Achieving Network Layer Connectivity in Mobile Ad Hoc Networks

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***Abstract*- Mobile Ad Hoc Networks (MANETs) is an area of networking which has been the focus of intense research in the past years. Due to their differences from traditional wire line networks, MANETs require a completely different set of protocols to cope with their decentralized nature. As such both evolution and innovation is required in many sectors. One such sector is the network layer which encompasses numerous important functions. This paper focuses on providing a comprehensive guide on achieving node connectivity at this layer. This includes selecting a proper routing protocol, as well as an auto configuration algorithm. These are assumed to operate around an IP protocol, more specifically IPv6. Finally we will discuss possibilities for ensuring QoS in Ad Hoc networks.**

Keywords-ad hoc routing, QoS, auto configuration

I. Introduction

Mobile Ad Hoc Networks are considered one of the most promising areas of networking. An Ad Hoc network consists of mobile nodes, which may vary in size & capabilities which communicate to create a network without pre-existing infrastructure. Thus a MANET can be formed dynamically without any pre-existing infrastructure, reducing both deployment time and costs and increasing flexibility. Unfortunately these advantages provide us with a set of problems. The majority of current network protocols have been developed to operate in strictly defined, mostly static environment, so using them in an ad hoc environment is the very least problematic. Thus a new protocol stack should be defined, using mostly newly developed protocols that can answer the challenges met in ad hoc networks. To define this protocol stack it is imperative that we develop a framework upon which the evaluation of such protocols can be accomplished. The network layer is responsible for converting the facilities of the lower layer into services that the upper layers can use. It is responsible for a host of important tasks such as routing and addressing and configuring nodes. The nature of Ad Hoc nature makes it impossible to use current network layer protocols. Thus a host of new ones have been proposed to achieve connectivity at this layer. This paper examines Ad Hoc routing protocols as well as address auto configuration algorithms. The former are protocols specifically developed to forward packets in multi-hop networks & the later aim to allocate each node in a MANET a unique IP address. Then we attempt to use these mechanisms to provide QoS mechanisms at the network layer. QoS is a required for a number of applications particularly real-time and critical ones, which are dominant in several areas of possible MANET use, such as military or aviation applications.

Mobile Ad Hoc networks are very different from wire line networks. In the later everything predetermined, that is the network topology is already know as well as its infrastructure and the equipment used. This allows for network administrator and architects to carefully plan its deployment to meet their requirement. Unfortunately Ad Hoc Networks are very different in that there is no knowledge about any of the abovementioned parameters. So there is no real information about the physical or logical connectivity of other nodes, neither about the services provided by each. This comes in stark contrast with traditional networks where most information is preset and those that aren't can be discovered with a simple service discovery protocol.

The rest of this paper is structured as follows: In Section II we will an overview of auto-networking technologies for MANETs. In Section III we will analyze Ad Hoc routing. Section IV will investigate the application of Quality Of Service mechanisms in Ad Hoc Networks. Finally Section V combines the above elements and provides the groundwork for future work.

II. Auto Configuration Technologies for MANETs

One of the most important characteristics of Ad Hoc networks is their spontaneous creation. For this to be achieved a mechanism must be invented that is able to organize the network and manage resources (like IP address) and configuration parameters (like the maximum transmission unit – MTU). In most applications this is impossible to do manually. Configuring an Ad Hoc network at the network layer involves one fundamental task: Unicast Address Allocation.

Unicast Address Allocation is the first and absolutely essential goal of the presented auto-networking technologies. Without a unique network layer address unicast communication is impossible. Obviously a stateful method, such as DHCP cannot be used, because it is not possible to guarantee access to a DHCP server for each node and since introducing such an centralized component weakens one of the fundamental MANET advantages, namely distributed operation.

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The newest version of the internet network layer protocol IPv6 includes algorithms for both stateful and stateless address autoconfiguration. This algorithm involves three steps: The assignment of a tentative link local address to each node, the verification of the uniqueness of this address through a Duplicate Address Detection process and finally the construction of a site-local address through the acquisition of a Router Advertisement message.

This algorithm while useful is inadequate for use in Mobile Ad Hoc Networks for several reasons. First of all it requires the presence of router on a link to configure anything but link-local addresses, but provides no means for auto configuring routers. In Ad Hoc networks all nodes play the role of a router thus it is practically impossible to use this algorithm. Nevertheless it has served as an inspiration for other mechanisms, some of which are described below.

The issue of node autoconfiguration (and in particular address allocation) has been the focus of significant research. Over the past few years numerous solutions have been proposed. These solutions can be subdivided into three categories:

A. Conflict Detection Allocation

Conflict Detection Allocation algorithms present the most straightforward solution to the problem of unicast address allocation. They adopt a method of trial and error to assign each node a valid address. The process is quite simple. The new node selects a random tentative address, then broadcasts a message to the whole network asking if that address is unique. If no response is received after a finite number of retries the address is considered unique and assigned to an interface. If an answer is received then the selected tentative address is already occupied and the node must select a new one and repeat the process.

B. Conflict Free Allocation

Conflict Free Allocation algorithms assign each new node an address that is already known to be unique. This is accomplished by using disjoint address pools for each node. Thus there can be no conflicts among the allocated addresses. Obviously to accomplish this each node must keep some sort of state information for each address.

C . Best Effort Allocation

Best Effort Allocation algorithms attempt to assign a new node an unused – to the best of their knowledge – address, but still use conflict detection methods to ensure that this address is indeed unique. Each node keeps a state for each address, but because he cannot assume to always have up-to-date information regarding the entire network cannot be sure that the information upon which it bases its address allocation is valid.

Following is a table describing the most important characteristics of each algorithm:

	Conflict detection	**Conflict free**	**Best effort**
Network Organization	Flat/ Hierarchical	Flat	Flat/ Hierarchical
Overhead	High	Small	High
Network Settling	Time	High	-
Node Join Time	High	Small	High
Address Reclamation	Not needed	Needed	Needed
Node Depart Time	-	Medium	Medium
Distributed	Yes	Yes	Yes
Complexity	Small	Medium	High
Evenness	Even	Uneven	Even
Scalability	Small	Medium	Small

In short we can say that best effort allocation algorithms tend to be the least useful, that is because the actually combine the worst of both worlds. To elaborate a little on this:

There are two important setbacks for Conflict Detection allocation. Firstly it broadcasts information on the network and it does it quite often, resulting in rather large overhead and secondly there is considerable delay until an address is assigned to an interface due to the timeouts involved. Best effort allocation has these disadvantages. Conflict Free allocation on the other hand has neither but is usually quite complex to implement and requires that an address state table is kept thus consuming memory which is not abundant in mobile nodes. Best effort allocation also maintains state tables, which is an additional problem. In general we can say that best effort allocation can be successfully used only with proactive routing protocols so as to take advantage of their periodic signals to update it's state tables.

To conclude we can say that both Conflict Detection and Conflict Free algorithms have their advantages. Conflict Detection Algorithms tend to be less scalable than Conflict Free ones, though the later cannot provide really large scalability either. For simple networks consisting of a few nodes a conflict detection algorithm like the one proposed in [6] would be ideal. For more demanding applications, complex solutions must be devised, possibly combining advantages from several categories.

III. Routing protocols for ad ho networks

A routing protocol must meet various requirements for its proper use in mobile ad hoc networks. Such requirements are low network and memory utilization, scalability, the ability to cope with increased node mobility, loop freedom, minimal routing overhead, Quality of Service capabilities, security and bandwidth efficiency.
Routing for MANETs has received the largest research focus in the past years. These efforts have yielded considerable results in the form of numerous protocols. These protocols can be classified into four categories: On-demand, Table-driven, Cluster-based and hybrid. Each of these categories follows a different approach and as such has its own different ups and downs. A short description of each category follows:

A. On Demand Protocols

On Demand protocols discover paths to a destination only when requested. Their function is compromised of two tasks. The first, route discovery involves finding valid routes to a destination. This is accomplished by broadcasting a Route Request (RREQ) packet on the network. This packet propagates through network until it reaches the destination node, which then retraces the route and replies with a Route Reply (RREP) packet. (Note that the route inversion is only possible when the links are symmetric). Since this is not always the case the node transmitting the RREP packet may also have to perform route discovery. When the node initiating route discovery receives a RREP packet it has at least one valid route to the destination node.
The second task that on-demand routing protocols must handle is route maintenance. This involves discovering and patching up problems with already discovered routes. This is handled through Route Error (RERR) packets that are transmitted when a node detects a broken link. Nodes receiving this packet stop forwarding packets using routes that use this link.
On-demand protocols have several advantages, the most important being low overhead, since routes are only discovered when requested. In addition since no routing tables are maintained they require relatively little memory to operate. On the downside they introduce a considerable delay from the request of a route until it's discovery. Examples of on demand protocols are the Ad hoc On Demand Distance Vector (AODV) and the Dynamic Source Routing (DSR).
AODV is the most sophisticated protocol for MANETs so far and has been at the epicentre of most research. AODV follows the on-demand protocol format described above. In order to avoid the infinite looping of packets of the "Bellman-Ford" algorithm, AODV uses sequence numbers to stamp routes from an originate to a destination node. AODV is also capable to manage security considerations and it has multicast and other abilities through the various existing extensions.

B. Table Driven Protocols

Table driven protocols maintain tables in which they attempt to have at least one valid route to each node in the network. This is accomplished by the periodic broadcast of messages. With these messages a node declares its presence and availability to its neighbours. When the network topology changes, nodes update their tables by transmitting update packets. These tables can also contain other useful information, such as a list of all the transmitting nodes neighbours or the nodes current routing table. The major strength of proactive protocols is that there is no delay until the route request is served. Their weakness is that they produce high overhead due to the continuous packet transmissions. An example of table-driven protocols is TBRPF (Topology dissemination Based on Reverse Path Forwarding).

C. Cluster based Protocols

Cluster based protocols are based on the concept of grouping nodes together depending various topology parameters. These protocols usually elect a cluster head node, which is responsible for the communication with other clusters. The connection between the different clusters can be achieved through intermediate nodes, known as gateways, which belong to many clusters at the same time. The advantages and disadvantages of these protocols may vary depending on the use of the ad hoc network. The most serious drawback is that they introduce a form a centralized structure which is difficult to maintain due to node mobility.
On the upside routing overhead is significantly limited. An example of these protocols is the Cluster Based Routing Protocol (CBRP).

D. Hybrid Protocols

Hybrid protocols combine various characteristics of all the above categories. Depending on the protocol, we have on demand protocols with enhanced use of procedures of table driven protocols and the opposite. Many protocols also use clustering concepts depending on the application for which the mobile ad hoc network is intended. An example of these protocols is the Zone Routing Protocol (ZRP).

IV. QOS MECHANISMS IN AD HOC NETWORKS

The mobility and dynamic topology of the nodes in a MANET make network management a really challenging. This is because the level of the offered "quality" in an established connection varies depended of a variety of external conditions. So the intention is the definition of a Quality of Service (QoS) model which will operate with the minimum resources and will adapt troublelesly in dynamic environments.
QoS is the mechanism which is responsible for the management of traffic in such a way that it can meet the demands of each application which wants to use the network each time without wasting the already scanty in MANETs resources.
When we refer to the availability of QoS we mean a set of quantitative metrics which define it. These are the available

bandwidth, the packet loss rate, delay, packet jitter, hop count, path reliability.

The use of QoS is essential in applications which are sensitive to the time of their transmission, such as real time applications. People will be using MANETs to connect each other via very common devices (PDAs, laptops, mobile phones etc.) from almost anywhere and use services such as video on demand, videoconference, and internet telephony.

Some additional difficulties for providing QoS in MANETs arise from their decentralized nature, their limited - due to the wireless links - bandwidth, the case of overload, the signal attenuation, noise, external elements, limited resources, power management, end to end protocols and demands of the applications.

Up to today most research on providing QoS for MANETs is the evolution of the two main architectures for wired networks, Integrated Services and Differentiated Services. The later dissever each flow of the traffic and treat each independently according to its demands, while the in former all the flow is been treated using a single method.

QoS metrics should be taken into account when designing a routing protocol. Usually these are either the minimum bandwidth or the maximum delay, as well as the method for path calculation, the way by which the QoS will be forwarded to the other nodes and remain stable and dissever priorities. All these ought to dynamically adjusted with each topological change of the network.

CEDAR (Core-Extraction Distributed ad hoc Routing Algorithm) is an algorithm which provides routing with quality of service in MANETs. To establish a connection the algorithm divides the network into smaller subnets in which the core extraction mechanism chooses an appropriate node to be responsible for route computation. The core nodes are then informed about the condition of surrounding and their bandwidth availability. The next step is the establishment of a connection between the source and destination nodes, considering the information provided by the core nodes. The main advantage of the algorithm is its simple routing structure, as well as the fact that it's cluster based architecture assigns most of the work to the core nodes. This architecture proves to be the algorithms main setbacks as these nodes can become overwhelmed in scenarios with high node mobility or a large number of nodes.

Research on the two aforementioned architecture had yielded a number of mechanisms for providing QoS, the most important of them being the ReSerVation Protocol, DiffServ, Multi Protocol Label Switching, Subnet Bandwidth Management.

RSVP is a very promising algorithm. It differentiates each flow from the traffic stream. A session defines the destination address, destination port and a protocol identifier. The messages needed for the propagation of the QoS metrics are transmitted to the same direction as the media flow. It supports both multicast and unicast flows, which are reserved in one direction only. It is a soft state, receiver oriented protocol, which allows transparent flow through non-RSVP routers and switches. RSVP does not control directly the behavior of the network devices.

Another way to establish QoS conditions in a network is the through signaling. INSIGNIA is the most prominent signaling protocol. It is quite effective since it accomplishes not to use many acknowledgment packets thus not imposing a significant amount of additional overhead. It also includes a feedback mechanism, which decreases the error probability.

Finally the use of IPv6 as the default network protocol provides as with some built-in QoS capabilities, through an option in the hop by hop extension header (QoS Object Option).

V. Conclusion

In this paper we described numerous technologies that attempt to answer the most important challenges met in the network layer in Mobile Ad Hoc Networks. These technologies can be combined in various ways to achieve the desired result, which is a reliable network layer protocol under the IPv6 umbrella.

Future work includes the realization of this combination and it's incorporation in a complete protocol stack.

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