A New Gateway Location Protocol for Mesh Networks

Giresse M. Komba, Okuthe P. Kogeda and T. Zuva

Abstract—**Wireless Mesh Network (WMN) is a promising technology that can provide broadband Internet access. Traffic often routed in Wireless Mesh Backbone (WMB). This also extended to the mesh clients and the Internet and forward to then to mesh gateways. Strategically providing efficient and supervising of WMN is a tedious task in connecting places gateway. In this paper, we provide a New Gateway Location Algorithm (NGLA) to address the challenges of gateway location in WMN. This algorithm incrementally identifies gateways, allocates mesh routers to recognize gateways and guarantees to find a feasible gateway location to satisfy the all Quality of Service (QoS) constraints. Simulation results of our proposed NGLA algorithm when compared with other algorithm outperform others with a large margin with 50% less gateway. Furthermore the NGLA is easy to implement thus, it can be employed for WMB.**

Index Terms—**Wireless Mesh Network, Gateway Location Protocol, Quality of Service.**

I. INTRODUCTION

WIRELESS Mesh Network (WMN) consists of mesh routers and mesh clients. The mesh routers are immobile nodes and form a multi-hop wireless mesh backbone between the mesh clients and the gateway straight linked to the wired network [1]. Every mesh router operates not only as a host but also as a router, transferring package of information on behalf of other nodes that may not be within direct wireless transmission range of their destinations.

WMN offers all the benefits of ad hoc wireless networks including several additional benefits from the architecture and rapidly deployed with minimal cost, efficient and flexible system that supports the network access for mesh clients [2]. The Gateway and bridge functionalities in mesh routers allow the WMNs integrations through several existing Wireless Networks such as cellular network, Wireless Sensor, Microwave Access (WiMAX), and Wireless-Fidelity (Wi-Fi) [3].

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Each of these benefices supplements WMNs as a promising wireless technology for numerous applications, such as, broadband home networking, enterprise networking, community, etc.

Several research problems still stay open in WMNs [4] Gateway location is a meaningful issue in the design of Wireless Mesh Backbone. It determines network points, or gateways, through which a Mesh Backbone communicates with other networks.

The aim is to minimize the entire number of gateways issue to QoS constraints. There are three common QoS constraints in the design of WMB: Gateways throughput constraint, delay constraint and relay constraint[5]. The throughput capacity of a WMB consequently hinges on the bandwidth and processing speed of the gateways. The delay is a function of the number of communication hops among the mesh router and its gateway. It is imperative to optimize the throughput for individual traffic flows [6] .

In this research, it is presumed that a Wireless Mesh Backbone has several communication channels, which allow interfering wireless links work on diverse communication channels simultaneously, the bottleneck on throughput is consequently reduced to the load on the link individual links between mesh routers as relay.

In this paper, we propose a novel algorithm, namely New Gateway Location Algorithm (NGLA) for the gateway location problem. Compared with existing algorithms for the gateway location problem, the novel algorithm has the following benefits: first, it guarantees to find a gateway location satisfying all the Qos constraints; second, it has competitive performance; third, it can be used for the Mesh Backbone.

The remaining of the paper is structured as follows: In Section I we present a background on the Wireless Mesh Network and some related works while in Section II the gateway location problem is formulated. We present clustering approach in Section III. We discuss our NGLA in Section IV. We discussed in Section VII an experimentation Comparison with existing algorithm

We present a demonstration of the NGLA in Section V. Simulation Results is provided in Section VI. Finally we draw Conclusion in the succeeding Section.

Gateway location protocol in Wireless Mesh Network has attracted various researchers with distinctive point of views.

Sanni [7] presents a gateway location problems for deployment cost and this algorithm increased to take into account delay, scalability and throughput constraint, and this algorithm claim two hops for sharing.

Vinh addressed [8] a WMN planning schemes where the placement of routers and gateways are fixed in advance. All this researches consider in a way or another minimization of a single objective based on the deployment cost. We stressed the fact that users reliability is not considered in [9] while QoS claims, such as delay, throughput and relay are not take into account in [10].

The Algorithm proposed by Zhang in [11] benefits of the clustering method and optimize the gateway placement issue in four stages: appoint each node and select cluster head to a recognize cluster optimization delay constraint, break down the clusters that do not gratify the coverage constraint or the gateway delay constraint, and select gateways to decrease the maximum coverage. However, the algorithm does not involve any competition of performance.

The work similar to ours is the algorithm suggested by Sanni [7], which transformers the gateway location problem into the minimum dominating set problem. The algorithm considers the throughput, delay, relay constraint and improves better than Vinh's algorithm, the Sanni's algorithm, and Zhang's algorithm. Nevertheless, it has the following deficiencies: first, it can be utilized for the WMB that form a connect component; second, it requests to set the initial radius size correctly; besides, it would not produce sufficient results.

II. NETWORK MODEL AND PROBLEM FORMULATION

Network Model: A mesh network is modelled by a directed graph $G = (V, E)$. Where $V = (a, b, r) \in V$ mesh router, where a and b are the a -coordinate and b-coordinate of the location of V and r is the radius of the circular transmission range of V. Arc $(v_i, v_j) \in E$ if and only if the mesh router v_i is in the transmission range of mesh router VI, or $\sqrt{(a_i - a_j)}^2 + \sqrt{(b_i - b_j)}^2 \le r_i$, where $v_i = (a_i, b_i, r_i)$ $v_j = (a_j, b_j, k_j)$ Note that $(v_i, v_j) \in E$ does not hint because the radiuses of their transmission range may be distinctive.

A mesh cluster is a set of vertices $C \subseteq V$. A mesh cluster has a cluster head $h \in C$. The nodes in C, the arcs between them explain a *cluster graph* $G_C = (C, E_C)$, where an arc $(v_i, v_j) \in E_C$ if and only if $v_i \in C$, $v_j \in C$, and $(v_i, v_j) \in E$. A mesh cluster is connected if and if only the corresponding cluster graph is connected. The delay constraint is translated into upper bound D on the mesh cluster radius.

The shortest path spanning tree is a Gc, T(Gc) spanning tree, which is made by composing the shortest path from the cluster heard h to all the other node in c. The nodes at i^{th} level of the shortest path spanning tree have i hops to the cluster head h. The depth of $T(G_C)$ is denoted $d(T(G_C))$. Let v be a node in $T(G_C)$. The number of nodes in the sub tree rooted v is denoted $\pi(v)$. Given a WMB represented by a directed graph $G = (V, E)$, a delay constraint D, a relay constraint S and a gateway throughput constraint Q, the WMB gateway location problem is to find a set of connected clusters $\{C_1, C_2, \ldots C_n\}$ and their corresponding clusters' shortest path spanning threes such as n is minimal subject (a) $C_1 \cup C_2 \cup \ldots \cup C_n = V$; (b) $|C_k| \le S$, where $1 \le k \le n$; (c) $d(C_k) \le R$, where $1 \le k \le n$; (d) $\forall v \in T(G_{C_k}), \pi(v) \le L$.

The shortest path three give a gateway location solution where the roots represent the mesh router where a gateway is located and the links specify the communication topology. Condition (a) guarantees that a WMB gateway location solution covers all mesh routers; Condition (b) ensures that the throughput constraint S is satisfied; Condition (c) enforces that the delay constraint D is met; Condition (d) makes sure that the Relay constraint S is respected.

III. NEW GATEWAY LOCATION ALGORITHM

The purpose of our clustering approach is to guarantee a maximum bound length for each mesh node capability path between any Mesh Node and its nearby Gateway. In this paper, the transitive closure of a directed graph G= (V, E) is a directed graph $G^+ = (V, E^+)$ such that for $\forall < u,v > \in E^+$ if and only if there exists a non-null path from u to v. The n-step transitive closure of a directed graph $G = (V, E)$ is a directed graph $G^n = (V, E^n)$ such that for $\forall (u,v) \in E^n$ if and only if there exists a non-null path from u to v and the length of the path is less than or equals to n. Figure 1 shows WMB graph. The transitive closure and the 2-step transitive closure are displayed in Fig. 2 and Fig. 3 respectively.

A WMB graph $G = (V, E)$ can be represented by $n \times n$ adjacency matrix $A = \lfloor a_{ij} \rfloor_{nXn}$ where

$$a_{ij} = \begin{cases} 1, if\ v_i, v_j \in V\ and < v_i, v_j > \in E \\ 0,\ otherwise \end{cases}; \qquad (1)$$

For example, WMB graph show in Equation 2. The adjacent matrix representations for its transitive closure and its 2-step transitive closure are displayed in Equation 3 and Equation 4 respectively.

$$Z_1 = \begin{pmatrix} 0\,1\,0\,0 \\ 0\,0\,1\,0 \\ 0\,0\,0\,1 \\ 0\,0\,0\,0 \end{pmatrix} \qquad (2)$$

$$Z_2 = \begin{pmatrix} 0\,1\,11 \\ 0\,0\,1\,1 \\ 0\,0\,0\,1 \\ 0\,0\,0\,0 \end{pmatrix} \qquad (3)$$

$$Z_3 = \begin{pmatrix} 0\,1\,1\,0 \\ 0\,0\,1\,1 \\ 0\,0\,0\,1 \\ 0\,0\,0\,0 \end{pmatrix} \quad (4)$$

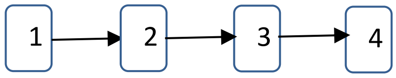

Fig 2. Graph G of MB

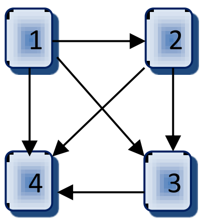

Fig. 3. Graph G's transitive closure

IV. DESCRIPTIONS OF THE ALGORITHMS

The New Gateway Location Algorithm (NGLA) resolves the gateway location problem by repetitively and incrementally recognizing gateways and appointing mesh routers to recognize gateways.

Algorithm 1 is the descriptive Algorithm.

Algorithm1 New Gateway location Algorithm

While $U \neq \phi$ **do**

Design a WMB graph from U;
Construct the R-step transitive closure;
Appoint mesh routers U to recognize gateways subject to the R, L and S constraint;
Delete the appointed mesh routers from U.
End while

U is the group of mesh routers in the algorithm 1: R, L and S illustrate the delay, relay and throughput constraint, respectively.

The NGLA begins with building a WMB graph in every iteration graph from the current not signed mesh routers to the recognized mesh router set U, design the R-step transitive closure of MB graph, recognizes gateways based on R-step transitive closure, and finally appoints mesh routers to the recognized gateways and removes the recognized mesh routers from U. This algorithm is incremental as it incrementally identifies gateways and appoints mesh routers to recognize gateways. The i^{th} mesh router is the head of the mesh cluster.

Algorithm 2 is the algorithm for recognizing or identifying gateway.

Algorithm 2 Location gateways

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for i =1 to $|U|$ **do**

if resembling mesh router cluster of the i^{th} row of the R-step transitive closure is discover mesh network
then
the mesh router cluster head is selected as a gateway;
end for
if no discover mesh cluster discovered then find a mesh router cluster has a maximum size; the head of the mesh router is selected as a gateway.
End if

Once gateways have been recognizing applying the technique depicted above, we appoint as many mesh routers as possible to those recognized gateway subjects to delay, relay and throughput constraints decrease the total number of gateways. Algorithm 3 is the algorithm appointing mesh routers to locate gateways.

Algorithm 3 Appointing mesh routers to Locate Gateways

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for each gateway g **do**
for h=0 to R **do**
for any mesh router that is covered by g the shortest distance to g is h **do**
if not transgressing any of the constraints
then
appoint the mesh router to g;
remove the mesh router from the gateways,
if any;
end if
end for

V. ALGORITHM DEMONSTRATION

This paragraph uses an example to demonstrate how the NGLA works. The WMB gateway location problem is provided in WMB graph shown in Figure 4. The coverage radiuses may have nine different mesh router R_8 .The coverage radius of mesh router R_8 can reach router R_9 , but R_9 cannot reached R_8 . Figure 5 is the matrix representation of the WMB graph shown in Figure 4. For this WMB gateway location problem, we suppose that the delay constraint R=2, the relay constraint L=2, the gateway throughput S=3, for this WMB gateway location problem.
A solution needs to be found such the optimum hop from whatever mesh router to its gateway must not surpass 2. Each mesh router must not relay packets for more than 2 mesh routers, and every gateway must not serve for more than

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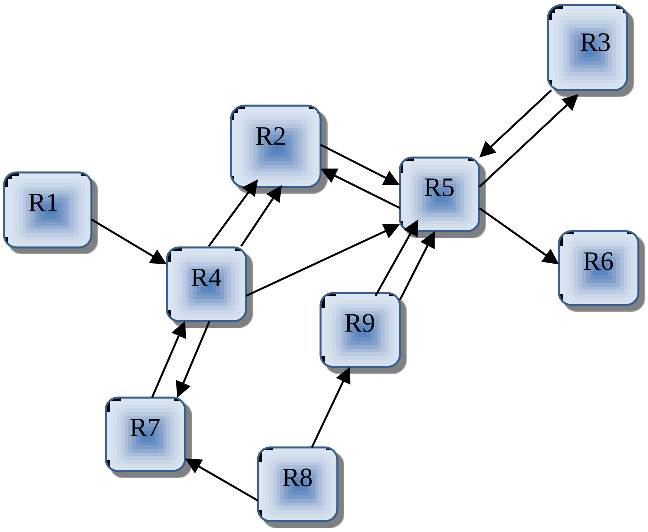

Fig. 4: Mesh backbone graph.

$$\begin{pmatrix} 0&0&0&1&0&0&0&0&0 \\ 0&0&0&1&1&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0 \\ 0&1&0&0&1&0&1&0&0 \\ 0&1&1&0&0&1&0&0&1 \\ 0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&1&0&1 \\ 0&0&0&0&1&0&0&0&0 \end{pmatrix}$$

Fig 5: WMB graph matrix representation

The 2 transitive closure of the WMB is found by the algorithm in the beginning. Figure 6 reveals the matrix representation of the 2-step transitive closure of the BB graph. Afterwards, the algorithm recognizes gateways using the technique described in Algorithm 2.

Since the mesh router clusters corresponding to 1th and the 8th rows of the 2-step transitive closure are the only uncovered mesh router clusters, R1 and R8 are recognized as gateways. The algorithm afterwards exploits the procedure depicted in A U to R1 and R8 as much as possible subject to R, L and S constrains. The appointing procedure starts with R1.

$$\begin{pmatrix} 1&1&0&1&1&0&1&0&0 \\ 0&1&1&1&1&1&1&0&1 \\ 0&0&1&0&0&0&0&0&0 \\ 0&1&1&1&1&0&1&0&1 \\ 0&1&1&1&1&1&0&0&1 \\ 0&0&0&0&0&0&0&0&0 \\ 0&1&0&1&1&0&1&0&0 \\ 0&0&1&1&0&0&1&1&1 \\ 0&1&1&0&1&1&0&0&1 \end{pmatrix}$$

Fig 6: WMB graph matrix representation of the 2 transitive closures.

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The WMB intermediate state considers all the mesh routers than covered by R1 according to the information given in the 2-step transitive closure in Figure 6 in the descending order of the hops numbers from the mesh router to R_1.

The result shows R_1, R_4 and R_2 are allocated to gateway R_1 in the order. The allocating procedure, then the same idea is used to allocate mesh routers to R_8, R_7 and R_9 to gateway R_8. The state has been shown in Figure 7 after this iteration of recognizing gateways and allocating mesh routers.

In the figure 7, the components drawn in broken lines symbolize the allocated mesh routers and the components drawn in solid lines symbolize the mesh routers that have not been allocated to any gateway, the algorithm reprises the above method. It generates a Wireless Mesh Backbone graph for the remaining mesh routers and then generates a 2-step transitive closure of the backbone wireless graph.

Figures 8 and 9 display the matrix illustration of the WMB and the 2-step transitive closure of the Wireless Mesh Backbone graph, respectively. From the 2-step transitive closure of the Wireless Mesh Backbone graph, the algorithm identifies gateways using the technique described in Algorithm 2.

Since the entire mesh router is covered ones, the mesh router that has the largest size, which is R_5, is selected as a gateway. The NGLA then allocates the rest mesh routers to gateway R_5. Figure 10 showed the final location result. As displayed in the figure, three gateways are required to be located.

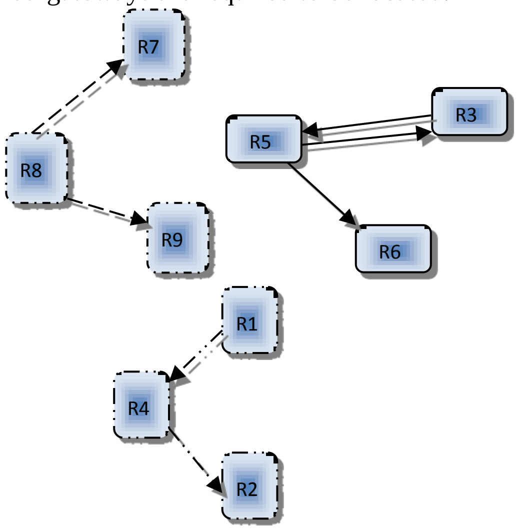

Fig. 7: WMB graph's intermediate state

$$\begin{pmatrix} 0&1&1 \\ 1&0&1 \\ 0&0&0 \end{pmatrix}$$

Fig. 8. Matrix of WMB graph

$$\begin{pmatrix} 1&1&1 \\ 1&1&1 \\ 0&0&0 \end{pmatrix}$$

Fig. 9. Matrix of 2 transitive WMB graph

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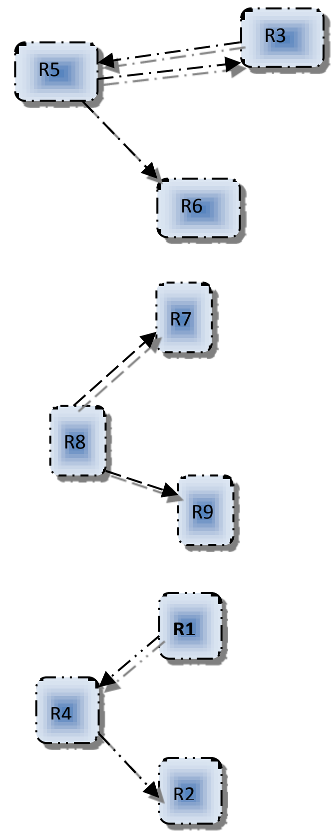

Fig. 10. The solution.

VI. SIMULATION RESULTS

The Simulation results of the NGLA performance by comparing it with three top algorithms for the gateway location problem has been evaluated in this Section. The three algorithms are the weighted recursive algorithm addressed by Sanni [7], the iterative greedy algorithm suggested by Vinh [8], and an augmenting algorithm similar to those proposed by Sanni [7] and by Zhang [11]. The performance of the four algorithms is evaluated and compared in terms of the delay constraint, the relay constraint, and the gateway throughput constraint respectively.

We designed a Matlab program randomly to create gateway location problems have 180 mesh routers on a 9x9 plane. 1.5 is the connecting radius, and 0.5 is the lowest distance between any pair of mesh routers. The program has been utilized to create 29 instances for every of the setups, and lastly the four algorithms have been utilized to resolve the gateway location problems. The algorithm performance has been evaluated by the 31 runs average number gateways for every of the set-ups in every of the evaluations.

The employment of the augmenting algorithm weighted recursive algorithm, the iterative greedy algorithm, and the utilized in the valuations is the ones used by Sanni [7].

However, the program developed in [7] is altered from the program utilized for randomly creating check problems. Given a parameter n, the test problem generator used in [8] randomly creates a test problem that contains up to n mesh routers.

VII. EXPERIMENTATION COMPARISON WITH EXISTING ALGORITHM

A. *Effects of Delay*

In this section, we appraise the impact of the delay constraint on the rendering of the four algorithms. The delay value constraint varies from 1 to 10. The appraisal result has been shown in Figure 11.

The figure 11 shows the performance of the NGLA that is similar to the iterative greedy algorithm and the augmenting algorithm; however it has improved than that of the weighted recursive algorithm under the delay constraints.

B. *Effects of Relay*

The effects of the relay constraint on the four algorithm performance are evaluated in this section. In this evaluation, the link capacity constraint is relaxed and the delay constraint is stabilized or fixed to 8. Figure 12 embellishes the evaluation results.

The evaluation result shows that the NGLA achieved much better than of the iterative greedy algorithm and the augmenting algorithm. The weighted recursive algorithm also outperforms when the relay constraint is 1 and when the relay constraint is greater than 8. But, it is not as good as that of the weighted recursive algorithm when the link throughput is between 2 and 8.

In general, the NGLA performance is as good as that of the weighted recursive algorithm, In general .Which is the highest between the existing gateway location algorithms, under the relay constraints.

C. *Effects of Throughput*

In this section Throughput Constraint's effect on the performance of the four algorithms are studied. The four algorithms are tested in this estimation. The relay constraint is relaxed when the throughput constraint varies from 1 to 16 and the delay is set to 7. Figure 13 shows the performance of the four algorithms in relation to the throughput constraint.

The figure displays that the performance of the weighted recursive algorithm is the best among the four algorithms.

The NGLA performance is similar to that of the weighted recursive algorithm, and it is better than that of the iterative algorithm and the augmenting algorithm when the throughput constraint is tight.

When the throughput constraint is relaxed, the performances of the recursive clustering, the assignment algorithm, the iterative greedy algorithm, and the augmenting algorithm are close.

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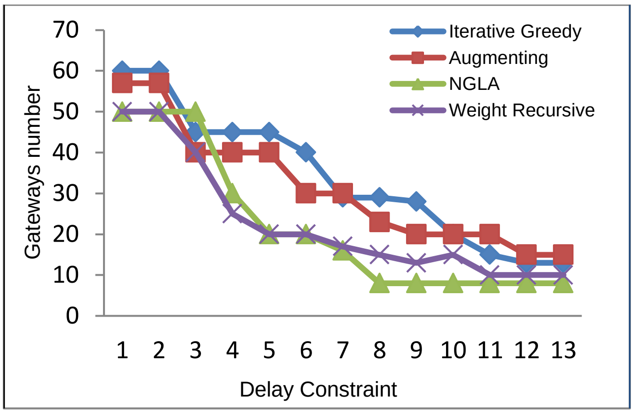

Fig. 11. The impacts of the hop constraint on the algorithms.

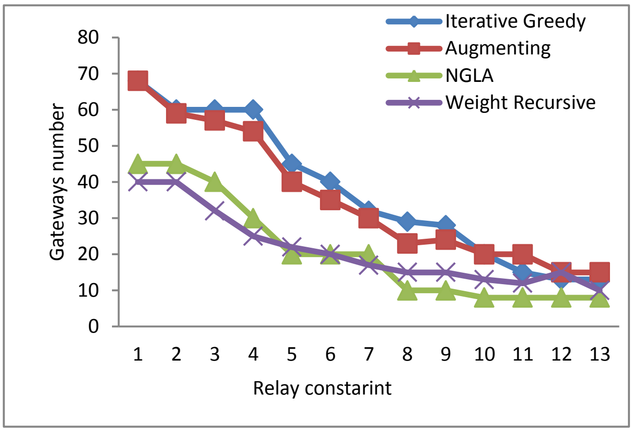

Fig 12. The impacts of the link capacity constraint on the four algorithm comparison.

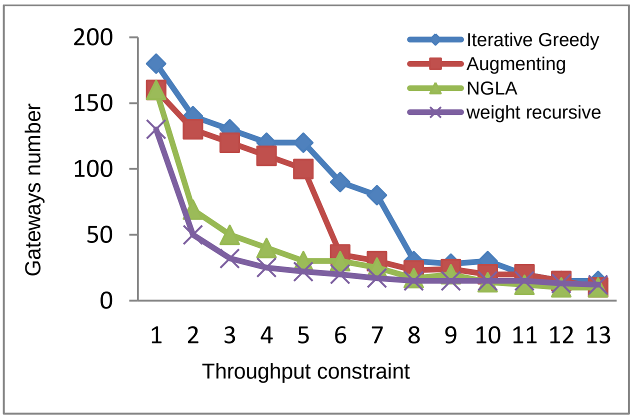

Fig 13. The impact of the Throughput Constraint on the performance of the algorithm.

VI. CONCLUSIONS & FUTURE WORK

This paper proposed a novel algorithm for the gateway location problem. Different from existing algorithms for the gateway location problem, the NGLA increasingly recognizes gateways and appoints remaining mesh routers to the recognized gateways. By increasingly recognizing gateways, the NGLA can fully explore mesh router assignment options, thus benefit to reduce in the number of gateways.

Simulation results have shown that in general the performance of the NGLA outperforms the best algorithm. Moreover, the NGLA has the following benefits:

first, it guarantees to find a gateway location sustaining all the QoS constraints; second, it has competitive performance; third, it is utilized in the WMB that does not form a linked component; fourth, it is easy to implement. The possible direction for future work is to take into account wireless interference would provide a better estimation of the capacity available for Mesh Routers to generate traffic.

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