A Graph-Theoretic Approach for IP Address Autoconfiguration in Mobile Ad Hoc Network

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Abstract

In this paper, we propose a new approach in IP address auto configuration mechanism in Mobile Ad Hoc Network (MANET). This introduces the use of Master Server and Secondary Master Servers to adapt to the dynamic characteristic of MANET. In election of these servers, we propose a Graph-theoretic approach, which includes Graph Eccentricity, Articulation Point, Degree of Vertex, Djikstra's Algorithm, Breadth-First Search, and Depth-First Search Traversals. It was found out that to address the dynamic and unpredictable nature of MANET, servers were dynamically elected by primarily identifying the Central Node of the Network through Graph Eccentricity. The Master Server was determined if it is an Articulation Point during its Election for anticipation of Network Partitioning.

Keywords: MANET, auto configuration, IP address, Graph Theory, Graph Eccentricity

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Introduction

A mobile ad hoc network (MANET) is a set of mobile, wireless nodes which communicate among themselves through wireless links. This type of network can operate in a stand-alone fashion, or may be connected to the Internet. In a stand-alone fashion, the network is independent of any type of infrastructure and all the nodes within have the capability to maintain all the resources of the network in a distributed fashion. One of the most important resources is the set of Internet Protocol (IP) addresses that is assigned to the network (Mohsin & Prakash, 2002).

During the last two decades, routing in MANET has received tremendous amount of attention from researchers. The number of research studies in ad hoc routing protocols has increased significantly (Kumar & Prabhu, 2015) but the same attention has not been applied on address auto configuration. There is no standard mechanism to provide MANET nodes with IP address (Bernardos, Calderon & Moustafa, 2010). Thus, it is required for nodes to be manually pre-configured before they become part of the network. Nodes in MANET should be able to enter and leave the network at will. Thus, the intent of this study is to design an IP address auto configuration mechanism of MANET that will dynamically allocate IP address to the nodes upon their entry in the network.

The mechanism includes the use of master and secondary master servers for easier adaptability to frequent network changes. The Master server is the node elected to provide IP addresses to all nodes and assured convergence within the network while the secondary master server will assume the responsibilities of the master server as backup. These servers are selected from among connected nodes that produce the lowest possible overhead in assigning IP address to the other connected nodes.

In server's election, we propose a Graph-theoretic approach. Graphs have an important application in modeling communication networks. Physically, vertices in graph represent terminals, processors, node devices; and, edges represent transmission channels like wires, fibers, wireless links etc. through which data flows.

Specifically, this study envisions to do the following:

1) Determine the criteria and techniques used in electing a master server.
2) Determine the number of secondary master servers in a given topology and the criteria in electing it.

Related Work

Address auto configuration in MANET is an essential phase before nodes in MANET could communicate. Traditionally, Dynamic Host Configuration Protocol (DHCP) and IPv4 Link-Local Addresses are used in dealing with address auto configuration (Cheshire et al., 2005; and, Wehbi, 2005).

The DHCP is defined in RFC 1531as the first mechanism proposed for dynamically assigning IP addresses. It is based on the client/server architecture where a central entity, the DHCP server, is responsible for assigning IPs for requesting nodes. Because of the dynamic nature of MANET, topology changes frequently which may produce a situation where several servers with conflicting configuration parameters (e.g. managing non-disjoint pools of local addresses) become part of the same MANET. Servers may thus require dynamic reconfiguration. So, a DHCP infrastructure is not suitable in case of dynamic networks where centralizing the address configuration is not appropriate (Baccelli, 2008).

In the event that DHCP infrastructure does not exist or not suitable, Zeroconf working group has proposed IPv4 Link-Local Addresses to allow nodes to auto configure themselves with link local addresses in the range of 169.254/16. However, using link-Local addresses is only suitable for communication with other devices connected to the same physical (or logical) link. Link-Local communication using IPv4 Link-Local addresses is not suitable for communication with devices not directly connected to the same physical (or logical) link. Thus, it is not applicable in a multi hop topology of MANET (Cheshire et al., 2005).

Since traditional approaches are not suitable in MANET, a new approach must be adopted. In designing address auto configuration in MANET, researchers Rohit and Singh (2014) provided some of the particular characteristics that should be taken into account:

1) Address Uniqueness;
2) Address Reclamation;
3) Multi-Hop Support; and,
4) Packet Traffic Minimization.

Researchers Nesargi and Prakash (2002) presented a new approach MANET conf: Configuration of Hosts in Mobile Ad Hoc Network. In this approach, every time the currently connected node assigns IP address to a new node, it floods the whole network to ask permission to assign the chosen address to be given to the new node. While in the Buddy system approach (Mohsin & Prakash, 2002), each node synchronizes periodically to keep track of the IP addresses assigned. Both of these approaches proved to be inefficient as it produces additional communication overhead when asking for permission and on periodic synchronization. The Backup Source Node approach (Jan & Ullah, 2011) assures uniqueness through the use of centralized assignment of IP address and also providing a backup source node to cope with the dynamic nature of MANET. Using centralized assignment of IP address limits the use of periodic updates thus minimizing communication overhea, but, the centralized approach degrades heavily on a scenario in which client nodes are multi-hops away from the source node (Singh & Nipur, 2011).

In terms of Address Reclamation, there are two ways that a node may leave: gracefully or abruptly. When a node leaves gracefully, it notifies one of its directly reachable node. When a node leaves abruptly, the remaining nodes are responsible in detecting and reclaiming the IP address of the departed nodes through periodic synchronization (Jan & Ullah, 2011), or when the remaining nodes attempt to contact the departed node (Kumar & Prabhu, 2015; and, Nesargi & Prakash, 2002).

In MANETconf (Nesargi & Prakash, 2002) when a new node, A, enters the network, it chooses a reachable connected node, B, which will perform address allocation on its behalf. In Buddy System (Mohsin & Prakash, 2002) if node, C, is the one who will assign IP address to the new node has allocated all the IP addresses from its block, then node C will search for an IP address table from its neighbour that still has some available addresses. If none of the neighbors has free IP addresses available, node C will search for nodes which are at a distance of two hops and so on.

In a fully distributed approach such as Prophet Address Allocation (Zhou et al., 2003) and Dynamic Address Allocation Approach (Kahtri et al., 2016) multi hop support is not needed in allocation of IP address. Also, it has the lowest communication overhead and latency in assigning of addresses as it gives address on its directly connected nodes only.

IP Address Auto Configuration of Mobile Ad Hoc Network

Let **graph** *G* be the representation of a MANET with a collection of nodes to be represented with vertices $v_1, v_2, ..., v_n$(denoted by the set *V*) and a collection with wireless links to be represented with edges$e_1, e_2, ..., e_n$(denoted by the set *E*) joining all or some of these vertices. The **graph** *G* is then fully described and denoted by the doublet (*V,E*).

Master Server is represented by vertex v_{ms} in which it is elected to assign IP to new vertices that join the graph. It will also initiate the election process of the new Master Server every time there are changes in the graph *G* such as a new vertex connects and connected vertex leaves. It is also its responsibility to assure convergence among all connected vertices in the graph *G*. The Secondary Master Server is represented by vertex v_{sms}in which it will assume the responsibilities of the v_{ms} in case the latter goes down.

Preliminaries Before Electing the Master Server

There are preliminaries needed to be discussed that are necessary in the actual Master Server Election process. These are the Necessary Data Stored in Each Vertex, Multi-Hop Communication Algorithm, A New Node Joining the Network, and A Node Leaves the Network.

Necessary Data Stored in Each Vertex

Since in a MANET there is no central entity, vertices operate in distributed fashion in such a way that any vertex can be a v_{ms} or a v_{sms} as long as it meets the required criteria. This is possible by having each connected vertex store necessary data for election of v_{ms} and v_{sms}.

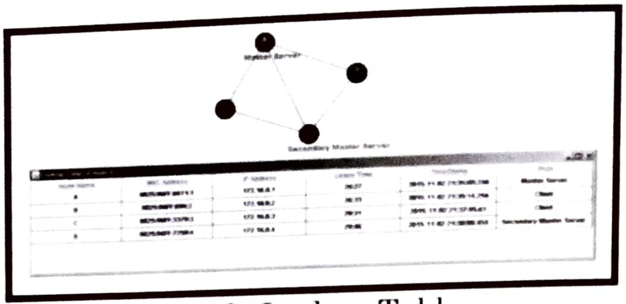

Figure 1. Sample Lookup Table

The necessary data stored in each vertex are the lookup table, and the adjacency matrix. The lookup table stores the IP address and lease time of each connected vertex in the network. It indicates also the position of each vertex whether it is a v_{ms}, v_{sms} or a client v_c. The following are the fields within the lookup table:

1) MAC address (unique key) – hardware address of the vertex.
2) IP address – logical address of the node assigned by the v_{ms}. It uses the Class B IP address of 172.16.0.0/16.
3) Acknowledged Timestamp – is the time the new vertex becomes a part of the graph G and acknowledged by the v_{ms}. It uses a 24-hour time notation.
4) Lease Time - determines how long the client v_c can use the assigned IP address. The unit is in minutes.
5) Role – indicates whether the vertex is a v_{ms}, v_{sms} or a v_c.

Figure 2 shows a sample lookup table.

	A	B	C	D
A	0	1	1	1
B	1	0	1	1
C	1	1	0	0
D	1	1	0	0

Figure 3. Sample Adjacency Matrix

The adjacency matrix represents the topology of the graph *G*. It shows the connections of vertices to each other in the graph *G*. The adjacency matrix of the v_{sms} differs from the adjacency matrix of v_{ms} and the v_c. The v_{sms} will assume the responsibilities of the v_{ms} when it goes down. For smooth and less overhead transition when v_{ms} goes down, the v_{sms} holds the adjacency matrix representation of the future topology of the network without the v_{ms}. The v_{ms} and the clients hold the adjacency matrix representation of the current topology of the graph *G*. Figure 3 the adjacency matrix for the graph shown in Figure 2.

Multi-Hop Communication Mechanism

MANET by nature sends message through broadcast messaging and since this study is independent from routing protocols, it is necessary to describe this mechanism when a node communicates with another node in a multi-hop topology.

Since broadcast messaging can greatly increase communication overhead especially in decentralized networks such as the MANET (Sze-Yao et al, 2002), there are requirements to satisfy before a node can accept the message, otherwise it will be discarded, for the purpose of reducing broadcast overhead:

1) The recipient vertex should be included in the shortest path attached within the received message, and,
2) The source vertex should not be one of the successors of the recipient vertex in the shortest path attached within the received message as this will indicate that a loop was formed.

The mechanism for the Multi-Hop Communication is as follows:

Let vertex *A* be the starting source node and Node *C* be the destination node of Graph *G*, as shown in Figure 4.

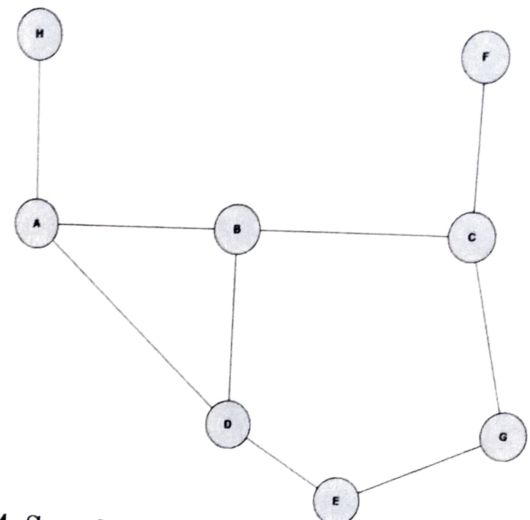

Figure 4. Sample Graph for Multi-Hop Communication

REPEAT

SEQUENCE

1) The source vertex generates the shortest path from the source node to the destination node C using Dijkstra's Algorithm.
2) The source vertex broadcasts the message (including the shortest path) to its adjacent vertices.
3) The adjacent vertex of the source node that satisfies the above-mentioned requirements will accept the message and becomes the new source vertex.

UNTIL the destination vertex becomes the source vertex.

Master Server Election

The Master Server v_{ms} is the vertex that will allocate an IP address and lease time to all of the connected vertices in the graph G. It will be elected among all connected vertices depending on its position in the topology that could provide the lowest communication overhead when allocating IP address and communicating with other connected nodes. The following are the criteria in accordance with their order of consideration:

1) Central Vertex of the Graph;
2) Degree; and,
3) Timestamp.

The first criterion is determining the **central vertex of the graph** by getting the minimum graph eccentricity or graph radius. Eccentricity of a vertex refers to the length of a longest path starting at that vertex. Eccentricity can be defined also as the measurement of the centrality of the vertex (Takes & Costers, 2013). It indicates that the vertex with very low eccentricity value is relatively close to every other vertex. Thus, such vertex is appropriate to be a v_{ms} to lessen the overhead incurs during multi-hop communication. Figure 5shows two nodes with the same minimum graph eccentricity.

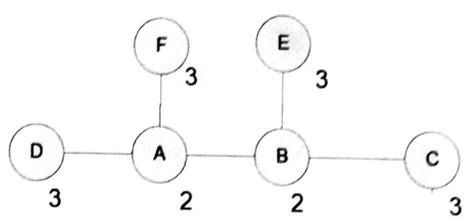

Figure 5. Graph Eccentricity

The second criterion is the **degree of vertices**. The v_{ms} will be selected on the node with the highest degree from the multiple vertices with the minimum graph eccentricity. The degree of a node is the number of edges incident to the vertex. The vertex with higher degree means more vertices are within the wireless transmission range of it. A sample graph with two vertices with the same minimum graph eccentricity with their degrees is shown in Figure 6.

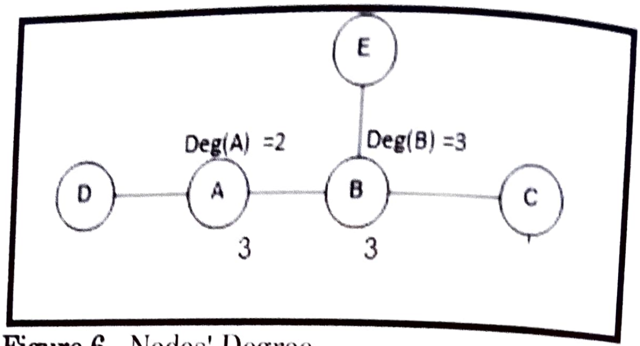

Figure 6. Nodes' Degree

Timestamp is the time the node becomes a part of the network and acknowledged by the v_{ms}. The reason for using the acknowledgment timestamp is that the node with the oldest acknowledgment timestamp means it is the most stable and reliable node.

The mechanism of Master Server Election is as follows:

SEQUENCE
IF a graph is a singleton **THEN** the vertex will be the Master Server

ELSE IF a graph *G* has two or more vertices **AND** only one vertex of *G* having the minimum graph eccentricity **THEN** such vertex will become the new Master Server

ELSE IF a graph *G* has two or more vertices **AND** two or more vertices of *G* having the minimum graph eccentricity **THEN** the vertex having the highest degree and with the minimum graph eccentricity of *G* will be the new Master Server.

ELSE IF a graph *G* has two or more vertices **AND** two or more vertices of *G* having the minimum graph eccentricity **AND** two or more vertices have the highest degree from the vertices with minimum graph eccentricity of *G*. **THEN** the vertex having the highest degree and with the minimum graph eccentricity of *G* **AND** the oldest timestamp will be the new Master Server.

ENDIF

Secondary Master Server Election

After the new Master Server Election Process, the Secondary Master Server Election will be initiated.
The mechanism of Secondary Master Server Election is as follows:

Let vertex *A* be the Master Server of Graph *G*.

SEQUENCE

IF vertex *A* is an Articulation Point of *G* **THEN** the number of Secondary Master Servers of *G* is less than or equal to the degree (*G*) **ELSE** there is only one Secondary Master Server in *G*.

IF vertex *A* elects the Secondary Master Server per partition **THEN** the criteria and process of electing a Secondary Master server per partition is the same as electing the Master Server.

ENDIF
Figure 7 shows a graph with a Master Server as an Articulation Point. This will produce two components of *G* if vertex *C* goes down. In these two components, two Secondary Master Servers will be elected.

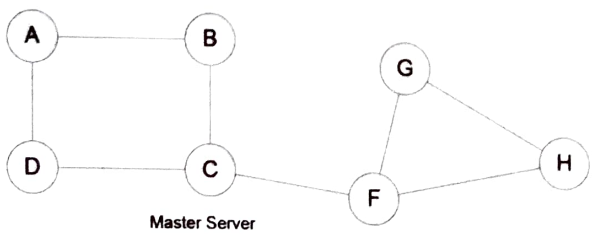

Figure 7. Master Server is an Articulation Point

Synchronization

After the election of v_{ms} and v_{sms}, the vertex that initiates the election of servers will inform all connected vertices about the newly elected server by sending its lookup table and adjacency matrix through broadcast messaging. All vertices within the graph ***G*** should have the update lookup table and adjacency matrix.

1) If all vertices are within the wireless transmission range of the previous v_{ms} then it will simply synchronize it by broadcast messaging.

2) If not all nodes are within the wireless transmission range of the previous v_{ms} then it will synchronize it by the use of Multi-Hop Synchronization as explained in the next sub-section.

Multi-Hop Synchronization

The vertex that initiates the election of servers will broadcast a synchronization message intended to all connected vertices of the network. Within the synchronization message is the latest lookup table and adjacency matrix, and a version number. The purpose of the version number is to track if the lookup table and adjacency matrix received are the latest or not. In order to prevent broadcast storm, there are protocols to follow by the nodes when to accept or reject the synchronization message:

1) If the vertex does not have yet lookup table and adjacency matrix then the synchronization message will be accepted.

2) If the vertex already has a lookup table and adjacency matrix but the version number of it is lower than the received new synchronization message's version number, then the new synchronization message will be accepted.

3) If the vertex already has a lookup table and adjacency matrix but the version number of it is higher or equal than the received new synchronization message's version number, then the new synchronization message will be rejected.

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3) If the vertex already has a lookup table and adjacency matrix but the version number of it is higher or equal than the received new synchronization message's version number, then the new synchronization message will be rejected.

The algorithm for Multi-Hop Synchronization is as follows:

Let vertex ***A*** be the vertex that initiates the synchronization process and the initial source vertex.

REPEAT

SEQUENCE

1) The source vertex broadcasts the message.
2) The neighbors of the source vertex that accepts the message based on the above-mentioned protocols will become the source vertex.

UNTIL all vertices receive the message.

Conclusion and Future Works

The study presented a new approach in IP address auto configuration mechanism in MANET. The approach uses Graph Theory Techniques. To address the dynamic and unpredictable nature of MANET, Master Server and Secondary Master Servers were used. These servers are dynamically elected by mainly identifying the central vertex of the graph through graph eccentricity. The Master Server is determined if it is an Articulation Point during its Election for anticipation of Network Partitioning. Dijkstra's Algorithm is used in Multi-Hop Communication to get the shortest path from a source node to the destination node. Breadth-First Search and Depth-First Search Traversals, Order and Size of the Graph, and Degree of the Node are also used. Each node holds an Adjacency Matrix of the network to be used in implementing the necessary functions.

By using Graph Theory, this study is able to achieve some necessary characteristics of an address auto configuration mechanism for MANET. These characteristics are address uniqueness, multi-hop support and packet traffic minimization.

In order to have fully functional address auto configuration for MANET, a mechanism for network partitioning and merging and address reclamation are needed. We are working on designing graph-theoretic mechanisms for these needed functions.

Also, the study recommends using a decentralized and distributed approach in the allocation of addressing by using a function that will generate unique IP address. This is desirable to greatly lessen the overhead allocation of IP Address by the Master Server in a multi-hop topology. The content and algorithm of the function may depend on several factors such as the hierarchical level of the new node to the Master Server or the number of connected nodes in the network. The function will be given to the new node by its directly connected neighbor. So, the new node will not depend anymore on the Master Server. Thus, it will prevent the multi-hop communication in the allocation of IP address. The study further recommends the possibility of using connected dominating set in the synchronization of data stored in each node. This could lessen the synchronization overhead. The node initiating synchronization will just send the updated data to the connected dominating sets. Finally, in order for all nodes to have the updated data, the connected dominating sets will simply broadcast the data to its neighbors.

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