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Multi-gateway association in wireless mesh networks ☆

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ABSTRACT

Most traditional models of wireless mesh networks involve a mobile device connecting to the backbone through one of the available gateways in a wireless mesh network. In this paper, we present an alternate model, in which mobile devices are allowed to connect through more than one of the available gateways. We call the model multi-gateway association (MGA). We present arguments for why such a model can result in better capacity, fairness, diversity and security when compared to the default single-association model. We also identify the primary challenges that need to be addressed when using multiple-gateway associations, and propose solutions to handle these challenges. Using simulations, we show that throughput benefits ranging from 10% to 125% can be obtained by the proposed model as compared to a default single association model with just two gateways and more importantly, benefits linear in the number of gateways are obtainable. Through simulations and analysis, we establish why only intelligent multi-gateway association and neither single or simple multi-gateway association strategies can yield significant benefits.

1. Introduction

Wireless mesh networks (WMNs) constitute a specific class of multihop wireless networks that have recently received research focus. Some application scenarios envisioned for such networks are campus wide networks, community networks, hospital networks and rural area networks. WMNs have several economic advantages, such as the possibility of using free unlicensed spectrum and the ease of construction,expansion and maintenance. This has generated considerable interest and attention from the industry. Further, in areas which do not have an already existing wired infrastructure (such as rural areas), these form the only data communications technology. There have been several successful commercial deployments in recent years [1,2,4–6]. Thus wireless mesh networks have an immense potential to succeed as an ubiquitously viable wireless technology.

Although WMNs are currently seeing initial deployments, there are several issues that need to be addressed before they can succeed as the future wireless technology. These issues can be categorized into issues that are prevalent in multihop wireless networks and issues that are specific to WMNs. There are several issues with multihop wireless networks and they have been well documented in the literature [17,18]. These issues apply to WMNs as well. However, there are several new advantages and disadvantages of WMNs when compared to a general multihop wireless network.

The capacity of a WMN is significantly reduced due to the additional bottlenecks created by the nature of the traffic pattern. The two main factors are the gateway bottleneck and the client communication bottleneck. Since all traffic is directed towards the gateway and the gateway has a fixed bandwidth that has to be shared by all its clients, the throughput per client is reduced as the number

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of client nodes increases. In addition, when several clients associate with a single router (access point) the available client communication bandwidth has to be shared by all the clients as well. With WMNs, fairness among clients is also a significant issue. While nodes near a gateway typically enjoy a high share of the gateway capacity, nodes farther away have a significant capacity degradation. In addition, with the gateway as the single entry point of all data into the wired internet, the security risk is higher because the environment around the gateway is a single area where an eavesdropper gets access to packets of all flows served by the network.

However, mesh networks have several advantages inherent in their architecture compared to generic multi-hop wireless networks. Some of the dominant advantages are as follows. With a static routing infrastructure, the possibilities of route failures is greatly reduced. Moreover, the problems of connectivity are reduced due to the redundant deployment of mesh routers. The high node degree of a mesh architecture also provides advantages such as loss-resiliency, reduced probability of path failures and self-healing. Although mesh architectures come with several advantages, leveraging the advantages fully depends on the central challenges being addressed effectively. These challenges are exacerbated by several practical problems that occur due to the high and varying user density, improper association, improper load balancing, unbalanced resource allocation, etc.

Given these set of problems of conventional WMNs, we investigate the benefits that can be obtained by moving away from a single-association model. Specifically, we consider the gateway association problem where a client associates with more than one gateway in order to transport its traffic to the backbone Internet and likewise from the backbone Internet. The essential contributions of this work are as follows:

- We present a new association model for WMNs called Multiple-Gateway Association (MGA) and evaluate its benefits and trade-offs both qualitatively and quantitatively.
- We identify the essential challenges that need to be addressed in order to leverage the benefits of multiple-gateway association.
- We propose a layer 3.5 solution to tackle the problems and leverage the benefits of the proposed model.

The rest of the paper is organized as follows. Section 2 describes the proposed model and also lists the assumptions made in this paper. Section 3 motivates the use of multiple-gateway association from the four main perspectives of capacity, fairness, diversity and security. In Section 4, we identify the key challenges that need to be addressed in order to truly leverage the benefits of multiple-gateway association. Section 5 describes the proposed solution suite, its mechanisms and interactions in the protocol stack. In Section 6, we evaluate the performance of the proposed solution using simulations. Section 7 provides an analysis of achievable benefits and factors affecting the benefits. Section 8 presents related work and Section 9 concludes the paper.

2. Model and assumptions

We consider a multi-hop wireless network with three sets of nodes: clients, mesh routers and gateways. Every mobile client connects to the router nearest to it in finding a path towards a gateway. The gateways, routers and clients all use omni directional antennas and operate on the same channel with the same capacity C. The clients do not perform any co-operative relaying and only serve as sources for their own traffic. Data is directed only from the gateway to client nodes or vice versa and not between clients. For the single-gateway association, every client node chooses the gateway nearest to it for its association and directs all its traffic towards this gateway alone. We call this model single nearest gateway association. This model will be used throughout the paper for comparison purposes and referred to as SGA. More sophisticated single gateway association mechanisms such as, association based on load can be devised. However, we contend that the flow splittability inherent in MGA innately comes with the several advantages outlined in Section 3, and established in prior works [9,10]. (We also highlight it in Section 6.)

In the multiple-gateway association model (MGA), we consider every client node to choose more than one gateway for its communication. The specific number of gateways and the exact gateways that each client will associate with will be elaborated later on.

3. Motivation

Multiple association can provide several benefits. This section provides illustrative scenarios for each benefit using flow graphs.[1] The intent of this section is to describe through arguments and practical considerations, the benefits possible. The four main categories of benefits are as follows:

3.1. Capacity

The use of multiple gateway association can provide significant capacity benefits. While, it is well known that the gateway bottleneck is the dominant reason for capacity constriction in a mesh network [12], the introduction of multiple gateways does not enable a straight-forward increase in capacity. Network capacity can increase linearly with the number of gateways only with proper load balancing and resource provisioning. Thus proper association, which prevents the formation of bottlenecks and distributes the network load evenly, is needed to realize the linear capacity increase. In this section, we argue that multiple gateway association is a practical necessity for achieving the capacity gains possible with the deployment of multiple gateways.

While several studies about the performance of protocols assume that load is uniformly distributed throughout a network, it is seldom the case in practice. The two main

[1] The set of active edges carrying flow traffic in the network.