Crowdcloud: Cloud of the Crowd

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***Abstract*—The ever increasing utilisation of crowdsourcing in various domains and its popularity as a method of accessing free or inexpensive labour, services, and innovation, and also as a method of providing fast solutions is observed as a good opportunity for both non-profit and for-profit organisations while it also appeals to members of the crowd. In particular, many cloud-based projects have benefited from crowdsourcing their needs for resources and they rely on the crowd and the resources they provide, either for free or for a nominal fee. However, current cloud platforms either provide services to the crowd or request services from them. Moreover, cloud services generally include a legally binding contract between the cloud service providers and cloud service clients. In this paper, the possible opportunities for applying crowdsourcing principles in the cloud in a new fashion are reviewed by proposing the idea of crowdcloud. Crowdcloud simply refers to the availability of cloud infrastructure, cloud platform, and cloud software services to the crowd by the crowd with or without a legally binding contract. This paper discusses the differences between crowdcloud and other similar notions already in existence. Then, a functional architecture is proposed for crowdcloud and its constituents. Some of the advantages of crowdcloud, along with potential issues in crowdcloud and how to circumvent or minimise them are also reviewed and discussed.**

***Index Terms*—Crowdsourcing; Cloud of the crowd; Cloud services; Crowdcloud**

I. Introduction

Cloud computing is a method of providing computing as a service rather than a product. It is extensively used by both for-profit organisations such as Google App Engine [1], [2] and non-profit organisations such as Science Cloud [3] to provide services in three different ways: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). The many powerful characteristics of cloud computing, such as cost reduction, device and location independence, easier maintenance, higher performance capabilities, more reliability, and higher scalability have helped to expand the notion of cloud computing and broaden its applications and usage [4].

Crowdsourcing is a method of outsourcing tasks to a usually large, undefined group of people via an open call [5]. Crowdsourcing provides an opportunity for crowdsourcers to reduce the costs of the crowdsourced task and usually find faster solutions for them. The reduction of both money and time in obtaining possible solutions, plus opening the in-house innovation and problem-solving processes to the large, diverse crowd can also mean attracting more creativity and wisdom that might otherwise not be found inside organisations. Crowdsourcing potentials have since been utilised in numerous domains of study, such as business, computer sciences, and medicine [6]. Crowdsourcing has also been utilised in several commercial and non-commercial platforms, such as Amazon Mechanical Turk [7] and Threadless [8], and has been structured in several forms, such as micro tasking [9], crowdfunding [10], and the application of the wisdom of the crowd within enterprises [11].

The extensive capabilities of cloud computing and the stimulating advantages of crowdsourcing, plus the existence of similar characteristics, such as reducing costs and increasing diversity, facilitate a solid ground for their unification. Such unification has already been noticed and utilised in several cloud projects such as SETI@home [12] and BOINC [13]. However, these cloud projects belong to corporations and organisations, i.e., the crowd resources have been utilised not by other crowd members but by organisations. For example, SETI@home belongs to Berkeley and Microsoft Azure belongs to Microsoft. There is still a lack of a comprehensive cloud infrastructure that can actually be stemmed from the crowd, be organised by the crowd, and be utilised for the crowd. While Torrent clients and similar peer-to-peer platforms do exist, they are mainly used for file sharing and not for sharing other resources such as computing power, cloud storage, and software on-demand services.

Implementing and utilising such a cloud service, where the crowd can share their cloud resources such as storage and computing power, can introduce many benefits to cloud clients. These benefits, which will be discussed later in this paper, inspire the foundation for this study. In this paper, crowdcloud is proposed as a cloud environment that meets the above-mentioned criteria. In a nutshell, crowdcloud is a cloud service provided by the crowd for the crowd. This paper provides a theoretical background work for crowdcloud as a cloud infrastructure where the crowd provide the necessary cloud resources for the crowd, and where the crowd can also meet their cloud requirements provided by the crowd. As a vision paper, this paper will not delve into the technical implementation of crowdcloud, but it will introduce the foundation and architectural aspects of crowdcloud.

The rest of the paper is structured as follows. In Section II, crowdcloud and its theoretical foundations are presented, and the similarities and differences between crowdcloud and other similar cloud services already investigated in the literature are elaborated. In Section III, an architecture for crowdcloud is proposed and its constituents are explained. In Section IV, some advantages of crowdcloud are discussed and some of the challenges that may rise in crowdcloud are mentioned with possible solutions to circumvent or mitigate them. Section V concludes the paper and suggests the future work.

TABLE I
DIFFERENCES BETWEEN ORDINARY CLOUD SERVICES, CLOUDSOURCING, VOLUNTEER CLOUD COMPUTING, SOCIAL CLOUD, AND CROWDCLOUD

Cloud Service	Service Providers	Service Clients	Management	Contract
Ordinary Cloud Services	Organisations	People or Organisations	Centralised	Yes
Cloudsourcing	Organisations	Organisations	Centralised	Yes
Volunteer Cloud Computing	People	Organisations	Centralised	No
Social Cloud	People	People	Decentralised	No
Crowdcloud	People (or Organisations)	People (or Organisations)	Decentralised	Yes/No

II. FOUNDATION OF CROWDCLOUD

Crowdcloud refers to the provision of computing services at different levels of IaaS, PaaS, and SaaS by the crowd and for the crowd. The crowd, in this definition, can include both individuals and organisations. Crowdcloud acts like an online free market where every individual and every organisation can supply their resources or demand for other's resources, following the regulations of the free market. The idea of crowdcloud applies several features of crowdsourcing such as largeness, diversity, and incentives provision [14] in the cloud. Crowdcloud lets the crowd provide their idle resources to other individuals or organisations in the crowd, and also request their required resources from other crowd members. This can happen at the infrastructure level (i.e., IaaS), e.g., by providing or asking for CPU power and storage space, at the platform level (i.e., PaaS), e.g., by providing or asking for runtime libraries and web servers, or at the software level (i.e., SaaS), e.g., by providing or asking for email applications and on-demand software systems.

Ordinary cloud services, such as Amazon EC2 or Google Drive, are cloud services which are provided by organisations for other organisations or people. These cloud services come with a legally binding contract between the cloud service provider and the cloud service client and are mostly costly for other organisations, but they are usually free or inexpensive for individuals to use. In some cases where provided cloud services are free of charge, organisations usually compensate for the costs by introducing advertisements along with their free cloud services. Furthermore, these services are generally managed in a centralised way, and this has instigated issues related to data control and privacy [15] as well as legal issues [16]. Crowdcloud, on the other hand, is fully decentralised, provides cloud services from the crowd to the crowd, and can be contract-free.

Crowdcloud bears some similarities with a few concepts in the literature, such as *cloudsourcing*, *volunteer cloud computing*, and *social cloud*. However, the differences between crowdcloud and these concepts render crowdcloud as a novel idea and make crowdcloud stand out as an entirely free market model for cloud service provision. These differences will be discussed in detail in the following paragraphs.

Cloudsourcing refers to outsourcing various elements of a business or organisation IT infrastructure to other companies or organisations which provide such services [17], [18]. Therefore, the first difference between cloudsourcing and crowdcloud lies both in the cloud service providers and cloud service clients. In cloudsourcing, organisations provide some cloud services to other organisations. In crowdcloud, however, the crowd provide some cloud services to the crowd. The second difference between the two is that cloudsourcing is centralised while crowdcloud is not. The last difference between cloudsourcing and crowdcloud is that cloudsourcing is always based on a contract between two organisations, while crowdcloud may or may not be contract-based.

Volunteer cloud computing, also known as peer-to-peer computing or global computing, refers to the use of computers volunteered by the general public for distributed scientific computations [19], [20]. SETI@home and BOINC are examples of volunteer cloud computing. In this case, and apart from its aforementioned purpose, two main differences exist between volunteer cloud computing and crowdcloud. The first difference is that in volunteer cloud computing, the crowd provides a service, such as CPU power or storage, solely for organisations (and normally for research purposes) and not for other people. The second difference is that volunteer cloud computing, unlike ordinary cloud services, is not based on a contract and people have no obligations whatsoever to provide cloud services or keep providing cloud services to their beneficiaries. Crowdcloud, however, can be both contract-free and contract-based.

Social cloud is probably the closest in meaning and application to crowdcloud. Social cloud refers to a framework for sharing resources and services based on relationships amongst the members of a social network [21]. The notion of social cloud implies three ideas that form the differences between social cloud and crowdcloud. The first difference is that social cloud depends on a social network and relationships amongst the members of that social network. This limits the cloud service provision to socially connected members within the social network. Crowdcloud, on the other hand, is not necessarily a social network, and can exist independently as an online free market for cloud services. This provides a wider range of services to acquaintances and non-acquaintances alike. The second difference is that social cloud works solely on social contracts, while crowdcloud can work on legally binding contracts or be contract-free. Finally, social cloud explicitly limits the use of each individual's resources to other individuals. Crowdcloud, on the other hand, is open to both individuals and organisations, for-profit or non-profit, for the use of resources.

The differences between crowdcloud and other similar cloud services are shown in Table I. These differences include who the service providers and service clients are, how these platforms are managed, and whether a contract is needed between cloud service providers and cloud service clients for the use of cloud services.

III. Crowdcloud Architecture

The proposed architecture for crowdcloud is presented in this section along with a short description of its constituents. It is depicted in Fig. 1.

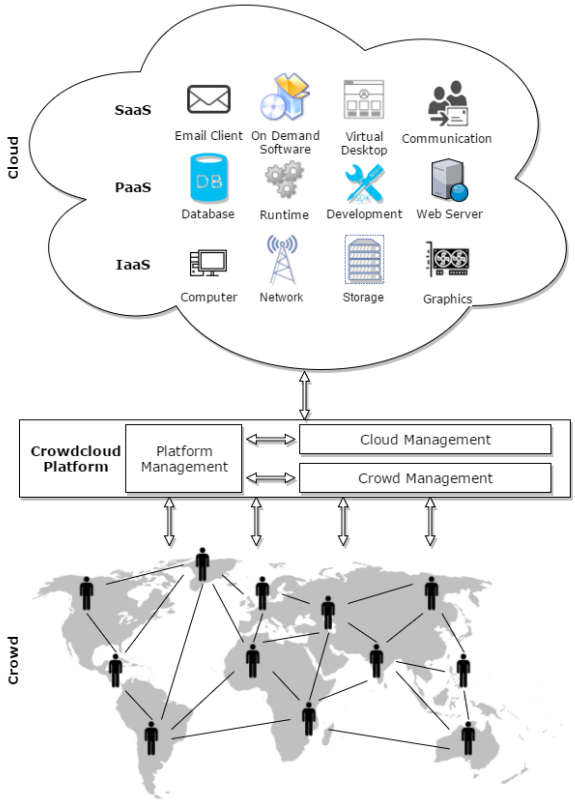

Fig. 1. The proposed architecture for crowdcloud

As Fig. 1 illustrates, crowdcloud has the following three constituents: the cloud, the crowd, and the crowdcloud platform. The crowdcloud platform utilises three distinct modules which interact with each other. These modules are explained below:

- **Crowd management module:** This module is responsible for managing the crowd and their interactions. In particular, this module manages crowd members' registration, records their service agreements, handles availability of service contracts (if any), and facilitates interactions amongst cloud service providers and cloud service clients in the crowd.
- **Cloud management module:** This module is responsible for managing the crowd resources in the cloud. In particular, this module records the list of all available cloud resources, documents their providers and clients, keeps track of cloud resources availability status, and manages cloud resource allocation.
- **Platform management module:** This module is responsible for managing the crowdcloud platform. In particular, it serves as the interaction gateway between the other two modules and coordinates their functionalities.

IV. Advantages and Challenges of Crowdcloud

In this section, some of the characteristics and advantages of crowdcloud are presented. In the same fashion, some challenges that the implementation of crowdcloud can introduce are discussed and possible solutions to avoid or mitigate them are presented. It should be noted that crowdcloud, as a novel concept, will need more theoretical research to be conducted before any implementation attempts are made in order to guarantee a quality service which addresses all benefits and possible challenges accordingly.

A. Crowdcloud Characteristics and Benefits

Crowdcloud brings about a set of features and advantages that can be exploited to the benefit of the crowd, as well as organisations, and which can differentiate crowdcloud from other cloud services already in existence and give it a competitive advantage. These features include, but are not limited to, the following features.

Decentralised resource management. Resource management, as a crucial factor in cloud computing [22], is usually performed by organisations in ordinary cloud services and in cloudsourcing, and is therefore conducted in a centralised way, i.e., they are centrally managed by one organisation. In volunteer cloud computing the resources are distributed inherently, but their management is still usually centralised by the service clients, i.e., the service client decides when and how to use the resources.

Crowdcloud, on the other hand, is completely decentralised in its resource management, meaning that each cloud service provider (i.e., an individual or an organisation) in the crowdcloud environment is responsible for managing the cloud resources they have provided, and there is no central authority to manage all the provided resources on a crowdcloud platform. The cloud management module on the crowdcloud platform is not a central entity either, but a distributed one where every crowd member will manage their own cloud resources through their own local copy, while interacting with other crowdcloud platforms over the network for coordination and interaction purposes.

Bidirectional service exchange. In ordinary cloud service providers, cloudsourcing and volunteer cloud computing, organisations either provide services (e.g., Google Drive provides storage space for its clients) or they request services (e.g., SETI@home requests CPU power to analyse radio telescope data). This means that service provision in these cloud environments in unidirectional.

Crowdcloud, similar to social cloud, provides the opportunity for the ordinary crowd to both provide services and request them, thus providing a bidirectional service exchange. For example, a crowd member may provide a storage space for another crowd member while requesting a specific software program from the same or different member. The key difference, however, between social cloud and crowdcloud is that crowdcloud is not restricted to individuals, and organisations can also play the role of single entities in providing and requesting cloud services.

Democratised service provision. When cloud service providers are corporations and organisations (for-profit or non-profit), they are fundamentally the ones who set the trends, determine the prices, obligate terms of services, etc. This means that the crowd will have no say and no control over these domains and have to abide by the rules set for them.

On crowdcloud, however, and similar to social cloud, everything is determined by the people. It is a free market where it is people who decide, possibly in a democratic way, which services to provide and how these services should be priced, how quality of service should be ensured, etc. Furthermore, it is possible for the crowd members to bargain over prices, terms and conditions, etc. This means that, for example, you may even find free virtual desktops or free on-demand software services for your needs. Here, the difference between crowdcloud and social cloud is that social cloud is based on a social network and relations amongst people, which limits the provision of services to a pre-defined list of friends, or friends of friends, etc. In crowdcloud, however, resource requests can originate from anybody in the crowd towards anybody in the crowd, whether such requests are accepted or not.

Pricing. Using several existing cloud services usually incurs a price on the clients, especially when the client is an organisation. Free cloud services do exist, but they also usually come with a set of limitations, such as bandwidth or data volume limitations, or with unwanted, usually obtrusive advertisements. However, paying for cloud services is justified because of the costs of running, maintenance, upgrade, personnel, etc.

Crowdcloud offers the possibility of getting cloud services either for free or for a nominal cost. In social cloud, this possibility also exists, but only for a certain group of people in an individual's social network, e.g., one's friends or friends of friends. In crowdcloud, on the other hand, people may have different motivations to provide free or inexpensive cloud services, friendship only being one of them. Other reasons might include a mutual agreement to use each other's resources, getting social incentives such as a better visibility in an online forum, or simply as an act of altruism and helping towards a good cause, such as providing one's resources for global awareness about a certain topic. While it is acknowledged that this may not be a noticeable difference between crowdcloud and other cloud services, the possibility of tapping into an overwhelmingly large and possibly free pool of cloud services is still an advantage of crowdcloud.

Free market model. Crowdcloud follows a free market model where the crowd provide and request cloud services. In this free market model, the crowd can determine the revenues and the costs, they can bid for services, and they can exchange one service for another. The crowd can cooperate on service provision or compete to receive them, and in the long run, the crowd will learn from past experiences and adapt to new emerging situations. Last but not least, the crowd will self-organise their interactions, service provisions and requests, and their forthcoming challenges. This idea of free market is probably the most prominent feature of crowdcloud.

B. Challenges in Crowdcloud

While the idea of crowdcloud can potentially offer several advantages to the clients of cloud services, it amplifies several already existing challenges in cloud service provisioning that should be addressed and introduces new challenges to this paradigm as well. Without appropriate consideration of these challenges, a successful, useful implementation of crowdcloud cannot be guaranteed. Below, these major challenges are discussed and possible solutions are proposed.

Availability. One issue that should be addressed in crowdcloud is availability. In ordinary cloud services and cloudsourcing, a certain percentage of availability is guaranteed for cloud services clients [23]. Although sometimes organisations fail to hold onto their promises about the level of availability [24], clients can generally rely on these promises, and they usually get compensated in situations where availability is compromised.

Such availability promises are often absent and cannot be guaranteed in a crowdcloud environment. When service providers in crowdcloud provide their services in an ad-hoc manner with no contractual bindings, they may withdraw from service provision without proper notice at any time. But even with contracts made between cloud service providers and clients in crowdcloud, the nature of crowdcloud still overshadows its availability. While this may not be a big issue in some instances such as CPU power, i.e., the client may connect to another client and use their CPU power, this can cause a huge problem in some other instances such as cloud storage, i.e., if a client becomes unavailable while providing cloud storage, all files on their storage device will be unavailable to their client during that period of time.

To overcome availability issues, a number of solutions can be adopted. One possible solution, when applicable, can be redundancy, i.e., a client may use several similar cloud services in crowdcloud to guarantee their desired level of availability for that certain service, e.g., a client may copy their files on several storage services just to make sure they will never lose the availability of their data. Another possible solution is for service providers and service clients to sign a binding contract, negotiating and detailing the level of service availability. Another possible partial solution is the trust-based solution, i.e., people will less likely stop providing their cloud service to their friends without at least notifying them about it in a reasonable time to let them find alternative cloud solutions. Reputation systems can also be put in practice to make clients aware of those cloud service providers who have gained more reputation based on their service provision availability.

Security. Another prominent issue that cloud clients may encounter in crowdcloud is the security. Ordinary cloud services have their own security issues [25], but it can get much aggravated in crowdcloud. When well-established, reputable organisations provide cloud services, their clients generally trust them as they request resources from them. If any security breaches occur, clients are usually assured that certain measures will be taken to both reduce the adverse effects and to ensure that the possibilities of such breaches in the future are minimised.

On the other hand, this is not the case on a crowdcloud platform. Given that resources are provided by ordinary people, clients cannot be guaranteed to benefit from any security measures if and when security breaches occur. Furthermore, trusting cloud service providers or clients is also an issue when they are individuals rather than organisations, especially in the absence of a legally binding contract. For example, providing CPU power as a resource to another individual could raise the possibility of one's system being hacked, inducing harm to the service provider. Similarly, receiving storage space as a resource from another individual could also raise the possibility of ones' personal information being misused, inducing harm to the service client.

It should be noted that even big organisations sometimes fail to take good care of their clients' security, leading to many research into security issues in the cloud [26]. Furthermore, in a crowdcloud platform, a trust-based system can be formulated between every service provider and service client as a possible solution to security issues. For example, clients should be able to share certain resources only with certain people, e.g., only with their friends or with their friends and their friends of friends, as in the case of social cloud. Furthermore, leaving a certain degree of responsibility of ensuring security on its stakeholders is not a new idea and many cloud service providers are already practising this. For example, it is up to the Google Drive client to decide which files to share and with whom. While the consequences of sharing infrastructure resources with the wrong people is probably more dire, it is still observed as a good practice to leave it for the people to decide on it and enforce it when and if necessary.

Privacy. Given the nature of crowdcloud, which is providing cloud services by the ordinary crowd to the ordinary crowd, privacy issues constitute an instant threat. In ordinary cloud computing, cloudsourcing and volunteer cloud computing, organisations have a data security policy that ensures data privacy and enforces clients' data protection. Even with big organisations and cloud service providers, privacy always remains an issue in the cloud [27] and it makes big news in the media every now and again [28], but it can get even more exacerbated in the case of crowdcloud.

Cloud service providers in crowdcloud usually comprise of ordinary individuals, whose locations might sometimes be unknown, and whose local privacy regulations may differ significantly from privacy regulations in the countries where cloud service clients reside. Then it is also the issue of malicious service providers, which arises in many contexts where the crowd is given authority or responsibility [29], [30]. Combined together, these issues can form significant threats to clients' privacy.

There are a number of measures to take in order to minimise clients' privacy breaches in crowdcloud. Reputation systems help the clients understand which cloud service providers are well-famed or ill-famed, and request for their services accordingly. Trust-based solutions also help the clients and providers in determining where their data can be stored, who can use the CPU power, etc. User-driven privacy enforcements [31] is another solution that can help increase privacy in crowdcloud.

Legal issues. Providing cloud services at the infrastructure level or platform level may pose legal threats, but providing software as a service probably introduces the majority of legal issues in crowdcloud. As for organisations, they usually provide software as a service when they own the rights to the software or to the provision of the software as a service. In this case, the organisation will have all the rights to determine how to distribute the software and to determine pricing mechanisms. Apart from this, organisations usually provide their clients with Service Level Agreements (SLAs) which usually clearly defines each party's rights and duties, which can later be referred to when disagreements arise between service providers and service clients [32].

The ordinary crowd, on the other hand, may own the software they have on their systems through the purchase of that software, but they usually do not have the rights to redistribute the software or provide it as a service to other people. Furthermore, there are usually no contracts or SLAs between service providers and service clients in crowdcloud, making it difficult to settle disagreements and legal disputes if and when legal issues arise.

In order to resolve general legal issues in crowdcloud, it seems necessary that service providers and service clients should be required by the crowdcloud platform to agree with certain rights and responsibilities before committing to any service provision or initiating any service request. However, providing software as a service will be impossible for several software systems under copyright laws with current legislations. Providing other forms of software as a service, such as freeware software, open source software, and software under copyleft laws, may not pose legal threats.

Retention. A significant issue in crowd-based systems is that, in the absence of an appropriate type of motivation, crowd members may lose their interest in actively participating in crowdsourced activities. Crowdcloud is no exception in this case and will require an incentive model for the engagement and retention of the crowd in providing cloud services.

The problem of crowd engagement and retention in crowdcloud can be circumvented or minimised in several ways. First, crowd members' active participation can be encouraged through the free market model, where crowd members can fulfil their cloud requirements through a supply and demand model. That is to say, crowd members will need to stay engaged and active on the crowdcloud if they want to maintain their access to cloud services they require.

Second, as with other similar crowd-based systems and platforms [33], [34], gamification has been shown to be a plausible method of motivating and retaining crowd engagement through points, badges, and leaderboards [35]. For instance, crowd members can be incentivised for each cloud service provision through points, and they can appear on leaderboards based on the most positive feedback they get from their clients. When carefully engineered and implemented, such immersion in gamification can cause crowd members to fully engage in crowdcloud, while it also makes them commit to higher quality cloud service provision for more points, more badges, and higher ranks in leaderboards.

V. Conclusion and Future Work

In this paper, crowdcloud was proposed, which brings the notion of crowdsourcing into the domain of cloud computing. Crowdcloud is an emerging paradigm in cloud service supply and demand which has the potential to provide a free market of cloud resources where both individuals and organisations can participate in cloud service provision and cloud service request. This paper proposed an architecture for crowdcloud, and then some of the more prominent features and advantages of crowdcloud were discussed, and some of the disadvantages of crowdcloud were also addressed along with how to possibly avoid or minimise them.

Since the idea of crowdcloud is new, there is still much space for future work, especially for the solidification of the theoretical background of crowdcloud as well as its implementation as a new cloud service. Other venues for exploration and research include investigations on methods and principles to address and solve the existing challenges in crowdcloud, while maximising its many advantages and potentials as a crowd-based cloud service. Particularly, more research on the potential threats must be carried out before the implementation of crowdcloud to ensure the security and privacy of crowdcloud clients.

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