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A Double-Layer Heartbeat Detection Algorithm Orienting to Embedded Heterogeneous Cluster

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Abstract

The heartbeat detection is an important technology to detect faults of cluster nodes. This paper proposes a Double-layer Heartbeat Detection Model and a Double-layer Heartbeat Detection Algorithm (DLHB) orienting to embedded heterogeneous clusters to obtain high availability of embedded heterogeneous clusters. This algorithm divides the nodes in the embedded heterogeneous cluster into different areas by their physical positions. In each node area, a node is selected as the master control node. The inter-area detection uses heartbeat ring mechanism. The intra-area detection can only be made among master control nodes. The experiment results show that, DLHB is more accurate in prediction compared with DHB, and can detect faults concurrently occurring on multiple nodes with less time compared with the heartbeat ring algorithm.

Keywords: *Heartbeat detection, embedded, heterogeneous cluster, heartbeat ring*

1. Introduction

With the development of high-speed computer network and high-performance Industrial Personal Computers (IPC), distributed systems have been widely applied in various fields such as the control system of aircraft, ships, nuclear power, *etc*., and have increasingly played a core role [1]. Today, it has become more and more important to ensure the continuous and reliable operation of the server cluster. To achieve this goal, two main techniques, fault detection and fault recovery will be used and the former one is the basis.

The heartbeat detection technique is commonly used in fault detection because of its simple theories and high rate of success. Each node in the cluster will inform each other of its own health status by sending a network exchange data packet called the heartbeat packet on a regular basis. By exchanging the heartbeat packets, each node can detect the status of others, and if it finds out a node fault, the fault recovery mechanism will start to run. Time-out of heartbeat packets is critical to determine whether there is a node fault. Timeout may be caused by various reasons, but the node fault and the network delay are two basic ones.

The performance of computer systems develops continuously, but meanwhile power consumption and cost are also increased and programming is made more complex, especially in the embedded computer system [2]. In the embedded heterogeneous cluster system, the network delay is inevitable because of the limited calculation and communications capabilities, node heterogeneity and the diversity of network environments. Consequently, the network delay is one of the main causes of faults in the embedded heterogeneous cluster system, especially for the wireless network.

The current heartbeat detection algorithms cannot be well applied to heterogeneous embedded clusters. About this issue, this paper proposes a double-layer heartbeat detection algorithm orienting to embedded heterogeneous cluster (DLHB). This algorithm divides the areas of nodes in the embedded heterogeneous cluster by their physical

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positions, and respectively conducts the inter-domain and intra-domain heartbeat detections for nodes. The experiment results show that this algorithm is applicable to the heterogeneous embedded cluster environment.

2. Related Researches

The basic heartbeat models include “push model” [3] and “pull model” [4]. The “push model” refers to the heartbeat packet that is sent actively by the monitored node to the monitoring node, while the “pull model” refers to the heartbeat packet that is sent by the monitored node to reply to the inquiry of its health status from the monitoring node. However, both models have their own disadvantages. The “push model” will easily cause timeout or loss the heartbeat packet as a result of resending the packet when the network load is heavy, making the monitoring node falsely judge the status of the monitored node; while for the “pull model”, information needs to be transmitted twice to determine the status of the monitored node each time, so it’s not efficient. For the past few years, on the basis of these two models, a series of heartbeat detection techniques have been widely studied and applied.

To compensate for the frequent false decision of the “push model” and the high communication overhead of the “pull model”, the “dual model”[5], which combines advantages of the two models, is designed. This “dual model” runs in two phases. In the first phase, all the monitored nodes periodically send their own heartbeat packets. If the monitoring nodes do not receive the heartbeat packets from the monitored nodes in a certain heartbeat cycle, then it will go to the second phase. In the second phase, the monitoring nodes will inquire about the status of the monitored nodes. If there is no fault in the monitored nodes, they will send their heartbeat packets after receiving the inquiry. The “dual model” can be easily achieved through the combination of the “push model” and the “pull model”, but for large- scale cluster systems, a large number of heartbeat packets will cause network congestion

Paper [6] proposes the Distributed Heartbeat Mechanism (DHM). It includes one master node and multiple slave nodes, in which each node runs the same heartbeat process but in different states. The master node is elected by all nodes and it detects the status of the nodes through the “pull model”. However, its own status is judged jointly by all other slave nodes. The slave nodes firstly “pull” the status information from the master node. If there is no replay within an expected period, the slave nodes will judge the status of the master node by election. If the master node fails, a new master node will be elected by all slave nodes, which is a high cost for large-scale cluster systems.

Paper [7] proposes a Multi-level Heartbeat Protocol. It classifies the nodes into the control node and the calculation node according to their functions and each control node controls a group of calculation nodes. The control nodes detect the heartbeat of each other. If a control node fails, it will be deleted from the topological structure. The status of calculation nodes is detected by their corresponding control node. The control node regularly “pulls” the status information from the calculation nodes that are within its control domain. If any calculation node fails, it will be deleted. And meanwhile, the calculation node will run a timer. If it has not received the “inquiry” from its control node, it will look for another control node and join the control domain of this new control node. This protocol has a good performance in large-scale cluster systems because it can detect heartbeat in different node groups with no interaction of heartbeat packets among all nodes, reducing significantly the network load caused by heartbeat detection. However, it needs additional nodes to control the calculation nodes, and all heartbeat packets have fixed timeout, so it can’t be well adapted to uncertainties of the network.

Time delay in embedded heterogeneous clusters is considered in none of the algorithms above. Because of the limited calculation capability and heterogeneity of nodes in the embedded heterogeneous cluster, the communication costs among nodes may vary and the network delay is uncertain. If it still uses the fixed threshold of heartbeat packet timeout, the probability of misjudgment may increase because the monitored nodes at that time may be in its normal state, but the heartbeat packets they send to the monitoring nodes are delayed or lost due to the network during the transmission. For this reason, it is incorrect if the monitoring node judges that the monitored nodes are invalid. At present, in some researches, the arrival time of heartbeat packets is predicted to reduce misjudgment. For instance, paper [8] uses the average delay time of the latest heartbeat packets (DHB) to predict the arrival time of the next heartbeat packet. It's easy to operate this algorithm and it also considers effects of the network delay on the arrival time of heartbeat packets, but its prediction accuracy is very low. Paper [9] predicts the arrival time of heartbeat packets with the artificial neural network. Although this method indeed improves prediction accuracy, it is too complicated to be used in the embedded cluster systems which have higher requirements for the real-time attribute.

Based on the analysis of advantages and disadvantages of the existing research, this paper proposes a Double-layer Heartbeat Detection Algorithm (DLHB) orienting to embedded heterogeneous clusters. This paper divides the nodes in the embedded heterogeneous cluster into different areas by their physical positions. For the inter-domain heartbeat detection, heartbeat prediction mechanism is introduced to reduce misjudgment caused by network latency, while for the intra-domain heartbeat detection, the heartbeat ring mechanism of lower message complexity is adopted. This algorithm not only has higher detection success rate, but also has shorter detection duration.

3. Algorithm Design

3.1. Double-Layer Heartbeat Detection Model

Usually, in the embedded heterogeneous cluster application, the network communication costs differ greatly among the heterogeneous nodes. Generally speaking, the network communication cost is low among nodes in the same small-scale cluster or on the same rack, but cost is higher and unstable among nodes in different small-scale clusters or different physical areas [10]. For this reason, a double-layer heartbeat detection algorithm orienting to embedded heterogeneous cluster is designed, as shown in Figure 1. In Figure 1, the small circle marked with M is the master control node, and other small blank circles without any symbol represent the normal nodes. HB_t is the token heartbeat packet, and HB_r is the response heartbeat packet.

For the real-time requirement of the embedded system, the topology of the model is based on the logic token ring. The intra-domain heartbeat detection can be conducted only through the simple token heartbeat detection and the response heartbeat package, while the inter-domain heartbeat detection only through the status packets designed uniformly, so complexity of the heterogeneous system can be avoided. The cluster node areas are divided according to their physical positions and the nodes with a low network communication cost and relatively stable network conditions are categorized into the same area. In every node area, a master control node is elected, and the left nodes are the normal ones. All the intra-domain nodes form a logic heartbeat ring, in which the master control nodes constitute the intra-domain heartbeat packets and transmit them downwards in turn along the heartbeat ring so as to detect the node status in the ring. The inter-domain node heartbeat detection is conducted among master control nodes which collect the status information of all nodes within their domains and send them to other master control nodes through heartbeat packets. According to the model shown in figure 1, the DLHB algorithm is comprised of two parts, the heartbeat detection algorithm of the inter-domain master node and the heartbeat detection algorithm of the intra-domain node.

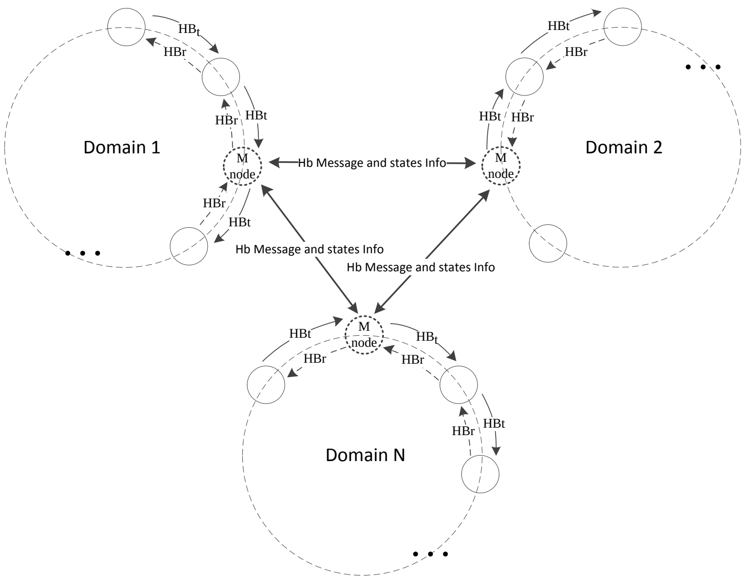

Figure 1. Algorithm Model

3.2. ARMA-Based Prediction Method for Heartbeat Packet

Auto-Regressive and Moving Average Model (ARMA) is an important method of studying time series. It's composed of AR mode and MA mode. ARMA mode requires that time series should be random and stable [11]. In the sequence of ARMA model, the nth time observed value is dependent on the n-1th time observed value and the (n-1)th time noise value, so a model can be created to predict future value[12]. The mathematical formula of ARMA model [13] is:

$$D_t = \varphi_1 D_{t-1} + \varphi_2 D_{t-2} + \ldots + \varphi_p D_{t-p} + a_t - \theta_1 a_{t-1} - \theta_2 a_{t-2} - \ldots - \theta_q a_{t-q} \quad (1)$$

D is the sequence of predictive value, p and q are order, φ_p and θ_q are undetermined coefficients, a_t is the sequence of random variables that are independently distributed, representing the error between the observed value and the predicted value, and t represents the observed value of the time.

Lots of scholars have applied prediction models to the prediction of network flow, such as flow prediction based on auto-regressive and moving average model (ARMA) [14]and prediction based on fractal auto-regressive and moving average model f (F-ARMA) [15], *etc*.

In the heterogeneous cluster system, the network flow directly affects the arrival time of heartbeat packets. Moreover, paper [16] points that the ARMA model can effectively analyze the relevance of stability data and it has smaller prediction error variance than AR model, so it's suitable for short-term prediction and environments in which the sampling cycle is second[13]. Therefore, ARMA is used to predict the arrival time of heartbeat packets.

Definition 1: Assume the time interval between the arrival time of the tth heartbeat packet and the arrival time of the (t-1)th heartbeat packet is D_t. As the time elapses, the data sequence can be considered as a set of random sequences $\{D_t\}$, t = 1,2….

As the arrival time intervals of heartbeat packets are not necessarily periodic and they may fluctuate around a fixed value level with no linear trends, they are steady and smooth sequences [13]. Here, backward shift operator B is introduced, where $\boldsymbol{B} D_t = D_{t-1}$, $\boldsymbol{B}^2 D_t = D_{t-2}$ …. According to definition 1, formula(1) can be transferred to:

$$\varphi(\boldsymbol{B}) D_t = \theta(\boldsymbol{B}) a_t \quad (2)$$

$\varphi(\boldsymbol{B})$ and $\theta(\boldsymbol{B})$ are p steps and q steps polynomials of B. The formula(2) can be extended to formula(3)[15]:

$$\begin{cases} \varphi(\boldsymbol{B}) = 1 - \varphi_1\boldsymbol{B} - \varphi_2\boldsymbol{B}^2 - \varphi_3\boldsymbol{B}^3 - \ldots - \varphi_p\boldsymbol{B}^p \\ \theta(\boldsymbol{B}) = 1 - \theta_1\boldsymbol{B} - \theta_2\boldsymbol{B}^2 - \theta_3\boldsymbol{B}^3 - \ldots - \theta_q\boldsymbol{B}^q \end{cases} \tag{3}$$

ARMA (p, q) model has p+q+1 parameters, including $\varphi_1, \varphi_2, \ldots\varphi_p, \theta_1, \theta_2, \ldots\theta_q, \delta^2$. If p and q are too big, there will be a heavy calculation burden. According to the time sequence theory, ARMA (2s, 2s-1) is selected, where s is a positive integer. In this way, the model can be automatically completed on the computer without human-machine coordination [14]. Here ARMA (2, 1) is used, so there will be less calculation and it can meet the real-time requirement of the system. Therefore, formula (3) can be written as formula (4).

$$\begin{cases} \varphi(\boldsymbol{B}) = 1 - \varphi_1\boldsymbol{B} - \varphi_2\boldsymbol{B}^2 \\ \theta(\boldsymbol{B}) = 1 - \theta_1\boldsymbol{B} \end{cases}$$

(4)

In order to make the prediction result more real and practical, the error mean between the predicted value and the real value that are got in a recent period is used to correct D_t. Respectively set the predicted value and the real value of the arrival time interval of the last m heartbeat packets as Sequence $\{X_{t-1}, \ldots, X_{t-m}\}$ and Sequence $\{Y_{t-1}, \ldots, Y_{t-m}\}$. When t>m, the predicted arrival time interval X_t after being corrected can be calculated through formula(5), where i =1,2,…,m.

$$X_t = D_t + \sum_{i=1}^{m} \frac{Y_{t-i} - X_{t-i}}{m} \tag{5}$$

3.3. ARMA-Prediction-Based Inter-Domain Heartbeat Detection Algorithm

Inter-domain heartbeat detection works between each master process. The heartbeat packet sent by each master process contains status information of all the nodes in the same domain, so each master process will obtain status information of all nodes. In 3.1, ARMA model is used to predict the arrival time internal X_t of heartbeat packets, and sequence $\{Y_{t-1} \;\ldots\; Y_{t-m}\}$ is used to record the real value of the arrival time interval of the last m heartbeat packets. Assume the real arrival time sequence of the heartbeat packet is $\{A_t\}$, and the predicted arrival time sequence is $\{B_t\}$. The algorithm model is shown in Figure.2, where the sending interval of the heartbeat packets by the monitored nodes processes is a fixed value σ.

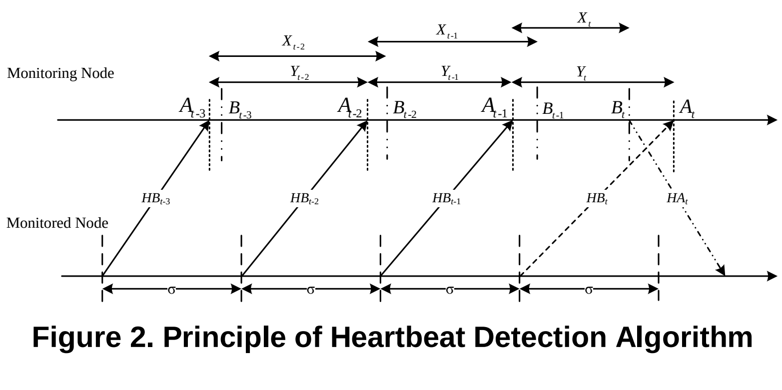

Figure 2. Principle of Heartbeat Detection Algorithm

The method of predicting the arrival time of heartbeat packets is shown as formula(6).

$$B_t = A_{t-1} + X_t \tag{6}$$

Every node will keep a timetable which records the real and predicted arrival time of the last m heartbeat packets from all the other nodes. Assume that the timeout of the first m heartbeat packets will be calculated with the fixed timeout threshold as the arrival time of a heartbeat packet needs to be predicted on the basis of m previous records. Later then, the record will be updated once every packet is received, so there are always the latest m records, enabling the prediction result to reflect the current network status. In order to reduce the wrong decision caused by the fact that the predicted arrival time of heartbeat packet is earlier than the real arrival time, the formula(7) is used to set the timeout of heartbeat packets.

$$T_{timeout} = \begin{cases} T_{thr}, t \le m \\ B_t, t > m \end{cases} \tag{7}$$

Formula(6) and formula(7) will lead to formula(8) – the calculation formula of $T_{timeout}$.

$$T_{timeout} = \begin{cases} T_{thr}, t \le m \\ A_{t-1} + X_t, t > m \end{cases} \tag{8}$$

If the heartbeat packet from the corresponding node arrives within the expected time, then the real arrival time of this heartbeat packet will be recorded and the record of the corresponding node will also be updated. After that, the arrival time of the next heartbeat packet will be predicted on the basis of the latest record. If the heartbeat packet can't arrive within the expected time, then the corresponding node will send the health inquiry packet to the monitored node to pull back the status information.

From what has been discussed above, the ARMA-prediction-based heartbeat detection algorithm is described as follows:

Step 1: Start the periodic sending process of heartbeat packets;

Step 2: Start the receiving process of heartbeat packets. Record the real arrival time A_t of heartbeat packet t from node M_k;

Step 3: If the recorded time of the heartbeat packets of node M_k is equal to or greater than m, then go to Step 5;

Step 4: Use formula(8) to set T_{thr} as the timeout $T_{timeout}$ of the heartbeat packet t+1, and then go to Step 8;

Step 5: Calculate and record the real arrival time interval Y_t between heartbeat packet t and heartbeat packet t-1 from node M_k;

Step 6: Use ARMA to predict the arrival time interval between the heartbeat packet t+1 and the heartbeat packet t, and use formula(5) to calculate the predicted value X_t after being corrected;

Step 7: Use formula(8) to set $T_{timeout}$ as the timeout of the heartbeat packet t+1 from node M_k;

Step 8: Start the timeout timer of the heartbeat packet t+1 from node M_k, and wait for the arrival of the heartbeat packet t+1. For the rest heartbeat packets, repeat Step2 ~ Step8.

The description of the master node heartbeat detection algorithm DLHB - 1 is shown in Figure 3.


```
Input：Heartbeat packet t
Output：The timeout of heartbeat t+1
While system works well
{
        If Heartbeat timer timeout
        T_timeout= T_thr
        Else
        {
                Record down the real arrival time；
                Calculate and record down the real arrival time interval;
                Use ARMA to predict the arrival time interval between the
                heartbeat   packet t+1 and the heartbeat packet t；
                Calculate the predicted value after correction；
                Set the time-out  of the heartbeat packet t+1.
        }
}
```

Figure 3. Pseudo-Code of Inter-Domain Heartbeat Algorithm DLHB-1

3.4. Intra-Domain Heartbeat Detection Algorithm

As the node areas are divided by their physical position in this paper, the network among nodes from the same area is relatively reliable, and the heartbeat ring of low message complexity is used to design the intra-domain heartbeat detection algorithm.

Paper [17] proposes a heartbeat ring algorithm with a message complexity of O(n), which can detect the single-point failure with a few heartbeat packets. Obviously the disadvantage is that if only the major and assistant coordinators are used to save the configuration information of the heartbeat ring, the configuration information will be lost when all the nodes used as the major and assistant coordinators fail, and faults concurrently occurring on multiple nodes cannot be detected.

Definition 2: The intra-domain node set is $\{N_1, \ N_2, \ \ldots, \ N_m\}$, where m is the number of nodes in the ring. All nodes make up a heartbeat ring, where $\langle N_k, N_{k+1}\rangle$ means N_k and N_{k+1}, which are logic neighbor nodes in the heartbeat ring, and N_k is the neighbor node before N_{k+1}, and N_{k+1} is the neighbor node after N_k. Each node in the ring maintains the topological structure of the whole ring. There are two kinds of heartbeat packets in the ring: HB_t and HB_r. HB_t is the token heartbeat packet, while HB_r is the response heartbeat packet. Node N_k receives HB_t from the former neighbor node N_{k-1} and then transmits it to the later neighbor node N_{k+1}. It also sends a HB_r back to the former neighbor node N_{k-1} to show its own status.

From Definition 2, HB_t is being transmitted in a cycle within the ring like a token, and only one node can hold it at one time point. Every node maintains a timer. Timing begins when node N_k transmits HB_t to the later neighbor node N_{k+1}. If node N_k doesn't receive the HB_r answered by the later neighbor node N_{k+1} within the threshold time, the later neighbor node N_{k+1} will be considered to be failed. At this moment, this node will reset the timer, set a new HB_r and send it to the neighbor node after N_{k+1}. If N_k receives the heartbeat packet answered by node N_{k+2} within the threshold time, then no action will be taken and node N_{k+2} will continue to transmit the token heartbeat packet HB_t; otherwise the node N_{k+2} is also considered to be failed, and then it will further send HB_t to node N_{k+3}; the rest can be done in the same manner till the replied heartbeat packet HB_r is received. The whole process is shown in Figure 4.

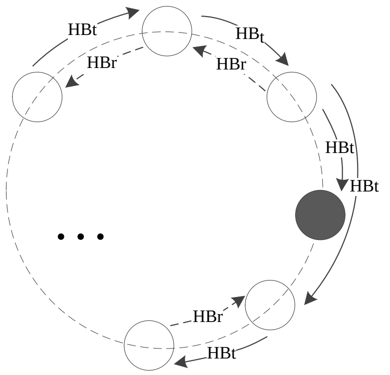

Figure 4. Intra-Domain Heartbeat Ring Algorithm Model

Figure 5 has described the heartbeat detection process intra-domain.

```
Input：Token heartbeat packet HBt
Output：Heartbeat packet HBt with fault information
While system works well
{
        If node Nk has received token HBt
        {
                Reply responsive heartbeat packet HBr；
                Transmit HBt to node Nk+1 and start heartbeat timer；
                if node Nk has not received responsive packet HBr from
                node Nk+1
                {
                        Reset heartbeat timer；
                        Add the fault information of node Nk+1 to token HBr ；
                        Send token HBr to node Nk+2；
                }
                Else
                {
                        Node Nk+1 was health, do nothing；
                }
        }
}
```

Figure 5. Pseudo-Code of Intra-Domain Heartbeat Algorithm DLHB-2

4. Simulation Experiment and Performance Analysis

There are 16 PCs used in the experiment and they form a LAN via a switch. Each of them continuously broadcasts the data packets to each other. As the main novelty of the heartbeat algorithm in this paper lies in that it uses ARMA to predict the arrival time of inter-domain heartbeat packets, the mean prediction error of these 16 PCs are used to judge the performance of the algorithm.

Let m in formula(8) be 3 and the sending cycle of heartbeat packets 5s. Because of the limited table size, the 101st to the 110th results of the experiment are listed, i.e. the values of $\{Y_t \mid 101 \le t \le 110\}$ and $\{A_t \mid 101 \le t \le 110\}$. Values of $\{X_t \mid 101 \le t \le 110\}$ and $\{B_t \mid 101 \le t \le 110\}$ that are respectively calculated through DHB and DLHB are also listed in Table 1.

Table 1. Partial Data of Experiment Results

Times	Actual Conditions		DHB Algorithm		DLHB Algorithm	
	Y_t **(ms)**	A_t **(m: s: ms)**	X_t **(ms)**	B_t **(m: s: ms)**	X_t **(ms)**	B_t **(m: s: ms)**
101	5156	35:05:012	5974	35:05:959	5845	35:05:747

102	5287	35:10:299	6181	35:11:193	5997	35:11:009
103	5098	35:15:397	5973	35:16:272	5855	35:16:154
104	4987	35:20:384	5923	35:21:320	5750	35:21:147
105	5321	35:25:705	6288	35:26:672	6193	35:26:577
106	4896	35:30:601	5984	35:31:689	5602	35:31:307
107	5405	35:36:006	6423	35:37:024	6228	35:36:829
108	5136	35:41:142	5954	35:41:960	6004	35:42:010
109	4818	35:45:960	5797	35:46:939	5676	35:46:818
110	5247	35:51:207	6243	35:52:203	6014	35:51:974

From the above, it is assumed $\{A_t\}$ is the real arrival time sequence of heartbeat packets and $\{B_t\}$ is the predicted arrival time sequence. Because for the former m heartbeat packets, the timeout is set with the fixed threshold, the sub-sequences $\{A_t | n \le t \le N\}$ and $\{B_t | n \le t \le N\}$ of $\{A_t\}$ and $\{B_t\}$ are analyzed, where n>m. Set $s_t = |B_t - A_t|$, ($n < t \le N$) is the absolute value of the difference between the predict arrival time and real arrival time.

It can be seen from above that the smaller s_t is, the smaller the error predicted by the algorithm is and the greater the performance will be. Assume n is 100 and N is 200, and then a comparison between experiments based upon DLHB proposed in this paper and DHB proposed in paper [7] can be seen in Figure 6. Figure 6 shows that the prediction error of DLHB is obviously smaller than that of DHB.

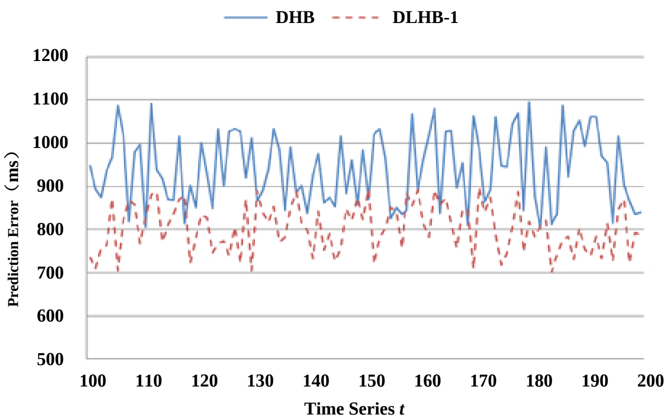

Figure 6. Prediction Error of Node Heartbeat

In respect of the intra-domain heartbeat detection algorithm, comparative experiments are conducted between DLHB proposed in this paper and heartbeat ring algorithm proposed in paper [17]. In each experiment, only one fault node is set and the detection duration of the fault node is considered as the evaluation index of the algorithm. Assume that the timeout of the heartbeat timer is 3000ms. The detection duration of the intra-domain heartbeat ring in the experiments is shown in Figure 7. As the number of nodes increases, the detection duration becomes longer. However, DLHB proposed in this paper always has shorter detection duration than the heartbeat ring algorithm.

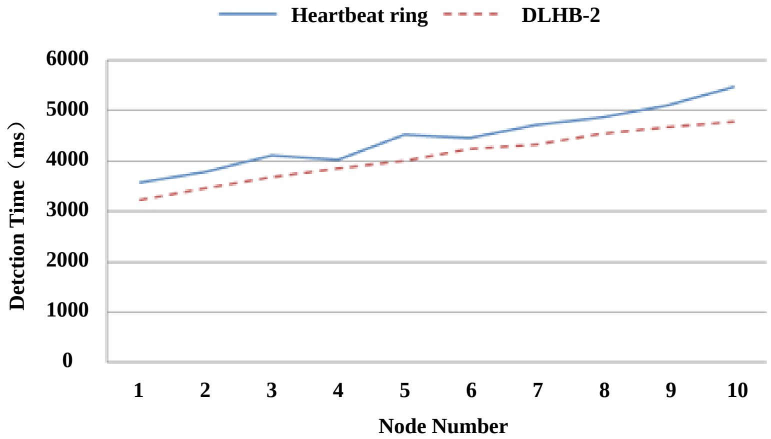

Figure 7. Intra-Domain Heartbeat Ring Detection Time

5. Conclusion

In this paper, for embedded heterogeneous clusters, a double-layer heartbeat detection model and ARMA-prediction-based double-layer heartbeat detection algorithm are proposed. A comparison between the DLHB and DHB algorithms is made through experiments. The experiment shows that the DLHB model and the algorithm proposed in this paper has a low rate of false detection and a great performance in heterogeneous clusters, so the model and the algorithm can be actually applied to heterogeneous clusters which have the real-time requirement.

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References

[1] Y. Aihua, "Design and Implement of Distributed Reak-time Fault-tolerant System", Dalian, Dalian University of Technology.
[2] Y. Wenxuan, G. Xiang, Z. Xiaojing and G. Deyuan, "Shared Memory Based Embedded Cluster Model with High Scalability", Journal of Computer Research and Development, vol. 49, **(2012)**, pp. 245-251.
[3] M. G. Gouda and T. M. McGuire, "Accelerated heartbeat protocols", Proceedings of the 1998 18th International Conference on Distributed Computing Systems, **(1998)**, May 26.
[4] E. G. Coffman, J. L. Bruno, "Computer and job-shop scheduling theory", John Wiley & Sons, **(1976)**.
[5] W. Ming, Z. Chunxi and Yi Xiaosu, "Fault detector of fault-tolerant distributed systems based on self-adaptive heartbeat algorithm, Journal of Beijing University of Aeronautics and Astronautics, **(2013)**, vol. 39, no. 7, pp. 952-956.
[6] Z. Hou, Y. Huang, S. Zheng, X. Dong and B. Wang, "Design and Impleme ntation of Heartbeat in Multi-machine Environment", Proceedings of the 17th International Conference on Advanced Information Networking and Applications, Xi'an, pp.583-586, March **(2003)**, China.
[7] F. f. Li, X. Z. Yu, G. Wu, "Design and Implementation of High Availability Distributed System Based on Multi-level Heartbeat Protocol", 2009 IITA International Conference on Control, Automation and Systems Engineering, Zhangjiajie, pp. 83-87, **(2009)** July, China.
[8] L. Feng, Y. Songhua and Z. Heng, "Dynamic heartbeat algorithm of redundant mechanisms in WIA-PA", 3rd IEEE International Conference on Computer Science and Information Technology (ICCSIT), Chengdu, pp. 621-624, **(2010)** July China.

[9] H. J. Zhao, M. Y. Huang, X. Hong and Z. Fang, "Forecasting Heartbeat Delay for Failure Detection over Internet using Nonlinear System", 2009 World Congress on Computer Science and Information Engineering, CA, **(2009)** April, pp. 589-593, Los Angeles.
[10] Weiss A A. ARMA models with ARCH errors, "Journal of Time Series Analysis", **(1984),** vol. 5, no. 2, pp. 129-143.
[11] X. Chaoqun, Z. Yi, Z. Wei, "A Cluster Heartbeat Algorithm with ARMA-based Prediction", Proceedings of 3nd International Conference on Computer Science and Network Technology, **(2013)**, pp. 218-221.
[12] L. Wang, "Non-stationary Time Series Analysis for Economy Based on the ARMA model", Journal of Wuhan University of Technology (Transportation Science & Engineering), vol. 28, no. 1, **(2004)**, pp. 133-136.
[13] R. Y. Li, "Research on failure rate forecasting method based on ARMA model", System Engineering and Electronics, vol. 30, no. 8, **(2008)**, pp. 1588-1591.
[14] D. Wen-xuan, J. Wen-xian, "An Congestion Control Algorithm for Wireless Sensor Networks Based on ARMA Traffic Prediction", Journal of Chinese Computer System, vol. 33, no. 5, **(2012)**, pp. 1098-1103.
[15] Z. Bo-xian and L. Qiang, "ARMA-Based Traffic Prediction and Overload Detection of Network", Journal of Computer Research and Development, vol. 39, no. 12, **(2002)**, pp. 1645-1652.
[16] X. Ren, Y. Yu, J. f. Zhang, L. Ma and X. D. Ma, "Parameter Estimation and Application of Time-varying FARIMA Model", International Journal of Advancements in Computing Technology, vol. 3, no. 3, **(2011)**, pp. 89-94.
[17] Y. Lu and M. Wang, "A New Heartbeat Mechanism for Large-Scale Cluster", The first International Workshop on Metropolis/Enterprise Grid and Application Harbin, **(2006)** January, pp. 16-18, China.

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