L-MODEL MANAGEMENT FOR WIRELESS MESH DEPLOYMENT

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Abstract- Wireless Mesh Network (WMN) has recently emerged as a cost-effective solution for the next generation of wireless networking. It has the potential to be widely deployed and widely used by Internet Service Providers (ISPs) worldwide. Unfortunately, current standards and protocols are severely inadequate to achieve the architectural design goals of wireless backbone multi-hop mesh networks because they do not meet evolving network performance and cost requirements. In this paper, a novel algorithm called "Zero-degree (L)" is proposed. Performance evaluation results using extensive simulations show that the proposed algorithm outperforms other algorithms by comparing the number of gateways needed in various scenarios.

I. INTRODUCTION

Wireless networks have become more popular [1] as the last hop technology over the last few decades for their flexibility. They are now, in the home, workplace, airports, university campuses, cafes and street corners as one of the most important access network technologies in the Internet today. People around the world commonly use many kinds of mobile devices such as laptop computers, smart phones, and tablets. Consequently, wireless access to the Internet has become an important demand. Base stations or Access Points (APs) have mainly provided wireless access to the Internet via a single wireless hop for cellular data or for wireless Local Area Network (LAN) access respectively. Fast growing demand for high-speed connectivity from network consumers due to the rapid development of wireless technologies in the last few years, have encouraged the use of WMNs. Wireless mesh architecture offers the potential of providing a high-bandwidth network over a large coverage area at low costs as compared to traditional access network. One of the WMN promises is to provide a cost-effective alternative of high-speed Internet connectivity to wireless users by replacing conventional expensive cables. There are some typical services such as voice, messaging, e-mail, information services (e.g. news, stocks, weather, travel, and sports), Internet fax, e-commerce, location-based services and health-care services, that WMN can support. In addition, WMN could also support those applications that require high bandwidth communications such as online data, video broadcasting, video conference, and other multimedia services [2]. "network capacity" is a performance key evaluation index for a wireless network. It represents the long time achievable data transmission rate that can be supported by a network [3]. The capacity of wireless network depends on many aspects of the network: network architecture, routing strategy and radio interference model, communication paradigm, transmission power and bandwidth constraints. Among all of these factors, network architecture should be addressed carefully because it is especially critical [4]. In order to maximize the network capacity and optimize the network performance, designing high bandwidth WMNs has been addressed in the past few years from different angles which include location of the Internet GateWays (IGWs) and the Wireless Mesh Routers (WMRs), the number of IGWs, the interface configuration and the channel assignment on each IGW and WMR.

II. PROBLEM STATEMENTS

Wireless mesh architecture design is a first step towards providing high-bandwidth Internet access over a specific coverage area. WMNs consist of MCs and WMRs, which relay each other's packets in a multi-hop fashion, and form the backbone of WMNs where mesh routers have minimal mobility. The design of Backbone WMN (BWMN) has a main issue which is the placement of WMRs and IGWs. With the intention to maximize the network capacity by appropriately deploying IGWs, this research will answer the following problems in WMN: *(i)* In a WMN, which kind of architecture should the IGW and WMRs be organized? *(ii)* How many IGWs should be deployed? *(iii)* Where these IGWs should be placed? *(iv)* How many and which WMRs should be served by which IGW? One of the main focuses of this research is to propose an architecture design model that provides maximum network capacity while minimizing the investment cost. In order to model or formulate the problem, a BWMN considered as a multi-channel, multi-hop, and infrastructure-based wireless network, which is represented by an undirected graph G(V,E), called connectivity graph. V = {v1, v2, . . . , vn} is a set of n network nodes where each node v ∈ V representsa wireless mesh router or IGW with a circular transmission range (radius) ri. Thus, the IGW placement problem is given as a network with n WMRs, to select a set of m nodes IGW = {igw1, igw2, ・ ・ ・, igwm} and igwi ∈ V , to serve as IGWs with which the WMN can satisfy the Internet traffic demand for each WMR (i.e., Tl(vi)) where Tl(v) (local traffic) is generated traffic from its own mesh clients in its servicing area. Apart from that, placing the IGWs in the locations that are closest to available wired network or Internet connection points should be taking into account as a constraint.

III. RELATED WORKS

In the few past years, some researchers have begun to design BWMNs and studied the IGW placement problem. They formulated this problem using linear programming and solved it using different heuristic algorithms because of NPhard specification of such a problem. Clustering technique is widely used for facility location, location management, and routing in wireless networks. It can be applicable in IGW placement problem, too. Bejerano [5] was the first researcher who started to develop the way of wireless mesh network design using clustering technique. He divided all the wireless network nodes into clusters and for each cluster, a node is selected as an access point. Bejerano breaks the problem into two sub-problems: (*i*) finding the minimal number of disjoint connected clusters that contain all the nodes, and satisfying the Delay constraint; (*ii*) dividing the clusters that iolate the cluster size constraint. However, splitting a cluster without considering re-assigning those wireless mesh routers to existing clusters may create some unnecessary clusters and therefore increase significantly the number of clusters. Bassam [6] tried to minimize the disadvantages of Bejerano's technique by combining the two sub-problems, where the spanning tree and cluster coverage evolve in parallel subject to satisfy the QoS constraints. This algorithm has two drawbacks: first, it can only be used for those BWMNs that form a connected component; second, it needs to set the initial radius size properly in order to create satisfactory results. Another algorithm to be used for the BWMNs, that does not form a connected component, is presented by Maolin Tang [7]. The name of the algorithm is incremental clustering, which is an iterative algorithm. Unlike our proposed algorithm in this paper, in incremental clustering algorithm, R-step transitive closure should be built in every teration and only the last step of transitive closure will be used for IGW selection. Using last step of transitive losure in order to select the IGWs may produce some nodes with zero connection due to unseen condition of network in middle steps of transitive closure. Therefore, those nodes with zero connection should be selected as IGW in the next iterations and consequently, number of IGWs will be increased. In [4] two architectures are considered: tree-based and cluster-based. In tree-based, He proposed two algorithms based on Greedy Dominating Tree Set Partitioning (GDTSP), which is degree-based GDTSP and weight-based GDTSP. Both algorithms aim to minimize the number of IGWs as well as reduce IGW-WMR hops. Similar to [7], this approach uses the last step of R-step transitive closure and does not consider the IGWs location controlling. Having reviewed the previous studies on IGW placement problem, we discovered a reason for the unnecessary placement of IGWs, that is, zero degree nodes or those WMRs with no connection to other nodes in the network. The proposed solution should prevent producing nodes with zero connections. The other problem realized is that no attention has been paid to controlling the IGWs location. In restricted geographical areas that IGWs should be placed in the locations that are closest to available wired network/Internet connection points, controlled distribution of IGWs is an important issue. Therefore, we introduce a new unique factor as an objective parameter called "IGW-IGW hop". This factor is for the purpose of comparing the location of each IGW to other IGWs. One of the main advantage of the proposed Zero-Degree (L) algorithm is that predicting the condition of next iterations and having the chance to prevent producing zero-degree nodes in order to form feasible clusters satisfying all QoS constraints. Distribute the IGWs in the locations that are closest to available wired network/Internet connection points is added advantage of Zero- Degree (L) algorithm.

IV. L-MODEL ARCHITECTURE

L-Model architecture consists of the minimum number of IGWs far from each other. The L-Model architecture is suitable for a network with its Internet connection points sparsely located around the given network size such as rural environments. In this paper the focus is on L-model architecture and formulate the IGW placement in such a way that all IGWs are placed close to the Internet connection points and in longest distance as possible from each other. This means that, the proposed algorithm has control on determining the IGW positions for a given WMN. Based on the specific L-Model architecture, the objective presented here in the following way:

Maximizing the distance between IGWs: To determine the locations of m IGWs in the network that result in maximum distance from each other to meet the constraint requirements.

A.L-Model Linear Programming Formulation

The IGW placement problem is modelled as a CFLP issue with multiple optimization objectives and additional constraints in the linear program.

$$max\frac{1}{2}\sum_{i\in IGW}\sum_{j\in IGW} h_{igw(i)}^{igw(j)}\cdot I_i \Rightarrow WMR(v_i) = largest\ \partial N(v_{igw}) \quad (1)$$

In (1) if the largest degree of IGW's neighbor nodes is selected as the WMRs, the IGWs will be placed closer to the edges of plane or wired network connection points and sparsely located. " 1 2 " is used in (1) in order to remove the duplication of number of hops from igwi to igwj and igwj to igwi. The IGW placement problem is formulated as a MOLP. Heuristic approach is used in this research to solve the IGW placement problem.

B.Heuristic IGW Placement Approach

This section introduces an algorithm called **"Zero-Degree (L)"**. The graph G = (V,E) in this algorithm is divided into disjoint clusters and each cluster has a head-cluster which is IGW. The aim of the algorithm is (i) minimizing the number of clusters, and consequently, minimizing the number of IGWs, (ii) reducing the number of IGW-WMR hops, and accordingly, increasing the throughput performance of the network, and (iii) distributing the IGWs sparsely in the locations that are closest to available Internet connection points while satisfying the constraints.

1. System Initializing and Network Generating: First information collection, and then generating the adjacency matrix. In addition, node degree can be calculated using the adjacency matrix of the network graph. The node degree and adjacency matrix are used to select the IGWs in the following step.

2. L-Model IGW Selection: In L-Model IGW Selection algorithm, an IGW is selected from G = (V,E) based on node degree. In order to find an IGW in L-Model architecture, first, the largest-degree node in adjacency matrix should be found. Second, finding all other nodes with the same degree as largest-degree node, if there are any. Otherwise, the only largest-degree node will be the IGW. If there is more than one largest-degree node, the algorithm will look for second hop nodes in order to find nodes with only one connection link. Then, if there is the same situation for more than one node, it will look for a third hop for the same reason as the second hop and so on. For the first attempt, a node with largest nodedegree will be selected as an IGW, which is also connected to the largest number of single connection nodes, through single or multiple hop while satisfying all constraints such as QoS parameters. If there are still some nodes with the same situation, IGW will be the node which has the largest degree nodes among its neighbors. Node index will be used if two or more nodes have the same situation. After all, assigning the WMRs to the selected IGW is the next step, which is explained in the next section.

3. L-WMRs Assigning and Network Updating: A cluster is created by selecting a set of WMRs using L-WMRs assigning algorithm. Largest degree model is used to select the nodes that have highest connectivity links from one hop away nodes to DQoS hop away nodes. This model, guarantees two objectives *(i)* the closer neighboring WMRs to the IGW will be assigned before those which are far away. Thus, a minimum IGW-WMRhops objective will be met. *(ii)* the possibility of having the largest degree nodes around assigned IGW will be reduced,and next IGW will be assigned far from selected IGWs, which will be placed but not close to each other. After assigning WMRs to the IGW, assigned WMRs will be deleted from the adjacency matrix. Finally, after deleting the assigned WMRs, node degree will be updated for the next attempt. At the sametime, assigning procedure of any WMR to the IGW should satisfy the constraints imposed by cluster capacity and WMR traffic load.

4. Zero-Degree (L) Algorithm: Zero-Degree (L) algorithm solves the problem using node degree technique.

Algorithm 1 Zero-Degree (L) Algorithm

```
Input ← ⟨Adj_matrix, Delay, Relay, Capacity⟩
Output ← ⟨formed_clusters⟩
Calculate the node degree
while Adj_matrix ≠ ∅ do
    L − Model_IGW_Selection()  % Algorithm IV-B2
    L − WMR_Assigning()  % Algorithm IV-B3
    Delete IGW from Adj_matrix
end while
Plot the formed clusters
```

V. ZERO-DEGREE (L) ALGORITHM ANALYSIS

This section addresses the runtime and the approximation factor of Zero-Degree (L) algorithm. It is proved that Zero- Degree (L) algorithm has a polynomial time complexity.

Lemma 3: The Zero-Degree (L) IGW placement algorithm has a polynomial time complexity O(n2).
Proof: To prove this, first, look at Algorithm IV-B2. There are two FOR loops which have the complexity O(n2). Similarly, in Algorithm IV-B3 a FOR loop and IF condition are O(n2) complexed together. Finally, the time spent in Algorithm 1, which is the main algorithm, is Tn = T (n − C) + n2. C is a constant variable, which is deducted from the number of nodes in each iteration. Thus, the algorithm can be implemented to run in O(n2). _

VI. PERFORMANCE EVALUATION

In this section, a simulation-based analysis on proposed heuristic IGW placement algorithm (Zero-Degree (L)) is performed. The algorithm were evaluated by comparing it with four top algorithms for the gateway placement problem. This four top algorithms are Incremental proposed by Maolin [7] similar to the one proposed by He in [4], [8] in terms of the method they both use in their work (i.e., R-step transitive closure), Recursive algorithm proposed by Aoun et al. in [6], Iterative algorithm proposed by Bejerano in [5], and Augmenting algorithm similar to those proposed in [9] and [10].

A. Effects of Hop-Based Delay

This section evaluates the effects of delay constraint, which is hop-based, on the performance of five algorithms. The relay load and IGW capacity constrains are relaxed. Delay constraint value varies from 1 to 10. As shown in Fig. 1, the performances of the Zero-Degree (L) is better than the other four algorithms. For D = 4, 7, 9, and 10, Iterative algorithm places the same number of IGWs required by Zero-Degree (L) while Incremental algorithm places the same number of IGWs required by Zero-Degree (L) when D = 6 and 7. Recursive algorithm has the worst performance compared to others.

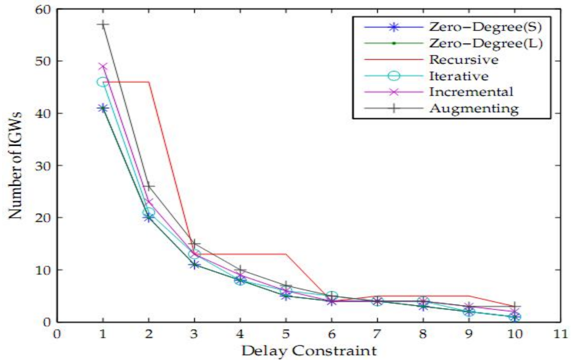

Fig. 1: Effects of delay constraint

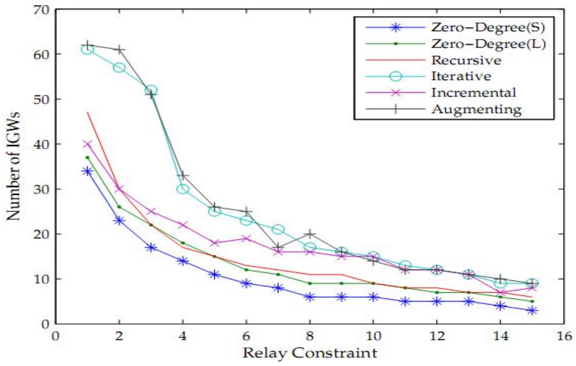

Fig. 2: Effects of relay constraint

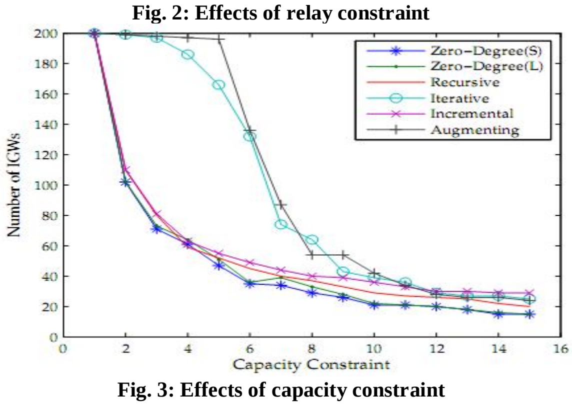

Fig. 3: Effects of capacity constraint

B. Effects of Relay Load

The effects of relay load constraint on the performance of five algorithms are evaluated in this section. In this evaluation, the relay constraint varies from 1 to 15, IGW capacity is relaxed, and the delay constraint is fixed at 8. Fig. 2 illustrates the results. The evaluation results show that Zero-Degree (L) is similar to Recursive but better than Iterative, Incremental, and Augmenting algorithms. The effect of relay load constraint is mainly pronounced when it is very limited. In addition, when R exceeds 10, the ratio number of required gateways by each algorithm remains constant.

C. Effects of Cluster Size

This section evaluates the IGW capacity constraint. The IGW capacity varies from 1 to 15, delay constraint set to 8, and relay constraint is relaxed. Fig. 3 shows that Zero- Degree (L) algorithm has better performance compared to other algorithms. The Iterative and Augmenting algorithms are heavily penalized when the cluster size constraint is strict. As C decreases, the number of required IGWs increases exponentially since each cluster is subdivided further as long as the cluster size constraint is violated [5].

CONCLUSION

A novel Zero-Degree (L) algorithm is proposed for clustering the BWMN based on WMRs degree (number of WMRs' connections), while ensuring delay, relay load and cluster size constraints. It was shown that the performance of proposed algorithm outperforms the other algorithms. It places less IGWs, and exhibits smooth and consistent performance when subject to various QoS constraints. One of the main advantages of the proposed Zero-Degree (L) algorithm is that it can predict the condition of next iterations and has the chance to prevent the production of zero-degree nodes in order to form feasible clusters satisfying all QoS constraints. Distribute the IGWs in the locations that are closest to available wired network or Internet connection points is an added advantage of Zero-Degree (L) algorithm.

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