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Volume 1

Availability Assessment of a Cloud Server System: Comparing Markov and Semi-Markov Models

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***Abstract*—Nowadays Markov Modelling Processes (MMP) found widely use into realm pertaining to availability assessments of diverse complex technical systems and devices. In this regard, Cloud Server Systems (CSSs) are no exception. However, in order to leverage MMPs for the availability evaluation of CSSs the researchers should take into account that this assessment procedure based on the utilization of just one distribution, that is exponential distribution of times to failure, times to repair etc. It is a serious constraint, which would be need preliminary substantiate considering different negative events and impacts. In that regard, to note that some groups of researchers into realm pertaining to CSSs availability are increasingly trying to leverage approaches based on Semi-Markov Modelling Processes (SMMPs). Using SMMPs the researchers can consider more number of parametric characteristics and have a realistic picture as regards change of availability level for the server system. In addition, seeking to improve overall availability of CSSs, the researchers can determine accuracy of numerical modeling results for SMMPs in the so-called borders' states, when Non-Markovian Process transforms at Markovian Process. By considering significance of these aspects, authors of this paper propose to perform mathematical modeling of behavior of a cloud server system based on joint usage of MMPs and SMMPs and get availability assessments considering diverse influence factors on states of the concrete CSS. This information is to be studded and can be used by developers in order to as well as design of the CSSs considering different influence factors.**

Keywords—Cloud Server System; Markov and Semi-Markov Modelling Processes; availabilty assessments

I. INTRODUCTION

In fact, currently contemporary clouds outperformed grid-computing systems considering their scalability, flexibility, efficient usage and support of virtualization features. Accordingly, server systems are essential part of any cloud deployment model. Hence, how to ensure effective functioning of Cloud Server Systems (CSSs) considering impacts of different negative factors is a major complex issue that to be additional studded. It is common knowledge that considerable part of CSSs failures are result of influence of negative external and internal factors. For instance, in accordance with [1] diverse faults and failures of hardware and software components have a devastating on functionality of the CSSs. In this situation, ability to assess real availability level of CSSs has significant role. In order to solve this multifaceted task several researchers prefer to use Markov Modelling Processes (MMPs). However, other researchers should remember that applying for just one stochastic distribution of time random characteristics for the system under study is substantially reduced adequacy of the numerical modeling results. This fact complicates the analysis process of the researches results.

On this basis, the authors propose to extend the modelling row by using Semi-Markov Modelling Processes (SMMPs). In the proposed paper, authors got modeling results to assessment of availability level for a concrete CSS considering failures of its components based on the use of MMPs and SMMPs. This paper consists of five sections. The most interesting works, which reflect certain key features of the MMPs and SMMPs, are depicted in Section II. Main provisions regarding MMPs and SMMPs are considered in Section III. Comparative analysis of numerical modelling results for Markov models and Semi-Markov availability models of the cloud server system is considered in Section IV. Conclusions and future steps are outlined in Section V.

II. RELATED WORKS

In real life, some cloud service providers prefer to use servers of single type. Therefore, so it makes sense to perform analysis of well-known models for a concrete cloud server system. Authors propose to consider solution of this task using basic apparatus of MMPs and SMMPs.

As demand rises for service-oriented applications, Cloud Service Providers (CSPs) must ensure high availability and dependability of CSSs. One such tasks, the researchers are regarded in [2]. The researchers obtained availability estimations for an application server applying hierarchical Markov reward modeling techniques [3]. Another direction of CSPs activity is devoted to create smart services based on Internet of Things (IoT). Toward this end, some researchers develop IoT behavior models using different stochastic techniques. For instance, in [4] researchers leveraged suitable queueing models and Markovian Arrival Process, when modeled different negative events, when studied influence of different negative events on the IoT devices.

In the last years, developers try to design CSSs for fog-nodes considering fault-tolerance principles. The Continuous Time Markov Chains (CTMCs) [5] have been employed by them in order to estimate steady-state probabilities and implement fault-tolerance service strategies for the fog-nodes. The next paper [6] is dedicated to a methodology in order to design of clouds infrastructure with optimization procedure of virtual machines placement. The proposed methodology is developed based on models, which implemented in a concrete algorithm. On the other hand, a hierarchical heterogeneous approach based on MMPs to availability assessments of different cloud environment was suggested by authors in [7]. They also conducted a comparative analysis of private and public cloud architectures considering their cost policy.

Meanwhile, the following group of scientists developed a toolkit, which uses to receive performance and dependability assessments for complex technical systems based on known techniques, such as Reliability Block Diagrams, Fault Trees, Stochastic Petri Nets, including usage of the CTMCs and Discrete Time Markov Chains. The developed toolkit is submitted by them in the scientific paper [8]. One must admit that availability models based on MMPs are losing assess positions due to their restricts to use other stochastic distributions, which are different from exponential distribution. From these arguments, one may conclude that it expedient to use the SMMPs, since they allow considering different types of stochastic distributions for different technical and temporal parameters of components of the separate CSS.

It is a well known that robust defense system must curbs attempts of the cyber-attacks on physical and virtual resources of a cloud infrastructure, which contains CSSs of the same type. This issue can be solved by developers if they utilize cyberprotection devices and applications with previous assess of effectiveness of the defense system based on numerical modeling results. In this case, advantages of the availability models for CSSs based on the use of SMMPs are obviously. Comparative analysis of MMPs and SMMPs with demonstration of advantages of the use Non-Markovian approach for development of diverse dependability and availability mathematical models of the CTSs was outlined by author in [9]. This scientific work is really one of the best research is devoted to development methodology of different types of Semi-Markov dependability and availability models for CTSs.

It is noticeable that using SMMPs the researchers can develop greater numbers of new variants of assurance of availability of the CSSs. For instance, in [10] authors have considered Semi-Markov availability model of Infrastructure as a Service Cloud (IaaS Cloud) considering its overall architecture, which included some pools of physical and virtual machines. Therefore, how to employ MMPs and SMMPs in order to estimate availability level of the separate cloud server system, which forms the basis of the concrete IaaS Cloud is a significant issue that to be investigated.

III. Main Provisions of Markov and Semi-Markov Modelling Processes for Availability Assessments of CSS

In view of the above mentioned, Fig. 1 shows the role and place of the CSS in a typical cloud computing system [1]. Let us try to perform comparative analysis of possibilities for utilization of both Markovian model and Semi-Markovian model in order to estimate overall availability level of the CSS.

According to overall framework for building of the availability model based on MMPs [3], on the first phase researchers build a finite graph. The finite graph of this availability model is shown on Fig. 2. Solution of the task in order to determine availability assessment for the CSS is described in [1]. There is stochastic model, which can present as a CTMC with five states. Theoretical base for solution of this CTMC is provisions that set out in [9]. In fact, the researcher has considered solution for this CTMC using an approach for determination of limit probabilities. These limit probabilities can be determined as the following [9]:

$$\lim_{t\to\infty} p_j(t) = \lim_{t\to\infty} p_{ij}(t) = p_j, \;\; j \in S. \qquad (1)$$

Using the mathematical expression (1) with countable state space $S = \{0,1,2,3,4\}$ the linear equations [9] can be written as

$$\sum_{i\in S} p_i \lambda_{ij} = 0, \;\; j \in S. \qquad (2)$$

In [1] the author has solved the system of linear equations (2) considering the mathematical expression (1). As a result, the availability assessment for the CSS was determined 0.9910. The obtaining result characterizes availability level of the CSS, when time to failure and time to repair are exponential distributed random values. At the same time, this numerical Markovian modeling result can be deemed by researchers as the steady-state availability assessment of the CSS. The authors of this scientific paper will be further adhere and contemplate the provision as a true and robust. Let us now take up the Semi-Markov availability model of the CSS.

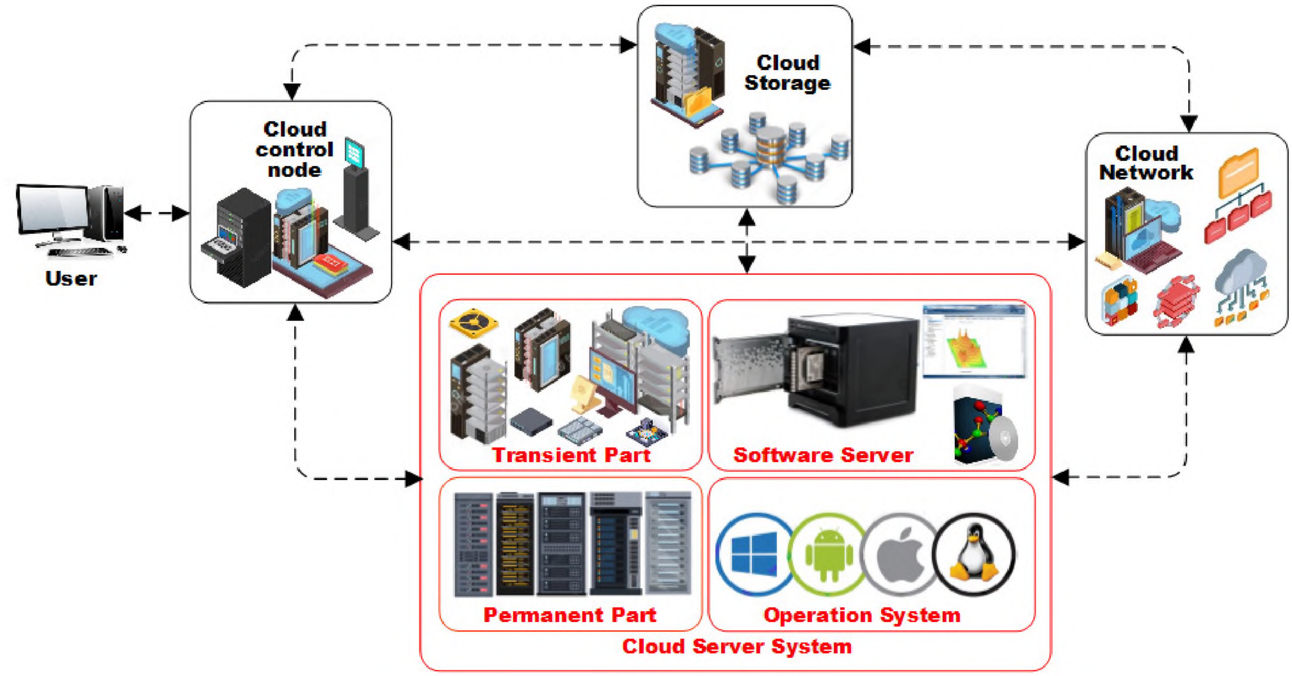

Figure 1. A typical cloud computing system [1]

The researchers can use the SMMPs in order to build availability models of a separate cloud server system at situation, when its overall dependability level deteriorates due to increasing rapidly of failure rate of the systems' components, it should be remembered. Accordingly, seeking to improve the approach for determination of the availability assessments based on SMMPs would be useful consider and analyze some concrete situations, when time's characteristics of the model are having by different stochastic distributions. If slicked to SMMPs theory than researchers would be able to examine situations based on modeling results of the cloud service system behavior considering stochastic diverseness of its availability assuring processes. Two situations, pertaining to failures and repairs of the CSS components have been contemplated by authors of this paper.

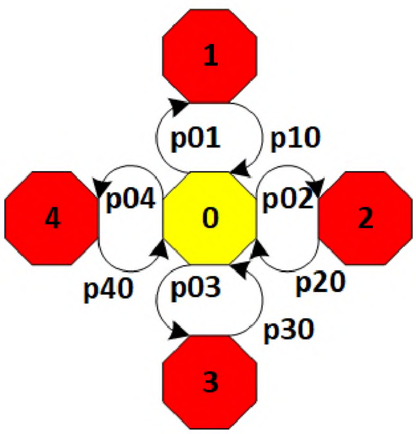

Figure 2. Finite graph of the availability model

In practical sense, the paper [11] is interesting, since it demonstrates how simulation modeling process may be employed in order to identify hidden faults of digital components of the CSS. The finite graph that describes on Fig. 2 was been utilized by authors for implementation of planning Semi-Markov availability model. In order to simplify the modeling process understanding, the suggested finite graph (Fig. 2) was as well as added by relevant transition probabilities p_{ij} , which describe failures and recoveries of the CSS components. The authors propose to focus on most characteristic negative events that need to consider and analyze. In particular, growing number of failures of a separate system's component and second situation, when repair time is a deterministic or non-exponential distributed value.

Doubtless, the researchers usually treat Markov Modeling Process as a special case of the SMMP [9]. Therefore, the proposed Semi-Markov availability model can be received by us in a similar way, applying described the finite graph (Fig. 2) and assumptions for Markov model, which leveraged in [1]. Suppose that set of possible states $S=\{0,1,2,3,4\}$ for this model specifies as the following: 1) S_0 – the CSS system is in up state, i.e. available; 2) S_1 – the CSS system is in down state, i.e. unavailable due to failure of systems' permanent part (PP); 3) S_2 – the CSS system is in down state, i.e. unavailable due to failure of operation system (OS); 4) S_3 – the CSS system is in down state, i.e. unavailable due to failure of a software server (SS); 5)

S_4 – the CSS system is in down state, i.e. unavailable due to failure of systems' transient part (TP).

As already mentioned, the authors proposals have been directed for consideration of two situations, related with modeling behavior of the CSS using SMMPs techniques. In accordance with first situation, the Semi-Markovian modeling behavior process for the CSS has been considered by authors for dynamic in nature of transient probabilities changes, i.e. transient probabilities are estimated during the time no more than $t \in [0,T]$. The transient probabilities matrix can be written as

$$P = \left[p_{ij}\right] = \begin{bmatrix} 0 & p_{01} & p_{02} & p_{03} & p_{04} \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix}. \quad (3)$$

The elements of the transient probabilities matrix (3) are given by:

$$p_{ij} = P_{ij}(t) = \int_0^t \prod_{\ell \neq j} \left(1 - Q_{i\ell}(u)\right) dQ_{ij}(u). \quad (4)$$

According to [10] in the equation (4) cumulative distribution function (CDF) [3] of failures $Q_{ij}(t)$, which outlines a transition from S_i to S_j can written as

$$Q_{ij}(t) = 1 - e^{-\lambda_i t} = Exp(\lambda_i), \quad (5)$$

where λ_i – failure rates of the CSS components (Fig.1).

Then, the equation for CDF of repair time [3, 10] of the CSS components that describes another transition from S_j to S_i is given by

$$Q_{ji}(t) = 1 - \left(1 + \mu_j t\right) e^{-\mu_j t} = Erlang\left(2, \mu_j\right), \quad (6)$$

where μ_j – repair rates of the CSS components (Fig.1).

Figure 3 is shown modeling results for the transient probabilities p_{ij} utilizing equations (3)–(6).

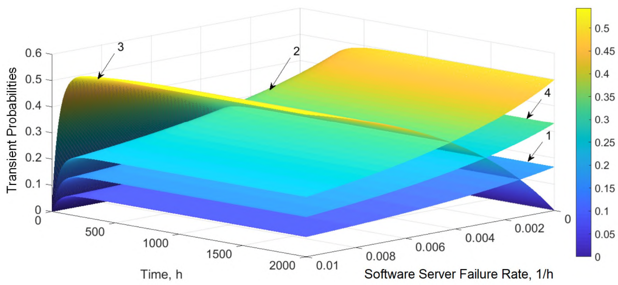

Figure 3. Modeling results for the transient probabilities: 1 – for p_{01}; 2 – for p_{02}; 3 – for p_{03}; 4 – for p_{04}

Further, the authors found overall solution for the embedded Markov chain [3, 12]. In fact, they solved equations' system form $v = vP$. The solution can written as

$$v_0 = \frac{1}{1 + p_{01} + p_{02} + p_{03} + p_{04}}, \; v_1 = p_{01} v_0,$$

$$v_2 = p_{02} v_0, \; v_3 = p_{03} v_0, \; v_4 = p_{04} v_0.$$

Next two important characteristics such as, sojourn time distribution $H_i(t)$ and mean sojourn time h_i at state i have been determined by authors according to main provisions for the SMMPs that explained in [12]. Hence, the steady-state availability of CSS for relevant vector $\pi = \{\pi_0, \pi_1, \pi_2, \pi_3, \pi_4\}$ is given by:

$$A_{CSS} = \frac{h_0}{h_0 + \frac{2}{\mu_1} + \frac{2}{\mu_2} + \frac{2}{\mu_3} + \frac{2}{\mu_4}}. \quad (7)$$

The second situation, related with modeling behavior of the CSS using SMMPs techniques, including numerical modeling results are presented in next section.

IV. Numerical Modeling Results for Availability Assessments of CSS

Unlike first situation, the second situation is described behavior of the CSS, when failure rate of a separate component of the system rapidly increases. Assume that failure rate of the software server (Fig. 1) is dramatically increasing. The relevant Semi-Markov process has been considered by authors for steady-state in nature of transient probabilities changes. In this case, the elements of the transient probabilities matrix (3) can be written as

$$p_{ij} = P_{ij}(\infty) = \int_0^\infty \prod_{\ell \neq j} \left(1 - Q_{i\ell}(u)\right) dQ_{ij}(u). \quad (7)$$

In accordance with second situation and equation (7), the expression for CDF that considers the dramatic increase in their number of the software server's failures is given by

$$Q_{03}(t) = 1 - e^{-(t/\beta_3)^{\alpha_3}} = Weibull\left(\alpha_3, \beta_3\right), \quad (8)$$

where $\lambda_3 = 1/\beta_3$ – failure rate of the software server.

The proposed Semi-Markov availability model of the CSS has been implemented by authors considering equations (7), (8). This SMMP has been performed based on assumptions, which already deemed. The equations (6), (7) have been also used in order to get need availability assessments for the CSS system, it should be noted. Let us examine numerical modeling results considering dynamic changes of the availability assessments that need to receive. It is within this connection, as an initial data the authors leveraged failures and repairs parameters that described in [1].

The real numerical data of these parameters for relevant familiar availability model [1] are mentioned in Table 1.

TABLE I. NUMERICAL VALUES OF MODELING PARAMETERS

Parameters	Value (1/hour)	Parameters	Value (1/hour)
$\lambda_{P.P}$	0,0014	$\mu_{P.P}$	0,1667
λ_{OS}	0,0042	μ_{OS}	12
$\lambda_{S.S}$	0,...,0,01	$\mu_{S.S}$	20,…,70
$\lambda_{T.P}$	0,0028	$\mu_{T.P}$	30

The authors performed modeling of behavior for the CSS system for above mentioned input data considering three familiar approaches. Basically, they got assessments for three approaches based on the use of Reliability Block Diagram (RBD) method [13–15], methods in order to build availability models based on Markov Modeling Processes and Semi-Markov Modeling Processes.

Accordingly Fig. 4 and Fig. 5 are shown availability assessments and comparative availability assessments based on MMPs and SMMPs for first situation considering failures of software server of the CSS system.

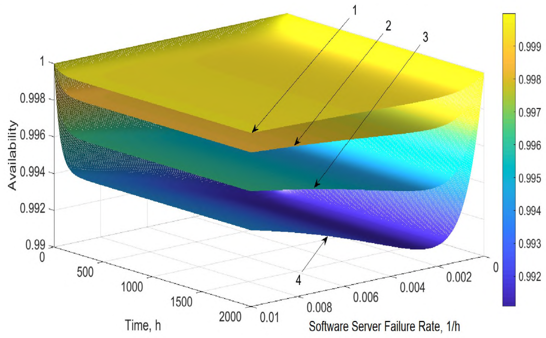

Figure 4. Availability assessments for first situation: 1 – for *Erlang(11,μ_j)*; 2 – for *Erlang(7,μ_j)*; 3 – for *Erlang(3,μ_j)*; 4 – for *Erlang(1,μ_j)*

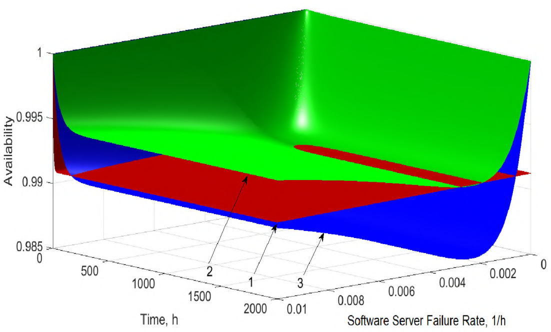

Figure 5. Comparative availability assessments for MMPs and SMMPs: 1 – for MMPs; 2 – for SMMPs with CDF *Erlang(18,μ_j)*; 3 – for SMMPs with CDF *Erlang(11,μ_j)*

Reliability Block Diagram of the CSS is presented in Fig. 6. Fig. 7 proves that numerical modeling results based on the use of RBD method, MMPs [16–18] and SMMPs [19] for values of some concrete parameters may be not differ substantially.

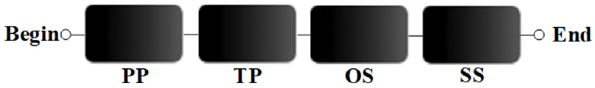

Figure 6. RBD of the cloud server system

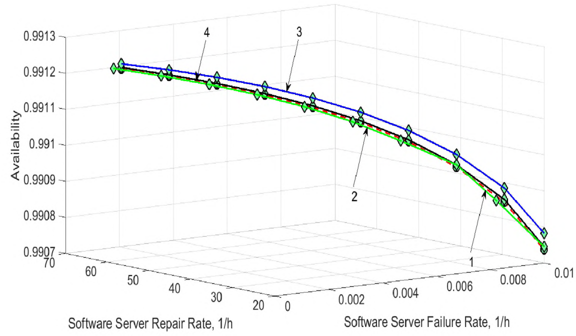

Figure 4. Availability assessments for second situation: 1 – for RBD method; 2 – for SMM method with CDF *Exp(λ_i)*; 3 – for SMM method with CDF *Weibull(1,5,β_3*; 4 – for Markovian method

Fig. 7 is shown comparative availability assessments of the MMPs and SMMPs for second situation. The received modeling results (Fig. 7) are testified to the fact that availability assessments based on MMPs and SMMPs are associated and can be employed developers of the CSSs in order to create effective functioning systems considering dependability facets.

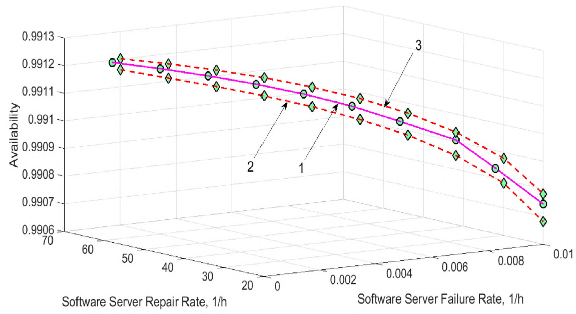

Figure 7. Comparative availability assessments for MMPs and SMMPs: 1 – for MMPs; 2 – for SMMPs with CDF *Weibull(0,5,β_3)*; 3 – for SMMPs with CDF *Weibull(1,5,β_3)*

These numerical modelling results are essential, since can be used by developers and service personnel of the CSS systems in order to describe dynamic of degradation of them availability level on different design and functioning phases considering impact facets of diverse inception.

V. Conclusions and Future Steps

In this scientific paper authors tried to focus on reviewing of two types of famous modelling processes for availability assess of a concrete cloud server system that plays important role in meeting operational functioning tasks for a cloud infrastructure. In particular, the authors propose to consider most commonly used Markov Modelling Processes and Semi-Markov Modelling Processes. Authors of this paper don't also urge other researchers to end the use of just one type of the stochastic distribution and try to apply other multi-parametric distributions. At the same time, the researchers should remember that usage of just one exponential distribution in order to describe functioning process of different components of the cloud computing systems, which work in diverse functional and virtual modes is a serious restricting assumption that need to preliminary substantiate. Meanwhile, the numerical modeling results based on the use of different distributions would be the best proof of this proposal. In the context of the proposed paper, the authors can appear their position regarding availability assess of the cloud server system as the following: 'if researchers wanted to make a deep availability analysis of the cloud server system based on modeling results of its behavior considering influence of failures of different systems' components and facets of DevOps Engineering for this system they would be able to use both the proposed Semi-Markov models and familiar Reliability Block Diagram assessments, including Markovian modeling results.'

The proposal to leverage Semi-Markov availability models is based on the assumption of Non-Markovian Property true for different time characteristics distributions of the cloud server system. These modelling resultas can ba used by scientists in order to advance some provisions of DevOps engineering.

In fact, the authors have been considered the concrete types of mathematical availability models for the cloud server system exclusively based on the use Markov Modelling Processes and Semi-Markov Modelling Processes. In the near future time, of course the authors will additional investigate in order to get more modeling results about behavior of the cloud server system utilizing others types of models.

As an important result, note that different researchers as well may utilize this comparative analysis in order to design the improved cloud server systems

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