CONSTRUCTION AND MAINTENANCE OF BACKBONE FOR ROUTING PROTOCOLS ENHANCEMENT IN MOBILE AD HOC NETWORKS

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ABSTRACT

This paper proposes to use virtual backbone structure to handle control messages and reduce the effect of node mobility in mobile ad hoc networks. This structure is effective in reducing the overhead of disseminating control information and can be useful for routing protocols to enhance their performance. This paper presents a new approach to construct and maintain a virtual backbone for ad hoc mobile networks. The construction of backbone is based on the Minimum Connected Dominating Set (MCDS). A distributed procedure is presented to maintain the backbone when the mobility is introduced. Terminals in ad hoc networks are free to move anywhere and anytime. Each terminal which changes position has to execute a maintenance procedure to connect to the backbone. Simulations results show the performance of this procedure when mobility and scalability is considered. To validate our approach, we used simulation to show that using backbone, routing protocols can enhance their performances in high dynamic environment. Three reactive protocols (AODV, DSR and TORA) have been used in this simulation.

1. INTRODUCTION

Wireless Ad hoc networks are very useful in emergency operations such as search and rescue, crowd control, and commando operations. The major factors that favour ad hoc wireless networks for such tasks are self-configuration of the system with a minimal overhead, independent of fixed or centralized infrastructure, the nature of the terrain of such applications, the freedom and flexibility of mobility, and the unavailability of conventional communication infrastructure [1]. Ad hoc wireless networks provide a flexible and quick means of establishing wireless peer-to-peer communications. However, routing remains a challenging problem in an ad hoc network due to its multi-hop nature and dynamic network topology [2].

In Ad hoc environment, the network is distributed, where all network activity including discovering the topology and delivering messages must be executed by the nodes themselves, i.e. routing functionality will be incorporated into mobile nodes. Also, energy efficiency in a multi-hop network necessitates coordination between the nodes, so that they avoid wasting system resources like energy and bandwidth. While these goals can not be using centralized control, this is not practical in a mobile ad hoc network, or at least not scalable due to the high overhead to monitor and convey the control information throughout the network.

Communications in wireless ad hoc networks suppose that there is no physical infrastructure. This supposition makes the communication more costly and conduct to a severe problem; the broadcast storm problem. This problem is induced by flooding inherent in on-demand routing protocols. Recently many propositions have been studied, which are inspired by physical backbone to maximize resource utilization and to minimize the number of exchanged messages caused by flooding. Furthermore, backbone can be used to collect topology information for routing, to provide a backup route, to send multicast or broadcast messages.

The study of virtual infrastructures or backbones in wireless ad hoc networks gets more attention in the hope of reducing the communication overhead. But the backbone structure is very vulnerable due to various factors like node mobility and unstable links, and so on. Backbone has been used extensively in various aspects (*e.g.*, routing, route maintenance, broadcast, scheduling) for wireless networks [4].

In most previous propositions [3, 5, 4], the same idea is used. One algorithm will be charged for the construction and the maintenance of virtual backbone. These propositions differ on the approach used to find the MCDS. They are based on combinatorial technique, graph coloration or marking process approaches. Different from previous approaches, our approach to construct and maintain the backbone is based on two independent algorithms. The first algorithm constructs the backbone on the setup phase of the network where global information is available (number of node, capability, node position, etc.). This algorithm guarantees a minimal size of the backbone [7]. Smaller the size of the backbone, the better the maintenance will be. When mobility is introduced, distributed maintenance procedure will be applied to maintain, locally, the backbone. In other words, when a node changes its position it will try to connect to the existing backbone by applying the maintenance procedure. This procedure guarantees a high level of connectivity in a dynamic environment caused by the movement of nodes. Routing protocols can benefit from the presence of the backbone structure and use this structure to reduce traffic control and enhance their performance.

Routing is one of the primary functions that have to be performed in order to enable connections between nodes that are not directly within each other's transmission range. Many routing protocols have been proposed to ensure the multi-hop relaying. The existing ad hoc routing protocols can be classified into the following categories:

- Proactive protocols (e.g. OLSR, DSDV, WRP): by broadcasting control packets containing routing table information (e.g. link state or distance vectors). These protocols attempt to maintain at all times up-to-date routing information at each node.
- Reactive protocols (e.g. AODV, DSR, TORA): only when a route to a destination is required, a node initiates a route discovery process.
- Hybrid protocols (e.g. ZRP, CEDAR): by combining the reactive and proactive protocols. Neighborhood is realized in proactive manner and when a destination is not in the transmission zone; route finding is then established using proactive approach.

Three routing protocols have been selected in this work, namely Ad hoc on Demand Distance Vector (AODV), Dynamic Source Routing (DSR) and Temporary ORdered Algorithm (TORA). These three protocols were selected because they are already implemented in OPNET simulator.

The remainder of this paper is organized as follows: section 2 presents a description of backbone generation the setup phase of the network. In section 3, a distributed maintenance procedure will be described and evaluated. In section 4, performance comparisons are made of routing protocols with and without the virtual backbone. Section 5 will conclude this paper.

2. VIRTUAL BACKBONE GENERATION

Using the above definitions, the minimum connected dominating set (MCDS) in a given graph can be found as a minimum size subset S of nodes, such that the sub-graph induced by S is connected and S forms a dominating set. Unfortunately, as mentioned in the introduction, finding a MCDS in UDG is known to be NP-complete [2].

In order to reduce complexity of the MCDS computation, decomposition into two steps is proposed by applying LP approach in each step. The first step finds the MDS in a given graph and the second step computes the spanning tree of the MDS set to get the final solution of the MCDS.

2.2. Finding the Minimum Dominating Set (MDS)

Finding the minimum dominating set can be formulated using the integer linear programming approach. A binary variable x_i is defined as a decision variable,

$$x_i = \begin{cases} 1 & \text{if the node } i \text{ is an element in the dominating set, MDS} \\ 0 & \text{otherwise} \end{cases}$$

The objective function minimizes the number of node of the dominating set:

$$\min \sum_{i \in V} x_i \qquad (1)$$

Domination constraint:

$$X + M \times X \geq 1 \qquad (2)$$

$$\text{where} \quad x_i \in \{0,1\} \qquad (3)$$

Where $X = [x_1 \ldots x_n]^t$ represents the decision vector, and M is $n \times n$ 0/1 adjacent matrix of G, each element of M, $m_{ij} = 1$ if and only if node i is connected to node j.

In general, there is no guarantee on the connectivity of the solution $\{x_i\}$, which represents nodes member of the backbone. To get final solution, where backbone nodes are connected, the next step determines the spanning tree of the MDS.

2.3 Finding the Connected Set of MDS

This step consists on:

- Constructing a reduced graph G' such as :
  - Nodes formed this graph is the MDS set,
  - Two nodes are connected by the short path calculated in number of hops from the original graph,
  - Weight on each link represents the number of hops between two nodes.
- Finding the minimal spanning tree (MST), T in the graph G'
- Extracting the set of intermediary nodes by replacing the selected link in the original graph.

Dijsktra algorithm is used to find the short path between two nodes and *Kruskal* algorithm is used to find the MST. A detailed description and evaluation can be finding in [7].

3. VIRTUAL BACKBONE MAINTENANCE

The main feature of ad hoc networks is the mobility of terminals; they are free to move anywhere. In order to maintain the connectivity of the virtual backbone when topology changes. A distributed procedure will be applied by the terminal that changes position and tries to connect to the backbone. The maintenance will be executed locally; only on the part of the network where the topology changed; a new terminal comes or a terminal lefts. The following state diagram, figure 1, presents four states, in any time; a terminal can be in one of these four states. It can be:

- dominant, a member of the backbone,
- dominate, not a member of the backbone and has at least one neighbor dominant,
- Active, in the process to be dominant or dominate, or
- IDLE, an instantaneously state when terminal changes position.

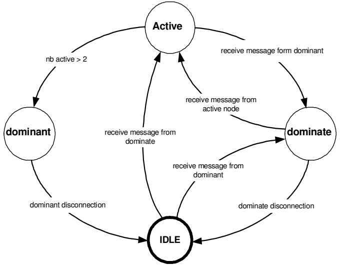


Fig. 1. - State diagram

To realize the maintenance procedure, we propose to add some field on the *hello* packet. *Hello* packet is used by protocols routing in ad hoc network for discovering. Figure 2 illustrates the modified hello packet.

3.1. Mobility model

In order to evaluate the maintenance procedure, we used Opnet to implement our solution and to modulate the mobility of nodes we used a modified version of the Random Waypoint Model proposed by [8]. In [9] and [10], authors analyzed and discovered many problems with the original RWP model. It is the most common mobility model used in the literature. In this model, nodes are initially distributed in a (usually bidimensionnel) region S. Then, every node chooses uniformly at random a destination in R and moves toward it along a straight line with a velocity chosen uniformly at random in the interval $[v_{min}; v_{max}]$. When the node reaches the destination, it remains stationary for a predefined pause time t_p and, then, it starts moving again according to the same rule. The most problems of WRP are the border effect [9] and the speed decay phenomenon [10]. Bettstetter et al. give some recommendations to perform this model [9]. These recommendations can be resumed by:

- Uniform distribution of nodes,
- Uniform distribution of speed, $v\in[v_{min}\ v_{max}]$, where $v_{min}\neq 0$
- pause time $t_p\in[t_{pmin}; t_{pmax}]$
- stability parameter, p_s where $0\leq p_s \leq 1$

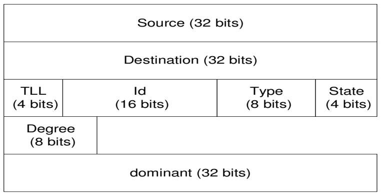


Fig. 2 – Modified *hello* packet

3.2. Maintenance procedure evaluation

The size of the network is 50 nodes, with an average degree equal to 6. Nodes are uniformly distributed and the average speed is set to 15*m/s*. A node has a transmission range equal to 300*m*, a default parameter in Opnet. The life time of the network is one hour (3600*s*).

3.2.1. Connectivity

We would like to observe the variation of the number of dominant and the % of connectivity. Figure 3 and 4 illustrate these two parameters versus time. Results show that even if the variation of the number of dominant in the network is important, when terminals move, more than 95% of nodes still connected to the backbone.

3.2.2. Mobility and scalability

Two set of simulation have been produced. The fist one, we vary the average speed of each node from 1m/s to 30m/s for a network size equal to 50 nodes. The second set, we vary the size of the network from 20 to 80 nodes and the average speed is constant and equal to 15m/s. Simulation results show clearly that the designed procedure is invariant to the network size, figure 5, the % of connection doesn't is almost constant when the network size vary. The mobility has a small effect to the performance of our procedure, figure 6. For a high mobility environment, the connection still over 90%.

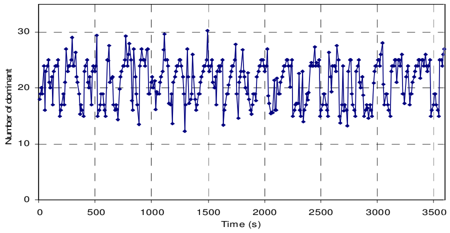


Fig. 3 – Variation of the number of dominants

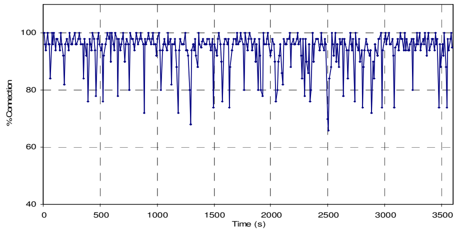


Fig. 4 – Variation of % of node connection

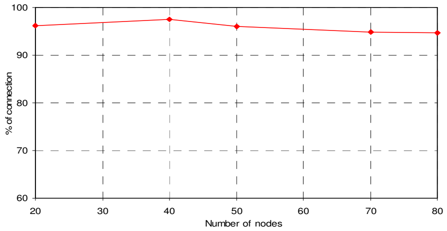


Fig. 5 – % of connection *vs* network size

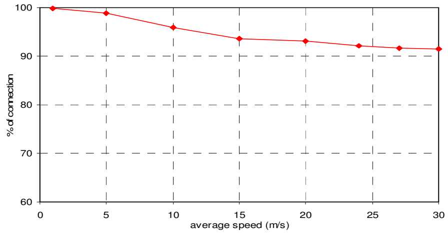


Fig. 6 – % of connection *vs* mobility

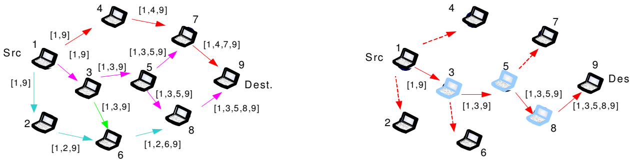
4. ROUTING PROTOCOLS OVER BACKBONE

A key issue in MANETs is the necessity that the routing protocols must be able to respond rapidly to topology dynamic in the network [11]. Moreover, due to the limited bandwidth available, the quantity of control traffic, used by the routing protocols, should be minimized. With virtual backbone structure, a subset of nodes is selected to be dominants and others as dominated. For example, dominants participate in diffusion of control messages in order to minimize bandwidth consumption and then the energy consumption in the network. Packet delivery rate and delay are measured for the considered protocols with two levels of load and mobility as variable in a random network scenario.

4.1. DSR over Backbone (*DSRoB*)

DSR is an on demand routing protocol that makes use of routing and an aggressive caching policy. Several features of DSR including on demand route requests, source routing, and aggressive caching are desirable in ad hoc networks. DSR uses network-wide floods as its basic mechanism for computation routes. The use of caching in DSR will effective in limiting the area of propagation of a RREQ (route request) as long as there exist active flows that pass through, originate from or are destined for the required destination and the cached information is present at enough number of node to prevent the RREQ precalculating through the network. In addition to RREQ, DSR uses RREP (route replies) and RERR (route error). DSRoB retains the above feature of DSR and bringing in the advantages of the backbone structure. DSRoB uses RREQ, RREP and RERR for route request, route replies and route error. However, the route query mechanism is based on the backbone broadcast, rather than the conventional flooding of the RREQ messages.

Figure 7 shows the basic idea to diffuse a message in the presence of the backbone. The backbone, is formed by nodes 3, 5 and 8, their state is dominant. When a control message has to be diffused only dominant nodes have to rely it. In this example, the RREQ message is relayed only by nodes 3, 5 and 8. Other nodes, in dominate state; they don't have to rely control messages even if they receive them. It's very clear that this method reduces the number of control messages in the network and then the amount of bandwidth used by the traffic control.



a- RREQ propagation (original DSR) b- RREQ propagation (DSRoB)

Fig. 7 – Messages propagation in DSR and DSRoB

4.2. AODV over Backbone (*AODVoB*)

In AODV, nodes in the network maintain distance vector tables to facilitate routing. AODV has an effective feature, it uses a lower byte overheads in relatively static networks (not like DSR, it has to stamp source route on every data packet) Like DSR, AODV uses network-wide floods as its basic mechanism for computation routes. In AODV, the problem is more pronounced because intermediate nodes can respond to a RREQ message only if they have an entry in their distance vector table that particular destination and a node will have an entry in its table only if a flow that originates from or is destined for the destination traverses the node. The AODV protocol includes three components: i- initiation and propagation of RREQ messages, ii- initiation and propagation of RREP and iii- the maintenance of the distance vector table. AODVoB uses the same messages but the way to flood the message is different. Like DSRoB, only nodes from the backbone have to relay the RREQ message. However, the propagation of the RREP message is the same as in AODV. When the RREQ message reaches a domain in which one of the nodes has a route to the destination, the intermediate node replies with the RREP message as in AODV. Using the backbone can be beneficial to AODV since a significant part of the overhead can be removed from the RREQ messages.

4.3. TORA over Backbone (*TORAoB*)

TORA protocol is loop-free and distributed routing algorithm. It's based on the concept of link reversal. It is source initiated and provides multiple routes for any desired source/destination pair. There are 3 basic functions of the protocol, namely route creation, route maintenance and route erasure. It uses query (QRY), update (UPD) and clear (CLR) for route creation, route maintenance and route erasure. In the presence of a backbone, TORAoB can reduce reactions/communication overhead and thus conserves available bandwidth and increases adaptability. Also, TORAoB can reduce the routes length where dominants are optimally connected and the route should follow up using the backbone. Recall that TORA doesn't have a mechanism to find the short path between source and destination,

4.4. Simulation results

In this section, we compare the performance of the modified protocols DSRoB, AODVoB and TORAoB to their original versions through simulation using OPNET simulator. Topology consists of a grid with dimensions 1500mx1500m and 50 nodes are randomly distributed. CBR traffic with a packet size of 512 bytes was used for the data traffic. In this simulation, two load levels have been considered: 40 simultaneous sessions for medium load and 80 simultaneous sessions for high load. The average speed of nodes varies from 0 to 20 *m/s*. Each simulation was run for a period of 300 seconds. The link layer consists of a wireless LAN using a media access control (MAC) function based on the IEEE 802.11 standard. Several parameters have been checked in this simulation such as packet delivery ratio, average number of retransmission, number of bytes used of traffic control and end to end delay. Due to space constraints, only end to end delay and packet delivery rate are presented in this paper.

4.4.1. End to end delay

The first set of result presents the average end to end delay of CBR packets in the network. Figure 8 shows the average end to end delay for three protocols and for different load level. For low mobility and medium load, protocols over backbone show an increased end to end delay because the additional control traffic comes from the backbone maintenance. The additional traffic causes more processing delay in the intermediary nodes. When the mobility increases, the three protocols benefit from the presence of the backbone, for the two levels load, and the end to end delay decreases considerably. The effect of mobility has been reduced by the stability of the backbone realized by the maintenance procedure.

4.4.2. Packet data delivery

The second set of result presents the delivery packet rate. From figure 9, we can see that performances of protocols over backbone improve their original versions for medium and high load. This is especially can be observed when the mobility increases. The improvement in the packet data delivery rate is because of: i - minimizing the number of control messages and then reducing the bandwidth occupied by control traffic; more bandwidth will be available for data traffic. With backbone structure, diffusion not based on flooding and hence have higher throughput.

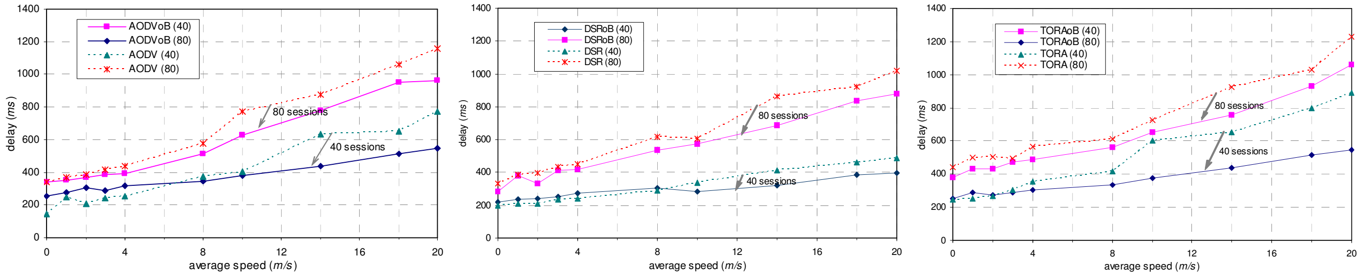


Fig. 8 – end to end delay versus mobility

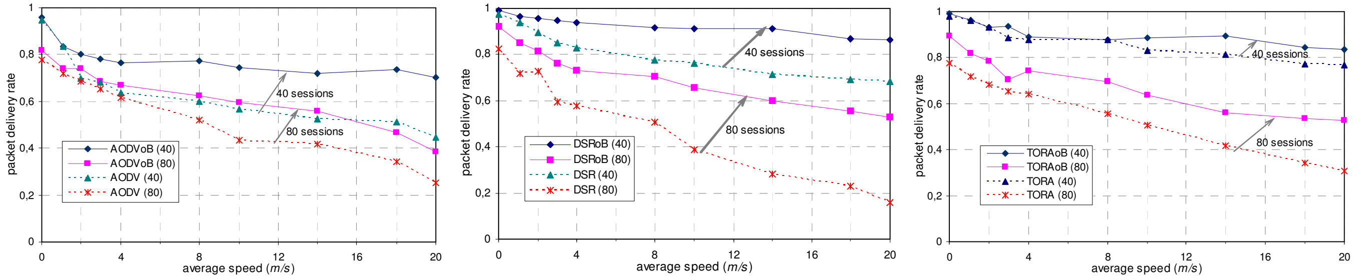


Fig. 9 – packet delivery rate versus mobility

5. CONCLUSION

In this paper, a new approach to construct a structure of virtual backbone in mobile ad hoc networks is proposed. This approach ensures a minimal size of the backbone. Due to the dynamic nature of ad hoc networks, caused by the terminal's movement, we are designed a performed maintenance procedure of the virtual backbone. This procedure guarantees high level node connectivity to the backbone even in a dynamic environment. The main issue in the ad hoc networks is the absence of a fixed infrastructure; nodes have to do routing functionalities. As a consequence, a large amount of control messages will be generated and hence bandwidth consumption increases by the traffic control. In order to minimize traffic control and bandwidth consumption, a virtual backbone can be useful. Indeed, only a subset of nodes will be responsible to handle traffic control in the network. Another issue in mobile ad hoc networks is the nodes mobility causes a dynamic topology environment. Indeed, the effect of the mobility can be reduced by the presence of the virtual backbone. The maintenance procedure guarantees the connectivity of the backbone.

Routing protocols such as AODV, DSR and TORA involve all the nodes in the network for routing and use flooding as a mechanism for route query. Most of existing routing protocols don't perform well in the dynamic environment as the static one. Simulation results show that routing protocols enhance their performance in presence of the backbone. A significant increase of the packet delivery rate has been noticed. Also, the end to end delay has been reduced for high mobility and for medium and high load. This work is the first of a set of simulation studies in mobile ad hoc networks. Studies will include additional performance evaluation of other proposed protocols (including multicast) over backbone and other traffics than CBR (e.g. TCP transfers). A TCP flow requires data flows in both directions between the source and the destination.

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