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Simulation of Routing Protocols in Wireless Ad-hoc Networks

[1] Ms. Snehal Chaflekar [2] Ms. Deepika Bhatiya[3] Ms. S. Wankhede
[1] [2][3] Professor
Priyadarshini Bhagwati College of Engineering,(PBCOE), Nagpur
[1] snehalchaflekar@gmail.com [2] shrunkhala.wankhede@gmail.com[3] deepika.18850@gmail.com

***Abstract*— Ad-hoc networking is a concept in computer communications, which means that users wanting to communicate with each other form a temporary network, without any form of centralized administration. Each node participating in the network acts both as host and a router and must therefore be willing to forward packets for other nodes. For this purpose, a routing protocol is needed. An ad-hoc network has certain characteristics, which imposes new demands on the routing protocol. The most important characteristic is the dynamic topology, which is a consequence of node mobility. Nodes can change position quite frequently, which means that we need a routing protocol that quickly adapts to topology changes. The nodes in an ad-hoc network can consist of laptops and personal digital assistants and are often very limited in resources such as CPU capacity, storage capacity, battery power and bandwidth. This means that the routing protocol should try to minimize control traffic, such as periodic update messages. Two of the proposed protocols are DSR and AODV. They perform very well when mobility is high. However, we have found that a routing protocol that entirely depends on messages at the IP-level will not perform well. Some sort of support from the lower layer, for instance link failure detection or neighbor discovery is necessary for high performance. A large network with many mobile nodes and high offered load will increase the overhead for DSR quite drastically. In these situations, a hop-by-hop based routing protocol like AODV is more desirable.**

I. INTRODUCTION

Wireless communication between mobile users is becoming more popular than ever before. This due to recent technological advances in laptop computers and wireless data communication devices, such as wireless modems and wireless LANs. This has lead to lower prices and higher data rates, which are the two main reasons why mobile computing continues to enjoy rapid growth. There are two distinct approaches for enabling wireless communication between two hosts. The first approach is to let the existing cellular network infrastructure carry data as well as voice. The major problems include the problem of handoff, which tries to handle the situation when a connection should be smoothly handed over from one base station to another base station without noticeable delay or packet loss. Another problem is that networks based on the cellular infrastructure are limited to places where there exists such a cellular network infrastructure.

The second approach is to form an ad-hoc network among all users wanting to communicate with each other. This means that all users participating in the ad-hoc network must be willing to forward data packets to make sure that the packets are delivered from source to destination. This form of networking is limited in range by the individual nodes transmission ranges and is typically smaller compared to the range of cellular systems. This does not mean that the cellular approach is better than the ad-hoc approach. Ad-hoc networks have several advantages compared to traditional cellular systems. These advantages include:

- On demand setup
- Fault tolerance
- Unconstrained connectivity

Ad-hoc networks do not rely on any pre-established infrastructure and can therefore be deployed in places with no infrastructure. This is useful in disaster recovery situations and places with non-existing or damaged communication infrastructure where rapid deployment of a communication network is needed. Ad-hoc networks can also be useful on conferences where people participating in the conference can form a temporary network without engaging the services of any pre-existing network. Because nodes are forwarding packets for each other, some sort of routing protocol is necessary to make the routing decisions. Currently there does not exist any standard for a routing protocol for ad-hoc networks, instead this is work in progress. Many problems remain to be solved before any standard can be determined. This thesis looks at some of these problems and tries to evaluate some of the currently proposed protocols.

II. WIRELESS AD-HOC NETWORKS

2.1 General

A wireless ad-hoc network is a collection of mobile/semi-mobile nodes with no pre-established infrastructure, forming a temporary network. Each of the nodes has a wireless interface and communicates with each other over either radio or infrared. Laptop computers and personal digital assistants that communicate directly with each other are some examples of nodes in an ad-hoc network. Nodes in the ad-hoc network are often mobile, but can also consist of stationary nodes, such as access points to the Internet. Semi mobile nodes can be used to deploy relay points in areas where relay points might be needed temporarily. Figure 1 shows a simple ad-hoc network with three nodes. The outermost nodes are not within transmitter range of each other. However the middle node can be used to forward packets between the utermost nodes. The middle node is acting as a router and the three nodes have formed an ad-hoc network.

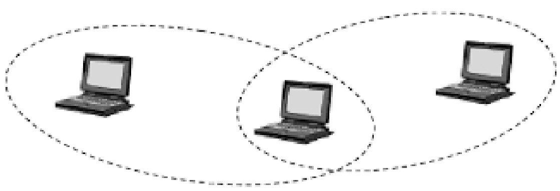

Figure 1:Example of a simple ad-hoc network with three participating nodes.

An ad-hoc network uses no centralized administration. This is to be sure that the network wont collapse ust because one of the mobile nodes moves out of transmitter range of the others. Nodes should be able to enter/leave the network as they wish. Because of the limited transmitter range of the nodes, multiple hops ay be needed to reach other nodes. Every node wishing to participate in an ad-hoc network must be willing to forward packets for other nodes. Thus every node acts both as a host and as a router. A node can be viewed as an abstract entity consisting of a router and a set of affiliated mobile hosts (Figure 2). A router is an entity, which, among other things runs a routing protocol. A mobile host is simply an IP-addressable host/entity in the traditional sense.

Ad-hoc networks are also capable of handling topology changes and malfunctions in nodes. It is fixed through network reconfiguration. For instance, if a node leaves the network and causes link breakages, affected nodes can easily request new routes and the problem will be solved. This will slightly increase the delay, but the network will still be operational. Wireless ad-hoc networks take advantage of the nature of the wireless communication medium.

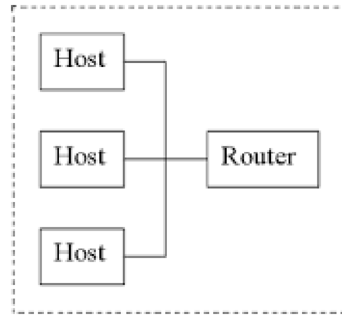

Figure 2: Block diagram of a mobile node acting both as hosts and as router.

In other words, in a wired network the physical cabling is done a priori restricting the connection topology of the nodes. This restriction is not present in the wireless domain and, provided that two nodes are within transmitter range of each other, an instantaneous link between them may form.

2.2 Usage

There is no clear picture of what these kinds of networks will be used for. The suggestions vary from document sharing at conferences to infrastructure enhancements and military applications. In areas where no infrastructure such as the Internet is available an ad-hoc network could be used by a group of wireless mobile hosts. This can be the case in areas where a network infrastructure may be undesirable due to reasons such as cost or convenience. Examples of such situations include disaster recovery personnel or military troops in cases where the normal infrastructure is either unavailable or destroyed. Other examples include business associates wishing to share files in an airport terminal, or a class of students needing to interact during a lecture. If each mobile host wishing to communicate is equipped with a wireless local area network interface, the group of mobile hosts may form an ad-hoc network. Access to the Internet and access to resources in networks such as printers are features that probably also will be supported.

2.3 Characteristics

Ad-hoc networks are often characterized by a dynamic topology due to the fact that nodes change their physical location by moving around. This favors routing protocols that dynamically discover routes over conventional routing algorithms like distant vector and link state [23]. Another characteristic is that a host/node have very limited CPU capacity, storage capacity, battery power and bandwidth, also referred to as a "thin client". This means that the power usage must be limited thus leading to a limited transmitter range. The access media, the radio environment, also has special characteristics that must be considered when designing protocols for ad-hoc networks. One example of this may be unidirectional links. These links arise when for example two nodes have different strength on their transmitters, allowing only one of the host to hear the other, but can also arise from disturbances from the surroundings. Multihop in a radio environment may result in an overall transmit capacity gain and power gain, due to the squared relation between coverage and required output power. By using multihop, nodes can transmit the packets with a much lower output power.

2.4 Routing

Because of the fact that it may be necessary to hop several hops (multi-hop) before a packet reaches the destination, a routing protocol is needed. The routing protocol has two main functions, selection of routes for various source-destination pairs and the delivery of messages to their correct destination. The second function is conceptually straightforward using a variety of protocols and data structures (routing tables). This report is focused on selecting and finding routes.

2.4.1 Conventional protocols

If a routing protocol is needed, why not use a conventional routing protocol like link state or distance vector? They are well tested and most computer communications people are familiar with them. The main problem with link-state and distance vector is that they are designed for a static topology, which means that they would have problems to converge to a steady state in an ad-hoc network with a very frequently changing topology. Link state and distance vector would probably work very well in an ad-hoc network with low mobility, i.e. a network where the topology is not changing very often. The problem that still remains is that link-state and distance-vector are highly dependent on periodic control messages. As the number of network nodes can be large, the potential number of destinations is also large. This requires large and frequent exchange of data among the network nodes. This is in contradiction with the fact that all updates in a wireless interconnected ad hoc network are transmitted over the air and thus are costly in resources such as bandwidth, battery power and CPU. Because both link-state and distance vector tries to maintain routes to all reachable destinations, it is necessary to maintain these routes and this also wastes resources for the same reason as above. Another characteristic for conventional protocols are that they assume bi-directional links, e.g. that the transmission between two hosts works equally well in both directions. In the wireless radio environment this is not always the case. Because many of the proposed ad-hoc routing protocols have a traditional routing protocol as underlying algorithm, it is necessary to understand the basic operation for conventional protocols like distance vector, link state and source routing.

2.4.2 Link State

In link-state routing [23], each node maintains a view of the complete topology with a cost for each link. To keep these costs consistent; each node periodically broadcasts the link costs of its outgoing links to all other nodes using flooding. As each node receives this information, it updates its view of the network and applies a shortest path algorithm to choose the next-hop for each destination. Some link costs in a node view can be incorrect because of long propagation delays, partitioned networks, etc. Such inconsistent network topology views can lead to formation of routing-loops. These loops are however short-lived, because they disappear in the time it takes a message to traverse the diameter of the network.

2.4.3 Source Routing

Source routing [23] means that each packet must carry the complete path that the packet should take through the network. The routing decision is therefore made at the source. The advantage with this approach is that it is very easy to avoid routing loops. The disadvantage is that each packet requires a slight overhead.

2.4.4 Classification

Routing protocols can be classified [1] into different categories depending on their properties.

- Centralized vs. Distributed
- Static vs. Adaptive
- Reactive vs. Proactive

One way to categorize the routing protocols is to divide them into centralized and distributed algorithms. In centralized algorithms, all route choices are made at a central node, while in distributed algorithms, the computation of routes is shared among the network nodes.
Another classification of routing protocols relates to whether they change routes in response to the traffic input patterns. In static algorithms, the route used by source-destination pairs is fixed regardless of traffic conditions. It can only change in response to a node or link failure. This type of algorithm cannot achieve high throughput under a broad variety of traffic input patterns. Most major packet networks uses some form of adaptive routing where the routes used to route between source-destination pairs may change in response to congestion A third classification that is more related to ad-hoc networks is to classify the routing

algorithms as either proactive or reactive. Proactive protocols attempt to continuously evaluate the routes within the network, so that when a packet needs to be forwarded, the route is already known and can be immediately used.

III. AD-HOC ROUTING PROTOCOLS

This chapter describes the different ad-hoc routing protocols that we have chosen to simulate and analyze.

a. Desirable properties

If the conventional routing protocols do not meet our demands, we need a new routing protocol. The question is what properties such protocols should have? These are some of the properties [5] that are desirable:

b. Distributed operation

The protocol should of course be distributed. It should not be dependent on a centralized controlling node. This is the case even for stationary networks. The difference is that nodes in an ad-hoc network can enter/leave the network very easily and because of mobility the network can be partitioned.

c. Loop free

To improve the overall performance, we want the routing protocol to guarantee that the routes supplied are loop-free. This avoids any waste of bandwidth or CPU consumption.

d. Demand based operation

To minimize the control overhead in the network and thus not wasting network resources more than necessary, the protocol should be reactive. This means that the protocol should only react when needed and that the protocol should not periodically broadcast control information.

e. Unidirectional link support

The radio environment can cause the formation of unidirectional links. Utilization of these links and not only the bi-directional links improves the routing protocol performance.

f. Security

The radio environment is especially vulnerable to impersonation attacks, so to ensure the wanted behavior from the routing protocol, we need some sort of preventive security measures. Authentication and encryption is probably the way to go and the problem here lies within distributing keys among the nodes in the ad-hoc network. There are also discussions about using IP-sec [14] that uses tunneling to transport all packets.

g. Power conservation

The nodes in an ad-hoc network can be laptops and thin clients, such as PDAs that are very limited in battery power and therefore uses some sort of stand-by mode to save power. It is therefore important that the routing protocol has support for these sleep-modes.

h. Multiple routes

To reduce the number of reactions to topological changes and congestion multiple routes could be used. If one route has become invalid, it is possible that another stored route could still be valid and thus saving the routing protocol from initiating another route discovery procedure.

Quality of service support Some sort of Quality of Service support is probably necessary to incorporate into the routing protocol. This has a lot to do with what these networks will be used for. It could for instance be real-time traffic support. None of the proposed protocols from MANET have all these properties, but it is necessary to remember that the protocols are still under development and are probably extended with more functionality. The primary function is still to find a route to the destination, not to find the best/optimal/shortest-path route. The remainder of this chapter will describe the different routing protocols and analyze them theoretically.

IV. NETWORK SIMULATOR

Network simulator 2 is the result of an on-going effort of research and development that is administrated by researchers at Berkeley. It is a discrete event simulator targeted at networking research. It provides substantial support for simulation of TCP, routing, and multicast protocols.

The simulator is written in C++ and a script language called OTcl 2 . Ns uses an Otcl interpreter towards the user. This means that the user writes an OTcl script that defines the network (number of nodes, links), the traffic in the network (sources, destinations, type of traffic) and which protocols it will use. This script is then used by ns during the simulations. The result of the simulations is an output trace file that can be used to do data processing (calculate delay, throughput etc) and to visualize the simulation with a program called Network Animator (NAM).

4.1 Mobility extension

There currently exist two mobility extensions to NS. These are:

- ❖ Wireless mobility extension developed by the CMU Monarch projects
- ❖ Mobility support, mobile IP and wireless channel support developed by C. Perkins at Sun Microsystems.

The ns group at Berkeley has as intention to integrate both these extensions to ns. This work is however not complete yet. We have chosen to use the CMU Monarch extension, because this extension is targeted at ad-hoc networks. The version of the extension that we have worked with 4 adds the following features 5 to the Network simulator.

4.2 Node mobility

Each mobile node is an independent entity that is responsible for computing its own position and velocity as a function of time. Nodes move around according to a movement pattern specified at the beginning of the simulation.

Realistic physical layers

Propagation models are used to decide how far packets can travel in air. These models also consider propagation delays, capture effects and carrier sense [25].

MAC 802.11

An implementation of the IEEE 802.11 Media Access Protocol (MAC) [9] protocol was included in the extension. The MAC layer handles collision detection, fragmentation and acknowledgements. This protocol may also be used to detect transmission errors. 802.11 is a CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) protocol. It avoids collisions by checking the channel before using it. If the channel is free, it can start sending, if not, it must wait a random amount of time before checking again. For each retry an exponential backoff algorithm will be used. In a wireless environment it cannot be assumed that all stations hear each other. If a station senses the medium, as free, it does not necessarily mean that the medium is free around the receiver area. This problem is known as the hidden terminal problem and to overcome these problems the Collision Avoidance mechanism together with a positive acknowledgement scheme is used. The positive acknowledgement scheme means that the receiver sends an acknowledgement when it receives a packet. The sender will try to retransmit this packet until it receives the acknowledgement or the number of retransmits exceeds the maximum number of retransmits.

Address Resolution Protocol

The Address Resolution Protocol, ARP [24] is implemented. ARP translates IP-addresses to hardware MAC addresses. This takes place before the packets are sent down to the MAC layer.

Ad-hockey

Ad-hockey is an application that makes it possible to visualize the mobile nodes as they move around and send/receives packets. Ad-hockey can also be used as a scenario generator tool to create the input files necessary for the simulations. This is done, by positioning nodes in a specified area. Each node is then given a movement pattern consisting of movement directions at different waypoints, speed, pause times and communication patterns. Screenshots of ad-hockey can be seen in Appendix C.

Radio network interfaces

This is a model of the hardware that actually transmits the packet onto the channel with a certain power and modulation scheme [25].

Transmission power

The radius of the transmitter with an Omni-directional antenna is about 250 meters in this extension.

Antenna gain and receiver sensitivity

Different antennas are available for simulations.

Ad-hoc routing protocols

Both DSR and DSDV have been implemented and added to this extension.

4.2 Shared media

The extension is based on a shared media model (Ethernet in the air). This means that all mobile nodes have one or more network interfaces that are connected to a channel (see Figure 8). A channel represents a particular radio frequency with a particular modulation and coding scheme. Channels are orthogonal, meaning that packets sent on one channel do not interfere with the transmission and reception of packets on another channel. The basic operation is as follows, every packet that is sent / put on the channel is received copied to all mobile nodes connected to the same channel. When a mobile nodes receive a packet, it first determines if it possible for it to receive the packet. This is determined by the radio propagation model, based on the transmitter range, the distance that the packet has traveled and the amount of bit errors.

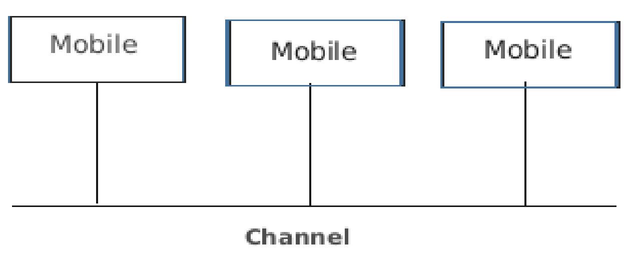

Figure 8: Shared media model.

4.3 Mobile node

Each mobile node makes use of a routing agent for the purpose of calculating routes to other nodes in the ad-hoc network. Packets are sent from the application and are received by the routing agent. The agent decides a path that the packet must travel in order to reach its destination and stamps it with this information. It then sends the packet down to the link layer. The link layer level uses an Address Resolution Protocol (ARP) to decide the hardware addresses of neighboring nodes and map IP addresses to their correct interfaces. When this information is known, the packet is sent down to the interface queue and awaits a signal from the Multiple Access Control (MAC) protocol. When the MAC layer decides it is ok to send it onto the channel, it fetches the packet from the queue and hands it over to the network interface which in turn sends the packet onto the radio channel. This packet is copied and is delivered to all network interfaces at the time at which the first bit of the packet would begin arriving at the interface in a physical system. Each network interface stamps the packet with the receiving interfaces properties and then invokes the propagation model.

The propagation model uses the transmit and receive stamps to determine the power with which the interface will receive the packet. The receiving network interfaces then use their properties to determine if they actually successfully received the packet, and sends it to the MAC layer if appropriate. If the MAC layer
receives the packet error- and collision- free, it passes the packet to the mobiles entry point. From there it reaches a demultiplexer, which decides if the packet should be forwarded again, or if it has reached its destination node.

V. CONCLUSIONS

The simulations have shown that there certainly is a need for a special ad-hoc routing protocol when the mobility increases. It is however necessary to have some sort of feedback from the link-layer protocol like IEEE MAC 802.11 when links go up and down or for neighbor discovery. To only be dependent on periodic messages at the IP-level will result in a very high degree of packet losses even when mobility increases a little. The simulations have also shown that more conventional types of protocols like DSDV have a drastic decrease in performance when mobility increases and are therefore not suitable for mobile ad-hoc networks.

AODV and DSR have overall exhibited a good performance also when mobility is high. DSR is however based on source routing, which means that the byte overhead in each packet can affect the total byte overhead in the network quite drastically when the offered load to the network and the size of the network increases. In these situations, a hop-by-hop based routing protocol like AODV is more desirable. One advantage with the source routing approach is however that in its route discovery operation it learns more routes. Source routing is however not desirable in ordinary forwarding of data packets because of the large byte overhead. A combination of AODV and DSR could therefore be a solution with even better performance than AODV and DSR.

Another key aspect when evaluating these protocols is to test them in realistic scenarios. We have tested them in three types of scenarios. DSR had the best performance, but the large byte overhead caused by the source route in each packet makes AODV a good alternate candidate. It has almost as good performance.

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