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Review of Mobile Crowd Computing

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ABSTRACT: Although smart phones are increasingly becoming more and more powerful, enabling pervasiveness is severely hindered by the resource limitations of mobile devices. The combination of social interactions and mobile devices in the form of 'crowd computing' has the potential to surpass these limitations. In this paper, we review a crowd computing for mobile devices. Here we explore this concept of 'work stealing' for crowd computing on an opportunistic network of mobile devices, for both machine and human computation. We also present experimental data and discuss the findings.

KEYWORDS: mobile crowd computing, mobile cloud computing, work stealing;

I. Introduction

Today's Smartphone is a powerful computer. It is equipped with a range of sensors, a gigahertz-range CPU and high-bandwidth wireless networking capabilities[2]. Inspired by the increasing prevalence of smart phones, and research into opportunistic networking, we have evaluated the potential of using these devices to carry out large-scale distributed computations. Crowd computing, in which opportunistic networks can be used to spread computation and collect results. A crowd computation spreads opportunistically through a network, using ad-hoc wireless connections that form as devices come into proximity. The devices can exchange input data and intermediate results. In parallel work, we are developing programming languages that enable developers to implement a crowd computation; this paper focuses on the aggregate utility of such a computation, in terms of how much work each device can carry out[3].

Crowd computing is a term that has been used only recently in the literature, with a few references to the term in the early 2000's and most work from about 2009 onwards, featured in conference papers rather than academic journals. It has attracted attention in the Computer Science community from researchers with interests in fields such as CSCWD (Computer Supported Cooperative Work in Design), artificial intelligence and pervasive computing.

Crowd computing been conceptualized in various ways as being related to crowd sourcing, human computation, social computing, cloud computing and mobile computing. A number of authors have put forward their own definitions to address a perceived lack of a common definition. Bessis et al. have noted that the emergence of differently labelled technologies with somewhat similar purposes can cause confusion, and in response have offered conceptions on how these technologies relate to each other. Schneider et al. have elaborated on earlier work and offer their own characterization of crowd computing systems, mapping out the application space that is encompassed by crowd computing. Some authors have referenced work on crowd computing by other researchers but it appears that the multiple streams of research and definitions[6] have evolved somewhat independently, perhaps due to the relative newness of this area of interest. By reviewing the extant literature on the subject of crowd computing, this paper aims to reconcile and integrate various descriptions that have been put forward in order to derive a definition of crowd computing. According to Pozzi, a definition serves to delimit an entity with respect to all others, and plays a central role in any inquiry. A definition of crowd computing can be used to position the research already conducted on this subject to understand its relevance and coverage. Therefore a clear definition is the starting point for further research, to articulate a meaningful research problem to address gaps in prior research[3].

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II. CONCEPT OF MOBILE CROWD

Mobile computing can provide a computing tool when and where it is needed irrespective of user movement, thereby supporting location independence. However, the inherent problems of mobile computing such as resource scarcity, finite energy and low connectivity pose problems for most applications. These problems can be addressed by 'sharing' resource intensive work with a resource rich server. However in situations concerning mobile devices, connecting to a remote resource cloud via WiFi or 3G is not feasible because of bandwidth issues, data access fees, and the battery drain. Increasing usage and capabilities of smart phones, combined with the potential of crowd computing [1] can provide a collaborative opportunistic resource pool to solve these problems. We define 'mobile crowd computing' as a local 'mobile resource cloud' comprising of a collection of local nearby mobile devices, utilized to achieve a common goal in a distributed manner.

Work distribution in a mobile environment poses a different set of issues than a typical distributed/grid environment:

1) Less processing power on a mobile device than on s node in distributed processing system.
2) A mobile node has on a finite energy source.
3) A resource pool made up of mobile devices is highly volatile, and hence node availability is inconsistent.
4) In a mobile cloud, the devices will be unknown to each other a priori, unlike in a grid environment where nodes are established and approved beforehand. Therefore a mobile cloud calls for a more opportunistic and ad hoc behaviour.
5) A mobile cloud is most likely to be heterogeneous.

Therefore, a mobile resource pool requires a dynamic load balancing method that is decentralized[4], proactive and self adaptive instead of the static master-slave work farming. 'Work stealing' is a good candidate for this since it possesses the aforementioned characteristics, and the aim of this paper is to present a work stealing approach to dynamically load balanced mobile crowd computing. By mobile crowd computing, we mean machine computation as well as human computation on a crowd (pool) of mobile devices. Here, machine computation refers to work done purely on computers without human intervention, and human computation refers to work done on computers using human expertise[1].

Although 'work stealing' method has been employed for job scheduling with load balancing in distributed environments such as Cilk, and Parallel XML processing, it has not yet been used in mobile computing domain, as far as we know. The need for dynamic load balancing was demonstrated in, where distributed Mandelbrot set generation was done over a set of mobile devices. Mandelbrot set generation is one of the two applications used here as well, but here, we use the work stealing mechanism to efficiently distribute tasks. Work stealing in a 'mobile cloud' would mean connecting opportunistically to unfamiliar devices, while considering the demands of connectivity on the limited battery as well. Therefore, our implementation employs an adjusted version of the traditional work stealing scheme to better suit mobile computing. We show that this mechanism will always give a speedup gain, provided the devices are in no great distance from each other.

III. LITERATURE SURVEY

Mobile crowd computing is applicable for any instance where a group of people are likely to work in close proximity to each other. Although it is not necessary that the group of people are not total strangers, users could be reluctant to share their mobile resources with strangers due to security and privacy reasons. Therefore, a situation consisting of a 'known' community is most likely to succeed. It needs to be noted that we only suggest the users are 'known' to each other, not the devices.

3.1 Human interaction tasks with mobile devices

Murray et al. appear to be the first authors to put forward a description of crowd computing. According to Murray et al. in crowd computing, "opportunistic networks can be used to spread computation and collect results. Where the nodes in such networks are mobile phones, large bandwidth is available and crowd computing can be used "as a means of distributing human interaction tasks to mobile devices. Fernando et al. have adopted this description for the term 'mobile crowd computing', where machine and human computation takes place on a crowd of mobile devices.

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3.2 Cloud computing with humans

Miller et al. have suggested that “One way to think about crowd computing is as the human analogue to cloud computing.” Here the cloud provides elastic, available access to computation and storage resources and the crowd provides similar access to human capabilities. Integrating human computing ability into the cloud can spawn different emergent and evolving online communities.

3.3 Scalable human problem solving

The idea of utilising human problem solving capabilities is embodied by Cooke and Gillam in their description of crowd computing as “the use of a number of people who are offering human intellect and their computers to solve problems which are at present unsuitable for computational approaches.” Similar ideas are expressed by Bernstein and Lasecki et al. Bernstein encapsulates this notion of the human intelligence element in his concept of ‘crowd-powered systems’ that “combine computation with human intelligence, drawn from large groups of people connecting and coordinating online.” He describes two crowd sourcing applications, a word processor and a camera application. Lasecki et al. suggest that crowd computing provides software with abilities of individual humans and describe a system (Chorus) that facilitates a natural language, real-time two-way conversation[8].

3.4 An umbrella term for human interaction tools

Schneider et al. offer a broad definition of crowd computing as an “umbrella term to define a myriad of human interaction tools that allow the exchange of ideas, non hierarchical decision making, and full use of the world’s mind space”. Schneider et al. have cited the above definition and offer a characterization of crowd computing systems in the context of CSCWD.

3.5 Narrower descriptions of crowd computing concept

Some authors have described crowd computing in a more narrow sense in and/or used the term interchangeably with other concepts. However, there is still variation amongst these narrower descriptions. Bessis et al. and Asimakopoulou and Bessis characterise crowd computing as akin to crowdsourcing or citizen science where citizens are engaged in participatory data collection, allowing up to date information to be collected from distributed data sources and used for integrated action or responses (for example in a disaster situation). Muhammadi and Rabiee describe crowd computing as crowd sourcing, where human perception and intellect are used for problem solving. Kucherbaev et al. have taken the concepts of outsourcing tasks to crowds with harnessing collective intelligence as the aims of the crowd computer, a programmable platform to develop crowd sourcing applications. They refer to the practice of using humans in computation as crowd sourcing or social computing. Gration and Miah have interpreted crowd computing as crowd sourcing, a technology for crowd management. Lim et al. view crowd computing as a type of locative media, based on the concept of crowd computer interaction, where interaction takes place with people sharing a large display in collocated public settings.. Roughton et al. extend crowd computing in the context of crowd computer interaction to also encompass virtual crowds[5].

Crowd computing is viewed by Lima et al. as emerging from social computing and they describe it as human interaction for task and idea sharing making use of various Web 2.0 tools. Medeiros et al. apply the definition from Schneider et al. in a narrower context of large group decision making, looking at tools for idea exchange, decision-making and collaboration. As can be seen from the descriptions outlined above, the focus tends to be on specific aspects of crowd computing rather than describing the concept as a whole[6]. These narrower descriptions of crowd computing can be positioned within specific classes of crowd computing applications as outlined later in this paper. Areas of commonality across descriptions are also synthesized to identify the core characteristics of crowd computing, towards providing an encompassing definition of this term[9].

IV. CHARACTERISTICS OF MOBILE CROWD

Four specific characteristics of crowd computing can be identified from the descriptions, examples and discussions in the literature. Together, these elements can be used as a basis for a definition of crowd computing. A fifth element, i.e. collective intelligence, is also highlighted due to its prevalence in the literature. However, this should be considered

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an optional element rather than central to the definition of crowd computing, as it does not present in all instances of crowd computing[5].

Application class	Crowd	Computing platform	Predetermined purpose	Human capabilities	Collective intelligence
Web 2.0 and social computing	Yes, online	Yes, mostly Internet	Sometimes, may be used just for sharing or social activity	Yes, social behaviour, creativity	Sometimes
Crowdsourcing	Yes, mostly online	Mostly, Internet, but can involve no technology	Yes, includes creation, problem-solving, idea generation	Yes, various	Yes
Human computation	Mostly, but can involve individuals	Yes, mostly Internet	Yes, performing tasks, e.g. problem solving	Yes, various	Sometimes
Audience/crowd computer interaction	Yes, online and physical	Yes, can include mobile, sensors, other	Yes, typically for engagement	Yes, social behaviour, coordination	Sometimes

Table 4.1. Characteristics of crowd computing applications

The literature offers a host of examples of crowd computing applications and platforms that have been built as well as conceptual applications of how crowd computing could be used. Conceptual examples include data collection, integration and communication for disaster management, photographic coverage of events, emergency response communication at events and organisation and management of contests. Some real-world examples are mapped to the crowd computing characteristics and application classes described in the previous sections. Rather than the list being exhaustive it aims to illustrate commonly cited and representative examples across the breadth of the application classes[7].

Application example	Description	Application class	Crowd	Computing platform	Purpose	Human capabilities	Collective intelligence
ESP Game	Players suggest labels for images	Human computation Crowdsourcing Web 2.0	Online Collective – anonymous Different times, different places Members work independently	Internet-based	Problem solving – image identification	Visual recognition	Implied
Missile Command Game	Players coordinate to destroy missiles	Audience-Computer Interaction	Physical collocated crowd Same time, same place Members work cooperatively	Camera tracks movement, computer displays and processes.	Engaging the audience	Physical coordination	Not applicable
Wikipedia	People contribute to online encyclopaedia	Crowdsourcing Web 2.0 Social computing	Online Collective Different times, different places Members build on others' contributions	Internet-based	Creation	Knowledge, writing	Yes, diversity of contributors
FixMy-Street	Citizens report, update and track resolution of community problems	Crowdsourcing Web 2.0	Online Collective – focus on local communities Different times, same place Members can post and update	Internet-based	Problem reporting and resolution (information flow)	Local knowledge, sense of interest and identity	Yes, by fostering cooperation to address problems
Innovation Jam	Participants submit and refine business ideas	Crowdsourcing Social computing	Online large Group or Collective Same time, different places Members contribute ideas, may build on each other's contributions	Internet-based	Ideation and development	Creativity, knowledge, analytical or strategic skills	Yes, by incorporating stakeholders into innovation process

Table 4.2 Examples of crowd computing applications

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V. Conclusions

The core characteristics of crowd computing are participation by a crowd of humans, interaction with computing technology, activity that is predetermined by the initiator or application itself and the execution of tasks by the crowd utilizing innate human capabilities. We have proposed 'mobile crowd computing with advanced Security' as a local 'mobile resource cloud' comprising of a collection of local nearby mobile devices, utilized to achieve a common goal in a distributed manner. Our results with work stealing on mobile devices show that it is a viable method for efficient work distribution in a mobile cloud. Work distribution in a mobile environment poses a different set of issues than a typical distributed/grid environment.

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