Priority-based hierarchical Application Layer Multicast Management Model

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Summary

ALM (Application Layer Multicast) has been widely used recently. According to the organizing of multicast node(s), the paper proposes an ALM management model PBHM (Priority-Based Hierarchical Model, PBHM). Because it is grounded on hierarchy, the model has many merits, such as little control overhead, high efficiency, distributed build, better expansibility, independent topology of bottom and so on. The paper introduces priority for each multicast node for the purpose of making the selection of group leader more rational, so the network can be constringed fleetly and can elect group leader over again rapidly even though the network invalidates frequently, and consequently the method can ameliorate the network performance with only clusters management. Further more, the paper sets up priority mathematical model PRIORITY in order to calculate the priority of each group member, in addition, the paper tests and proves the correlative conclusions by simulation experiment, and it's proved that the model improves the forwarding efficiency of ALM and administers its consumers in a more efficient way.

key words

Application-Layer Multicast; Priority; Hierarchical Structure; Multicast Management; Efficiency

1. Introduction

Multicast is an efficient communication way of sending data from one to multi-receivers, In ALM (Application Layer Multicast, ALM)，application ends first self-organize into a logical overlay tree in the application layer, and then multicast is achieved by transmitting data from one peer to another along the tree edges using unicast communications. Nowadays ALM is applied universally in file dissemination, live streaming, media on-demand and so on. Because multicast is achieved by transmitting data along the tree edges using unicast connections in ALM, it does not require multicast-capable routers, and data in ALM may be read by a non-member using a network sniffer, Furthermore, data is transmitted by hosts with low reliability, therefore, it is necessary to make further development on the security of ALM, and the user management of ALM is rather significant.

In term of user management, if all the members are distributed in the same layer, then every member is equal to each other, all group members share a universal management group key. In this case, whenever there is a membership change, a new group key is generated which has to be communicated and made known to all the members. Such re-key messages have to be processed by all the peers in the network so as to agree on a common new group key. This leads to re-key processing overhead depending on how often group membership changes. While for a tree-topology, in forwarding packets from one host to another, each host has to first decrypt the packets received from its parent, and then re-encrypt the packets before forwarding them to each of its children using the corresponding encryption key of the connection. It can be seen clearly that a node in this approach needs to continuously decrypt and re-encrypt packets. This leads to continuous decryption/re-encryption processing overhead depending on packet arrival rate. For a large and dynamic group, these re-encryption and re-keying operations incur high processing overhead at the nodes. Though NICE hierarchical structure has less control charge, it has no corresponding solution whenever Leader is invalidated and can't make full use of connect resources, what's worse, the out-degrees of nodes in high layer are larger. Because of all this above, this paper proposes a secure management model PBHM. The PBHM elects the group member with the highest priority in each group as group Leader and uses reasonable number of layer in order to make the whole framework in optimization.

2. The design of the model

2.1 The framework of the model

There are three kinds of entity defined according to their roles in the model: Root, Leader and Group member. The framework of the model is shown as in Fig.1.

Root, possessing the highest priority, lies in the highest layer in the hierarchical structure and takes charge of the authentication and the creation of information-lists of new members. All the information-lists of group members joined and the name list of hostile members are stored in Root, and Root updates the information-lists periodically based on the information sent by lower-layer members, while Root also manages member joining and departure. When the system is encountering huge destruction, for example, when the departure of massive nodes causes the model expired or when the Leaders of upper-layer are lost, Root can turn the system resume itself into the equilibrium state again and make the model stay in the balanced state.

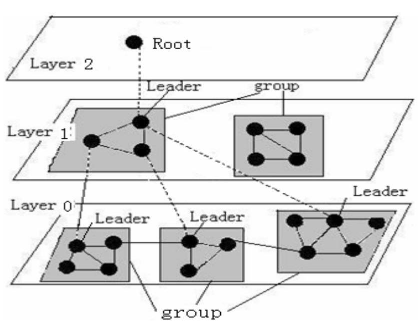

Fig.1 The framework of the model

Leader is the group manager and possesses the highest priority within its own group, and the choice of the group leader is important to guarantee that a new joining member is quickly able to find its appropriate position in the hierarchy using a very small number of queries to other members. In addition, all leaders lying in Layer (i) are group members of Layer (i+1). Leader preserves all the information-lists of its own group members, calculates the priority of its members periodically by the PRIORITY mathematical model, elects group leader for the group it belongs to by comparing all the group members' priority, and sends its members' information and the modified information to Root periodically.

Group member is the client who participates in the multicast communications and carried out the multicast group communications, each group member maintains the state about all the peers in its group and about all of its leader's peers in the upper-layer.

2.2 The basis of the model

This is a priority-based hierarchical management model, and it founds PRIORITY mathematical model in order to calculate the priority of each group member, which increases the priority of the dependable group member and reduces the priority of the undependable one contrarily. When the priority drops to zero, the relevant member is recorded in the blacklist stored in Root. Leader elects the group member with the highest priority as cluster leader periodically by comparing all the group members' priority. In the model, Root is the imperator, which manages the system as a whole and preserves all the information lists of the group members joined; Group members lying in lower layers are administered by their own leaders, and leader preserves all the information-lists of its own group members.

2.3 PRIORITY mathematical model

In the PRIORITY mathematical model, Num expresses the frequency of a member's movement, defined as the times member moves within the time $\triangle t$; Sour expresses the percents of the already inclusive resource of a group member accounting for the total amount; Priority (Num, Sour, ρ , $\triangle$t) is defined as the group member's priority. Supposing L_G(i,j,k) denotes that the group member is the k^{th} group member of Layer(i) group(j), while N(i,j) denotes the member account of Layer(i) group(j); $t(rT_0)$ denotes the r^{th} sample time, (r =1,2,3,4,5,…, $\triangle t/T_0$), T_0 is the sample interval.

The resource is divided into segments, and the segments compose a resources matrix {s[1], s[2] , s[3] ,…, s[k], …, s[n] } (n is the total account of the segments, $1 \le k \le n$), so the total resource of the source node is :

S= s[1]+ s[2]+ s[3]+…s[k]+…+ s[n] (1)

Supposing $D_{a\text{->}b}(s[i])$ denotes the data delivered from node a to node b, then in the sample time $t(rT_0)$, the data $D_{rev}(rT_0)_{\text{L\_G(i,j,k)}}$ received by the node L_G(i,j,k) is shown as in Eq(2), while the data $D_{rev}(rT_0)_{\text{L\_G(i,j,k)}}$ sent by the node L_G(i,j,k) is shown as in Eq(3).a≠ b≠ c (1≤a, b, c ≤n), m≠ n≠ p≠ k (1≤m, n, p, k≤ $N_{(i,j)}$).

$$D_{rev}(rT_0)_{\text{L\_G(i,j,k)}} = D_{\text{L\_G(i,j,m)}\to\text{L\_G(i,j,k)}}[a]+\cdots+ D_{\text{L\_G(i,j,n)}\to\text{L\_G(i,j,k)}}[b]+D_{\text{L\_G(i,j,p)}\to\text{L\_G(i,j,k)}}[c]$$

(2)

$$D_{sent}(rT_0)_{\text{L\_G(i,j,k)}} = D_{\text{L\_G(i,j,k)}\to\text{L\_G(i,j,m)}}[a]+\cdots+ D_{\text{L\_G(i,j,k)}\to\text{L\_G(i,j,n)}}[a]+D_{\text{L\_G(i,j,k)}\to\text{L\_G(i,j,p)}}[a]$$

(3)

Therefore, the efficiency of node L_G(i,j,k) in the sample time $t(rT_0)$ is shown as in Eq(4), if ignoring the variety of the delivering ratio, it can be calculated approximately the data received and sent by the node L_G(i,j,k) within the time $\triangle$t shown separately as in Eq(5) and Eq(6.)

$$\rho(rT_0) = \frac{D_{sent}(rT_0)_{\text{L\_G(i,j,k)}}}{D_{rev}(rT_0)_{\text{L\_G(i,j,k)}} + D_{sent}(rT_0)_{\text{L\_G(i,j,k)}}} \quad (4)$$

$$D_{rev}(\text{L\_G(i,j,k)}) = \sum_{r=1}^{r=R}\int_0^{T_0} D_{rev}(rT_0)_{\text{L\_G(i,j,k)}}dt \quad (5)$$

$$D_{sent}(\text{L\_G(i,j,k)}) = \sum_{r=1}^{r=R}\int_0^{T_0} D_{sent}(rT_0)_{\text{L\_G(i,j,k)}}dt \quad (6)$$

It can also be calculated the total data D(L_G(i,j,k)) delivered by the node L_G(i,j,k) and the percents Sour of the resource it has included accounting for the total amount shown separately as in Eq(7) and Eq(8.), therefore the average efficiency during the time $\triangle$t is shown as in Eq(9).

$$D(\text{L\_G(i,j,k)}) = D_{rev}(\text{L\_G(i,j,k)}) + D_{sent}(\text{L\_G(i,j,k)}) \quad (7)$$

$$\text{Sour} = D_{rev}(\text{L\_G(i,j,k)})/S \quad (8)$$

$$\rho = \frac{D_{sent}(\text{L\_G(i,j,k)})}{\text{D(L\_G(i,j,k))}} = \frac{D_{sent}(\text{L\_G(i,j,k)})}{D_{sent}(\text{L\_G(i,j,k)}) + D_{rev}(\text{L\_G(i,j,k)})}$$

（9）

Supposing P _sour(Sour) denotes the change of the group member's priority following the variable Sour's change, and P _ effc(ρ) denotes the change of the group member's priority following the variable ρ 's change. P _sour(Sour) and P _ effc(ρ) are defined by the function equation shown separately as in Eq(10) and Eq(11.)

$$\text{P \_sour(Sour)} = \frac{\text{Sour}}{\text{1-Sour}} e^{\alpha\frac{Sour}{1-Sour}} \qquad (0 \le \alpha \le 1) \quad (10)$$

$$\text{P \_ effc}(\rho) = \frac{\rho}{1\text{-}\rho} \text{e}^{\beta\frac{\rho^2}{1-\rho^2}} \qquad (0 \le \beta \le 1) \quad (11)$$

The analog variable Sour and ρ make P _sour(Sour) and P _ effc(ρ) be analog variables, so it is necessary to convert P _sour(Sour) and P _ effc(ρ) to digital variables. For the purpose of decreasing system quantization error, this paper introduces uneven quantization to put it into practice, and actually adopts 13 curving lines characteristic approximated to A compression function, and A compression function is determined by the equation shown as in Eq(12). And it's changing as shown in Fig 2.

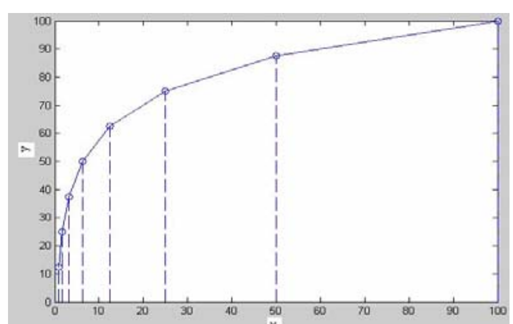

Fig 2 The sketch map of 13 curving lines characteristic

$$y = \begin{cases} \dfrac{Ax}{1+\ln A} & 0 < x \le \dfrac{1}{A} \\ \dfrac{1+\ln Ax}{1+\ln A} & \dfrac{1}{A} \le x \le 1 \end{cases} \quad (12)$$

A is the extend parameter, which denotes the degree of compression, corresponding to 13 curving lines, A=87.6; x denote the unitary input, such as P _sour(Sour) or P _ effc(ρ) in this paper; y denotes the unitary output. x and y are defined separately as following.

$$x = \frac{\text{input}}{\text{the max input impossible}}$$

$$y = \frac{\text{output}}{\text{the max output impossible}}$$

The vibration of a node is determined by the frequency of a node joining and departure, a large vibration, which means that nodes join or depart the system frequently, has great influence on the system stability and slows down the convergence speed. Supposing P _ num (Num), showing the change of a member's priority when the variable Num changes, is defined by the function equation determined by the distribution similar to Fibonacci shown as in Eq(13), Fig .3 represents the changing trend of P _ num (Num).

$$P\_\text{num}(\text{Num}) = \begin{cases} -1 & \text{Num}=1,2 \\ P\_\text{num}(\text{Num}-1)+P\_\text{num}(\text{Num}-2) & \text{Num}\ge 3 \end{cases} \quad (13)$$

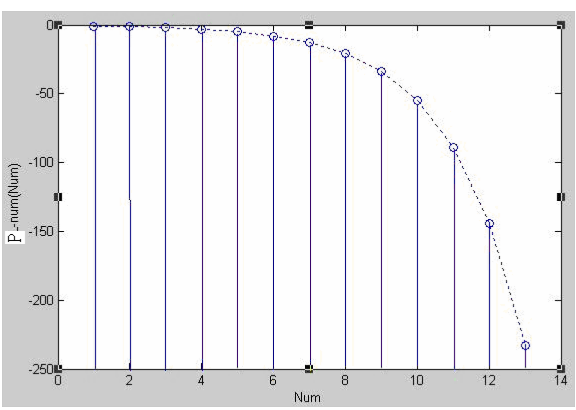

Fig 3 The sketch map of P_ num(Num)

Taking efficiency and stability into account, the priority of node L_G(i,j,k) after it has joined the group for the time △t is defined as Priority(Num, Sour, ρ , △t) shown as in Eq(14) with $(0 \le \eta \le 1)$.

$$\Pr iorit(Num, Sour, \rho, \Delta t) = \lceil \eta P\_num(Num) \rceil + 2 + P\_effc(\rho) + P\_sour(Sour) \quad (14)$$

Considering the actual network environment, the priority of a group member is determined by three parameters $\alpha, \beta, \eta\,(0 \le \alpha, \beta, \eta \le 1)$, and the model must calculate at least one parameter. therefore the model can decide deferent coefficients according to the actual situation in different network environment to adjust a reasonable network topology, for example, it's useful to increase the value η to improve the priority of the elder nodes in order to increase system stability in a network where nodes join and depart frequently.

2.4 The establishment of administrant layer

In this model, the establishment of the administrant layer is the process of electing leader continuously for each group according to the priority of all the group members, Each Leader calculates each group member's priority using the PRIORITY mathematical model. The PBHM assumes the existence of the special group member Root that all members know of a-priori. Each host that intends to join the application layer multicast group contacts Root to initiate the join process. For ease of exposition, it assumes that the Root is always the leader of the single group in the highest layer of the hierarchy, and any host applying for joining the multicast group should first queries Root to initiate the join process.

Table 1 The initial list

Priority	Num	Mac-id	Leader	Sour	Activity	Hostile
2	0	0	0	0	0	0

Supposing a new host applying for joining the multicast group, Firstly, the joining host contacts Root with its join query, after the new member is authenticated and authorized, Root fabricates and preserves initial list of the new member shown as in table 1, then Root initiates the join process and responds with the hosts that are present in the highest layer of the hierarchy. The joining host then contacts all members in the highest layer to identify the member with the highest priority, and then the joining host then contacts each of the members in the lower-layer group with the join query to identify the appropriate member among them, and iteratively uses this procedure to find its optimal cluster L_G(i,j). After the joining host has joined, it periodically sends its own state to the Leader it belongs to. When the system is stable, each group Leader periodically checks the priority of all the group members by the heart-beat message and elects the group member with highest priority in the group as group leader based on the information it detects, judges whether the group needs change Leader or not, If not, Leader holds the line; If yes, Leader sets the item "Leader=1, Activity++" of the member elected as the new Leader, transmits the modification to the its own Leader in the upper-layer and all the group members of the group. The Leader in the upper-layer sets the item "Leader=0, Activity--" of the old Leader and the items "Leader=1, Activity++" of the member elected as the new Leader.

In case that there are several group members with the same highest priority in one group, the member with the highest "Activity" will be the selected Leader; On condition that the elected Leader is reluctance to be a Leader, it informs the old Leader, then the primary Leader sets the item "Activity--" of the elected Leader and elects again from the rest group members until it detects the new Leader.

2.5 Member management

(1). Member joining

When a host applies for joining the multicast group, it sends application to Root, and Root compares this application with the existed information-lists and estimates the status of the applying host as: 1) never joining host (Cont=0,Num=0), 2) moving from one group to anther ($Cont \neq 0, Num \neq 0$), 3) member in the blacklist (Hostile=1). Supposing L_G(i,j) denotes Layer(i) group(j).

For Cont=0, Num=0, Root authenticates and authorizes the new member and fabricates initial list for it, then Root initiates the join process and responds with the hosts that are present in the highest layer of the hierarchy, and the joining host queries each layer in succession from the top of the hierarchy to the most appropriate layer L_i group L_G(i,j) to join, then the leader of the chosen group L_G(i,j) transmits the position information to its own Leader in layer L_{i+1} and all the group members of the group L_G(i,j), and then the Leader in layer L_{i+1} and all the group members of the group L_G(i,j) send the state of themselves to the new member, all the group members related maintain the update modification.

For Sour≠0,Num≠0, Supposing that the member moves from L_G(i,j) to L_G(m,n), firstly, the Leader of L_G(i,j) sets the item "Num++" and reduces the priority of the moving member according to the PRIORITY mathematical model and modified the item "Priority" of the member, then the Leader of L_G(i,j) transmits the member's information list to its own Leader in layer L_{i+1} and all the group members of the group L_G(i,j), the Leader of L_G(i,j) deletes the moving member's information list it preserves. If Priority<0 after modified, Root refuses the application and sets the item "Hostile=1" of the joining member.

For Hostile=1, if Root receives the application for the first time, then Root refuses the application and sets the item "Num++" of the joining host, if Root receives the application again, then Root permits the joining application, sets the item "Num++", and modifies the member's priority according to the PRIORITY mathematical model.

For the management above, if the group is oversize (beyond 3k, k is a constant) after members joining, the primary group will split according to a certain standard, and the Leaders of new groups are elected by the primary Leader, what's more, the primary Leader need to transmit the new Leaders' information to its own Leader in layer L_{i+1} and all the group members of the group L_G(i,j), and to inform Root in succession. If the group is still oversize, the splitting operation will go on till the group size is propriety.

Supposing that the moving member lies in group L_G(i,j), member departure may be a graceful leave or an ungraceful leave. For a graceful leave, it transmits application for departure to its Leader, and the Leader transmits the application to Root; while for an ungraceful leave, its Leader may detect an absence after several Heart-Beat messages, then the Leader informs its own

Leader in layer L_{i+1} and all the group members of the group L_G(i,j) about member departure, and informs Root in succession. According to the roles of members in group, members can be divided into Leader member (Leader=1) and non-Leader member (Leader=0).

For Leader=0, firstly, the Leader of L_G(i,j) sets the item "Num++" of the departure member it maintains when the Leader detects the departure of member L_G(i,j,p), and the Leader of L_G(i,j) reduces the priority of the moving member according to the PRIORITY mathematical model and modifies the item "Priority" of the member, If Priority<0 after modified, the Leader of L_G(i,j) sets the item "Hostile=1" of the departure member, sets up the timer and informs Root, After a period of time T, if Root receives the joining application forwarded by the Leader of L_G(m,n), then Root sets the item "Num++" of the joining member it maintains, reduces the priority of the moving member according to the PRIORITY mathematical model, and then treats the joining member as a new host never joining; if not, Root and all the group members maintaining the departure's state delete the member's information list. A group L_G(i,j) may degenerate into a group member on condition that all the members in the group have left, then the Leader in L_{i+1} sets the item "Leader=0" of the Leader of L_G(i,j) and enlists it into other group as a group member, but its priority needn't modified.

For Leader=1, It is necessary to elect Leader for the group again when the group Leader is invalidated, if a member in L_G(i,j) first detect the invalidation of its Leader, the member will sent the Leader of Layer (i+1) the application of electing Leader for L_G(i,j) after it detects the Leader of L_G(i,j)'s invalidation, the Leader in L_{i+1} will initiate the electing-leader process; if the Leader in L_{i+1} first detects the invalidation of L_G(i,j)'s Leader, it will initiate the electing-leader process directly. the Leader in L_{i+1} goes through all the information lists of the group members in L_G(i,j) and elects the member with the highest priority as the new Leader, sets the new Leader's item "Leader=1,Activity++", and informs all the group member in L_G(i,j) about the new Leader. The process above is no more than the substitution of a new Leader for the primary Leader, and the whole hierarchical structure doesn't change at all. Besides electing new Leader for the group, the Leader in Layer (i+1) must deal with the invalidated Leader as a non-Leader departure.

It's necessary to merge the over small group after members departure no matter whether the invalidated member is a Leader or not, and the Leader of the group needed to merge initials the merging process. The Leader of L_G(i,j) sends merging request message Cluster-Merge-Request to its peer L_G(i+1,m,n) in L_G(i+1,m) where the Leader of L_G(i,j) is a group member, the Leader of L_G(i,j) updates the members of L_G(i,j) with the merge information, and L_G(i+1,m,n) similarly updates its members in layer (i), and checks whether the group will be oversize supposing the merging operation is successful, if the merged group's size is suitable, then the Leader of L_G(i,j) quits from layer (i+1), and all the members of L_G(i,j) join the group in layer (i) with L_G(i+1,m,n) as the Leader. If the merged group is oversize, then the Leader of L_G(i,j) will send the merging request message to its another peer in L_G(i+1,m,n) until it finds the suitable group.

3. Simulation results

The paper establishes a software environment to simulate PBHM on a Linux operation system, and the simulation environment is a transit-stub topology of 250 nodes generated using the GT-ITM[6][7][8] topology generator. Members of the multicast group are randomly selected. The overlay size, N, (i.e., the number of group members) varies from 20 to 160. All the members join the multicast group uniformly at random between simulation time 0 and 300 seconds. Members are allowed to stabilize into an appropriate overlay topology and then an end-host is chosen uniformly at random to be the data source generating data packets. In both PBHM and NICE, measurements are taken after the overlay topology stabilizes and each simulation result is an average of 5 simulation runs.

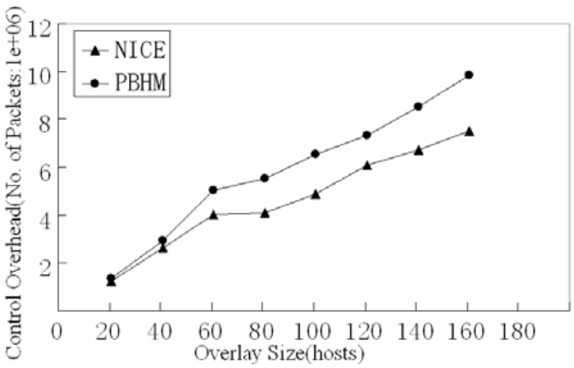

Fig 4 Overlay size vs control overhead

Figure 4 depicts the control overhead measured in terms of number of control packets sent or received by all members in the multicast group, as we can see, the control overhead of PBHM is larger than that of NICE, that's because PBHM introduces the control of priority of group member, Root fabricates initialization list for each new joining member, what's worse, Root and each Leader calculate the priority of each group member according to the PRIORITY mathematical model, and the modified information of the moving members must be interchanged between Root and the Leader the moving member belongs to.

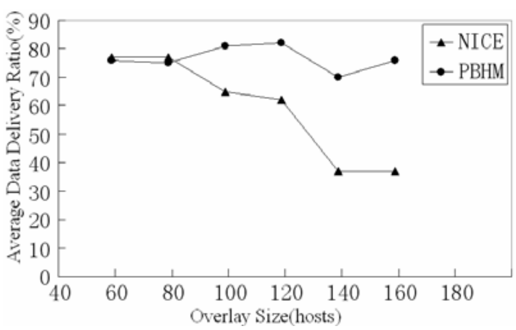

Fig 5 Overlay size vs average data delivery ratio

To study the effect of member failure/leave events on the performance of PBHM and NICE, we carry out experiments in which 40 group members abruptly and simultaneously leave the multicast group without notifying other group members. The multicast source generates 10000 data packets with a constant bit rate of one packet per 50 ms, and the time at which the 40 members leave is after the multicast source has sent 15 % of the data (i.e. 1500 packets). At the end of the simulation, we measure the average data delivery ratio for the remaining group members. Figure 5 shows the average data delivery ratios of PBHM and NICE versus the overlay size. For relatively small group sizes (e.g., 60-80 members), the average data delivery ratio of PBHM is comparable to that of NICE. However, as the overlay size increases, PBHM outperforms NICE in terms of the average data delivery ratio. This is because the higher node degree in NICE (especially for larger overlay sizes) causes the failure/leave of a member to potentially lead to a larger number of members (i.e., the neighbors of the failing/leaving member) to be temporarily disrupted from the data delivery path, thus causing a reduction in the data delivery ratio. Furthermore, a member failure/leave in a higher layer in NICE may have severe effects on the time it takes for remaining members to restore the data delivery path because a member that is present in layer Li is also present in all the lower layers, L_0, L_1, ..., L_{i-1}.

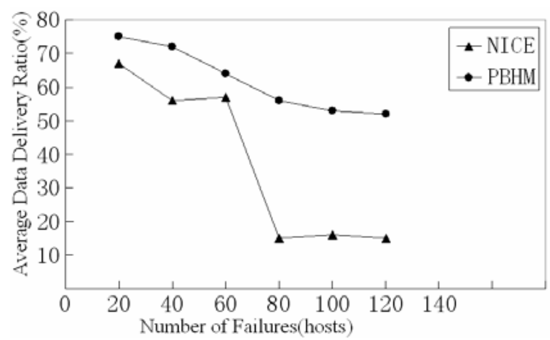

Fig 6 Number of failures vs average data delivery ratio

In order to investigate the effect of the number of member failure/leave events, we vary the number of group members that abruptly and simultaneously leave without notifying other group members and calculate separately. For the same reasons as those mentioned above, NICE has a lower data delivery ratio than PBHM when the number of failing/leaving members increases (as shown in Figure 6 for an overlay size of 160 members).

4. Conclusion

This paper proposes a priority-based hierarchical ALM secure management model (PBHM) and introduces PRIORITY mathematical model in order to calculate the priority of each group member, and it also describes the treatments with member joining and departure in detail so that it can ameliorate the network performance with only group management, Further more, it can make full use of the connection resource with better expansibility, therefore, PBHM is the most efficient management of ALM users. The key point of PBHM is the introduction of member priority for electing group Leader, which reduces the disposal time and optimizes network performance.

Though deep search has done on the management of ALM, it's rather necessary to make further research on ALM security while ALM is being widely used.

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