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Gateway Location Algorithm for Wireless Mesh Networks

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Abstract: Wireless mesh networks are expected to be a key technology for the next decades. Their ability for self-organization considerably decreases the complexity of the network deployment and their capability of self-healing reduces the network maintenance, therefore, claim minimal investment. In fact, connecting wireless mesh backbone networks to gateways are required and increase of more gateways improves the quality of service. However, due to the creation of wired links in gateways, adding redundant gateways increases the investment cost substantially. We therefore, designed a New gateway location algorithm based on graph theory by coupling the weighted recursive algorithm in order to deploy as less as possible number of gateways by assigning mesh routers having the highest degree as candidate gateways and eventually ensuring the quality of service in terms of throughput capacity, end-to-end delay and relay load constraint are at a reduced cost. It is demonstrated by MATLAB Simulator that the proposed algorithm after comparison outperformed other heuristic algorithms in terms of number of gateways and the quality of service. The proposed algorithm produces 30% less gateways and improves gateway throughput capacity by 10%, reduces end-to-end delay by 20% and improves relay load by 10%.

Key words: Wireless mesh networks, gateways, quality of service, algorithm, mesh clients, mesh routers, optimization

INTRODUCTION

Wireless Mesh Networks (WMNs) are expected to be a key technology for the next decade (Akyildiz and Wang, 2005; Aoun *et al*., 2006). They bring a seamlessly connected world into reality with simplicity and low cost (Benyamina *et al*., 2008). They are therefore playing a key role within next generation internet (He *et al*., 2008). Their ability for self-organization considerably decreases the complexity of the network deployment and their capability of self-healing reduces the network maintenance costs (He *et al*., 2008; Eslami *et al*., 2014).

WMNs consist of Mesh Clients (MCs) and Mesh Routers (MRs) where MRs are devices which link two or more wireless mesh networks together and have some intelligence of routing table and algorithms for guiding traffic along chosen routes (Akyildiz and Wang, 2005). MCs are mobile devices such as laptops, desktops, smartphones, tablets, etc. WMNs can be integrated with other networks such as the internet, IEEE 802, sensor networks, cellular networks, etc. and this can be achieved through the GateWays (GWs) and bridging functions in the MRs (Pathak and Dutta, 2011). GateWay (GW) is a router which has direct access to the wired infrastructure/backbone internet of the MRs nodes on a wireless mesh network. It communicates with the wired infrastructure for information delivered over the World Wide Web (WWW), video, emails and audio (Benyamina *et al*., 2009). The gateways are usually more costly, both to install and maneuver, since, they have multiple interfaces (wired and wireless).

A GW location is the problem of finding an optimal strategy of locating the gateway node or multiples of gateway nodes in a wireless mesh network. A GW location strategy decides where GWs should be located and how many GWs are required (Waharte *et al*., 2009). In addition, finding proper locations and how many GWs to be designed in a WMN can optimize network topology and improve Quality of Service (QoS) (Komba *et al*., 2014). This is an open research problem that existing GW locating solutions have not adequately addressed (Riaz and Ali, 2011). This study explores a newer method involving an intergrated graph theory and weighted recursive algorithm in order to optimize the GW location design for the WMN. This study will refer to this new method as New Gateway Location Algorithm (NGLA) (Komba *et al*., 2014). The NGLA is an improvement of the previous work in which graph theory and weighted

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recursion are introduced to obtain a minimum spanning tree, minimum dominating set, minimum hops and shortest path. The NGLA developed minimizes the number of gateways resulting in lower cost of the GWs deployment while satisfying end-to-end delay, relay load and gateway throughput capacity. Graph theory is introduced at the layers 2 and 3 of the network protocol layers to execute the link creation, packet routing and clustering. The key contribution of this study is the development of a novel strategy merging graph theory and weighted recursive algorithm known as NGLA for gateways location in WMNs the developed NGLA improves the QoS in terms of end-to-end delay, relay and network throughput.

Leterature review: In the recent past, researchers have started to design wireless mesh backbone network and planned the gateway location (Benyamina *et al*., 2009). Gateways location in wireless mesh backbone networks is the key in settling the network and improving the network throughput capacity (Drabu and Peyravi, 2008). This problem has been formulated by researchers using graph theory and various algorithms (Riaz and Ali, 2011). The gateway location from a given wireless mesh network remains a difficult problem or complex issue. Several problems are entangling such as deployment cost, link capacity, etc. Nevertheless, we have discovered that fewer approaches on these themes exist. None of the researcher studied all of these problems all together and only few use graph theory. The graph theory and the augmenting algorithm was proposed by Chandra *et al*. (2004) to minimize the number of gateways while satisfying the mesh clients bandwidth constraint and fault tolerance assurance. The used peak load base location to optimize constraint of the house at time, assigns more flow to a house than its request methods for workload difference and fault tolerance, respectively. The ideal connection model and general connection model are taken into consideration. For the ideal connection model, it is program's function to locate gateway in wireless mesh network and this algorithm considers only one constraint, which is to mesh client's throughput constraints. However, in the study, we also used the graph theory for location of gateway and our proposed scheme considers all QoS to be optimized simultaneously. The graph theory and Iterative algorithm cluster based selection proposed by Bejerano (2004) performs the gateway location problem in four stages; select the cluster heads, assign each node to an identified cluster satisfying delay constraint, he breaks down the clusters that do not satisfy the relay load constraint or the gateway throughput capacity and eventually the gateways are selected to minimize the maximum relay load. However, the iterative algorithm does not have competitive performance because of the following two reasons: first, when identifying cluster heads, assign mesh routers to the identified cluster heads and this algorithm does not make use of global information about the wireless mesh backbone network. Secondly, splitting a cluster without taking into account re-assigning those mesh routers to existing clusters may create some unnecessary clusters and therefore, increases the number of clusters significantly. The Bejerano's algorithm is similar to the new gateway location algorithm by identifying the cluster head and by assigning mesh routers to the identified cluster heads. However, Bejerano's algorithm failed to re-assign those mesh routers to existing clusters which lead to create unnecessary clusters and therefore, increase the number of clusters that increase the number of gateways and result into increase in the investment cost. The new gateway location algorithm re-assign those mesh routers to existing clusters. The weighted recursive algorithm proposed by Aoun *et al*. (2006) minimized the number of gateways and at the same time gratified the QoS demands. In this scheme, first a one-hop dominating set of novel graph is desirously discovered and this solution is used as the contribution of the following recursion. The one hop dominating set signifies that each node is linked to a cluster head undeviatingly. The desirously dominating set looking for process continues until the cluster radius is achieved. This algorithm is close to the new gateway location algorithm (Komba *et al*., 2014) as it finds the dominating set by applying the graph theory for locating gateways in wireless mesh networks. However, in our study, we strongly consider minimizing the hop from mesh router to the gateway and we also care about the location of gateway. Two approaches are developed by Prasad and Wu (2006) to select the optimal number of gateways and determine the location of gateways.

Given a network with mesh routers, the gateways selection approach determines the proper location for a gateway. The first approach is based on Integer Linear Programming (ILP) Model to greedily select gateway from a set of possible options and calculates all possible solutions of gateway location in terms of establishment, investment cost and communication capacity among gateways and mesh routers. The second approach is an OPEN/CLOSE heuristic to find a sub-optimal solution. The heuristic scheme starts from any feasible solution and repeatedly decreases the investment cost by a certain percentage. If no more solution can be found, the current solution is requested to be the best approximation. Nevertheless, the computational complexity of this approach increases with the number of possible gateways which limits its effectiveness for a large wireless mesh network. This is carefully taken care of in this study. A graph theory and cluster based gateway algorithm is proposed by Benyamina *et al*. (2008). The algorithm ensures end-to-end delay and good network scalability. It divides the entire network into a set of clusters. In each cluster, a mesh router is appointed as the gateway to serve nodes in cluster. Gateway degree based tree algorithm is proposed by Imboden *et al*. (2012) to solve gateways location issue related to QoS. The researchers used graph theory for gateway location. However, the solution focused only on cost minimization rather than improving the performance. This is a drawback of this approach because one cannot improve throughput performance without increasing the gateway numbers. This automatically increases the investment cost and it therefore leads to a paradox with the assumption of decreasing the investment cost. Graph theory and multiple algorithms to obtain an optimal location for a single gateway in wireless mesh network were proposed by Xu *et al*. (2010). Their algorithm achieved a good performance in terms of throughput. However, this scheme can only be applied in network with a single gateway while most of the wireless mesh networks today utilize multiple gateways. Wireless mesh network as a graph theory tree was modeled by He *et al*. (2008). In this model, gateway is the tree root and all mesh routers are connected to the tree and the researchers formulated the gateway location as the problem of selecting multiples of trees. Then two heuristic algorithms have been developed: greedy dominating tree set partitioning and weighted based greedy dominating tree set partitioning for the optimal gateway location. Both algorithms try to partition primary network in several trees while considering the mesh router and gateway throughput capacity. The drawback of this approach is that it failed to consider the multiple paths that allow each mesh router in the tree to connect the gateway through multiple paths. Our approach is similar to this scheme by utilizing the same technique. However, the new gateway location algorithm (Komba *et al*., 2014) strongly considered the multiple path communication.

Internet Transit Access Points (ITAPs) was proposed by Qiu *et al*. (2004). The researchers developed algorithm for the gateway location problem based on neighborhood layouts, wireless link characteristics demands and client demands. However, their algorithms consider only one constraint that is throughput of clients demands. Grid-based gateway deployment method was proposed by Li *et al*. (2008). The researchers used cross-layer throughput optimization and linear program flow-throughput was utilized as an evaluation tool. The evaluation shows that, the scheme uses the existing resources effectively and the scheme achieves better than the random and fixed deployment schemes. Though, this proposed scheme performed better throughput and end-to-end delay because of deploying many gateways. In addition, this scheme did not take into account mesh router's number connected to the particular gateway, therefore, the balancing in mesh route's number per gateway has been overlooked. This scheme is similar to the new gateway location algorithm by achieving better throughput and end-to-end delay. However, this scheme increases the cost of equipment. In our scheme, we kept as small as possible the number of gateways and the proposed scheme considered the number of routers per gateway. Hsu *et al*. (2008) proposed two algorithms. Self-Constituted Gateway Algorithm (SCSA) and Predefined Gateway Set Algorithm (PGSA). SCSA and PGSA use genetic search algorithm to explore for viability configurations and exploit an adapted version of Dijkstra algorithm to find for paths with limited delays. In PGSA, one augments the number of gateways at first set to one, iteratively until a viable configuration is found. Although, in SCGA, the gateway's number is fixed dynamically, when required. The PSGA may gather but slowly to obtain a viable solution in a real-size network. A minimum number of gateways needed to support the traffic demand is found after iterations whereas, several iterations could be avoided if the information of ingress traffic demand is used to compute the initial value of g. In SCGA, the dynamicity of gateways location may lead to premature convergence of the search algorithm. Muthaiah and Rosenburg proposed many heuristics algorithms to get an optimal position for a single gateway in wireless mesh networks. Their algorithms can achieve good performance by attaining the optimum throughput. The proposed algorithm is similar to their algorithms as they both optimize throughput. Their algorithms can only be used in networks with a single gateway and the authors did not consider end-to-end delay and relay load constraints. However, the new gateway location algorithm can be used in networks with multiple gateways and end-to-end delay and relay load constraints are strongly considered in our approach. Hu and Verma (2011) have studied gateway location problem in wireless mesh networks using directional antenna. The researchers proposed a heuristic gateway location algorithm to minimize the number of gateways and the total number of hop count between mesh routers and gateways. Here, the gateway location problem addressed is quite different because of directional antennas. Their proposed algorithm functions as follow: the highest degree is selected as a gateway. A minimum distance is set to assure that the gateways are kept apart from each other. And then the minimum number of gateways is set. This algorithm is similar to the proposed algorithm as both algorithms used the same method which is to select node with the highest degree as a gateway. Li and Xie (2013) proposed graph theory and a two-phase heuristic algorithm to find the optimal GWs in wireless mesh network and their locations. The algorithm greedily rejects the candidate nodes that do not cause the uncovered hole by testing all the nodes. The remaining candidate node set, called coverage set can guaranty the network coverage but not the connectivity. In this scheme, some nodes still have no route to the GW. The nodes covered can connect to each other to form a cluster. Then the algorithm adopted and adds a merge technique to select minimal number candidate nodes and add these candidate nodes into clusters thus that clusters can merge together.

The mergence procedure took place only if the aggregated traffic of the resulting cluster will not disrupt the traffic demand constraint. Our proposed algorithm is similar to Haopeng algorithm as both elect a candidate note as a gateway using clustering technique to find an optimal location of gateways and minimize the number of gateways and optimize the network throughput and end-to-end delay. The drawback of this approach is that, they failed to consider the relay load constraint. However, our proposed scheme strongly considered the relay load constraint. Lin *et al*. (2016) presented adaptive router node placement with gateway positions and QoS constraints in dynamic wireless mesh networks. They investigated adaptive placement using swarm optimization approach and characterized mesh clients by Markov chain.

MATERIALS AND METHODS

Graph theory: Graph theory is the study of points and lines. In specific, it consists of the sets of points called vertices that can be linked by lines, called edges Barros *et al*. (2012). A wireless mesh network can be modelled by graphs, the nodes are vertices and the communication links are edges as shown in Fig. 1 and Table 1.

Graphs are categorized based on their difficulty, the edges allowed among any two vertices and whether or not directions (for example, up or down) are allocated to edges. Several rules result in specific properties which can be defined as theorems (Lin *et al*., 2016). Graph theory can be utilized in research such as networking, clustering, image segmentation, etc. (Drabu and Peyravi, 2008).

Problem of efficient packet routing, modeling an effective network topology, node density and link creation among nodes can be done applying graph theory. Graphs can be algebraically denoted as matrices and network can be automated by means of algorithms. Graph consists of trees with no cycles, a sub-graph of a graph G which has the same set of vertices of G. A minimum spanning tree of a weighted graph G in graph theory is the spanning tree of G whose edges sum to minimum weight. There can be more than one minimum spanning tree in a graph. Minimum spanning trees are useful in constructing network by describing the way to link a set of sites using the smallest total amount of wires/cables. Minimum spanning trees provide a reasonable way for clustering in space. Numerous varieties of minimum spanning problems are suggested for the sake of defining the issues on the topology control, constrained routing protocol design fault tolerant in wireless mesh networks (Li *et al*., 2008).

Table 1: Notations

Notations	Description
v	Node
i	The number of iterations
v	The MDS of the previous iterations
H_d	Delay
Lc	Reload load
Sc	Throughput capacity
y_i	Binary variable
x_i	Binary variable
$P_{i,j}^k$	Binary variable
$h_{i,j}$	The minimum number of hops between mesh route
E	A set of all links or edges

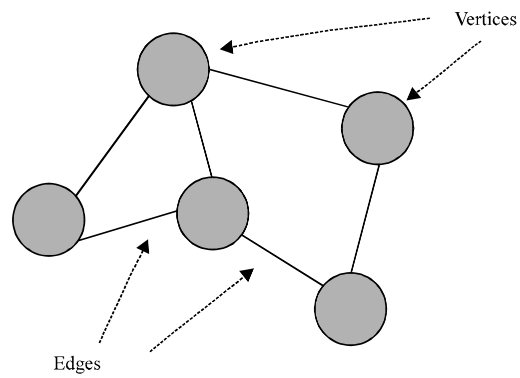

Fig. 1: A typical graph with 5 vertices and 6 edge

System design and architecture: We illustrated gateways location scenario in wireless mesh network in Fig. 2. In the proposed architecture, mesh routers are wirelessly connected in multi-hop fashions that form a wireless mesh backbone network. Mesh routers are provided with multiple interfaces which have capability to set up several non-overlapping channels with which mesh router can concurrently receive packets and transmit among others

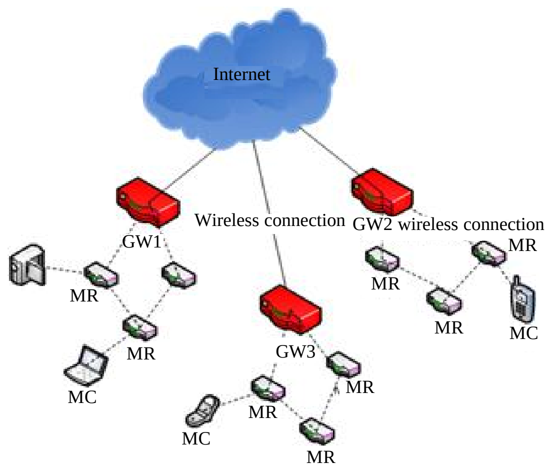

Fig. 2: A typical wireless mesh backbone network consisting of 3 gateways

to the nearby mesh routers. Wireless mesh network emphasizes on using multiple channels to increase throughput. Moreover, multi-hop wireless mesh networks provide long distance communication through intermediate nodes. In this architecture, we consider a simple wireless mesh network with 3 wired gateways. Each wired gateway constitutes a cluster with 3 mesh routers in each of the clusters. Each gateway in the proposed architecture is set up with wired connection and performs as a bridge between the wireless mesh backbone and the internet.

Integer linear programming formulation: We formulate the location problem as an Integer Linear Programming (ILP). The Minimum Dominating Set (MDS) solves problems related to the gateway location problem, since, the given problem is an NP-hard problem (He *et al*., 2008). Where N = V be the set of nodes or MRs and $G \subseteq V$ be the set of gateways. To indicate whether $i \in G$ is set up, we introduce a binary variable y_i . We define another variable $x_{i,j}$ to represent gateways allocation for MRs which takes the value of 1 whenever mesh router $j \in N$ is assigned to Gateway $i \in G$. Where i represents the number of iterations, the binary variable $h_{i,j}$ represents the minimum number of hops between mesh router $j \in N$ and gateway $i \in G$. The binary variable $p^k_{i,j}$, shows whether the route from i to j can pass through node k. The integer linear program searches the entire provided space to find the optimal results. Before starting the search, it has to stipulate the gateway and mesh routers hops upper bounds, total traffic, relay traffic which are delay constraint H_d, throughput capacity (cluster size) constraint S_c and relay load constraint L_c. We formulate the functions of our objectives as follows:

The first Eq. 1 signifies that a minimum number of nodes should be selected as the gateway between N = V nodes in order to have the minimum number of gateways and therefore fulfill the objective Eq. 1:

$$\min \sum_{i \in G_i} y_i \qquad (1)$$

The second Eq. 2 signifies that the entire number of gateways and mesh router hops is minimized as given by Eq. 2:

$$\min \sum_{i \in G_i} \sum_{j \in N} h_{i,j} x_{i,j} \qquad (2)$$

Subject to the Eq. 3 means that each mesh router is assigned to only one gateway as given by Eq. 3:

$$\forall j \in N : \sum_{i,j} = 1 \qquad (3)$$

Equation 4 denotes that a gateway needs to be set up before being assigned mesh routers Eq. 4:

$$\forall j \in N, i \in G : y_i \geq x_{i,j} \qquad (4)$$

Equation 5 guarantees that there is a path L_c between the assigned gateway and the router. This constraint signifies that a bounded cluster radius can be fashioned using Eq. 5:

$$\forall j \in N : \sum_{i \in G} h_{i,j} x_{i,j} \leq H_d \qquad (5)$$

Equation 6 and 7 offer an upper bound on the relay load and cluster size constraints as given by Eq. 6 and 7, respectively:

$$\forall i \in G : k \in N \sum_{j \in N} P^k_{i,j} \leq L_c \qquad (6)$$

$$\forall i \in G : \sum_{j \in N} x_{i,j} \leq S_c \qquad (7)$$

Eventually the Eq. 8-10 mean that y_i , $x_{i,j}$ and $p^k_{i,j}$ are binary variables Eq. 8-10

$$\forall i \in G : y_i \in \{0, 1\} \qquad (8)$$

$$\forall j \in N, i \in G : x_{i,j} \in \{0, 1\} \qquad (9)$$

$$\forall j \in N, k \in N, i \in G : p^k_{i,j} \in \{0, 1\} \qquad (10)$$

In order to minimize the number of gateways while satisfying the QoS mentioned in this study, we merged weighted recursive algorithm with graph theory. The aim here is to deploy fewer gateways in wireless mesh backbone networks, thus, leading to the low deployment cost and to the optimization of the QoS. In this study, graph represents a problem as a graph to make a problem much simple. Weighted recursive algorithm call itself with simple or small input values. The algorithm obtains the results for the initial input by using simple procedures to the returned value for simple input. Weighted recursive algorithm was invented to solve the shortest path problem and to find the locally optimal choice at each phase with the hope of finding a whole optimum. The algorithm consists of recursively computing minimum spanning trees and it works by recursively constructing a set of objects from the smallest possible constituent parts (Aoun *et al*., 2006).

However, weighted recursive algorithm can possibly optimize short-term solutions while it may lead to the worst possible long-term outcome and it can also find shortest path between two nodes. We adapted weighted recursive algorithm and added features (Algorithm 1).

The proposed algorithm consists of recursively computing Minimum Dominating Sets (MDS) at iteration graph. A MDS MDV^i is computed of the graph $G^{i-1} = (MDV^{i-1})$ which is a result from the previous iteration. In addition, the core algorithm comprises of recursive approximations of MDS which is the NP-hard (Lin *et al*., 2016). Since, the MDS is problem NP-hard, therefore, we rely on a greedy approach to find an approximation solution. In fact, a greedy approach consists of making a locally optimal choice at each phase with confidence of finding a total optimum (Aoun *et al*., 2006).

Algorithm 1; New gateway location algorithm:

```
Initialization
1. Adj= Adjacency_matrix (V, i)

2. U←V
3. C←[ ]
4. while U≠[ ]
5.    v = Greedy_selection (Adj)
6.    S' = vU Neighbors (v, Adj)
7.   Min_ SP_tree = build_tree (v, S', Adj)
8.  if Satisfy QoS Min_SP_tree, Lc, Sc
9.    C←Uv
10.     U←U-S'
11. Adj =_Adjacency_matrix (U, i)
12. else
13.  //limiting the neighbors of v in i G
14.  //such that S' does not occur again
15.   revise_adjacency_matrix (v, Adj)
16.     end
17. end
18. if Cluster_radius Hc (i+1)>Hc
19. return C
20. end
21. return recursive_MDS ( V, I, Hd, Lc, Sc)
```

The NGLA therefore, works as follows: the set U contains the set of residual uncovered nodes while the set C consists of the cover being created (i.e., the minimum dominating nodes):

- Line 5 represents the stage of the greedy execution. A node v is selected which covers as many uncovered nodes as possible
- Line 6 represents the result subset S' constituted of v as well as its neighbors. Afterwards v is chosen, the nodes belonging to S' are detached from U
- At line 7 we create minimum spanning tree
- At line 8 we verify if the constraints are fulfilled
- On lines 9 and 10, v is located in C When the algorithm stops, the set C holds the set of dominating nodes or highest decree at stage i
- From the lines 18-20 contains the recursive calls stopping criteria. If the cluster radius of the following iteration is greater than H_c, the set C is therefore, returned which contains the required gateways set

The gateways strategically located covers as many as uncovered mesh routers as possible. This minimized the number of gateways deployed and satisfied the QoS constraints.

The NGLA is a software-based solution. Thus, wireless mesh network would not have to purchase any new hardware equipment to implement the proposed system.

RESULTS AND DISCUSSION

To measure the impact of introducing graph theory into routing and weighted recursive algorithm for gateways selection on the performance of the proposed algorithm, experiment evaluations were provided. We used MATLAB Version R2013a 8.10.604 32 bits. MATLAB has been chosen, mainly because it can support integer linear program algorithms, allows matrix manipulation, it is easy to set-up, moderate to use, high scalability network, large scale networks, allow and can simulate IEEE 802.11s protocol. We assume 100 random nodes were deployed in the 100×100 m region (Fig. 3).

In this scenario, we considered that the nodes using multi-radio multi-channel and each node was assumed to be having at most 4 network interface cards or radios, separated non-overlapping unified channel graph, the 4 radios are located at each node, using IEEE 802.11 sec protocol. We set the speed to 512 bytes per second, the connection radius is 1 unit and the minimum distance between any pair of nodes is 0.5 cm. Every simulation run was executed long enough for the output statistics to

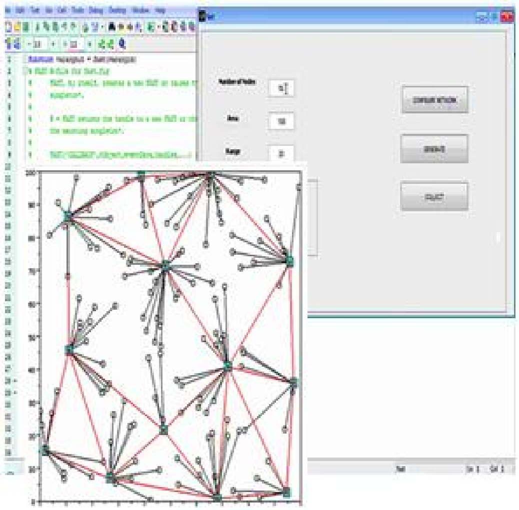

Fig. 3: The configuration parameters

maintain the same level and stabilize, 60 simulation times, the frequency was set to 2.27 GHz and the average results are eventually used as final experimental results. To record the result, Simulink sink blocks (scopes) were used to view the performance gains. Analyzed results were displayed graphically using x, y graph calls X graph, where we gave behavioral comparison to evaluate performance between the new gateway location algorithm, weighted recursive algorithms, iterative greedy algorithm and augmenting algorithm. Weighted recursive algorithm was chosen to solve the shortest path problem and find a destination efficiently. It does not support a shortest route with negative weight which leads to acyclic graphs and most often cannot find the correct shortest route. When weighted recursive algorithm is utilized in a network, the delay constraint is satisfied. Iterative algorithm is compared with the proposed algorithm. The idea behind this algorithm is to divide the problem into two different sub problems and solving each one individually. In the first sub problem, the algorithm pursues to minimize a number of separated clusters. In the second sub problem each cluster is divided into different sub clusters. We compared our algorithm to the Iterative algorithm because both utilize graph theory, clusters technique and reduced end-to-end delay. Augmenting algorithm is similar to the iterative algorithm by using graph theory, cluster technique and minimized the number of gateways. However, it does not consider making the greedy decision concerning the next location of additional gateway. Any given location succeeding coverage to uncovered node is considered. Therefore, our proposed algorithm considered the next location of additional gateway. However, our proposed algorithm used graph theory and it considers all QoS to be optimized, simultaneously.

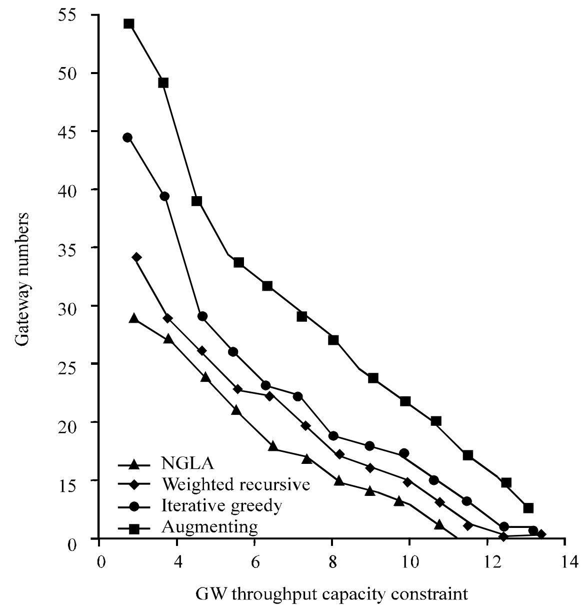

Fig. 4: Comparison of the impacts of the GW constraint on the performance of the four algorithms; Gateways number vs. GW throughput capacity for 200 nodes

Performance evaluation was conducted on the stated metrics such as throughput, end-to-end delay, relay load mostly because these metrics were the main ones that we needed to improve on. Thus, in order for us to perceive an improvement on these metrics, computer simulation has to be done.

We compared the performance of the NGLA with three algorithms, weighted recursive algorithm, iterative algorithm and augmenting algorithm. This was done to support evidence of performance enhancement when NGLA is used when wireless mesh networks decrease the number of gateways. Graph theory is utilized to minimize dominating set, appoints the node with the highest degree as a gateway in each of the clusters, minimize the number of hops which leads to minimize the deployment cost.

Effects of gateway throughput capacity: The effects of gateway throughput capacity on the performance results of the four algorithms are shown in Fig. 4. When the GW throughput capacity constraint varies from 1-14 while the end-to-end delay constraint is set at 10 and the relay load constraint is relaxed. Increasing GW throughput result in lower number of GWs. The performance of the NGLA is best among the four algorithms to that of the weighted recursive algorithm and it is better than that of the iterative algorithm and the augmenting algorithm when the GWs are close to each other. When the GWs are not close to each other, the performances of the weighted recursive

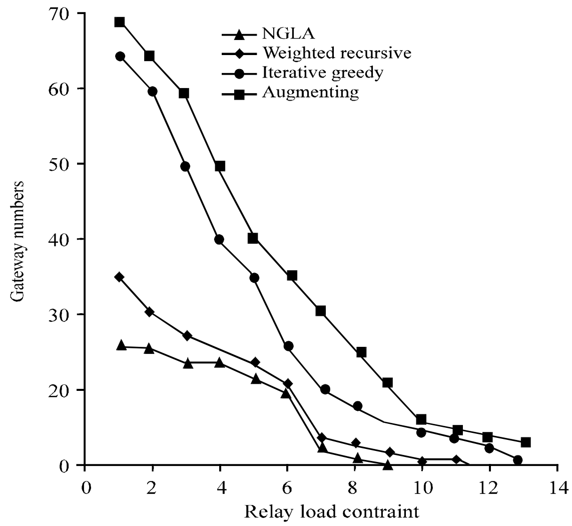

Fig. 5: Comparison of the effects of the hop capacity constraint on the four algorithms effects of end to end delay; Gateways number vs. relay load. Relay constraints for 200 nodes

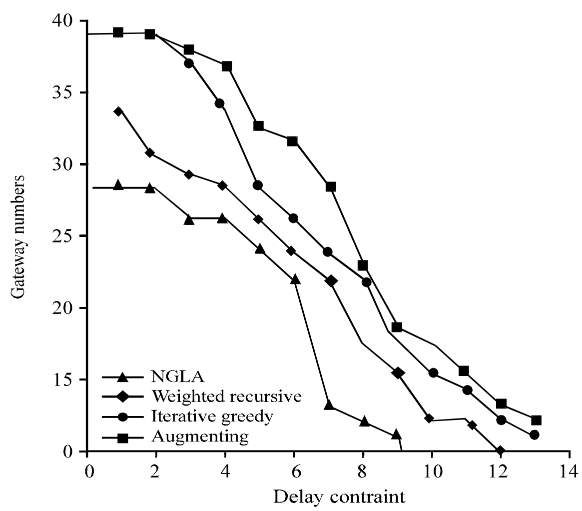

Fig. 6: Comparison of the effects of the constraint on the four algorithms; Gateways number vs. End-to-end delay. End-to-end delay constraint for 200 nodes

algorithm, the iterative algorithm and the augmenting algorithm are close to each other, thus, achieve a higher GW convergence cluster.

Effects of relay load constraint: The effects of relay load constraint on the performance results of the four algorithms are presented in Fig. 5. In this evaluation, the link throughput capacity constraint varies from 1-14, the GW throughput capacity constraint is relaxed and the delay constraint is fixed to 4. The evaluation results show that the performance of the NGLA is better than iterative algorithm and augmenting algorithm. It also outperforms the weighted recursive algorithm when the relay load constraint is 1. For instance, the iterative and augmenting algorithm place twice the number of GWs demanded by the NGLA when the relay load = 1. In overall, the performance of NGLA is as good as three algorithms.

The effects of delay constraint hop based on the four algorithm performance results are shown in Fig. 6. The GW throughput capacity and the relay load constraint are relaxed. Delay values vary from 1-14. The performance of the NGLA outperforms the three algorithms by deploying less GWs and by improving the delay.

CONCLUSION

In this study, we presented the design of New gateway location algorithm by merging graph theory and weighted recursive algorithm. The proposed algorithm minimized the GW throughput capacity for 200 nodes number of gateways and satisfied the throughput capacity constraint and delay load constraint which is associated to the number of hops a packet traversed by selecting a path with least link load. We introduced graph theory into link creation, packet routing and clustering in order to improve the performance of wireless mesh network. The weighted recursive algorithm alone cannot solve our multiple objectives. Therefore, we combined weighted recursive algorithm and graph theory. The simulation results for numerical example showed performance improvement in terms of number gateways deployed end-to end delay, gateway throughput capacity and relay load. A decrease by 30% of number of gateways, a reduction by 20% of end-to-end delay an increase by 10% of throughput capacity and an increase by 10% of relay load when compared to weighed recursive, iterative algorithm and augmenting algorithm. Future work will investigate the security of wireless mesh networks.

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