Grenze International Journal of Engineering and Technology, Jan 2020

Systematic Review of Gateways Placement Methods in Wireless Networks

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***Abstract*—Internet of Things (IoT) allows devices to share and control data among each other as things are connected through the Internet. Communication among these devices which are part of Wireless Sensor Networks (WSNs) and the Internet is eased with the help of Internet Gateway which is termed as IoT gateway. To increase the performance of the network, the placement of the gateways should be optimal which will not only reduce the deployment cost but also increase throughput. To reduce congestion within the IoT network more than one Gateways are placed which will result in noise and increase the cost. Many different methods have been given by various researchers for placements of Gateways considering different parameters. Most of the researchers focused placement of internet gateway in the wireless mesh network. More research is needed in the IoT network where heterogeneous wireless technologies are used for machine to machine communication. It is challenging to deal with different wireless technologies along with gateway placement for network through maximization. This article presents comparative analysis of various approaches for gateway placement problem. The article concludes by articulating research gaps in the current approaches of gateway placement to achieve maximum throughput under various constraints.**

***Index Terms*— Internet of Things, Multiple gateways, IoT network, Gateway Placement Problem.**

I. INTRODUCTION

In the world of IoT technology, the number of connected devices is predicted to reach 50 billion by 2020 [1]. Devices can interface within a network with help of a various network interface such as Wi-Fi (802.11 a/b/n/g), ZigBee (802.16) or Bluetooth (802.15) and is embedded with suitable sensors and actuators. The IoT is thought as one of the third famous wave of latest evolving information technology after mobile communication network and the Internet, which have added characteristics of detailed sense and data measure, network interoperability and smart intelligence. These emerging technologies of smart IoT can efficiently ease the integration of smart products, services and controlling of these services, and also the physical world is merged into the world of digital. IoT application areas constitute disaster management, smart city areas, infrastructure construction, smart agriculture, public security, intelligent environment protection, smart industry, modern urbanization and smart business service [2]. This is possible because of the development of IoT technologies in the recent world.

Grenze ID: 01.GIJET.6.1.505

The concept of IoT was first proposed in 1999 by MIT Auto-ID, they investigated to recognize two main aspects of networking that is object localization & state recognition applying for WSNs and radio frequency identification technologies [3]. In 2005, 'ITU Internet Report 2005' was released by International Telecommunication Union (ITU) The report highlighted the concept of 'Internet of Things', which noted that ubiquitous Internet of Things communication era has emerged effectively, which stated that all objects in the network throughout the world can exchange information through the networks actively[4]. Again in 2009 "Smart-Planet" was introduced by IBM which focused to embed sensors in several physical objects such as railway, city malls, traffic areas, power grids, buildings, and intelligent processing technologies are used to act all these embedded objects as smart object [5]. As per the perspective of information technology in the world of wireless network, Internet of Things is termed as a large global information intelligence system which comprised of hundreds of millions of embedded objects that are meant for identification, sensing the various parameters & processing of collected data based on communication protocols in standardized and interoperable formats. The IoT system can process the state of an object, managed and controlled to achieve decision-making, and cooperation among all these objects autonomously without human's intervention with the support of broadband mobile communication, machine to machine communication, advanced networking and latest cloud computing technologies.

It is also considered as Internet connectivity into physical devices and everyday objects. IoT is comprised of embedded systems, wireless networks, wireless sensor networks, various control systems, automation, and many other fields. In a wireless network, data is transmitted from source node to destination node through various intermediate heterogeneous nodes (coordinating devices and intermediate gateways), termed as multi-hop communication heterogeneous networks. Multi-hop wireless networks comprised of nodes such as routers, coordinating device, gateways, and sensor networks. These intermediate nodes are mobile or stationary. They can access the internet through an internet gateway. All traffic is flowing towards the internet gateway. As the number of internet gateways is less, appropriate selection of gateway is needed to increase network performance in consideration with network throughput. Location of these gateways is also important to maintain network performance.

Apart from this, the performance of wireless networks is measured by many factors. In these heterogeneous wireless networks, communication link and network node are the main cause of failure. There exists the possibility that the communication link is disconnected and the power of the network node is deprived. Failure of link or node may decrease network performance.

The solution to this problem is proper placement of the gateway. In IoT scenario, wireless networks gateways are termed as Internet Gateway (IGW). Placement the IGWs in a proper way is challenging in the IoT network as it increases the overall cost. Most of the research focused on the placement of IGW with considering different parameters such as heterogeneity, traffic delay, load balancing, and fault tolerance. Apart from this research have not considered some significant parameters such as fairness and energy efficiency together and an investigation is needed for these parameters to increase network performance. Major concerns for this research are the number of IGWs along with placement. which leads to high deployment cost, a multi-hop count which causes the network delay, interference due to simultaneous transmission, static and dynamic load balancing and dropping of the packet. Reliability which has a great impact on the performance of the network also not studied in most research work.

For communication within the IoT network, all devices should be connected to the Internet. To get access to the internet, users need to be directly or indirectly linked to internet gateway through intermediate gateways. Appropriate internet gateway should be selected for having proper network coverage and communication capability. This problem of IGW selection which guarantee maximum throughput is to be investigated. This is an NP problem [4]. Areas where disaster happens at a higher rate, in such area when there is a need to recover the communication where some nodes are overloaded and some are underloaded. In such a scenario, the deployment of IGW at the center is not a feasible solution. Proper selection of IGW to guarantee maximum throughput in the network is a challenging problem [6]. Few authors concentrated on IGW selection to achieve effective routing within the network. In network, packets are transmitted from one node to another node. For efficient routing, next node selection is carried out by considering parameters such as load balancing, hop- count and delay. Most of the research articles on wireless networks have focused on multicasting, link scheduling, and channel assignment.

Lots of research articles have been conducted for gateway placement in the wireless network and wireless mesh network but more research needs to be done in gateway placement for IoT network. Gateway placement with load balancing, with interference with multiple routers and multiple clients in Wireless Mesh Network, are research topics in recent studies. Most of the research work considered these issues together.

Few authors have presented a solution on clustering and selection of IGW to achieve throughput, but some authors have considered separately causing a significant difference in obtaining overall network performance. We aim to focus on the research challenges of this emerging IoT technology for an efficient machine to machine communication in IoT network. In this paper, we focused on the analysis of different solutions in the literature and studied different approaches with their features and limitations. More investigation is carried out to understand better services for the users and studied parameters which will satisfy QoS requirements and throughput to achieve more network performance.

II. Literature Review On Gateway Placement

In the wireless network, the most challenging problem is the proper selection of gateways and placement of the gateway. In this section, Gateway Placement problem is reviewed considering various network parameters such as heterogeneity, energy consumption, traffic delay, resource constraints, overall network cost, throughput, quality of service, load balancing and fault tolerance. Most of the researchers have concentrated on wireless mesh network using homogeneous wireless technologies for the machine to machine communication but not considered IoT network using heterogeneous wireless technologies for communication. We aim to concentrate on IoT network gateway placement problem.

In [21], multiple objectives were proposed which is handled by linear programming to solve gateway placement problem. Algorithm for gateway selection is used in this approach which proposed to optimize the count of mesh routers which are directly attached to the gateway. This approach accomplished the goal of load balancing efficiently as compared to the others, but in their approach, the two criteria of the number of gateways and the number of hop counts are not taken into consideration. Authors in [22] proposed a model for a WMN which achieved the throughput optimization. Achieved throughput considered wireless nodes at fixed locations and logical dissemination of data flow. Besides, it focused on the configuration of the network to accomplish the maximum network throughput. In this paper, the optimization framework is studied which is used to achieve the throughput optimization and the network configuration is set. Authors investigated enumerative methods to obtain expected numerical results for various situations and also understanding of the network structure with different schedules, the optimal routes, and various parameters of the physical layer. This proposed model also able to achieve the optimal throughput in the equivalent scenario.

Authors proposed an approach of gateway problem to investigate the challenging problem in the wireless mesh network at each gateway which successfully achieved the goal of improving the performance of network [23]. Authors also stated the important concept that mesh routers in a network were distributed properly to assume it as nodes. Node with maximum throughput and good connectivity among these nodes were deployed as gateways. To choose gateway among all these nodes, authors have used tree-set partition (TSP) algorithm. In [24], the authors used the grid-based method for deployment of the gateway method along with throughput optimization for cross-layer method. Evaluation parameter used in this method is LP-Flow-Throughput. The evaluation method estimated the proposed method to exploit the available resources effectively. It performed better as compared to the existing fixed and random methods. As a greater number of gateways are used in this approach, hence this approach was able to achieve better optimal throughput, better coverage, and connectivity. But this approach has increased the overall network cost. As future research this approach not considered that specific gateway should control limited the number of routers in the wireless mesh network. The load balancing constraints for each gateway associated with mesh routers have not been considered.

Authors [25] proposed an algorithm to unfold the gateway placement problem with help of clustering technique using four steps: choose cluster heads, assignment of every node to existing cluster such that the delay constraint to be satisfied, drop the clusters that fail to satisfy constraints the gateway capability or the relay node. After that, the system chooses the best gateways to reduce the load on the relay was studied [26]. Clustering-based gateway Placement algorithm (CBGPA) studied in [27] guaranteed that end-to-end communication with a bounded delay which handled network measurability. This approach split the network into clusters with network constraints and is also disjoint. Among all these clusters, the gateway for every cluster is selected. The main task of this gateway is to provide service to all the nodes in the cluster. In [28-29] authors have used clustering-based techniques to achieve QoS requirements of wireless networks and obtain the optimal and efficient solutions for the problem of the gateway placement. Authors proposed heuristics algorithm for placement of gateway to achieving optimization, the proposed algorithm is compared its performance with previously investigated suboptimal solutions. In [29], proper placement of gateway is addressed to achieve QoS with the concept of placing of the optimal and minimum number of gateways.

QoS is achieved with the proposed algorithm termed as polynomial-time near-optimal algorithm. This proposed algorithm computed minimum weighted Dominating sets (DS). It is compared with different similar existing schemes in terms of important parameters such as the number of gateways to be placed within network and QoS. This approach concluded that it outperforms than other alternatives algorithms. Authors in [30] focused on gateway placement problem with load balancing and greedy algorithm, which invented techniques to partition the given WMN into load-balanced and independent clusters which are not connected sequentially. In this approach, every cluster in a network satisfied QoS requirements which are based on the proposed formula. The main principles of the genetic algorithm are injected into this approach. A hybrid algorithm is proposed to find the nearest optimal solution and performs better than other existing approaches.

In [31] authors solved the capacitated facility location problem (CFLP) using a clustering approach as a solution for gateway placement problem. In this approach, each gateway provides service to the cluster of its associated MRs. For message delivery, a spanning tree was used at the rooted gateway or cluster head. In this approach, algorithms involved two steps algorithm. First, i.e. the primary step was used to search a variety of disjoint clusters with a minimal variation which included nodes subjected to clusters' radius as an upper bound. In the last step of this approach spanning tree is determined in each cluster. This cluster is divided into sub-clusters. These clusters not considered relay node and constraints on cluster size. In [32], different clustering algorithms are proposed for measuring the performance of the network for gateway placement problem in WMNs are compared by considering the network topology of the network. In this paper, the authors investigated that throughput affects the quality of service of WMN. In [33] also, a throughput-based problem was studied. But the problem with these schemes failed to update step by step, here locations of gateways were invented sequentially. Particle Swarm Optimization (PSO) based method is proposed in [34]-[35] which studied the problem of gateway placement optimization which focused the throughput optimization in WMNs. They are updated step by step with the random and independent methodology. Stated methodology realized the best scheme and achieved a higher result as compared to previous methods. Apart from considering throughput and quality of service, constructing the computation model to calculate the turnout of WMNs is equally important, but it is difficult to achieve this approach. Several computation models [36]-[40] are studied, except approach studied in [40], are not appropriate for throughput optimization of WMNs. In [41], the authors proposed the load balancing issues in the mesh network. In this approach, the interference-free graph model is used to achieve load balancing as a central point outside the mesh NETWORK. In [42], an algorithm was implemented to calculate top load-balanced tree with the full balanced distributed approach using an interference-free model. Also, authors in [43] used the Hyacinth architecture for multi-radio multi-channel WMNs. Authors in [46] proposed a delay-optimal routing forest, which used the concept of selecting a root of a tree at every entree. The cost calculated wasn't load-dependent which fails to achieve considerable gains than shortest path routing in minimum balanced topologies.

III. Multiple Gateways Placement Problem in Wireless Network

In this section, we discussed the approaches that dealt with gateway placement problem in wireless networks. We investigated the research parameters studied to analyse the performance of the entire wireless network. Due to the complex structure and heterogeneity of the IoT network, effective deployment of network is the main focus. Hence, many conflicting research parameters or constraints such as heterogeneity, network connectivity, coverage, resource constraints, bandwidth allocation and location of gateways need to be analysed to develop energy-efficient IoT network. Hence, the focus is given on the placement of minimum and the optimal number of gateways within the network to increase the network performance. Various research parameters are observed while studying gateway placement algorithm. Detailed comparative analysis for different gateway placement approaches for the wireless networks is as follows,

From table 1 it is cleared that the existing solutions for gateway placement do not fulfil the requirements for an energy-efficient machine to machine communication in IoT network. Most of the research focused on increasing throughput of WMN, not heterogeneous network using diverse wired technologies. The main objective is the proper gateway placement for energy-efficient and cost-effective IoT system with maximum coverage.

TABLE I. COMPARATIVE ANALYSIS OF GATEWAY PLACEMENT ALGORITHM

Solution	Remarks	Algorithms Used	Research Gap
[9]	• Assumed nodes with no mobility. • No security aspects and load balancing are considered. • Assuming that every end device may have minimum one neighbour it can communicate directly.	Integrated Linear Programming Problem (ILP) Problem and low-end transmission device allocation problem	• Load balancing is not considered on the network since optimal installation cost is considered.
[10]	• Mesh routers and mesh clients using the same radio interface in local communications and mesh routers can receive packets from only one sender at a time and simultaneous transmission and receiving of packets is not allowed. The same constraint is applied to mesh clients. • In this section, TDMA schemes are applied for traffic scheduling. Based on these schemes, a framework for throughput computation in WMNs is designed. • Assumed that mesh clients are connected with router and it is located multiple hops from its associated gateway. • Channel capacity of mesh clients should be doubled otherwise improvements by gateway placement algorithms may not be observed.	Multi-Hop Traffic-Flow Weight Gateway Placement Algorithm (MTWP)	• Local Communication interference is not considered. • Both clients and routers cannot send and receive at the same time.
[11]	• Due to unfairness in wireless multi-hop communication, the mesh routers associated with gateways can get better QoS than mesh routers far from gateways. • In WMNs, to achieve optimal throughput, load balancing and QoS requirements, proper placement of gateways is important. If more gateways are placed, the better performance will be gained but the higher cost is imposed. • The main goal of this problem is the minimum-cost solution, not the minimum-number solution.	Weight matrix-based Limited Dominating set algorithm (WMB-LDS) and Genetic algorithm-LDS algorithm (GA-LDS)	• Focus is given on the design of WMNs, and there are still some other QoS elements not considered. It is proposed to consider a decentralized version of the algorithm.
[12]	• To improve throughput more gateways can be added and selecting appropriate locations of these gateways helped to optimize network topology and traffic distribution. But more gateways will increase the cost due to costly wired links used to connect gateways. • Gateway placement is an important aspect of WMN. Placement of a large number of gateways improved the throughput and reduced congestion resulting in increased interference and cost.	Load balanced Gateway placement algorithm	• Fault-tolerant is not considered and proper simulation model proved that the proposed algorithm is better than others.
[13]	• In this solution, network topology has mesh clients distributed on a square area associated with routers and gateways. This square area is partitioned into cells evenly and placement of mesh router at the center of each cell. Each cell is connected to at least one mesh router within the coverage. Direct communication is not possible with each other. • No interference between Local and backbone communications.	PSO Based MTWP algorithm	• Found that when the number of gateways increased, better throughput is not achieved. In the WMN design, the number of gateways suitably chosen to achieve maximum throughput of WMN and reduced the cost.
[14]	• Investigated optimal gateway placement with energy-minimization constraint for Wireless Network. • In this paper, authors contributed by developing a Mixed-Integer Linear Programming formulation which satisfied the data flow demands and minimized the global energy consumption within the network. • Proposed a heuristic-based greedy algorithm to efficiently solve large instances of the problem.	Energy-Aware Gateway Placement (EAGP)	Fairness is not considered for better network performance
[15]	• Studied gateway placement for cost minimization (GPCM) for WMN. • One of Mesh Router out of deployed Mesh Routers selected as a gateway to provide service to rest of the routers.	Centralized and Distributed GPCM (Gateway Placement Cost Minimization)	Optimal placement of the gateway is not concentrated because of connection cost. Still, more work on the assignment of each router to

	• In this solution, the Centralised and distributed algorithm is implemented with a constant approximation ratio.		different gateways is essential.
[16]	• It is based on Evolutionary algorithm to solve the optimization problem for placing gateways for maximum throughput in WMN. • Random Selection of location of gateway. Calculate fitness value and update it step by step with the best method to find the optimal value.	MTW (Multi-hop Traffic-flow weight) -BASED GATEWAY PLACEMENT with Evolutionary Algorithm	Optimizing gateway placement together with throughput maximization is not achieved.
[17]	• Heterogeneous network scenario where wireless sensors deliver data to intermediate gateways supporting diverse wireless technologies and are interconnected together. Each WSN is connected to at least one sink. • Integer Linear Programming (ILP) based optimization framework is developed to find the proper location of wireless gateways and minimizing the overall installation cost. Hence the energy consumption is minimized with multi-hop coverage between sensors and gateways in WMN. Also, connectivity among wireless gateways is focused.	Heuristic algorithms based on the continuous relaxation of ILP models.	The number of gateways is not taken into account while selecting the location of the gateway.
[18]	• Using the Genetic Algorithm (GA) to solve the Gateway Placement Problem (GPP) to achieve a near-optimal solution. To achieve this goal, the number of Internet gateways and multiple hops to traverse the packet from the IG to the source/ destination MR or MR gateway are considered. • Main Objective of this approach is to minimize the variation among the MRs in the whole network considering hop counts which indicated the traversal of the packets to the nearest IG (VAR-MR-IG-Hop) because MR is to be associated with a specific IG.	GPP using Genetic Algorithm	Considered only population size, tournament size, and crossover-type in GA.
[19]	• It determined the location of a gateway based on multi-hop traffic-flow weight (MTW) as a performance parameter. • The proposed gateway placement scheme provides a framework for the proper placement of the network to improve the throughput of WMNs.	Multi-hop Traffic-Flow Weight Gateway Placement (MTWP)	The proposed algorithm did not consider the cross-optimization between gateway placement and throughput of WMNs. Hence, the throughput achieved by MTWP is not necessarily optimal and can be lower than the max throughput.
[20]	• Studied the joint gateway placement, routing, and transmission slot allocation problem of wireless mesh networks. • Employed the k-opt local search heuristic to obtain more robust gateway sets. • Presented two alternative formulations for the IGP problem and proposed a set of valid inequalities.	Robust Gateway Placement	When selecting among alternative gateway sets to deliver forecasted traffic to the Internet in the shortest time is an alternative solution
[21]	• Studied how to place k gateways for a mesh network so that the total throughput achieved by interference-free scheduling is maximized. • Proposed a novel grid-based gateway deployment method using a cross-layer throughput optimization and proved that the achieved throughput by the proposed method is a constant time of the optimal.	Novel grid-based gateway deployment method using a cross-layer throughput optimization	Not considered multi-channel and multi-radio mesh networks under different interference models.
[22]	• Used the logarithm normal distribution model of shadow which affects in wireless communication to design a weighted objective function to guarantee node's connectivity and coverage, attained the deployment location of the candidate GW. • A heuristic TSP (tree-set partition) algorithm based on degree/weighted is used to get a good choice of nodes with high throughput.	Gateway Deployment Algorithm	Not Considered load balancing

IV. CONCLUSIONS

This article presented an exhaustive literature survey on gateway placement approaches. Several approaches are studied to achieve optimization to select the minimum number of gateways by considering various

network parameters such as heterogeneity, link failure, traffic demand, gateway failure, network throughput, link bandwidth, node capability, delay, congestion, etc. to achieve better network performance. In IoT scenario, it has become crucial to optimize the number of internet gateways, but the network throughput and overall network cost should not be avoided. In this paper, we have analysed several approaches by various researchers to evaluate various parameters needed for gateway placement and articulated research gaps in gateway placement methods. Most of the approaches focused on Wireless Mesh Networks. Only a few of them considered gateway placement in IoT network. Gateway selection and gateway placement in heterogeneous IoT network are not studied. One of the challenges of the research is to select proper gateway including intermediate nodes and proper placement of those gateways by considering load balancing, QoS and maximum network throughput to increase the overall network performance.

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