Socially-Motivated Wireless Neighborhood Communities

Panayotis Antoniadis, Bénédicte Le Grand, and Marcelo Dias de Amorim

LIP6/CNRS – UPMC Univ Paris 06

***Abstract*—In this paper, we promote the use of online communities as a means to provide incentives for people to collaborate in building wireless community networks. To achieve this goal, we define a novel type of online community spanning a specific physical area (i.e., a neighborhood) called *Wireless Neighborhood Community* (WNC). On the one hand, in addition to the standard activities of an online neighborhood community (e.g. i-neighbors), a WNC's members cooperate to build a network and share their resources at different layers. On the other hand, in addition to standard Wireless Community Networks being deployed today in big cities, a WNC incorporates the social layer in its design. It is a hybrid (both virtual and physical) community whose activities are linked to the operation and management of the underlying network. If designed appropriately, this cross-layer community will provide incentive to users to participate and share their resources, build trust, and increase the social capital in the city. We provide insights for exploiting this special characteristic of the WNC towards these objectives, introducing the notion of a *cross-layer* incentive mechanism and the corresponding *network-aware* social software.**

I. Context and orientation

Motivation and problem statement. It is expected that future pervasive systems will rely in part on user-owned wireless communication infrastructures. Their potential high density will be of great utility for providing seamless internet connectivity to end-users but also for enabling users to create their own independent networks to support a large variety of collaborative applications. A typical scenario is the one where user-owned wireless access points will be interconnected through the wireless medium forming a wireless mesh network (WMN). Such networks would be particularly useful not only in environments where there is no or little wired infrastructure [11], but also in urban environments, as a cost-efficient way to provide free internet access to citizens (as demonstrated by various user initiatives in most big cities in the world, the so-called Community Wireless Networks, like SeattleWireless, NYCWireless, Paris sans fil, and many more). Additionally, they would empower local communities with their own communication network to increase social capital and civic engagement [25], [29].

There are two main challenges to bring this vision closer to reality.[1] The first challenge is *technical*. One should build the appropriate hardware to improve the quality of the wireless links, keep their cost low, and design network protocols for addressing highly dynamic and often unpredictable conditions. The second challenge is *social*. The creation and efficient operation of the network depends on decisions taken by humans. Suitable *incentive mechanisms* are therefore required to motivate users first to participate, and then to behave toward improving the performance of the network and the benefit of the community as a whole (i.e., share their network and computing resources). Additionally, trust relationships between potential participants will play a critical role both for the bootstrapping and efficient operation of the system. Existing research work in this area has focused mainly on the technical aspects; in this paper, we address the social aspect proposing a holistic approach towards addressing all three participation, trust, and incentive issues. Our overall objective is not restricted to the creation of a backbone wireless mesh network that will offer free Internet access to citizens but also a network over which people live in close distance will have the ability to socialize, exchange services, and take decisions that can affect their physical environment.

Related work. Regarding incentives for resource sharing, there is significant literature addressing the case of packet forwarding in mobile ad hoc networks [8], [16], [34], [35], [32], [19], [17]. All proposed mechanisms are based on the rationality principle of economics and assume that the main incentive for participants to contribute resources is to acquire the required credit or reputation to have their own demand satisfied. Their objective is to achieve an economically efficient or at least fair provision and allocation of resources. However, they don't address the incentives for participation and the required investments on infrastructure. Additionally, there are various concerns for their applicability related to enforcement, complexity, and critical mass issues [15].

Most importantly, such approaches ignore a wide range of more intrinsic human motivations, such as pride, self-efficacy, moral obligations, and social norms, which could be quite effective. In our case, this is especially so because costs are not significant as in the case of mobile nodes (e.g., there are no battery constraints). Moreover, according to several theories in social sciences, as for example the self-determination theory [28], extrinsic motivations can even undermine (crowd-out) intrinsic motivations, which is an observation also supported by other crowding theories as well [12]. Clearly, economic approaches belong to the category of extrinsic, "controlling", incentive mechanisms, and this is one of the reasons why they might not be the most effective solution in our context.

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[1] As pictured by Nicholas Negroponte, a "Wi-Fi lily pads and frogs broadband system built by people for the people" [23].

Note also that most successful collaborative systems (from peer-to-peer file sharing to Wikipedia) are disproportional, as they rely on the high contributions of a relatively small number of participants. That is, contribution follows a power law distribution (see [30]). The motivations of these individuals are clearly more intrinsic than extrinsic. And crowding them out with the deployment of an economic mechanism could prove disastrous. Interestingly, current successful wireless community networks (e.g., NYCWireless) rely exactly on such intrinsic motivations of technical enthusiasts to provide satisfactory levels of connectivity and performance [25].

However, small contributions by a large number of participants can increase dramatically the efficiency of the system. We believe that one should explore the space of social, intrinsic motivation to further encourage participation and resource sharing in this context. To this end, there is a growing literature analyzing mechanisms for encouraging participation and content sharing in online communities through the design of *social software*[2] stimulating such motivations [5], [6], [26]. The success of numerous real-life online communities along these lines [9], supports our objective to devise similar techniques for providing social, instead of economic, incentives for the creation and operation of self-organized wireless mesh networks in the neighborhood. Interestingly, such incentives are being taken into account to reward people for sharing their Internet access bandwidth through their Wi-Fi access points [2].

Our approach. The majority of intrinsic motivations require a coherent social context in order to be stimulated; this is why we often call them "social". This means that unlike economic mechanisms that can be implemented in the network layer (requiring only the input of the user's strategy), social incentives need continuous interactions between the application and the network layer. We argue in this paper that when the application is a well-designed online community it can become a powerful tool to stimulate a variety of social motivations. Nevertheless, there is a drawback of this cross-layer approach: how to provide connectivity. This is because neighboring nodes in an ad hoc network do not necessarily share the same interests.

In order to address this issue, we introduce a special online community spanning a physical neighborhood, which we call a *Wireless Neighborhood Community* (WNC). In existing online communities such as Flickr, Facebook, or Last.fm, a user belongs *by default* to a global community with a common interest (photography, social groups, and music respectively), but also has the ability to create her own groups based on more specific interests. Following a similar reasoning, the WNC is formed as a community of broad interest that is relevant to all people living in the same neighborhood – on top of which users will be able to form their own groups of interest or run a wide variety of collaborative applications.

The critical difference in comparison with existing neighborhood-oriented online communities (e.g., Meetup, i-neighbors) is that the WNC is *also responsible for the creation and operation of the underlying network*. This will allow us to design appropriate incentive mechanisms for building a network with wide coverage and capacity. More specifically, the inclusion of network management in the WNC's responsibilities will enable the deployment of *cross-layer incentive mechanisms*, i.e., mechanisms encoded in the community rules that encourage resource sharing by rewarding good behavior through social motivations generated at a higher layer.

[2]See [3] for the evolution of social software as a term and concept.

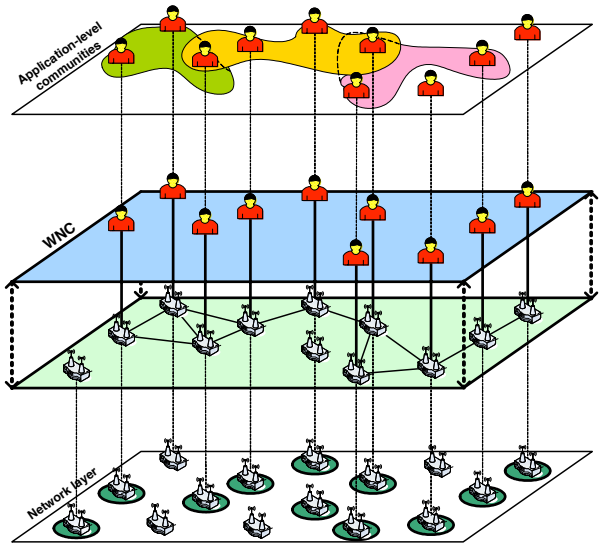


Fig. 1. Between the traditional application and network layers we introduce two new sub-layers tightly coupled: a network-aware online community and a community-aware network.

But we should first design our community in a way to provide an added value to the existing alternatives. Interestingly, we can exploit our proposed cross-layer structure to motivate user participation by means of building feelings of solidarity and independence and increase at the same time the social capital of the physical community. Then, if our primary goal to design community applications that attach a clear value to the WNC is accomplished, the online social interactions will also generate trust information, which is critical for the network formation and operation.

Note that a significant part of the research work required to build a successful wireless neighborhood community is multidisciplinary, involving application design, social software, sociology, and networking. In any case, the final solutions will depend on the specific cultural environment that are to be applied. So, to facilitate the required interactions between the networking research community with researchers from social sciences we identify the main interdependencies between the network protocols and the community activity (i.e., the required information exchange and interactions between the community and the network layers). Our final goal is to abstract these interactions and provide a clear interface to community designers corresponding to a set of required network functionalities that will enable them to implement and experiment with a variety of wireless neighborhood communities and different types of incentive mechanisms.

This paper is organized as follows. In Section II we elaborate a little more on the cross-layer aspect of our proposed

community and its effect on the system architecture.Then, in Section III, we provide insights for the design of the WNC toward encouraging participation, trust building and resource sharing exploiting the interaction between the social and the network layer. In Section IV we discuss the possible future directions of this on-going work.

II. Architectural principles

In our approach, network formation is an inherent part of the creation and operation of an online neighborhood community. So, the process of a WNC creation comprises a number of conditions and steps. First, from all the access points available in a certain neighborhood, those that run the neighborhood community software form the necessary basic (connectivity) network. But in order for a node to be part of the operational network, the corresponding user should be a member of the WNC community; as a consequence, the user undergoes the trust constraints and incentives for resource sharing defined by the community. This means that WNC is a cross-layer community acting as a "proxy" between the application-level communities and the physical network (Fig. 1).

Note that the deployment of any incentive mechanism requires certain functionalities to be supported by the network: (1) the provision of the required monitoring information and (2) the ability to control the amount of resources offered to different participants (resource allocation). In the case of economic mechanisms, the decisions for the resources allocated to a certain user or not, through (2), depend explicitly on her own observed contributions, through (1), as depicted in Fig. 2(a). That is, resource control and monitoring are tightly coupled.

However, this dependence of resource allocation on past provision could lead to an undesirable equilibrium when users are heterogeneous in terms of capabilities and value, which is often the case (especially in the case of a mesh network where there is inherent heterogeneity and border effects due to the static topology). This is exactly due to the fact that the only alternative way for participants to acquire resources is to provide the same type of resources, which is unfair for users at the edge of the network. And possibly, it would also discourage inherently motivated users to contribute large amounts of resources [30].

In our approach, the existence of a community that is responsible for the management of the network allows the decoupling of these two main attributes of an incentive mechanism. As depicted in Fig. 2(b), on the one hand, monitoring information from the network layer (expressing the level of contribution) would result in a variety of actions taken by the community internally. For example, the update of the status or privileges of a user inside the community, explicit or implicit feedback of one's contribution, visualization of the overall activity and participation, and more (cf., Section III-C).

To this end, trustworthy accounting is the most challenging problem and various sophisticated mechanisms have been proposed in the literature regarding the reliable accounting in terms of packet forwarding [20], [21]. Notably, the less trusted the environment is, the more challenging this task becomes. Our goal is to define a general set of required information to be provided by the network, and exploit the trust generated at the community layer to ensure for its reliability.

In our context, one could also exploit the possible pre-existing trust relationships, the long time scales, the alternative channels of communication, and the potential approximate location information to further increase the levels of trust. For example, pre-existing trust relationships could facilitate the trustworthiness of the accounting information through distributed probing [20]. Based on the existence of a physical channel of communication (e.g. through physical meetings in the neighborhood) one could rely on otherwise unreliable encryption techniques for securing user communication and dissemination of accounting information. Finally, the approximate location information could enhance the notion of identity. For example, it could exploit the relatively static network configuration in order to detect (at least statistically) possible whitewashing attacks. Moreover, it could exploit the existence of possible pre-trusted nodes in the network to verify claims of unknown nodes (e.g., the existence of a non-visible neighbor).

In summary, a *community-aware* network is one that provides a set of useful monitoring information and configurable resource allocation policies based on decisions taken at the community layer. Depending on the environment, more or less sophisticated mechanisms would be required for ensuring the trustworthiness of the information and the efficiency of the resource allocation policies. But in any case, the existence of a generic and simple community-network interface is crucial for community designers to easily implement and experiment with a variety of neighborhood *network-aware* online communities (WNCs) in different cultural environments. In the next section we elaborate more on these aspects and provide insights for the design of a WNC.

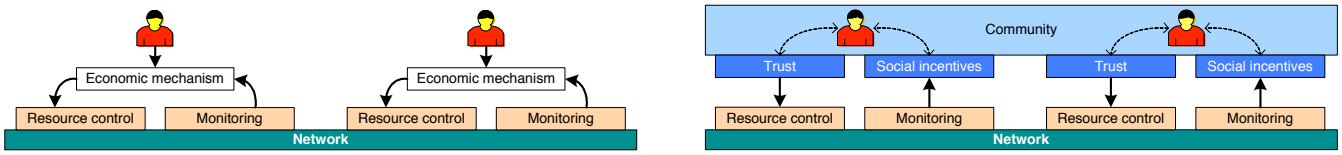
III. WNC: A cross-layer community

In this section we will present some basic principles for the design of a WNC in order to address the three main challenges related to user behavior in a self-organized distributed system: participation, trust building, and resource sharing.

A. Participation

A wireless neighborhood community could contribute toward two distinct objectives: (i) to increase the social capital in a neighborhood and (ii) to build a wireless mesh network which will provide cheap and efficient communication and possibly access to the internet. There are efforts today to achieve these goals independently.

Regarding social capital, various projects like Netville [14] and the Blacksburg Electronic Village [1], demonstrated that, if exploited correctly, technology can actually increase physical social interactions rather than weaken them. More recent experiments support this premise [13]. In addition to social capital, such communities seek to exploit networks and technology to engage their members in collaborative action related to urban planning, governance, security, and health. We imagine different subsets of these functionalities to be provided by wireless neighborhood communities, which would



(a) The economic approach.

(b) The WNC (social) approach.

Fig. 2. Decoupling of resource allocation (control) and resource provision (monitoring).

constitute them attractive and useful at the same time.[3] Similarly, numerous municipality-operated or grassroots wireless community networks aim to accomplish the second objective.

So, there is significant progress in both directions. We argue, however, that these two goals would be more effectively addressed if they were linked together in the context of the proposed wireless neighborhood community. Under the light of all existing alternatives in terms of online communities and connectivity (and even more possibly to come), the first challenge one should address is to motivate users to participate in such a community.

Let us consider first the social aspect. In what ways would a WNC be more attractive than a web-based neighborhood online community? To answer this question, the community design should incorporate the specific characteristics arising from the fact that the members of the WNC community are responsible themselves for building and operating the underlying communication network.

First, the fact that users participate in a collective action could become itself an important motivation and a first level of users' civic engagement. Additionally, it could become an "excuse" for socialization, which is important for reserved people. Second, the independence from ISPs and companies managing the content and the activities of the community could again offer important psychological but also practical benefits related to censorship, advertising, and privacy issues. Third, users in a WNC are *de facto* in physical proximity, while this is not sure in the case of web-based communities. In addition to increasing the feelings of locality, this fact could be further exploited for building interesting applications (for example, one could imagine random walks in the neighborhood over the underlying physical network). Finally, resource allocation policies at the network layer could be used as incentives for trust building at the community layer; see Section III-B.

Let us assume now that our main objective is just to include end-users in the creation and operation of a wireless mesh network spanning the city. The implementation of a suitable online community according to the specific cultural environment (possibly with the collaboration of sociologists and urban planners) could play an instrumental role in motivating a wider range of types of users to participate. But most importantly, as already argued, such a community will also provide a social context that will enable a wide variety of incentive mechanisms for resource sharing. We analyze in more depth this dimension in Section III-C.

[3]For example, see our parallel effort to exploit this community structure to support and encourage the participation of users in the urban planning process [4].

B. Trust building

As analyzed above, there could be many good reasons for people to participate in a WNC. However, privacy and trust are essential, as a lack of confidence toward the community members could make people reluctant to participate. We could say that privacy is related to the reluctance to disclose personal information to others, and trust to the reluctance to interact with them (e.g., because of possible disagreements with their actions or security threats).

Notably, there exist two major concerns regarding privacy: private information being stored in central databases of companies (which could be exploited for commercial purposes [24] and/or being exposed in the Internet [7]) and 2) private information made available to unknown or non-trusted users, or captured "in the air" by malicious ones. For the former, the distributed nature of the WNC provides an attractive solution since it does not require central databases for storing all available information and even make it susceptible to public visibility due to software bugs or security holes [31]. In a distributed community, users' sensitive information could be made available only to trusted people using encryption techniques. The same techniques could be used to avoid the capturing of private information over the wireless medium.

But note that security measures cannot guarantee a fully protected environment without a sufficient number of strong trust relationships between users. So, it is also critical to generate trust by supporting rich and healthy activities at the social layer. Toward this end, a WNC should build on the possible pre-existing trust relationships in a neighborhood and encourage various interactions of users both at the virtual and the physical space in order to increase the level of trust in the community. Additionally, it should exploit the common interests shared by people living in the same neighborhood and the fact that they collaborate sharing their resources.

The policies employed at the network layer could further contribute to build trust. For example, one could define different types of links formed between neighbors. Then trusted people could benefit from an unrestricted network usage while others could be limited in quality and/or restricted to certain types of communication (e.g., specific ports). Tuning accordingly the relative quality of these levels could become an incentive itself for trust building at the social layer. Additionally, malicious behavior could result to the exclusion of the corresponding user from the network.

Our goal is not to enforce a global policy, but only to give incentives. Statistically, users who have more trust relationships will have a better quality at the network level and on the other hand those who do not behave well at the community

level will most probably have limited service. We follow then a positive approach: our goal is not to punish users but just to motivate them to build trust. Malicious behavior will be treated as an exception rather than the rule.

C. Social incentives for resource sharing

There exist numerous theories in social sciences trying to formalize and understand the human motivations for investing effort, time and resources toward contributing in various forms of collective action including learning [28], organizational behavior [27], knowledge sharing [33], and more. Based on these theories, organizations, governments, communities, and system designers try to devise specific *incentive mechanisms* (or reinforcers) to stimulate the different human motivations toward their goals.

In this paper we focus on more self-determined types of motivation because they are associated with more positive experiences and continued motivation to participate [28]. There is a large variety of such predominantly intrinsic motivations, derived by users themselves and the community as a whole. Self-esteem, self-efficacy, community spirit, emotional connections, social norms, interest, and fun are some of them. And numerous theories focus on a subset of such motivations and analyze the different mechanisms that could be used to stimulate them and their corresponding trade-offs. For example, the collective effort model [18] and the Sense of Community (SOC) [22] to cite a few that are highly relevant in our context. Some important such mechanisms include feedback, goal setting, social recognition, interest, socializing opportunities, community identity, personal responsibility (accountability) (see [33] and references therein).

However, these theories have been developed in different contexts than the one we are considering: we wish to motivate users to contribute network resources toward building a wireless mesh network and make these resources part of their identity, their social image. We do not aim to devise a new theory of human motivation but get inspired by the ones that are close to our approach, and implement a set of practical mechanisms. Experimenting with real users will hopefully give us insights on the various trade-offs that exist in this context, especially the one related to the extrinsic/controlling vs. intrinsic/informative motivations.

Today there are many successful online communities that owe their success exactly to some clever details incorporated in the design of their "social" software toward stimulating such human motivations [9]. We promote this principle as the foundation of a WNC. In the following, we categorize the practical mechanisms used in the social software of various communities and imagine possible ways to extend these techniques in the design of the WNC.[4] This process will help us evaluate and weight the different mechanisms (an example of a similar approach is the MovieLens project [5]).

[4]Note that the proposed mechanisms could be also effective in more dynamic settings, e.g., mobile ad hoc networks, if there is a stable (virtual) social context on which they can operate, for example a popular web-based online community.

Status, roles, privileges. Expertise sharing communities (e.g., Slashdot) rank users according to the usefulness or interestingness of their contributions and give them specific characterizations. High rated users acquire also extra privileges (e.g., moderation of other users' contributions). This approach can stimulate the self-image and self-efficacy motivations but could also constitute an extrinsic reward. In our context, we could directly apply such rewards for the "top contributors" of the community, which could also materialize in advanced roles in the community and network management.

User home page. A critical component of an online community is a user's home page (including profile information, content, activity, social network, comments, and more). This is her personal image to the community. Users' behaviors highly depend on what information the community designer decided to place on this page and the level of control provided to the owner of the page. The different choices of various communities toward this end are an indication of its importance – compare for example Slashdot, Flickr, MySpace, and Facebook. In our case, it is critical to decide how the network infrastructure of each user and the corresponding contribution and feedback are displayed in her home page. This will build the technologically-enhanced social image of a user.

Feedback. It is critical for stimulating the sense of efficacy of users, one of the most important intrinsic motivations, to provide them with meaningful personal feedback concerning their contribution (in addition to possible explicit rewards for high contributors as described above). Text messages (MovieLens), encoded "thank you" messages (Jango), recorded history (Wikipedia), comparisons (Facebook) and visualization [10] are some examples of feedback that could stimulate self-efficacy and competence.

Information management. The part of the user activity revealed to the interested parties and/or made public (e.g., visits, when a user is online, etc.) could affect the way people behave both socially and in terms of resource sharing. Increased visibility strengthens the personal responsibility and the opportunities for social interactions. However, in the case of social interactions, increased transparency raises privacy issues. In our context, information concerning a user's contribution should also be carefully exposed focusing on promoting/rewarding positive behavior rather than punishing small levels of contribution.

Community identity. The description of the community and its purposes, the identification of its members, the assessment of the overall activity and value provided are also critical. These aspects will stimulate the community spirit, create social norms and well-defined goals. In our context, it is important to highlight the vision and collaborative aspect of the WNC toward providing a cost-effective communication network, feelings of solidarity, and opportunities to increase social capital and civic engagement.

Social relationships and interactions. The type of relationships supported between users (e.g., friends vs. contacts), the protocols for their establishment (e.g., symmetric vs. asymmetric), the types of interactions supported, and the flexibility of private group management affect the way people socialize in

an online community. Additionally, the WNC should promote physical interactions by providing appropriate tools for organizing face-to-face meetings and feedback for the outcome and the participants. Moreover, new types of relationships could be introduced through the definition of resource sharing specific groups (e.g., "my network neighbors"), which could lead to socialization and further motivate resource sharing.

IV. Discussion

We argue in favor of a holistic approach toward building a wireless community network. We advocated that the design of a cross-layer community, namely the Wireless Neighborhood Community, is a strong candidate solution for both the increase of the social capital in the city and the creation and efficient operation of the underlying network.

The notion of a social incentive mechanism for motivating contributions of low level resources is a new concept, and still needs significant cross-disciplinary research work. As it is difficult to analytically model such incentives, they have not been included yet in economic and game-theoretic approaches. Additionally, they are also related to the specific environment that are to be deployed. We have provided a categorization of such incentives encoded in a WNC's social software design that we believe will help community designers to choose and implement a subset of them and experiment with real users. The availability of a generic network layer supporting the required interactions is crucial to facilitate this process.

In addition to the research directions discussed in this paper, there are other challenging issues: distributed management of an online community when needed, representation of technology to end users both in terms of the level of control exposed to them and in terms of their own social image, as well as security issues. In practice, efforts of municipalities and local organizations are required in collaboration with social and computer scientists to configure the software according to the specific environment, define the appropriate vision and objectives of the WNC, and bootstrap its creation by informing citizens and encouraging them to participate.

We believe that this on-going work provides a suitable framework for researchers from the networking and social sciences to cooperate and contribute toward enhancing our understanding of human motivations in this context and design successful WNCs along the lines proposed in this paper.

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