Multimedia Streaming in Large-Scale Sensor Networks with Mobile Swarms *

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ABSTRACT

Sensor networking technologies have developed very rapidly in the last ten years. In many situations, high quality multimedia streams may be required for providing detailed information of the hot spots in a large scale network. With the limited capabilities of sensor node and sensor network, it is very difficult to support multimedia streams in current sensor network structure. In this paper, we propose to enhance the sensor network by deploying limited number of mobile "swarms". The swarm nodes have much higher capabilities than the sensor nodes in terms of both hardware functionalities and networking capabilities. The mobile swarms can be directed to the hot spots in the sensor network to provide detailed information of the intended area. With the help of mobile swarms, high quality of multimedia streams can be supported in the large scale sensor network without too much cost. The wireless backbone network for connecting different swarms and the routing schemes for supporting such a unified architecture is also discussed and verified via simulations.

1. INTRODUCTION

Sensor networking technologies have developed very quickly in the last ten years. It shows big potential in the future battlefield and disaster discovery. One of the major research issues in this field is data dissemination [2]. In the previous research, usually only low rate data and information dissemination is considered. However, in many environment, high rate, bandwidth intensive and delay sensitive information dissemination is required. For example, in the battlefield, once the sensor network detects the intruders, the commanders may want to see detail of the intruders through video images. Similarly, in the disaster recovery environment, high quality video or audio streams are also appreciated. However, a typical sensor network usually has many limitations to support multimedia streaming such as hardware limitation (e.g. no high quality camera or other equipment), bandwidth limitation as well as power limitation. To better support high quality multimedia streams in a sensor network, in this paper, we propose to enhance the sensor network with mobile swarms.

A "swarm" is a group of nodes which physically close to each other, and usually share the same mobility pattern. Comparing to the sensor nodes, we assume in this paper that the swarm nodes have better capabilities such as high quality video cameras, long radio range and high channel bandwidth. The swarm node may also be able to talk with satellites. More important, unlike sensors, the swarm nodes are mobile with relatively high speed. In the battlefield, a mobile swarm can be a group of tanks or even unmanned aerial vehicles (UAV) moving together. With the concept of mobile swarms, in this paper, we propose to enhance the limited functionality of a sensor network by deploying several mobile swarms in the sensor network. With the cheap price of sensors, a sensor network can be in very large scale. It is impossible to deploy swarms to cover the whole sensor network. Instead, we propose to deploy only limited number of swarms. Once there is a hot spot (e.g. detection of intruders), a swarm can then be directed to the area where it is highly desired to help forwarding high quality multimedia streams. Different mobile swarms can talk to each other and to the command center via a backbone network or even via the satellite.

Deployment of mobile swarms can enhance the sensor network in many ways. Firstly, the swarm nodes have much higher hardware capabilities than the sensor nodes. They can provide detailed information of the intended area (e.g. the hot spot). Secondly, the wireless radios of the swarm nodes usually have much longer range and higher channel bandwidth, which can support high quality and delay sensitive multimedia streams. Thirdly, the swarms are mobile. They can be easily directed to the hot spots. A limited number of mobile swarms can easily cover a large scale sensor network.

The rest of the paper is organized in the following way. In section 2, we briefly review the proposed architecture of the mobile swarm enhanced sensor network. We describe the directed group mobility model in section 3 and the mobile backbone network in section 4. The routing scheme in the proposed network architecture is then present in section 5. Performance evaluation results are given in section 6 and we conclude the paper in section 7.

2. OVERVIEW OF THE ARCHITECTURE

Fig. 1 illustrates an overview of the proposed sensor network architecture with enhancement of mobile swarms. As we can see, the sensor network can be deployed to cover a very large field due to the low cost of sensor nodes. Sensors nodes perform the basic simple functionalities such as detecting

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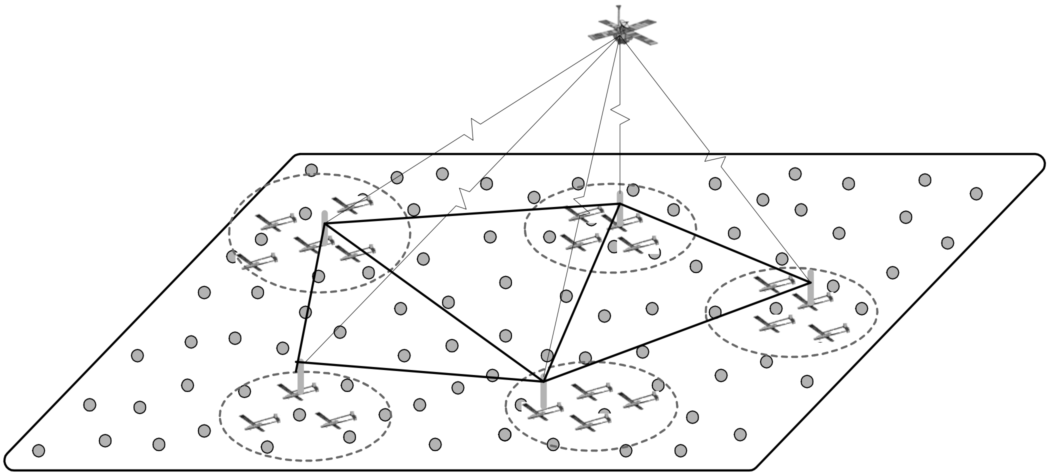

Figure 1: Overview of a large-scale sensor network enhanced by mobile swarms.

intruders and monitoring the environment changes. Once the sensor network detects something wrong in a certain area, one or more mobile swarms can then be directed to that area for discovering more detailed information perhaps by streaming video and audio data. In Fig. 1, the mobile swarms consist of unmanned aerial vehicles (UAVs). A UAV has multiple wireless radios. One is for talking to sensor nodes and one for talking to other UAVs. Another radio may also be installed for UAVs to talk to a satellite. The satellite can play as a forwarding node to connect different swarms for exchanging information. If no satellite available, we can then build a mobile backbone network among the different swarms. The network of swarms is then connected to the control center.

3. DIRECTED GROUP MOBILITY

Since only a very limited number of swarms are deployed, they must be directed to the "hot spots" in the sensor network for efficient utilization of the mobile swarms. In addition, nodes in the same swarm should move in groups. This mobility model can be called a directed group mobility model similar to those group mobility models proposed in the literature [6]. Here we describe how we model it in our simulator. First, the sensor network randomly generate the hot spots with a certain probability. Once a hot spot is decided, a nearby swarm will be notified. This swarm then will move towards the hot spots. This is the mobility vector of the whole group referred as group mobility vectors $\overrightarrow{V_g}$. In addition to the group mobility vector, each node in the swarm can also randomly move within the boundary of the group. This mobility vector is then called the internal mobility vector $\overrightarrow{V_i}$. Combining both the two mobility vectors, we can then get the final mobility vector of a node. This model is illustrated in Fig. 2. We can see the actual mobility vector $\overrightarrow{V}$ of a node is given as $\overrightarrow{V} = \overrightarrow{V_g} + \overrightarrow{V_i}$. In our implementation, the group destination point is randomly generated in the whole field. The internal mobility is then modelled as the random waypoint mobility [3] with the constraint of the group boundary.

4. MOBILE BACKBONE NETWORK

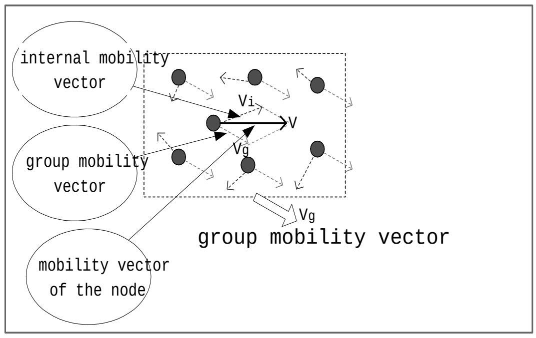

Figure 2: Illustration of directed group mobility model.

The mobile swarms usually need to communicate with the command centers and perhaps with other peer swarms. Since the mobile swarms may be far away from each other, the normal radio installed on a swarm node sometimes is not powerful enough to reach other swarms. To solve this problem, we propose a Mobile Backbone Network (MBN) over multiple swarms. In each swarm, we select a node to be the swarm leader. The swarm leader will be installed an additional powerful radio with a longer range. This power radio is called backbone radio. It will be used to connect the swarm leaders of nearby swarms to form a mobile backbone network. Since the radio range of the backbone radio is also limited, the backbone network is also a multihop ad hoc network.

Usually, radios at the backbone level use some form of channel separation (eg, antenna directivity, different codes, different frequencies, or combinations thereof) in order to minimize interference across levels. Radios in the same level share the same frequency and channel resources. Unlike the wired network, the nodes in the mobile backbone network are also moving, thus the backbone topology is dynamically changing. In many scenarios such as the battlefield, the hierarchical structure is an inherent feature of the application. Different units have different communication devices

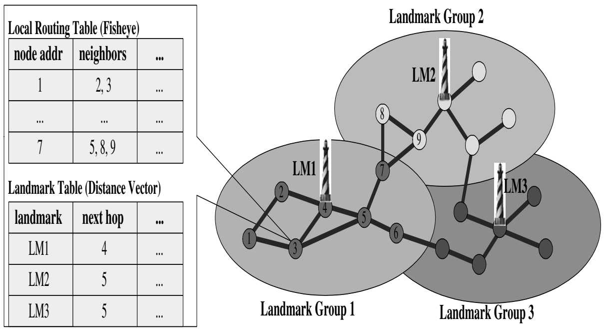

Figure 3: Illustration of LANMAR routing scheme.

and capacities. For example, the wireless radios installed in military vehicles have a more ample energy supply and thus are more powerful than those installed on the sensors.

5. MOBILE SWARMS AND LANMAR ROUTING

As shown in Fig. 1, this sensor network architecture is kind of a hierarchical ad hoc network. Routing scheme is very important for efficiently operating it. Firstly, the routing scheme must be able to explore the group mobility feature of the swarms. Secondly, the routing scheme should be able to work over the mobile backbones connecting different swarms. In this paper, we propose to adopt the Landmark Ad Hoc Routing (LANMAR) protocol [1]. Each mobile swarm can be treated as a LANNMAR group. The swarm leader can then be ideally recognized as the landmark node of each swarm. To integrate the sensor nodes into whole routing scheme, we can also divide the sensor nodes into multiple LANMAR groups and adopt LANMAR routing for the sensor network too. In this section, we first review the basic concept of LANMAR routing. Then we describe in detail on how to cooperate the LANMAR routing with the mobile backbone network.

5.1 Landmark Ad Hoc Routing (LANMAR)

LANMAR [1] is an efficient routing protocol designed for ad hoc networks that exhibit group mobility (e.g. as the mobile swarms proposed in this paper). Namely, one can identify logical subnets in which the members have a commonality of interests and are likely to move as a "group". The logical grouping is reflected in the address used within the ad hoc network, namely the two field address $< GroupID, HostID >$. One may notice a similarity between the group address and the IP address. In the group address the "network" address is replaced by the "group" address. The Internet uses network IDs to drive the packet to its final destination. In the Internet, the networks have a temporal and geographical permanency. In a mobile ad hoc system, there are no permanent, geographically meaningful subnetworks. There are, instead, groups of nodes moving together. It is thus natural to exploit these temporally persistent groups to support the type of hierarchical routing used in the Internet. The Internet uses Link State or Distance Vector routing schemes. Instead, LANMAR uses the notion of landmarks to keep track of such logical groups. Each logical group has one node serving as a "landmark". The landmark node is dynamically elected. The routes to landmarks are propagated throughout the network using a distance vector mechanism (in this study, we assume DSDV). In addition to landmark distance vector propagation, LANMAR relies also on a local, myopic routing algorithm (in this paper, we use Fisheye State Routing (FSR) [4], with limited scope; but, any other proactive routing scheme could work. Within the Fisheye scope, LANMAR thus runs link state routing. For nodes outside of the Fisheye scope, only landmark distance vectors are broadcast. In local FSR routing, each node periodically exchanges in-scope topology information with its immediate neighbors. Updates carry the sequence numbers assigned by the sources. To the Fisheye update, the source also piggybacks a distance vector of all landmarks. Thus, in LANMAR each node has detailed topology information about nodes within its scope and has a distance and routing vector to all landmarks.

When a node needs to relay a packet to a destination that is within its Fisheye scope, it uses accurate routing information available from the Fisheye Routing Tables. The packet will be forwarded directly. Otherwise, the packet will be routed towards the landmark corresponding to the destination's logical subnet, carried in the packet header. When the packet arrives within the scope of the destination, it is routed to it directly (possibly without going through the landmark).

LANMAR reduces the control overhead largely through the truncation (i.e., scoping) of local routing tables and the "summarization" of routing information to remote groups of nodes. The above features reduce line and processing O/H and thus greatly improve routing scalability to large, mobile ad hoc networks. As a final note, we must stress that the LANMAR addressing and routing scheme has significance only within the ad hoc network (e.g., battlefield). Each node has also an IP address, which is distinct from the LANMAR address. Moreover, Mobile IP can be used to route packets from remote Hosts (in the internet) to the mobile user that happens to roam in an ad hoc network. If IPv6 is used, the LANMAR address can be stored in the local subnet address field. This way, the same IPv6 address can be used within the ad hoc network, and across wired and ad hoc networks.

The basic concept of the LANMAR routing is illustrated in Fig. 3, where the local routing protocol is assumed to be Fisheye. In the figure, nodes are divided into three landmark groups. Each group elects one landmark as ($LM1$, $LM2$ and $LM3$). Fig. 3 also depicts the contents of the local routing table along with the landmark routing table for node 3. Clearly, node 3 only maintains those nodes within its local scope in the local routing table. For remote nodes, node 3 has no exact information. Instead, it maintains only the routing information to all landmarks as listed in the landmark table.

5.2 LANMAR Routing and Mobile Backbone Network

LANMAR can be well integrated into the mobile backbone network (MBN) 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 a logical

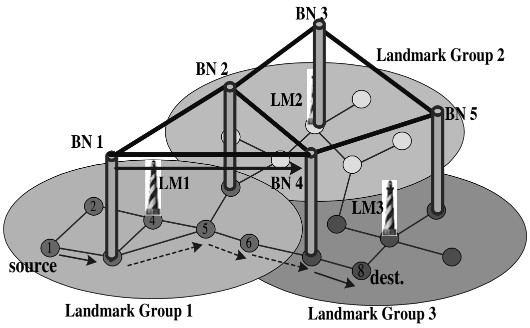

Figure 4: Illustration of LANMAR routing over mobile backbone network.

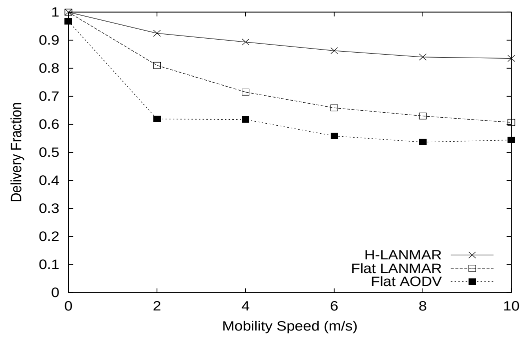

Figure 5: Comparison of delivery fraction vs. mobility.

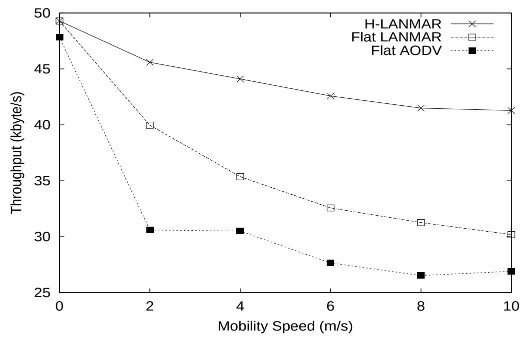

Figure 6: Comparison of throughput vs. mobility.

hierarchical structure to utilize the physical hierarchy. In the original LANMAR scheme, we route the packet toward the corresponding remote landmark along a long multi-hop path. In the hierarchical MBN, we can route the packet to the nearest backbone node, which then forwards it through a chain of backbone links to a remote backbone node near the remote landmark. Finally, the remote backbone node sends the packet to the remote landmark or directly to the destination if it is within its scope. This will greatly reduce the number of hops. The procedure is illustrated in Fig. 4. We can see that by utilizing the backbone links, the 5-hop path is reduced to be 3 hops long, a great improvement!

We extend the LANMAR routing protocol so that it can take the "short cut" described above. First, all mobile nodes, including ordinary nodes and backbone nodes, are running the original LANMAR routing via the short-range radios. This is the foundation for falling back to "flat" multi-hop routing if backbone nodes fail. Second, a backbone node will broadcast the landmark distance vectors to neighbor backbone nodes via the backbone links. The neighbor backbone nodes will treat this packet as a normal landmark update packet. Since the higher level paths are usually shorter, they will win over (and thus replace) the long multi-hop path in the level 1 network. From landmark updates the ordinary nodes thus learn the best path to the remote landmarks, including the paths that utilize the backbone links.

One important feature of our routing scheme is reliability and fault tolerance. The ordinary nodes are prevented from knowing the backbone links explicitly. The backbone links are indirectly learned via backbone node routing broadcasts. Now, suppose a backbone node of one group is destroyed by enemies, the shorter paths via this backbone node will expire. Then new landmark information broadcasted from other nodes will replace the expired information. Thus, in the worst case, routing in this group goes back to original landmark routing while other groups with backbone nodes can still benefit from backbone links among themselves.

6. PERFORMANCE EVALUATION

6.1 Simulation Environment

We use GloMoSim [7], a packet level simulator specifically designed for ad hoc networks, to evaluate the proposed swarm enhanced sensor network. Since we are targeting large-scale sensor networks, 1000 sensor nodes are deployed uniformly in a 3200mX3200m field. These sensor nodes are divided into 36 groups for running LANMAR routing. In addition, 5 swarms with 5 UAVs in each swarm is deployed. The swarm nodes has a wireless radio with range as 367m and channel bandwidth as 2Mbps. Each swarm elects a swarm leader with an additional backbone radio to form the backbone network. The backbone radio has a radio range as 800m and channel bandwidth as 11 Mbps. Simulation time of each run is 6 minutes.

6.2 Simulation Results

We have done a series of experiments to compare the LANMAR over MBN (H-LANMAR) with the original LANMAR routing and AODV routing [5] in a "flat" sensor network without mobile swarms. The purpose of these experiments is to show that how the mobile swarms on top of a large scale sensor network can improve the network performance effectively. 30 randomly selected CBR pairs are used to generate traffic. We increase the node mobility from 0m/sec to 10m/sec to compare the performance. Results are given from Fig. 5 to Fig. 8.

In Fig. 5, the delivery fraction of H-LANMAR clearly outperforms "flat" LANMAR and AODV as mobility increases. Without mobility, all three protocols have delivery fraction nearly equal to 1. This is due to the fact that in a stationary network the routing information in the node routing table is always accurate. Only few packets are dropped on the way to destinations. Note that the CBR traffic load was chosen so as not to saturate the network. However, when the nodes are moving, routing information tends to become obsolete

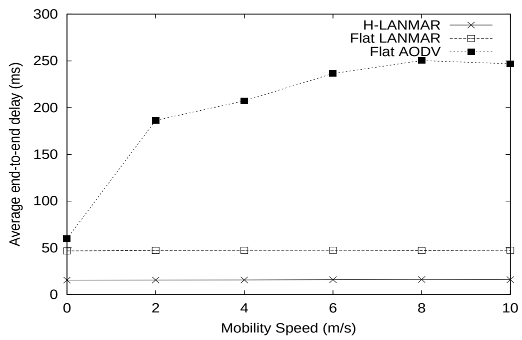

Figure 7: Comparison of end to end delay vs. mobility.

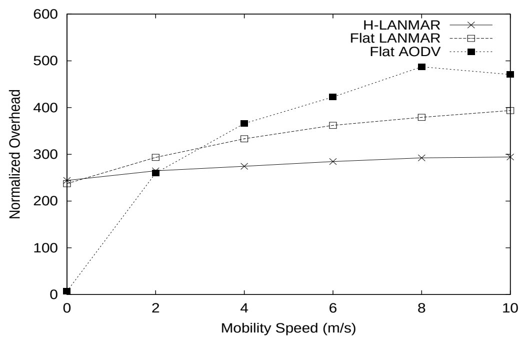

Figure 8: Comparison of routing overhead vs. mobility.

very rapidly. By utilizing the mobile swarms, H-LANMAR can propagate new routing information very quickly and efficiently and keep the routing table more up-to-date than the other schemes. This is why H-LANMAR can achieve a high delivery fraction in high mobility while the other two degrade quickly. Similar results, this time in terms of network throughput, are reported in Fig. 6

Fig. 7 shows average delay as a function of mobility speed. The average end-to-end delay of AODV increases rapidly with mobility speed. This is due to the on-demand routing maintenance feature of AODV. With increased mobility speed, path interruptions and expirations are more frequent. AODV delays packets in intermediate queues as it searches for new paths. In contrast, LANMAR and H-LANMAR are proactive, thus the average delay (of the packets that actually get delivered to destination) is not significantly affected by speed. H-LANMAR further reduces the delay by using backbone links.

Fig. 8 gives the normalized routing overhead (NRO) of the three protocols. The normalized routing overhead is defined as the number of routing packets used in order to route one data packet successfully. In low mobility or no mobility, the routing overhead of AODV is much smaller than LANMAR and H-LANMAR. In fact, AODV re-computes a route only when it expires because of lack of user traffic. Thus, its NRO is very small. However, with increasing mobility, the frequent link breaks and path expirations cause the overhead of AODV to increase sharply. As a result, the NRO increases very quickly. This is an indication that AODV has a scalability problem in large-scale, mobile ad hoc networks. Compared with AODV, the overhead of LANMAR and H-LANMAR is only minimally affected by mobility.

7. CONCLUSION

In this paper, we propose to use mobile swarms to enhance the performance of large scale sensor networks. A large scale sensor network has many hardware and network limitations. To remove these limitations, a limited number of mobile swarms are introduced and deployed. The swarm nodes have powerful hardware equipment, especially the network connectivity. By directing the mobile swarms to the "hot spots" happening in the sensor network, more detailed information of the "hot spots" area can be propagated to the command center or other swarms efficiently and effectively via the swarm backbone network. By this way, we can greatly improve the performance of large scale sensor network without much additional cost.

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