2016 IEEE 24th International Conference on Network Protocols (ICNP)
Workshop on Hot Topics in Practical Networked Systems (HotPNS 2016)

How Sustainable is Social Based Mobile Crowdsensing? An Experimental Study

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***Abstract*—The wide spread of smart mobile devices such as tablets and phones makes mobile crowdsensing a viable approach for collecting data and monitoring phenomena of common interest. Smart devices can sense and compute their surroundings and contribute to mechanisms that examine social and collective behaviours. Crowdsensing offers a feasible alternative to exchange and compute sensing tasks and data between devices. Due to the limited resources (i.e., battery, processing power, memory) of smart mobile devices, the cooperation and hence, the performance of the mobile crowdsensing applications may be affected. We empirically show that collective incentives, such as trust (social ties) among participants, and resources availability can boost the performance of mobile crowdsensing applications. This collective incentive together with the existing cooperation enforcing mechanisms, can enhance the cooperation of the participants and incentify them to cooperate in social based mobile crowdsensing applications.**

***Index Terms*—Crowdsensing, Cooperation enforcing mechanisms, social-ties**

I. Introduction

The capabilities of modern smart devices (SDs) provide new possibilities for more refined and precise studies in various areas due to their ability to contribute in crowd computing and networking procedures. These mobile devices have the potential to sense their surroundings with spatial granularity and accuracy in negligible time. Mobile SDs can contribute to the analysis of human behaviour and natural phenomenon such as pollution, CO2 levels, traffic, and collective mobility patterns. SDs also have wireless capabilities that allow them to transfer the collected data with each other or to upload them to Cloud servers. For instance, the data exchanged between mobile phones can inform users how long is the queue in a particular bus stop. Also, mobile crowdsensing mechanisms can monitor environmental condition in a particular area such as humidity, pollen and pollution to provide meaningful information to a Cloud service that detects potential health risks. However, due to the inherent human selfish behaviour, the benefits of crowdsensing applications may not be clear to the participants in the field, and the requested tasks may not be executed due to low resource availability or trust issues. Given that any mobile user is self-interested and he ideally uses others' resources/sensors without sharing any of his, *cooperation enforcing mechanisms* have to be proposed.

Cooperation enforcing mechanisms can be categorized in many ways. The first way to categorize them is based on their core component, which is the units that are employed to stimulate users' cooperation. These are: *credits* and *reputation*.

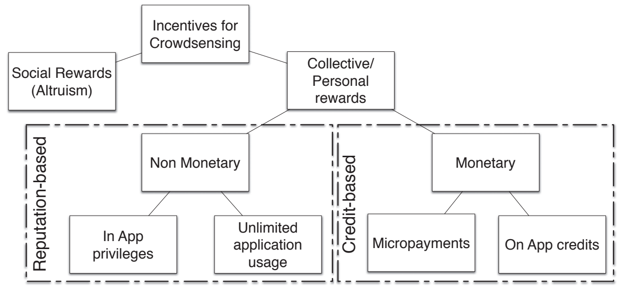

Fig. 1: Categorisation of cooperation enforcing mechanisms.

Credit based systems work as currencies. The key idea is that users providing a service should be remunerated, while nodes receiving a service should be charged. On the other hand, reputation based systems are based on the trust that has built between the mobile users and their contribution to the community. Reputation based schemes discourage misbehaviour by estimating users' reputation and punishing the ones with bad behaviour. The main difference between the reputation based schemes and the credit based schemes is that in the former each user can give different trust score to a user while in the latter, all the users should know how many credits a user has. Any personal or collective reward can be of two types: monetary and non-monetary. Monetary rewards are easier for the users to understand and to examine whether it is beneficial for them to share their resources or not but it is difficult from the crowdsensing mechanism to decide the monetary rewards. On the other hand, non-monetary rewards are much simpler for the crowdsensing mechanism to handle but each user can give different evaluation of such rewards. Figure 1 shows a categorisation of different techniques that can be implemented. The baseline scenario in mobile crowdsensing applications is the one that does not incorporate any cooperation enforcing mechanisms and the mobile users share their resources in an altruistic manner.

Figure 2 visualises the examined crowdsensing application, where mobile devices can be interconnected and exchange collected data, which can be either processed locally, autonomously or collaboratively, or uploaded to a server who is handling the crowdsensing application. A set of cooperation enforcing mechanisms can be utilised depending on the requirements and the type of the application while the users of the crowdsensing application can impose their requests to the server and receive the results.

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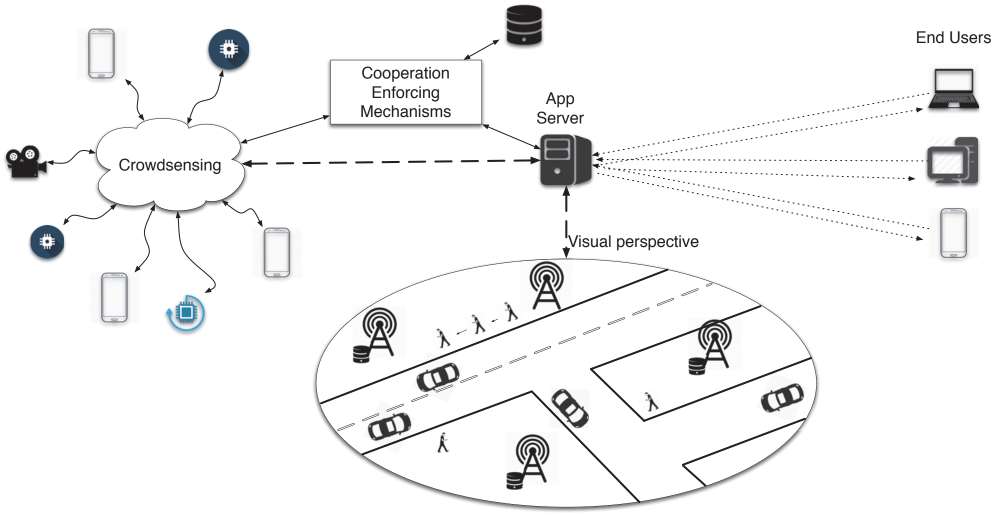


Fig. 2: Devices are dynamically connected and are collecting and exchanging data. The crowdsensing application server utilises the collected information and responds to queries. In order for the crowdsensing application to be functional, the mobile users have to be incentivised to dedicate parts of their resources.

In this article, we initially present, via our experimental results, that the crowdsensing users have a particular behaviour regarding their location and the confidence on the mobile crowdsensing application. These insights can lead to non-monetary incentive techniques, such as a better reliability and privacy settings on the server application that can concern users and degrade performance of the whole sensing ecosystem; or establish/predict the location of a particular user in order to request a sensing task and improve the acceptance ratio. As we show in the experiment Section II, mobile crowdsensing applications which consider user location and trustiness on the service can boost their performance.

II. Experiment Setup

The main goal of our experiments is to depict the importance of the mobile users' state, in terms of location and resource availability as well as their relationship with the other mobile users and the crowdsensing application provider. We designed a set of experiments to analyse these factors and examine whether it is feasible for a crowdsensing application provider to employ non-monetary incentive schemes to motivate mobile users to participate. Every crowdsensing task will consume the users' limited resources (i.e., battery, processing power, memory, Bluetooth interface), and this fact will affect crowdsensing users' behaviour. An example of a crowdsensing task can be the discovery of nearby devices via Bluetooth to measure the number of users in a particular area and use their accelerometer to detect possible traffic jams.

The resources availability is of high importance for mobile users, as they might not be able to use their devices for their needs, and hence, the crowdsensing tasks should not be assigned to mobile users whenever they do not have spare resources. For example, if a mobile user is at work, where she can charge her phone at any time, which resources stay idle, a crowdsensing application can send a task to this user as there will be available resources, and the user will be not reject the task. On the other hand, another user may be commuting, and the availability of resources will be limited since she might not be able to charge her phone shortly and she is also using her device at the same time, and in this case the probability of her to reject the crowdsensing task is higher.

Another important factor that affects the performance in crowdsensing applications is the trust between the mobile users and the crowdsensing task generators. Similar to human interactions, people behave in a more confident and relaxing way when they know the other person; this situation can be extrapolated to mobile crowdsensing scenarios, where the crowdsensing providers that are known by a user will have a higher probability of acceptance of their sensing task, and therefore, improve their system performance. Furthermore, one of the features of mobile crowdsensing applications is the possibility of sensing and collecting data between peers (other mobile devices) without accessing the Internet; this provides aggregated data of the surroundings to all participants (i.e., number of persons in the bus line via the WiFi interface).

A. *Testbed and crowdsensing requests*

We developed an Android application which emulates a mobile crowdsensing application in order to perform our experiments. This application tracks users' locations when they reply to a sensing task request, and it simulates the trust of the ecosystem using the social context offered by Facebook (Facebook API), which provides to the crowdsensing application a social network layer. Facebook offers the social ties (friendships) that play the same role as a trusted server/peer - user relation in a real crowdsensing scenario, whose impact will be equal in our analysis.

The application creates requests on the users' devices to process/sense small tasks from other peers (Facebook social tie) with a corresponding battery consumption (0-2%). The

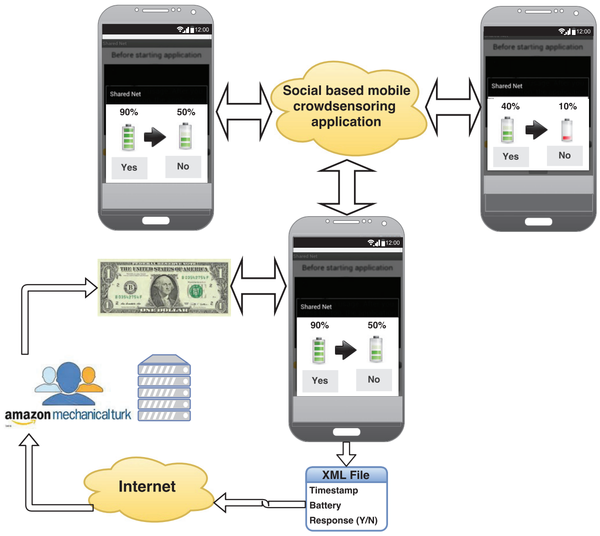


Fig. 3: Implemented testbed for experimentation on cooperation enforcing mechanisms on mobile crowdsensing.

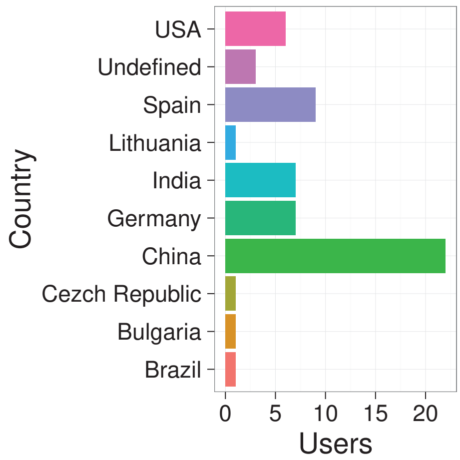


Fig. 4: Demography of the users that participated in our experiment.

participants are requested to accept 20 tasks, in a period of time that can vary from hours (requests time span is 30-60 minutes) to days, depending on user task response rate. The request will show the current battery level, the size of the sensing task, the estimated battery level at the end of the task execution (battery consumed), and the social relationship with the sensing task owner (either a Facebook friend or an unknown peer). Each request shows the real devices' battery level; the battery cost (0-2%) is a virtual measurement that does not imply an actual battery drain on users' devices. The visualization of the battery cost is a sufficient parameter to measure participants response behaviour; the real implementation of a background process that decreases battery is part of our future work. Figure 3 presents the design of the implemented testbed. The experimenters were recruited using Amazon Mechanical Turk (AMT)[1], a crowdsourcing platform;

[1]https://www.mturk.com/mturk/

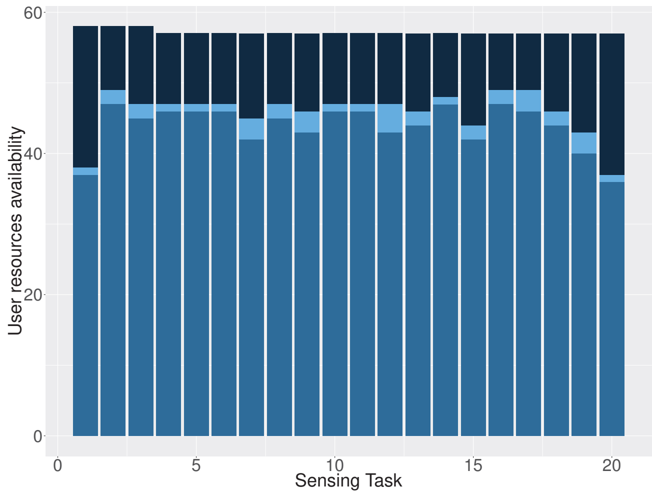


Fig. 5: High (baseline blue), restricted (lightest) and limited (darkest blue) resources availability according to sensing task requests.

where they can download the Android application to their devices and they receive a reward of 1 dollar, after they have finished the experiment. The demography of our experiment is shown in Figure 4.

B. *Resources availability*

We initially examine the case regarding the resource availability when a crowdsensing task is executed and the location of users' mobile device. To track the users' locations we collect the devices GPS in the moment the users reply to the sensing task request; we have analysed the location patterns of users during the experiment (i.e., user location does not change and corresponds to particular house/building). The resource availability is related to the users' location, fixed or common locations such as work/office, home or coffee shops that may offer to the users battery charging possibilities, and hence they affect their behaviour and the mobile crowdsensing performance. We classify the availability of the resources into three groups:

- **High:** home, offices, or any place that the user may stay for longer periods and offer the possibility of charging the mobile device.
- **Restricted:** coffee shops, gym, libraries, places which can offer battery charging options but that is not always the case.
- **Limited:** streets (walking), commuting situations, scenarios where the user is moving or there is not available charging infrastracture.

Figure 5 shows the distribution of users' resources availability for each sensing task request. The restricted availability (light blue), due to the probability of scenario chances is lower in comparison to the other groups. We decide not to include any insights regarding this group as the collected data is not comparable to the other (highly and limited).

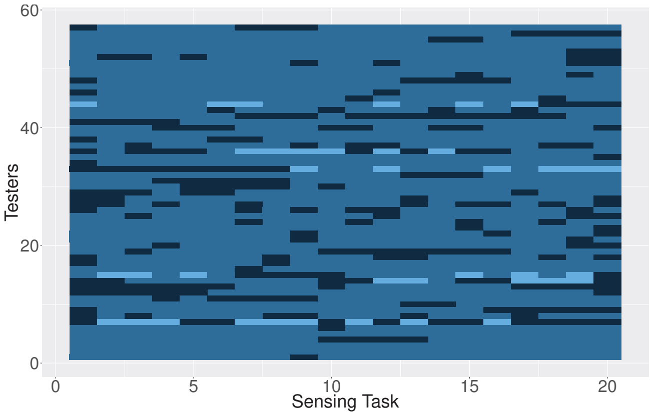


Fig. 6: Heatmap of resources availability for each user at the moment of the crowdsensing task generation. The darkest blue correspond to the group highly, base blue to restricted, and lightest blue to limited.

We illustrate the users location at the time of the generation of each crowdsensing task request in Figure 6. We observe the users' movement along the experiment timespan, and the different resource availability scenarios and we illustrate how the users movement behaviour can provide the fundamentals to predict resources availability in the near future before a crowdsensing task request. We also observe that some users do not change their location (resources availability is stable) during the experiment.

The following Figures will focus on the analysis of the two cases regarding the resource availability: high and limited. Figure 7 shows the scenario where a user executes the sensing task in a location with chances of charging her device. It illustrates the probability of acceptance, which is the probability of the user to execute the crowdsensing task. We can see that on average this probability is around 42%. Moreover the probability of acceptance does not change with time (number of sensing task requests). On the other hand, in Figure 8 we observe the opposite case, where the users do not have charging possibilities. The probability of acceptance is lower when we compare to the case of existing available resources (highly); its average is around 25%, and the probability of executing a task decreases with the number of sensing task request. Due to the nature of acceptance applications the battery consumption will be progressive, and hence will decrease device battery life with the number of sensing task request. Moreover, the increasing of the number of requests affects the performance on the probability of acceptance, and therefore, the mobile crowdsensing application.

The study of users location (resources availability) leads to non-monetary incentive techniques that can improve the performance of the whole crowdsensing ecosystem. Such applications will require to analyse users location and previous sensing task requests in order to offer the sensing task when the user is for example in the highly group, as the probability of acceptance is higher. Furthermore, the crowdsensing application can schedule the sensing task in situations where the app knows that the user is in a particular location where she can charge her mobile device (user mobility patterns and prediction).

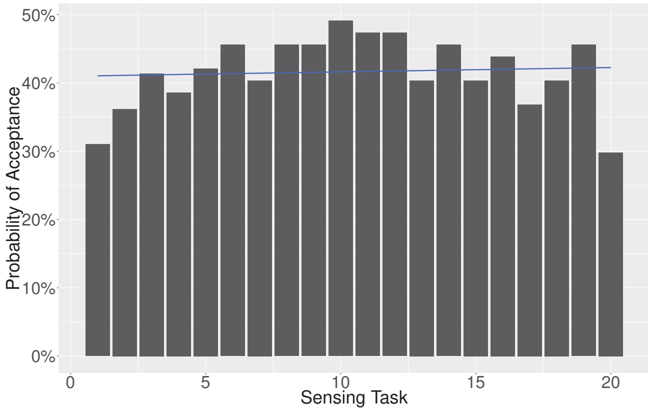


Fig. 7: Probability of a mobile user to accept a crowdsensing task in the case of having available resources.

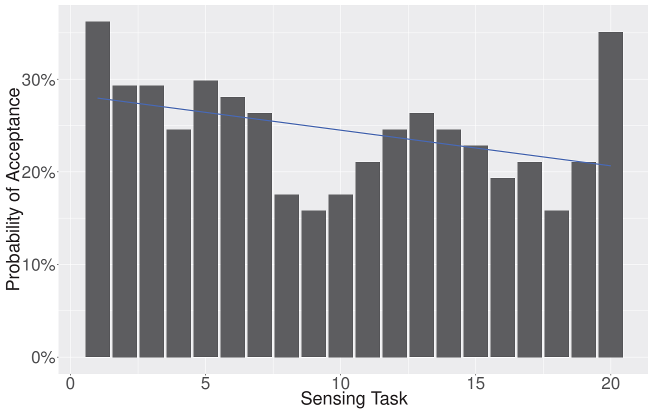


Fig. 8: Probability of a mobile user to accept a crowdsensing task in the case of not having available resources.

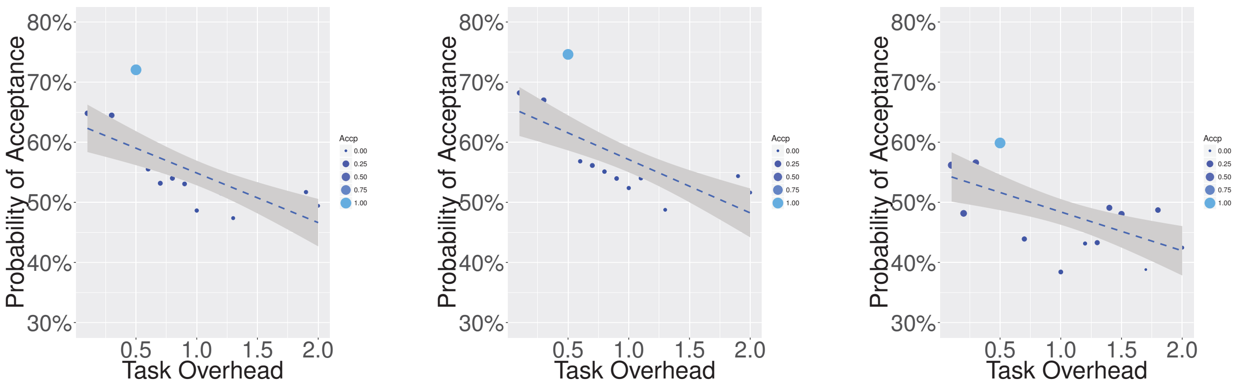
C. User interrelationship

In this Subsection, we aim to analyse the importance of social ties (trust) among crowdsensing application participants (servers/peers) to boost the system performance. We emulate our social layer using Facebook API, which offers the required social relationships between a user and crowdsensing task creator/owner (peer or server): our mobile social based crowdsensing application. The developed Android application emulates the task request, and it will show the battery consumption and the social tie with the task owner/creator.

For the social ties (user interrelationship) we consider the following two cases:

Case 1: The user/participant knows the task creator/owner.
Case 2: The user/participant does not know the task creator.

The emulation of server/peer trust using Facebook offer a feasible solution for our experiment, and a reliable simulation of a real social mobile crowdsensing application. As we present in this Subsection, the application's performance increase with the trust (social relationship) between participants.



(a) All Requests (b) Requests between friends (c) Requests between unknowns

Fig. 9: Probability of accepting a crowdsensing task request as a function of the overhead of the task. The size of the points are the normalized number of task executed for that particular task overhead.

Furthermore, in this experiment scenario we also focus our interest in the *task overhead*: the amount of resources (i.e., battery, processing, memory) that a particular task will consume in user's device. As the user location can not be fixed by the crowdsensing application (only schedule the task request), the overhead can be decreased with non-monetary incentive techniques such as server/peer trust, which can be controlled by the mobile crowdsensing application.

Figure 9a shows the probability of acceptance regarding the task overhead. We observe the linear relationship between both parameters, and how the task overhead affects the users' behaviour and the crowdsensing task execution. The probability of acceptance is approximate 55%. The most important aspect is the difference when the task overhead is near 0.5% (battery in our experiment scenario): 62% probability of acceptance, and 2% task overhead: 47% probability of acceptance. This points out the importance of the task overhead in a mobile crowdsensing ecosystem, and how applications have to target low resources consumption (battery, memory, CPU) in order to achieve better performance. One solution to reduce the impact of task overhead in the performance of mobile crowdsensing applications is the addition of the commented social layer or trusted servers/peers to the system. This can be seen as a non-monetary incentive technique (cooperation enforcing mechanisms) which can improve the performance on the probability of crowdsensing task acceptance. In Figure 9b we illustrate the probability of acceptance a particular crowdsensing task with its respective overhead in scenarios where the participants trust (case 1) the task owners/creators. If we compare with Figure 9c (case 2) we can observe the difference in the probability of acceptance a crowdsensing task. The addition of a social layer in our experiment, and therefore trusted servers/peers in a real application can boost the performance in scenarios where the task overhead can be the main constrain in users/participants willingness to execute a task.

In this Section we demonstrated how the resources availability and the trust in servers/peers, both feasible non-monetary incentive techniques to implement, can improve the cooperation, and hence the performance, of mobile crowdsensing applications. Moreover, we described some users' patterns regarding their location (resources availability) and the behaviour when the server or a peer is non a trusted source (crowdsensing task creator). We have to highlight the constrain that task overhead can become in mobile scenarios, where resources are limited. All these insights can be the foundation of better crowdsensing applications, that can employ non-monetary incentive techniques such as: enforcing mechanisms (trusted servers); and the collection of users' locations. These results prove that social mobile crowdsensing applications can boost the performance of baseline mobile crowdsensing applications. However, it is not always possible to find mobile users that are socially close to the crowdsensing task initiator and have available resources to help. In the next Section we discuss how incentives can be utilised to attract more mobile users and how the proper selection of the mobile users can improve the efficiency of the crowdsensing mechanism.

III. Adaptation to Social based Mobile Crowdsensing Application

Although social ties between mobile users can affect the performance of a mobile crowdsensing application, if the initiator of the task is a cloud service, the mobile users should be rewarded in order to be cooperative. The social relationships can improve the performance of the application in the case where a mobile user has received a crowdsensing task and she offloads parts of it to her neighbours in order to be able to provide a more robust result to the requester.

The sustainability of cooperation enforcing mechanism in crowdsensing is aligned with the architectural design of crowdsensing mechanism. The number of available devices that can sense a multitude of parameters of cyberphysical space can produce huge amounts of data that are highly correlated and that should not be uploaded to the cloud or exchanged with between SDs unfiltered. The selection of which users to select for uploading their data is not trivial and not static. However, the social relationships (trust) between the mobile users can help on the selection of the most suitable ones (the most popular).

The high variance on the possible crowdsensing applications makes reputation based incentives not applicable for a generalised crowdsensing mechanism that is based on mobile devices. The core reasoning behind is the fact that the service exchange is asymmetric, in the sense that users are sharing their resources in order to earn something and they are not motivated to build good reputation in order to utilise the service later. A second reason is the wide spectrum of the possible crowdsensing tasks. On the other hand, it is difficult to determine a representative valuation for a credit based cooperation enforcing mechanism for a generalised crowdsensing mechanism. A habitual approach can be based on auctions. Whenever there is a crowdsensing task the application provider broadcasts the characteristics of the task he wants to execute and the interested mobile devices bid for the task and propose their valuation. However, this requires the implementation of a component to the mobile devices that would be able to estimate the evaluation of the task and bid for it. The implementation of such software component is not trivial.

Related works such as [4], [5], [6] and [7], assign a specific cost per action that does not depend on the user that performs the task. Any Credit Based Cooperation Enforcing mechanisms has to guarantee consistency and the difficulty of this depends on whether it uses any complementary infrastructure or not. One case where the mechanism uses a remote service for the bookkeeping. At the end of each interaction, only the two participants need to connect to the remote server in order to update their credit score. In the case of not existing a remote service, the mechanism has to integrate a local storage service on each mobile device and guarantee consistency. However, this approach requires too many messages to be exchanged in order to inform every node in the crowdsensing application about any transaction, if possible. A decentralised cooperation enforcing mechanism for a large scale crowdsensing mechanism is not implementable without the use of internet connectivity and a bitcoin-like proof-of-work scheme that may requires many resources from the participants and that constraint limits its implementation [12].

Furthermore, credit based schemes for crowdsensing applications with a variety of tasks have to deal with two more issues that are not important in application specific credit-based schemes. Given that different tasks may have different valuation and different users may have different needs, the credits may accumulate to a subset of the users that have available computational resources to help others but they do not ask frequently for help from others. Also the users' mobility pattern and users' configuration may not help them gain credits.

IV. Conclusion

In this paper we discussed what kind of cooperation enforcing mechanisms that are implemented for mobile ecosystems can be adapted in crowdsensing applications. Furthermore, we discussed the required complementary infrastructure by cooperation enforcing mechanisms for both centralised and distributed approaches. These mechanisms can affect heavily the impact of mobile crowd sense scenarios.

We justified our arguments via experimentation with real users. The insights we obtained from the experiments show how a collective reward (social relationships) can change users' psychological status and thus lead to large different participation behaviour. This suggest that proper incentive mechanism should be introduced into mobile crowdsensing applications to improve its feasibility. Another important fact that has been presented is the existence of a non cooperative behaviour in cases where the crowdsensing task overhead increases. We have shown that participants are relatively more cooperative, higher probability of acceptance, when their devices are in zones with high resources availability (device charging possibilities). The combination of the cooperative mechanisms together with appropriate user incentive schemas will boost the performance and adoption of mobile crowdsensing applications. More sophisticated incentive techniques, that can be implemented on top of our concept of social mobile crowdsensing applications, are part of our future work.

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