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Mathematical Analysis of the Elements Affecting Mobile Cloud Computing Adoption in the Technological Age

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Abstract: For smartphones, cloud computing has been one of the hottest topics in the field of information systems. Although several technologies have been embraced, mobile devices have certain limitations with regards to processor, storage, scalability, battery, confidentiality and security, and price. Mating with cloud computing also presents some alternative solutions for the limitations with mobile devices. This allows users to install the latest and greatest applications on their smartphones or devices. Research in that should be more appropriate, specifically with regards to this choice of application for mobile cloud computing in developing nations. Thus, the present study aims to examine core opportunities and challenges of implementing a new type of mobile cloud computing and, moreover, to discuss the major theoretical frameworks for such applications. The methods adopted were triangulation based on the nature which required for this study. Left out of this milestone were 23 expert-in-depth interviews, two focus group discussions, direct observation as well as 223 qualitative questionnaires. The data were treated using several technologies, with the most prominent among them being NVivo Software.

Keywords: Cloud Computing, Mobile cloud, technology information.

1 Introduction

Cloud computing is a web-based technology that allows users to store data, process it, and exhibit it through servers situated in the Internet rather than on resources in local areas [1,2,3]. The cloud provides nearly unlimited processing and storage capacity using virtual resources according to the demands of the user [4,5,6]. Therefore, it is easy and cheap to scale up or scale down these resources [7,9,8]. As resources scale up or down, the user will be charged for the usage [10,11,12]. Therefore, with the help of cloud computing technologies, a normal user or a business can avoid the initial capital expenditure of having to invest in complex infrastructure [13,14]. Cloud technology virtually represents any internal technology or service, such as servers, virtual desktops, software applications, and data storage. With the ability to connect cloud resources onto the internet virtually immediately, a virtual company can be launched by spending next to nothing [15,16]. In the early 2000s, Apple Corporation launched the new technology that has changed the music business. The iTunes music store was the first venture into the world of cloud computing by Apple [17,18]. At this store are millions of music tracks, films, and images online, which can be streamed, uploaded, or downloaded to Apple servers for Apple

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devices like iPods, iPads, and iPhones. The end consumers are charged based on the units they consume, and the price has been greatly reduced. Apple, however, really does benefit a lot from this branch of the economy [19,20].

1.1 Mobile Cloud Computing

With the merging of mobile and cloud computing, a great opportunity for almost unlimited resources has opened [19]. Enterprise houses like Apple, Samsung, and Huawei admitted that the cloud offers a safer environment to even their products despite the very real issues of security and privacy. Apple users, for example, could track their devices when stolen or lost. Furthermore, without the iCloud user name and password, such devices are of no use. On the other hand, with the help of cloud computing, Samsung and Huawei give the ability to disable any cellphone online. Several authors categorically state that cloud technology is mainly utilized in web applications such as blogs, Wikis, Twitter, Facebook, and YouTube [21,22]. In the light of this, one can infer that mainstream applications are indisputably directed by cloud computing. Such applications may reside on servers hosted on the internet and be brought to a user's aid through mobile devices. [23,24] has mentioned that there are a billion views of videos every day from millions of viewers on YouTube. Further, billions of gigabytes of data are transferred and stored by Facebook. Mobile devices are given the preferred choice for accessing these applications.

1.2 Cloud Computing Model

Depending on what customers need, the cloud providers offer various cloud technology solutions. Generally, cloud computing was divided by many researchers on the deployment methodology and the service model. The first category comprises private cloud, public cloud, hybrid cloud, and community cloud [25]. In a private cloud, the resources are owned by a single user [26]. Being, therefore, the most expensive and most secure option, in comparison with other cloud deployment types, this means it is costlier as it is basically utilized by a single organization [27]. On the other hand, the public model opens wide grant on a common pool of applications to several cloud users. Public cloud is actually the least expensive and least secure form of deployment [28]. The hybrid cloud model is actually produced from the union of the private cloud and the public cloud. Such a model can comprise two or more community, private, and public cloud models [25]. The hybrid cloud model lies in between the public and private cloud architecture, since it is considered an expensive alternative to the public cloud. But it is the private cloud technology that gets really used by hybrid clouds [28].

2 Research Methodology

The research methodology, as mentioned in the study, entails a clear research concept, method of data collection, and analysis steps [27]. This study adopts the position that applying vertical limitation, data has to be culled from various sources such as 22 semi-structured interviews, two focus groups, 223 surveys, in addition to some secondary sources. For the purpose of analysis, Excel, NVivo, and Microsoft Visio were used. The data sets gathered were from estimated private companies in Jordan. Data acquisition should be done in phases, analyzed, and collected according to [30]. The study started by picturing how the research would pan out, arguing for the relevancy of the main concepts of the study, their conceptual foundation being mobile cloud computing, its theoretical background, and the theories that could bear on the study during the process of a literature review and the collection of data, and finally, presenting the results [31]. In line with the qualitative approach to analysis by Miles and Huberman [29], data were analyzed by examining a series of specific steps, that is, data condensation, data display, and drawing and verification of conclusions.

2.1 Conducting the Pilot Study

The design phase, which involves reviewing whether it is possible to set one up in time for another study, is involved in taking a pilot study into consideration for an interview, questionnaire, and direct observation schedule. Another part of pilot work is to see if it is possible to put in place an implementable regime. Thus, pilot studies provide a basis for assessing the validity and reliability of the complete data. Therefore, pilot study was conducted to ensure the data's validity and reliability, thus avoiding possible errors in the furtherance of research, while more so, it aided in preparing the course toward the collection of data from prospective research subjects. All participants contributed to the generation of the instrument's questions. The researcher and an MIS professor who taught in the program conducted three unstructured

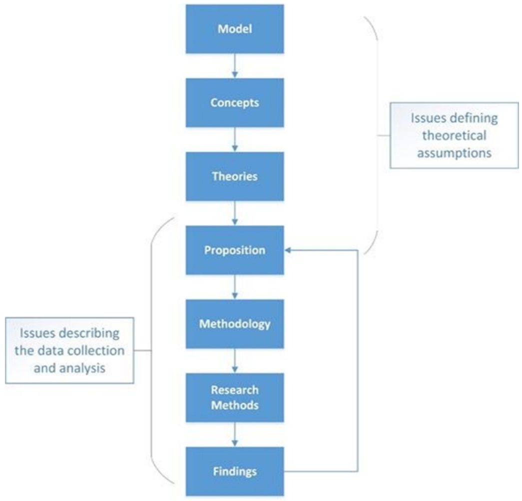

Fig. 1: Stages of the methodology used in this research [30].

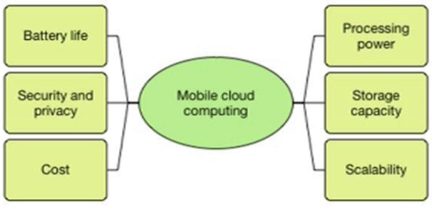

Fig. 2: Key variables affecting the use of mobile cloud computing for NVivo mind-map analysis of mobile processing power.

interviews jointly, developing the questions that were used for the survey, focus groups, and interviews. The researcher made use of the inputs of five persons. Since the pilot study revealed a number of weaknesses in the interview and survey questions, the questions were modified before the real data collection started.

3 Results

According to the findings of the qualitative study, one of the major drawbacks of mobile devices has been the fact that their processing capabilities are limited. Unlike servers, edge computing, and workgroups, supercomputers, and so forth, it is really apparent that the mobile devices' processing capacity is surely more limited. From a mobile technology expert's point of view of an associate professor in an information technology department, the limitations of capability are there, and indeed, contrary to what is alleged by mobile service providers that the commonwealth of the customer's device is fairly advanced and can fairly carry considerable processing capability these capabilities exist only very thinly at best in practice. The software available for use in operating smartphones will definitely and more than creditably meet the demands of operating smartphones. However, advanced software of 3D rendering or engineering programs like MATLAB would simply be unusable. Eleven percent of the respondents from Figures 1 and 2 believed and agreed that the processing power provided by today's mobile devices was sufficient for what they required to do. An alternate opinion of about twelve percent of the respondents was that they were unsure with their answer, as opposed to the wrong view held by seventy-seven percent. If cloud computing really exists, it is meant to provide practically infinite processing power to mobile devices by having the users share their data with distant servers somewhere in the far-away cloud to be processed and then take back the results. This would include the mobile devices, such as smartphones, tapping into huge processing resources offered by the cloud so as to compensate for the limited capabilities that they honestly possess.

3.1 Mobile Storage Capacity

Many research authors indicate that there is a definite limitation on the storage capacities of mobile devices, such as in the case of smartphones. Cloud computing has a multitude of services to offer; online cloud storage is simply one such service. This limitation is overridden by some cloud technology service providers (like Apple and Microsoft) by offering a certain extent of free storage to their users, albeit with some restrictions [25]. Mobile cloud technologies, however, assure this limitation by providing a good enough amount of storage for consumption-based charges, which can be paid for either monthly or yearly. Some respondents stated that it was very clear that from a cost perspective, buying storage servers in the cloud would definitely be much cheaper than buying actual hardware towards the same end. Yet another advantage is that the data related to a user can be accessed anytime from anywhere [26]. A computer scientist from the engineering department said that modern mobile gadgets evidently have enough capacity for normal usage, because camera snapshots, updating on social media, and recording video wherever in high-quality and in 1080p inches capacity would be enough for a normal usage.

Let a mobile app use cloud storage for a fraction of its data and cache a working set locally.

Local footprint (MB):

$$S_{\text{local}} = S_{\text{app}} + S_{\text{cache}}, \qquad S_{\text{cache}} = h\,\alpha D\,\rho + (1-\alpha)D$$
$$\Rightarrow\ S_{\text{local}} = S_{\text{app}} + (1-\alpha)D + h\,\alpha D\,\rho$$

S_{app} : static app binaries/resources;
D_D : total user data volume;
$\alpha \in [0,1]$: fraction of D_D stored in the cloud;
$h \in [0,1]$: cache hit ratio for cloud-resident data;
$\rho \in (0,1]$: effective compression/dedup factor for cached cloud data.

Interpretation. If $\alpha \to 1$ and caching is efficient (small $h\rho$), local footprint approaches S_{app}. If network/caching are poor (low h), the term $(1-\alpha)D_D$ dominates. Cloudlet/near-edge designs reduce the need for large caches by lowering fetch latency.

3.2 Battery Life

Mobile devices like smartphones are increasingly being faced with bigger problems when it comes to increasing their battery life. Many techniques have been proposed to improve the performance and battery life. However, the drawback to it was in some cases, depending on the software, there arose as much as a 45% increment in its power requirement by the batteries. Thus, it may be argued that mobile cloud would actually be the only way to facilitate the run of applications by any mobile device on platforms other than the mobile devices themselves, since the battery life of mobile devices is finite. Keeping the energy intact using application of mobile cloud computing to remote processing will go a long way to preserve the already scanty energy for remote applications. Generating 3D images efficiently may reduce energy consumption of mobile devices up to 41 percent in less than 30 minutes. According to the poll, the results are crucial for several reasons; one being the finding that 46% of respondents felt that battery power of their smart gadgets had to last more than 72 hours to be satisfying. Theoretically, a cellphone is never supposed to have its battery last more than forty-eight hours in best and ideal conditions with average usage.

Total energy for a session of length T:

$$E_{\text{tot}} = E_{\text{base}} + (1-\alpha)E_{\text{comp}} + \alpha E_{\text{net}}$$

$$E_{\text{comp}} = P_{\text{CPU}}t_{\text{CPU}} + P_{\text{GPU}}t_{\text{GPU}}$$

$$E_{\text{net}} = e_{\text{tx}}V_{\text{tx}} + e_{\text{rx}}V_{\text{rx}} + P_{\text{idle}}t_{\text{wait}}$$

Battery life (hours):

$$L = \frac{B}{E_{\text{tot}}/T}$$

Parameter definitions:

– B: battery energy capacity (Wh);
– E_{base}: screen, radios, OS background;
– $e_{\text{tx}}, e_{\text{rx}}$ (J/MB): energy per MB uplink/downlink; $V_{\text{tx}}, V_{\text{rx}}$ (MB);
– Offloading share α shifts energy from on-device compute to network transfers.

Empirically, offloading saves energy when $E_{\text{net}} < E_{\text{comp}}$, especially over Wi-Fi/edge vs. 3G/4G.

3.3 Security and Privacy

Privacy concerns comprise rules and permissions that define who may view data, for what reason, and by what methods, whereas security is to defend unauthorized access to data. The study's findings, which were realized through questionnaires, group discussions, and personal interviews, all stressed that privacy and protection of data remain the major concerns afflicting mobile cloud computing. On some levels, participants elaborated that security and privacy guarantees must be met by the cloud service providers; otherwise, a cloud would generally be rejected, particularly where mobile cloud computing is concerned. This finding certainly raises interesting questions. One decision maker stated: "For us, privacy is the primary concern. This is not a joke; if somebody gets through into our data, we might very well lose everything." The snag is that our data is not being stored on our company's own servers. Hence, there would have to be a very clear answer in the cloud SLA with regard to how confidentiality of data is maintained, in particular, who can access the files and why. "I think security would be fine because I'm confident in the safety of private cloud servers." Most respondents in the survey conducted for this research identified security and privacy concerns as the major challenges posed by mobile cloud computing. As can be seen from the data charted in Figure 3, 69% of the respondents stated that privacy and security concerns present the most important challenges to the implementation of mobile cloud computing technology. They also raised additional issues related to cost, processing power, storage capacity, battery life, and scalability.

Following NIST SP 800-30, risk is a function of likelihood and impact; you can extend with vulnerability and control effectiveness terms:

Risk assessment formulation:

$$R = \sum_{i=1}^{m} (L_i \times I_i \times V_i \times (1 - C_i))$$

For each threat i: L_i = likelihood, I_i = impact (financial/clinical/legal), V_i = vulnerability exposure (e.g., attack surface), C_i = control effectiveness (0–1).

Privacy sub-score (per dataset j) to weight identifiability and sensitivity:

$$R_{\text{priv}} = \sum_{j} w_j (S_j \times ID_j \times E_j)$$

where:

– S_j — data sensitivity;
– ID_j — re-identification risk;
– E_j — exposure (recipients, retention, cross-border transfer);
– w_j — weights set by policy/regulation.

Report overall:

$$R^* = \lambda R + (1 - \lambda) R_{\text{priv}}$$

3.4 Cost of Mobile Cloud Computing

Cost-benefit analysis is considered by the study participants as one of the paramount elements for cloud computing. This procedure, which can be used in mobile cloud computing scenarios as a leverage point while alleviating advanced processing demands, stands as one of the most important aspects of cloud computing. Most respondents working on the pay-per-use pricing model showed that one of the cost benefits of cloud computing is its ability to make the user pay only if he or she uses a resource. Features like this can be major catalysts toward the large-scale adoption of mobile cloud computing technologies. That aside, a group of specialists in the industry recommends looking into an ROI study before opting for cloud technology. According to one landmark expert on cloud computing who considers this one of the most important things to consider. In order to adopt mobile cloud computing, ROI especially long-term costs for processing and storage should be an imperative consideration. You may also be aware that while the initial cost of cloud computing is nearly threescore and ten to practically zero, the running costs turn out to be very different and dramatically higher than if one would, without use, outright buy a storage device, say to store some movie files, instead of rent one through iCloud services. It is because cloud computing requires so much bandwidth for storing and retrieving data (Pn13). Another participant stated that cloud computing and technology may constitute a very good mix of saving costs when using large quantities of capacity, for instance, terabytes, that is to say, while storing huge amounts of data. But then again, should you want to use this actually quite often, this might not turn out to be the right choice. Big data usage results in the transformation of a mobile phone or smartphone into a data access point (Pn18). From participants' perspectives, the survey results are disclosed in Figure 3. A total of 74% of participants think mobile cloud computing can be capable of reducing overall expenses, whereas 17% think it is not beneficial to use mobile cloud technology for the purpose of cost-saving. The rest 9% either did not know or refused to answer.

Cost model parameters: τ (device lifetime, months); H_{cloud} (VM/container hours); S_{cloud} (GB stored); G_{egress} (GB transferred out); c_{egr} often dominates for data-intensive apps; S_{prod} can be estimated via value-of-time.

Berkeley's analysis emphasizes egress/transfer as a hidden driver of cloud cost.

4 A Model for the Factors Affecting the Adoption of Mobile Cloud Computing

Mobile cloud computing is an approach that the author wants to recommend. In the author's opinion, this suggestion is founded on the result of this study [31]. On the right side of the page, we can find a sequence diagram that portrays the probable stages of mobile cloud technology adoptions. The understanding of what mobile cloud computing is, along with its potential benefits and disadvantages, appears to be the very first step of the process for mobile cloud computing adoption. The criteria of this study and their influences on mobile cloud technology might be a good basis for creating such an awareness. Also, worth looking at is the study's identification of the very first prerequisite of the adoption process. The second stage goes into the first decision reached through the process for adopting mobile cloud applications. This normally began with a

$$\begin{aligned}\text{TCO} = {} & \frac{C_{\text{device}}}{\tau} + C_{\text{data}} + C_{\text{fix svc}} \\ & + C_{\text{cpu}} H_{\text{cloud}} + C_{\text{store}} S_{\text{cloud}} \\ & + C_{\text{egr}} G_{\text{egress}} + C_{\text{mgmt}} + C_{\text{sec}} \\ & - S_{\text{prod}}\end{aligned}$$

where:

- τ: device lifetime (months);
- H_{cloud}: VM/container hours;
- S_{cloud}: GB stored;
- G_{egress}: GB transferred out;
- C_{egr}: cost per GB transferred (often dominates for data-intensive apps);
- S_{prod}: productivity/time saved (can be estimated via value-of-time).

Berkeley's analysis emphasizes egress/transfer as a hidden driver of cloud cost.

Trial version of an advanced application. Accept, positive reject, or negative reject might be options on the first one. Positive rejection will give an opportunity to try again after drafting a report for the reason of rejection; negative rejection will terminate the mobile cloud adoption process without any reason provided. When accepted, the first confirmation must take place, and the necessary mobile cloud applications must be implemented. Finally, mobile cloud computing will be placed in long-term usage, along with updates for software, maintenance, and update procedures.

After the formulation of the mobile cloud computing framework based on the findings of this research, the need to ascertain whether such a framework could be utilized in the real world led to the evaluation and validation of the framework by three companies and people not involved in the first stages of the research project.

4.1 Latent-variable (SEM-ready) Equations

Let Adoption Intention (AI) and Use (U) be driven by technology perceptions (UTAUT/TAM & DOI), organizational/market context (TOE), and constraints (cost, risk, infrastructure):

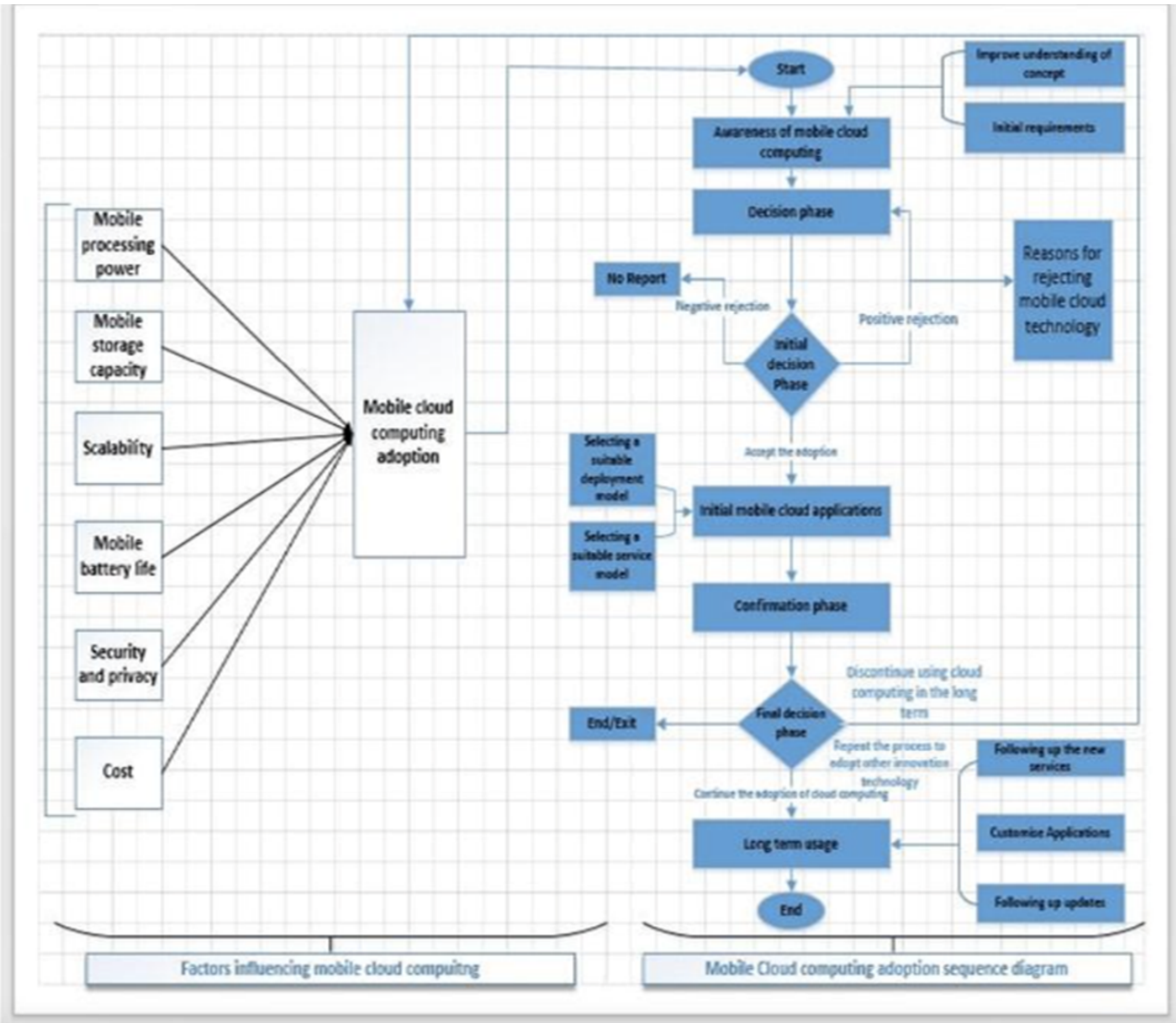

Fig. 3: A suggested framework for the adoption of mobile cloud computing.

$$
\begin{aligned}
AI = {} & \beta_1 PE + \beta_2 EE + \beta_3 SI + \beta_4 FC \\
& + \beta_5 RA + \beta_6 COMP + \beta_7 TRIAL + \beta_8 OBS \\
& - \beta_9 R^* - \beta_{10} TCO + \beta_{11} INF + \beta_{12} REG + \varepsilon_1
\end{aligned}
$$

$$
U = \gamma_1 AI + \gamma_2 FC + \gamma_3 TOP + \gamma_4 SKILL - \gamma_5 LAT + \varepsilon_2
$$

Constructs.

–**UTAUT/TAM:** *PE* performance expectancy, *EE* effort expectancy, *SI* social influence, *FC* facilitating conditions.
–**DOI:** *RA* relative advantage, *COMP* compatibility, *TRIAL* trialability, *OBS* observability.
–**TOE/Context:** *INF* infrastructure readiness (coverage, bandwidth, edge/cloudlet access), *REG* regulatory support/pressure, *TOP* top-management support, *SKILL* IT skills.
–**Constraints:** R^* security/privacy risk , *TCO* total cost of ownership (from Section 3), *LAT* network latency.
–**Moderators:** firm size, sector (e.g., health), country income level, and *access network* (Wi-Fi/edge vs. cellular).

5 Conclusion

The study has given the support of the adoption of mobile cloud computing. Different data collection methods were used from direct observation, focus group, questionnaire, and interviews. The investigation revealed a wide gamut of factors which directly impinge upon mobile cloud computing: these include processing and storage limitations on mobile devices, scalability of cloud computing, battery-life limitations on smartphones, advantages of mobile cloud computing with respect to security and privacy, and the monetary rewards. According to the results revealed, the greater number of advantages over the very few disadvantages that mobile cloud technology has meant to emphasize that there are truly more benefits to mobile cloud technology than its disadvantages. Nevertheless, mobile cloud technology benefits end-users the most if employed for high-complexity application software only, and hence, it does not seem useful if mobile cloud technology is to be used for a few simple applications, which focus on cloud technology.

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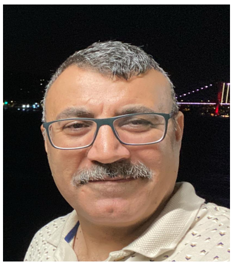

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