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A social cognitive heuristic for adaptive data dissemination in mobile Opportunistic Networks

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ABSTRACT

It is commonly agreed that data (and data-centric services) will be one of the cornerstones of Future Internet systems. In this context, mobile Opportunistic Networks (OppNets) are one of the key paradigms to efficiently support, in a self-organising and decentralised manner, the growth of data generated by localised interactions between users mobile devices, and between them and nearby smart devices such as IoT nodes. In OppNets scenarios, the spontaneous collaboration among mobile devices is exploited to disseminate data towards interested users. However, the limited resources and knowledge available at each node, and the vast amount of data available in the network, make it difficult to devise efficient schemes to accomplish this task. Recent solutions propose to equip each device with data filtering methods derived from human information processing schemes, known as Cognitive Heuristics. They are very effective methods used by human brains to quickly drop useless information and keep only the most relevant information. Although cognitive-based OppNet solutions proved to be efficient (with limited overheads), they can become less effective when facing dynamic scenarios or situations where nodes cannot fully collaborate with each other, as we show in this paper. One of the reasons is that the solutions proposed so far do not take into account the social structure of the environment where the nodes are moving in. In order to be more effective, the selection of information performed by each node should take into consideration not only the relevance of content for the local device, but also for other devices will encounter in the future due to mobility. To this end, in this paper we propose a social-based data dissemination scheme, based on a cognitive heuristic, known as the Social Circle Heuristic. This heuristic is an evaluation method that exploits the structure of the social environment to make inferences about the relevance of discovered information. We show how the Social Circle Heuristic, coupled with a cognitive-based community detection scheme, can be exploited to design an effective data dissemination algorithm for OppNets. We provide a detailed analysis of the performance of the proposed solution via simulation.

1. Introduction

The evolution of device-to-device (D2D) technologies for communications between mobile devices, and the increasing ability of such devices to collect, store and elaborate relevant amounts of data, is pushing forward the possibility of moving Future Internet functions and services from remote, centralised core network or cloud platform operators to the edge of the network. In this scenario, users' mobile devices will be continuously immersed in a pervasive "data space", where they

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will have the opportunity to exchange a huge amount of data with other devices and smart "things" nearby. Since this data could be of interest for many users dispersed throughout the network, one of the emerging key challenges is the design of effective, efficient, scalable and decentralised mechanisms that, through the direct exchange of locally available data between devices, optimise the information dissemination process towards interested users at the entire network level. With respect to these issues, Opportunistic Networks (OppNets) are nowadays one of the most popular paradigms for supporting direct D2D communications in self-organising mobile networks. In Opportunistic Networks there are no precomputed paths from sources to destinations. Rather, physical encounter events between nodes are opportunistically exploited to exchange data. In fact, nodes evaluate how suitable is another encountered node to bring data (closer) to interested users. In this way, opportunistic networks do not face some of the typical problems related to the instability of mobile networks that affect MANET solutions. OppNets are actively investigated by the research community since almost ten years now, and are likely to have a significant impact thanks to the standardisation of D2D Proximity Services (ProSe) in forthcoming LTE and 5G releases.[1] More in general, Opportunistic Networking is considered one of the basis for a number of technologies and applications [1,2], such as traffic offloading, communication in challenged areas, censorship circumvention, proximity-based applications. With respect to the latter, Opportunistic Networking is one of the elements of crowd sensing solutions, which is one of the most important evolutions of general sensor networks [3] considered in recent years [4].

In this paper, we describe and evaluate a OppNet data dissemination mechanism based on completely self-organising and distributed algorithms running on mobile devices. The contribution of this paper is the design and evaluation of an OppNet data dissemination scheme that allows each node to perform the data selection task by taking into account the needs of the social environment in which the user moves. Specifically, we exploit a scheme based on human *cognitive heuristics* [5,6]. Cognitive heuristics are simple models of the cognitive processes of the human brain derived in the cognitive psychology literature. The main intuition behind the use of cognitive heuristics is that the problem faced by a node in OppNet data dissemination closely resembles what our brain constantly has to do to acquire, retain, drop and spread information coming from the surrounding physical environment. Moreover, according to the cyber–physical convergence view [7], personal mobile devices (such as smartphones, tablets, wearable devices, etc.) can be seen as *proxies* of their human users in the cyber world, since, most frequently, it is through these devices that users access the vast amount of data available in the cyber world. Building self-organising algorithms on model of the human cognitive processes thus means making mobile devices act in the cyber world as they human users would do if facing the same task in the physical world, and thus allowing them to automatically filter information in the same way their human users would do.

We have recently proposed some solutions for disseminating data in OppNets based on cognitive heuristics (e.g., [8–11]). However, the data dissemination schemes proposed so far do not exploit any knowledge about the *social structure* of the environment where the users move. As such, nodes typically behave in a greedy way, i.e. they drop information that they consider irrelevant for themselves. While this may be appropriate in some cases, taking into consideration the requirements of other nodes frequently encountered (i.e., of the social context of the users) has proven very useful in data dissemination in general (see, e.g. [12–14]), and it is thus a direction worth exploring also for cognitive-based data dissemination schemes.

Based on these remarks, we propose a OppNet data dissemination method that exploits the *Social Circle* [15] cognitive heuristic (SCH). In our scheme, whenever two nodes meet, they decide what to replicate locally out of the data available on the other nodes. This is the basic mechanism through which data disseminates in the network and reaches interested nodes. Specifically, we assume that nodes have a limited amount of storage space allocated to help the dissemination process. Therefore, when they encounter other nodes, they have to decide what data to keep and what data to drop, if the amount of data available is larger than the available storage space. To take this decision, in our scheme each node assesses the relevance of data first for itself. In case this knowledge is not sufficient to take a decision (i.e., there are too many items that are all relevant or irrelevant for the individual), the heuristic assesses the relevance for other people in the individual's social context, ranking people according to their perceived social proximity to the individual (i.e., to their belonging to the different social circles of the individual). To this end, each node divides its social contacts into different groups on the basis of their social relevance. Starting from the most socially relevant group, the node ranks the data items using their average relevance for the users inside the group. If needed, the node continues to refine the selection of the available data items using the other social groups, one at a time, until the knowledge coming from these groups is enough to take a decision on which data items are worth storing. In this way, nodes store data items based on the preferences of the social groups they belong to, considering inner social circles first.

Similar to existing literature on OppNets, we consider social communities as groups of nodes that physically meet with each other frequently. While other types of definitions are possible, which do not necessarily require physical meetings, there is evidence that mobility and physical encounter patterns are very closely related to social structures, and very often frequency of physical interaction is strongly correlated with social proximity (e.g. [16–20]). Therefore, in the following, social communities are intended as groups of nodes that meet frequently with each other (see Section 3.4 for a more precise definition). As these nodes are very likely to be socially related, it is reasonable to assume that they are willing to help each other acquiring the data items they need.

We compare the performance of the proposed scheme with respect to other state-of-the-art non-social cognitive schemes, proposed in [8][2] . Results confirm our intuition about the advantage of using social information also in cognitive

[1] 3GPP LTE Release from 15 on, see http://www.3gpp.org/specifications/67-releases

[2] We do not compare with non-cognitive schemes, as they have been shown to be less efficient in general than cognitive-based schemes [8].

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