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A New Routing Algorithm for Large Wireless Battlefield Networks

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ABSTRACT

In the future automated battlefield, communications will be supported in part by a hierarchical wireless network that includes: ad hoc ground radio subnets; point to point wireless long haul backbone, and; Unmanned Aerial Vehicles (UAVs). In such a hierarchical network, nodes are generally partitioned into groups. Each group has one or more backbone nodes that provide access points to the backbone network and to UAVs. Communications between groups can thus utilize links at higher level. A critical protocol in the operation of such a large mobile network is routing. Previous research of UAV based systems has generally assumed the use of a hierarchical routing scheme, for example, Extended Hierarchical State Routing (EHSR). However, a hierarchical scheme like EHSR has some limitations. In this paper, we extend Landmark Ad Hoc Routing (LANMAR) to a hierarchical structure with backbone nodes, high quality backbone links and UAVs. We show that the basic LANMAR scheme can be extended to incorporate backbone and UAV links. We will also show how backbone links and UAV links are automatically discovered by the LANMAR routing algorithm and are used effectively to reach remote destinations (thus reducing the hop distance). In other words, our scheme will combine the benefits of "flat" LANMAR routing and physical network hierarchy, without suffering of the intrinsic EHSR limitations

I. INTRODUCTION

The ad hoc wireless networking technology shows great advantages and importance in the military environment because of its independence of a fixed infrastructure and its instant deployment and easy reconfiguration capabilities. However, many researches found that the large-scale ad hoc wireless network has performance limitations. The main reasons are "long hop" paths, heavy routing overhead, spatial concurrency constrains on nearby nodes and incorrect routing information of remote nodes because of mobility. Thus, it is natural that the "flat" architecture cannot fully support the military wireless environment where a very large-scale network is needed. Building a hierarchical ad hoc wireless network is a good way to solve this performance bottleneck. In the military environment, the hierarchical structure is really an inherent feature. Different units have different communication devices and capacities. For example, the wireless radios installed in vehicles are much more powerful than the radios of dismounted soldiers. Unmanned Aerial Vehicles (UAVs) and even satellites can be used for providing higher level connections. The key element of such a hierarchical structure is the routing protocol. It connects all units into an integrated communication system. Comparing with the "flat" ad hoc wireless network, the hierarchical network will greatly reduce the hops from sources to destinations. By utilizing the higher level links, the hierarchical structure will remove the performance bottleneck and efficiently support the large-scale military wireless network.

In this paper, we define a hierarchical structure. In this structure the ordinary ground nodes with limited short transmission range are divided into groups. Each group has one backbone node. These backbone nodes have an additional, powerful radio and can form a higher level backbone network. UAVs in the sky can further be used to connect the backbone nodes.

It is natural that such a UAV based system would use a hierarchical routing scheme, for example, the Extended Hierarchical State Routing (EHSR). However, a hierarchical scheme like EHSR has some limitations in terms of group size, concentration of traffic, vulnerability to attacks and routing overhead. As an alternative to conventional hierarchical routing, Landmark Ad Hoc Routing (LANMAR) was recently proposed to achieve scalability in large networks. LANMAR was shown to be very efficient in large, mobile, ad hoc wireless networks. It is a "logical" (instead of physical) hierarchical structure. In this paper, we will present an extension of LANMAR that can efficiently interwork with a wireless backbone. The resulting structure is a "flexible" hierarchical structure that enjoys the advantages of both landmark routing and EHSR, without suffering the limitations of the latter.

The rest of this paper is organized as follows. In section 2, we introduce the EHSR routing and LANMAR routing and discuss their advantages and disadvantages when applied to large-scale networks. In section 3, we describe in detail how we extend the LANMAR routing scheme into a hierarchical structure using a wireless backbone and discuss the reliability and fault tolerance of our scheme. In section 4, we present simulation results evaluating the performance of the proposed scheme. We conclude our paper in section 5.

II. ROUTING IN LARGE SCALE NETWORKS

In this section, we briefly review the two routing schemes – EHSR and LANMAR - which form the cornerstones of the proposed new scheme.

2.1 Extended Hierarchical State Routing (EHSR)

EHSR is an extension of the hierarchical state routing (HSR). Like HSR, EHSR is a hierarchical "link state" routing protocol. Nodes are clustered into groups. The cluster heads at the lower level will become the members of the next higher level. Each node has a hierarchical ID (HID), which is defined as the sequence of the MAC address of the nodes on the path from the top hierarchy to the node itself. In terms of the hierarchical structure we described above, EHSR has three levels, UAV network, backbone network and the ground ad hoc network. The HID of one node contains three part, the UAV address, backbone node address and address of node itself. This HID is also a routing ID in which it completely defines the path within the hierarchy.

Due to mobility, the nodes may move from one cluster to another. Thus the Hierarchical ID (HID) of one node needs to be changed. All other nodes must also be informed of such a change. To do so, each node has a permanent logical address and a home agent (HA) to register its current HID. It is very natural that UAVs can play a role as home agents of nodes within their areas. Each backbone node will broadcast a beacon periodically. After receiving these beacons, a node can determine which cluster head is closest to it. Then, it can join that cluster. If the new cluster is different from the old cluster, it updates its HID at the home agent.

EHSR routing comes very natural to the hierarchical network environment since it fully utilizes the higher level links. However, it has several limitations, which can impact its performance. First, all traffics need to go through backbone nodes, even for communications between members of the same cluster. This will cause contention and congestion at the backbone nodes. Second, strict EHSR routing requires that each node reach the backbone node in one hop. In other words, each group is actually a single hop cluster. While long multi-hop paths can be inefficient, it appears, however, that the limitation to single hop is not very effective either. It limits group size to be very small, which means that nodes are very likely to move from one group to another thus triggering a change in HID. Third, the hierarchical nodes are vulnerable to attacks. Since the backbone nodes must process all the local traffic, the destruction of a backbone node will break down the entire cluster, a situation we definitely must avoid in the battlefield. Likewise, the home agents are also critical points of failure.

2.2 Landmark Ad Hoc Routing (LANMAR)

LANMAR is an efficient routing protocol in a “flat” ad hoc wireless network . LANMAR assumes that the largescale ad hoc network is grouped into logical subnets in which the members have a commonality of interests and are likely to move as a “group” (e.g., a group of students from same class, or a team of co-workers at a convention, a brigade or tank battalion in the battlefield). LANMAR uses the notion of landmarks to keep track of such logical subnets. It uses an approach similar to the landmark hierarchical routing proposed for wired networks. More precisely, the network address of a mobile node contains its subnet ID: <Group ID, Host ID>. Each logical group has one node serving as “landmark”. The route to a landmark is propagated throughout the network using a Distance Vector mechanism. Further, the LANMAR routing scheme uses Fisheye State Routing (FSR) with the scope concept for local operation. That is, within the Fisheye scope, LANMAR runs link state routing. For nodes outside of the Fisheye scope, only landmark distance vectors are broadcasted. The routing update exchange of LANMAR routing is as follows. Each node periodically exchanges topology information with its immediate neighbors. In each update, the node sends entries within its Fisheye scope. Updates from each source are sequentially numbered. To the update, the source also piggybacks a distance vector of all landmarks. Through this exchange process, the table entries with larger sequence numbers replace the ones with smaller sequence numbers. As a result, each node has detailed topology information about nodes within its Fisheye scope and has a distance and routing vector to all landmarks.

When a node needs to relay a packet, if the destination is within its Fisheye scope, accurate routing information is available from the Fisheye Routing Tables. The packet will be forwarded directly. Otherwise, the packet will be routed towards the corresponding landmark of the destination logical subnet, which is read from the logical address carried in the packet header. However, if the packet arrives within the scope of the destination before reaching the landmark, it is routed to it directly without going through landmark.

Thus, the LANMAR scheme largely reduces the routing table size and the routing update traffic overhead. It greatly improves routing scalability to large, mobile ad hoc network. However, the LANMAR scheme as described above cannot take advantage of the potential “short cuts” offered by the physical backbone and UAV hierarchy.

III. LANDMARK ROUTING IN HIERARCHICAL STRUCTURE

LANMAR can be well integrated into the UAV based hierarchical structure by virtue of the fact that it is itself logically hierarchical. Routing information to remote nodes is summarized by landmarks. Now, we will extend such logical hierarchical structure to utilize the physical hierarchy. In the original LANMAR scheme, while routing packets to remote nodes, we route the packet toward the corresponding remote landmark along a long multi-hop path. In the hierarchical structure, we can route the packet to nearby backbone node. Then the backbone node can forward the packet to a remote backbone node near the remote landmark through the higher level links. Finally, the remote backbone node then can send the packet to the remote landmark or directly to the destination. This will greatly reduce the number of hops.

We want to extend the LANMAR routing protocol so that it can take the "short cut" described above. First, all ground nodes, including ordinary nodes and backbone nodes, are running the original LANMAR routing via the short range ground radios. This is the foundation for falling back to "flat" multi-hop routing if backbone nodes are destroyed. Second, a backbone node with a long range radio will broadcast the landmark distance vectors to neighbor backbone nodes via the backbone links, and even to UAVs. The content of this packet is the same as an ordinary landmark update packet. The neighbor backbone nodes will treat this packet as a normal landmark update packet. Since this higher level path is usually shorter, it will replace the long multihop paths. From landmark updates the ground nodes thus learn the best path to the remote landmarks, including the paths that utilize the higher level links. To route packets using the correct radio interface, each backbone node needs to remember the radio interface to next hop on each path.

One important feature of our system is reliability and fault tolerance. The ordinary nodes are prevented from knowing the higher level links explicitly. The higher level links are discovered automatically by the backbone nodes. Now, suppose a backbone node, of one group is destroyed by enemies. The shorter paths via this backbone node will soon expire. Then new landmark information broadcast via ground nodes will replace the expired information. Thus, the nodes in this group will go back to original landmark routing and use a "long hop" path to remote landmarks. Moreover the backbone node capable of connecting with the UAV can also broadcast routing information through the UAV to other backbone nodes. This path will be treated as two hops. So, when two backbone nodes cannot connect to each other directly, the two-hop path through UAV may be favored. In the worst case, when backbone nodes and UAVs are not operational, the whole system falls back to a "flat" ad hoc wireless network running the original LANMAR routing.Our scheme is also very easy to deploy since we didn't modify the ordinary ground nodes. All our modifications are limited to the backbone nodes.

IV. PERFORMANCE EVALUATION

4.1 Simulation environment

We use GloMoSim , a scalable simulation library to evaluate our system. The Future-Battlefield will deploy a very large-scale hierarchical wireless network. Thus, it is very important to evaluate routing protocols in large-scale scenarios. In our simulation, the field is as large as 3200mX3200m and 1000 nodes are deployed. These nodes are divided into 36 logical groups, thus there are 36 landmarks. An ordinary node has a small 802.11 wireless radio with power range 175m. The backbone node has three radios, one small radio same as the ordinary ground nodes, one powerful radio to communicate with other backbone nodes and a third radio for accessing the UAV. The mobility model is "group mobility" . We run our extended LANMAR routing on such a three level hierarchical wireless environment.

4.2 Fault tolerance and readability

As we mentioned above, system reliability and fault tolerance are key features of our design. So, it is very important to observe the system behavior while increasing the number of backbone nodes. In this simulation we increase the number of backbone nodes from 0 to 9, 18, 27 and 36. 0 backbone node means there is no backbone node, so the whole system is a "flat" ad hoc network running original LANMAR routing. 36 backbone nodes imply that each landmark group has its own backbone node. The source destination LANMAR routing in a "flat" ad hoc wireless network without UAVs LANMAR routing in a hierarchical ad hoc wireless network with UAVs source destination UAV 4 backbone nodes share the same mobility speed as the ordinary nodes as 10m/sec, which is realistic in the battlefield. In our simulation, there is only one UAV connecting all backbonenodes. The network performance is shown in Figure 1 and Figure 2.

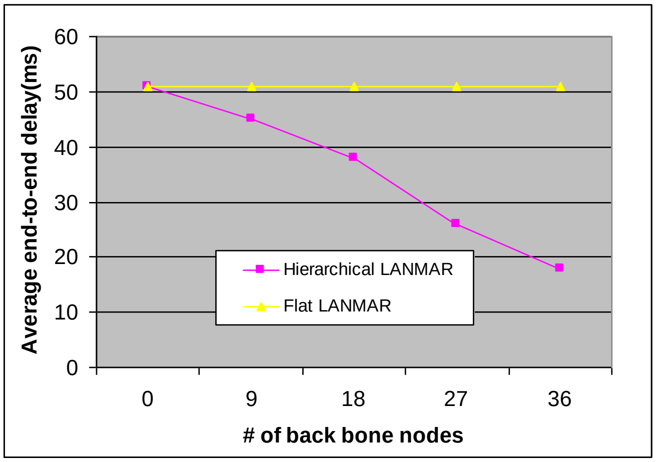

Figure 1: End-to-end delay as a function of # of backbone nodes

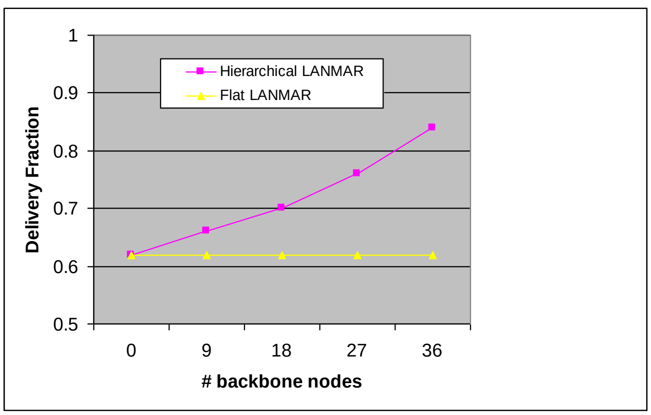

Figure 2: Delivery fraction as a function of # of backbone nodes

From Figure 1 and Figure 2 we note that while we increase the number of backbone nodes, the network performance increases greatly. Average end-to-end delay in Figure 1 is defined as the average delay of each packet routed from source to destination. This average delay is very important in the battlefield, which tends to require small delay because of its time-critical applications. With 36 backbone nodes, the average delay is decreased from 50ms to 17ms.

The delivery fraction (see Figure 2) also shows great improvement. The reliability and fault tolerance are very clear here. While there is no backbone node (number of backbone nodes is 0), the network can still provide reasonable performance. We believe this feature is valuable. The reason why we didn't increase the number of backbone nodes to be very large is that we believe that backbone nodes are expensive resources since they require additional powerful radios. From the figures above, we note that even a small number of backbone nodes can improve performance greatly.

4.3 Performance comparison with "flat" ad hoc routing protocols

In this experiment, we want to show the performance improvement while utilizing the hierarchical structure. We compare our LANMAR routing extension in the hierarchical network with the original LANMAR routing and AODV, a popular on-demand routing protocol in "flat" ad hoc networks. We still keep the network scenario as described above. Here, the number of backbone nodes is fixed as 36. We increase the node mobility from 0m/sec to 10m/sec to compare the performance. The simulation results are shown from Figures 3 to 5.

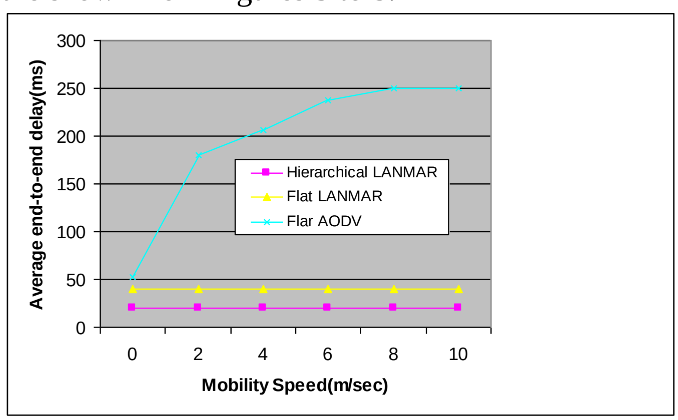

Figure 3: End-to-end delay as a function of mobility

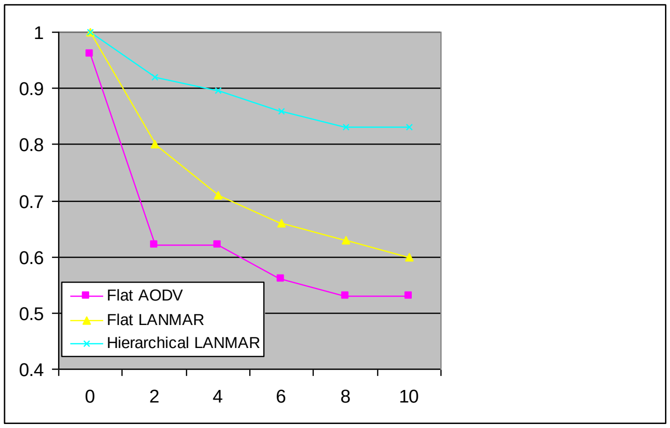

Figure 4: Delivery fraction as a function of mobility

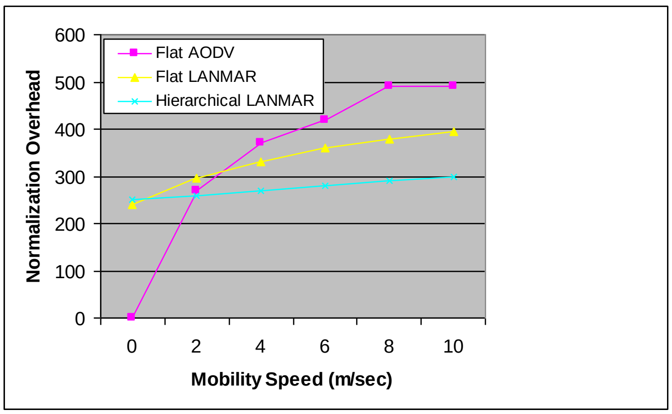

Figure 5: Normalized overhead as a function of mobility

In Figure 3, with the increase of mobility speed, the average end-to-end delay of AODV is increased greatly. This is because AODV is on-demand. While increasing the mobility speed, the links break and path expirations are more frequent. AODV needs to delay many packets as it struggles to find new paths from sources to destinations. In contrast, LANMAR routing is proactive, thus its average delay is not affected by the mobility speed. As we discussed before, in the battlefield, low latency is critical for many applications. The LANMAR routing extension in hierarchical structure further reduces the end-to-end delay by reducing the number of hops from sources to destinations. The delivery fraction of LANMAR routing extension is also improved greatly, as shown in Figure 5. In Figure 6, the normalized overhead is defined as the number of routing packets used to route one data packet successfully. This metric reflects the control overhead. In terms of normalized routing overhead, the LANMAR routing extension is only worse than AODV while there is no mobility. This is reasonable since AODV only generate few routing requests while there is no mobility. Unfortunately, mobility is an essential ingredient of ad hoc networks, especially in the battlefield. While there is mobility, the hierarchical LANMAR routing always shows better results.

V. CONCLUSION

In this paper, we proposed an extension of LANMAR routing to a hierarchical type structure with backbone nodes, backbone links and UAVs. Backbone links and UAV links are automatically discovered by the extended LANMAR routing algorithm and are used effectively to reach remote destinations (thus reducing the hop distance). It follows that the proposed scheme combines the benefits of "flat" LANMAR routing and physical network hierarchy, without suffering of EHSR limitations. Simulation results using Parsec/GloMoSim platform also show that our scheme improves the performance considerably, especially in high mobility environments. Fault tolerance and system reliability are key requirements in the real battlefield. Through simulation results, we have shown that our scheme does provide strong fault tolerance and reliability.

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