NQ-GPLS: N-Queen Inspired Gateway Placement and Learning Automata-based Gateway Selection in Wireless Mesh Network

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ABSTRACT

This paper discusses two issues with multi-channel multi-radio Wireless Mesh Networks (WMN): gateway placement and gateway selection. To address these issues, a method will be proposed that places gateways at strategic locations to avoid congestion and adaptively learns to select a more efficient gateway for each wireless router by using learning automata. This method, called the N-queen Inspired Gateway Placement and Learning Automata-based Selection (NQ-GPLS), considers multiple metrics such as loss ratio, throughput, load at the gateways and delay. Simulation results from NS-2 simulator demonstrate that NQ-GPLS can significantly improve the overall network performance compared to a standard WMN.

KEYWORDS

Wireless Mesh Networks; Gateway Placement; Gateway Selection; Learning Automata; Load Balancing.

1 INTRODUCTION

WMNs consist of mesh clients, wireless routers and gateways. Clients send their data to the stationary wireless routers, and then routers forward it to the gateways through multi-hop transmissions [2]. Gateways are routers with additional functionalities (such as a protocol translator) which are connected to outside networks by a wired infrastructure. They are integration points which can be easily configured to connect the WMN via wires to other networks. WMNs are typically used for internet access where most of the traffic goes through gateways. Because of this, gateways play a vital role in WMNs and may become potential network bottlenecks. There are many ways to improve the performance of a WMN, including: placing gateways in such a way to balance the traffic in the network, selecting the best gateway for each source router to communicate with and finding the best multi-hop route for each client to connect with the selected gateway.

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Gateway placement affects the way the load is distributed within the network and the overall communication cost. The distance between gateways should be chosen carefully. If they are placed too close together, interference can lower the network throughput. On the other hand, if the distance is too great, clients will require more intermediate hops to access the gateways resulting in higher transmission delay and negatively affecting the network performance. To address the gateway placement problem, we propose to formulate it as an N-queens puzzle. The N-queens puzzle places N queens on an N×N chessboard in such a way that no two queens share the same row, column, or diagonal, making it impossible the queens to attack each other. In this paper, we will represent gateways as queens and the network as the chessboard. Doing so will allow gateways to be properly placed in a simplistic manner. The gateway placement method is extendable to almost any number of gateways in the network. Also, our gateway selection method considers dynamic traffic demands instead of static demands. Many other gateway selection methods [3] assume that traffic demands are static, however this is typically not true in practice. Gateway placement can be considered as an optimization problem with different objectives. This includes: congestion, construction cost, interference and transmission delay. It is shown that solving this optimization problem is computationally hard to solve [4]. To have a solution in practice, heuristic and meta-heuristic approaches are proposed. Gateway placement solutions are categorized as fixed or unfixed [6]. The group of unfixed gateways has two different methods: clustered and non-clustered based placement.

Gateway selection has been shown it can be implemented in one of two ways: centralized and distributed. In centralized approaches [5,11], there exists a virtual node outside the network. This virtual node has the knowledge of the whole network topology and can make decisions centrally. It can assign every router a gateway considering different criteria. In distributed approaches [1], each router chooses the best gateway based on its selection and routing metrics. Distributed approaches must overcome several challenges, including communication overhead. Two advantages of using a distributed approach are scalability and redundancy. Reinforcement Learning-based Distributed Routing (RLBDR) is a distributed routing and gateway selection method for multi-channel multi-radio WMNs that uses a Q-learning algorithm to route traffic while considering several metrics [7]. Best Path to Best Gateway Scheme for Multichannel Multi-interface WMNs (BPBG) [8] is another technique for multi-channel multi-radio WMNs. In this scheme, both the available capacity of each gateway and the traffic distribution among the gateways are considered. Gateway selection has been formulated as an optimization problem for linear programming [9,10,14]. Some consider this problem in conjunction with other issues such as routing, power control, and transmission slot assignment. In [10], the objective is to maximize the minimum ratio of the allocated capacity to the demand of each node. The authors assume the physical interference model and the tree-based routing restriction for traffic flow. The primary deficiency of this formulation is the possibility that the set of noninterfering transmissions get exponentially large with increasing network sizes. Later, the authors of [9] address the previous problem of high memory consumption by proposing a three-stage heuristic method. In [14], the authors propose a mathematical formulation for both the incapacitated and capacitated joint gateway selection and routing. However, their method is not able to capture non-deterministic traffic demands.

2 DESCRIPTIONS OF THE PROPOSED METHOD

In the proposed NQ-GPLS method, gateways are placed according to N-queen algorithm using the layout with the highest throughput. Each router records the closest gateways (in its domain) in its routing table. When sending a frame, a source router selects a gateway in its routing table based on learning automata. If the selected gateway sends back a positive feedback, it is rewarded by learning automata and its probability of being selected in the future increases; otherwise, the selected action is penalized and the possibility of this gateway being chosen in the future decreases.

The routing technique used in the proposed method is aware of the network load, i.e., the frames do not pass through the congested nodes, and less crowded routes are selected. Thus, NQ-GPLS can monitor the network conditions and allow the source routers to choose the gateways adapting to the various conditions of the network.

2.1 Network model

WMNs are composed of fixed routers that use a set of gateways connected to wired infrastructure to exchange information. Mesh clients can access a WMN by connecting to any of the mesh routers. In the proposed gateway placement method, gateways are not placed at the edge of the WMN to improve the average client-gateway distance. Also, square-grid network topology is considered in this paper which has better performance compare to other types of grids [15]. Given Nr routers and Ng gateways, the square space is evenly divided into Nr+ Ng cells with a router or gateway within the center of each cell. In each cell, clients are connected to their router like star topology and they do not have direct communication to each other. Clients access the internet by using one or several links from their connected router to one of the gateway nodes.

2.2 Gateway placement optimization

While using the N-queen puzzle, consider the following: if we place a gateway at each of the cells selected for a queen, and a regular wireless router at each of the remaining cells, the gateways are at the proper distance apart; every router can reach a gateway with two intermediate hops, at most (less transmission delay); and reducing the number of hops that packets have to pass through also improves communication security. An example of applying the proposed gateway placement technique to a university campus using 8 gateways is illustrated in Figure 1. First, an imaginary chessboard is superimposed over the campus map. The proposed N-queen technique is then applied to determine the eight chessboard cells for the gateways. The remaining cells are deployed with regular wireless routers.

The N-queen technique has been used to determine the optimization of gateway placement based on throughput estimates. All distinct solutions to the N-queen puzzle have been have been calculated, with each corresponding to a possible gateway placement scheme. The network throughputs for these schemes are then compared to select the best gateway placement scheme. Due to the high cost of the gateway nodes, typically only a few gateways are used in WMNs. So the computational complexity of finding all the distinct solutions is not high due to small number of gateways.

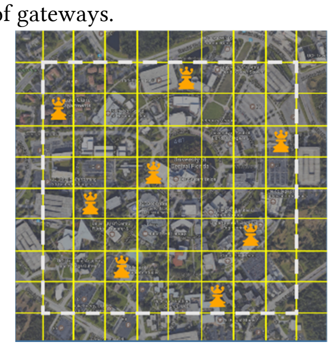

Figure 1: A gateway placement example with 8 gateways

2.3 Gateway selection using learning automata

Gateways show their existence by periodically sending out a Gateway Advertisement (GWADV) message. When a router receives this message, it records the information about the new gateway in its gateway table. To determine the available gateways, a router sends a Gateway Request (GW_RQ) to all the gateway nodes in its gateway table. If the buffer load of a gateway node is currently less than the threshold, it sends a Gateway Reply (GW_RP) to the router to accept its gateway request. When the router receives this gateway reply, it adds this gateway to its list of Available Gateways.

Given the list of Available Gateways, a router uses the technique presented in Algorithm 1 to select a gateway to transmit the next data packet. Each router maintains an Action Probability Vector (APV), with each component corresponding to one of the N available gateways. Each component in the APV records the probability of the respective gateway being selected by the learning automata for the router. Initially, all the components of the APV are initialized to 1/N (i.e., all the gateways are equally optimal, or equally likely to be selected). The gateway selection algorithm is an iterative process. In each iteration, a learning automaton randomly selects a gateway using the current probability values in the APV (this is referred to as an action).

The router then sends the next data packet to this selected gateway. Upon receiving a data packet from the router, the selected gateway sends a feedback (F) message to the router to report the condition of its current work load. This is the average interface queue length (gateway buffer length) computed as the number of frames buffered in the gateway interface over a time period. If the feedback value in F is less than the average of all the buffer queue lengths of all the gateways, then the probability of selecting this action increases and the router is rewarded according to Formula (1) below; otherwise, the action is penalized according to Formula (2) below, and the probability of selecting this router decreases.

$$p_i(t+1) = p_i(t) + \gamma\,[1-p_i(t)]$$
$$p_j(t+1) = (1-\gamma)\,p_j(t) \quad \text{for all } j \neq I \tag{1}$$

$$p_i(t+1) = (1-\rho)\,p_i(t)$$
$$p_j(t+1) = \rho/(r-1) + (1-\rho)\,p_j(t) \quad \text{for all } j \neq I \tag{2}$$

This iterative process terminates when some component of the APV reaches a probability of 0.89 (close to 1), which indicates an optimal action, i.e., an optimal gateway has been determined. The learning automaton Linear Reward Penalty (LR-P) used in the proposed method is known for being expedient in all stationary random environments [13].

In the proposed algorithm, the back-pressure routing algorithm [12] is used. This type of routing algorithm does not pre-calculate the paths and next step chosen dynamically. Inspired by the back-pressure graph, communications for connecting routers to gateways are minimized, so congestion is controlled. The traffic is passing through the path which has the lowest cost according to the back-pressure algorithm from gateway nodes toward routers (and vice versa). This cost is calculated by considering the client's buffer queue for transferring frames to routers and the router's buffer for transmitting frames to gateways.

Algorithm 1: Gateway Selection Technique at a Router

When a GWADV from some gateway arrives:
    Save the gateway ID in Gateway Table
For each gateway ID in Gateway Table
    Send a GW_RQ
End for
When a GW_RP message arrives from a gateway
    Put it in the list of Available Gateways
For each gateway in the list of Available Gateways
    Learning Automata selects a gateway according to its APV
    Send data to the selected gateway
    Wait for feedback
    If feedback < average buffer length of all gateways
        Increase the associate APV element of that gateway according to Formula (2)
    Else
        Decrease the associate APV element of that gateway according to Formula (1)
    End if
    Until APV element of one gateway reaches to 0.89

3 PERFORMANCE EVALUATION

In this section, the proposed method is evaluated using the NS-2 simulator. To demonstrate the performance of the method, the following metrics are collected: packet delivery ratio, the average delay, throughput, average number of the steps to the gateway and the number of lost packets. Required parameters to simulate the proposed method are shown in Table 1.

Table 1: Simulation parameters

Simulation parameters	Values
Network area	1000 m × 1000 m
MAC protocol	802.11s
Queue Size	200
Packet rate	4 packets/sec
Traffic type	CBR (UDP)
Data payload	512 bytes/packet

The proposed method has been compared in various scenarios, the appropriate values for the two parameters γ and ρ in formula (1) and (2) in this study are 0.5, and have been determined empirically. The proposed method (NQ-GPLS) has been compared to standard mesh network with no control. Simulation has been tested several times to present the performance of methods with respect to different data rates. The topology of our WMN consists of 8 gateways and 92 routers that are placed in 1000 m × 1000 m area. The clients are uniformly distributed over the WMN. The proposed algorithm is expandable with different number of gateways.

Throughput is always considered as one of the most important criteria for evaluating performance of networks. Throughput is the total number of bits which have been properly received by all nodes within one second (kbps). Figure 2 shows that the proposed method outperforms standard mesh network 6.4% in terms of average throughput, especially at data rates equal to 2000 kbps.

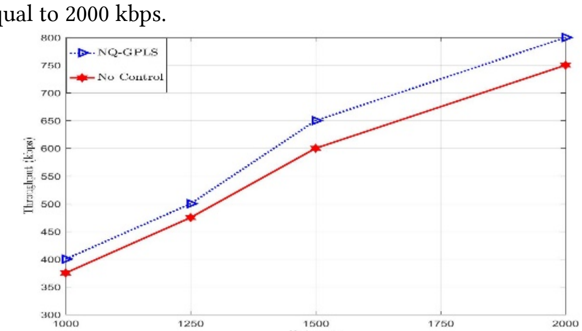

Figure 2: Throughput with different data rates

Figure 3 represents the average delay for sending packets from source node to gateways. All possible delays are included in it, such as retransmission delays, route discovery latencies, and buffering delays. The proposed method has improved delay compare of standard mesh network by 21%.

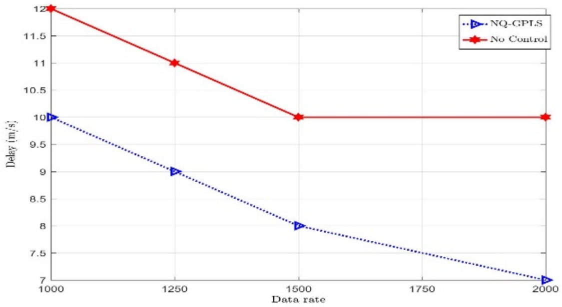

Figure 3: Delay with different data rates

Figure 4 represents the ratio of packet that are delivered to the gateways. The results of the simulation show that the proposed method reaches to 91% average packet delivery ratio. The NQ-GPLS method has the higher rate of delivery because the gateways are placed with proper distance in the proposed method and congestion is considered.

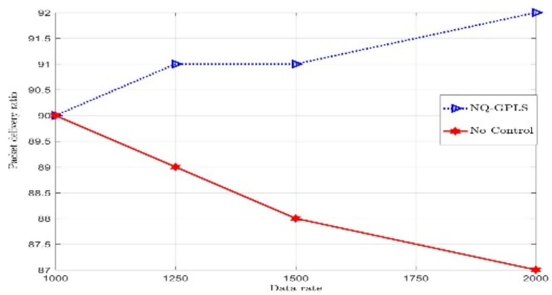

Figure 4: packet delivery ratio with different data rates

In WMNs, the number of lost packets is always high due to the traffic. Figure 5 shows that the standard mesh network have about 21% higher packet loss than the proposed method. This progress is due to the use of learning technique and a set of factors, including consideration of the level of congestion and load of the gateways dynamically.

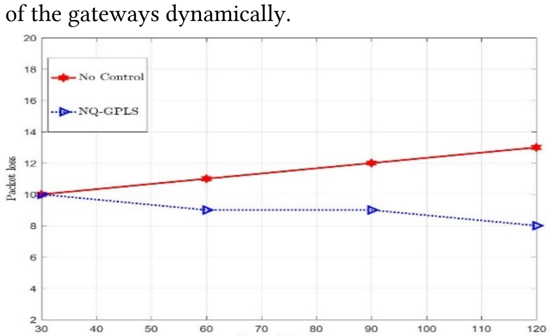

Figure 5: The comparison of lost packets

The fewer the number of intermediate hops that are used to send a packet in a network, the more efficient and secure it will be. Because there may be corrupted steps along the path. The simulation results represent that the average number of hops from a router to its gateway is 3 for the proposed method, and for standard mesh network with no control is 4, which is a great advantage for the NQ-GPLS method.

4 CONCLUSIONS

This paper has presented approaches for gateway placement and selection to improve the performance of WMNs. For the gateway placement, the N-queen puzzle formulation is used to deploy the gateways. This deployment strategy keeps the gateways in appropriate distance apart, thus allowing any router to connect to a gateway with short distance. One advantage of this gateway placement method is its expansibility. For the gateway selection, a new algorithm based on learning automata, has been applied to select the gateway. This technique balances the load on the gateway nodes to use network capacity efficiently. The results of the NS-2 simulation show that the proposed techniques outperform standard mesh network protocol.

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