Ants-Based Routing in Large Scale Mobile Ad-Hoc Networks*

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Abstract. In this paper, we address the problem of routing in large-scale mobile ad-hoc networks (MANETs), both in terms of number of nodes and coverage area. Our approach aims at abstracting from the dynamic, irregular topology of a MANET to obtain a topology with "logical routers" and "logical links", where logical router and logical links are just a collection of nodes and (multi-hop) paths between them, respectively. To "build" these logical routers, nodes geographically close to each other are grouped together. Logical links are established between selected logical routers. On top of this abstract topology, we propose to run a routing protocol based on mobile agents and inspired from social insects behaviour.

1 Related Work

The interest in MANETs has grown recently and many novel routing protocols were developed that deal with the special characteristics of such networks. Proactive routing protocols attempt to maintain at all times routing information from each node to every other node in the network (DSDV [1], WRP [2], OLSR [3], CGSR [4]), whereas reactive protocols only acquire routes on demand (AODV [5], DSR [6], TORA [7], LAR [8]). Obviously, both categories will not scale with large scale MANETs as considered in this paper. The signaling traffic constantly present in the network for proactive protocols is substantial because update messages are propagated throughout the network for any changes in the topology. Reactive protocols often employ a kind of flooding to acquire and sustain routes. The overhead induced becomes a serious limitation as well. Other approaches make use of location information such that almost stateless routing becomes feasible (GPSR [9], GRA [10], AGPF [11]). A packet is sent to a neighboring node, which reduces the distance to the destination. For the case that this greedy, simple method fails, different fallback mechanisms are proposed. These mechanisms could result in inefficiencies for scenarios where routing along the line-of-sight between source and destination nodes is often impossible. Further, those approaches do not consider routing around congested areas or where links suffer from poor quality, i.e. they normally only take

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only location information into account for routing decisions and not other criteria like, e.g., network load, congestion, available bandwidth.

There exist some approaches, which take the path quality for routing decisions into account (ABR [12], SSA [13]). But for large scale MANETs, not only the quality of wireless transmission over a single link or along a single path should be considered, but as well the quality of transmission and routes within whole geographical areas. If required, areas should be bypassed completely for transmission.

Lately, a new kind of completely distributed routing protocols for fixed, wired communication networks evolved inspired from social insects (e.g. ants) behaviour (ABC [14], AntNet [15], Max-Min [16], CAF [17]). Ants were shown to find shortest paths through a process called “stigmergy” [18], which could be described as indirect communication between individuals through the environment. Ants returning from a food source to the nest lay down pheromones (a chemical substance) behind them. Other ants are attracted by these pheromone trails and in turn reinforce them even more. As a result of this “auto-catalytic” effect, the shortest path will emerge rapidly. This process has been adapted for telecommunication networks. Current traffic conditions and link costs are measured by transmitting “artificial ants” (mobile routing agents) into the network, which not only update routing tables depending on the collected information, but as well mark the traveled path with an “artificial pheromone”. These protocols showed very promising results and turned out to be highly adaptive in dynamic network environments, and in fact, there already exist two different approaches for routing in mobile ad-hoc networks with ants-based algorithms. In ARA [19], ants are broadcasted into the network on demand to discover paths to destinations and mark them with pheromones. Again, this kind of flooding to acquire routes will not scale for large scale MANETs. GPSAL [20] employs ants only to accelerate the dissemination of routing information, and hence, does not make use of the above described “auto-catalytic” effect for finding shortest paths. Further, a shortest path algorithm is applied to determine the best possible route to a destination, therefore assuming that a node knows a lot about the links currently present in the network, and as well a lot about positions of other nodes, which certainly will not be true for the large scale MANETs considered in this paper.

2 Ants-based Routing for MANETs

2.1 Overview

The proposed two-layered concept introduces different new protocols, of which each tackles a different problem. TAP (Topology Abstracting Protocol) will be used to supply in a transparent manner a simplified topology with fixed “logical routers” and fixed “logical links”. (We will use the term “logical” in general to indicate that we mean paths, links, etc. in the upper layer.) In this context, the term logical router represents an aggregated collection of mobile hosts, which all together build and share among each other the same routing tables. A logical link represents a path along a roughly straight line to a distant logical router over possibly multiple hops. On top of this abstract topology the actual routing protocol MABR (Mobile Ants Based Routing) will be run. This ants-based protocol is responsible for updating the routing tables of logical routers and determining logical paths for routing packets over this abstract topology. Finally, the SPF (Straight Packet Forwarding) protocol is applied in order to transmit packets over a logical link. Therefore, it forwards packets along this logical link in a greedy manner. An overview of the architecture with the interactions between the protocols is depicted in Fig. 1.

We model large-scale mobile ad hoc networks as a set of wireless nodes distributed over a two-dimensional area. Nodes are connected over a wireless link, if they are within the transmission range of each other, whereas we assume bi-directional links that are not necessarily cost-symmetrical. Nodes are aware of their position by means of GPS or any other positioning service [21], and are able to determine other nodes position accurately enough through a location management scheme [22, 23].

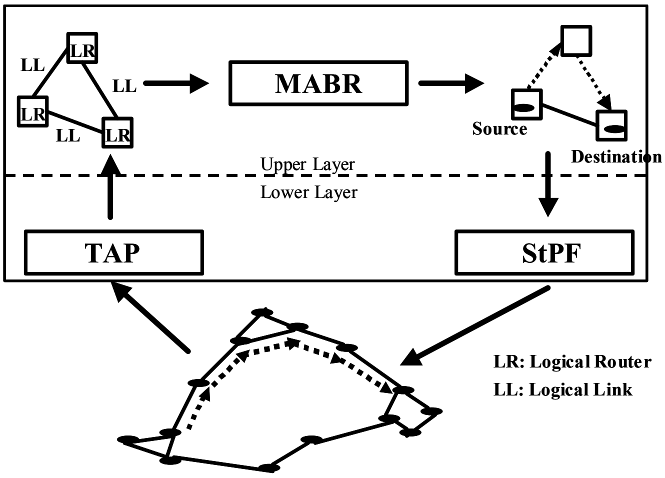

Fig. 1. Overview of the architecture

2.2 Topology Abstracting Protocol (TAP)

To offer a simplified topology with logical routers and logical links to MABR, TAP applies several mechanisms. The first aims at grouping nodes in the lower layer together based on their location to "build" logical routers in the upper layer. The plane is divided into geographical areas with all nodes within such an area belonging to the same logical router. (Unlike in cellular networks where these areas are often modeled as regular hexagons, we will approximate them by squares for simplicity reasons.) The plane is completely covered with logical routers and every node is part of a specific logical router on the upper layer depending on its current location. Consequently, when a node moves to another area, it participates within this new area in forming a logical router. Logical routers are identified by their coordinates, since geographical information is used for routing over logical links by SPF on the lower layer.

Each logical router maintains two tables, which will be used by MABR, and which are conjointly built from all nodes within the same logical router by exchanging their local routing information. In that way, all the nodes within a logical router share and use the same routing tables. Not all the data has to be stored at each node, the only requirement is that always up-to-date and consistent routing tables are available to all the nodes. The data stored in the tables can be distributed over the logical router's nodes through a mapping mechanism, which has to satisfy certain properties, like including redundancy in case that nodes move to another logical router or that they simply fail.

Further, every logical router has its own set of logical links depending on its location and encountered network conditions. Consequently, the view on the network is always relative, i.e., nodes at different locations, belonging to different logical routers, perceive different logical links. A set of logical routers is considered as communication end-point for the logical links. For that purpose, a logical router groups the other logical routers into zones depending on their position relative to it as shown in figure 2. More logical routers are grouped together as farther away they are located. It is important to notice that this is not a pure hierarchical approach, in the sense that even very long logical links are established for every logical router and there are no "elected" logical routers responsible for long logical links. This is a direct consequence of the fact that the view is built always relative and, thus, any logical router is located at the center of a zone in his view.

Figure 2 shows an example, where the most inner zones Z1,x consist just of one logical router each, namely one of the adjacent logical routers. The next outer zones Z2,x group always 9 logical routers together. The zones Z3,x then group 81 logical routers and so forth. Altogether there are only a certain number of rings, and the zones of the last (fifth) ring group the remaining outer nodes, which makes these outermost zones "indefinite" in size.

Logical links are now established from a specific logical router to all its zones. The logical routers located at the center of the zones approximate the end-points of the logical links, and these logical routers are connected by the logical link in a straight line. Thus, every square has logical links leading into different directions with different lengths. For example in Fig. 3, there would be 40 logical links, for the logical router LR1 located at the center of the figure, of 5 different lengths in 8 directions, if all were drawn. (Additionally the zones of LR1 are drawn, as well as the logical links of another logical router LR2. No zones are drawn for LR2, they would be constructed in the same as for LR1, but with LR2 located at the center.) Shorter logical links will be used for routing in the vicinity and to locally bypass obstacles, whereas longer logical links will be used for routing over long distances and to bypass distantly congested areas and large holes in the routing topology. Holes refer to areas in which nodes are so sparse that transmission is not feasible, e.g. lakes and mountains. To determine the costs associated with a logical link to specific zone, all routes from the current logical router to any logical router within that zone are taken into account.

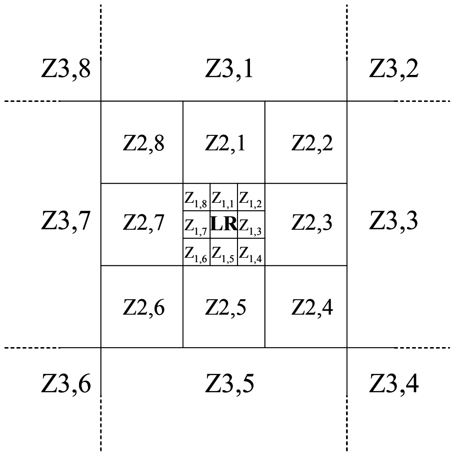

Fig. 2. Zones relative to specific LR

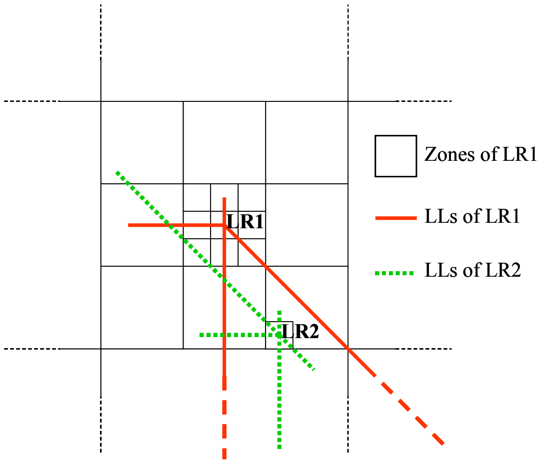

Fig. 3. Some example LLs of LR

2.3 Mobile Ants Based Routing (MABR)

Two data structures are maintained at each logical router k.

- The routing table Rk is organized as a table with a row for every outgoing logical link and a column for every zone Zi,j. The entries (Zi,j/LLk,l) represent the probability to select the logical router at the other end of LLk,l as a logical next hop, if the destination coordinates are located within zone Zi,j.

- The link-costs of all incoming logical links are stored in the Lk table. This information will be used to determine the quality of the followed path by the ants.

Ants and data packets are both marked in the header fields with the source and destination coordinates. Further, they keep track of the followed path by storing the coordinates of each intermediate relaying node. In order to limit their size, the followed path can be approximated by a sequence of straight lines. This information will be used for routing and updating of the two tables. Data packets and ants are routed basically in the same way. The logical router determines in which zone the destination coordinates are located and then selects an outgoing logical link for that zone with the probability given in the routing table. In this way, (redundant) routing over multiple paths is supported naturally, and the traffic load is shared proportionally between the existing logical links.

Two kinds of ants are applied to update the routing table. First, forward ants are launched periodically from every logical router s to randomly chosen destination coordinates d. Neighboring logical routers can coordinate forward ants for distant destinations since the ants would follow approximately the same paths anyway. Further, they keep track of the followed path. At the destination d, they turn into backward ants, which travels back over the recorded path in reverse direction. The backward ant is able to determine the quality of the path followed by the forward ant using the appropriate data stored in the link cost tables. Arriving at any logical router, the backward ant updates the routing table according to the logical link costs encountered so far, i.e., it marks the entries corresponding to its followed path with "artificial pheromones". Like natural pheromones, artificial pheromones will also decay. Consequently, if a path doesn't encounter any reinforcement for a long time, it will eventually not be marked anymore.

Updating the pheromone trails works as follows: The last logical router k at which the packet was routed in a "significant" different direction is determined due to the path recorded in the packet. This can result in a logical router k that is multiple logical hops away. The packet is considered to have arrived over the logical link l that matches best to this previously determined logical router k, i.e., over the incoming logical link l that originates in the zone to which this logical router k belongs. The reason is that SPF is applied for the routing over a logical link, which routes packets along a roughly straight line. Finally, the probability (Zi,j/LLl) in the routing table, corresponding to logical link l and to zone Zi,j in which the backward ant's source router d is located, is increased depending on the measured and summed up link costs. At the source s of the forward ant, the backward ant will be deleted.

Consider for example the scenario depicted in figure 4 with four different logical routers and two logical links (from LR1 to LR2 and to LR3). The hole in the topology marks an area where transmission is not feasible. A backward ant followed the indicated path. LR1 considers the ant to have arrived over LL2, and not LL3, because the last roughly straight part of the followed path starts in LR2. Hence, LR1 has theoretically a logical link LL3 to LR3, but no ants are received over that link. Consequently, no pheromone laying occurs on that link and, thus, it will not be used for routing of data packets. Thus, data packets sent from S destined for a node located in the area covered by LR3 will not be sent over LL3 but over LL2 to LR2. Arriving at LR2, there again a logical link is determined over which the packets will continue its journey to the destination node.

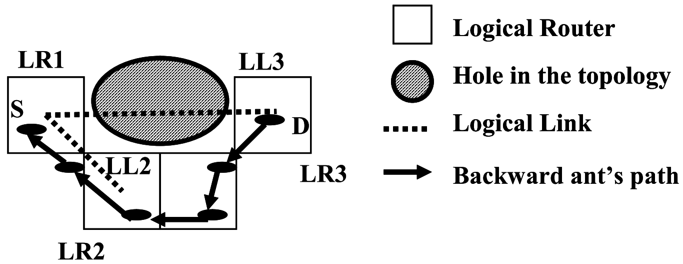

Fig. 4. Example for the path followed by backward ant

The updating of the link cost table Lk is done at a time when any packet is received at a logical router. In the same way as for ants, the logical link that matches best the "last part" of the packet's journey is considered to be the link over which the packet was received and, thus, the entry for that logical link is updated accordingly.

2.4 Straight Packet Forwarding (StPF)

SPF is located on the lower layer and responsible to deliver a packet to the next logical router, i.e. some geographical coordinates determined by MABR. The routing can be accomplished in a greedy manner by just sending the packet always to a node closer to these coordinates, since in general MABR should only provide paths for which this is feasible. Nevertheless, SPF has some fallback mechanism in case that forwarding fails. Different strategies could be applied to determine the next node, like selecting the one that reduces the distant most of all, or least of all, etc. Basically all the location based routing protocols already mentioned in the introduction could be employed [9, 10, 11].

2.5 Summary

First, we shortly describe the interactions between the different parts of the architecture. Each node is at every moment part of a specific logical router and, hence, makes uses of the corresponding routing tables. So when a node whishes to send a packet to another node, it first discovers that node's location through any location management scheme [20, 21] and stores these coordinates in the header fields of the packet. By applying MABR, it determines to which zone the destination coordinates belong in its view and selects any logical link with the probability given in the routing table R for that zone. The packet is tagged as well with the corresponding logical router k (geographical coordinates) as a next logical hop. Then SPF is employed in order to route the packet to these coordinates; i.e. the source node transmits the packet to a node closer to logical router k and so forth. Any node at logical router k in turn carries out the same procedure again, first determining a next outgoing logical link by MABR, and then routing the packet to these coordinates by SPF. Eventually the packet will arrive at the logical router for the destination coordinates. The receiving node finally sends the packet to the intended destination node.

3 Conclusions

In this paper, we have presented an approach that adapts ants-based routing to MANETs. In order to make ants-based routing applicable in such a highly dynamic environment, an abstract topology was laid on top of the network. Logical routers can be built and logical links established more or less locally at the beginning and only by-and-by, some logical links will be favored over other through the laying of pheromone on this logical links by mobile routing agents. We believe that some of the advantages of this kind of routing algorithms observed in fixed, wired networks could also be transferred in this way to MANETs. The advantages include the ability to react and deal quickly with local and global changes, not only in the network topology, but as well in the communication bandwidth, in the transmission delay, etc.

The work in progress includes the elaboration of the protocols and the consideration of additional mechanisms to make the protocols even more suitable for MANETs. These include the aggregation of pheromone trails and other hierarchical concepts to obtain fewer long distance logical links. Different routing schemes for ants and data need to be studied in more detail. Furthermore, a first version is being implemented on a network simulator to verify the performance of this concept empirically.

Further, we have focused in this paper on MABR as the routing protocol in the upper layer, but virtually, every existing routing protocol could be used in place of MABR. Even protocols designed for fixed wired network should be possible, since TAP is in fact offering a rather static topology to the upper layer. Therefore, the interworking of TAP und StPF with other existing routing protocol will be another direction of our future work.

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