Approach to parametric synthesis of a multiserver system with predefined risk

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Abstract. This paper proposes an approach to parametric synthesis of a multiserver system with a predetermined range of risk non-uniformness. By the type of the risk function of the whole system, and, consequently, the maximum allowable number of damages, analytical expressions for finding risk parameters for components were obtained so that the found overall risk of the system corresponds to the desired type. Some ways of specifying the type for overall system risk are defined, as well as points of extremes, while the number of maximums of the defined function whose graph fluctuates within the unevenness band is to be equal to the number of servers in the system. An algorithm is proposed for epy implementation of synthesis with a predefined level of risk.

[Deshina A.E., Ostapenko A.G., Ostapenko G.A., Ushkin I.A. **Approach to parametric synthesis of a multiserver system with predefined risk.** *Life Sci J* 2014;11(12):390-393] (ISSN:1097-8135). http://www.lifesciencesite.com. 74

Keywords: Risk, damage, multiserver system, parametric synthesis, extreme values

Introduction

A multiserver system is a system of servers built on a multiprocessor platform with distribution of queries for ensuring balanced load on elements. The balancing system constantly monitors load and readiness of each server. A multiserver system is described with load balancing that contains n $(n \geq 2)$ servers. To determine the specific server that a query will be sent to, the load balancer uses specified criteria that involve, in particular, the following current values: CPU and memory usage, the number of open TCP connections and the number of packets received at the interface board of a particular server. CPU load factor and the number of open TCP connections are the most important parameters involved in forming criteria for server selection [1, 2]. In this paper, for a given type of risk function for the whole system, analytical expressions were obtained for determining the limit values of risk parameters for functions of each component. Basing on the coordinates of extreme points, by equalizing the values of defined risk function at these points, and the value of the total risk function of the synthesized system found at the same points, parameters of a multiserver system required for synthesis and risks control are determined. Upon obtaining parameters of the synthesized system, values of system total risk are equalized in extreme points with values of the defined overall risk function at the same points [3-8].

Methods

The method of parametric synthesis of a multiserver system is finding acceptable parameters d_i and λ_i that are maximum permissible values of CPU load rate for a separate component and the number of open TCP ($i = 1(1)n$) connections respectively that define stable operation with a given probability of damage due to system components failure during DDoS attacks of UDP-flood type. In parametric synthesis, the overall risk curve of the system that oscillates in a given band of non-uniformity is analyzed. This method is also applicable in cases where the function of damage probability density is defined not only by the Weibull distribution, but also by other smooth functions of two-parameter distributions.

Main part

Let us now set a problem for a given kind of risk function for the whole system, and, consequently, the maximum allowable range of damages u arising as a result of an attack, finding parameters of components risks multiserver system so that the function of the total system risk fluctuates within the given band of non-uniformness. It is obvious that by controlling the position of the extremes $u_{extreme}$ and risk spread δ_i for each component one can adjust both non-uniformness δ and the band $\Delta\tau$ of overall characteristic. It should be noted that the Weibull distribution has a very real physical meaning and is convenient for control, as it has two degrees of freedom ($\lambda > 0$ - scale parameter and $d > 1$ - shape parameter), independent control of which in case of asynchronous attacks makes it possible to define system overall risk as a sum of risks of components:

$$Risk_{\sum}(u) = \sum_{i=1}^{n} Risk_i(u),$$

where $Risk_i(u)$ is risk assessment made independently for the *i-th* component of the system [7,8].

It has been previously shown that the time of system component failure during DDoS attacks of UDP-flood type is described by a two-parameter Weibull distribution:

$$\varphi_i(t, \lambda_i, d_i) = \lambda_i d_i (\lambda_i t)^{d_i - 1} \cdot \exp\left[-(\lambda_i t)^{d_i}\right], \; i = \overline{1, n},$$

where n is the number of items included into a multiserver system.

Risk of component failure in a multiserver system without discretization interval is defined by the following formula:

$$Risk(\bar{u}) = \bar{u}\,\varphi(\bar{u}),$$

where $\bar{u} = \lambda t$ is the average normalized damage; t is the duration of system denial of service.

Therefore, the risk function for i -th component will be:

$$Risk_i(t, \lambda_i, d_i) = \lambda_i d_i (\lambda_i t)^{d_i} \cdot \exp\left[-(\lambda_i t)^{d_i}\right], \quad (i = 1(1)n).$$

Let us set the value of limit risk $Risk_{\max}$ and coefficient $K < 1$ that define the required non-uniformity δ for the risk of the whole protection system. For a given threshold value of the risk for the whole system $Risk_{threshold}$ and the non-uniformness band $\delta = (1 - K) \cdot Risk_{threshold}$ ($K < 1$), analytical expressions were obtained for parameters of system components that ensure fluctuations of the graph of system risk function in a given band of non-uniformness under the condition of equalizing the maximum values of components risk [9-10].

Suppose now that the required form of the function for the whole system is set, and, consequently, the maximum allowed range of damages, and the graph of this function fluctuates within the given non-uniformness δ. Let us obtain analytical expressions for the parameters of components risk functions so that found overall risk of the system is of desired form.

To find parameters of the synthesized system components, let us first use the iteration method for solving nonlinear systems [10]. To compose equations (1) we will equalize values of the overall risk of the synthesized system in extremes $t_{\max i}$ and $t_{\min j}$ with values of the given function of the overall risk at the same points:

$$\begin{cases} \sum_{i=1}^{n} \lambda_i d_i (\lambda_i t_{\min 1})^{d_i} \cdot \exp\left[-(\lambda_i t_{\min 1})^{d_i}\right] = g(t_{\min 1}); \\ \sum_{i=1}^{n} \lambda_i d_i (\lambda_i t_{\max 1})^{d_i} \cdot \exp\left[-(\lambda_i t_{\max 1})^{d_d}\right] = g(t_{\max 1}); \\ \sum_{i=1}^{n} \lambda_i d_i (\lambda_i t_{\min 2})^{d_i} \cdot \exp\left[-(\lambda_i t_{\min 2})^{d_i}\right] = g(t_{\min 2}); \\ \quad \cdots \\ \sum_{i=1}^{n} \lambda_i d_i (\lambda_i t_{\min k})^{d_i} \cdot \exp\left[-(\lambda_i t_{\min k})^{d_i}\right] = g(t_{\min k}); \\ \sum_{i=1}^{n} \lambda_i d_i (\lambda_i t_{\max l})^{d_i} \cdot \exp\left[-(\lambda_i t_{\max l})^{d_i}\right] = g(t_{\max l}). \end{cases} \quad (1)$$

Due to smoothness of the function of Weibull distribution, we will obtain the desired type of the risk function. From the system (1) we obtain the following system of nonlinear equations for finding parameters of the synthesized multiserver system of the next iteration through their values in the previous iteration:

$$\begin{cases} d_1 = \dfrac{g(t_{\min 1}) - \sum_{i=2}^{n} \lambda_i d_i (\lambda_i t_{\min 1})^{d_i} \cdot \exp\left[-(\lambda_i t_{\min 1})^{d_i}\right]}{\lambda_1 (\lambda_1 t_{\min 1})^{d_1} \cdot \exp\left[-(\lambda_1 t_{\min 1})^{d_1}\right]}; \\ \lambda_1 = \dfrac{g(t_{\max 1}) - \sum_{i=2}^{n} \lambda_i d_i (\lambda_i t_{axn 1})^{d_i} \cdot \exp\left[-(\lambda_i t_{axn 1})^{d_{ii}}\right]}{d_1 (\lambda_1 t_{axn 1})^{d_1} \cdot \exp\left[-(\lambda_1 t_{\max 1})^{d_1}\right]}; \\ \quad \cdots \\ d_n = \dfrac{g(t_{\min k}) - \sum_{i=1}^{n-1} \lambda_i d_i (\lambda_i t_{\min k})^{d_i} \cdot \exp\left[-(\lambda_i t_{\min k})^{d_i}\right]}{\lambda_n (\lambda_n t_{\min k})^{d_{1n}} \cdot \exp\left[-(\lambda_n t_{i \min k})^{d_n}\right]}; \\ \lambda_n = \dfrac{g(t_{\max l}) - \sum_{i=2}^{n-1} \lambda_i d_i (\lambda_i t_{\max l})^{d_i} \cdot \exp\left[-(\lambda_i t_{\max l})^{d_i}\right]}{d_n (\lambda_n t_{\max 1})^{d_{1n}} \cdot \exp\left[-(\lambda_n t_{\max l})^{d_n}\right]}. \end{cases}$$

Thus, we obtain (2) a non-linear system with respect to parameters λ_i and d_i of components of the synthesized system:

$$\begin{cases} d_1^{(k+1)} = \dfrac{g(t_{\min 1}) - \sum_{i=2}^{n} \lambda^{(k)}{}_i d^{(k)}{}_i \left(\lambda^{(k)}{}_i t_{\min 1}\right)^{d^{(k)}{}_i} \cdot \exp\left[-\left(\lambda^{(k)}{}_i t_{\min 1}\right)^{(k)}{}^{d_i}\right]}{\lambda^{(k)}{}_1 \left(\lambda^{(k)}{}_1 t_{\min 1}\right)^{d^{(k)}{}_1} \cdot \exp\left[-\left(\lambda^{(k)}{}_1 t_{\min 1}\right)^{d^{(k)}{}_1}\right]}; \\ \lambda_1^{k+1)} = \dfrac{g(t_{\max 1}) - \sum_{i=2}^{n} \lambda^{(k)}{}_i d^{(k)}{}_i \left(\lambda^{(k)}{}_i t_{axn 1}\right)^{d^{(k)}{}_i} \cdot \exp\left[-\left(\lambda^{(k)}{}_i t_{axn 1}\right)^{d^{(k)}{}_{ii}}\right]}{d^{(k)}{}_1 \left(\lambda^{(k)}{}_1 t_{axn 1}\right)^{d^{(k)}{}_1} \cdot \exp\left[-\left(\lambda^{(k)}{}_1 t_{\max 1}\right)^{d^{(k)}{}_1}\right]}; \\ \quad \cdots \\ d_n^{k+1)} = \dfrac{g(t_{\min k}) - \sum_{i=1}^{n-1} \lambda^{(k)}{}_i d^{(k)}{}_i \left(\lambda^{(k)}{}_i t_{\min k}\right)^{d^{(k)}{}_i} \cdot \exp\left[-\left(\lambda^{(k)}{}_i t_{\min k}\right)^{d^{(k)}{}_i}\right]}{\lambda_n \left(\lambda_n t_{\min k}\right)^{d_{\ln}} \cdot \exp\left[-\left(\lambda_n t_{i \min k}\right)^{d_n}\right]}; \\ \lambda_n^{k+1)} = \dfrac{g(t_{\max l}) - \sum_{i=2}^{n-1} \lambda^{(k)}{}_i d^{(k)}{}_{i\,i} \left(\lambda^{(k)}{}_i t_{\max l}\right)^{d^{(k)}{}_i} \cdot \exp\left[-\left(\lambda^{(k)}{}_i t_{\max l}\right)^{d^{(k)}{}_i}\right]}{d^{(k)}{}_n \left(\lambda^{(k)}{}_n t_{\max 1}\right)^{d^{(k)}{}_{\ln}} \cdot \exp\left[-\left(\lambda^{(k)}{}_n t_{\max l}\right)^{d^{(k)}{}_n}\right]}. \end{cases}$$

(2)

The initial values are preset. Initial values can be the parameters of multiserver system components that had been found before, under the condition of equalizing the maximum values of components risk [3]. If k -*th* approximation $d_i^{(k)}$, $\lambda_i^{(k)}$ is set, then the $(k+1)$-*th* approximation can be found using formulas.

By the smoothness of Weibull probabilities density functions, the iterative method converges to the desired solution. In order to obtain a solution with a required accuracy, it is necessary to continue the process until two successive approximations match this precision. Function $g(t)$ can be set in different ways. For example, using a three-parameter Weibull distribution, one can set the number of oscillations of the required kind of the overall risk function by the number of servers in the system, as well as to obtain the values of extreme points that can be used to define the system (2) and to obtain the values of the component parameters for the synthesized system.

To set function $g(t)$, the Chebyshev approximation of the second kind can also be used. For a system that consists of two elements, the approximating function will be sought in the form of:

$$\tilde{Risk}(t_{\max 1}) = A(t - t_{\min})^4 + B(t - t_{\min})^2 + K \cdot Risk_{threshold},$$

(3)

where A, B are coefficients of the approximating polynomial; tmin is the time when the minimum of the total risk function is reached.

Let us find tp1 and tp2 of the band edge by solving the equation:

$$A(t - t_{\min})^4 + B(t - t_{\min})^2 + K \cdot Risk_{threshold} = K \cdot Risk_{threshold}$$

Now let us find values t_{max1} and t_{max2}, in which the function of the overall risk takes the maximum value equal to *Risk* *threshold*.

To solve this problem, let us find the derivative of function (3) and equate it to zero. As a result we will obtain: $(t - t_{\min})\left[4A(t - t_{\min})^2 + 2B\right] = 0$

Whence we find the minimum of the function at t = tmin and two maximums

$$t_{\max 1} = t_{\min} - \sqrt{-\frac{B}{2A}}, \; t_{\max 2} = t_{\min} + \sqrt{-\frac{B}{2A}}$$

Let us equate the overall risk function and the approximating function

$$\tilde{Risk}(t_{\max 1}) = Risk_{\sum}(t_{\max 1}).$$

From here we obtain value $\lambda_1 = \dfrac{1 + x_{12}}{t_{\min} - \sqrt{-\frac{B}{2A}}}$

The value of the scale parameter λ_2 for the second component of the system can be found from the condition the previously obtained equality of peak values $\lambda_j d_j = \lambda_1 d_1$ [3]. $(j = 2(1)n)$

Discussion

This paper shows how to solve the problem of finding the components risks parameters in a multiserver system so that the function of the total system risk fluctuates within the given band of non-uniformness. By controlling the position of the extremes $t_{extreme}$ and risk spread δ_i for each component, one can adjust both non-uniformness δ and the band $\Delta\tau$ of overall characteristic. It should be noted that the Weibull distribution has a very real physical meaning and is convenient for control, as it has two degrees of freedom ($\lambda > 0$ - scale parameter and - $d > 0(d \in N)$ - shape parameter), independent control of which makes it possible to define the system overall risk as a sum of risks of the components. Weibull distribution is often used to describe patterns of failures during DDoS attacks of UDP-flood type, failures of serial and duplicate elements. Weibull distribution is used especially often when the flow of failures is non-stationary and failure rate varies over time.

Conclusions

A method has been proposed for finding parameters of risk functions for components of a synthesized multiserver system by given parameters of the total risk function and the range of the maximum allowable damage. It has been taken into account that when the required kind of the overall risk of system is set, the number of maximums should be equal to the number of components in the system. Efficiency of the method of equalizing the values of required total risk function at the extreme points with values of the given risk function at the same points has been proven. It is important that the proposed method can not only obtain the necessary parameters of system components that ensure the required form of the total risk function with graph ranging within the band if non-uniformness, but also not to go beyond the predetermined damages range. This method is fairly general and can be applied in cases where the function of probability density is also given by other smooth functions of two-parameter distributions. The use of this methodology made it possible to avoid significant restrictions for parameters of its components that consist of aligning peak values of risks functions that had been actively used in obtaining parameters of system components. The obtained assessments of parameters will make it possible to assess damage from system failure during maintenance and to adopt effective control decisions in order to optimize risks to multiserver systems. The proposed methods make it possible to find parameters of system components risk functions to ensure servers load balancing, and this, in turn, will reduce response time for users; and implementation of innovative projects of distributed nature will promote efficient use of computing resources [2, 5, 6, 8].

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8/1/2014