TOWARDS ROBUST AND RELIABLE GROUP COMMUNICATION IN AD HOC MOBILE ENVIRONMENT

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ABSTRACT

Robust and reliable group communication plays a major role in developing distributed mobile application in which unannounced disconnections will occur frequently due to the mobility of the nodes which take part in mobile applications. The main objective is to achieve robust and reliable group communication in mobile ad hoc network based on a guarantee protocol that always considers the transmitting range, location, speed and direction of mobile nodes to ensure successful delivery of the message between the group members by calculating accurate delivery time. The consistent view of application state within the group of mobile nodes participating in application execution is necessary to achieve reliable message delivery. To solve any inconsistency during the group split or merge operation, when mobile hosts go out of the transmitting range, message delivery is assured and decided by guarantee protocol whether to deliver the message or not to avoid any inconsistent state. The guarantee protocol has been analyzed extensively to ensure the efficient communication among the participating hosts despite the high mobility environment and the mobility induced link failure cause inconsistent data and unrecoverability.

Keywords: Mobile ad hoc networks, group communication system, reliable communication, guarantee protocol.

1. INTRODUCTION

A mobile ad hoc network is an autonomous collection of mobile nodes that communicate over the wireless link. Due to node mobility, the network topology may change rapidly and unpredictably over time. It does not contain any fixed infrastructure and there is no central administration. Each node can act as a router and host. Ad hoc networks are used in wide range of applications like military operations, rescue operations, remote site construction, communication among a group of islands or ships, conferencing without the support of a wired infrastructure, and interactive information sharing. Unlike typical Internet applications, most applications of ad hoc networks involve one-to-many and many-to-many communication patterns. Reliable and efficient support of group communications is critical for almost all ad hoc network applications. However, Ad hoc networks group communications issues differ from those in wired network environments for the following reasons: The wireless communications medium has variable, highly dynamic, unpredictable characteristics, the signal strength and propagation fluctuate with respect to time and environment. Further, node mobility creates a continuously changing communication topology in which routing paths break and new ones form dynamically over the period of time. Due to the dynamic nature of ad hoc networks, reliable group communications present a challenging and complex task.

Robust and reliable group communication is the backbone of ad hoc mobile application in which mobile hosts join and leave the group frequently over the time. The survey of approaches and solutions to group communications for mobile adhoc networks has been discussed in [1]. When two or more mobile hosts come together to form a group working on the same problem, it is sometimes essential for all of them to have the same view of the joint computation state when they start working or when some of the members leave the group. Network partition and unannounced disconnections are the major problems to achieve reliable group communication due to the dynamic and unpredictable nature of mobile ad hoc networks. Network partition is a frequent event in ad hoc mobile environments and the cost of frequent inconsistency can be very high in mobile computation scenarios. Mobile hosts interact over wide spaces, and inconsistency can propagate indefinitely and cause irreparable and unrecoverable damage in mission critical applications. High mobility-induced link failures refer to the communication failures or disconnections caused by mobile units moving out of each other's communication coverage area [2]. The key characteristic of a mobility-induced link failure is that it is unrecoverable and unpredictable and more damaging than link failures in fixed networks in which network failure can be detected and recovered.

Group management is prime middleware functionality for assisting the development of applications over mobile wireless ad hoc networks [3]. Group management manages a dynamic network on top of which the application implements certain functional properties. Middleware software systems were also developed for coordination and communication in mobile systems, in order to make mobility totally transparent to the application programmer. Middleware simplifies mobile application development and makes the platform more reliable and robust. Typical examples of middleware are Lime, IBM TSpaces, and Sun Jini. LIME [4][5] is a middleware supporting the development of applications that exhibit physical mobility of hosts, logical mobility of agents, or both. LIME adopts a coordination perspective inspired by work on the Linda model. The context for computation, represented in Linda by a globally accessible, persistent tuple space, is refined in LIME to transient sharing of identically-named tuple spaces carried by individual mobile units. Tuple spaces are also extended with a notion of location and programs are given the ability to react to specified states. The resulting model provides a minimalist set of abstractions that promise to facilitate rapid and dependable development of mobile applications. TSpaces provides tuple space access and event notification capabilities in a mostly wired environment. Similar reliance on the client server architecture is found in Jini, which offers support for service registration and discovery.

To overcome the drawbacks of mobile ad hoc networks and provide reliable communication, guarantee protocol has been introduced. Guarantee protocol always keeps track of the transmitting range, location, speed and direction of mobile hosts participate in group communication to know the current state of each mobile host in the group. It provides guaranteed message delivery irrespective of the dynamic, variable and unpredictable nature of ad hoc networks. Guarantee protocol tries to help distributed application programmers in this matter by guaranteeing that communication between group members will not suffer from mobility-induced link failure and inconsistency caused by the network partition. We assume that the communication service is reliable in each physical network partition and has a bounded message delivery time within the partition, guarantee protocol ensure the delivery in time.

2. GROUP COMMUNICATION AND MEMBERSHIP

The Group Communication paradigm has already proven to be a useful tool for building reliable distributed systems [6][7]. Decentralized peer-to-peer cooperative environment is the basis for group cooperation in mobile Adhoc networks [8]. Group of member nodes therein interact and communicate in order to achieve a common goal. A group communication system usually integrates a group membership service with a reliable multicast service. The task of the group membership service is to keep members consistently informed about the current membership of a group by installing views [9]. The formal specification of Members in a group i.e. "nodes" share information, and need a consistent view of that information [10]. Formal specification of group communication is used to define the properties and terminologies [9][11]. Guaranteed message delivery in group communication needs consistent view of the participating hosts to avoid inconsistencies and mobility induced link failures [12]. To achieve this, nodes need a consistent view of all the other nodes involved in the communication. In this case, geographical location of nodes determines if they can become members of a group. We define later how the wide space of a group and the location of nodes help in establishing the group's membership. The membership service provides a dynamic view of the current membership to all nodes in the group.

The radio ranges of nodes in a group cover a certain geographical area, that is called coverage area or communication range [13]. Nodes have to explicitly issue a request to join a group if it is close enough and within the communication range of each other. When nodes leave the group i.e. when they go out of range and are removed from the group's membership. The nodes involved in the group communication service are mobile devices, requiring correct handling of frequent topology changes and of a dynamic set of interacting processors.

A group membership in an ad hoc mobile network maintains a list of the currently active and connected nodes in the group. When this list changes (with new members joining and old ones departing), the group membership reports the changes to the group members.

The specification of group communication and membership is given below

Let 'N' be the set of mobile nodes exist over time '*t*'.
Each node is identified by 'n' and maintains two state variables '*g*' and '*v*'.
Where '*g*' denotes group identifier and '*v*' denotes membership view.
Group (n,*t*) is the group identifier for node 'n' at time '*t*'.
Member (n,*t*) is the local membership view for node 'n' at time '*t*'.
Successor (*g*,n) is the successor of group '*g*' relative to node 'n'.
Predecessor (*g*,n) is the predecessor of group '*g*' relative to node 'n'.

In which,

1. If a group exists, all member nodes have access to the view of the partition in which they are the members.
2. Initially each mobile node starts as a singleton group containing itself as the only member. Group identifier is in increasing order.
3. When a new node enters a transmitting range of a group, it is provided with information about the group and an opportunity to join. A new node can choose to join the group and the group information should be available as long as there is any member of a group present in the range. If two nodes have the same group id, then they belong to the same view.
4. If nodes go out of each others, transmitting range will split into partitions. The group continues with disparate partitions.
5. Partitions from the different groups merge when their transmitting range overlap / intersect.
6. When partitions merge, the application is given an opportunity to initiate state transfer.
7. Messages are delivered, in an agreed order, to all members of a group that is in the same partition. If a group has partitioned, the members in different partitions continue to maintain the local total order for that partition.

2.1. Problem Description

The development of distributed applications over wireless ad hoc networks is highly influenced by the challenge of frequent change of environments and network topology. The complexity lies in the grouping of nodes over the network, i.e., applications execute on top of group services that manage the execution context dynamics, including node mobility. To achieve the reliable communication, all nodes need a consistent view of other nodes that participate in a group communication. Nodes in a same view-sending message from one node to another node must be guaranteed to deliver at a particular time *t*. In the reliable communication service, the message entrusted to have to be delivered within the time bound if the sender and the recipient are physically connected during that time.

Calculating delivery time plays a critical role in guaranteed message delivery between the nodes before any network partition or physical link failure occurs. To calculate the delivery time we rely on delivery protocol, which is the function of current state of transmitting range, location, speed and direction of mobile nodes participate in group communication. Delivery protocol precisely calculates delivery time based on the system model. Message delivery time must be less than the time taken by the nodes to go out of their communication range.

2.2. System Model

We consider an ad hoc mobile network consisting of set of N nodes. All the nodes randomly moving in different direction and speed and the communication links are bidirectional. Node speed is to the maximum speed *Vm*. We assume that all nodes have the different communication range and all nodes know their physical location all the time. We also assume that there is no system crashes due to hardware and software components. No network failure, traffic congestion and there is no performance failure in the network. Standard and best protocols have been selected and used in MAC, routing and upper layer of ad hoc mobile network by which the network provides best performance, expect failure in mobility induced link which occurs when mobile node goes out of range.

Our system model considers unannounced disconnection due to physical link failure as a major factor for system design comparing with other factors. Mobility induced link failure is unavoidable due to random motion of nodes in the space. To provide accurate measure of distance between nodes and message delivery time we consider variable communication range, speed and direction.

2.3. Guarantee Protocol

Guarantee protocol is used to determine the time required to reliably complete group membership services on which mobile applications are developed. We maintain a connectivity graph of all nodes within a group and nodes are continuously moving in different directions with a particular speed within the maximum speed limit *Vm*. The communication range also differs from one node to another. In this scenario groups merge and split over the time space to maintain the requirements of the group membership and all the nodes must know the membership view all the time for message delivery. Any message transfer between the nodes in a same view must be guaranteed if it is delivered within the time given by guarantee protocol. Guarantee protocol is designed and built on top of the group membership service as in Fig.1.

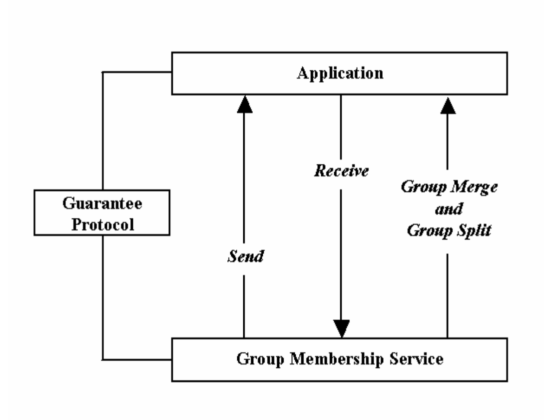

Fig.1. Architecture of guarantee protocol

Delivery time (*Td* = distance between the nodes / speed between the nodes) calculation is a critical factor in reliable message delivery. To simplify the process, two mobile nodes have been taken for initial study. Let us consider two mobile nodes n_1 and n_2 equipped with wireless transmitters with range r_1 and r_2. Nodes are moving in a random direction with a speed v_1 and v_2. We assume that the nodes belong to the same group and are within the communication range as in the Fig. 2.

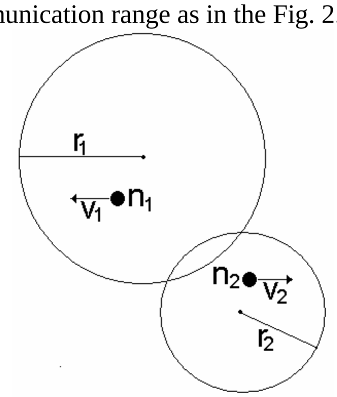

Fig. 2. An example of nodes of same group

Already we assumed that all nodes know their physical location all the time and it is too expensive for everyone to keep track of the location of others all the time, hence we designate a leader for each group. All hosts in a group constantly report their location to the leader, and the leader keeps the view of the group.

Distance between the nodes, $D = [(x_1,y_1) – (x_2,y_2)]$

Where (x_1,y_1) and (x_2,y_2) are the position of the node1 and node2.

Transmitting range $R = [(r_1 + r_2) / 2]$

If $D < R$, nodes are within the transmitting range so message could be delivered.

Vm is the maximum speed of the mobile.

Relative Speed (V)

$V = (v_1 + v_2)$ if nodes moving in opposite direction
$V = (v_1 – v_2)$ if $v_1 > v_2$ and nodes moving in same direction
$V = (v_2 – v_1)$ if $v_2 > v_1$ and nodes moving in same direction

Message delivery is guaranteed if $Td < (D/V)$.

2.3. Implementation

Developing a guarantee protocol needs a middleware, which satisfy the requirements of mobile ad-hoc networks. Developing middleware for mobile ad-hoc network applications [14] is not so easy task because mobile ad-hoc networks are typically very dynamic networks in terms of available communication partners, available network resources, connectivity, etc. Furthermore, the end-user devices are very heterogeneous, ranging from high-end laptops to low-end PDAs and mobile phones. Middleware has emerged as a new development tool, which can provide programmers with the benefits of a powerful virtual machine specialized and optimized for tasks common in a particular application setting without the major investments associated with the development of application specific languages and systems. For the programmer, middleware offers a clean model that can be easily understood and readily adopted without the need to acquire a new set of programming skills or to delve into the intricacies of a sophisticated formal model. Lime is a middleware inspired by Linda coordination model. It is implemented in java programming language due to the mobility support provided by java. LIME is a middleware specifically designed to support logical mobility of agents and physical mobility of hosts in both wired and wireless settings. Within this general context, its distinctive feature is the reliance on coordination to simplify the development of mobile applications. While building on the decoupling advantages of the original Linda model, LIME breaks new ground by extending coordination technology to mobile systems, including the ad hoc wireless setting. The LIME middleware as originally released required a mobile agent or host to explicitly announce its intention to engage or disengage from a group. The integration of this group membership protocol with the LIME middleware transforms the processes of engagement and disengagement of hosts move in the network, thereby changing their status with respect to the protocol's guarantee requirements. Guarantee protocol is developed on the top of the group membership service of Lime.

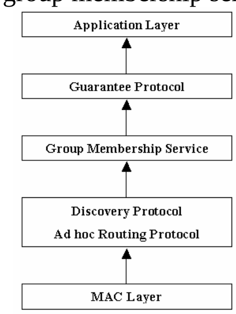

Fig.3. System architecture

In this system, discovery and routing protocol are built on the top of MAC layer. Discovery layer is developed based on beacon mechanism, which sends hello message periodically. Group membership layer discover this hello messages to discover location of the mobile host. We assume that AODV [15] or DSR [16] used in routing layer. Group membership layer is built on the routing and discovery protocol, which is implemented by group management package of Lime. Group management package supports group communication operations. The core part of the package is GroupManager class that maintains local group information and list of member host attached with the group. GroupManager responsible for coordinating group changes with members of the group, based on connection changes sent by the MemberDetector. It uses group change event object and listener to an event generated by a group configuration change and receive notifications of changes to the Group. An application running on a host that uses the group membership package to participate in groups in the network simply creates a GroupMember object. We implement guarantee protocol in java class called GuaranteeDetector. It uses MemberDetecter and Beacon server to check the member's close enough to join or moving beyond to remove. It implements GroupChangeListener and LocationListener to keep track of the location and present group. GuaranteeDetector takes range, speed, and network latency, location with direction to check the guarantee of the message delivery. FakeGPSMonitor is used to get simulated location information. We demonstrate the guarantee protocol using GuaranteeDetector by changing various parameters.

2.4. Analysis of guarantee protocol

We analyze various scenarios in which guarantee protocol performs well in group communication. The group membership service performs group merge, split and discovery service. The guarantee protocol is constructed in the upper layer of group membership service. The accuracy and performance of guarantee protocol is highly influenced by network delay and delay due to group membership operations. It is already presumed that the range, speed, direction and location are variables and not same for any two nodes.

Speed of the mobile nodes and the direction in which it is moving has major impact on delivery time. All nodes that participate in group communication has maximum speed limit *Vm*. When a mobile node is moving too fast, it simply becomes invisible to the network and induces unannounced disconnection. Speed monitoring would be needed to prevent this kind of unannounced disconnection from happening. If node speed is high and moving in the opposite direction, delivery time is very short. High communication range and low speed provides very good performance and delivery time is large enough to transfer the massage safely. Location reporting frequency is set to 500 ms. Each host knows the location all the time and reports it to the leader of the group. Node contains location information and it is updated when the node move from one location to another. Precise location detection has its impact on the delivery time.

Network delay should be measured to calculate accurate delivery time. There are two types of delays considered, maximum network delay between sender node and receiver node and delay due to group operations like group split and merge. Let's assume that t_d is a network delay and t_g is group operation delay; hence delivery time is modified as

$Td < [(D/V)$ – network delay – group operation delay]

$$Td < [(D/V) - t_d - t_g]$$

Message delivery is assured if the message is transferred within the time *Td*.

The key concept of our protocol is to calculate the guaranteed delivery time within the group members. The leader of a group frequently checks the members' location to make sure that only those that are guaranteed to stay connected with the group for at least *Td* units of time remain in the group, where *Td* is the delivery time available based on the speed and transmitting range of the node. We calculate the delivery time by changing transmitting range, speed, location and latency.

The relationship between the delivery time *Td* and transmitting range between nodes is given in Fig.4a. We take network latency and speed as fixed parameters. As we increase the transmitting range of the nodes delivery time also increases which shows enough time to do application level operations irrespective of network latency.

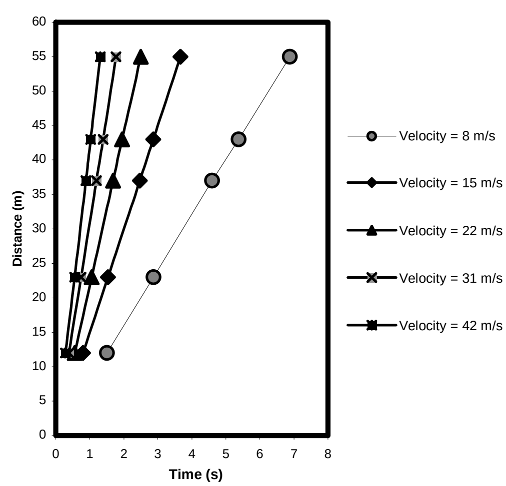

Fig.4a. Relationship between the delivery time and transmitting range in a simple group of nodes.

Fig.4b. shows the relationship between delivery time *Td* and relative velocity. The transmitting range of the nodes and network latency is considered as fixed parameters. When the velocity increases the *Td* dropped to low value, which shows that the application level operation has to finish within the time before partition takes place.

Hence we conclude that low speed and large transmitting range is a requirement for guaranteed completion of application level operations and most of the wireless ad hoc networks prefer this requirement.

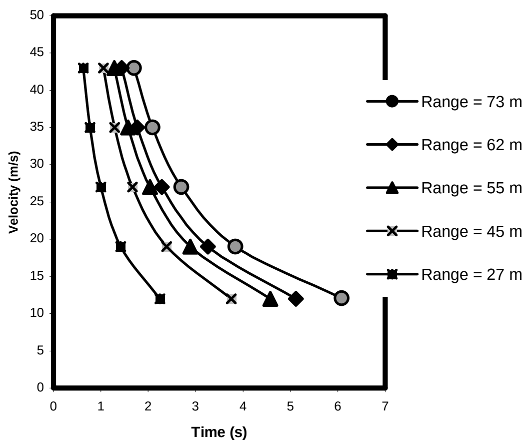

Fig.4b. Relationship between the delivery time and relative velocity in a simple group of nodes.

2.5. Future Work

This work considers only two mobile nodes to simplify the process. To develop robust system 'n' nodes have to be taken for analysis and the network is expected to guarantee the performance of a set of measurable prespecified service attributes such as delay, bandwidth, probability of packet loss, and delay variance. With the advances in support of group communications, the use of multimedia objects, such as video, audio, or images from various sites will proliferate in mobile ad hoc application domains. Thus, developers must design and integrate QoS support into group-communication protocols. To get the accurate measure of delivery time, efficient location tracking is important and even 3D coordinates may be used instead of 2D if participating nodes are moving in 3D space.

3. CONCLUSION

Demand for ad hoc mobile application increases day by day. This motivates the need for reliable communication to implement mobile applications in ad hoc networks. Reliable group membership service provides data consistency in applications that execute over ad hoc networks. In ad hoc mobile systems, mobility-induced unannounced disconnection occurs frequently as part of the normal operation of the network due to the dynamic nature. Maintaining a consistent view of the global state in a distributed network is difficult. In the presence of unannounced disconnections, design and development of fault-tolerant system is really challenging. The main objective is to assist software developers to design and build reliable mobile applications, which motivate us to develop guarantee protocol. This protocol represents a new direction in fault-tolerant distributed computing and reliable group communication in mobile ad hoc networks. We also analyze the delivery time based on range, speed, location and direction. By using the guarantee protocol, the membership service is able to provide guarantee to the application layer, a reliable message delivery service to group members in the presence of mobility-induced unannounced disconnection based on the system model.

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