LORD: A Locality-based Distributed Data Sharing System for Highly Dense and Dynamic MANETs

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***Abstract*—The rapid development of mobile communication techniques enables mobile video-on-demand and video sharing applications, which allow the sharing of video data among mobile handset users and vehicles whenever and wherever. These applications have been penetrating into our daily life with dramatic speed. Traditional video sharing systems built on infrastructure wireless networks suffer from the problems of single point of failure, hot spots, and low-scalable transmission. Mobile Ad Hoc Network (MANET) consisting of mobile nodes is a promising alternative structure for flexible and distributed video data sharing without central control. This paper presents a locality-based video sharing system for highly dense and dynamic MANET, namely LORD. LORD provides a series of protocols about region-based video centric storage and retrieval, which can provide highly efficient, scalable and dynamism-resilient video sharing services with low overhead. Simulation results are provided to show the superiority of LORD.**

I. INTRODUCTION

Video sharing is one of the most popular applications recently. The number of US on-line video viewers increases rapidly from 52.3 million in 2003 to 155.2 million in 2008 and has a projection about 183.0 millions in 2011 [1]. In 2008, USA president election, YouTube has played a significant role in persuading the electorate. Due to the mobility restrictions of wired communication, video sharing applications have been penetrating into our daily life with dramatic speed. The fast development of microelectronics and broadband wireless access techniques promise a large market in mobile peer-to-peer video sharing services. Nowadays, low cost laptops, PDAs and smart phones which enable people to "working while walking" are prevalent all over the world. Some areas such as urban cities will be covered by millions of mobile nodes with high mobility and density. An efficient video sharing system suitable for such highly dynamic and dense MANETs is indispensable for the envisioned highly dynamic and even highly dense wireless video sharing applications.

Currently, most wireless video sharing systems are infrastructure-based via a server and client architecture [2]. It may suffer from potential drawbacks such as single point of failure, hot spots, low scalability [3]. As the wireless devices are pervasive in the future, a large number of video requests may overload the centralized server, leading to video delivery delay, request lost or even system crash down. The failure of a server adversely affects the entire video sharing system. An alternative system is a distributed video sharing system, in which each node serves as a data server without central control. Some distributed data sharing approaches on MANETs can be possibly classified into two categories based on the underlying routing protocols employed: on-demand topological routing system [4]–[8] and geographic routing system [9]–[13].

In the topological routing a source node broadcasts query messages to locate data files. Due to the high volume of the query and routing maintenance overhead, the algorithms are not suitable for large-scale high dense systems, though they work well in systems with small or moderate size. In contrast, geographic routing protocols are scalable without explicit end-to-end route establishment and maintenance. The protocols forward data based on the location information of each node provided by positioning systems. Many data sharing systems [10]–[13] based on geographic routing map data to a location spot, store the data to the node closest to the location, and rely on geographic routing to retrieve the data. However, most of these systems are primarily targeted for low dynamic wireless sensor networks, and are not suitable for highly dynamic MANETs for mobile video sharing. High node mobility leads to frequent file position update, generates high system overhead and deteriorates system performance. Meanwhile, the proactive updating mechanism increases the system overhead and query failure uncertainty.

In order to build an efficient distributed video sharing system for highly dense and dynamic MANETs, we propose a LOcality-based distRibuted system (LORD). LOAD is a solution particularly for video storage and delivery in a high dense and dynamic MANET, since in this scenario, the server and client structure may not work well. LORD divides the entire MANET area into a number of geographic regions and maps the video *metadata* files to the a geographic region based on a structured peer to peer data allocation policy. Consider the video are normally large files, publishing metadata rather than real data can reduces system overhead. Mapping metadata to a region rather than a single node avoids frequent data transfers due to node mobility. Meanwhile, the reactive location updating mechanism can guarantee a success of localization. In addition to the basic video sharing and delivery, LORD can also be used to addresses the issues such as node location tracking, load balance, and data consistency maintenance.

The remainder of this paper is organized as follows. Sec-

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tion II summarizes related work In Section III, we present the overview and design of LORD with an emphasis on its data index and retrieval protocol. In Section IV, the performance of LORD is studied in comparison with other approaches. Section V concludes the paper.

II. Related Work

In mobile wireless communication, data sharing system are mainly implemented in infrastructure-based networks [2], [14]. In the networks, mobile nodes publish and retrieve data through centralized servers.

In order to resolve the problems faced by the infrastructure network, decentralized data sharing systems based on MANETs have been proposed recently. One group of data sharing systems include 7DS [4], PDI [5] and ORION [6] that employ traditional MANET topological routing protocols such as AODV [7] and DSR [8] for message transmission. AODV and DSR are on-demand multi-hop routing algorithms that build a route path when a source node wants to send a message to a destination node. Basically, the methods rely on message flooding to establish a route from the source to the destination and store the route information in routing table for subsequential use. In AODV, each node sets up backwards pointers to the source node in the route tables during the query flooding from source node. By this means the shortest path from destination node to the source node is chosen. In DSR, several route paths to the destination are recorded in the routing table after query message arrive the destination. The adopted route path is stored in the packet header for in packet transmission. Although these methods wisely combine the overlay network routing with underlying network routing, the flooding based multi-hops transmission nature generates tremendous number of messages which prevents them from achieving higher system scalability. These data sharing systems query data based on file name rather node ID. Thus, a node needs to maintain a routing table for each data name. In a system with tremendous volume of data, a large number of routing tables will consume extremely large amount of resource. The work in [15] proved that the topological routing is not applicable in a highly dynamic and large-scale environment.

Recently, a number of geographic data sharing systems [10]–[13] have been proposed that depend on geographic routing for data management in a wireless sensor network. Using the geographic data allocation policy, these systems map a file to a geographical location, and store the file to the node closest to the location. To query a file, a node calculates the mapped location of the file, and uses geographic routing to send its query to the file host. Two methods can be used to localize nodes needed in geographic routing: GPS-based [10]–[13] and virtual coordinator based [16], [17]. GPS-based systems rely on GPS or other devices for node localization. Virtual coordinator based systems depend on virtual coordinates to get relative locations of nodes. These data centric systems are mainly designed for low dynamic or static sensor networks. In a dynamic MANET, the home node closest to a file's location frequently changes. Thus, these systems need to update the home node of each file and transfer data frequently. Basically, the home node of a file periodically sends out a message inquiring the closest node of its file's mapped location. This location updating also generates dramatically high overhead. Third, the proactive data updating mechanism is not resilient to a scenario where mobile nodes change their speed at all the time, which has a high query failure uncertainty.

In LORD, the regions are geographically fixed unlike the topology-based clustering. Based on the relationship between these regions (i.e. virtual map), a geographic routing is conducted based on their location. LORD maps a file to a number of nodes in a region, avoiding the high overhead for home node updating. Meanwhile, the reactive data updating mechanism is mobility resilient to different mobility scenarios. Meanwhile, since the metadata are stored in a cluster of nodes, the query load balance can be easily guaranteed. LORD achieves high performance in a large-scale highly dynamic MANET due to its features of high scalability and dynamism-resilience.

III. The LORD File Sharing System

In this section, we describe the LORD file sharing system. We start off by describing the objectives of LORD and the strategies to achieve the goals.

The challenges in the design of a distributed data sharing system in the highly dense and dynamic MANET are to meet the requirements of high scalability, high mobility resilience. The LORD system mainly consists of the following components discussed below.

(1) Scalability. A large-scale MANET consists of a large number of nodes, which needs a highly scalable file sharing system that provides efficient data request routing without generating high overhead.
(2) Mobility resilience. A MANET is characterized by high dynamism with frequent topology changes, which requires a file sharing system to be resilient to node mobility. LORD intelligently employs metadata and region-based data mapping to keep track of the mobility of the data requester and reactively update their metadata, leading to high mobility resilience.
(3) File consistency and query load balance. A high dense and dynamic system need a effective mechanism to maintain the file consistency and avoid query congestion in certain nodes. LORD clusters the metadata holders in a region which can facilitate the file consistency and query load balance maintenance.

In LORD, the entire area is divided into a number of fixed geographic regions. The *metadata* of a file is mapped to a region and stored in all nodes in the region. The request for this file will be forwarded to the region efficiently. Based on the metadata received, the file requester queries the file from the file hosts.

LORD has four steps in data sharing: (1) Metadata publishing (2) Metadata querying (3) Retrieve replying (4) Data requesting and delivering. Figure 1 shows a state diagram of the LORD System. Specifically, in step one, a node hashes the keywords of its file and normalize the hash value to a location vector (X_N, Y_N). The metadata is routed through a multi-hop manner based on geographic routing to the destination region (x, y). After the metadata arrives at a node in the destination region, the node stores the metadata and broadcasts the metadata to all other nodes in this region. As indicated in step two, when a node wants to retrieve a data, it computes the destination of the data using the same method. Its query message is routed to the destination region using geographic routing. The query receiver in the region then sends the metadata of the requested data back to the requester. As indicated in step three, after receiving the metadata response, the requester sends a request to a geographically close data owner based on the location information indicated in the metadata. Step four shows that the requester will publish the metadata of its retrieved data in order to make the data fully shared among nodes. In order to maintain the mapping between data and regions, when a node enters the region, it stores all metadata in the region and when it leaves the region, it drops all metadata in the region. At the same time, in a highly dynamic MANET, nodes should update their location information to the metadata holder of its data as they move to a new region. In the next sections, we introduce region generation, and efficient data index and retrieval in more details.

A. Region Generation

We consider a highly dynamic and dense MANET with nodes spreading out over an area. The area is divided into a number of regions by landmarks. The landmarks can be the devices (e.g. base stations) that periodically emit identification beacons [18], [19]. The information of geographic boundaries of geographic regions is configured into a node when it joins in the system. The generated regions can be of any shape such as hexagon, triangle or even unregulated graph. Figure 1 shows the resultant regions in a MANET in LORD. The size of the basic region can be determined depending on the number of the regions m in the system, the transmission range R of the node, and the size S of the entire areas all together. For example, if we wish the basic region can be covered by the transmission range of each node, the diameter X of each basic region should satisfy $X < R$ and $\frac{S}{n} < \pi X^2$.

B. Efficient Data Index and Retrieval

Figure 1 shows the metadata publishing process of LORD. To publish a video, the video host hashes the keywords of the video. The keywords, denoted as k, can be video names or video labels. Two different Locality Sensitive Hash Functions (LSH) [20], H_1 and H_2, are used for the hashing. The resultant hash values $(H_1(k), H_2(k))$ are normalized to a virtual vector (x_k, y_k) in the network area. We use (x_k, y_k) as the ID of the file. The metadata is mapped to the region I_i that contains the virtual vector (x_k, y_k) based on pre-configured region map. I_i is the region ID of the file.

After locating the destination region, the video host then

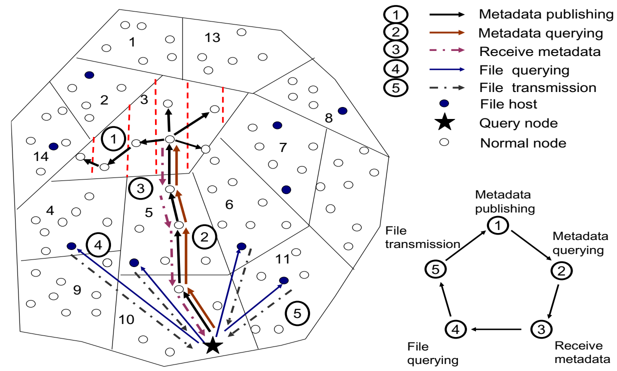

Fig. 1. The publishing and querying path in LORD

sends the metadata to the destination region based on geographic routing [21]. The destination is the center location of the destination region. In the geographic routing, a node always chooses a next hop node whose location is closest to the destination node. The metadata includes the IDs of the destination region, source region and video host ID as well as the keywords. When the metadata meets a node in the destination region, the node stores the metadata and broadcasts the metadata to all other nodes in this region in order to release the query congestion in certain nodes and facilitate file consistent maintainable.

In a dynamic MANET, it is important to maintain the mapping between video and regions by *mapping update*. It is because this location is the only clue for other nodes to accurately retrieve the metadata in a constant time O(1). Unlike previous proactive location updating mechanism [10], [11], a reactive location updating mechanism is used. More specifically, when a node moves from a region to another region, it gets all the metadata in the new region and drops the metadata in the old region. Meanwhile, each node needs to update its locating region to its published metadata to facilitate the file requests to find them. Specifically, it conducts the metadata publishing process again to update its locating region to its published metadata when move out the current region. The average number of updating messages for a movement is $k \cdot n_r$, where k is the average number of data metadata the node published and n_r denotes the average number of nodes in a region.

When a video requester wants to retrieve a video in the system, it hashes the desired video name to a destination region using the same metadata publishing hash function. After that, a metadata query message is sent to the region. Notice that, in order to balance the query load of the nodes in the destined region, the query always choose a node having the least query load in that region for the metadata query.

After receiving the metadata of queried data, the requester knows the nodes with their latest locations that hold the desired video file. It then sends a file request message to the nodes in the geographically closest regions according to the region ID and node ID indicated in the metadata. Then, the physically closed video holder can establish a transmission link to the

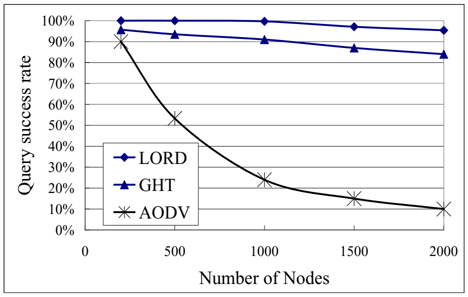

Fig. 2. Query success rate versus network size

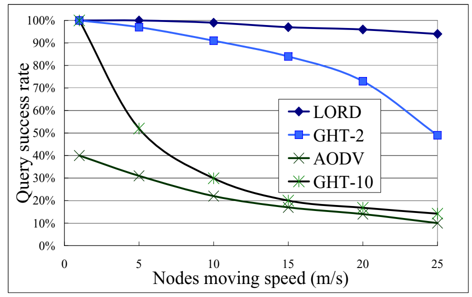

Fig. 3. Query success rate versus mobility

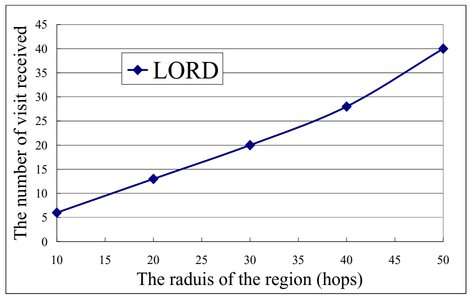

Fig. 4. Load balance

file requester.

IV. Performance Evaluation

The NS-2 simulator is limited to system size of hundreds of nodes. In order to simulate a large-scale network, we conducted simulation on an event-driven simulator ONE [22]. We evaluated the performance of LORD in comparison with GHT [11], LORD with AODV [7] topological routing rather than geographic routing. GHT employs geographic routing. The home node periodically sends out a mapping update message to check if there is a new closest node to the file's location. As in [11], in the experiment, we set the updating interval of GHT to 2s.

In the experiments, all nodes in the simulation move within a 2200m*2200m grid. The movement of all the nodes in the system complies to the Way-and-Point model [23] with 0 pause time, in which three categories of movement speeds are selected uniformly at random within [0.5-2.5]m/s, [1-5]m/s and [20-30]m/s respectively to represent of movement of walkers, bikers and cars in real life. The ratio of the number of nodes in the three groups of nodes was initially set to 4:3:3. The number of nodes was set to 1000. 400 files were randomly assigned to the nodes initially, and were queried by nodes randomly chosen. We set the transmission range of each mobile node to 150m, and set the size of a message to 2kb. The simulation time was set to 400s, and the warm up time was set to 100s. In the experiments, every message was transmitted once without retransmission.

A. Scalability

We varied the number of nodes in a network and measured the query success rate versus the number of nodes. Figure 2 shows that the query success rate of each system decreases as the network density increases. It is because more nodes in the network lead to higher channel contention which results in more message loss. The figure also shows that LORD produces the highest success rate, GHT produces higher success rate than AODV. Recall that GHT stores a file to the node closest to the file's location. Thus, a file's home node is always changing with node mobility in a dynamic MANET. If the mapping update rate is slow, GHT cannot maintain the correct mapping between files and nodes in high node mobility. As a result, a file query arrives at its new home node before the file is transferred to the new home node. Therefore, it has lower query success rate than LORD. It is very obvious to see that with the increase of nodes in the system, the query success rate of AODV drops sharply. This is due to the flooding-based on-demand routing in AODV. When a route from a source to the destination is determined, it is likely that a node in the observed route moves away before a message is forwarded to it, resulting in routing failure and subsequent query failure. Moreover, flooding makes the congestion situation worse, leading to more message drops. The results show that LORD outperforms others in terms of query success rate, and it can keep the high success rate in a large-scale MANET.

B. Mobility Resilience

This experiment tests the capability of different data sharing systems in dealing with node mobility in a dynamic MANET. Figure 3 shows the query success rate versus node average moving speed. In the figure, GHT-2 and GHT-10 are used to denote GHT with mapping updating interval 2s and 10s respectively. The results show that GHT-2 and GHT-10 lead to much lower success rate when nodes move in a faster speed, and AODV produces significantly lower success rate than others. Mapping update to ensure that a file or metadata is stored in the correct mapped node plays an important role to guarantee the successfulness of query in node mobility. In LORD, a metadata host drops its metadata before moving out of its region and receives new metadata when moving into a new region. Therefore, the mapping update occurs only when a node moves out of a region. In GHT, the mapping update is executed periodically. Fast mapping update helps to guarantee high success rate but at a high cost of overhead, while slow mapping update may fail to ensure success query. With the increase of the node movement speed, the periodical mapping update cannot guarantee that a file is always stored in its up-to-date home node, which leads to a sharp decrease of success rate in both GHT-2 and GHT-10. Since GHT-2 has a higher update rate than GHT-10, the success rate of GHT-2 is higher. The MANET is more likely to be partitioned with faster node moving speed. This causes AODV topological routing to drop many messages, leading to rapid decrease of success rate.

C. Load Balance

Recall that in LORD a node is overloaded when receiving a data query, it forwards the query to a lightly loaded node in its region. This experiment tests the performance of LOAD in achieving load balance. Since GHT and AODV have only one node for each data, we only tested the performance of LORD. We regard one region in LORD consisting of a number of concentric circles with different radius, and recorded the total number of queries received by the nodes along the different circles. In the experiment, 40 query messages were sent to the region at the same time from different directions. Figure 4 shows the total number of queries received by nodes in each circle identified by a radius. We can see that the number of queries increases linearly with the increase of the radius. The results indicate that LORD can achieve balanced load distribution in query processing. Although most of the query messages are received by the nodes at the edge of the region, the queries will be forwarded to the nodes inside the region if these nodes are overloaded. This result demonstrates the advantage of redundant metadata replicas, which enables LORD to distribute load in balance. metadata generates more maintenance overhead, it helps to avoid overloading nodes and enhance mobility resilience.

V. Conclusions

Traditional wireless video sharing based on infrastructure wireless networks cannot achieve higher performance in a highly dense and dynamic situation due to their centralized control. Current decentralized wireless data sharing systems either rely on topological routing or location spot based geographic mapping. The former fails to achieve high scalability due to flooding-based routing while the latter is not resilient to high node mobility with high location update overhead. In this paper, we propose a LOcality-based distRibuted Data sharing system (LORD) for highly dense and dynamic MANETs. LORD consists of a data index and retrieval protocol for video-centric storage and delivery. LORD divides the MANET area into fixed geographic regions. Without flooding, it maps and delivers the metadata of files to a region for data storage and retrieval. The reactive location update and metadata file control significantly reduce the system transmission overhead. Experiment results show the superiority of LORD over other data sharing systems in terms of scalability, efficiency and mobility-resilience.

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