Measurement Based Admission Control in multi-hop Wireless Mesh Networks

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I. Abstract

Wireless networks have witnessed a tremendous growth in the last few years. The increase in the deployment of wireless networks should be complimented by a robust management scheme that can guarantee the efficient working of the network. Several admission control schemes have been presented for wireless LANs and wireless ad-hoc networks. However, wireless mesh networks present a different scenario. They have different characteristics such as a static wireless back bone and multi-hop communication which call for a suitable management scheme. Some schemes have been presented for admission control in mesh networks. However these schemes suffer from inaccurate underlying interference models. A common assumption is that interference is a binary concept and two links either interfere or not. We propose a new measurement based scheme for implementing admission control. This scheme involves making informed decision based on statistics collected from the network. Since we are monitoring the network, the current conditions in the network are reflected in our measurements and hence incorporated in the admission control decision.

II. Introduction

Wireless mesh networks have witnessed a tremendous growth over the last few years, both in terms of commercial installations, and as a topic of academic research [1]. Numerous wireless mesh network test beds have sprung across universities and research groups. A lot of work has been done in terms of understanding the behavior of mesh networks, analyzing the impact of various factors like interference, number of hops and others on its performance and utilizing multiple radios and multiple channels to improve the performance of mesh networks [2] [3] [4]. Recently, the focus has been more on providing quality of service in wireless mesh networks. The aim is to design and implement schemes that can provide guaranteed services to the end users. Unlike wired networks, this is not an easy task in wireless networks. Owing to the highly dynamic nature of wireless networks, there are several issues that need to be taken care of in order to provide end-to-end service in wireless mesh networks.

In this paper, we design and implement a measurement based scheme for providing admission control in wireless mesh networks. By implementing admission control, we can control the amount of traffic in the network and hence provide guaranteed service to the end users. We follow a measurement based approach as it seems the ideal choice for wireless networks. As we will see, the parameters in a wireless network vary greatly with time and hence a measurement based scheme that continuously keeps track of the various network statistics, should provide us with more accurate data in order to provision QoS in the network. Our scheme in a centralized scheme, aimed at small scale mesh networks. A distributed version of this approach, which may be more suitable for larger networks, will be studied in our future work. The centralized controller keeps track of all the traffic in the network, based on which it makes admission control decisions for the new incoming flows. In case a flow is admitted, the central controller also does route allocation.

III. Related Work and Motivation

A lot of work has been done in the area of providing QoS in wireless networks. However, most of this work has been focused on Ad-hoc networks or single hop wireless LANs. Recently, some work has been done on providing QoS in multi-hop Ad-hoc networks. In [5] the authors propose a QoS aware routing scheme that incorporates admission control based on approximate bandwidth estimation. They estimate the residual bandwidth at each node to support new flows. In [6], the authors propose a modification to the existing AODV protocol to incorporate admission control and bandwidth reservation. Another approach is proposed in [7]. Here the authors propose Contention Aware Admission Control protocol (CACP) wherein they utilize the knowledge of available resources not only at the local node but also at all nodes in the contention neighborhood of the node. They introduce the concept of c-neighborhood available bandwidth, which takes into account the node's neighbors in its carrier sensing range. Another similar scheme was proposed in [8]. Here the authors propose to modify the carrier sensing range of each node to enable it to measure the available bandwidth in the surrounding region. They test the scheme for single hop Ad-hoc networks and show how it can be extended to multi-hop networks. Another closely related approach is presented in [9]. They propose an admission control scheme for Ad-hoc networks, integrated with a hop by hop Ad-hoc routing protocol. They use a passive monitoring technique to estimate available channel bandwidth. The protocol also uses temporal accounting to enable bandwidth estimation across links with different bit rates.

There are several discrepancies in the existing approaches. All of these have been validated using simulations only. Simulations do not capture the various characteristics of a wireless network, such as interference etcetera properly. The assumptions such as interference range being twice the transmission range, interference range is circular or only two hop neighbors interfere with each other are erroneous. Another drawback of most schemes proposed so far is their assumption of network capacity being a fixed value. Most works assume a fixed upper bound on the network capacity (usually 2 Mbps for 802.11b networks).This is also inaccurate.

In [10], the authors have proposed that interference is not a binary concept as assumed by most people. An interference model should be able to capture the amount of interference between two links, and should not just assume that either the links interfere or don't interfere. Our measurement based approach allows capturing this effect and basing our decision on that. We present a new scheme that is based on measurements and is verified via experimentation. This greatly increases our accuracy as the scheme relies only on the measured data from the network and not on any model. The most accurate way of characterizing the capacity and taking into account the impact of interference in a wireless network is to actually measure these quantities. Another reason for us to look at admission control in wireless mesh networks is that most of the schemes proposed above are for multi-hop Ad-hoc networks to be specific and not for mesh networks. Some of the characteristics are different for these networks and hence calls for a specific scheme for mesh networks.

IV. Proposed Methodology

We are given a wireless mesh network, represented by a graph G (V, E). V denotes the set of nodes in the mesh network, while E denotes the set of links between nodes that can communicate with each other. We also have as input the bandwidth requirements specified by each user. The monitoring infrastructure deployed in the network will provide us with the current network statistics, in terms of channel utilization and link interference, which will also be used as input to our admission control algorithm. The admission control algorithm runs at a node denoted as the central controller. Our scheme is a centralized scheme and all decisions are made by the central controller. Our objective is that given a client request, with B_{user} being the maximum requested bandwidth for that client, we aim to make a Yes/No admission control decision. Let $B_{avail,i}$ be the available bandwidth on link 'i' of the network. Then the admission control decision will be yes if the algorithm can find a path P from the source to the destination such that for every link 'i' on path P:

$B_{user} <= \alpha * B_{avail,i}$

where $\alpha \epsilon$ (0,1) is a slack parameter.

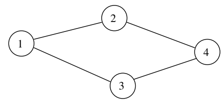
If the above condition is not satisfied, it means that the network does not have enough resources to support the new client and the request will be rejected.

There are three key components in which the problem can be sub-divided:

1) Building the connectivity graph: In order to decide what routes to allocate to the clients, the central controller should be aware of the network topology and any changes that occur due to addition or deletion of nodes and link failures.
2) Measurement of required statistics: The monitoring framework constantly needs to measure the required parameters and forward them to the central controller. This data will provide the controller with the current status of the network based on which the decision will be made.
3) Admission control algorithm: The controller uses the above pieces of information and checks if a new client can be allocated a path that satisfies the requirement.

A. Network Discovery

In the centralized scheme, we need the controller to have a global view of the network topology. We



Node ID	Neighbor Flag	Neighbor List
2	Yes	1,4
3	Yes	1,4
4	No	2,3

Fig. 1. Sample topology

thus need a protocol for neighbor discovery and setting up of control routes from each node to the gateway. For this, we use our version of a HELLO message protocol. Every node periodically transmits 'Keep Alive' messages, which tell the node's neighbors about that node's existence. Apart from the 'keep alive' messages, we also have the 'Add' and 'Delete' messages which are used by the nodes to propagate any changes in their routing tables caused by node addition or deletion or due to link failure. These messages are broadcast throughout the network. In this way, every node in the network has the global view of the network topology. A sample topology and the corresponding topology table for Node 1 in the network is shown in figure 1

The central controller node marks a special flag in its broadcast messages to inform the nodes of its special status. Each node then runs a simple shortest path algorithm to create a static control route to the gateway node. These control routes are used for sending control messages, such as route association request and replies, from the nodes to the central controller and vice versa. It is also used for sending the monitoring information from each node to the central controller. Another alternative is to broadcast this information through the network and it would eventually reach the central controller. However, this would consume too much network resources and create a lot of overhead. Each node starts broadcasting messages with a list of their neighbors included in the message. This information is used by the nodes to build their routing tables. The routing tables are in the form of MAC addresses specifying the next hop to be taken for a given source destination pair. The HELLO messages are sent periodically in order to keep track of any changes in the topology due to node failure etcetera. In order to minimize the number of HELLO messages sent out, each node waits for a deterministic amount of time before sending out the HELLO message. In other words, we are broadcasting changes in the routing tables in batches to minimize the message overhead. These messages are also propagated to the central controller where a centralized routing table is built, specifying the paths from each AP to the gateway node (for all traffic going out of the mesh network to the internet). At the same time, each node builds the control route to the controller using the HELLO messages it receives. This control route is used for two purposes. One is to send the client association request to the central controller. When a node receives an association request from a client, it sends a request to the controller to see if the client can be accepted. The control route is also used by each node to send the measurement data to the controller. Our admission control scheme is measurement based. Each node sends its modulation rate, the channel utilization it measures and the interference information to the central controller. This data is used by the controller for making the admission control decision.

B. *Measurement of Channel Utilization*

My admission control scheme is based on the measurement of certain parameters in the network and the periodic reporting of these updated statistics to the central controller, so that the controller can make informed decisions whether to accept a new client request or not. The quantity that me intend to measure is the available bandwidth on each link in the network. This parameter will give us an estimation of the amount of data that can be sent over the wireless network links, given the present traffic conditions. With this data, and the user requirement, we can decide whether to accept the new user or not.

However, this is not a trivial task. Measuring bandwidth in a wired link is a relatively simple task and several techniques and tools exist for the same. However, the same tools and techniques cannot be applied to wireless networks owing to the unique characteristics such as interference, shared medium and broadcast of data. In a wireless network, the data sent on one link, may affect the transmissions on the neighboring links and reduce its bandwidth. Also, the bandwidth measured in one direction on a link between two nodes may be different from the bandwidth in the opposite direction. All these factors need to be accounted for while measuring bandwidth in a wireless network.

In order to measure bandwidth on the wireless links, we represent bandwidth in its more basic form, which is, amount of data per unit time. Thus, if we can measure how much data we can send in a given unit time, and also estimate how much we have left, then we can easily measure the available bandwidth that we have. With this in mind, we define two quantities, viz, channel utilization and modulation rate. Channel utilization is the proportion of time for which the channel is not available to the node for transmitting data, owing to other activity on the channel. Modulation rate is the maximum rate at which a source can transmit data to a particular destination in the present network conditions.

In a given measurement period, we measure for how much time a node is busy in order to estimate the channel utilization. In the absence of RTS/CTS mechanism, the channel utilization in the network is obtained by measuring the period of time taken to transmit all data, management and control frames. During this period of time, the medium is not available to nodes other than the one that is already transmitting and hence the channel is busy. In order to measure the channel utilization, each node sniffs and calculates how many data, control and management packets were sent in the measurement period. Let t_{datai} denote the time to send a data packet i, t_{ACK} be the time taken to send an ACK and t_{beacon} be the time taken to send a beacon packet, then the time for which the channel is busy is given by:

Channel Busy Time (CBT) = $\sum_i n_{datai} * t_{datai} + n_{ACK} * t_{ACK} + n_{beacon} * t_{beacon}$

Then if t_{sample} is the sample measurement period, the utilization is given by:

channel utilization = CBT / t_{sample}

This utilization is measured by each node and transmitted periodically to the controller. Along with channel utilization, we also introduce another parameter: the modulation rate. In wireless networks, each node has a specific rate at which it can transmit to a destination. Higher rates would send data faster but lower rates would be more robust. The rate may be different from the same source to different destinations, based on several factors. We propose to use the modulation rate as a bound for the maximum rate at which data can be transmitted from the source to a specific destination. Each node constantly monitors its modulation rate and sends this to the central controller.

We use the concept of modulation rate along with channel utilization to find the resource availability at each node for accepting a new request. We can define the available bandwidth to a node on a particular link to a destination as:

$Av.BW$ = Modulation rate * (1- channel utilization)

Consider nodes A, B and C, such that all three can communicate with each other. Nodes B and C are connected to the gateway node. Let the modulation rate from A to B be 36 Mbps and that from A to C be 24 Mbps. Initially there are no flows. Now a client tries to associate with node A and has requested a bandwidth of 6 Mbps. Since A has enough capacity to support this link, this connection request will be accepted (here we are assuming that the link from B to the gateway node also has sufficient resources). Now suppose when A measures its channel utilization, it comes out to a value of 0.5 seconds in a sample period of 1 second (owing to the client at A and some other transmissions in the neighborhood). This means that for link A to C, the effective maximum rate at which A can transmit to C would be half of the modulation rate from A to C, which comes out to be 50% of 24 mbps, which is 12 Mbps. Similarly the maximum rate for the link from A to B is 18 Mbps. So now if another client comes in at A and requests a bandwidth of more than 18 Mbps, then this request cannot be satisfied as A does not have enough resources for this client. Similarly, if the bandwidth requested is between 12 and 18 Mbps, then only the link from A to B can be used and not the link from A to C.

Using the above approach, we can calculate, for each hop along a path from the source to the destination, the maximum rate at which we can transmit on that hop. We perform these calculations in both the directions as the rates may be different. If we are able to find a path that satisfies the bandwidth requirement, then the new request can be accepted. Note that the forward and the reverse paths need to be the same.

C. Centralized Admission Control Algorithm

The admission control scheme proposed is a centralized one. The central controller co-exists at the gateway node. Centralized schemes are apt for small size networks. A distributed approach may have the advantage of not having a single point of failure, but suffers from large messaging over-heads among the nodes. I plan to also implement a distributed scheme later and compare the performance of the two approaches.

At the central controller, we receive periodically the measurement data from various nodes in the network. This data is sent via the control routes that each node has to the central controller. The measurement data is unicast along the control routes and not broadcast as the latter would involve huge messaging over heads.

The centralized algorithm running at this node takes as input the measurement data and the topology graph constructed using the network discovery protocol. The topology graph provides information about the existing links in the network. This is required in order for the centralized controller to assign routes to incoming client requests. The topology graph is constantly updated. if a new node is added in the network, then the routing tables at some of the nodes will change. These nodes will propagate the change in the network and the updates will reach the centralized controller. Similarly, when a node fails, it will stop broadcasting the 'Keep alive' messages. If a node's neighbor does not receive three consecutive 'keep alive' messages, it will assume that the node is dead and will send an update to the central controller. The central controller will update its tables and re-route the traffic that was going through the failed node.

The measurement data is also transmitted periodically from each node to the central controller. The central controller matches the data to the links in the topology graph. The available bandwidth for each link is the weight of the link. We use a simple modified uniform cost search algorithm to determine whether a path exists from the source to the destination. A uniform cost search algorithm is a modified breadth-first-search algorithm for weighted graphs. At each node, it stores the outgoing links in a priority queue and sorts it in the increasing order of the link weights. It then chooses the path with the minimum weight. The procedure is repeated at each step till the destination node is reached. We modify this algorithm to sort the nodes in decreasing order of the weights. The weights here are the available bandwidths on the links. So we would like to choose a link with larger available bandwidth. If the first link itself cannot satisfy the user requirement, then the algorithm can stop as no path exists in the network that can satisfy the user's bandwidth requirement. If the link weight is greater than the bandwidth requested by the user, then that node is added to the path and the next hop is considered. The above procedure is repeated till the destination node is reached. If in the end a path is found from the source to the destination, it means that the network has sufficient resources to handle more traffic and the new client can be accepted. An reply is sent back to the client and the corresponding route is setup.

Admission Control Scheme

I) **At the mesh nodes:**

1) Client sends association request frame to an AP
2) AP sends association request to the central controller
3) AP receives association reply from the central controller
4) AP sends association/disassociation reply frame to clients
5) AP monitors channel utilization and modulation rate
6) AP sends measured data to the central controller periodically.
7) AP periodically sends 'keep alive' messages
8) AP propagates any changes in the routing table

II) **At the central controller**

1) Receives association request from the AP
2) Performs admission control on the request using the measurement data
3) If decision is no, then deny the request and send reply to AP
4) If decision is yes, then accept the request and send reply to AP
    i. Perform route setup
5) Central Controller receives monitoring data from the mesh nodes and updates the link weights
6) Central controller receives the topology information from the mesh nodes abd builds the connectivity graph

Fig. 2. Centralized Admission Control Algorithm

D. Client Association and Route Setup

The figure 3 (a) shows the process of client association. Suppose a client wants to join the network and sends an association request to a particular AP. This AP needs to contact the central controller which will decide whether enough resources are available in the network to satisfy this new request, without adversely affecting the existing flows in the network. For this purpose, the AP sends a client association request to the controller. This request contains the MAC address of the incoming client. When the controller receives a client association request, it checks the MAC address of the AP from which the request has come. It then looks up the routes that are available from the AP to the gateway node. For each of these routes, it sees if the available resources

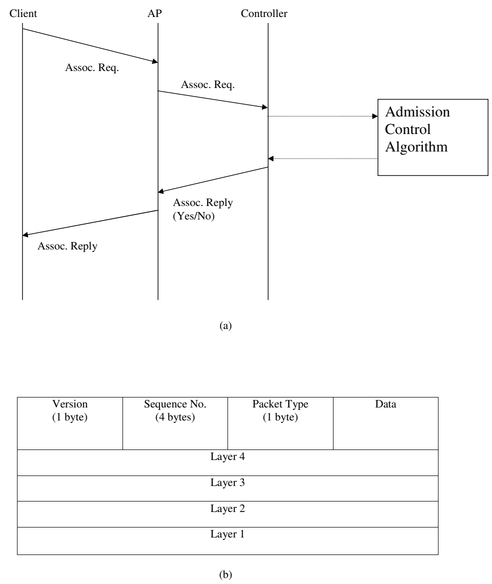


Fig. 3. Client Association and packet format

are enough to satisfy the bandwidth requested by the client. This is done by checking the requested bandwidth from the user against the available bandwidth on each link of the path. The available bandwidth of the links has been calculated before using the channel utilization and modulation rate. If the controller is able to find a path satisfying the bandwidth requirements, then the new client request can be accepted. In this case, it sends an association reply message to the AP saying that the client can be accepted. Upon receiving this request, the AP will send an association frame to the client. Also, if the client is accepted, then the controller needs to setup a route for this client. It does this by sending route creation messages to each node on the path that has been chosen. This message contains the MAC address of the source (i.e. the client) and the destination. For each hop, it will set an entry in the routing table specifying the next hop to be taken for the particular source-destination pair. The forward and the reverse paths may be different depending upon the bandwidth availability. The structure of the routing table at each node is shown in table I. So for each client, there will be one entry with client MAC as source MAC and gateway MAC as destination MAC for outgoing traffic and one entry with client MAC as destination MAC and gateway MAC as source MAC for incoming traffic.

SOURCE MAC	**DEST MAC**	**NEXT HOP MAC**
.	.	.
.	.	.

TABLE I
STRUCTURE OF ROUTING TABLE

V. EXPERIMENTAL TEST BED AND EVALUATION SCHEME

I plan to test the scheme using a 10 node test bed in our laboratory. Each node in our test bed consists of 2 radios. One radio in configured to be in the access point mode and serves the clients that want to access the network. The other radio is configured such that it is able to sniff packets in the surrounding area (like in monitor mode) and at the same time it able to send and receive packets from other nodes. Such a configuration allows us to sniff packets in the neighborhood (subsequently used for estimating channel utilization) and at the same time enables inter-node communication in the wireless mesh backbone. The radio in the AP mode is configured on one channel while the backbone radios are configured on another channel in order to minimize interference between the two. In the present scenario we are looking at a single channel back haul network. In our future work, we will be investigating the case of multiple channels. Our admission control scheme is currently a centralized one. We assume that the central controller co-exists with the gateway node. The gateway node is the one that provides wired connectivity from the mesh network to the internet. The nodes are configured to work in 802.11a mode. This is done to prevent interference between our test bed and other existing 802.11 b/g networks in the building.

This test bed was built using the small Soekris [11] net4826 embedded devices. This device runs on a 266 Mhz 586 processor with 128MB SD-RAM main memory and 64MB compact flash for the OS and other storage. They are optimized for wireless communications with dual Mini-PCI Type III sockets. We selected the Ubiquiti Networks SuperRange2 802.11b/g 400mW High Power Atheros Wireless mini-PCI card as the wireless radios for our devices because of the distances we must cover. These boards are driven by a custom built Linux distribution using a 2.6 Linux Kernel. The kernel and filesystem are optimized for running on the embedded systems without sacrificing speed. We use the madwifi-ng driver from Madwifi.org [12] on our AP due to their level of programmability. Each Soekris board acts as one node in the network. Linux Bridging is used to bind the multiple network interfaces to one IP address.

Some measurements that we would like to perform to test our scheme are:

- Test the HELLO message protocol. Check how much time does it take to learn the network topology. Also test whether it deals effectively with link failures or addition of new nodes.
- Test the correctness of the channel utilization scheme. A possible way to do this is to check our measurements against measurements using available bandwidth measurement tools.
- Check for message overheads (control over heads for network discovery protocol and monitoring data)
- Evaluate the working of the admission control scheme as a whole in terms of available throughput, delay, false admissions etc.

We have tested the HELLO message protocol scheme in our laboratory. The scheme works correctly and build a topology graph at each node in the network. We are currently implementing the Central Admission Control Algorithm and integrating it with the HELLO message protocol in parallel with the link bandwidth measurement scheme.

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