Improving Reactive Routing on Wireless Multi-rate Ad-hoc Networks

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Abstract— **Traditional ad-hoc routing protocols typically choose minimum hop paths for transmissions. In a multi-rate environment, where nodes may elect between several transmission rates in order to accommodate different channel conditions, these protocols usually choose paths that contain long range links, with low effective throughput and low reliability. In this paper, we propose a mechanism for reactive routing protocols that leads to the election of high throughput routes while not increasing significantly the signaling overhead. By allowing a node to have a complete knowledge of its one-hop neighborhood topology, we are able to increase significantly the performance of the network through the improvement of the route election process on multi-rate environments.**

I. INTRODUCTION

Wireless communications have been spread all over the world over the last years. Most of the commercially available wireless devices are based on the IEEE 802.11 standards family. Most of them, such as 802.11b [2], 802.11a [1] and 802.11g [3], allow the use of different transmission rates.

The election of which transmission rate should be used depends on the wireless medium conditions. The worse the channel quality, the stronger the code that should be used and, consequently, the lower the achieved transmission rate. Since channel quality is directly related to distance between nodes, we may say that usually, the closer two nodes are from each other, the higher the transmission rate used between them.

In 802.11a (and also in 802.11g), for example, the set of possible data transmission rates are 6, 9, 12, 18, 24, 36, 48, 54 Mbps while 802.11b supports 1, 2, 5.5 and 11 Mbps. In order to exploit this capability, some Medium Access Control (MAC) mechanisms are required, the Auto Rate Fallback (ARF) [8] protocol was the first to deal with this issue. The sender increases (or decreases) the transmission rate to be used in future transmissions based on the successes (or failures) in the previous ones. In other mechanisms, like the Receiver Based Auto Rate (RBAR) [6] protocol, the receiver measures the quality of the channel when it receives a Request To Send (RTS) message and selects the appropriate rate to be used under these conditions. It then informs the sender the rate to be used for data transmission through the Clear To Send (CTS) message.

However, in order to fully use the multi-rate capabilities on a wireless ad-hoc network, the routing protocol should also be aware of this information. There is no point on being able to transmit at so many different rates on the MAC layer, if at the end, the routing protocol always chooses routes based only on hop count. Traditional routing protocols, like the Ad-hoc On-demand Distance Vector (AODV) [9] or the Optimized Link State Routing Protocol (OLSR) [10], usually elect this kind of path, where long range links are preferred over short range ones. The use of long range links, while decreases the number of hops of the path, also decreases the overall throughput that can be achieved through it. If short range links were elected, although the number of hops would increase, higher transmission rates could be used, and the overall performance of the network could improve significantly. However, although it seems to be very important to take multi-rate into account in the routing layer, there are not many publications that deals with this issue.

In proactive routing protocols (like OLSR), the solution for this problem is quite straightforward. Since each node knows the (almost) entire network topology, information about link rates would be enough to choose an efficient path. In [4], the authors propose a routing metric that is able to maximize the achievable throughput on chosen paths. However, although the metric may be used on both proactive and reactive routing protocols, they only implement it on a proactive protocol and no further comments on how to do so on reactive protocols are made.

Reactive protocols (like AODV) do not have any previous information about the network topology, they choose their routes by flooding the network with Route Request messages trying to reach the destination node. This makes the problem much more complex, as we will discuss in further sections. Providing a simple and yet efficient solution is not trivial. Authors of [5] propose a solution for AODV that introduces too much signaling overhead, increasing heavily the number of broadcasted Route Request messages.

A totally different approach is proposed by [12]. It deals with the multi-rate issue completely in the Medium Access Control (MAC) layer. The MAC layer hides from upper layers the existence of low throughput links, by selectively filtering received frames. As a result, on the top one could use any standard routing protocol and high throughput path would always be elected. However, hiding topology information from

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the routing layer may not always be a good solution. Although solving multi-rate path election issues, it may degrade significantly the performance of mechanisms such as rapid route repair, or any other schemes which performance is directly related to the amount of topology knowledge that a node has.

In this paper, we propose an efficient solution for the election of high throughput paths through the use of reactive routing protocols. More specifically, we propose that each node keeps track of its 1-hop neighborhood topology, using a proactive approach for choosing the route in the neighborhood, and a reactive approach for choosing the route towards distant nodes. We believe that reactive routing can provide better response to the constant changes in the topology of a mobile ad-hoc network, while monitoring the 1-hop neighborhood may improve routing decisions and should not be a problem even when mobility is not so low. Furthermore, the knowledge of the 1-hop neighborhood may also be useful for other mechanisms that may improve the network overall performance, such as efficient route repairing and controlled flooding [7, 11].

Although we focus our attention to the AODV protocol throughout the paper, the proposed mechanism can be applied to any reactive routing protocol (as long as it is based on the exchange of Route Request / Route Reply messages).

The paper is organized in 4 additional sections. In the next section we discuss the problem of using traditional reactive protocols on multi-rate ad-hoc networks more deeply. We then propose in section III modifications on the routing election process in order to take transmission rates into account. In section IV we show through simulations the overall improvement that can be obtained when using our proposal under different scenarios. Finally, we present some conclusions in section V.

II. TRADITIONAL REACTIVE ROUTING

Wireless ad-hoc networks are usually composed by portable nodes – notebooks, palmtops or even mobile phones. This portability also brings an important issue: mobility. This is a key factor in ad-hoc networks. The mobility of the nodes causes the topology of the network to change constantly. Keeping track of this topology is not an easy task, and may consume too much resources in signaling. Reactive routing protocols were designed for these environments. They are based on the idea that there is no point on trying to have a picture of the entire network topology, since it will be constantly changing. Instead, whenever a node needs a route to a given destination, it initiates a route discovery process on the fly, for finding out a path.

This kind of protocols (which has AODV as its major example) is usually based on flooding the network with Route Request (RREQ) messages. The source node broadcasts a RREQ message with a time-to-live equal to 1, i.e., a broadcast limited to its 1-hop neighborhood. Each RREQ is uniquely identified through a sequence number, so that the first copy of a RREQ received by a node is processed, while duplicate messages are discarded. When a node receives the first copy of a given RREQ, it records the address of the node that sent the message, establishing thus a reverse route. When the first RREQ reaches the desired destination, a Route Reply (RREP) message is generated and sent back to the source node through the recorded reverse path, confirming then a path from the source to the destination.

This kind of protocol is usually very effective on single-rate networks. It usually minimizes the number of hops of the chosen path. However, on multi-rate networks, the number of hops is not as important as the throughput that can be obtained on a given path.

In figure 1, for example, if node A wants to transmit to node E and a reactive protocol is used to find a path, the elected path would be A-C-E. Node A would broadcast a RREQ, which would be received by B and C. Node B would re-broadcast the RREQ, that would be discarded by C (since it has previously received a copy of this RREQ from A). Node C would broadcast the RREQ and it would reach E (as well as D). Node E would then reply with a RREP, that would cross node d.

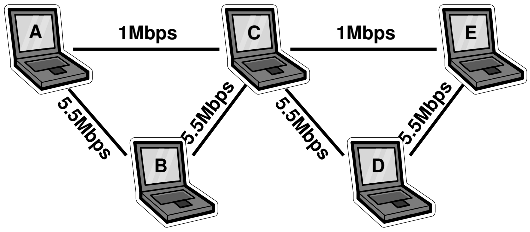


Fig. 1. An example of a multi-rate wireless ad-hoc network

It is not very difficult to notice that, in this case, the path A-B-C-D-E, although being longer, would have been a better choice. Data would be transmitted using a 5.5Mbps rate, instead of 1 Mbps. This simple example shows that traditional routing protocols do not cope with the multi-rate network requirements. We should, thus, take transmission rate into account when choosing the path towards a given destination, using it as a routing metric.

III. TAKING LINK RATE INTO ACCOUNT

There are already some proposals that use the transmission rate between wireless nodes as a routing decision metric. The Medium Time Metric (MTM) [4], for example, establishes a link cost for each transmission rate, which is computed through the analysis of how much time it takes to transmit a 1500 bytes packet on 802.11. The link costs for several transmission rates are presented in table I.

TABLE I

MTM METRICS

Transmission rate	MTM link cost
11.0 Mbps	5
5.5 Mbps	7
2.0 Mbps	14
1.0 Mbps	25

The implementation of this metric on a proactive routing protocol is very straightforward. Since each node already knows the topology of the network, it should only add this metric to each link and compute the less costly route towards the desired destination. Nevertheless, on reactive protocols, the problem becomes more complex.

The main problem with reactive protocols like AODV is the fact that nodes discard duplicate copies of received RREQ messages. In the example depicted by figure 1, the best path from node A to C would be through B, however, the RREQ sent by B only reaches C after the one sent by A, what causes it to be discarded.

A simple solution would be to accumulate the link cost on each retransmission of the RREQ and not to discard duplicate RREQs when its accumulated link cost is below the cost of all previously received RREQs. If this is the case, the RREQ would be re-broadcasted and the reverse path would be updated. The destination node would not reply the first received RREQ, but instead would wait for a certain period or for a given number of RREQs and then would reply the one with the lowest cost. This solution, presented in [5], although being simple, increases very much the number of RREQ messages on the network. Ad-hoc networks with a very dynamic behavior could suffer from performance degradation due to avalanches of RREQs. Notice that this increment in the number of broadcasted RREQs is concentrated in a very short period of time (during the route discovery procedure). The occurrence of these RREQ bursts would significantly increase the number of collisions among copies of the same RREQ. Since broadcast transmissions are not acknowledged in 802.11, many RREQs would be lost and the route discovery procedure would not perform well. Furthermore, as the number of nodes in the network increases, so will the number of duplicate RREQs that are transmitted.

Our proposal

In order to avoid an increase in the number of transmitted RREQs over the network, we propose that every node keeps track not only of their 1-hop neighborhood (what is already done by most of the existing ad-hoc routing protocols through the periodic exchange of HELLO messages), but also of the topology of these neighbors. That means that a node should know the links that exist between its neighbors. Notice that even on highly dynamic networks, this information is not difficult to be maintained, since a node is aware of any change on its 1 hop neighborhood very quickly.

Once a node is aware of the topology of its 1-hop neighborhood, the RREQ/RREP procedure can take place with minor changes. Whenever a node receives and processes a RREQ, it may compute the best path (it terms of throughput) towards the node that sent him the RREQ message, or towards any other node before in the path (if it is more efficient not to pass through the previous node). After computing this part of the path, the complete path information is updated in the RREQ message and it is re-broadcasted. When the first RREQ reaches the destination, a RREP is sent to the source following the path recorded in the request.

A. Keeping track of the 1-hop neighborhood topology

In order to keep track of the topology of the 1-hop neighborhood, nodes should include a list of their 1-hop neighbors (nodes from which they receive HELLO messages) in the HELLO messages that they periodically broadcast together with the link cost towards each of the neighbors. This link cost is computed based on the link rate (see table I), which can be easily obtained by looking at the Signal to Noise Ratio (SNR) of the last packet received from the neighbor [6]. We here assume that the MAC layer is able to provide this SNR value or the link rate directly.

By receiving HELLO messages from every neighbor, a node is able not only to have a complete view of the 1-hop neighborhood topology, but also to know its 2-hop neighbors and their connectivity with the 1-hop neighborhood (in order to have a complete 2-hop topology, it would be necessary also

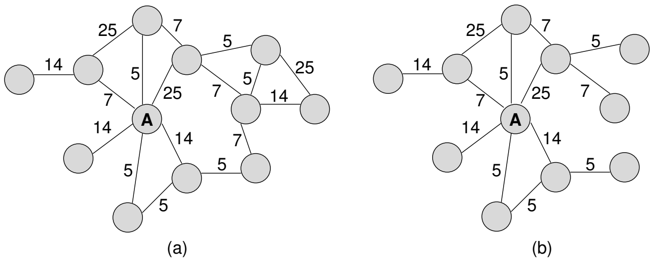


Fig. 2. (a) Complete ad-hoc network topology with link costs (b) Partial topology known by node A due to HELLO messages

B. The multi-rate route discovery procedure

Once the nodes know the complete 1-hop topology and a partial 2-hop topology, the route discovery procedure can be modified in order to retrieve not the minimum hop path, but the maximum throughput one.

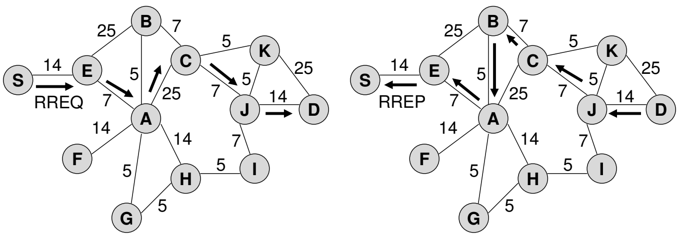
The first step toward achieving this objective is to extend the RREQ message by introducing a list of nodes and link costs that represents a maximum throughput path from the source node to the node that received the message. Every node that receives the RREQ completes this list using their 1-hop topology knowledge in order to create a complete path from the source to the destination.

The route discovery procedure works as follows:

1) The source node broadcasts a RREQ message to its 1-hop neighbors.
2) Each node that receives the RREQ message computes the maximum throughput (minimum cost) path to the last node through which the RREQ passed.
3) The node includes the maximum path it computed in the RREQ message by introducing the IP address of the nodes between the current node and the previous one together with the link cost to go from one node to another. In figure 3 for example, when node C receives a RREQ from node A, it computes that the maximum throughput path towards A is passing through node B. So it includes the IP address of B with 5 as the link cost (between B and the previous node A), and then its own

IP address with 7 as the link cost (between the current node C and node B).

4) Finally, when the RREQ reaches the destination node, it



(a) (b)

Fig. 3. (a) Path followed by the 1^{st} RREQ to reach the destination (b) Path followed by the RREP

In the ad-hoc network depicted by figure 3, if node S wants to find a route towards node D, it broadcasts a RREQ message that, at each intermediate node, receives a list of nodes that represents a candidate path. In this example, at each intermediate node through which a given RREQ message passes, the list of nodes that it carries is updated as follows. Notice that we are only dealing with the RREQ that first reaches the destination node.

at E: *E 14*
at A: E 14, *A 7*
at C: E 14, A 7, *B 5, C 7*
at J: E 14, A 7, B 5, C 7, *J 7*
at D: E 14, A 7, B 5, C 7, J 7, *D 14*

In fact, an intermediate node may not only insert new nodes in the candidate path included in the RREQ message, but it may also replace existing hops of the path by other hops that it considers more efficient. This may happen whenever the node is able to reach another node that is in the path included in the RREQ message with a lower cost than the one presented in the RREQ. Notice that the cost towards a given intermediate node can be obtained by summing the links costs from the last node in the list up to the one before the desired node. In the last example, the cost for node J to reach A is $7 + 7 + 5 = 19$. If this is the case, all the nodes included in the list after this intermediate node should be erased and substituted by the new path elected by the current node.

By doing this procedure, we can not guarantee that the minimum cost path is finally elected but, at least, we can guarantee that the chosen path, will perform better than the minimum hop path. In order to guarantee the the election of the minimum cost path, we should allow the re-broadcast of RREQs (as proposed by [5]), however we think that the collateral effect of such solution (high increase on the number of RREQs) is a very high price to pay. We believe that our mechanism provides a better trade-off between performance and overhead.

IV. SIMULATION RESULTS

V. FINAL REMARKS

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