Effective Quorum Construction for Consistency Management in Mobile Ad Hoc Networks

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1 Introduction

In *mobile ad hoc networks (MANETs)*, there are many applications in which mobile users share information by accessing data held by other users. Typical examples are collaborative rescue operations at a disaster site, military operations, and exchange of word-of-mouth information in a shopping mall. For such applications, preventing the deterioration of data availability at the point of network partitioning is a very significant issue. Data replication is the most promising solution to this problem [2, 5].

However, consistency management of data operations on replicas is generally very difficult in MANETs because of network partitioning. In our previous work, we have defined several consistency levels for MANET applications and designed protocols to achieve these consistency levels. These protocols are mainly based on a dynamic quorum system to cope with network partitioning and node and network failures [2]. In [3], we have further investigated the impact of quorum construction on the system performance through simulation studies. Specifically, we changed the number of mobile nodes that replicate data items and which nodes replicate each data item in the simulations and examined the impact on the system performance in terms of data availability and traffic.

In this paper, we first briefly present our recent work published in [3]. Then, we discuss future directions for adaptive quorum construction for consistency management.

2 Impact of Quorum Construction for System Performance

2.1 Quorum Systems

In a quorum system for database consistency management [1], a read (write) operation is performed on only replicas held by database servers that form a read (write) quorum. Here, these read and write quorums are constructed so that every pair of read and write quorums have an intersection. When a client issues an update request for a data item, it performs a write operation on replicas held by all database servers in a write quorum so that replicas of the latest version exist in the quorum. On the other hand, when a client reads a data item, it performs the read operation on replicas held by all database servers in a read quorum. Since there is an intersection between write and read quorums, at least one database server in a read quorum holds a replica of the latest version and thus the consistency of data operations can be kept by reading the latest version.

In dynamic quorum construction, quorums are dynamically constructed according to a certain rule in order to satisfy the intersection condition. The simplest way is setting the quorum size for a read operation $|QR|$ and that for a write operation $|QW|$ on condition that $|QR|+|QW| > P$, where P is the number of replica holders. Then, quorums can be arbitrary constructed where only the restriction of the quorum sizes is met.

2.2 Our previous work

In this subsection, we present data processing and quorum construction methods assumed in [3].

2.2.1 Data processing and quorum construction

For each data item D_j, a fixed number (k_j) of mobile nodes ($M_{r_j1}, \cdots, M_{r_jk_j}$), i.e., replica owners, are statically chosen as nodes having the right to replicate D_j. The value of k_j and how to choose k_j mobile nodes affect the system performance such as transaction success ratio (data availability) and traffic. We adopt a dynamic flat quorum system, in which the quorum size for a read operation on data item D_j, $|QR_j|$, and that for a write operation, $|QC_j|$, are determined where the condition $|QR_j| + |QW_j| > k_j$ is satisfied.

Here, in a quorum system, a write operation is not necessarily performed on all the replicas held by mobile nodes in the write quorum, but the consistency can be maintained by only performing the operation on some mobile nodes in the write quorum and informing the other nodes of the information on the time stamp (version) of the latest write operation and the replica holders of the latest version. Thus, we assume that a write operation is performed only on replicas held by h_j mobile nodes ($h_j \leq |QW_j|$) in the write quorum and the others store the information on the time stamp and the h_j nodes. This might be effective for reducing traffic for write operations.

How to select k_j replica owners:

There are a large number of possible choices of how to select k_j replica owners. In [3], we adopt a simple and intuitive manner where for each data item D_j, k_j mobile nodes with the highest access frequencies to D_j are chosen as the replica owners. Specifically, the following criterion G_{ij} is calculated for all mobile nodes.

$$G_{ij} = R_{ij} + W_{ij}. \quad (1)$$

Equation (1) represents how many data operations can be performed locally. Therefore, k_j mobile nodes with the highest G_{ij} are chosen as the replica owners for D_j.

This selection process is generally conducted once at the configuration phase of the MANET because changing replica owners requires the notification of the change to all the nodes and its overhead is very high.

How to select h_j nodes to which a write operation is performed:

Unlike replica owners, h_j nodes to which a write operation is actually performed can be chosen more flexibly and dynamically when a write operation is performed. This is because request-issued nodes do not need to know in advance which mobile nodes have been performed the latest write operation but it knows these nodes after constructing the quorum. However, the strategy to determine these h_j mobile nodes much affects the performance, e.g., data availability and traffic. Thus, we should carefully choose the strategy. In [3], we adopt two different strategies, *AF (Access Frequency)* and *DIST (Distance)*.

AF: AF aims to reduce traffic for data transmissions for future data operations. Specifically, for each candidate node, the request-issued node calculates the gain of data traffic reduction by equation (1), i.e., G_{ij}. AF chooses h_j nodes with the highest G_{ij} among all replica owners that responded to the quorum construction request.

DIST: DIST aims to reduce traffic for data transmissions for the current data operation by choosing closer mobile nodes for performing the write operation. Specifically, DIST checks the hopcounts between the request-issued node and all replica owners that responded to the quorum construction request. Then, it chooses h_j mobile nodes with the smallest hopcounts from it, to which the write operation is performed.

2.2.2 Knowledge obtained from the simulations

In [3], we conducted simulation experiments to investigate the impact of quorum construction on the system performance. In the simulations, we measured the success ratios of read and write operations, the message traffic, and data traffic to process a read/write operation. The success ratio is defined as the ratio of successful read/write operations to all requests of read/write operations issued during the simulation time. The message traffic is defined as the average of the total hopcount for message exchanges to process a read/write operation excluding transmissions of data items. The data traffic is defined as the average of the total hopcount to transmit a data item to perform a (successful) read/write operation. From the simulation results, we have obtained the following knowledge.

- Comparing the results for AF and DIST, there are almost no differences in the success ratio and the message traffic. As for the data traffic, AF produces smaller data traffic for read operations because request-issued nodes hold a latest replica with a higher probability. On the other hand, DIST produces smaller data traffic because it performs a write operation to h_j closest nodes.

- The value of k_j directly affects the message traffic, i.e., the larger k_j is, the larger the message traffic is.

  In terms of success ratio, very small k_j shows lower success ratio when the network is relatively dense. This is because mobile nodes cannot perform any data operations even when only most of replica owners are not accessible, i.e., the flexibility and the robustness to the network topology change are low.

  In terms of data traffic, larger k_j shows lower data traffic for write operations because there are more candidates for choosing the closest nodes to which a write operation is actually performed.

- The value of h_j directly affects the data traffic, i.e., the larger h_j is, the larger the data traffic for write operations is and the smaller that for read operations is. On the other hand, h_j does not much affect the message traffic.

3 Future Directions

In this section, we discuss future directions for effective quorum construction for consistency management in MANETs.

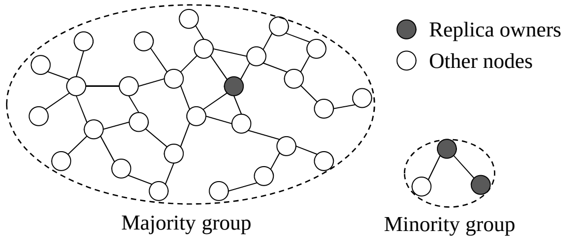

Figure 1. Example of network partitioning.

3.1 Dynamic change of replica owners according to the network topology

The simulation results in [3] show that setting k_j (the number of replica owners) very small effectively reduces message traffic, but decreases success ratios for data operations. Figure 1 briefly illustrates the reason. When many replica owners unluckily belong to the minority group at the point of network partitioning, all nodes in the majority group cannot perform any data operations.

To solve this problem, replica owners should be adaptively changed according to the network topology. We need to design some protocol to achieve this, e.g., checking periodically the number of replica owners in the majority group and changing replica owners by using a quorum system if necessary.

3.2 Quorum construction considering mobility patterns

In [4], we have revealed that mobility patterns of nodes heavily affect data availability in MANETs. Specifically, mobility patterns affect the characteristics of network partitioning, e.g., the number of partitions, partition sizes, and their distribution and stability. These characteristics could be useful information for quorum construction.

For this aim, we plan to provide some guideline for effectively constructing quorums, i.e., setting appropriate values of k_j and h_j and selecting k_j and h_j nodes, according to mobility patterns of nodes.

References

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