Research on Replica Placement Strategy for New Building Intelligent Platform

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Abstract. The new building intelligent platform adopts single point storage in the data storage mode, which does not reflect the distributed characteristics of the platform. Once the node is damaged, the data will be lost. To solve this problem, this paper improved the data storage mode of the new building intelligent platform, combined Hadoop distributed file system (HDFS) with the platform, and realized the reliable backup of the platform data. For the deficiency of HDFS default replica placement strategy, the paper advanced an algorithm of replica placement for the new building intelligent platform based on PSO, and obtained the optimized replica placement strategy by considering the storage space residual rate of nodes, bandwidth residual rate and network distance between nodes. Simulation was on the CloudSim platform. The results of experiment show that the proposed scheme was superior to the default replica placement strategy in load balancing, which can reduce the load pressure of single node to a certain extent and improve the load balancing of the whole platform.

1. Introduction

With the popularity of the Internet of Things and big data, the intelligent building industry is developing toward the diversity of data, which also makes the data in the building continue to grow, and data storage is facing great challenges. The data storage system in traditional buildings adopts centralized storage system, which cannot deal with the explosive growth of massive data effectively and makes the data easy to be lost. Distributed storage system is one of the commonly used storage methods at present, and its replica technology is one of the commonly used technologies to solve the problem of data backup. HDFS has become a popular storage mode in distributed storage systems due to its three-replica strategy [1-3].

The new intelligent building system is different from the traditional centralized control system. Based on the idea of flat and uncentered, we built a new intelligent building platform to solve the problems of difficult networking configuration and cross-system configuration under the traditional centralized architecture [4-5]. However, the platform mainly studies the control system at present, and no further expansion has been made in the data storage mode. The traditional single-point storage mode is still adopted, and the data collected by the platform node is not effectively backed up. Aiming at this problem,
this paper optimizes and improves the storage mode of the new building intelligent platform, combines HDFS with the platform, and realizes the distributed storage and backup of the platform data.

Due to the high randomness of HDFS default replica-placement strategy, cluster was not often load balance, leading to the collapse of the cluster [6-8]. At the same time, the network bandwidth and access overhead of storage nodes are not considered, which directly affects the reliability, availability, balance and reading efficiency of the data. In order to improve the replica placement technology more effectively, scholars studied the problems encountered in the replica placement strategy. Considering the data overhead and storage overhead, Literature [9] proposed a copy strategy that takes into account both cost and storage space, and optimized it by using genetic algorithm and Dijkstra algorithm, achieving good results. In order to improve QoS and operation overhead, Literature [10] proposed an effective greedy heuristic algorithm to solve the replica placement problem, optimized the calculation time through layout and refinement, and achieved good results. Literature [11] proposed to apply the firefly algorithm to the replica placement process and establish the relevant model based on the natural properties of fireflies, considering the problem of high cost of copy access in the cloud storage system. As it turns out the algorithm was good effect for placing replica. Literature [12] considered the unbalanced data distribution in the cluster system, the replica placement strategy of multi-layer consistent hashing was adopted to obtain the storage location of the replica. Compared with the original strategy, this strategy has a great improvement in data balanced storage and upload rate. Considering the difference of servers on each node, the load imbalance of the cluster was caused by Literature [13]. Therefore, a replica placement strategy based on SVM was proposed to find the best place node for the replicas by comprehensively considering the load situation of the node, the hardware performance of the node and the network distance of the node. This strategy can realize load balancing more effectively.

Based on the above research, the paper applied the particle-swarm-optimization algorithm combined with HDFS storage mode to the new intelligent building platform, proposed a copy placement strategy for the new intelligent building platform, solved the load imbalance in the HDFS for the default replica placement strategy in the platform, and optimized the data storage mode of the platform. Simulation results show that the proposed strategy is better than the default replica placement strategy in load balancing, reduces the load pressure of a single node, improves the load balancing of the whole platform, and verifies the effectiveness of the strategy.

2. Description of replica placement of the new intelligent building platform

2.1. The new intelligent building platform

New building intelligent platform is based on the building energy research center, tsinghua university development of swarm intelligence system, with CPN (computing processing node) for key equipment of intelligent control platform, the platform of the CPN node with the operating system, calculation module, storage module and control module, each node is homogeneous, there is no performance difference[5], as shown in Figure 1. The CPN node can realize data collection and storage in the spatial unit, including local information, local environmental information, equipment operating parameters and other data.
2.2. Replica placement problem of the new intelligent building platform
To improve the data storage persistence of the new intelligent building platform, this paper improved the storage mode of the platform, applied HDFS to the new intelligent building platform, and used the replica technology of HDFS to make safe backup of the data of the platform, so as to prevent the loss of data due to node failure, which will affect the normal operation of the platform. In the new intelligent building platform after improvement, each node has a DataNode responsible for data storage. When a data backup is performed on a CPN node, the node merges the data collected over a period of time into one large file. HDFS split a file into n Blocks of the same size (default Block size is 128M) and copied each Block into three replicas and stored them on different datanodes. The default HDFS replica-placement strategy to place the first replica on a local datanode, the second replica to place on a datanode in a remote rack, and the third replica on different datanode in the same remote rack[2]. While this replica placement strategy is simple and fast, and improves the fault-tolerance of the entire cluster, the following points are not taken into account when replicas are placed[14]:
- Storage space size left
  The larger the storage space size surplus of a node is, the higher the residual rate is, indicating that the storage space load capacity of the node is stronger. The system needs to store the replicas on the data nodes with more storage space, so that the storage load of the cluster is more balanced.
- Bandwidth residual rate
  The bandwidth will affect the load balance of the cluster as well. The bandwidth utilization rate refers to the percentage of the bandwidth that all datanodes actually use to run the cluster and the all of bandwidth size. The lower the utilization rate, the more idle the cluster is, and vice versa.
- Network distance between nodes
  The CPN distance between the datanode storing data and the copy datanode directly affects the bandwidth of data transmission. The smaller the CPN distance, the better the bandwidth, the better the efficiency of data transfer, and the less the time of data reading and writing.

3. Replica placement algorithm based on PSO
3.1. Description of Particle Swarm Optimization
After receiving the request of replica placement, the node of the new building intelligent platform first selects the node suitable for replica placement by particle swarm optimization algorithm, and then writes the replica. Suppose there are n CPNs in the platform corresponding to n DataNodes and m replica to
be placed. \( n_m \) represents the corresponding relationship between a replica and a node, that is, the mth replica is placed on the nth node. \( n_m \) as a particle. Set the amount of particles in the particle swarm to \( M \), denoted by \( P_i (i = 1, 2, ..., M) \); The replica number \( m \) is taken as the dimension of the particle; The position vector of the particle is set to \( \mathbf{X}_i = \{x_{i1}, x_{i2}, ..., x_{im}\} \); The velocity vector of the particle is set to \( \mathbf{V}_i = \{v_{i1}, v_{i2}, ..., v_{im}\} \); \( pBest_i \) represents the local optimal position passed by the ith particle.

In the t-th iteration; \( gBest \) represents the global optimal position after the t-th iteration (i.e. \( gBest \) is the global maximum \( pBest \) during the iteration). Therefore, Equations (1) and (2) can update velocity and position of the i-th particle:

\[
V_{i,t+1} = \omega V_i + c_1 \varepsilon_1 (pBest_i - X_i) + c_2 \varepsilon_2 (gBest - X_i)
\]

\[
X_{i,t+1} = X_i + V_{i,t+1}
\]

Where, \( \omega \) is the inertia factor, calculated by Equations (3), and its value is non-negative; When \( \omega \) is large, the global optimization ability is excellent, while the local optimization ability is not good. On the contrary, the global optimization ability is not good, and the local optimization ability is excellent. To improve the global and local optimization ability of PSO algorithm, dynamic \( \omega \) is selected in this mode and the inertia weight is constantly changed in the iteration[15].

\[
\omega = \omega_{\min} + (\omega_{\max} - \omega_{\min})\left(\frac{t_{\max} - t}{t_{\max}}\right)^{1/2}
\]

\( \omega_{\max} \) is the upper limit of the weight of \( \omega \), usually between 0.8 and 1.2, and \( \omega_{\min} \) is the lower limit of the weight of \( \omega \), usually 0.4, \( t_{\max} \) is the maximum number of iterations of the algorithm.

\( c_1 \) and \( c_2 \) are the evolution coefficient, and the local and global optimal particle velocity vectors are adjusted. In this model, \( c_1 = 0.5 \) and \( c_2 = 3.5 \). \( \varepsilon_1 \) and \( \varepsilon_2 \) are a random number between 0 and 1.

In addition, the objective function of particle swarm is:

\[
\text{fitness}_i = \alpha \times (1 - \text{StorageUsage}) + \beta \times \text{BandwidthUse}
\]

Where, \( \text{fitness}_i \) is the evaluation function value, \( \text{StorageUsage} \) is the storage space utilization rate of the node, \( \text{BandwidthUse} \) is the bandwidth utilization rate of the node, \( \alpha = 0.7, \beta = 0.3 \) is the set weight value.

3.2. Particle swarm optimization copy placement process

The following is the implementation steps of the replica placement algorithm based on PSO optimization:

Step 1. Initialize each particle \( P_i \) randomly, take the node number of replica as the initial position vector of the particles, and count the number of replica to be placed on each node;

Step 2. Get the evaluation function value of each particle by Equations (4);

Step 3. The particle with the largest evaluation function value was taken as the global optimal particle, the current \( X_i \) was taken as \( pBest_i \) of all particles, and \( gBest \) was updated;

Step 4. Use Equations (1) and (2) to update the velocity vector \( V \) and position vector \( X \) of each particle respectively;

Step 5. Count the number of replica to be placed on each node according to the updated position vector \( X \), and get the evaluation function value of the updated particle;
Step 6. If $fitness_i^t$ of particle $i$ is greater than the global optimal evaluation function value, then particle $i$ is regarded as the global optimal particle. If $fitness_i^t$ of particle $i$ is greater than its historical optimal fitness value, its $pBest_i^t$ is updated;

Step 7. Determine whether the current iteration number $t$ is the maximum iteration number $t_{max}$, or whether it satisfies multiple iterations without changing;

Step 8. If Step 7 satisfies any of the above, then proceed to Step 9; otherwise, skip to Step 4;

Step 9. End of iteration. And output the global optimal replica placement location.

Its algorithm flow chart is shown in Figure 2:

Figure 2. Flowchart of replica placement algorithm based on PSO optimization.

4. Replica placement simulation experiment

4.1. Experimental environment design

The new intelligent building platform has no storage mode at present, so this experiment adopts CloudSim cloud environment simulation platform. Since CloudSim is only a general cloud environment simulation platform without HDFS simulation function[16], this paper expands CloudSim by adding Block class, DataNode class, WriteTask class, etc., to complete the simulation of HDFS.

In this experiment, two replica placement strategies will be adopted to write a certain number of replicas into the cluster. In the experiment, the number of DataNodes in the cluster is set to be 30, and a total of 300 replicas are written at one time. Replicas were written by performing write tasks of different times, which were 50, 100, 150, 200, 250 and 300 times respectively.
4.2. Analysis of experimental results

4.2.1. Load balancing degree. During the experiment, the load balancing degree of evaluation was calculated according to the following Equations (5) under the replica writing task of different times[17]:

\[
LB = \left( \frac{1}{n} \sum_{i=1}^{n} (M_i - \bar{M})^2 \right)^{1/2}
\]

(5)

Where, \( LB \) represents the load balancing degree, \( n \) represents the amount of datanodes, \( M_i \) represents the space utilization rate of the \( i \)-th node, \( \bar{M} \) represents the average space utilization rate of \( n \) nodes.

As we can see from the Figure 3, the PSO optimized replica placement strategy performed better in load balancing than the default replica-placement strategy due to the addition of the PSO optimized replica placement strategy.

![Figure 3. Comparison diagram of load balancing degree of the two strategies.](image)

4.2.2. Node storage space size occupancy. The Figure 4 shows the cluster load before the write task performed. As shown in Figure 5 and Figure 6, the storage space occupied by each node of the two replica placement strategies under 300 write tasks. The comparison shows that under the default replica placement strategy, the number of node 0 in the cluster changes from 28% to 83%, and the load changes significantly and is relatively concentrated. The improved replica placement strategy is relatively balanced, with no heavily loaded nodes. By making each node participate in the storage task of the cluster, the load pressure of a single node is reduced, and the load of the platform reaches a balanced state.
Figure 4. The load of the cluster before the write task is performed.

Figure 5. Cluster load after 300 write tasks with default replica placement strategy.

Figure 6. Cluster load after 300 write tasks based on PSO-optimized replica placement strategy.
5. Conclusion
To solve the replica placement problem of new building intelligent platform, this paper proposes a replica placement algorithm based on PSO optimization. This paper is oriented to a new type of building intelligent platform, combined with the PSO optimization algorithm, the replica placement strategy is optimized and improved to realize the load balancing of the platform cluster. And this paper designed the HDFS default replica-placement strategy and the improved replica-placement strategy to complete the replica write experiment in different times of write tasks respectively, and carries out the experiment on CloudSim simulation platform. Finally, the experimental results are verified from the aspect of load balancing. As the results of experiment show that the PSO optimized replica placement strategy performs better in the cluster load balancing, and the load pressure of a single node is relatively reduced, and the cluster is more stable. In the following work, the study of replica location and replica read task is the main task.

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