Efficient Node Reconfiguration in Mobile Ad Hoc Networks (MANETs) for Wireless Internet Access Point Connection

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ABSTRACT

In this paper, we consider a multi-hop network where a mobile node can operate as a host as well as a router, helping other mobile nodes to connect to the access point. We propose a network reconfiguration algorithm to re-establish connections between mobile nodes, to achieve load-balancing for wireless access network. The current network topology is ignored, and by taking into consideration the mobility of nodes and the traffic load at access points, the destination node selects the best route to reach the access point. The proposed algorithm also aims to allow every node in the network to find a route to at least one of the access point. In this paper, we present a grid-representation that illustrates the distribution of nodes in the network based on the number of hops each node is away from the access points. This representation better illustrates the relationship between nodes in different regions in the network. We also define a new metric known as 'Index' for measuring the quality of each possible parent node, to which a node can connect to reach the access point. After reconfiguration is done using the proposed algorithm, NS2 network simulator is used to perform the simulations of the ad hoc network of 22 wireless mobile nodes. The performance of the algorithm will be evaluated based on the average throughput and average end-to-end delay.

Categories and Subject Descriptors

C.2.1 [**Computer – Communication Networks**]: Network Architecture and Design – *Distributed networks, Network communications, Wireless communication.*

General Terms

Algorithms, Design, Performance

Keywords

mobile ad hoc networks; network reconfiguration, load balancing

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1. INTRODUCTION

A Mobile Ad Hoc Network (MANET) is a multi-hop wireless network formed by a collection of mobile nodes without the use of existing network infrastructure. The nodes in the MANET are free to move around and multiple network hops may be required for one node to exchange data with another across the network. The concept of MANETs is not new and it dates back to the DARPA multi-hop multiple-access packet radio network (PRNET) project in the 1970s [1]. Being infrastructure-less and self-organized, a MANET is suitable to be used in application areas where rapid deployment and dynamic reconfiguration are necessary and the wireline network is not available [2].

In recent years, there has been much research on the various mobile ad hoc network routing protocols. Broch and others [3] were the first to provide a quantitative analysis comparing the performance of a variety of multi-hop wireless ad hoc network routing protocols including Destination-Sequenced Distance Vector (DSDV), Dynamic Source Routing (DSR) and Ad Hoc On-Demand Distance Vector (AODV). More recently, Raniwala and Chiueh [4] proposed a wireless mesh network (WMN) that operates just like a network of fixed routers but are connected by wireless links.

The focus of this paper is to propose a load-balancing algorithm for the wireless internet access points in a mobile ad hoc network scenario that is comparable to schemes like Ganjali and Keshavarzian [6], and Velayos et al. [10]. Assume that the coverage of wireless internet access points is not complete in an environment such as a university residence hall, the nodes outside the transmission range of the access points will not be able to detect the network. So and Vaidya [5] proposed a multi-hop network as an extension to infrastructure network, where a mobile node may connect to an access point using multi-hop wireless routes, via other mobile nodes or wireless routers.

In many books and papers today [1, 6], the wireless network is modeled with the well-known Unit Disk Graph (UDG) [7]. Using the reports from the APs, the balance index β for the network, first introduced by Chiu and Jain [8] and used by Balachandran and others [9], is computed. The balance index is 1 when all AP have the same throughput and tends to $1/n$ when the throughput is severely unbalanced [10]. We aim to define a new index that is a better representation of the load balance.

2. PROBLEM FORMULATION

In multi-hop architectures, a node may have multiple routes to different access points that operate on different channels. In this paper, we assumed that all nodes have a single network interface card (NIC) and nodes in the same path are on the same channel. As a node can only operate on one channel at a time, the selection of the 'best' route means choosing the channel that the node would be in. As each channel switching incurs a switching delay that can be quite expensive, it may be costly to improve the unbalanced load situation by analysing the whole topology and switches the channel of specific nodes. This is because whenever a node switches channel, all it's descendants in the route tree have to be considered as well.

Consider the scenario in a University hostel, where the limited numbers of access points are not able to provide Internet connectivity to the whole area. Multi-hop networking is used to cover a larger connectivity area without providing a large number of APs. The main hosts of this network are students who are either using desktop or laptop to establish connection with the Internet. It is assumed that once a student settles down at a location, he will stay there for a reasonable period of time. Hence, we consider the hosts in this network to be either stationary (desktop-users) or (laptop-users) do not move frequently. Although this environment is considered to be quite stable, unbalancing of load among access points may still occur after some period of time. In addition, some nodes may also move out of connectivity with its existing route tree.

Under such environment, we propose a network reconfiguration algorithm to re-establish connections between nodes to achieve load-balancing in the wireless network. The existing network topology is ignored, and each node will be connected to access point through the selection of the 'best' parent node. Parent of a node refers to the intermediate node that helps to relay packets from the node to its destination – the AP. Consequently, the node will operate on the channel where the access point is on.

3. PROPOSED ROUTING AND CHANNEL ASSIGNMENT ALGORITHM

3.1 Definitions and Assumptions

- ***Assignment of Different channel to APs.***
  To reduce interference, neighbouring APs are usually configured to operate on different frequency channel. In this paper, two access points (AP1 and AP2) are used in our investigation. Establishing routes in an adhoc network involves the selection of the parent node that will help to relay packets to and fro the access point. The child will assume the frequency of the parent node.

- ***Measuring Load:***
  The weighted load of the route tree L_1 is computed as follows:

  $$L = \sum_i (h_i \times l_i) \qquad (1)$$

  where i is the a node in the route tree rooted at AP, h is the number of hops, from AP to the node, and l is the amount of traffic destined for the node.

- ***Number of hops***
  It is critical to minimize the number of hops from a node to its associated access point as this reduces the access time and the total load at the access point.

- ***Positioning of wireless access points***.
  In our consideration, the wireless access points are positioned at a distance of $R\sqrt{2}$ apart, where R is the transmission range of each access point.

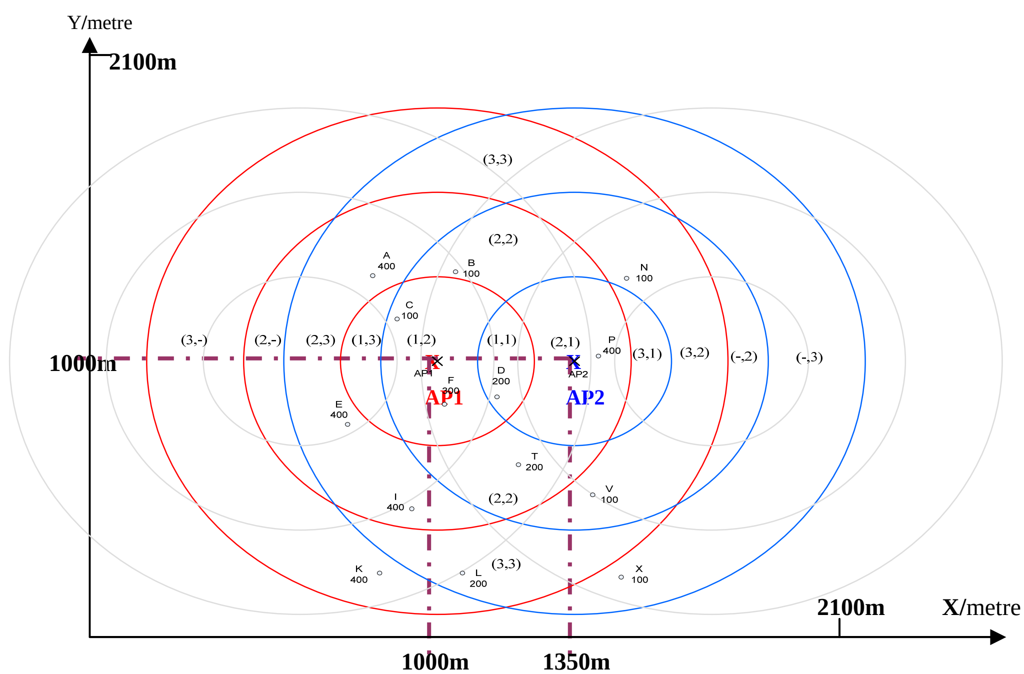

Figure 1: The network topology graph that depicts the position of the nodes

3.2 Representation of the problem

3.2.1 Graphical Representation

The network topology is represented on a graph, as illustrated in figure 1, with Y-axis plotted against X-axis. The actual location of the node is denoted by [x,y] coordinate. For instance, the AP1's location is at [1000m, 1000m] and AP2's location is at [1350m, 1000m]. Each node is represented by a unique alphabet and the number stated beside each node denotes the load, in kbps, at that node.

3.2.2 Proposed Representation

The above representation may have provided a clear overview of the network topology, but it does not clearly illustrate the relationships between the mobile nodes that are situated in different regions. A graphical representation that serves as a great tool in the proposed load-balancing algorithm is illustrated in figure 2. This representation is used in searching for the potential parents of each node in the network topology, and determining sequence of nodes to be considered, when establishing route to access points.

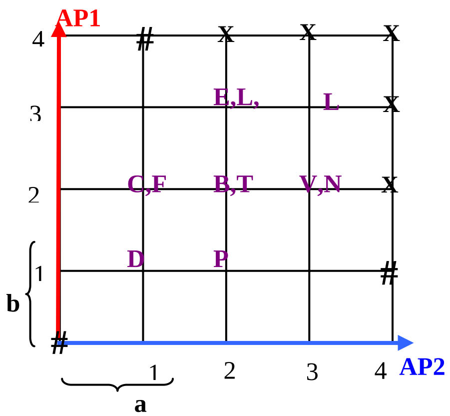

Figure 2: The proposed grid that represents the different regions in the topology graph.

(Nodes in figure 2 are directly translated into this grid based number of hops it is away from AP1 and AP2)

This new graphical depiction is effectively a 3 by 3 grid that represents the number of hops that is necessary to connect each of the 2 access points AP1 and AP2. The vertical axis represents the access point AP1 and the horizontal axis represents the access point AP2. (a,b) coordinate will be used to represent the different regions in the network topology in figure 1. Nodes in the topology graph are translated into different points in this 3-by-3 grid based on the region it is in. 'a' denotes the number of hops needed to reach AP1, and 'b' represents the number of hops needed to reach AP2

3.3 Searching Potential Parent for a particular node

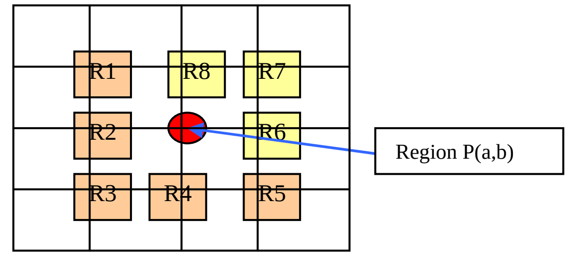

Figure 3: This diagram illustrates the 8 regions that are adjacent to region P with coordinate (a,b).

Consider a particular region P that has the coordinate (a,b) in the grid, as shown in figure 3. The 8 adjacent regions with respect to region P are denoted by R1, R2, R3, R4, R5, R6, R7 and R8. A node in region P may be connected to nodes in adjacent regions of P as they are 1 hop apart, relative to either AP1 or AP2. However, to determine if a node T is in connectivity with another node, say node S, we have to determine if node S is within the transmission radius of node T.

3.3.1 Analysing the Quality of Potential Parents

The following table shows the coordinates of the 8 regions that are adjacent to a particular region P(a,b). Region P is 'a' hops away from AP1 and 'b' hops away from AP2. Refer to figure 3 for the diagram that depict these regions.

Table 1: The coordinates of the 8 adjacent regions of a region P(a,b)

Region	Coordinate
R1	(a-1, b-1)
R2	(a-1,b)
R3	(a-1,b-1)
R4	(a,b-1)
R5	(a+1,b-1)
R6	(a+1,b)
R7	(a+1,b+1)
R8	(a,b+1)

In conclusion, nodes that is within the adjacent regions: R1, R2, R3, R4 and R5 of a particular region P, are either 1 hop closer to access point or equal distance away from the access point as nodes in Region P. These adjacent regions of R are classified as 'Good' regions, which may contain potential parents that are closer to the access points than the node that lies within region P. On the other hand, nodes that are within regions R6, R7 and R8 are either at equal or greater number hops away from the access points. Therefore, these adjacent regions of R are classified as 'Average' regions.

3.3.2 *Algorithm for Searching Potential Parent for a particular node*

The search for potential parents of a particular node, say node N, is divided into 2 phases -- the Initial and Backup Search phase. Consider the scenario of a particular node N in region P. An initial searching will be done in 'Good' adjacent regions of P, to look for nodes that are within the transmission range of node N. Nodes returned from this search are nearer to the access points in terms of the number of hops, and become the list of potential parents of node N. However, if no nodes are returned from the initial search, the region that the node is in (i.e. region P) will be searched. If potential parents still could not be found, the final search ('backup' search) will be done in 'Average' adjacent regions. In the worst scenario, node N is concluded to be out of the connectivity from the access points if no potential parent can be found after all the searching.

3.4 Establish Connectivity link between nodes

During the route establishment phase, the 'best' parent for each node will be selected from their corresponding list of potential parents. The quality of each potential parent will be assessed based on the traffic load at the access points, the number of hops away from the associated AP and the mobility of the node. In this paper, a new metric known as 'Index' is proposed to measure the quality of each potential parent. The smaller the Index value of the potential parent, the higher is the chance of choosing it as the parent node.

3.4.1 *Assess the quality of each potential parent of a particular node using the proposed metric -'Index'*

The formula used for measuring the quality of a potential parent node is as follows:

$$Index = 1.75H + (\frac{t}{T} xNL) = 1.75H + M \qquad (2)$$

where:

H (hop index) - is the factor that measures the quality of potential parent based on the number of hops from potential parent to the access point.

M (mobility index) - is the factor that measures the quality of potential parent based on its mobility.

The Hop Index (H) = (number of hops from AP/ max number hops). In our consideration, we assume that number of hops ranges from 1 to 3. Hence, 'H' can take either value 1/3, 2/3 or 3/3.

The Mobility Index (M) is made up of 2 factors, the t/T factor, and the NL factor.

<u>t/T factor</u>

For each mobile node, there is a time frame during which it will stay stationary in its current position. Let this time be known as time slice (T) and the amount of time that has passed since the mobile node moves into the current position be known as t. Figure 4 illustrates the period T.

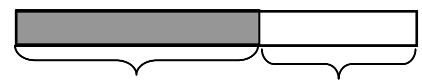

Figure 4: An illustration of the period of time (T) that that a node will stay static. (T-t): the time remaining before the mobile node start to move again.

<u>*NL factor*</u>

The **NL** (next location Index) is the factor that signifies if the next location where the potential parent is moving towards is still within the child's transmission range.

The value of NL is assigned based on the following conditions:

$$NL = \begin{cases} 0 & \text{-- Stationary Node} \\ 0.4 & \text{-- (Mobile Node) within range} \\ 1.0 & \text{-- (Mobile Node) out of range} \end{cases}$$

3.4.2 *Establishing Route*

The establishing of connection between nodes is done after the potential parents of all nodes in the network have been discovered.

The sequence in which different regions are considered is critical in the route establishment phase. This is because the route of nodes that are closer to access points will affect the route selection of nodes that are further away. This can also affect the total number of hops required for a node to reach the access point, and hence the total traffic loads of the network. In this paper, we attempt to connect nodes all those regions that are 1 hop away from AP1 or AP2 first, except nodes in region (1,1). As nodes in regions (1,1) are 1 hop away from both AP1 and AP2, they can be connected to either AP1 or AP2 within 1 hop and will be considered last. Note that whenever the parent of a node is chosen, the node will operate in the frequency channel of the parent node. Hence, the weighted load of the associated access point has to be updated according to the number of hops to AP and the load of the newly added node.

Following the connection of nodes in regions that are 1 hop away from AP, we will considered region (2,3), followed by (3,2). For nodes in region (**2**,3), the algorithm will attempt to connect the node to frequency 1, as it will take 2 hops to reach AP1, as compared to 3 hops to reach AP2. This is achieved with the help of the 'Index' that measures the quality of each potential parent of a node and gives higher 'priority' to potential parent that are closer to the APs. In cases where such node does not have a potential parent that has already connected to the network, it chooses among the list of potential parent that have yet to be connected (let it be $Po_{(-)}$). The weighted load of the unconnected potential parent is updated whenever a child node is added to it. Similar to the previous step, the algorithm attempts to connect nodes in region (3,**2**).

Next, nodes in the center regions (that is nodes that are equal distance away from both access points) are considered in order of region (3,3), followed by region (2,2) and lastly region (1,1). As these nodes are in center region, the amount of traffic load they add to the network is the same, regardless of the access point they is connected to.

The algorithm attempts to achieve load balancing by distributing these route trees among AP1 and AP2 after all other nodes have been connected.

Lastly, nodes in region (1,1) are connected. Route trees that are rooted at nodes that are within region (1,1) are connected to either AP1 or AP2 based on the weighted load of each route trees. Permutation of all possible set of distribution can be done to achieve the best distribution of load among the two APs.

4. SIMULATION

Simulation is done to evaluate the performance of the proposed protocol. In this section, we present and analyse the result of the simulation. This protocol will be executed either when the existing network has reached an unacceptable level of load imbalance, or run at a predetermined interval of time, monthly for instance. By ignoring the existing network topology, reconfiguration of the network topology is done with two main objectives. Firstly this proposed protocol should allow every node in the network to find a route to at least one of the access point. Secondly, load-balancing between access points should be achieved. To see how well the proposed protocol improves the network performance, we compare the performance of the network before and after the reconfiguration is done.

4.1 Simulation Setup

Ns2 simulator is used in our simulation. The simulation area is 2100m X 2100m square, where 22 nodes are randomly and evenly placed. The transmission range of each node is 250m, and the channel bit rate is 2Mbps. Two access points, AP1 and AP2, are used in this simulation. They are placed at (1000m, 1000m) and (1350m, 1000m) respectively, with a distance of $R\sqrt{2}$ apart, which is approximated to 350m. Constant bit rate (CBR) traffic that comes from the wired network through AP is used. 512 byte packets are used in simulation and the communications patterns were uni-directional. Connections were started at uniformly distributed time.

In this simulation, different channels are assigned to the two access points. We used static routing to connect nodes to the access points before the simulation of traffic sending started. As mentioned at the start of the paper, we assumed that mobile nodes will remain at their current position for a period of time before it started moving. Hence, in this simulation, we assumed that during the simulation period, there is no change in the location of nodes. We have created 4 different scenarios that have similar number of nodes and access points, placed at the same location in the simulation area. Each of these scenarios has different traffic profiles and topologies. The overall traffic flow of the network is increased with each scenario. For each scenario, we have two network topologies—before and after application of the proposed load-balancing routing algorithm and their performance will be evaluated. Every scenario is run three times, using 3 different random seeds for each run, and the average result is computed and analyzed by graphically.

4.2 Result

Two metrics are used to evaluate the performance of the load-balancing routing algorithm. Firstly, the average throughput, that is the average amount of data transferred in a specified amount of time. Throughput is measured in kbps. Secondly, the average end-to-end delay, that is the average time between the transmission of a data packet and a successful reception at the receiver. The results of the simulation are shown in figures 5 and 6.

4.2.1 Average Throughput

We measured the average throughput of the network before and after the reconfiguration is done using the proposed load-balancing algorithm. As shown in figure 5, the average throughput increases with increasing traffic flow. In general, the network after the reconfiguration achieves higher throughput than the one before the reconfiguration. As the reconfiguration attempts to select the best route for each node to reach the access points, the average number of hops is smaller so that the amount of throughput is improved.

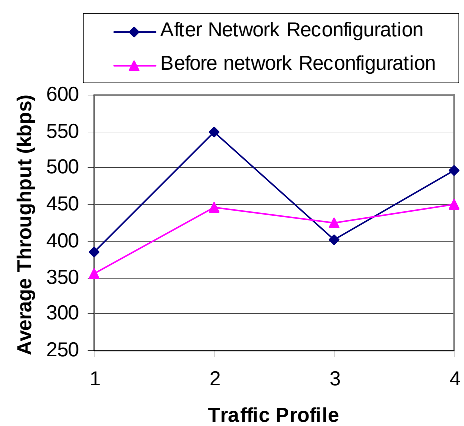

Figure 5: Average throughput

4.2.2 Average End-to-end Delay

The average End-to-end Delay of the two networks is measured under the 4 different scenarios, with increasing overall traffic flow. From Figure 6, it can be observed that the average delay in network after the reconfiguration is generally lower as compared to the other. This is due to the balanced distribution of load among the two access point that is achieved using the reconfiguration algorithm. In addition, the lower average number of hops is another contributing factor to the lower average end-to-end delay in network after the reconfiguration.

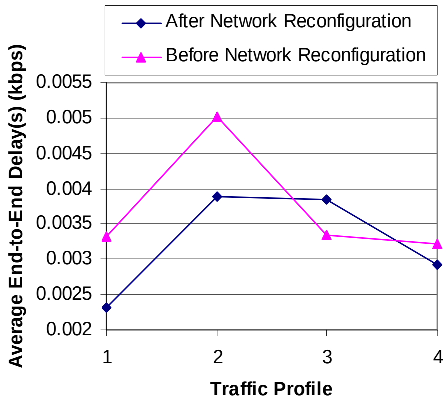

Figure 6: Average End-to- end Delay

5. CONCLUSION

In this paper, we have proposed a network reconfiguration algorithm that reconfigures the existing network topology to achieve load-balancing. Mobility and traffic load at access points are considered during the establishment of route. Mobility is considered in order to choose a route that would possibly have a longer lifetime. However, as we consider the application of this algorithm is at a hostel area, where there are mainly desktop and laptops users, nodes are assumed to be either stationary, or does not move frequently. Hence, higher consideration is still placed on load-balancing of traffic load between the APs. We define a grid model for the representing the position of nodes based on the number of hops away from the two access points. This model is used in the searching of 'best' parent for nodes in the network. In addition, we define an 'Index' metric to analyze and assess the quality of each potential parent of a particular node. The 'Index' metric considers the number of hops from the potential parent node to AP; the amount of time remains before a potential parent node moves to out of its current position, and whether the next location of the potential parent is still within the transmission range of the child node that is under consideration. This algorithm ensures that every node in the network has at least one route to an access point, and selects the best route to the access point such that the overall traffic load of the network is reduced.

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