A Fluctuation-Based Modelling Approach to Quantification of the Technical Debt on Mobile Cloud-Based Service Level

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Abstract—**Enterprise mobility has become a top technology priority for companies over recent years and many organizations are accelerating the adoption of mobile cloud application models. The mobile cloud can be considered as a marketplace, where the mobile services of the mobile cloud-based system architectures can be leased off via the cloud. In this context, this paper elaborates on a novel fluctuation-based quantification model, which is based on a cost-benefit appraisal, adopting a non-linear and asymmetric approach. The proposed model aims to predict the incurrence and the risk of entering into a new technical debt (TD) in the future and provide insights to inform effective investment decision making. The lease of a cloud-based mobile service was considered, when developing the formula, and the research approach is investigated with respect to the cost that derives from the unused capacity. The probability of overutilization or underutilization of the selected service is examined, as fluctuations in the number of users are forecasted. A quantification tool has been also developed as a proof of concept, implementing the proposed model and intending to quantify and evaluate the technical debt on mobile cloud-based service level, when fluctuations in the demand occur.**

Keywords—fluctuation-based modelling; non-linearity; technical debt quantification; technical debt evaluation; mobile cloud-based service level selection; lease web services

I. Introduction

The ongoing developments in mobile technologies, coupled with the advances in cloud services, have introduced the mobile cloud computing (MCC) technology [1]–[3]. Many organizations are turning to mobile cloud-based solutions to enhance productivity and enable new business models. In this context, the lease of cloud-supported mobile services is examined due to reduced costs, compared to building mobile applications from the scratch, by simultaneously ensuring the Quality of Service (QoS) and Quality of Experience (QoE). However, the mobile cloud-based service selection may introduce technical debt, which is essential to be predicted, quantified and managed promptly. Capturing the technical debt data enables enterprises to make accurate information technology (IT) investments, in terms of selecting the appropriate cloud-based mobile solutions, and identify the best practices for their implementation, by transforming these data into predictive strategic asset, which can have a significant impact on increasing the return on investment (ROI) in the long run. The mobile cloud-based service-oriented architectures are composed of web services. In mobile cloud marketplaces [4], [5], the web services of the mobile cloud-based system architectures can be leased off [6]. Such web services can be discriminated with respect to the non-functional requirements or the maximum number of users supported. In this work, the need for estimating the technical debt on mobile cloud-based service level is motivated when fluctuations in the demand are forecasted. The prediction and measurement of the technical debt contribute to effective investment decision making and payback strategies [7].

In this context, this research work is making progress beyond the current state-of-the-art, by contributing to a novel fluctuation-based quantification model, which aims to predict the incurrence of the technical debt on mobile cloud-based service level and the risk of entering into a new one in the future. The model formulation is based on the lease of a web service under the assumption of fluctuations in the number of users, adopting a non-linear and asymmetric approach. The size of the technical debt is explicitly affected by the service capacity and the need to abandon the selected service and switch to a more flexible capacity service in the market from the same or different mobile cloud services provider is investigated. The performance evaluation analysis indicates that a sheer increase in the number of users motivates the abandoning/termination and switch to a more flexible capacity service, resulting in the incurrence of accumulated technical debt and any positive technical debt to be further incurred can be hardly measured.

Following this introductory section, the reminder of this paper is organized as follows: Section II presents related research efforts and the research gap that motivates the need for quantifying the technical debt on mobile cloud-based service level, when fluctuations in the demand occur. Section III proposes the novel model, while Section IV provides a performance evaluation analysis for two different case scenarios. Section V concludes this work, highlighting directions for future research.

II. Related Work And Research Motivation

The technical debt metaphor [8] points out the correlation between the software development process and the financial debt and indicates the acceleration of the velocity for releasing software products, leading to implications and additional cost [9]. The technical debt has been described in different domains, such as code, testing, documentation, configuration or defect debt [10], while the authors in [11] notify that the measurement of the technical debt is critical. A proof in this respect is the fact that the flexibility of the software is increased once the source code is more readable [12], the poor design is improved or refactoring of the bugs occurs [9]. Marinescu in [13] proposes a novel framework for evaluating the technical debt using a technique for detecting design flaws. Paying interest on various forms of technical debt has been also met at Google [14]. In this context, there have been previous related work approaches on the technical debt, focusing on the financial aspect and explaining the relation to the underlying software engineering concepts [15]. The lifecycle and the business pressures might affect the size of the technical debt, while the lack of experience of the software development team, poor processes or the non-systematic verification of the software product quality might generate technical debt [16]. The improvements in the fields of interaction design and general software design principles are necessary to minimize the risk of entering into technical debt [17], whereas the authors in [18] discuss issues related to the improvement of the quality of the software architecture by managing promptly the technical debt during modelling. Furthermore, Nugroho et al. in [19] adopt a quantification approach associated with debts and interest and the evaluation results reveal insights, which may lead to better IT investment decisions, such as the ROI in software quality improvement. An architecture and measurement-based perspective is researched in [20], as the need for establishing a metric to manage effectively the technical debt when delivering a product, is motivated. Additionally, an economics-driven approach in cloud-based architectures is discussed in [21], while a critical evaluation using real options is performed in [22].

Although there have been previous research efforts from different viewpoints, a research gap for measuring the technical debt on mobile cloud-based service level is witnessed and, more specifically, when fluctuations in the number of users occur; therefore, the need for predicting it, is imperative. Authors in [23] contribute to a new concept at the cloud service level using real options, arguing that the web service selection decision might incur technical debt that is essential to be managed. Skourletopoulos et al. in [24] present two novel models for predicting and quantifying the technical debt on cloud service level respectively, along with extended evaluation results for discussion [25]. In this research work, the proposed quantification model is exploited, incorporating specific parameters that apply to the mobile cloud computing paradigm under the assumption that fluctuations in the demand occur.

III. Research Approach

The proposed model aims to predict, estimate and quantify the technical debt when leasing cloud-supported mobile services under the assumption that fluctuations in the demand occur. The hypothesis is that the service selection decision is affected by the service capacity and it is made with respect to the predicted fluctuations in the number of users (i.e. a non-linear and asymmetric approach is adopted) over the period of λ-years and the way the technical debt is gradually paid off. The model formulation is based on a cost-benefit analysis, measuring the amount of profit not earned due to the underutilization of a given service and considering the probability of overutilization of the selected service that would lead to accumulated technical debt. Any candidate service to be leased off is evaluated with respect to the following assumptions and statements:

- Any candidate cloud-supported mobile service is subscription-based and there are charges for servicing a user in the mobile cloud. The pricing and billing schemes vary over the period of λ-years due to the fluctuations in the demand.
- Fluctuations in the number of users are forecasted over the period of λ-years, affecting the total cost for servicing a user in the mobile cloud in order to ensure the QoS and QoE. Elasticity is considered as the cost variations that emanate from the annual variation in the demand are composed of document and data storage, technical support, maintenance services, network bandwidth and server costs.
- The flexibility of a mobile service entails its adaptability to meet evolving market needs, such as the fluctuations in the number of users.
- The cloud-based, always-on mobile services are usually sensitive to network bandwidth and latency. Therefore, the additional network bandwidth cost, which originates from a potential increase in the number of users, is expected to satisfy the outbound network traffic demands

in order to avoid delays. In addition, the overall additional server cost includes those costs that derive from the additional CPU cores and the amount of memory required for processing.

- The offered web services have comparable functional requirements, while the non-functional ones can be either comparable or not; however, the cloud-based mobile services are differentiated with respect to the capacity in terms of the maximum number of users that can be supported.

Two possible types of technical debt are encountered, when selecting the appropriate cloud-based mobile service to lease:

- Positive technical debt: It reveals the underutilization of the service and the probability to satisfy a possible future increase in the number of users against the unused capacity.
- Negative technical debt: It points out the overutilization of the service and, hence, possible SLA violations. The need to abandon/terminate the existing one and switch to a more flexible service is imperative in terms of capacity, QoS and QoE.

The modelling phase examines the lease of a cloud-supported mobile service under the assumption that fluctuations in the number of users occur. Hence, the modelling for quantifying the technical debt during the first year (i.e. equation 1) and from the second and onwards respectively (i.e. equation 2), takes the following form and a description for each abbreviation is presented thoroughly in Table 1 below:

$$TD_1 = 12 * \left[ppm * (U_{max} - U_{curr}) - Cu_{/m} * (U_{max} - U_{curr})\right] = 12 * (U_{max} - U_{curr}) * \left(ppm - Cu_{/m}\right) \quad (1)$$

$$TD_i = 12 * \{K_{i-2} * [U_{max} - L_{i-2}] - M_{i-2} * [U_{max} - L_{i-2}]\} = 12 * (U_{max} - L_{i-2}) * (K_{i-2} - M_{i-2}), \ i > 1 \quad (2)$$

where, $$K_0 = (1 + \Delta_1\%) * ppm$$

$$K_i = K_{i-1} * (1 + \Delta_{i+1}\%), i > 0$$

$$L_0 = (1 + \beta_1\%) * U_{curr}$$

$$L_i = L_{i-1} * (1 + \beta_{i+1}\%), i > 0$$

$$M_0 = (1 + VoC_1\%) * Cu_{/m}$$

$$M_i = M_{i-1} * (1 + VoC_{i+1}\%), i > 0$$

$$VoC_i\% = a_i\% + \gamma_i\% + \theta_i\% + \mu_i\% + \sigma_i\% + \eta_i\%, i > 0$$

Table 1. ABBREVIATIONS AND PARAMETER DESCRIPTION.

Abbreviations	Parameter Description
TD	The technical debt calculation result represented in monetary units.
i	The index of the year.
U_{max}	The maximum number of users that can be supported.
K_0	The new subscription price formation regarding the second year of the period of λ-years, once the corresponding variation in the monthly subscription price is applied (represented in monetary units).
$\Delta_1\%$	The variation in the monthly subscription price regarding the second year of the period of λ-years, which is represented as percentage.
ppm	The initial monthly subscription price represented in monetary units.
K_i	The new subscription price formation from the third year until the end of the period of λ-years, once the corresponding variation in the monthly subscription price is applied (represented in monetary units).
$\Delta_i\%$	The variation in the monthly subscription price from the third year until the end of the period of λ-years, which is represented as percentage.
L_0	The number of users that is formed during the second year of the period of λ-years, once the corresponding variation in the demand is applied.
$\beta_1\%$	The variation in the number of users regarding the second year of the period of λ-years represented as percentage.
U_{curr}	The initial number of users.
L_i	The number of users that is formed from the third year until the end of the period of λ-years, once the corresponding variation in the demand is applied.
$\beta_i\%$	The variation in the number of users from the third year until the end of the period of λ-years, which is represented as percentage.
M_0	The cost formation for servicing a user in the mobile cloud regarding the second year of the period of λ-years, once the corresponding variation in the monthly cost is applied (represented in monetary units).
$VoC_1\%$	The total variation regarding the cost for servicing a user in the mobile cloud for the second year of the period of λ-years, which is represented as percentage.
$Cu_{/m}$	The initial monthly cost for servicing a user in the mobile cloud represented in monetary units.
M_i	The cost formation for servicing a user in the mobile cloud from the third year until the end of the period of λ-years, once the corresponding variation in the monthly cost is applied (represented in monetary units).
$VoC_i\%$	The total variation regarding the cost for servicing a user in the mobile cloud from the third year until the end of the period of λ-years, which is represented as percentage.
$\alpha_i\%$	The variation in the monthly document storage cost represented as percentage.
$\gamma_i\%$	The variation in the monthly data storage cost represented as percentage.
$\theta_i\%$	The variation in the monthly technical support cost represented as percentage.
$\mu_i\%$	The variation in the monthly maintenance services cost represented as percentage.
$\sigma_i\%$	The variation in the monthly network bandwidth cost represented as percentage.
$\eta_i\%$	The variation in the monthly server cost represented as percentage.

IV. Performance Evaluation Analysis, Experimental Results And Discussion

This research work contributes to a novel quantification model that supports the prediction of the technical debt on mobile cloud-based service level from the service capacity perspective and under the assumption that fluctuations in the number of users occur. From the research viewpoint, a quantification perspective of the technical debt is adopted when leasing a web service and a complex model is proposed. The model is characterized by extensibility as more parameters can be added, indicating how customizable the formula is. The level of comprehension of the model formulation depends on the expertise of the user. Furthermore, a quantification tool has been developed as a proof of concept (PoC), which implements the proposed formulas (1) and (2), intending to quantify and forecast the technical debt on mobile cloud-based service level. From the technical point of view, the web application is targeted to be deployed in the Google Cloud Platform supported by the Google App Engine and it was implemented using the Java programming language. The tool emphasizes on shedding light on the technical debt on the mobile cloud-based service level from the service capacity perspective. Likewise, the calculations are significant in order to understand the progress of different case scenarios and notify if the variation in the number of users can risk the incurrence of accumulated technical debt in the future; such a situation may lead to implications, such as the options of abandoning/termination and switching, and a new accumulated technical debt hard to be measured. Therefore, the technical debt data provide insights about the underutilization or overutilization of a web service in the long term, the gradual payoff of the technical debt and the time that will be totally cleared out.

An indicative and illustrative example of the evaluation that was performed, emphasizes on the need to lease a cloud-supported mobile service, which is intended to be integrated into the existing IT systems. A business-to-consumer (B2C) web service will enable improved customer service as it enriches the retail experience and boosts customer loyalty. Throughout the evaluation stage, a 5-year technical debt prediction (λ = 5) has been examined prior to adoption of the mobile cloud application model, enabling to do a what-if analysis on different case scenarios, web services and lease options. Insights about the ROI and the time the technical debt will be totally paid off are also provided. The following three mobile services are offered by the same provider and they are investigated with respect to their different features:

- Corporate Service (C): It is a high-capacity service as the maximum number of active users that can be supported is 18,000. The service is considered better than the Premium and Basic ones in terms of QoS, QoE and non-functional requirements, elaborating on the high-priced strategy that is adopted as the estimated monthly cost for servicing a user in the mobile cloud is high. The variations in the monthly cost due to the fluctuations in the number of users, such as the network bandwidth or server costs, are different from services that have lower quality and smaller capacity.
- Premium Service (P): It is a medium-capacity service as the maximum number of active users that can be supported is 11,000. This service is better than Basic in terms of QoS, QoE and non-functional requirements.
- Basic Service (B): It is a low-capacity service as the maximum number of users that can be supported is 5,000.

The technical debt estimates are made over the 5-year period of time for two different case scenarios. The probability of underutilization or overutilization of any of the three services is examined. The assumption is based on the fact that fluctuations in the number of users occur with the adopted variations regarding the case scenarios to be presented in Tables 2 and 3.

Table 2. DESCRIPTION OF CASE SCENARIO 1.

Term	Variation in the Demand
Year 1 to 2	$\beta_1\% = 12\%$
Year 2 to 3	$\beta_2\% = 40\%$
Year 3 to 4	$\beta_3\% = -18\%$
Year 4 to 5	$\beta_4\% = 35\%$

Table 3. DESCRIPTION OF CASE SCENARIO 2.

Term	Variation in the Demand
Year 1 to 2	$\beta_1\% = 20\%$
Year 2 to 3	$\beta_2\% = -10\%$
Year 3 to 4	$\beta_3\% = 60\%$
Year 4 to 5	$\beta_4\% = 65\%$

Towards a better understanding of the technical debt quantification, the calculations for the first two years would take the following form:

$$TD_1 = 12 * \left[ppm * (U_{max} - U_{curr}) - Cu_{/m} * (U_{max} - U_{curr})\right] = 12 * (U_{max} - U_{curr}) * \left(ppm - Cu_{/m}\right)$$

$$TD_2 = 12 * \left\{(1 + \Delta_1\%) * ppm * [U_{max} - (1 + \beta_1\%) * U_{curr}] - (1 + VoC_1\%) * Cu_{/m} * [U_{max} - (1 + \beta_1\%) * U_{curr}]\right\} = 12 * [U_{max} - (1 + \beta_1\%) * U_{curr}] * \left[(1 + \Delta_1\%) * ppm - (1 + VoC_1\%) * Cu_{/m}\right]$$

Having explained the technical debt quantification rules, the values presented in Tables 4, 5 and 6 are applied to formulas (1) and (2) accordingly. The choice of these specific values and case scenarios enables to obtain accurate and comparable results, which reveal the overutilization of a service along with the appropriate web services to lease off in order to increase the ROI. Tables 5 and 6 include the variations regarding the monthly subscription price and the cost for servicing a user in the mobile cloud, which are dependent on the variations in the number of users, the service capacity and the QoS/QoE benefits. Finally, the obtained evaluation results are shown explicitly in Tables 7 and 8, while the flow and comparisons of the technical debt calculations over the 5-year period are observed in Fig. 1 and 2.

The first case scenario indicates that the Corporate and Premium services are always underutilized over the 5-year period of time due to the positive technical debt results. Despite the fluctuations in the demand that are witnessed, a gradual payoff of the technical debt is observed as the amount of monetary units for both services is less in the end of the period than in the beginning. The interpretation of the technical debt results concerning the Basic service reveals the underutilization of the service for the first four years. During the fifth year, the technical debt becomes zero, which constitutes the optimal condition, as it is totally cleared out. However, the technical debt result becomes negative until the end of the 5-year period of time, pointing out that the service is overutilized due to the variation in the number of users. Hence, the need for abandoning/terminating the existing service and switching to a more flexible one (i.e. in terms of capacity) will be faced in the future in order to meet the evolving market needs. The options of abandoning/termination and switching would create additional costs and the risk of entering into a new and accumulated technical debt in the future is high, having a significant impact on the ROI. Having explained that any positive technical debt to be further incurred can be hardly managed, the lease of the Premium service constitutes the best investment decision for that case scenario in terms of ROI and gradual payoff of the technical debt, as the calculation results have the minimum positive values and the problem of overutilization does not lurk over the 5-year period.

Table 4. VALUES TO BE APPLIED TO FORMULAS (1) AND (2).

Parameter Description	**Corporate (C)**	**Premium (P)**	**Basic (B)**
Maximum number of users that can be supported	$U_{max} = 18{,}000$	$U_{max} = 11{,}000$	$U_{max} = 5{,}000$
Initial number of users	$U_{curr} = 3{,}000$	$U_{curr} = 3{,}000$	$U_{curr} = 3{,}000$
Initial monthly subscription price (in USD)	$ppm = 12$	$ppm = 8$	$ppm = 6$
Estimated monthly cost for servicing a user in the mobile cloud (in USD)	$Cu_{/m} = 7$	$Cu_{/m} = 4$	$Cu_{/m} = 3$

Table 5. VARIATIONS IN THE MONTHLY SUBSCRIPTION PRICE AND THE COST FOR SERVICING A USER IN THE MOBILE CLOUD ACCORDING TO CASE SCENARIO 1.

Parameter Description	**Corporate (C)**	**Premium (P)**	**Basic (B)**
Variation in the monthly subscription price	$\Delta_1\% = 0.3\%$ $\Delta_2\% = 1\%$ $\Delta_3\% = -0.4\%$ $\Delta_4\% = 1.8\%$	$\Delta_1\% = 0.4\%$ $\Delta_2\% = 1.2\%$ $\Delta_3\% = -0.5\%$ $\Delta_4\% = 2\%$	$\Delta_1\% = 0.5\%$ $\Delta_2\% = 1.5\%$ $\Delta_3\% = -0.4\%$ $\Delta_4\% = 2.5\%$
Total variation regarding the cost for servicing a user in the mobile cloud	$VoC_1\% = 2\%$ $VoC_2\% = 4\%$ $VoC_3\% = -2\%$ $VoC_4\% = 4.5\%$	$VoC_1\% = 3\%$ $VoC_2\% = 6\%$ $VoC_3\% = -3.1\%$ $VoC_4\% = 7\%$	$VoC_1\% = 5\%$ $VoC_2\% = 10\%$ $VoC_3\% = -4\%$ $VoC_4\% = 12\%$

The second case scenario points out that the Corporate and Premium services are always underutilized due to the positive technical debt results and a gradual payoff of the technical debt is witnessed. On the contrary, although the Basic service is underutilized the first three years, the technical debt calculation results become negative during the last two years. The technical debt is totally cleared out during the fourth year, achieving the optimal condition; however, the variations in the demand affect the flexibility and adaptability of the service, as it is overutilized until the end of the 5-year period of time. The need for abandoning/terminating the existing service and switching to a more flexible capacity one will be faced again in the future. The options of abandoning/termination and switching entail a new and accumulated technical debt. Therefore, the lease of the Premium service constitutes the appropriate investment decision for that case scenario in terms of ROI and gradual payoff of the technical debt, as the calculation results have the minimum positive values once again. It is significant to mention that in case of all three services were overutilized, the options of abandoning and switching would be inevitable and the need to examine other more flexible capacity services in the market from the same or different mobile cloud services providers would be motivated in order to meet the demand requirements and avoid entering into a new and accumulated technical debt in the future.

Table 6. VARIATIONS IN THE MONTHLY SUBSCRIPTION PRICE AND THE COST FOR SERVICING A USER IN THE MOBILE CLOUD ACCORDING TO CASE SCENARIO 2.

Parameter Description	**Corporate (C)**	**Premium (P)**	**Basic (B)**
Variation in the monthly subscription price	$\Delta_1\% = 0.5\%$ $\Delta_2\% = -0.2\%$ $\Delta_3\% = 1.2\%$ $\Delta_4\% = 2.5\%$	$\Delta_1\% = 0.6\%$ $\Delta_2\% = -0.3\%$ $\Delta_3\% = 1.4\%$ $\Delta_4\% = 2.8\%$	$\Delta_1\% = 0.7\%$ $\Delta_2\% = -0.4\%$ $\Delta_3\% = 1.6\%$ $\Delta_4\% = 3\%$
Total variation regarding the cost for servicing a user in the mobile cloud	$VoC_1\% = 2.3\%$ $VoC_2\% = -1\%$ $VoC_3\% = 5\%$ $VoC_4\% = 10\%$	$VoC_1\% = 3.4\%$ $VoC_2\% = -1.5\%$ $VoC_3\% = 6\%$ $VoC_4\% = 12\%$	$VoC_1\% = 5.8\%$ $VoC_2\% = -2\%$ $VoC_3\% = 11\%$ $VoC_4\% = 20\%$

Table 7. THE TECHNICAL DEBT RESULTS FOR THE THREE SERVICES ACCORDING TO CASE SCENARIO 1.

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
C	900000	860129.28	754802.22	819821.78	724748.39
P	384000	358652.16	284164.97	330501.54	258685.88
B	72000	56678.4	9432.16	37978.09	-6276.56

Table 8. THE TECHNICAL DEBT RESULTS FOR THE THREE SERVICES ACCORDING TO CASE SCENARIO 2.

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
C	900000	846547.2	876122.31	728428.28	487045.75
P	384000	347385.6	367814.32	266451.37	103553.12
B	72000	48182.4	61402.43	-5876.46	-91867.48

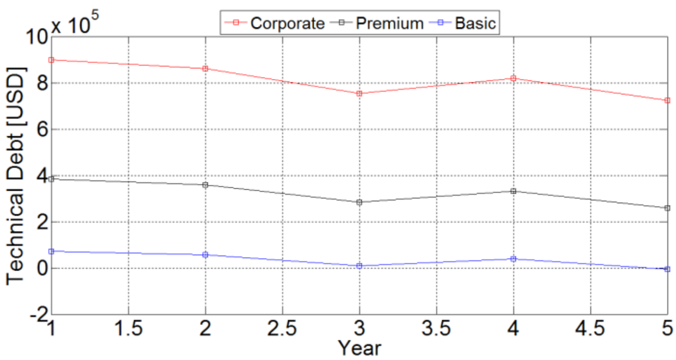

Fig. 1. Case Scenario 1: The flow of the technical debt.

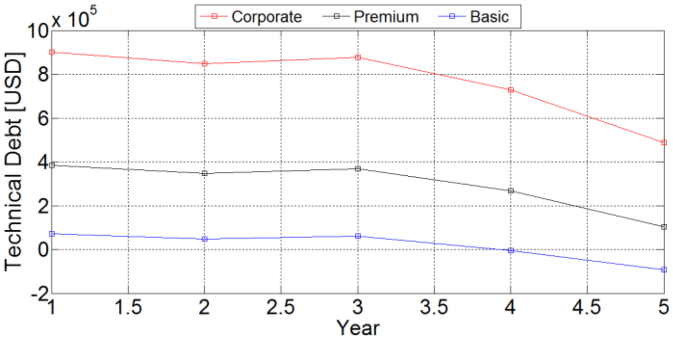

Fig. 2. Case Scenario 2: The flow of the technical debt.

V. Conclusion And Future Work

In this paper, a novel fluctuation-based model for quantifying the technical debt is proposed, when leasing cloud-supported mobile services. The adopted research approach is based on a cost-benefit analysis and it is researched from the service capacity viewpoint under the assumption that fluctuations in the number of users occur. The formula aims to predict the incurrence of the technical debt and the risk of entering into a new one in the future, adopting a non-linear and asymmetric approach; the prediction of the technical debt leads to more accurate mobile cloud service selection decisions. The performance evaluation analysis of different case scenarios provides insights to software project managers, mobile cloud-based system architects and analysts to interpret the results and be more technical debt-aware in order to avoid critical options, such as the abandoning/termination and switching. In the future, methods to quantify and evaluate the technical debt using real options will be further investigated.

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