodes, they are replaced with them and considered for next generation.

5. PERFORMANCE EVALUATION

In this section, a simulation-based analysis on our proposed method, GSCS, is performed. The performance of the proposed method is evaluated in terms of network throughput, network energy consumption and average delay in a randomly generated WMN. GSCS is compared to two methods in the literature which are weight-based GDTSP [21] and zero-degree algorithm [22], respectively.

To validate the proposed method we have conducted NS2. In the simulation, 50 mesh nodes are randomly generated. The position of mesh nodes are randomly chosen within a [500m, 500m] area.

Table II. Simulation Parameters

Parameter	Value
Terrain dimensions	500m x 500m
Protocol	IEEE 802.11
Packet size	50 bytes
Transmission range	100 m
Transmission power	2.0×10^{-8} W
Reception power	$2.0 \times \times 10^{-8}$ W
Number of nodes	50
Number of IGCs	5
Traffic demand	1 Mb/s- 5 Mb/s

We use IEEE 802.11 standard for our MAC protocol. All mesh nodes are given a coefficient in $[\alpha \quad \beta]$ and these values are set to 0.5 and 0.9, respectively. Among these nodes in the network some of them are selected as IGCs according to Algorithm 1. The length of the transmitted packets is 50 bytes. It is assumed that nodes are connected if the distance between them is less than 30 m. We have used Poisson distribution traffic model. Each MR is supposed to manage an amount of traffic demand between 1 to 5 Mb/s that is generated by the node itself and the connected nodes. All the mesh nodes consume a particular amount of power for transmitting and receiving a packet. The energy consumption level of a node at any time of the simulation can be obtained by finding the difference between the current energy value and the initial energy value. For the energy consumption optimization algorithm, we have decided to calculate the consumed energy of the nodes in the interference range of the IGCs after the 100-th iteration since the result is more stable. Simulation parameters are briefly shown in Table II.

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Moreover, in our simulation we use DSDV protocol for routing between nodes. Furthermore, in the fitness function section of the proposed GA, when some paths have the same situation, we have used the information about the position and reliability of the nodes provided by NS2 to choose the right path. Considering the QoS constraints defined, we set the values as R_{QoS}=3, C_{QoS}=4 and S=3.

To evaluate the effectiveness of GSCS three prospective schemes have been selected. We have evaluated the algorithms in terms of network throughput,by considering different data rates for the links i.e, 1, 2, 4 and 6 Mb/s, network energy consumption and average delay.

5.1. Evaluation in terms of Network Throughput

The average throughput of all the mesh nodes in the network is calculated and shown by network throughput as in 7. In our simulation, 3000 fix-sized packets with different data transmission rate are sent between source and destination nodes.

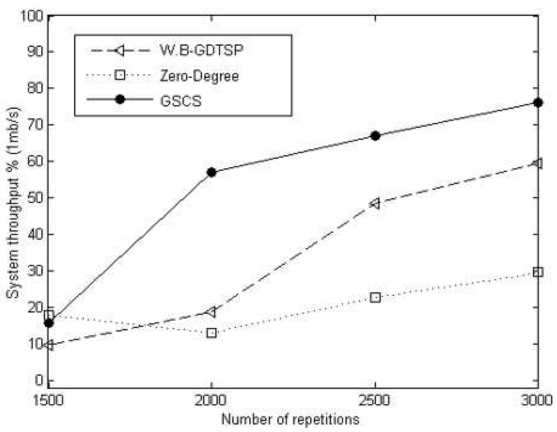

Figure 2. The comparison of Network Throughput 1 Mb/s

According to the result shown in Figure 2, when network data rate is 1 Mb/s after sending 1500 packets the throughput of the network in the three methods is nearly the same. However, when the number of repetitions increases the effectiveness of our proposed method in terms of network throughput is obvious.

The comparison of network throughput in different data rate of 2, 4, 6 Mb/s in different methods for 1500 repetitions is illustrated in Figure 3. As seen our proposed method has a better network throughput when the data rate is 2 Mb/s. Moreover, when the data rate is 4 Mb/s the effectiveness of our method is maximized and it is by far better than Zero-degree algorithm [22] and W.B-GDTSP [21]. Although traffic demand for each node in the network is in 1 Mb/s to 5 Mb/s range, when the link data rate goes up to 6 Mb/s our proposed scheme still has a better network throughput. When the data rate is 4 or 6 Mb/s nearly 75% of the packets have been successfully received and this is a great result for the proposed method.

Considering the reliability for selecting a node as gateway has a great impact on the throughput. Since the gateways are selected in areas with high number of paths to send a packet and, thus, in case of a link failure the packets are sent from an alternative link. Moreover, by giving the priority to the nodes closer to gateways when clustering the mesh nodes, packets are sent to the cluster heads with fewer hops. Furthermore, the defined constraints and the deletion criteria explained in the GA have a significant effect on the throughput.

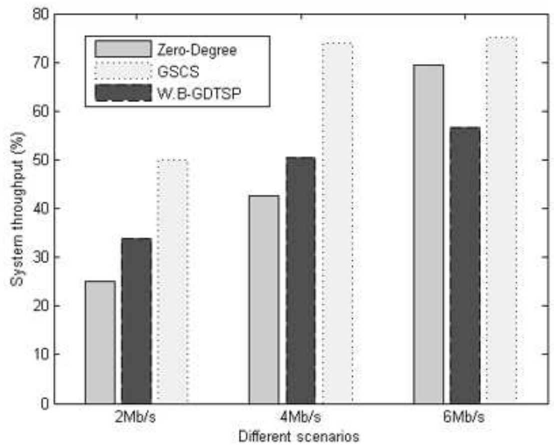

Figure 3. The comparison of Network Throughput 2, 4, 6 Mb/s

5.2. Evaluation in terms of Network Energy Consumption

The higher the computational complexity, the higher energy is consumed by the mesh nodes to transmit and receive packets.

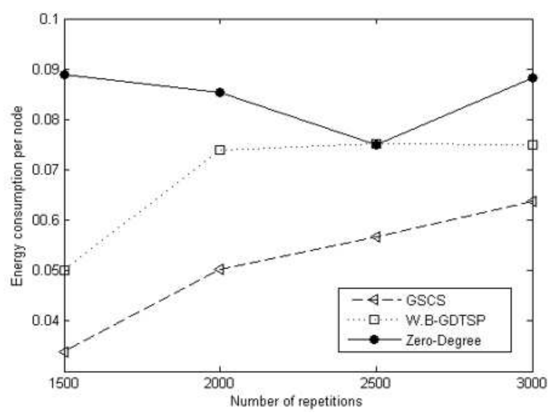

Figure 4. The comparison of Energy Consumption for a single node

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In Figure 4, the comparison of energy consumption for a single node in the three methods is illustrated. As illustrated in Figure 4, after sending 1500 packets in the network the energy consumption for a node in our method is less than 0.04 J which is less than W.B-GDTSP and by far less than Zero-degree algorithm. Even after transmitting 3000 packets the energy consumption in a single node in our method is less than the other works. This outperformance is due to the optimization of the energy consumption proposed in Section 4.

To show the effectiveness of this proposed algorithm, we take a close look at Figure 5 which is a comparison of the two other solutions along with the energy consumption of our method without considering the optimization.

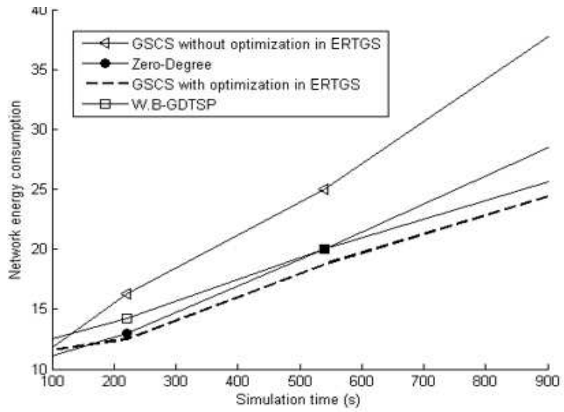

Figure 5. The comparison of Network Energy Consumption

As seen in the figure without considering the proposed optimization our method has the highest energy consumption and when we apply the optimization in the simulation, the result shows our method has the lowest network consumption. This demonstrates the usefulness of the proposed method and the role of the optimization in the performance of the network.

To compare the effectiveness of the optimization in the result, let us have a closer examination on the Figure 6. After sending 500 packets the network energy consumption without considering the optimization is 45 J while after conducting the optimization this factor is 35 J. As the number of repetitions raises the energy consumption for the proposed method without considering the optimization increases for nearly 40 J. However, when considering the optimization this factor goes up only for nearly 5 J. This shows the significant effect of the optimization on the final result of our proposed method.

Due to the optimization of the energy consumption which was proposed, the consumption of energy for each node in GSCS is less than the two other works. Energy consumption in the network was the worst without the optimization algorithm but considering this scheme the

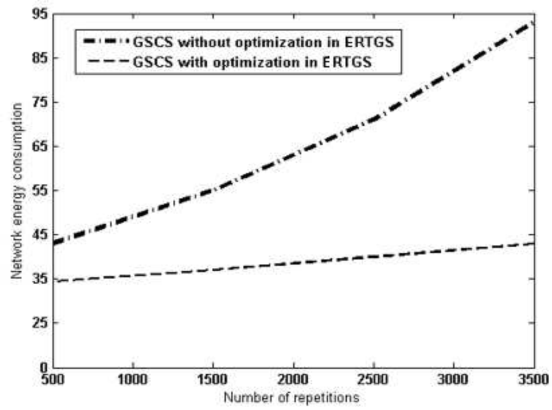

Figure 6. The comparison of Network Energy Consumption when considering the optimization

energy consumption is the lowest comparing to the two other works.

5.3. Evaluation in terms of Network Average Delay

The average delay time in our work is shown in Figure 7. The average delay time in the proposed scheme for 1500 to 3000 packets is approximately the same, which is nearly 0.6 s. This amount is higher than the two other algorithms. Computing the reliability between the IGCs and the repetition of the algorithm defined with GA, lead to a delay in the network. Although this delay is approximately 0.3 s more than the other works, the performance improvement in GSCS pays for the price for the delay.

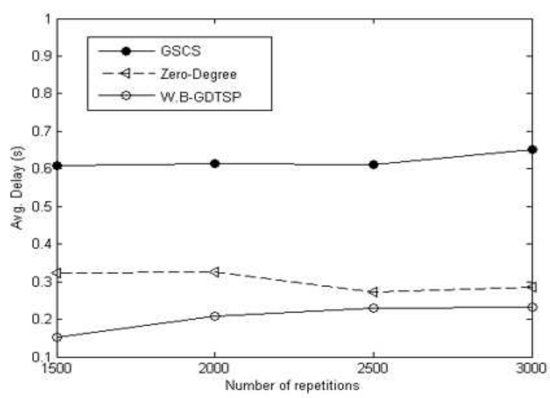

Figure 7. The comparison of Network Average Delay

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6. CONCLUDING REMARKS AND FUTURE WORKS

In this work, the focus was on gateway selection and clustering in a multi-interface WMN. Exploiting path tracing method and network traffic a gateway selection algorithm named ERTGS was developed. Some IGCs were selected according to network traffic and later calculating the reliability between the IGCs we have selected the nodes placed in areas with high number of paths or higher reliability to be the gateways. Moreover, to reduce network energy consumption, an optimization algorithm is proposed. The impact of this algorithm is clearly demonstrated in simulation results.

Later, a clustering scheme was proposed giving the priority to the nodes close to gateway to be in the same cluster. We have exploited GA to propose this novel idea. The simulation result illustrates that GSCS has a better throughput in different data rates and lower network energy consumption.

In the end, our work is more appropriate for small networks due to the amount of computation. However, energy consumption in our scheme was far lower than the other works. Besides, in our work network delay was more than the other works due to the clustering scheme. In our future research, we would like to improve our work to be used in extended networks and, also, we would like to reduce the delay in the network.

REFERENCES

1. Akyildiz IF, Wang X, Wang W. Wireless mesh networks: a survey. *Computer Networks* 2005; **47**:445–487.
2. Nader Tehrani M, Uysal M, Yanikomeroglu H. Device-to-device communication in 5G cellular networks: challenges, solutions, and future directions. *IEEE Communications Magazine* 2014; **52**:86–92.
3. Ashraf U, Abdellatif S, Juanole G. Gateway selection in backbone wireless mesh networks. *2009 IEEE Wireless Communications and Networking Conference*, Budapest, Hungary, 2009; 1–6.
4. Chung NG P, Liew SC. Throughput analysis of IEEE 802.11 multi-hop ad hoc networks. *IEEE/ACM Transactions on networking* 2007; **15**:309–322.
5. Bhatia R, Li L. Throughput optimization of wireless mesh networks with MIMO links. *IEEE INFOCOM 2007 - 26th IEEE International Conference on Computer Communications*, Anchorage, AK, USA, 2007; 2326–2330.
6. Bianchi G. Performance analysis of the IEEE 802.11 distributed coordination function. *IEEE Journal on Selected Areas in Communications* 2000; **18**:535–547.
7. Liu W, Nishiyama H, Kato N, Shimizu Y, Kumagai T. A novel gateway selection technique for throughput optimization in configurable wireless mesh networks. *Wireless Information Networks* 2013; **20**:195–203.
8. Boushaba M, Hafid A, Gendreau M. Source-based routing in wireless mesh networks. *IEEE Systems Journal* Mar 2016; **10**(1):262–270.
9. JGalvez J, MRuiz P, Skarmeta A. Responsive on-line gateway load balancing for wireless mesh networks. *Ad Hoc Neworks* 2011; **10**:46–61.
10. Jahanshahi M, Dehghan M, Meybodi MR. LAMR: Learning automata based multicast routing protocol in multi-channel multi-radio wireless mesh networks. *Applied Intelligence* 2013; **38**:58–77.
11. Lakshmanan S, Sivakumar R, Sundaresan K. Multi-gateway association in wireless mesh networks. *Ad Hoc Networks* 2009; **7**:622–637.
12. Gerstel O, Ramaswami R. Optical layer survivability - an implementation perspective. *IEEE Journal on Selected Areas in Communications* 2006; **18**:1885–1899.
13. Wong J, Jafari R, Potkonjak M. Gateway placement for latency and energy efficient data aggregation. *29th Annual IEEE International Conference on Local Computer Networks*, Tampa, FL, USA, 2004.
14. Huan X, Bang W, Mo Y, Yang L. Rechargeable router placement based on efficiency and fairness in green wireless mesh networks. *Computer Networks* 2015; **78**:83–94.
15. Wang B, Xiaoli H, Yang L, Yijun M. Hybrid placement of internet gateways and rechargeable routers with guaranteed QoS for green wireless mesh networks. *Mobile Networks and Applications* 2015; **20**:543–555.
16. Nasre S, Malathi P, Sharma M. Wireless mesh network deployed in disaster area using gateway selection. *International Journal of Research in Computer and Communication* 2015; **4**(6):405–409.
17. Aoun B, Boutaba R, Iraqi Y, Kenward G. Gateway placement optimization in wireless mesh networks with QoS constraints. *IEEE Journal on Selected Areas in Communications* 2006; **24**:2127–2136.
18. Li F, Wang Y, Li X, Nusairat A, Wu Y. Gateway placement for throughput optimization in wireless mesh networks. *Mobile Networks and Applications* 2008; **13**:198–211.
19. Chandra R, Qiu L, Jain K, Mahdian M. Optimizing the placement of Internet TAPs in wireless neighborhood networks. *Proceedings of the 12th IEEE International Conference on Network Protocols, 2004. ICNP 2004.*, 2004; 271–282.
20. Xin Q, Wang YJ. Gateway selection scheme for throughput optimization in multi-radio multi-channel wireless mesh networks. *2009 Fifth International Conference on Mobile Ad-hoc and Sensor Networks*, Wu Yi Mountain, Fujian, China, 2009; 187–195.
21. He B, Xie B, P Agrawal D. Optimizing deployment of internet gateway in wireless mesh networks. *Computer Communication* 2008; **31**:1259–1275.

22. Seyedazadegan M, Othman M, Mohd Ali B, Subramaniam S. Zero-degree algorithm for internet gateway placement in backbone wireless mesh networks. *Network and Computer Applications* 2013; **36**:1705–1723.
23. Tokito H, Sasabe M, Hasegawa G, Nakano H. Routing method for gateway load balancing in wireless mesh networks. *2009 Eighth International Conference on Networks*, Gosier, Guadeloupe, France, 2009; 127–132.
24. Huang CF, Lee HW, Tseng YC. A two-tier heterogeneous mobile ad hoc network architecture and its load-balance routing problem. *Mobile Networks and Applications* 2004; **9**:379–391.
25. Xie B, Yu Y, Kumar A, Agrawal DP. Load-balancing and inter-domain mobility for wireless mesh networks. *IEEE Globecom 2006*, San Francisco, CA, USA, 2006.
26. Acharjee T, Rajkonwar S, Roy S. An improved hierarchical cluster based routing approach for wireless mesh network. *2016 International Conference on Computer Communication and Informatics (ICCCI)*, Coimbatore, India, 2016.
27. Zhou A, Liu M, Li Z, Dutkiewicz E. Cross-layer design with optimal dynamic gateway selection for wireless mesh networks. *Computer Communications* 2015; **55**:69–79.
28. Shanthi V, Selvi M, Muniyasamy Alias Anand E. Cluster based hybrid routing to improve qos in wireless mesh network. *International Journal of Emerging Technologies in Computational and Applied Sciences* 2014; **2**:196–200.
29. Behravesh R, Jahanshahi M. Interference-aware and cluster based multicast routing in multi-radio multi-channel wireless mesh networks. *Journal of Computer and Robotics* 2017; **10**:21–30.
30. Gokbayrak K, Yildirim E. Exact and heuristic approaches based on noninterfering transmissions for joint gateway selection, time slot allocation, routing and power control for wireless mesh networks. *Computers and Operations Research* 2017; **81**:102–118.
31. Bouabdallah F, Bouabdallah N, Boutaba R. On balancing energy consumption in wireless sensor networks. *IEEE Transactions on Vehicular Technology* 2009; **58**:2909 – 2924.
32. Shukla S, Jayant S, Kumar A. Gbc-td: Gateway based congestion and traffic distribution model for load sharing in wmn. *Journal of Computer Engineering* 2014; **16**:67–72.
33. Jahanshahi M, Talebi Barmi A. Multicast routing protocols in wireless mesh networks: A survey. *Computing* 2014; **96**:1029–1057.
34. Galvez JJ, Ruiz PM, Skarmeta AF. Responsive on-line gateway load-balancing for wireless mesh networks. *Ad Hoc Networks* 2012; **10**(1):46 – 61.
35. Egeland G, Engelstad PE. The reliability and availability of wireless backhaul mesh networks. *2008 IEEE International Symposium on Wireless Communication Systems*, Reykjavik, Iceland, 2008; 178–183.
36. Azarfar A, Frigon J, Sanso B. Improving the reliability of wireless networks using cognitive radios. *IEEE Communications Surveys and Tutorials* 2012; **14**:338–354.
37. Hussain S, W Matin A, Islam O. Genetic algorithm for energy efficient clusters in wireless sensor networks. *Fourth International Conference on Information Technology (ITNG '07)*, Las Vegas, NV, USA, 2007; 147–154.
38. Jia J, Jian C, Chang G, Tan Z. Energy efficient coverage control in wireless sensor networks based on multi-objective genetic algorithm. *Computers and Mathematics with Applications* 2009; **57**:1756–1766.
39. Jenn Long L, Ravishankar CV. Leach-ga: Genetic algorithm-based energy-efficient adaptive clustering protocol for wireless sensor networks. *International Journal of Machine Learning and Computing* 2011; **1**:79–85.
40. Coley DA. *An Introduction to Genetic Algorithms for Scientists and Engineers*. NJ World Scientific Publishing Co. Pte. Ltd.: Singapore, 1999.