A MECHANISM FOR ENHANCING INTERNET CONNECTIVITY FOR MOBILE AD HOC NETWORKS

Shane Bracher[1]

[1]Faculty of Information Technology,
Bond University

ABSTRACT: Mobile ad hoc networks are an emerging wireless technology which differs from other networking technologies in that they are infrastructureless, autonomous, stand-alone networks. Although these characteristics enable simple deployment, ad hoc networks are limited in terms of connectivity as communication is confined to the boundaries of the local network. Due to this constraint, plus the growing trend towards establishing an "all IP environment", efforts are being made to integrate ad hoc networks with Mobile IP in order to ultimately bridge ad hoc networks to the Internet. This paper focuses on the connectivity of ad hoc network hosts to the Internet and proposes a mechanism for extending the periods of reachability of these hosts from the viewpoint of external hosts. From the simulation tests conducted on the custom built network simulator used to implement this proposal, positive results were produced showing an overall increase in the reachability times of ad hoc network hosts plus a decrease in the percentage of packet loss of incoming packets to the ad hoc network.

INTRODUCTION

Mobile ad hoc networks are essentially a type of wireless network consisting solely of a group of mobile devices (otherwise known as mobile hosts). For a mobile device to communicate with another device within its network, all mobile hosts in an ad hoc network perform packet forwarding. One of the main problems with these networks is that network splits can frequently occur due to mobile host mobility. Consequently, this can potentially lead to continuous disconnections and the ad hoc network being partitioned into many smaller ad hoc networks.

This research expands on the concept of traditional stand-alone ad hoc networks and explores the area of bridging ad hoc networks to the Internet. For an ad hoc network to possess Internet connectivity, it requires connection to a gateway node. Assuming that this gateway node (from here on referred to as the access router) is reliable in terms of Internet connectivity, the question is that would it be possible to utilise this node in such a way that the connectivity and communications of mobile hosts with other Internet hosts is less disrupted from potentially frequent, ad hoc network related disconnections? To answer this question, this paper investigates whether packet buffering within the access router combined with delayed disconnection notifications can assist in improving the connectivity of mobile hosts from the viewpoint of correspondent nodes on the Internet. It is important to note that this investigation will focus solely on incoming packets from correspondent nodes to mobile hosts and not the opposite direction as only the ad hoc network is assumed to be unreliable in terms of connectivity.

In relation to the practicability of this work, it could potentially prove to be beneficial towards enhancing the operation of streaming applications (eg. audio and video) running on top of UDP (User Datagram Protocol) over ad hoc networks. Given the prediction of multimedia based communications playing a much more dominate role in mobile computing in the not too distant future, this investigation is significant towards improving the prospects of ad hoc networks for mainstream usage which consequently assists in the progression and widening of the wireless Internet. However, due to the periodic time constraints associated with these applications, separate quality of service (QoS) mechanisms out of the scope of this research would need to be deployed in conjunction with this proposal.

This paper is organised in the following order: related work including the issues faced by researchers in this field; outline of the design of the mechanism; summary of the network simulator built to implement and test this mechanism; the results of the simulation tests followed by the conclusions of this research and future directions to improve upon this work.

RELATED WORK

To comprehend the difficulties and problems faced when communicating over ad hoc networks, it is important to realise some of the issues and characteristics associated with these networks. Some of these issues include mobility (highly dynamic movement of mobile hosts can lead to frequent topology changes), bandwidth consumption (ad hoc networks have a tendency to be frequently flooded with control packets) and routing (wired network routing protocols do not function over ad hoc networks due to mobility) [Hac03]. The development of a suitable ad hoc routing protocol has, in particular, been an area of high interest in recent times and this has resulted in the emergence of several popular routing protocol proposals [MSS03, PB94].

When communicating over the Internet, this is performed using IP (Internet Protocol). Although this protocol works well for wired networks, problems would emerge if it was used over ad hoc networks since IP does not support mobility. To resolve this, the Internet Engineering Task Force (IETF) proposed Mobile IP and later Mobile IPv6 (MIPv6); the latter supports larger (128-bit) IP addresses and incorporates new optimisation techniques. Explanations on the functioning of these protocols can be found in [FH00, Per97].

Therefore, one possible method for providing Internet connectivity to ad hoc networks would be to implement MIPv6 over them. However, this introduces some new issues including network architecture (how to integrate an infrastructureless network with a fixed infrastructure based network), addressing (a single ad hoc network is capable of spanning across several foreign subnets) and routing (how to find and route packets to the access router). One of the first major proposals for integrating Mobile IP and ad hoc networks was MIPMANET [JAL99]. As well as providing mobile hosts with Internet connectivity, it suggested how to provide roaming capabilities to mobile hosts for when they move into foreign networks. To improve on this proposal, [RK03] suggested deploying an alternative ad hoc routing protocol plus proposed a few techniques for reducing the level of flooding in the ad hoc network. In a separate study, [TSC03] identified the different communication scenarios possible when bridging ad hoc networks to the Internet. In relation to addressing strategies, a mechanism for providing global connectivity to mobile hosts is proposed in [DP02] which makes use of IPv6 addresses and eliminates the need for duplicate address detection.

DESIGN

The network model illustrated in Figure 1 was used for this investigation. This model consists of the following entities: correspondent node, access router, access point and mobile host. The correspondent node is simply a host on the Internet in a separate network external to the access router. The access router serves as the entry point from the Internet into the local network. The access points act as interfaces between the wired and wireless nodes within the local network. Finally, the mobile hosts essentially form the ad hoc network itself.

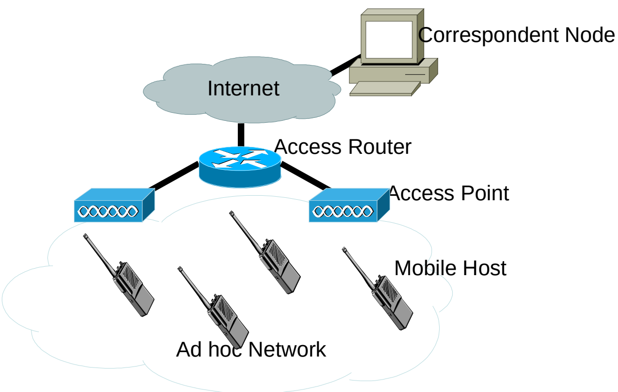

Figure 1. Network model.

In this model, a mobile host can possess Internet connectivity by either being within direct reach of an access point or within reach of another mobile host which possesses Internet connectivity (referred to as indirect reach). In the case of direct reach, the reliability of the mobile host's Internet connectivity is dependent upon its own mobility. However, in the case of indirect reach, not only is the mobile host's own mobility an issue, but also the mobility of all intermediary mobile hosts between itself and the access point. Particularly in this second case, it is easy to realise the potential for frequent disconnections and consequently, the need for a mechanism to lower the severity of this.

To prolong the connectivity of mobile hosts, a buffering system within the access router has been proposed. This system primarily affects the routing of incoming packets from the Internet into the local network and also affects the processing of route update control packets from the access points to the access router. The reachability states recognised in this system are given in Figure 2. This diagram shows the inclusion of a new reachability state (temporarily unreachable state) which signifies the period for when a mobile host is still reachable from the correspondent node's viewpoint but physically disconnected. The philosophy behind this system is that mobile hosts are anticipated to be unreachable for only a very short period of time before re-establishing connectivity again.

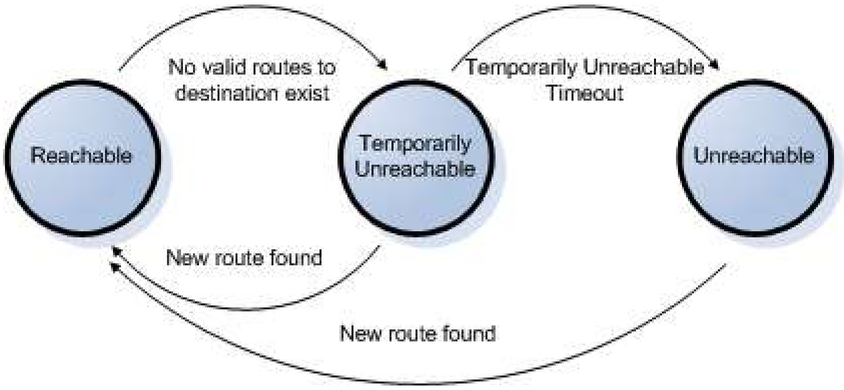

Figure 2. Reachability states of mobile hosts.

The data structures used in this proposed system include a packet buffer, a two-tier routing table and a list containing temporarily unreachable mobile hosts (known as the temporarily unreachable destinations list). As routing in ad hoc networks is host based (as opposed to being network based as the case with wired IP networks), a two-tier routing table design has been suggested given that the access router routes packets to both network types. The top tier is network based and contains routes only to external networks whereas the ad hoc tier is host based and contains only routes to mobile hosts reachable within the ad hoc network. The packet buffer holds incoming packets destined to temporarily unreachable mobile hosts. Once a mobile host becomes either reachable or unreachable, any buffered packets to this host are extracted from the buffer and processed accordingly.

Some of the system variables to consider in this design include the buffer timeout period (which also signifies the maximum duration which a mobile host can be temporarily unreachable for before being declared as unreachable), route entry expiry, periodic route update interval and the buffer size. To conceptualise the entire design of the proposed mechanism, in Table 1, a brief description of each system component is provided and following this, Figure 3 shows how all of these components interconnect.

Table 1. Buffering system components.

Component	Description
Incoming Packet Listener (IPL)	Listens for incoming packets; checks the reachability status of the packet's destination before processing the packet accordingly.
Periodic Route Update Request Coordinator (PRURC)	Periodically requests all access points to send the access router a route update packet.
Route Update Listener (RUL)	Listens for incoming route update packets from access points and updates the routing table.
Reachable Destinations Coordinator (RDC)	Manages all of the reachable destination monitors. Also, when a new destination is found, informs the Temporarily Unreachable Destinations Coordinator.

Reachable Destination Monitor (RMC)	Manages all of the route monitors for a single reachable destination. When all of the destination's route monitors expire, the Temporarily Unreachable Destinations Coordinator is alerted.
Route Monitor (RM)	Manages a single routing table entry. Removes the entry from the routing table when it expires.
Temporarily Unreachable Destinations Coordinator (TUDC)	Manages all of the temporarily unreachable destination monitors and the Temporarily Unreachable Destinations List.
Temporarily Unreachable Destination Monitor (TUDM)	Manages a single temporarily unreachable destination. When this monitor expires, it alerts the Temporarily Unreachable Destinations Coordinator to consider this destination as now unreachable.
Destination Found Coordinator (DFC)	Processes buffered packets destined to a temporarily unreachable destination which has just become reachable again.
Destination Lost Coordinator (DLC)	Processes buffered packets destined to a temporarily unreachable destination which has suddenly been declared as unreachable.

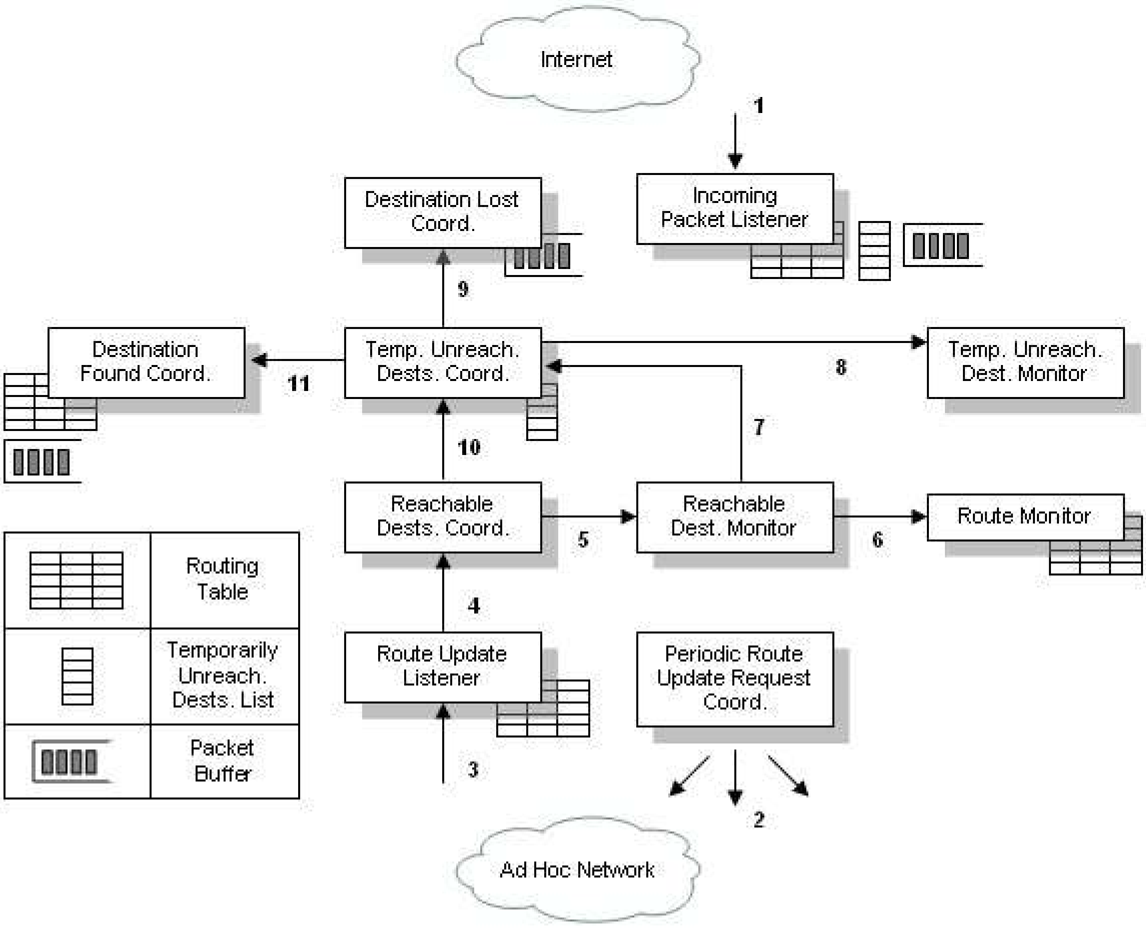

Figure 3. Architecture of the buffering system.

To elaborate on how this proposed mechanism works, provided below is an explanation on each of the numerical references shown in Figure 3:

1. All incoming packets from the Internet are intercepted by the IPL. On receiving a packet, the IPL looks up the routing table (RT) to find a route. If a route is found, the packet is forwarded to the next hop given in the route. Otherwise, the IPL checks if the packet's destination

address is listed in the temporarily unreachable destinations list (TUDL). If so, the packet is added to the packet buffer. If not, the packet is deemed as undeliverable and consequently, an ICMP Destination Unreachable packet is sent to the packet's source.

2. Periodically, a new route update request packet is broadcasted by the PRURC to all of the access points residing in the ad hoc network.
3. When a route update packet from an access point is received, it is handled by the RUL.
4. For each route extracted from the route update packet, the RUL first adds it to the RT before alerting the RDC of this route.
5. The RDC checks the destination address of the route information it has received and passes this on to the monitor handling this particular destination.
6. When a new route is received, the RDM creates a new RM to monitor this route. When the route expires (denoted by the route entry expiry variable), the RM informs the RDM of this and removes the route from the RT.
7. The RDM alerts the TUDC of the destination address it is monitoring when it no longer has any active RMs. This alert signifies that the destination has now changed state from being reachable to temporarily unreachable.
8. When the above alert is received by the TUDC, it first adds the destination address to the TUDL before creating a new TUDM to monitor the status of the destination. The TUDM remains active for the duration of the buffer timeout period. After this time, it alerts the TUDC indicating that the destination should now be considered unreachable.
9. When a destination changes from being temporarily unreachable to unreachable, the TUDC removes the destination address from the TUDL and sends an alert to the DLC to process any buffered packets to that destination. The DLC extracts all buffered packets to the unreachable destination from the buffer and sends ICMP Destination Unreachable packets to the source addresses.
10. In addition to Reference 5, when the RDC cannot find an existing RDM for a new route, it alerts the TUDC indicating that a new reachable destination has been found.
11. When a new reachable destination has been found, the TUDC first checks to see if the destination's address is listed on the TUDL. If so, the TUDM monitoring that address is destroyed before an alert is sent to the DFC to process any buffered packets destined to that address. The DFC performs a RT lookup for the destination address, extracts all buffered packets to the address from the buffer before finally forwarding the packets to the next hop address.

IMPLEMENTATION

To test the effectiveness of the proposed buffering system, a custom built network simulator in Java was created. This implementation and testing phase involved both evaluating the effect this mechanism has in terms of packet loss and transmission delay of incoming packets from the Internet to the ad hoc network as well as gathering statistics relating to mobile host reachability periods with and without the buffering system in use.

The network simulator was broken up into three components with each component being deployed on separate machines. These components were namely correspondent node, access router and ad hoc network. The correspondent node component basically functioned as a packet generator which periodically transmitted UDP datagram packets to the access router destined to one of the mobile hosts in the ad hoc network. The access router component implemented all of the buffering system components and data structures outlined in the previous section. Finally, the ad hoc network component provided a simulated ad hoc network containing two fixed access points connected to the access router and numerous mobile hosts. Each mobile host and access point was instantiated as a separate thread in the simulation and was designated an individual virtual network interface possessing separate IP addresses. The movement path of each mobile host was completely randomised but bounded within a pre-defined area of 800 by 600 metres. As well as the correspondent node and access router, each mobile host and access point maintained separate log files recording all of the data packets it processed.

In relation to ad hoc routing protocols, the decision was made not to base the simulation on any particular ad hoc routing protocol proposal but rather a "best case" routing protocol whereby route discovery and maintenance were performed without excessive delay costs. This decision was based on the view that an adequate ad hoc routing protocol proposal currently does not yet exist for ad hoc networks desiring Internet connectivity given the high levels of consumed bandwidth and long route setup delays associated with some of the existing proposals. For this reason, the proposed buffering system was designed to work independently of any ad hoc routing protocol so that any future routing protocol proposal can be accommodated for.

Throughout all of the simulation tests conducted, there were a number of variables tested. A list of the properties and values tested is given in Table 2. Provided in Table 3 is a list of all of the constant properties set for each test. In total, 27 different test scenarios were tested.

Table 2. Variable properties of simulation tests.

Property	Values
Buffer timeout	0, 5, 10 seconds
Packet arrival rate	500, 1000, 2000 ms
Number of mobile hosts	5, 10, 15

Table 3. Constant properties of simulation tests.

Property	Value
Test duration	5 minutes
Route entry expiry	3000 ms
Route update interval	2000 ms
Mobility rate	100%
Buffer size	1000
Ad hoc node transmission range	200 metres

SIMULATION RESULTS

Figure 4 shows the results of the packet loss analysis for the test scenarios which had a packet arrival rate of 500 ms. From this chart, it is clear, particularly in the case where the buffer timeout value was 10,000 ms, that a reduction in packet loss was achieved as a result of implementing the proposed buffering system.

However, in Figure 5, which shows the results of the transmission delay analysis, the proposed mechanism performed less favourably in this regard producing higher transmission delay times than the scenarios not implementing the buffering system. Given that the buffering system design incorporates a time delay (in the form of the buffer timeout value), this outcome for the transmission delay analysis was anticipated. These results though still don't clearly indicate whether the improvements attained from the reductions in packet loss outweigh the increased costs gained in transmission delay times.

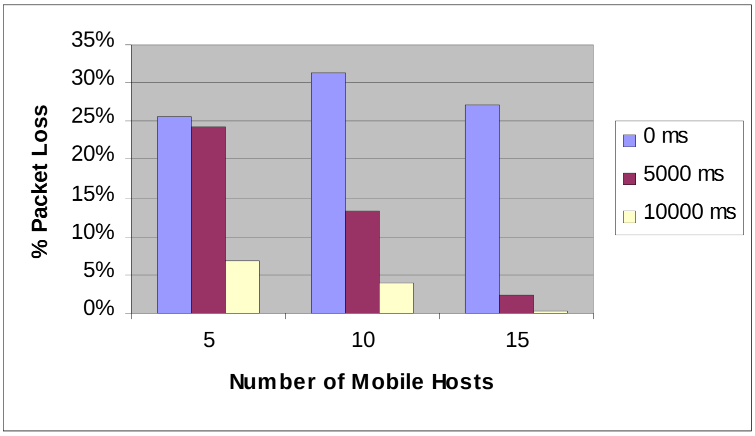

Figure 4. Packet loss (packet arrival rate 500 ms).

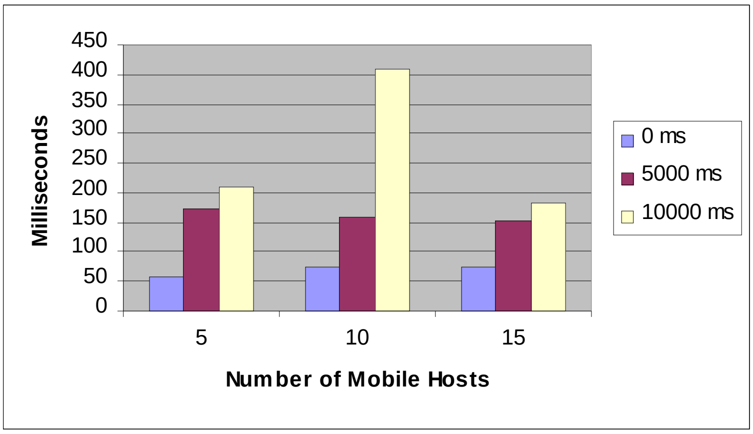

Figure 5. Transmission delay (packet arrival rate 500 ms).

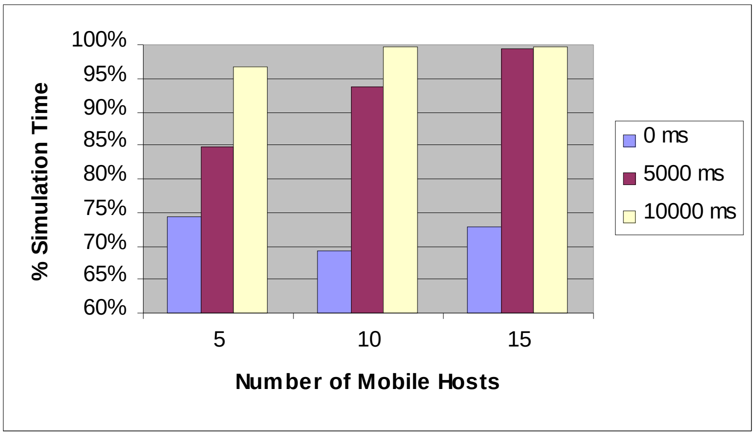

Figure 6. Comparison of mobile host connectivity periods.

The aim behind the third analysis was to compare, from the viewpoint of the correspondent node, the reachability times of a mobile host for when the buffering system was in use and absent. As illustrated in Figure 6, the mobile host appeared reachable much more often to the correspondent node when the proposed mechanism was deployed. In fact, the mobile host appeared reachable more than 10% longer when the buffering system was in use. Furthermore, in many cases, when the buffering system was used, the mobile host appeared reachable for more than 93% of the simulation time. From these results, it can easily be seen that the mechanism has enhanced the connectivity of mobile hosts.

CONCLUSIONS AND FUTURE DIRECTIONS

From the simulation tests, a trade off is evident between packet loss and transmission delay levels when analysing the effectiveness of this proposed buffering system. Although it was found that lower packet loss rates are produced in comparison to networks not deploying this mechanism, the trade off is an increase in the transmission delay costs. As for reachability periods, this mechanism significantly extended the reachable duration of mobile hosts from the correspondent node's perspective.

To extend and improve on this design, there are a number of limitations which need resolving. Firstly, to calculate a more accurate and optimal buffer timeout period, there is the need to replace the currently static buffer timeout value with a dynamic value which automatically reacts to round trip times and other dynamic network variables associated with each communication session of the mobile hosts. Secondly, an extension to this design is required to accommodate for mobile hosts roaming into foreign ad hoc networks. Such an extension would require collaboration between buffering systems deployed on multiple access routers on different networks. Finally, another extension which assists in the recovery of packet loss occurring from within the ad hoc network itself is a third possible future direction which may enhance this mechanism.

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