Quantifying and Evaluating the Technical Debt on Mobile Cloud-Based Service Level

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***Abstract*—As network bandwidth and coverage continue to increase, the adoption rates of mobile devices are growing over time and the mobile technology is becoming increasingly industrialized. In mobile cloud marketplaces, the cloud-supported mobile services can be leased off. However, the mobile service selection may introduce technical debt (TD), which is essential to be predicted and quantified. In this context, this paper examines the incurrence of technical debt in the future when leasing cloud-based mobile services by proposing a novel quantitative model, which adopts a linear and symmetric approach as a linear growth in the number of users is predicted. The formulation of the problem is based on a cost-benefit analysis, elaborating on the potential profit that could be obtained if the number of users would be equal to the maximum value. The probability of overutilization of the selected service in the long run is also researched. Finally, a quantification tool has been developed as a proof of concept (PoC), which initiates the technical debt analysis and optimization on mobile cloud-based service level and aims to provide insights into the overutilization or underutilization of a web service when a linear increase in the number of users occurs.**

Keywords*—*technical debt quantification; technical debt evaluation; quantitative model; service level selection; linearity; decision making

I. Introduction

As rapid advances in mobile technologies and devices occur, enterprises adopt cloud migration approaches and digital transformation strategies leveraging mobile as the catalyst for innovation, future growth, competitive advantage and profitability. The architectural considerations are critical when developing mobile applications by exploiting cloud computing and web services. As a result, selecting the appropriate mobile solutions and identifying the best practices for their implementation have a significant impact on increasing the return on investment (ROI). In addition, technological advances, especially in the telecommunications industry, have made it possible to offer innovative, location-sensitive services on ubiquitous basis to customers on the move [1], [2]. A proof in this respect is the fact that the mobile devices are among the newest channels to conduct transactions electronically as the mobile banking is of vital importance in mobile commerce and financial services [3]. In this context, the mobile cloud computing (MCC) paradigm has been introduced as a mobile computing technology that leverages the elastic resources of the cloud towards unrestricted functionality, storage and mobility in order to serve a multitude of mobile devices anywhere and anytime, based on the pay-as-you-use model [4], [5]. A conceptual mobile cloud architecture is witnessed in Fig. 1.

The mobile cloud-based service-oriented architectures are composed of web services, which are offered via the cloud. The mobile cloud can be considered as a marketplace [6], where the web services of the mobile cloud-based system architectures can be leased off [7]. Such web services are differentiated on the subject of the non-functional requirements or the maximum number of users that can be supported (i.e., service capacity). A conceptual pricing and billing policy a cloud provider adopts is presented in [8]. In this research work, the technical debt concept is introduced in the mobile cloud computing paradigm, as the need for predicting and managing the technical debt on mobile cloud-based service level is motivated. The quantification results will contribute to inform effective decision making and create payback strategies, such as for incurring or paying off the technical debt instances [9]. In this direction, this paper contributes to a novel quantification model for applying the technical debt over cloud-supported mobile services, adopting a linear and symmetric approach as a linear growth in the number of users is forecasted. The model formulation is based on the assumption that the cloud-based mobile services are leased off. The size of the technical debt can be affected either by the service capacity or the need to abandon/terminate the existing service and switch to a more flexible one in terms of Quality of Service (QoS) and Quality of Experience (QoE). The performance evaluation analysis indicates that a sheer increase in the number of users constitutes a major cause for abandoning/terminating and switching to a more flexible capacity service, resulting in accumulated technical debt and any positive technical debt to be further incurred can be hardly managed.

Following this introductory section, related work approaches are presented in the next section along with the research gap that motivates the need for quantifying the technical debt on mobile cloud-based service level. Section III elaborates on the proposed quantitative model, while Section IV provides a case study for detailed evaluation, exploiting the decision-support tool. Finally, Section V concludes this work, highlighting directions for future research.

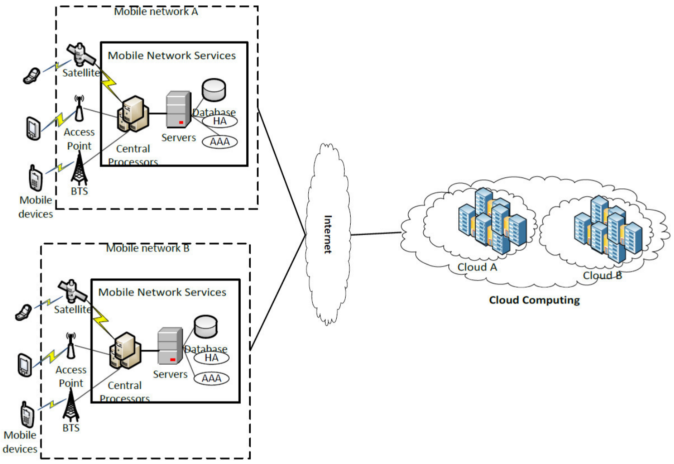

Fig. 1. A conceptual mobile cloud architecture.

II. Related Work And Research Motivation

The technical debt term [10] indicates the correlation between software engineering concepts and the financial debt [11]. In this direction, the acceleration of the velocity for releasing software products will lead to implications, additional cost and interest payments in the long run [12]. The technical debt has been described in different domains, such as code, testing, documentation or configuration debt [13]. Sterling [14] mentions that the lifecycle and the business pressures might affect the size of the technical debt, while the authors in [15] explain that the lack of experience of the software development team and the non-systematic verification of the software product quality will definitely generate technical debt. A novel framework for evaluating the technical debt is presented in [16], which aims to establish a technique for detecting design flaws, while a cost-oriented approach is adopted in [17] by monitoring the technical debt management activities in an on-going software project. The authors in [18] confer that the quality of the software architecture can be substantially improved by managing the technical debt during modelling. Furthermore, a quantification approach associated with debts and interest is examined in [19], while the authors in [20] attempt to model and analyse the technical debt on system reliability, exploiting a longitudinal data set of a commercial enterprise system. The need for establishing a metric to manage effectively the technical debt, when delivering a product, is also emphasized in [21], pointing out that the value of the delivered features and the impact of the cost should be considered in the decision-making process. On the other hand, an economics-driven approach in cloud-based architectures is discussed in [22], where the problem of the web service substitution and its technical debt valuation is described as an option problem, while a critical evaluation of the technical debt in cloud-based architectures using real options is performed in [23].

Although there are related work approaches in the literature regarding the technical debt from different viewpoints, there is currently little work in the area of technical debt estimation in mobile cloud computing and, therefore, a research gap for introducing a linear technical debt metric, which applies to the mobile cloud computing paradigm from the service capacity perspective, is witnessed. In this direction, this study fills that gap by proposing a novel quantitative technical debt model. Considering the need for empirically predicting and quantifying the technical debt, the authors in [24] contribute to a new concept at the cloud service level using real options, introducing the debt that derives from substitution decisions and arguing that the web service selection decision might incur a technical debt that is essential to be managed. Skourletopoulos et al. in [25] present two novel models for predicting and quantifying the technical debt on cloud-based software engineering and cloud-based service level respectively, along with extended evaluation results for discussion in [26]. Cost-benefit analysis and return on investment approaches in mobile cloud computing environments are discussed in [27], while a fluctuation-based modelling perspective (i.e., adoption of a non-linear approach) to quantification of the technical debt on mobile cloud-based service level has been also studied by Skourletopoulos et al. in [28]. In this paper, the proposed quantification model is a substantial extension of these previous research works, adopting a linear and symmetric approach from the technical debt perspective and incorporating specific predictors that are fully applicable to the mobile cloud computing paradigm.

III. Research Approach And Model Formulation

In this study, the proposed research approach intends to predict and quantify the technical debt when leasing cloud-supported mobile services. The hypothesis is that the selection decision is affected by the service capacity, taking into account an annual increase in the demand and the way the technical debt is gradually paid off. The quantitative approach is based on a cost-benefit analysis under the assumption of a linear growth in the number of users. Narrowing in, the potential profit that could be obtained in case that the number of users would be equal to the maximum value is investigated, taking into consideration the probability of overutilization of the service that would lead to accumulated technical debt difficult to be managed. Any candidate cloud-based mobile service to be leased off is evaluated with respect to the following assumptions and statements:

- The period of λ-years is examined, aiming to provide insights into the ROI and the time the technical debt will be totally paid off. The optimal condition is the zero point (zero monetary units), where the service capacity meets also the evolving market needs.

- Any candidate cloud-supported mobile service is subscription-based and there are charges for servicing an end-user in the mobile cloud. The pricing and billing schemes vary over the period of λ-years.
- A linear growth in the number of users is predicted over the period of λ-years with simultaneous increase in the total cost for servicing an end-user in the mobile cloud in order to ensure the QoS and QoE. The scalability and elasticity in the cloud are taken into account as the additional costs are composed of document and data storage, technical support, maintenance services, network bandwidth and server costs.
- The flexibility of a service encompasses the adaptability to meet the evolving market needs, such as the linear increase in the number of users.
- The cloud-based, always-on mobile services are usually sensitive to network bandwidth and latency. Hence, the additional network bandwidth cost is expected to satisfy the outbound network traffic demands to avoid delays. The total additional server cost includes those costs that derive from the additional CPU cores and the amount of memory required for processing, as more processing capacity is added to handle anticipated transaction volumes.
- The offered web services have comparable functional requirements, while the non-functional ones can be either comparable or not (i.e., capacity, flexibility and maintainability). However, the cloud-supported mobile services are differentiated with respect to the maximum number of users that can be supported.

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

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

Having adopted a linear increase in the number of users, the equation modelling approach for quantifying the technical debt when leasing cloud-supported mobile services takes the following form and the description for each variable used is presented below:

$$\mathrm{TD_i} = 12 * \left\{\left(1+\frac{\Delta\%}{\lambda}\right)^{i-1} * \mathrm{ppm} * [\mathrm{U_{max}} - (1+\beta\%)^{i-1} * \mathrm{U_{curr}}] - \left(1+\frac{\alpha\%}{\lambda}+\frac{\gamma\%}{\lambda}+\frac{\theta\%}{\lambda}+\frac{\mu\%}{\lambda}+\frac{\sigma\%}{\lambda}+\frac{\eta\%}{\lambda}\right)^{i-1} * \mathrm{Cu}_{/m} * [\mathrm{U_{max}} - (1+\beta\%)^{i-1} * \mathrm{U_{curr}}]\right\} = 12 * [\mathrm{U_{max}} - (1+\beta\%)^{i-1} * \mathrm{U_{curr}}] * \left[\left(1+\frac{\Delta\%}{\lambda}\right)^{i-1} * \mathrm{ppm} - \left(1+\frac{\alpha\%+\gamma\%+\theta\%+\mu\%+\sigma\%+\eta\%}{\lambda}\right)^{i-1} * \mathrm{Cu}_{/m}\right], \text{with } i = 1,2,\ldots\lambda \qquad (1)$$

where,

- λ: the period of years,
- i: the index of the year,
- U_{max}: the maximum number of users that can be supported,
- U_{curr}: the initial number of active users,
- $\beta\%$: the estimated average annual increase in the number of users, which is represented by a percentage value,
- *ppm*: the initial monthly subscription price, which is expressed in monetary units,
- $\Delta\%$: the estimated average increase in the monthly subscription price over the period of λ-years, which is represented by a percentage value,
- $Cu_{/m}$: the estimated initial monthly cost for servicing an end-user in the mobile cloud, which is expressed in monetary units,
- $\alpha\%$: the estimated average increase in the monthly document storage cost over the period of λ-years, which is represented by a percentage value,
- $\gamma\%$: the estimated average increase in the monthly data storage cost over the period of λ-years, which is represented by a percentage value,
- $\theta\%$: the estimated average increase in the monthly technical support cost over the period of λ-years, which is represented by a percentage value,
- $\mu\%$: the estimated average increase in the monthly maintenance services cost over the period of λ-years, which is represented by a percentage value,
- $\sigma\%$: the estimated average increase in the monthly network bandwidth cost over the period of λ-years, which is represented by a percentage value,
- $\eta\%$: the estimated average increase in the monthly server cost over the period of λ-years, which is represented by a percentage value,
- *TD*: the technical debt numerical result, which is expressed in monetary units.

IV. Performance Evaluation Analysis, Experimental Results And Discussion

This work contributes to a novel quantitative model that supports the prediction of the technical debt on mobile cloud-based service level under the assumption of a linear growth in the number of users. From the research viewpoint, a quantification perspective of the technical debt is adopted when leasing cloud-based mobile services and a complex model is proposed, which is characterized by extensibility as more variables can be added, indicating how customizable the mathematical 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, initiating the technical debt analysis and optimization on mobile cloud-based service level, as the proposed formula (1) is implemented. From the technical viewpoint, 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. Towards a better understanding of the technical debt from the service capacity viewpoint, the calculations are necessary to figure out the progress of different case scenarios when leasing cloud-supported mobile services and inform about the incurrence of accumulated technical debt in the future, once a linear growth in the number of users occurs. The incurrence of technical debt might have implications, such as the options of abandoning/terminating and switching, leading to a new accumulated technical debt difficult to be managed. Hence, the technical debt data can be used to make effective information technology (IT) investment decisions as it provides insights into the underutilization or overutilization of a service in the long run, the gradual payoff of the technical debt and the time that will be totally cleared out.

An indicative and illustrative case study emphasizes on the need to lease a cloud-supported mobile service intended to be integrated into existing enterprise infrastructures in order to connect employees and customers. The accumulated cost that arises from the development process is avoided, as building software from the scratch requires additional cost. Throughout the evaluation of the adopted case scenarios, a detailed 4-year technical debt prediction has been made prior to mobile cloud adoption, enabling to do a what-if analysis on different case scenarios, web services and lease options. The following three mobile services are offered by the same provider and they are investigated with respect to the different features they have:

- Service A: The maximum number of active users that can be supported is fifteen thousand (15,000). Service A is more flexible than services B and C in terms of QoS, QoE and non-functional requirements, such as the performance and maintainability. A high-priced strategy is adopted as the estimated monthly cost for servicing an end-user in the mobile cloud is high. Once a linear increase in the number of users occurs, small-scale variations in the monthly cost (for instance, network bandwidth or server costs) are observed compared to those variations witnessed in services that have lower quality and smaller capacity.
- Service B: The maximum number of active users that can be supported is ten thousand (10,000). Service B is more flexible than C in terms of QoS, QoE and non-functional requirements.
- Service C: The maximum number of active users that can be supported is five thousand (5,000). This is a lower-quality service compared to the other offered services.

The technical debt estimates are made against three different case scenarios over a 4-year period, investigating the probability of overutilization of any of the three services under the assumption of an annual and linear growth in the number of users (i.e., parameter *β%*). Hence, the first case scenario forecasts a 10% annual increase in the number of users, the second one adopts a 55% annual increase in the demand and the third one examines an 80% annual increase in the number of users.

Table 1. VALUES TO BE APPLIED TO THE VARIABLES OF THE FORMULA (1)

Variable Description	**Service A**	**Service B**	**Service C**
Period of λ-years	$\lambda = 4$	$\lambda = 4$	$\lambda = 4$
Maximum number of users that can be supported	$U_{max} = 15{,}000$	$U_{max} = 10{,}000$	$U_{max} = 5{,}000$
Initial number of users	$U_{curr} = 2{,}000$	$U_{curr} = 2{,}000$	$U_{curr} = 2{,}000$
Initial monthly subscription price (in USD)	$ppm = 15$	$ppm = 10$	$ppm = 8$
Estimated average increase in the monthly subscription price over the period of λ-years	$\Delta\% = 2\%$	$\Delta\% = 2\%$	$\Delta\% = 2\%$
Estimated initial monthly cost for servicing an end-user in the mobile cloud (in USD)	$Cu_{/m} = 6$	$Cu_{/m} = 3$	$Cu_{/m} = 2$
Estimated average increase in the monthly document storage cost over the period of λ-years	$\alpha\% = 1\%$	$\alpha\% = 1.5\%$	$\alpha\% = 2\%$
Estimated average increase in the monthly data storage cost over the period of λ-years	$\gamma\% = 0.5\%$	$\gamma\% = 1\%$	$\gamma\% = 2\%$
Estimated average increase in the monthly technical support cost over the period of λ-years	$\theta\% = 0.5\%$	$\theta\% = 0.5\%$	$\theta\% = 1\%$
Estimated average increase in the monthly maintenance services cost over the period of λ-years	$\mu\% = 0.5\%$	$\mu\% = 1\%$	$\mu\% = 2\%$
Estimated average increase in the monthly network bandwidth cost over the period of λ-years	$\sigma\% = 0.5\%$	$\sigma\% = 1\%$	$\sigma\% = 2\%$
Estimated average increase in the monthly server cost over the period of λ-years	$\eta\% = 1\%$	$\eta\% = 2\%$	$\eta\% = 2\%$

Towards the quantification of the technical debt when leasing cloud-based mobile services, the values that are shown thoroughly in Table 1, were applied to the corresponding variables of the formula (1). The choice of these specific values and case scenarios enables to obtain accurate and comparable results, which reveal the overutilization of a service and the most cost-effective web services to lease off in order to avoid accumulated costs and the risk of entering into new technical debt in the long run. The evaluation results are presented in Tables 2, 3 and 4, whereas the flow and comparisons of the technical debt over the 4-year period are indicated in Fig. 2, 3 and 4, respectively.

The first case scenario indicates that the services A, B and C are always underutilized over the 4-year period due to the positive technical debt results. In addition, the technical debt is gradually paid off, as the amount of monetary units is constantly decreasing for the three services, due to the mild linear increase in the number of users per year (10%). Despite the fact that services A and B are considered better than C in terms of QoS and non-functional requirements and more flexible to meet the evolving market needs, the lease of service C is recommended for that case scenario, as the market needs are met over the 4-year period and there are also reduced costs compared to services A and B. In addition, there would not be a risk of entering into a new accumulated technical debt in the future, as the problem of overutilization along with the options of abandoning/terminating and switching do not lurk.

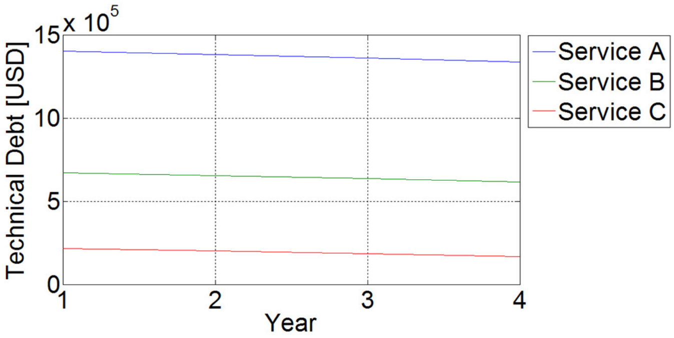

Fig. 2. Case Scenario 1: The flow of the technical debt results over the 4-year period with respect to a 10% annual increase in the demand.

Table 2. CASE SCENARIO 1: THE TECHNICAL DEBT RESULTS OVER THE 4-YEAR PERIOD ACCORDING TO A 10% ANNUAL INCREASE IN THE NUMBERS OF USERS.

	Year 1	Year 2	Year 3	Year 4
Service A	1,404,000	1,384,704	1,363,135	1,339,066
Service B	672,000	654,966	636,204.4	615,553.6
Service C	216,000	201,096	184,790.6	166,961.9

The second case scenario points out that the services A and B are always underutilized over the 4-year period, because of the positive technical debt calculations that are observed. For both services, a gradual payoff of the technical debt is witnessed as a result of the continuous decrease in the amount of monetary units. The interpretation of the technical debt results concerning service C reveals underutilization for the first three years. During the fourth year, the technical debt becomes zero, which constitutes the optimal condition, pointing out that it is totally cleared out. However, the technical debt results become negative until the end of the period, indicating that the service is overutilized due to the adopted assumption of the linear growth in the number of users. Hence, the need for abandoning/terminating the existing service and switching to a more flexible service 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 explained that any positive technical debt to be further incurred can be hardly managed, the lease of service B is the most cost-effective option for that case scenario in terms of ROI and gradual payoff of the technical debt, as the calculation results have the minimum positive values, not to mention that the problem of overutilization does not lurk over the 4-year period.

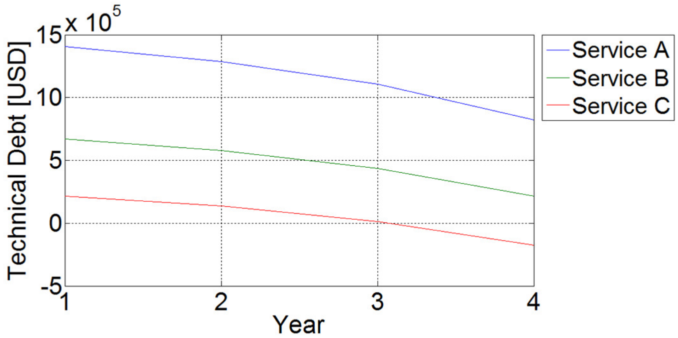

Fig. 3. Case Scenario 2: The flow of the technical debt results over the 4-year period with respect to a 55% annual increase in the demand.

Table 3. CASE SCENARIO 2: THE TECHNICAL DEBT RESULTS OVER THE 4-YEAR PERIOD ACCORDING TO A 55% ANNUAL INCREASE IN THE NUMBER OF USERS.

	Year 1	Year 2	Year 3	Year 4
Service A	1,404,000	1,287,342	1,104,703	819,659.7
Service B	672,000	579,393	436,026.6	214,097.4
Service C	216,000	136,458	13,966.7	-174,799

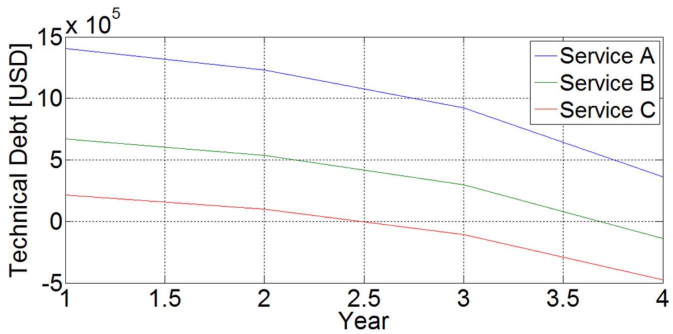

Figure 4. Case Scenario 3: The flow of the technical debt results over the 4-year period with respect to an 80% annual increase in the demand.

Table 4. CASE SCENARIO 3: THE TECHNICAL DEBT RESULTS OVER THE 4-YEAR PERIOD ACCORDING TO AN 80% ANNUAL INCREASE IN THE NUMBER OF USERS.

	Year 1	Year 2	Year 3	Year 4
Service A	1,404,000	1,233,252	923,204.2	362,062.3
Service B	672,000	537,408	295,440.6	-139,585.9
Service C	216,000	100,548	-106,003.9	-475,891.3

The third case scenario demonstrates that service A is still underutilized over the period of time and the technical debt is gradually paid off, despite the sheer annual increase in the number of users (80%). The interpretation of the technical debt results with respect to service B shows underutilization of the service from the first until the end of the third year. During the fourth year, the technical debt becomes zero (i.e., optimal condition), revealing that it is totally cleared out. However, the technical debt results become negative until the end of the period as a result of the linear growth in the number of users, disclosing that the service is overutilized. On the other hand, service C is underutilized the first two years. During the third year, the technical debt is totally paid off (i.e., optimal condition), whereas the technical debt results become negative until the end of the period as a result of the linear increase in the number of users. The negative results imply the overutilization of the service; hence, a sheer increase in the demand (80%) will motivate the need for abandoning/terminating either service B or C and switching to a more flexible capacity service. The risk of entering into a new and accumulated technical debt in the future is high, as these options would create additional costs. The analysis of the results for this case scenario points out that the most cost-effective cloud-supported mobile service to lease off is A, as the problem of overutilization does not lurk over the 4-year period, the technical debt is gradually paid off and the risk of entering into a new technical debt in the future is low. In addition, the flexibility of this particular service to adapt to the evolving market needs and the fact that the users will be able to enjoy a better service in terms of QoS/QoE should be also considered during the decision-making process.

V. Conclusion And Future Work

In this research work, a quantitative approach of applying the technical debt on the mobile cloud computing environment is examined, taking into consideration the lease of cloud-based mobile services. The model formulation is based on a cost-benefit appraisal from the service capacity perspective, adopting a linear and symmetric approach as a linear growth in the number of users is assumed. The proposed novel quantitative model aims to predict the incurrence of the technical debt in the long run and provide insights into how to eliminate the risk of entering into new and accumulated technical debt. The evaluation analysis of different case scenarios enables software engineering experts, software project managers, mobile cloud-based system architects and analysts to interpret the results and be more technical debt-aware in order to avoid options, such as the abandoning/termination and switching. In the future, methods to quantify the technical debt using real options and exploit the model from the big data-as-a-service (BDaaS) viewpoint will be further investigated.

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