Adding Node Absence Dynamics to Data Replication Strategies for Unreliable Wireless Grid Environments

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Abstract. To the existing data replication approaches, we add more dynamics about occasional data absence whereby files are replicated in advance in order to make all sites as suitable for job executions as possible. Occasional node or edge absence resulting in data absence is inevitable in wireless network environments. This approach offers several advantages to wireless grids, such as improved fault-tolerance, and less overhead due to dynamic data replication.

Keywords: Wireless Data Grids, Node Absence Model, Unreliable Networks.

1 Introduction

Grid is a parallel and distributed system that enables dynamic sharing, selection, and aggregation of geographically distributed resources, depending on their availability, capability, performance, cost, and user quality-of-service requirements [1]. The main aim of a grid is to connect geographically distributed resources into one large system that enables users to have transparent access to data and computing resources across the grid. These resources are usually much bigger and powerful than the resources available at the users' local sites. Grids can be classified into computational grids and data grids [2]. The main task of a data grid is to manage huge amounts of data and data intensive tasks. In data grids, data management applications often use data replication. Data replication improves data access time and provides fault tolerance by maintaining copies of data at different locations. If the replicas of the objects are well placed, each computational task can access the nearest replica of the required object, thus reducing its execution time. The throughput of the whole system can be increased as a result.

The function of the data replication is to replicate a specified set of files onto a local storage system and register the new files in appropriate catalogs. It builds on lower-level grid data services. The data replication must ensure that a specified set of files exist on a storage site. Therefore the operations of the data replication include discovery of identifying where desired data files exist on the grid, transfer of copying the desired data files to the local storage system efficiently and registration of adding location mapping information to the manager so that other sites may discover newly

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created replicas. Our scheme reduces the burden of the data replication manager especially in the discovery phase. Current approaches to data replication on data grids are mainly dynamic in the sense that the replication of objects depends on the progress of the scheduled jobs.

The remainder of this paper is organized as follows. In Section 2, we discuss related work. In Section 3 we present our node absence model. Section 4 describes simulation data. Finally, we conclude in Section 5.

2 Related Work

The major bottleneck to supporting fast data access in grids is the high latencies of network. Effective scheduling in such network architecture can reduce the amount of data transferred across the network. One solution for it is to use a data replication mechanism to generate multiple copies of the existing data to reduce access opportunities from a remote site. In [2] data grid replication taxonomy tree is given as shown in Figure 1.

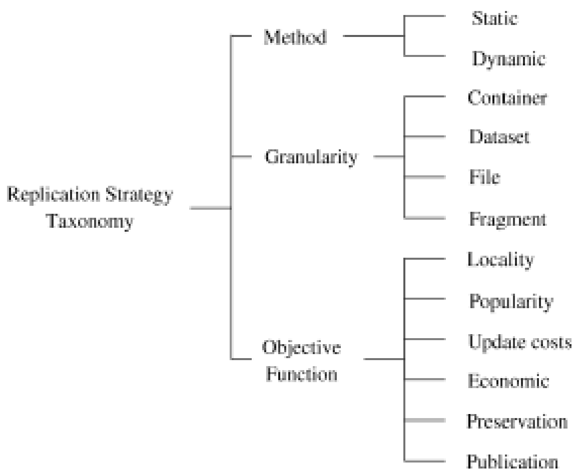

Fig. 1. Replication strategy taxonomy [2]

Categorized as in Figure 1, a set of data replication management services and protocols that offer high data availability is introduced [3,4,5]. However despite of amount of suggestions, ensuring efficient and fast access to such huge and widely distributed data is hindered by the occasional node or edge absence in wireless grids. To address these problems, we elaborate the existing method to offer high data availability. To the given dynamic approaches, we add more dynamics to data replication where by files are replicated in advance in order to make all sites as suitable for job executions as possible. Replication decisions are made based on a network reliability model that evaluates data management costs maintaining each replica. This approach offers improved fault-tolerance, and less overhead due to dynamic data replication.

3 Node Absence Model

The primary goal of data replication is to shorten the data access time that is experienced by the job and reduce the job turnaround time as a consequence. After introducing data grid architecture, many dynamic data replication algorithm is suggested. However in wireless grids, mobile nodes are usually severely constrained in computation, storage, communication and power resources. A grid member node can be in presence or absence occasionally. Therefore the use of a data replication mechanism in wireless grids needs elaboration to replication strategy compensating unreliable network environments.

For transmission of messages a sender suspects that its receiver is faulty when it fails to receive response. The analysis of the distribution of the number of nodes is based on the statistical population of the node having required data. Since the assignment of the required data is assumed to be randomly uniform, this population can be captured by the binomial distribution. Our analysis techniques assume that the nodes having required data join according to a Poisson process with rate λ and leave according to an exponential distribution with the rate parameter μ. But we also evaluate our techniques using realistic node arrival and departure patterns. We assume a fail-stop model and conservatively assume that all nodes leave suddenly without informing other nodes. Poisson distribution can be obtained from binomial distribution *B(k; p, n)* by substituting $p = \lambda t / n,\ \ q = 1 - \lambda t / n$ and letting *n* goes to infinity. We assume that nodes leave according to an exponential distribution with the rate parameter μ. Exponential distribution is derived from Poisson distribution. In Exponential distribution with the rate parameter μ, the node fault rate is μ and the average life span is $1/\mu$. We let new nodes arrive and leave according to a Poisson process with the same rate to keep the number of nodes in the system roughly constant. The probability of forwarding a message to a faulty node at each level can be obtained through the following induction. The probability density function (pdf) of an exponential distribution has the form shown in Equation (1) and the cumulative distribution function(cdf) is given by Equation (2).

$$f(t) = \mu\, e^{-\mu t}, \quad t \geq 0 \tag{1}$$

$$F(t) = \int_0^t f(x)dx = \int_0^t \mu e^{-\mu x} dx = 1 - e^{-\mu t} \tag{2}$$

Equation (2) represents the probability of fault in time *t*. In wireless grids, it forwards messages using UDP with no acknowledgement by default. This is fast and simple, but messages forwarded to a faulty node can be lost. The probability of forwarding a message to a faulty node at each node, P_n is as shown in Equation (3).

$$\begin{aligned} P_n &= 1 - F(T) \cdot \frac{1}{\mu} \cdot \frac{1}{T} \\ &= 1 - (1 - e^{-T\mu}) \cdot \frac{1}{\mu} \cdot \frac{1}{T} \end{aligned} \tag{3}$$

T is the maximum time it takes to detect the fault. The message loss rate, L, is as shown in Equation (4).

$$L = 1-(1-P_n)^h = 1-\left(\frac{1-e^{-\mu T}}{\mu T}\right)^h \tag{4}$$

h is the hop distance corresponding to the number of hops required to access the required data. If we make a copy of data on an adjacent node then h equals to 1. The message loss rate, L, becomes Equation (5).

$$L = 1-\left(\frac{1-e^{\mu T}}{\mu T}\right) \tag{5}$$

If we do not have any adjacent node available for producing a copy of data, h is greater than 1.

In real world implementation, reliability can be improved by applications if required. Applications can retransmit messages and set a flag indicating that they should be acknowledged. This provides very strong reliability guarantees because nodes can choose another node if the previously chosen one is detected to be faulty. But waiting for timeouts to detect that the next node is faulty can lead to bad performance. Therefore, we use the message loss rate, L, in this paper because it enhances both performance and reliability – the probability of being able to route efficiently without waiting for timeouts.

We can also derive an equation to compute the cost of maintaining the data availability. Each node generates control traffic dominated by the two operations. The operations are the update operation following node creation and the maintenance operation in the link information table. Thus the cost, C, becomes Equation (6).

$$\begin{aligned} C &= \{1+L(1+L(1+L\cdots))\}\cdot 2\cdot(\lambda_c+\lambda_m)+N\cdot\frac{K}{T_K} \\ &= \frac{2(\lambda_c+\lambda_m)}{1-L}+\frac{N\cdot K}{T_K} \\ &= \frac{2\cdot(\lambda_c+\lambda_m)\cdot(\mu\cdot T)^l}{(1-e^{-\mu\cdot T})^l}+\frac{N\cdot K}{T_K} \end{aligned} \tag{6}$$

The first term is the cost of the link information table update: λ_c is the rate of the data creation event. λ_m is the rate of the data modification event. The two messages for request and reply are considered. *1/(1-L)* is the number of packet transmissions compensating the message loss. For the number of entries in the link information table, N, the second term is the number of packet transmissions per second. The K maintenance packets such as keep-alives are transmitted every T_k seconds.

4 Performance Evaluation

We let new nodes arrive/present and depart/absent according to Poisson processes with the same rate to keep the number of nodes in the system roughly constant as $\lambda_c = \mu$. When modifications of data are frequent, we should reduce the values of hop distance (h).

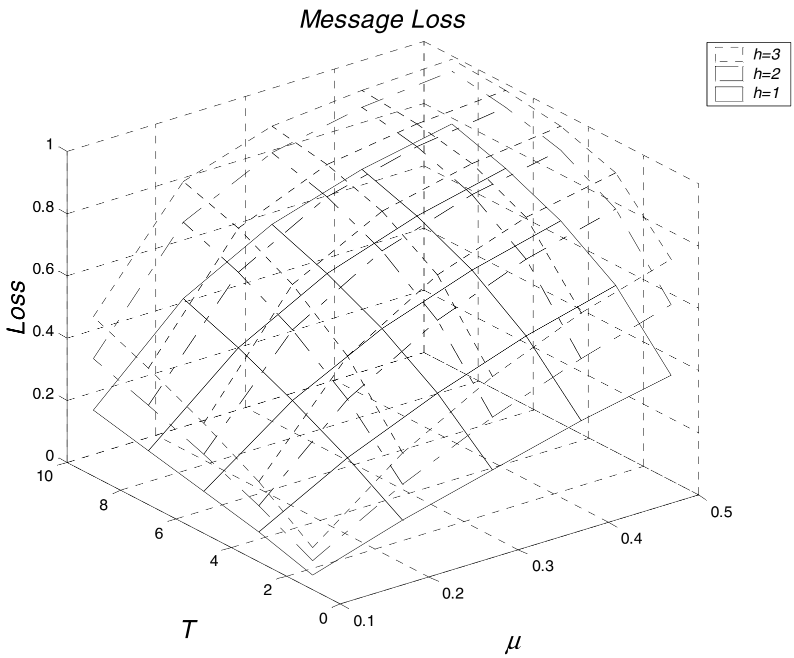

Fig. 2. Expected Values of the Message Loss

In Figure 1, the expected value of the message loss is given for the cases with different hop distances. For the fixed node fault rate (μ), as the hop distance (h) increases, the message loss (L) increases in all cases of the maximum time it takes to detect the fault (T). When h gets smaller value, the expected values of the message loss decrease more. The high hop distance suffers very high message loss. For the fixed hop distance, as the node fault rate increases, the message loss increases in all cases of the time T. It increases fast to saturation incurring more copy of data.

In Figure 2, the expected value of the managing cost is given for the cases with different hop distances. For the fixed node fault rate (μ), as the hop distance (h) increases, the managing cost (C) increases in all cases of the data modification rate (λ_m). When λ_m gets larger value, the expected values of the managing cost increase more. We can also see that the effect of λ_m is larger than the that of μ.

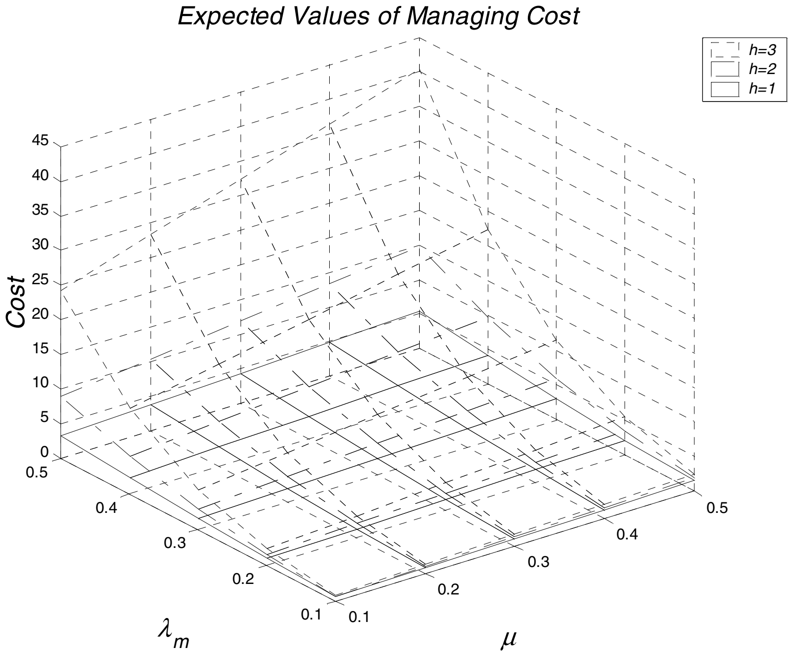

Fig. 3. Expected Values of the Managing Cost

5 Conclusion

For efficient data location for wireless grids, we take into account the characteristics of wireless network environments. These environments are generally heterogeneous, decentralized, large-scale and unreliable. It needs more elaborate data replication strategy.

We have been developing a node absence model that allows for reliable data existence over wireless grid environment. With our production ready method we have proven that existing data replication tools can be upgraded as more reliable middleware in a data grid. We have simulated the proposed model and suggest dynamic node absence compensation scheme.

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