Influence estimation method of network factors in Internetware reliability

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Abstract

The reliability of Internet ware system is greatly influenced by the network factors. In some classical reliability calculation methods, the component reliability, the connection reliability between components, transition probability and so on, all are set into some fixed values, without considering the network factors. the main factors of network influence for reliability estimation are analyzed and researched in Internetware system, according to these factors, the Markov characteristics of Internetware is analyzed. Using the principle of DTMC and the minimum quadratic difference, the estimation method for reliability is proposed, the new models are defined, and the algorithm for reliability estimation is designed. The experiment proves that the presented method and the designed algorithm can effectively quantitative estimation with great value in Internetware reliability analysis, also provides effective reference value.

Keywords: Internetware, reliability, method, models, algorithm, influence, factor.

1 Introduction

Internetware is a trend of the software application to bring a new application model in future [1, 2], its build and running is based on computer network, has the remarkable characteristics of adaptability and dynamic characteristic under open network. Its reliability estimation is effected by Internet factor, and different from traditional software system.

Reliability would be a very important characteristic of Internetware on the Internet. Factors such as network transmission, the connection between the components in Internetware system, Execution transition between the components, so it is of great significance and application value to study the reliability of Internetware, Great result has been achieved on Internetware reliability study [3-5], Documents [6] and [7] put forward the reliability model and computation based on DTMC (Discrete Time Markov Chain) which computed the system reliability by using the component reliability and the transition probability, but they did not analyze the influence of the network factors on the reliability computation. Component reliability and transition probability are considered to be fixed, not considering the influence of network environment. In fact, the reliability of each component and its transition probability are different in different applications under network environment. Document [8] puts forward the reliability computation by using execution route information and component transition probability under certain testing condition. Document [9] puts forward convex programming optimized transition probability computation based on maximum a posteriori and maximum likelihood by using Bayesian estimation. Document [10] puts forward approximate recursion method of posterior probability density function by using Bayesian theory on Markov jump systems, and then puts forward four mean square deviation estimation computation of transition probability matrix. These research have achieved a certain value, but not consider the quantitative influence of network factors. So, analysis of the component reliability, the transition probability, the connection reliability under network, all affect the reliability of Internetware system, and the quantitative influence is a key research for reliability estimation.

2 Reliability estimation of Internetware

Internetware components have their corresponding Markov chain state [4-6].

State set is $E=\{1,2,\ldots,N\}$, transition probability matrix among states is $P=[p_{ij}]$. When the system is on the state of i at k point of time, the probability is $x_i(k)$, $x_i(k)\geq 0$, $\sum_{i=1}^{n} x_i(k)=1$; when at $k+1$ point of time, probability distribution is $x(k+1)$, then $x(k+1)=x(k)P$, that is:

$$x_j(k+1)=\sum_{i=1}^{n} x_i(k)\,p_{ij} \tag{1}$$

Reliability computation model is constructed by using

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DTMC. Internetware DTMC is a two-tuples (S,Q), in which S is finite state, $s=\{s_1,s_2,\ldots,s_n\}$, $P:S\times S\to[0,1]$ Q is the state transition probability, $Q_s=\{q_{ij}\},i,j\in[1,2,\ldots,n]$, $|I-Q_s|\neq 0$.

$$T(1,n)=I(1,n)+Q_s(1,n)+Q_s^{\,2}(1,n)+Q_s^{\,3}(1,n)+\ldots$$
$$=\sum_0^{\infty}Q_s^{\,n}(1,n)=(-1)^{n+1}\frac{|(I-Q_s)_{n,1}|}{|(I-Q_s)|}$$

I is characteristic matrix $n\times n$, $(I-Q_s)_{n,1}$ means matrix $(I-Q_s)$ deleting the first line of row n. So, the reliability is:

$$R_s=T(1,n)\times r_n\,. \tag{2}$$

3 Connection reliability computing

Internetware connection reliability is mainly influenced by component invocation and network transmission performance. Internetware can achieve component invocation through network, and invocation time obeys Poisson distribution [11]. Network failure rate λ means the network connection. Suppose it has N times invocation, each time the data bit to be transmitted is D_i, and network bandwidth is B, then connection reliability is:

$$RL=\prod_{1\le i\le N}e^{-\lambda(Di/B)} \tag{3}$$

According to the character of the index in Equation (5), connection reliability is increased while the network bandwidth is increased, and it is decreased while the amount of the data to be transmitted is increased.

4 Transition probability and its approximate calculation

Suppose Markov chain is composed of m states, and according to software operation, it changes into the sequence composed of these m states.

Transition probability matrix has the following characteristics:

1) non-negative condition, $0\le p_{ij}\le 1$;

2) row sum condition $\sum_{j=1}^{n}p_{ij}=1$, that is, the sum of transition probability of each row in matrix P is 1.

Transition probability among components is influenced not only by executing invocation among the components, but by network transmission. Whether the transition among components is successful or not is influenced by network environment and it can be evaluated by the statistics of the data transmitted among components. Under normal network conditions, the more times to transmit data successfully, the higher frequency to execute transition. If the performance of network transmission is poor (for example, long-time delay), there are less times to transmit data successfully and the lower frequency to execute transition. Therefore, the ratio of the times to transmit data successfully (shortly transmission ratio) can be used to express transition probability.

If the time of component c_i transmitting data to component c_j is t_{ij}, the transmission ratio is:

$$ps_{ij}=t_{ij}/\sum_{k=1}^{n}t_{ik} \tag{4}$$

Transition probability is p_{ij}, $fp: ps_{ij}\to p_{ij}$, $p_{ij}=k\times ps_{ij}$. If load is less than or equals to rated load, the system works normally, $k=1$. If load is more than rated load, the system cannot work normally, $k=0$.

To sum up, transition probability is revised to be:

$$pt_{ij}=p_{ij}\times RL_{ij}\times R_i \tag{5}$$

In fact, transition probability is a random variable effected by Internet factors. We can also explore the precise calculation of transition probability, to improve reliability analysis of Internetware software system.

5 Transition probability computation

Equation (1) can be written as $Y(t)=Y(t-1)P$. The error is:

$$e_j(t)=y_j(t)-\sum_{i=1}^{m}p_{ij}y_i(t-1)$$

$i,j=1,2,\ldots,m$, $t=0,1,2,\ldots,n$.

The sum of squares of error is：

$$Q=\sum_{j=1}^{m}\sum_{t=1}^{n}(e_j(t))^2$$

Least square method is:

$$\begin{cases}\min \quad Q=\sum_{j=1}^{m}\sum_{t=1}^{n}(e_j(t))^2\\ s.t.\quad \sum_{j=1}^{n}p_{ij}=1 \quad i=1,2,\ldots,m\\ \qquad p_{ij}\ge 0\end{cases} \tag{6}$$

Introduce Lagrange parameter $\xi_i(i=1,2,\ldots,m)$, obtain Lagrange function:

$$f=\sum_{j=1}^{m}\sum_{t=1}^{n}(e_j(t))^2+\sum_{i=1}^{m}\xi_i\times(\sum_{t=1}^{n}p_{ij}-1)$$

The condition of minimum value is : $\partial f/\partial p_{ij}=0$, $\partial f/\partial\xi_i=0$

Obtain:

$$\sum_{t=1}^{n} y_i(t-1)y_1(t-1),...,\sum_{t=1}^{n} y_i(t-1)y_m(t-1)][p_{ij},...,p_{mj}]^T =$$
$$\sum_{t=1}^{n} y_i(t-1)y_j(t-1)$$

Now define matrix X_1, X_2 :

$$X_1 = \begin{bmatrix} y_1(0) & y_2(0) & \dots & y_m(0) \\ y_1(1) & y_2(1) & \dots & y_m(1) \\ \dots & \dots & \dots & \dots \\ y_1(n-1) & y_2(n-1) & \dots & y_m(n-1) \end{bmatrix}$$

$$X_2 = \begin{bmatrix} y_1(1) & y_2(1) & \dots & y_m(1) \\ y_1(2) & y_2(2) & \dots & y_m(2) \\ \dots & \dots & \dots & \dots \\ y_1(n) & y_2(n) & \dots & y_m(n) \end{bmatrix}$$

Then

$$X_1^T X_1 P = X_1^T X_2$$

Transition probability matrix:

$$P = (X_1^T X_1)^{-1}(X_1^T X_2) \quad (7)$$

At the same time non negative condition should be introduced as constraints to compute best approximation.

In Equation (1), *X* and *Y* may not meet Markov chain model, and there would not be the solution to *P* in the above equations, so the minimum square method is used to compute best approximation of Equation (1). *D* means the random matrix set of total order *n*, which is bounded closed set of Euclidean space, *f*(*p*) is continuous function on *D*, the minimum p is regarded as the estimation of transition matrix determined by *X* and *Y* on *D*, and the minimum *p* exists. Let be

$$f(p) = \sum_{i=1}^{m}\sum_{j=1}^{n}(\sum_{k=1}^{n} x_{ik}p_{kj} - y_{ij})^2 \quad (8)$$

$$f(p) = \sum_{j=1}^{n}(Xp_j - y_j)^T(Xp_j - y_j)$$

$$= \sum_{j=1}^{n}(p_j{}^T X^T p_j - 2p_j{}^T X^T y_j + y_j{}^T y_j)$$

For the sake of simplicity, remember it as: $H = diag(X^T X,\dots,X^T X)$, $q = (p_1, p_2,\dots,p_n)^T$, $C = (X^T y_1, X^T y_2,\dots,X^T y_n)^T$, in which, $A = [I, I,\dots,I], e = (1,1,\dots,1)^T$, H is a square matrix of n^2 order, q, c is a n^2-dimensional column vector, I is a unit matrix of n order, A is a $n \times n^2$ matrix, e is *n*-dimensional vector.

Equation (8) changes into:

$$f(p) = q^T Hq - 2C^T q + \sum_{j=1}^{n} y_j{}^T y_j \quad (9)$$

So Equation (9) is transformed to the solution of the following question. The model is as follows:

$$\begin{cases} \min & f = q^T Hq - 2C^T q \\ s.t. & Aq = e \\ & q \ge 0 \end{cases} \quad (10)$$

Suppose $D = \{q : Aq = e, q \ge 0\}$, and $D_1 = \{q : Aq = e, q > 0\}$, $D_2 = \{q : Aq = 0\}$, project on space D_2, projection matrix is $S = (I - A^T(AA^T)^{-1}A) = I - \frac{1}{n}A^T A$.

The algorithm design of transition probability computation is as follows:

1) the initial feasible solution to q is $q^{(1)}$, let be each component of $q^{(1)}$ is $1/n$, $k = 1$;

2) compute the gradient of *f*, $\nabla f = 2Hq^{(k)} - 2C$;

3) compute the projection of negative gradient $-\nabla f$, $d = S(-\nabla f)$;

4) compute the minimum point t^* of $f(t) = f(q + td)$, $t^* = (c^T d - d^T Hq^{(k)})/(d^T Hd)$;

5) search the upper bound τ^*, $\tau^* = \min\{-q_i / d_i; d_i < 0)$;

6) get the new approximate solution $q^{(k+1)}$, suppose $\tau_1 = 0.9\tau^*$, $t_1 = \min\{\tau_1, t^*\}$, $q^{(k+1)} = q^{(k)} + t_1 d$;

7) let be $k = k + 1$, go to step (2).

Iteration condition $\min(|q^{(k+1)} - q^{(k)}|) < \rho$, take $\rho = 0.0001$.

In the end, test the model computation result. According to regression analysis theory, the unbiased estimation of the variance σ^2 :

$$\sigma^2 = \sum_{i=1}^{m}\sum_{j=1}^{n}(\Delta_{ij})^2 / (mn - n^2 + n - 1) \quad (11)$$

6 Illustration

1) Reliability estimation considering the network factors.

About a certain Internetware, by grasping concerned operation blog, after identification and extraction, the structure is obtained as in Figure 1. Figure 1 is the parameter of connection reliability and Table 2, the parameter of component transition probability.

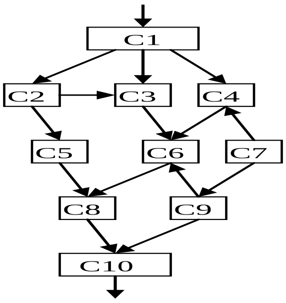

FIGURE 1 System structure

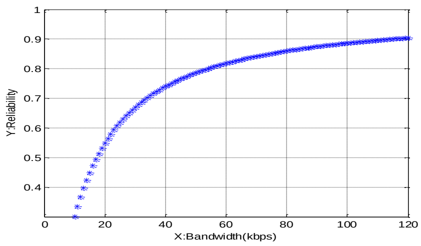

FIGURE 2 Component connection reliability

Component connection reliability is tested in different network bandwidth. According to Figure 2, when network failure rate does not change a lot, the connection reliability is increased as the network bandwidth is increased. When Internetware the transmission time of finishing the activity in high network bandwidth is short, the reliability is to be increased.

According to Figure 1 and Equation (3), the connection reliability as in Table 1 is obtained.

According to Figure 1, Table 1 and Table 2, transition probability matrix is obtained as follows.

By Equation (1), get T; by matrix formula $T(1,n)$, get $T(1,10)$=0.7223; by Equation (2), get this Internetware system reliability R=0.7151. If connection reliability is not taken into consideration, system reliability is R= 0.8316. The reliability of connection between network and component will influence Internetware system reliability directly. If network transmission performance, component interface and connection are to be improved, the Internetware reliability can be highly increased.

2) Transition probability estimation.

Data obtained by a Internetware system is as follows:

x=[0.2 0.2 0.3 0.1 0.2; 0.4 0.2 0.1 0.3 0;
0.1 0.3 0.2 0.3 0.1; 0 0.1 0.2 0.3 0.4;
0.2 0.3 0.4 0.1 0; 0 0.2 0.3 0.3 0.2;
0.4 0 0.2 0.1 0.3; 0.6 0 0 0.4 0.1];

y=[0.26 0.20 0.24 0.23 0.07; 0.12 0.14 0.36 0.28 0.10;
0.19 0.18 0.29 0.22 0.12; 0.25 0.19 0.20 0.25 0.11;
0.21 0.23 0.25 0.22 0.08; 0.25 0.18 0.23 0.23 0.11;
0.24 0.16 0.24 0.30 0.16; 0.10 0.10 0.35 0.33 0.12];

According to Equation (7), compute and get transition matrix P1, but the value on row 3 line 3 is negative. This value is not transition probability. According to Equation (10) and computation method based on projection gradient, and get the following result:

P2=[0.0814 0.0963 0.3774 0.3327 0.1122;
0.1588 0.2432 0.4895 0.0830 0.0255;
0.3784 0.2933 0.0033 0.2384 0.0867;
0.0751 0.0964 0.3369 0.3283 0.1632;
0.3656 0.1551 0.1251 0.2252 0.1290];

σ^2 =4.2632e-004, $\sigma^2 < \sigma_\Delta$ (the given threshold: 0.001), so it is Markov chain model.

The comparison of computation results as in Figure 3 shows that these two have the approximate trend result. But P2 is the best result. It makes sure Markov chain transfer law and the characteristics of transition matrix.

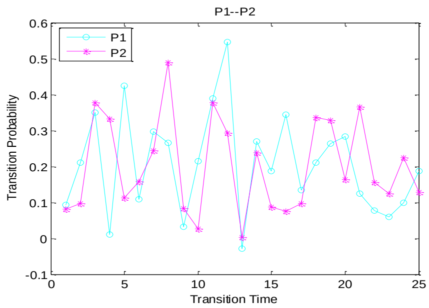

FIGURE 3 Comparison of computation results

TABLE 1 Parameter list of component connection reliability

Component	C1	C2	C3	C4	C5	C6	C7	C8	C9
λ	0.055	0.051	0.057	0.052	0.053	0.056	0.052	0.053	0.056
Di(Kbyte)	d12:0.3 d13:0.28 d14:0.2	d23:0.1 d25:0.2	d36:0.1	d43:0.18	d58:0.2	d63:0.25	d79:0.24 d74:0.15	d810:0.1	d96:0.1 d910:0.25
B(KByte)	B12:40 B13:50 B14:100	B23:100 B25:100	B36:100	B46:100	B58:100	B63:70	B79:100 B74:20	B810:80	B96:100 B910:60
N(times)	30	30	30	30	30	30	30	30	30
rl(link reliability)	rl12:0.9 rl13:0.93 rl14:0.97	rl23:0.99 rl25:0.98	rl36:0.99	rl46:0.98	r58:0.97	rl63:0.95	rl79:0.97 rl74:0.9	rl810:0.98	rl96 :0.99 rl910:0.95

TABLE 2 Parameter list of component transition probability

Component	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
component reliability	0.98	0.99	0.97	0.98	0.95	0.98	0.97	0.96	0.97	0.99
(transition probability	pr12:0.6 pr13:0.1 pr14:0.3	pr23:0.3 pr25:0.7	pr36:0.98	pr46:0.97	pr58:0.96	pr63:0.97	pr74:0.2 pr79:0.8	pr810:0.99	pr910:0.9 pr96:0.1	

7 Conclusions

Based on the analysis and study of Internetware reliability, and its network Influence factors, Internetware reliability model and the method to compute its reliability have been presented. Component connection reliability and transition probability computation under network environment have been put forward to get Internetware reliability. It has also analyzed the acquisition of component transition probability, proposed the method to calculate transition probability by using the occupancy of component executing transition as sample data, studied transition probability matrix computation method based on the minimum quadratic difference. According to the analysis of the experiment, the specific reliability metric of Internetware computed quantitatively is accord with the practical analysis; the presented computing method and its result are scientific and reasonable with practical value. Internetware's self-adaption, cooperativity, reactivity and evolution determine that its reliability is dynamic and evolutionary. It will be an important research direction to analyze the dynamics and evolution of the Internetware reliability.

Conflict of interest

CONFLICT OF INTEREST: Financial contributions to the work being reported should be clearly acknowledged, as should any potential conflict of interest.

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