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Internetware Reliability Computation under the Network Environment

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Abstract: The internetware structure relationship, the network transmission performance, the component connection and the transition probability are important factors to influence the internetware reliability. The model of the component connection, the matrix of the structural relationship and the extraction algorithm of the structural relationship of the internetware are designed. The computation of the transition probability among the components is proposed. Using the Markov chain theory, a new method of internetwork reliability computation is put forward based on the structure, the connection and the transition probability of the internetware. The experiment proves that the designed reliability model, the corresponding algorithm and the computation method of the reliability are reasonable and efficient with important practical value.

Key words: Internetware, reliability, models, computational methods, structure, connecting, transition probability

INTRODUCTION

Internetware, an important software modality at present, is a software entity supported by the technology such as software components. It exists at every node of the Internet in an open and independent way. Any software entity can release in an open environment in some way and interconnects, interworks, cooperates and forms an alliance with other software entities on the cross network to form an internet application software system. Internetware has some characteristics such as being adaptive, cooperative, reactivity, evolutionary and with multi-forms (Yang *et al*., 2008). Internetware is able to fully share and reuse the software resources such as network components and form unified resource platform, computing platform and service platform to provide excellent intelligent service. It will be a trend of the software application to bring a new application model for software development and application under the situation of the open, dynamic and changing Internet. Reliability would be a very important characteristic of internetware on the Internet (Yang *et al*., 2008; Mei *et al*., 2012). Factors such as network transmission, software entities in the system, the connection between the entities and the structure among the entities influence the reliability of internetware, so it is of great significance and application value to study the reliability computation of internetware.

The study of the internetware reliability computation is mainly based on state analysis (Cheung, 1980), path (Lo *et al*., 2005) and test data (Lyu, 2007). The model based on the state analysis shows the architecture of the system through control flow graph and assumes that the control transfer among software modules has the Markov character, that is, the future action of the system is independent from the past action under certain conditions. The model based on path computes the reliability of the software system through all the execution paths and related frequency. The model based on test data does not take the architecture of the software system into consideration but concerns about modeling of the growth of the system reliability and predicts the reliability of the whole system based on the failed data of the components. The testing environment and method will influence the result.

Cheung (1980) and 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. Wang *et al*. (1999) proposed the reliability computation method of the components based on structure which decreased the reliability computation complexity by using the component composition but it did not take the analysis and the acquisition of the structure of Internetware into consideration. Hu and Lu (2006) put forward an analysis of the reliability of component composition orienting to internetware but

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does not mention the practical reliability computation. Yan (2011) realized the evaluation of internetware reliability with monitoring and feedback but it was complex and lack of effective formal models and reliability computation of the system. The above internetware analyses and studies put forward some modeling and computation of the reliability but there are still some deficiencies. The method based on test is difficult to compute the reliability because of the influence of the system movement and test environment and its result is not very accurate. The method based on structure analysis regards the structure and the transition probability as being fixed, which is not accord with the reality. It makes no further study on the acquisition of the structure and the transition probability computation and does not take the influence of the internet into consideration in computation.

This study studies the architecture, connection relation and transition probability of internet ware under network environment. A reliability computing method based on Markov chain is put forward. The corresponding algorithm is designed to realize internetware reliability computation for internetware reliability prediction and assessment.

RELIABILITY MODEL

Internetware is a software system with some functions that software component entities with certain reliability are connected by network.

Definition 1 component: Component is a software entity with certain reliability and function. Components can be connected by interface. The definition of component is C = (F, R, I, D), in which F stands for the set of function provided by the component through interface, R means the component reliability, R:D→(0..1), I is the component interface and protocol specifications and D is the component application mode, D: C×C→F.

Definition 2 component connection: The component connection leads to component interaction. The connection has directivity and reliability. Component connection L_i→j = (LC, $RL_{i\to j}$, LT), in which L_i→j means the connection between c_i and c_j. LC = (c_i, c_j) means the component pairs in the component connection and that after successful execution of component c_i, it executes c_j. $RL_{i\to j}$ refers to the connection reliability when c_i is connected to c_j. $RL_{i\to j}$ and LT stands for the time of connection execution and it is related to the system load and network transmission performance.

Definition 3 internetware: Internetware is the network system software composed of components and component connection on the network. ITW = (C, L, c_i, c_t, p), in which C means the set of components composed of internetware, C = {c_1, c_2,···, c_m} m∈N^+; L stands for the set of connection of component C, L = l1, l_2,···, l_m}, c_i, c_t refers to the first and the last executed components of the internetware; P is the successively executed transition probability among the components, P = (c_i, c_j, $Pt_{i\to j}$) I, j∈ [1, 2,···, m], that is, the probability of executing c_j after c_i.

Definition 4 model of internetware reliability: The reliability of executing from c_i to c_j is R_{ij} = R_{ci}×R_{ci}×$Pt_{i\to j}$×$RL_{i\to j}$, in which R_{ci} is the reliability of c_i; $Pt_{i\to j}$ is the transition probability of executing from c_i to c_j; $Rl_{i\to j}$ is the connection reliability from c_i to c_j.

REALIABILITY COMPUTING

Component reliability: When component is designed, its system structure and condition are well known. Based on component based software system structure, Model UML is automatically transformed to reliability analysis model Markov chain (Liu *et al*., 2010) to compute reliability by using DTMC (Lo *et al*., 2005). Model DTMC is a binary group (S, Q), in which S is a finite state, s = (s_1, s_2,···, s_n); P: S×S→[0, 1] Q is state transition probability, Q = {q_{ij}}, i, j∈ [1, 2,···n].

The reliability of state s_i is η and its transition probability is q_{ij}, then the reliability of s_n is:

$$R_j = \begin{cases} r_i \times q_{ij} & \text{if } c_i \to c_j \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where, $Q^k_{1,n}$ stands for the transition probability of executing K steps from s_1 to s_n and r_n is the reliability of s_n, then the component reliability is:

$$R_c = Q^k_{1,n} \times r_n \quad (2)$$

According to:

$$\lim_{k\to\infty}\sum_{i=0}^{k} Q^i = \sum_{i=0}^{\infty} Q^i = I + Q + Q^2 + ... = (I - Q)^{-1}$$

define the matrix T = $(I\text{-}Q)^{-1}$, then:

$$T = I + Q + Q^2 + \ldots = \sum_{i=0}^{\infty} Q^i \quad (3)$$

Because the determinant of the full-rank matrix is not zero, $|I-Q| \neq 0$:

$$T(1,n) = I(1,n) + Q(1,n) + Q^2(1,n) + Q^3(1,n) + \ldots = \sum_{0}^{\infty} Q^n(1,n)$$
$$= (-1)^{n+1} \frac{|(I-Q)_{n,1}|}{|(I-Q)|}$$

$$T(1,n) = (-1)^{n+1} \frac{|(I-Q)_{n,1}|}{|(I-Q)|} \quad (4)$$

In formula 4, I is characteristic identity matrix, expressed as $I_{n\times n}$ and $(I-Q)_{n,1}$ means deleting the n-line and the 1 column in the matrix (1-Q). The component reliability is:

$$R_c = T(1,n) \times r_n \quad (5)$$

Structure acquisition

Definition 5 internetware structure: Internetware structure S = (C, T, R), in which C means the components set of internetware, T is the type and R is the reliability.

Software program can be realized by three structures, sequence, selection and circulation (Bohm and Jacopini, 1966). It results in the composite component reliability composed of these three structures (Wang *et al*., 1999). Then by using component compound operation, the composite component reliability can be achieved and then it is used in system reliability computation.

Definition 6 composite component reliability operation: Suppose internetware system S is composed of $c_1, c_2, \cdots, c_n$ the component reliability degree is R (c_1), R (c_2),$\cdots$, R (c_n), respectively, then component reliability operation is as follows:

- **Component sequential operation reliability:**

$$R(S) = \prod_{i=1}^{m} R(c_i) \quad (6)$$

- **Component selection operation:** When the probability of component executes is p (c_i), the reliability is:

$$R(S) = \prod_{i=1}^{m} [R(c_i)p(c_i)] \quad (7)$$

- **Component circulation operation:** If the loop body is A∈C in which C is the component unity, A executes t times, then the system reliability is:

$$R(S) = \prod_{i=1}^{t} R(A)$$

if A stops under special conditions, the probability of process control returning to A is P (A) and the stop and jump-out-of-circulation probability is 1-p (A), then the reliability is:

$$R(S) = \frac{(1-p(A))R(A)}{(1-R(A)p(A))} \quad (8)$$

The recognition and extraction of the structural relationship between the internetware components can be achieved by using IP message and the operational principle of internet route (Yu-Xin *et al*., 2010). The information can be transmitted through component interface and it ensures it is the latest information and also reduces computation complexity. Design component interface and connection information, including IP address, name of component, time of component execution, component call relation and so on, then internetware transmits the information interactively through internet connection to obtain the execution and connection relationship of the components and then to get system structure and transference.

Definition 7 connection model of component: Connection model is composed of connection identifier ID, connection identifier LinkName, IP address (source IP and target IP), StartTime, EndTime, precursor, successor, Link = (id, name, start, end, precusor, succeed) ST = $[st_{ij}]$, I, j∈ [1, 2,$\cdots$, m] in which precursor and successor indicate present invocation and being invocated of the connection.

Definition 8 structure relationship matrix: Matrix ST = (st_{ij}), st∈ [sequence, select, loop] shows the call execution relation between c_i and c_j (sequence, selection and circulation).

The main idea of structure extraction algorithm is as follows:

Step 1: Extract blog and obtain connection $link_i$ (i = 1, 2,$\cdots$,n) and the related ID, IP, LinkName, StartTime, EndTime, precursor, succeed of the related information

Step 2: If link. ip.dest = link. ip.sour, then it is invocated among the components (it is not studied in this study); otherwise, go to step 3

Step 3: If $link_i$. Precursor = null, the present node is the root node;

Step 4: if $link_j$. Start>$Link_i$.end & &$link_j$.end>$link_j$ start, then $link_i \rightarrow link_j$, that is, sequential activity, st_{ij} = sequence

Step 5: In sequential activity $link_1 \rightarrow link_2, \rightarrow \cdots \rightarrow link_m$, k, l∈ [1, 2,⋯, m], k≤l, if ∀ $Link_k$.succeed==$Link_j$precusor, then $link_k \rightarrow link_j$, that is, circulation structure, st_{kl} = loop

Step 6: If precursor is the same and only one, $link_i$. precursor = $link_j$. precursor, then precusor→$link_i$+$link_j$, which is precursor's selection structure, st_{kl} = select matrix obtained, system reliability can be computed by

Step 7: Internetware system structure comes into being based on structure relationship.

Transition probability computing: 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:

$$ps_{ij} = t_{ij} / \sum_{k=1}^{n} t_{ik} \qquad (9)$$

Transition probability is p_{ij}, $fp: ps_{ij} \rightarrow p_{ij}$:

$$P_{ij} = k \times ps_{ij} \qquad (10)$$

In formula 10, 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 can not work normally, k = 0.

To sum up, transition probability is revised to be:

$$pt_{ij} = p_{ij} \times RL_{ij} \times R_i \qquad (11)$$

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. Network failure rate λ means the network connection. Suppose it has N times invocation, each time the data bit to be transmitted is Di and network bandwidth is B, then connection reliability is:

$$RL = \prod_{1 \le i \le N} e^{-\lambda(Di/B)} \qquad (12)$$

According to the character of the index in formula 12, 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.

Internetware system reliability computation method: The software system architecture and its transition probability using Markov chain theory. Each state of Markov chain is corresponding to a certain component of Internetware. When it operates to a certain component, the system is in the state of that component. Transition after a certain state is corresponding to the transition among components. When the operation goes from one component to another, there will be the transition from the related state to another state. The impact of network transmission is taken into consideration and then component connection reliability in network environment is computed. Based on this, internetware reliability computing is to be perfected.

The component set of internetware is $C = \{c_1, c_2, \cdots, c_m\}$; component reliability set is $R = \{r_1, r_2, \cdots, r_m\}$.

Component connection reliability is:

$$rl_{ij} = \prod_{1 \le i, j \le m, j \ne i} e^{-\lambda(Dij/B)} \qquad (13)$$

where, D_{ij} is the network bandwidth between component i and component j.

Transition probability is: $pt_{ij} = p_{ij} \times rl_{ij} \times r_i$, in which p_{ij} is computed by formula 11. The matrix of transition probability is:

$$QPT_{ij} = \begin{cases} pt_{ij} & \text{if } c_i \rightarrow c_j, i, j \in [1, m] \\ 0 & \text{otherwise} \end{cases} \qquad (14)$$

System reliability of Internetware is:

$$SRR = (-1)^{m+1} \frac{|(I - QPT)_{m,1}|}{|(I - QPT)|} \times r_m \qquad (15)$$

in which I is characteristic identity matrix.

The key steps of internetware system reliability computation are as follows:

Step 1: Analyze the relationship among component states; compute and obtain component reliability $r_1, r_2, \cdots, r_n$

Step 2: Extract structure relation of internetware component st_{ij}

Step 3: Compute and obtain internetware connection reliability $rl_1, rl_2, \cdots, rl_n$

Step 4: Compute transition probability, then obtain transition matrix Q

Step 5: Compute the system reliability

Because of the influence of the network environment, system reliability will be reduced to some extent.

ILLUSTRATION

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

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

According to Fig. 1 and formula 12, the connection reliability as in Table 1 is obtained.

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

$$\begin{aligned}
Q = (&0\ 0.98*0.9*0.6\ 0.98*0.93*0.1\ 0.98*0.97*0.3\ 0\ 0\ 0\ 0\ 0\ 0;\\
&0\ 0\ 0.99*0.99*0.3\ 0\ 0.99*0.98*0.7\ 0\ 0\ 0\ 0\ 0;\\
&0\ 0\ 0\ 0\ 0\ 0.97*0.99*0.98\ 0\ 0\ 0\ 0;\\
&0\ 0\ 0\ 0\ 0\ 0.98*0.98*0.97\ 0\ 0\ 0\ 0;\\
&0\ 0\ 0\ 0\ 0\ 0\ 0\ 0.95*0.97*0.96\ 0\ 0;\\
&0\ 0\ 0\ 0\ 0\ 0\ 0\ 0.98*0.95*0.97\ 0\ 0;\\
&0\ 0\ 0\ 0.97*0.9*0.2\ 0\ 0\ 0\ 0\ 0.97*0.97*0.8\ 0;\\
&0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0.97*0.98*0.99;\\
&0\ 0\ 0\ 0\ 0\ 0\ 0.97*0.99*0.1\ 0\ 0.98*0.95*0.9;\\
&0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0)
\end{aligned}$$

By formulas 14 and 15, get :

$$(-1)^{m+1}\frac{|(I-QPT)_{m,1}|}{|(I-QPT)|}\bigg|_{m=10} = 0.7223$$

by formula 16, get this internetware system reliability R = 0.7151. If the intluence of the network is not taken into consideration, system reliability is R = 0.8316. This shows that network transmission and component interfaces will affect system reliability.

So, according to extracted structure relation and the computed transition probability, internetware reliability can be accurately computed. Meanwhile, the reliability of connection between network and component will influence internetware system reliability directly and it is accord with internetware qualitative analysis. So, if

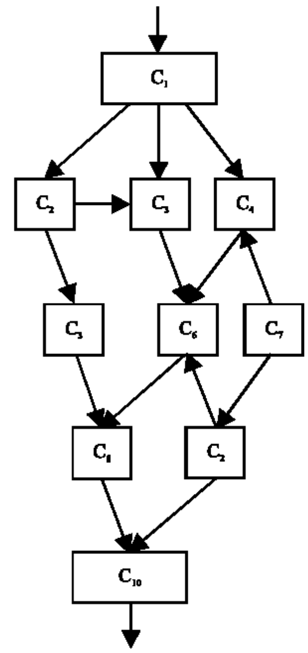

Fig. 1: Structure chart of component connection, C_1, $C_2, \cdots$ and C_{10} represent, respectively component 1, component 2,··· and component 10

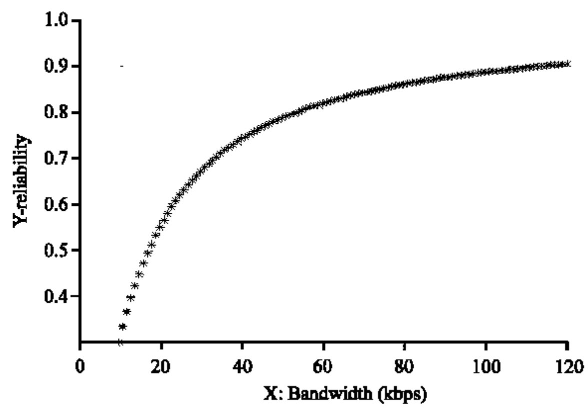

Fig. 2: Component connection reliability with bandwidth increase

Table 1: Parameter list of component connection reliability

Component	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
λ (failure rate of network)	0.055	0.051	0.057	0.052	0.053	0.056	0.052	0.053	0.056
di (average data of transferring a call: 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 (bandwidth of network: kbps)	B12:40 B13:50 B14:100	B23:100	B36:100 B25:100	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)	l12:0.9 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

C_1, C_2… and C_9 represent respectively component 1, component 2, … and component 9

Table 2: Parameter list of component transition probability

Component	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
ri (component reliability)	0.98	0.99	0.97	0.98	0.95	0.98	0.97	0.96	0.97	0.99
pr (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	pr810:0.99 pr79:0.8	pr910:0.9 pr96:0.1	

C_1, C_2… and C_{10} represent respectively component 1, component 2… and component 10

network transmission performance, component interface and connection are to be improved, the internetware reliability can be highly increased.

CONCLUSION AND FUTURE WORK

Internetware operates autonomously on the dynamic and open network. Its reliability is influenced not only by the components themselves but also by the network operation environment, mainly the network performance, component connection, transition probability, etc. Based on the analysis and study of internetware and its reliability, internetware reliability model and the way to compute its reliability have been presented; component connection model and extraction method have been designed to obtain internetware structure relationship; component connection reliability and transition probability computation under network environment have been put forward to get internetware reliability. 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. It will also be valuable to study how system structure, component and network connection reliability influence internetware system reliability in the future.

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REFERENCES

Bohm, C. and G. Jacopini, 1966. Flow diagrams, turing machines and languages with only two formation Commun. ACM, 9: 366-371.

Cheung, R.C., 1980. A user-oriented software reliability model. IEEE Trans. Software Eng., 6: 118-125.

Hu, H.Y. and J. Lu, 2006. Research on reliability analysis of component assembly. Sciencepaper Online, 1: 165-174.

Liu, Y., Z.Y. Ma, X. He and W.Z. Shao, 2010. Approach to transforming UML model to reliability analysis. J. Software, 21: 287-304.

Lo, J.H., C.Y. Huang, I.Y. Chen, S.Y. Kuo and M.R. Lyu, 2005. Reliability assessment and sensitivity analysis of software reliability growth modeling based on software module structure. J. Syst. Software, 76: 3-13.

Lyu, M.R., 2007. Software reliability engineering: A roadmap. Proceedings of the Future of Software Engineering, May 23-25, 2007, Minneapolis, Minnesota, pp: 153-170.

Mei, H., G. Huang and T. Xie, 2012. Internetware: A software paradigm for internet computing. Computer, 45: 26-31.

Wang, W.L., Y. Wu and M.H. Chen, 1999. An architecture-based software reliability. Proceedings of the Pacific Rim International Symposium on Dependable Computing, December 16-17, 1999, Hong Kong, China, pp: 143-150.

Yan, G.L., 2011. Model for tectonic method of reliable internetware based on monitoring. Proceedings of the International Conference on Computer Science and Network, Deceber 24-26, 2011, Beijing, China, pp: 2429-2432.

Yang, F.Q., J. Lu and H. Mei, 2008. Technology system of internetware software: One way of architecture-centric approach. Sci. China (Series E: Inform. Sci.), 38: 818-828.

Yu-Xin, D., Y. Gui-Sheng, W. Ji-Jie, D.H. Bin and Z. Jian-Guo, 2010. A trust evaluation and recommendation algorithm based on internetware. Proceedings of the 3rd IEEE International Conference on Computer Science and Information Technology, July 9-11, 2010, Chengdu, pp: 374-378.