IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received May 31, 2016, accepted June 11, 2016, date of publication June 29, 2016, date of current version August 4, 2016.

Digital Object Identifier 10.1109/ACCESS.2016.2586305

Green Cooperative Device–to–Device Communication: A Social–Aware Perspective

EFTYCHIA DATSIKA[1], ANGELOS ANTONOPOULOS[2], NIZAR ZORBA[3], AND CHRISTOS VERIKOUKIS[2]
[1]Iquadrat Informatica S. L., Barcelona 08009, Spain
[2]Telecommunications Technological Center of Catalonia, Castelldefels 08860, Spain
[3]Qatar University, Doha 2713, Qatar

Corresponding author: E. Datsika (edatsika@iquadrat.com)

This work was supported by the Qatar National Research Fund (a member of Qatar Foundation) through the National Priorities Research Program under Grant NPRP 5-319-2-121.

ABSTRACT As the mobile operators strive to accommodate the increasing load and capacity requirements, direct communication among users' devices, namely, device-to-device (D2D) communication, emerges as an advantageous solution for cellular traffic offloading. However, the formation and the operation of D2D networks are challenging, as D2D peers must satisfy various network-related constraints. Although existing approaches address the D2D communication technical challenges, they usually neglect the fact that devices are used by humans possibly reluctant to communicate with unknown users, introducing an additional constraint. Following the proliferation of social networks and cutting edge mobile devices, social ties among users can promote D2D cooperation. In D2D cooperative communication, multiple devices in close proximity attempt to access the wireless medium. Their interactions at medium access level are affected by the users' social features, as socially connected users are more likely to engage in D2D cooperation. Moreover, the energy consumption of power-constrained mobile devices affects the effectiveness of D2D cooperative communication, stressing the need for incorporating energy awareness in D2D networking. In this paper, we outline the challenges that appear in D2D cooperative networking and medium access control (MAC) design under the influence of social characteristics and the energy consumption concerns that arise in modern D2D networking scenarios. Considering the users' social ties, we present an energy efficient social-aware cooperative D2D MAC protocol as a paradigm of social information inclusion in the green D2D MAC design. Last, we discuss the practical issues of the adoption of social awareness in green D2D cooperation, which may affect the D2D performance in realistic scenarios. Our simulation results demonstrate the effectiveness of exploiting the existence of users' social connections in D2D cooperation, highlighting the need for green social-aware D2D cooperative schemes.

INDEX TERMS Cooperation, D2D, energy efficiency, resource management, social awareness.

I. INTRODUCTION

Online social networking has offered unparalleled potential to communication among individuals in a plethora of everyday life activities. Indicatively, the 2014 football world cup in Brazil, apart from a sporting mega–event, was also a demonstration of social networks' power. In particular, 1.5 TB of data related to social media posts were circulated by the 75,000 spectators of the final match, corroborating the proliferation of mobile social networking [1]. Nowadays, instant sharing information of personal or professional interest is a matter of few clicks, bringing the human interactions to a new level.

Modern mobile devices play an active role in social networking, as the users are able to enjoy media services similar to those of desktop computers, and share their experiences with their peers on the fly. The advent of mobile social applications has multiplied the amount of data circulating in cellular networks, motivating the development of the fifth generation (5G) wireless communications technologies, based on Long Term Evolution Advanced (LTE–A).

Facing challenging user demands for network capacity, 5G is destined to accommodate the high traffic volume induced by mobile social networking. Among other technologies, the direct connectivity between mobile devices, namely Device–to–Device (D2D) communication, emerges as a promising solution for cellular network offloading [2]. Cellular resources support D2D links, circumventing the LTE–A evolved NodeB base stations (eNBs) and allowing data transmissions over licensed spectrum. The escalating traffic load has motivated D2D connectivity over unlicensed spectrum, using the IEEE 802.11 Standard technologies, e.g., Wi–Fi Direct. In addition to the case of cellular traffic offloading to D2D connections with the aim of load reduction in eNBs, users may decide to cooperate and exchange data directly for personal purposes.

In D2D social networking, cooperation among users is inherent. Regular issues of D2D cooperative communication are affected by social parameters that rule users' interactions. Even though physical distance among devices determines the quality of D2D connections, the users' eagerness to collaborate actually creates them. The first step towards D2D cooperation initiation is the discovery of neighboring users willing to engage in D2D communication, namely peer discovery. However, the existence of D2D links might be hampered by users' lack of interest for cooperation, due to inadequate incentives offered by the cellular network or low trust levels among users. Similarly, the communication mode selection, cellular or D2D, can be affected by the existence of social ties among users, as D2D communication is more likely to be established among friendly devices. Moreover, once D2D connections are set up, spectrum resources should be allocated to the users. If cellular resources are utilized and cellular users coexist with D2D users in a cell, the spectrum must be shared among all users with the aim of interference minimization between the two types of connections. If the D2D links reside in unlicensed spectrum, interference is provoked by concurrent efforts of multiple adjacent users to access the wireless medium. In both cases, users may be reluctant to cooperate or allow their devices to act as relays that assist D2D communication of possibly unknown users. The users' choices regarding the peers they prefer for cooperation affects channel access coordination. Therefore, D2D cooperation must be appropriately managed in order to actualize efficient bandwidth utilization, e.g., by properly designed Medium Access Control (MAC) schemes that exploit users' social connections, promoting cooperation among users that share a certain trust level [3].

An additional concern that arises in cooperative D2D networking is the energy consumption of involved mobile devices, as they are usually battery–powered. In practice, better resource utilization can be realized in D2D cooperation if proper selection of D2D peers is performed. If social connections among users are exploited in a way that fairness is ensured, the knowledge of social characteristics can be beneficial for the Quality of Service (QoS) of D2D cooperative communication. In fact, improving the QoS might simultaneously increase the energy efficiency of D2D cooperation [4]. Therefore, examining D2D cooperation under the social–aware prism can reveal ways of reducing energy consumption without hindering the offered QoS by suitably grouping the users in cooperative D2D structures [5].

As demonstrated by the aforementioned technical challenges, the D2D cooperation is influenced by a multifaceted context related to network parameters and users' social relations and activities [6]. In the communication domain, context refers to network status and channel conditions, as well as users' geographical location or battery level of devices. In the social domain, it is associated with the information about users' social relations, their willingness to cooperate, the applications they use for social networking or the type of content they share. Thus, properties of both domains should be considered when D2D cooperative communication issues are addressed.

In this article, we aim to shed some light on the implications of green D2D cooperation from a social–aware perspective and provide intuition towards their resolution. To this end, the contribution of our work is threefold:

1) We examine the arising challenges in social aware D2D cooperation that affect the D2D energy efficiency in cooperative D2D social networking scenarios, as derived by modern human activities.
2) We focus on the integration of social awareness in green D2D–MAC design. Specifically, we present a Social–aware Cooperative D2D MAC protocol (SCD2D–MAC) that promotes cooperation among socially related neighboring users and evaluate it in D2D networking scenarios. SCD2D–MAC exploits social awareness in order to improve the energy efficiency of D2D cooperative communication. The performance assessment of the proposed protocol reveals that significant gains can be achieved in terms of energy consumption without hindering the content exchange completion time, when social features are considered.
3) We outline the practical concerns that arise, from the network and the users' perspective, by the adoption of social awareness in green D2D cooperation. The discussed issues may hinder the actual benefits of social–aware design of green D2D cooperation and should be taken into account when D2D cooperative structures are orchestrated.

II. D2D SOCIAL NETWORKING SCENARIOS

Mobile users install a wide range of social networking applications on their devices and collaborate through them for personal and professional purposes. With the Wi–Fi capability of hand–held devices, users share their pictures with friends, edit and organize documents with co–workers or disseminate digital content to peers during social events. Thus, it becomes perceivable that D2D social networking involves communication among users that may or may not know each other, introducing different levels of trust among them. Moreover, it encompasses different application and content types and can lead to the formation of various cooperative networking topologies.

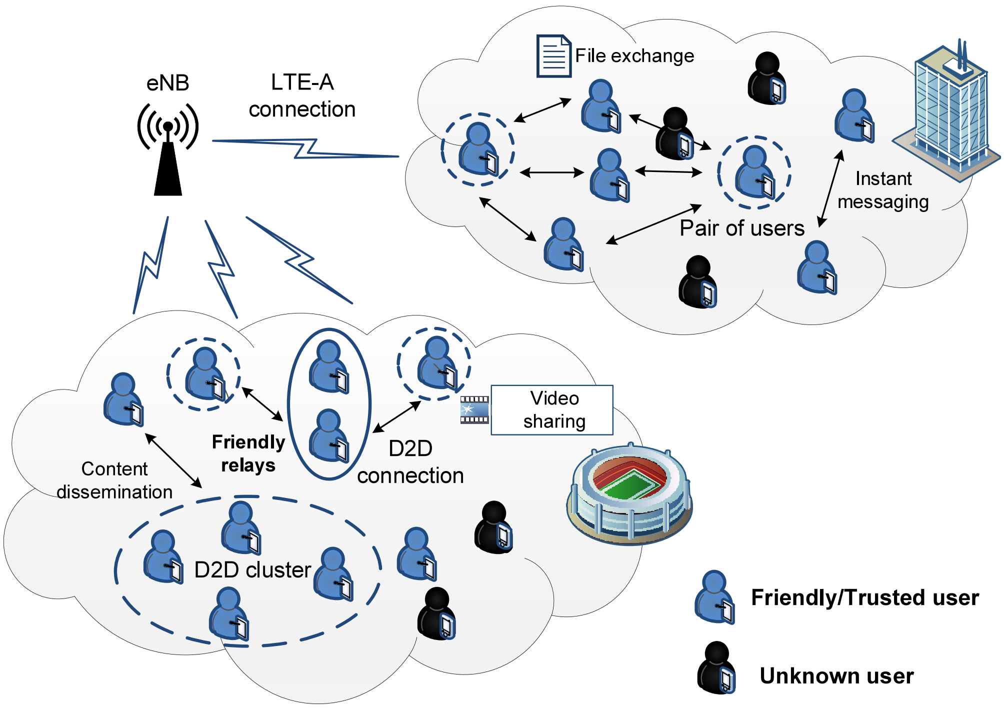

FIGURE 1. **D2D social networking scenarios.**

From the networking perspective, cooperating users maintaining D2D connections create different network topologies that stem from communication flows among adjacent users. Naturally, physical proximity of users is a prerequisite for D2D networking. The D2D network structure varies depending on the location and the density of peers eligible for D2D communication. Apparently, a D2D network can be comprised of multiple pairs of users that share content fractions through bidirectional flows (D2D data exchange) or clusters, where users act as source nodes and transmit content to others (D2D content dissemination).

The differentiation of D2D use cases is better illustrated by contrasting the scenarios of a pair of colleagues jointly editing the same documents and a user group recording scenes of a football game and sending them to interested users in a stadium (Fig. 1). We thereupon describe D2D cooperative communication scenarios that occur when users interact using mobile applications, inducing different D2D network topologies.

A. COOPERATIVE INFORMATION EXCHANGE IN D2D SOCIAL NETWORKING

A common social networking scenario involves information exchange among users connected with interpersonal relations, such as friends on Facebook or colleagues on LinkedIn. People that already know each other are likely to share data when their devices are in Wi–Fi range.

D2D cooperation is realized at a personal level for content sharing between pairs of adjacent users, as shown in Fig. 1. Similarly, neighboring users exchange real–time information for specific purposes related to their location, e.g., a workplace [7]. In this case, multiple pairwise D2D connections coexist in the same premise or region. The exchanged information is private, as only the source and destination users are interested in it, whereas other users, might overhear the D2D transmissions. The existence of "friendly" users can be beneficial for D2D cooperation.

Lately, social D2D networking has expanded to mobile crowdsourcing applications, where cooperation is motivated by the existence of common goals, e.g., sharing live information on traffic conditions in order to or contributing to online communities. Another example is the technology of mobile augmented reality that enables mobile users to collaborate actively for the construction of accurate 3D models based on human perception of the environment. The D2D cooperative data exchange can also serve as an enabler of Machine–to–Machine (M2M) communication, which involves the interconnection of smart devices, usually without human intervention. The peer–to–peer model of D2D cooperation can support various smart applications, such as intelligent transportation systems or environmental monitoring [8].

B. SOCIAL COOPERATIVE D2D CONTENT DISSEMINATION

D2D cooperation can become an efficient means of content dissemination. Social events are a typical example of this scenario, given the high number of attendees and the coexistence of multiple devices in close proximity. Users are likely to be strangers but might belong to the same online community, usually related to their location, e.g., a stadium.

D2D cooperation issue	Scheme	Mechanism	Use of social information	Energy consumption issues
Network formation	peer discovery [13]	classification of D2D users in groups and probing rate optimization in each group	Users are separated in groups according to social centrality metrics.	Mobile devices of users with high centrality in social networks are preferred for D2D cooperation leading to a significant increase of battery usage. Uneven traffic distribution inside D2D coalitions may increase the energy consumption for highly preferred devices.
	cluster formation [14]	coalitional game theoretic distributed algorithm	Socially related users are organized in groups for cooperative video multicast.	
	D2D link establishment [15]	social-aware graph-based greedy algorithm	Users-members of the same community are interested in similar content but are reluctant to share content with users outside the community.	
Resource management	resource allocation in cellular and D2D users [17]	social graph based delay minimization algorithm	D2D users prefer to use the resources of cellular users in the same community.	Resource allocation according to social information only may result in unfairness in both resource utilization and energy consumption among users.
	spectrum allocation in D2D users [18]	matching game with peer effects	D2D users with higher number of social ties are prioritized in spectrum allocation.	
Peer selection for relaying	probing scheme for relay selection [22]	optimal stopping problem formulation	Relay probing is performed according to users' social distances that define trust levels.	The D2D relay selection process that relies on social features may lead to over-use of some devices as relays, unless proper energy aware strategies are employed or incentives for cooperation are provided.
	network-assisted relay selection [23]	coalitional game theoretic model	Users prefer relays they know (social trust) or agree to cooperate with strangers by reciprocally assisting their transmissions (social reciprocity).	

FIGURE 2. Overview of existing social–aware approaches for D2D cooperation issues.

As depicted in Fig. 1, the attendees of a sports event share information with their peers through social media applications. Users can be organized in D2D groups, where some of them act as source nodes and the rest as destination nodes. The shared content is either user or cellular network originated. For instance, users transmit their own pictures to friends or other interested users or share videos previously downloaded via cellular connections. Users might also act as relays, supporting the content dissemination within groups of cooperating users.

As the density of users with social ties increases, more relay candidates that can assist the D2D transmissions of neighboring users exist. This feature could be useful in M2M communication scenarios, as a means to alleviate the cellular network congestion problem induced by the M2M links, using properly designed D2D cooperative schemes [9] or forming cooperative groups of ''smart objects'' that can improve the spectrum utilization [10].

III. ARISING CHALLENGES OF SOCIAL–AWARE D2D COOPERATIVE COMMUNICATION

D2D communication can mitigate cellular network congestion by exploiting users' physical proximity and offloading part of cellular traffic onto D2D links. Users' cooperation in this case is an initiative from the cellular network. D2D connections can be also initiated by users that wish to collaborate through mobile applications. Considering two devices within Wi–Fi range that interact through a social networking application, a D2D link can be established between them. Moreover, content sharing among community members in short physical distance can be realized by D2D cooperation.

The social D2D communication faces challenges similar to those of cooperative networking, which correspond to two basic questions: *i) In which cases are D2D cooperative networks formed?* and *ii) Which are the conditions for D2D cooperation?* Although these questions seem to revolve around networking issues only, they are accentuated by the users' social interactions.

The nature of mobile social networking stresses the need to consider the social factor when examining D2D cooperation. However, in realistic scenarios, the social awareness might induce energy consumption issues for the mobile devices that participate in cooperative transmissions. Hence, another crucial question arises: *how can social awareness be adapted to the green context of D2D cooperation?* In essence, the approaches that address issues of D2D cooperative networks should also have a green aspect that will enable them to utilize social awareness in a way that the D2D QoS is improved. Such an extension would lead to higher D2D cooperative energy efficiency, which is an important performance metric when battery–driven devices are involved in D2D transmissions. A qualitative overview of existing approaches for the aforementioned challenges is shown in Fig 2.

A. EXPLOITING SOCIAL FEATURES FOR GREEN COOPERATIVE D2D NETWORK FORMATION

At the D2D cooperative network formation phase, the peer discovery and communication mode selection issues arise, as users suitable to engage in D2D cooperation must be identified. In practice though, an adversity in D2D communication is the users' reluctance to cooperate by giving access to their devices to others or allowing the circulation of their own data via other devices [11]. These trust issues can be alleviated by offering the users proper incentives to "share" their devices with peers in area. Additionally to business level adjustments that motivate users to adopt D2D connectivity, social interactions among users can build a trustworthy D2D environment. Normally, users' mobile devices can maintain social preference lists that include contacts, namely friends, colleagues, etc., from installed social mobile applications. Thus, social characteristics can be easily extracted by social networking applications and serve as a guideline for D2D cooperative structures formation, e.g., using coalitional game theoretic models [12].

Users' social relations are long–term characteristics that can facilitate the discovery of proper D2D peers. The D2D candidate identification process can rely on information about the frequency of communication among users in communities [13]. Furthermore, centrality metrics characterizing the importance of users in social networks, can be utilized for D2D network formation. In content sharing scenarios, as the one depicted in Fig. 1, several central users can be the source nodes and disseminate information to neighboring users–members of the same community. Instead of retrieving data from content providers, users can rely on data similarity in order to identify suitable peers, e.g., create user clusters for video multicast [14]. Under the assumption that users in the same community show interest in the same digital content, D2D connections can provide users in physical and social proximity with the desired content [15].

Similar social–aware rationale can be followed for users' communication mode selection. Users might not be eager to allow their devices to use D2D mode, even if D2D link quality is estimated to be higher than that of cellular link. Even though high peer density favors D2D networking, users' cooperation is finally endorsed in light of social factors, such as common desire for popular content and high trust among users, since the circulating data are of public interest (Fig. 1). Social information can be incorporated in cooperative game formulation, performing joint mode selection for sets of neighboring socially related users.

An aspect often neglected in existing social–aware approaches for D2D network formation issues is the energy consumption of participating devices. The D2D network design should incorporate energy–aware mechanisms that distribute equitably the traffic load among cooperating devices, without draining the resources of users with high centrality. For example, the MAC mechanism can allow cooperation only among peers with stronger social ties, e.g., peers that users contact more often. Moreover, energy efficient D2D cooperative structures could be established by enhancing D2D coalition formation approaches, such as [16], with social awareness.

B. ALLOCATING RESOURCES FOR GREEN D2D COOPERATION USING THE USERS' SOCIAL INFORMATION

Currently, LTE–A specification enables D2D connectivity over licensed or unlicensed spectrum. In the first case, cellular users coexist with D2D users. D2D links may share the same resources with cellular links or use dedicated spectrum. To mitigate the interference among the two types of links, resource allocation mechanisms can exploit social characteristics of D2D users. A point often overlooked is that the users are likely to show willingness for cooperation with their social connections but may not be interested in helping unknown users. Consequently, social–unaware spectrum allocation may become inefficient when users ignore opportunities for D2D cooperation.

In cooperative D2D networks underlaying cellular network, after deriving the social information, portions of spectrum can be allocated accordingly. For instance, users can be selected as cluster heads downloading content from the eNB and be allocated resource blocks in order to let neighboring users–friends receive data through D2D connections. In this way, spectrum efficiency is improved and eNBs fairly distribute available resources among users. Resource sharing can be performed among cellular and D2D users of the same community, in order to reduce the D2D transmission duration [17]. The resource allocation problem can be also formulated as a matching game between users and spectrum resource blocks [18]. Bipartite graphs [19] could be also used for social aware resource allocation. As users with similar interests tend to request similar content, clusters are formed by users with strong social ties, increasing the number of requests offloaded to D2D links.

Particularly for D2D communication over unlicensed spectrum, D2D MAC protocols perform bandwidth allocation by coordinating channel access of multiple users. Examining a cooperative D2D clustering scenario, we see that if D2D transmissions of users with high centrality are favored by the MAC scheme, higher number of receivers is served at each communication round. However, the cooperation of a highly connected user as source node is hindered by the fact that it sacrifices his resources to benefit others. To that end, the exploitation of users' social interacting patterns could improve the performance of existing game theoretic MAC approaches [20].

Nevertheless, the existence of social ties is not a guarantee for users' willingness for cooperation. Given that the battery capacity of mobile devices is limited, there exists the contingency that spectrum allocation is not acceptable by the users due to high energy consumption. Therefore, D2D resource allocation schemes need to be energy–aware, considering at the same time the users' social information. Resource allocation and power control schemes that already exist in the literature, e.g., [21], could jointly consider the energy consumption factor with the social context and provide energy efficient D2D resource management.

C. SELECTING SOCIALLY CONNECTED USERS FOR ENERGY EFFICIENT INFORMATION RELAYING

D2D MAC schemes can promote D2D cooperation among socially related users by employing social–aware relay selection. Users desirable for relaying should gain channel access or be assigned spectrum resources with higher priority. As these preferences are defined in the social domain, the integration of social interactions in MAC design would reduce privacy concerns of D2D relaying, forming trustworthy cooperative D2D networks.

Once D2D pairs or groups are formed, the broadcast nature of the wireless channel enables opportunistic listening of circulating data fragments, creating fertile soil for D2D cooperation. Similarly to peer discovery, relay selection can be improved if users' social ties are exploited. A relay probing scheme can differentiate users with regard to both physical distance and social trust level [22]. In practice, users are more willing to assist the D2D communication of users that they know and trust than that of strangers [23].

The decision for cooperation is a dilemma between selecting suitable relays as mandated by wireless channel conditions and possible throughput gains, and preferring relays that maintain social ties with D2D users. Depending on the application, social trust may have higher priority than D2D performance, e.g., data exchange among colleagues in workplaces might have higher privacy demands than video sharing during sports events. This context information can be retrieved by eNBs and used for user–relay association in matching theoretic tools with social–aware utility functions.

Arguably, when D2D trust is an issue, users with high number of social ties are mostly preferred as source nodes or relays. Nonetheless, even though cooperation may be beneficial for some users, it may result in relays' battery depletion. Proper relays that are able to assist the D2D communication of neighboring users should be selected, e.g., relays powered by renewable energy resources [24]. The energy consumption issue becomes more crucial in content distribution scenarios within D2D clusters, highlighting the need for incorporating the social information in energy–aware relay selection schemes. Furthermore, cooperation would be profitable for users eligible for relaying, if incentive mechanisms were applied by D2D cooperative schemes. Tangible profits, such as reduction of network service cost, could compensate for the energy consumed for relaying.

IV. DESIGNING SOCIAL AWARE D2D MAC FOR ENERGY EFFICIENCY IMPROVEMENT

An overall inspection of the aforementioned challenges shows that social awareness can improve D2D networking and make the traits of cooperating over unlicensed spectrum more appealing to the users. Taking into account the context of social networking and the energy consumption issues that arise by the social awareness, we present a Social–aware Cooperative D2D MAC (SCD2D–MAC) protocol as a paradigm of incorporation of social information in D2D MAC design that can improve the D2D energy efficiency. SCD2D–MAC promotes cooperation among users with social ties in case of D2D communication between a pair of users, reducing the overall energy consumption of D2D cooperative communication. Furthermore, we investigate the influence of social characteristics in D2D cooperation by assessing the performance of the proposed protocol.

A. PROTOCOL OVERVIEW

The main functionality of SCD2D–MAC relies on the availability of context information to the pair. The users may engage in D2D communication either by their own initiative during interaction through a specific mobile application or switch to D2D mode as indicated from the cellular network. In both cases, network and social information must be available to the users and the eNB that serves them.

Initially, the eNB determines D2D candidates during the peer discovery phase, by paging possible friendly users and determining D2D pairs. After D2D connections are established, a social preference list for each D2D pair is constructed, including ''identification details'' of users eligible for D2D communication with each pair. Friendly users opportunistically encountered in vicinity can serve as relays.

The existence of social connection between the relays and the pair is the criterion that determines the decision of relays to engage in D2D cooperation. Users belonging to the pair's social network or are members of the same online community are willing to help the pair's communication. Conversely, unknown relays are not bound to cooperate and are likely to content for channel access aiming to serve D2D transmissions for their own benefit. Thus, their participation in D2D cooperation might cause a series of unfruitful communication rounds, from the pair's viewpoint. As more D2D transmissions might be required to deliver the pair's data due to unknown relays' intervention, the energy efficiency of D2D cooperation might deteriorate.

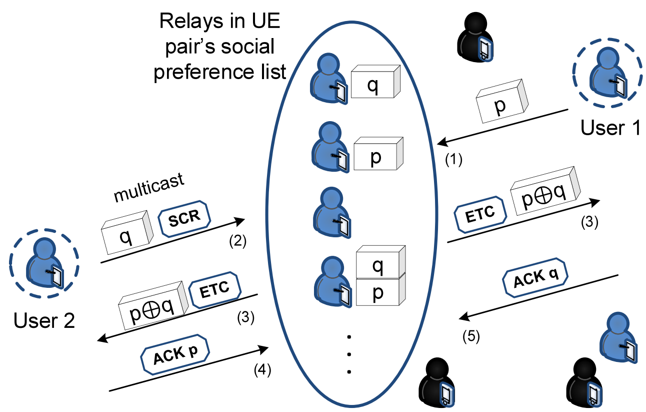

FIGURE 3. D2D cooperative data exchange with SCD2D–MAC.

Let us consider the D2D pair of User 1 and User 2, who desire to exchange data directly using Wi–Fi, after having obtained the social preference list (Fig. 3). At each communication round, a user gains channel access using the

Distributed Coordination Function (DCF) of the IEEE 802.11 Standard specification [25] and transmits its packet (step 1). The other user fails to decode it correctly and in step 2, it sends a *Social-Cooperation-Request* (SCR) packet to request for cooperation from adjacent users–friends. In the D2D pair's Wi–Fi range, two types of users may co–exist:

1) Users without social ties with the pair.
2) Users that maintain social connections with the pair.

Preferably, users–contacts of the pair are utilized as relays. The SCR packet contains the necessary information for the identification of the pair by the possible relays. It should be noted that in social–unaware D2D MAC protocols, the contingency that friendly and unknown users coexist is not explicitly handled. Thus, the relay candidates gain channel access equitably, according to the IEEE 802.11 rules, regardless of the users' social ties. In SCD2D–MAC, the social dimension of D2D cooperation is reflected in relay selection process, which prioritizes the use of friendly users as relays. More specifically, in the cooperation phase, the SCR packet is transmitted to a multicast group that consists exclusively of users–friends of the pair. Only the users in this group are considered to be trusted and receive the SCR packet, which indicates their eligibility as relays.

After distinguishing the friendly relays and organizing them in a multicast group, the SCD2D–MAC protocol prioritizes them according to the number of packets they manage to decode, improving the D2D cooperation performance. In each cooperation round, a relay may overhear up to two packets, namely it may receive either packets from both users in the D2D pair, or only one packet (the packet of one user, either User 1 or User 2) or it may not be able to correctly decode any packet. Each relay that wishes to transmit uses a backoff counter, as required by the DCF method. The relay prioritization is accomplished using non-overlapping ranges for the backoff counter of the relays. The backoff range is divided into several ranges according to the number of packets existing in each relay, in a way that relays with more packets can gain channel access. For instance, relays with both packets select their backoff counter from a backoff range with lower values than those used by relays with one packet.

With regard to the number of packets received by the eligible relays, the cooperation phase may lead to one out of three possible outcomes. First, if at least one of the relays receives packets of both users, namely packets p and q, network coding can be performed. In this case, an encoded packet is transmitted by the relay (step 3 in Fig. 3). Second, if no relay receives both packets but there exist relays with one packet, either p or q, the selected relay transmits the packet it has received. Last, there is the contingency that no packets are correctly decoded by any friendly adjacent user, leading to an unfruitful cooperation round. Subsequently, the selected relay indicates the number of packets it will transmit in the *Eager-To-Cooperate* (ETC) packet, sent along with data packets correctly decoded. Once ETC is received, the pair is aware of the number of ACKs that will terminate the cooperation phase. For the example of Fig. 3, two ACKs are transmitted, indicating the successful reception of p and q (steps 4 and 5). If no data packet is transmitted, the cooperation ends with the ETC transmission.

B. EFFECTS OF SOCIAL AWARENESS ON D2D COOPERATION PERFORMANCE

We quantitatively evaluate the SCD2D–MAC protocol under the influence of information about users' social structures in the D2D cooperative communication scenarios of a socially connected pair of users that exchange data of user or cellular network origination. Aiming to highlight the effect of social characteristics in D2D cooperation, we compare SCD2D–MAC with two state-of-the-art protocols that do not consider the social dimension, the ACNC–MAC and NCCARQ–MAC [26] protocols, under different proportions of friendly relays within the pair's range. We have developed a C++ simulator that implements the three protocols. The D2D cooperative communication performance is assessed in terms of data exchange completion time, namely the time required for successful reception of exchanged content by both users. Furthermore, we estimate the energy efficiency [27] and the average battery drain [28] of the D2D network, considering the energy consumption of all participating users.

1) D2D COMMUNICATION SCENARIOS UNDER STUDY

The D2D pair in Fig. 3 resides in the coverage area of an LTE–A cell with 30 active users, out of which a number of 20 users are relay candidates. They either maintain social ties with the pair or are strangers. We define as $\alpha \in \{0.2, 0.4, 0.7, 0.9\}$ the proportion of friendly relays in the pair's area, corresponding to 20%, 40%, 70% and 90% of the relay candidates' number. As already discussed, SCD2D–MAC distinguishes the friendly relays by explicitly asking for their cooperation. Conversely, the ACNC–MAC and NCCARQ–MAC protocols cannot perform relay discrimination, allowing the use of any adjacent user as relay. Hence, there exists the risk that unknown relays may gain channel access and serve transmissions of their own interest. With NCCARQ-MAC, the cooperation phase begins only if the relays receive packets from both users and can perform NC, whereas with ACNC–MAC, cooperation may be initiated even with fewer packets at the relays.

All protocols are tested in two D2D communication scenarios, denoted as A and B, using the settings in Table 1. The users' devices are equipped with 1300 milliampere-hour (mAh) batteries and LTE–A and Wi–Fi radio interfaces that can be used simultaneously. In the presented results, a fixed packet error rate (PER) is used, as different PER values influence the protocols' performance as anticipated, without affecting our conclusions. In scenario A, the two users exchange two files of 5 MB size, already existing in their devices. The network operates under saturated conditions. In scenario B, the users exchange video content they receive from cellular connections. The resources scheduling policy for downlink transmissions determines the packet arrival rate at the pair, creating non–saturated conditions.

TABLE 1. Simulation parameters.

Cellular network parameters (scenario A)		D2D network parameters (both scenarios)	
Parameter	Value	Parameter	Value
Bandwidth	20 MHz	MAC+PHY header	52 bytes
Resources scheduling	Round Robin	time slot	10 μs
Noise power spectral density (dBm/Hz)	-174 dBm/Hz	data Tx rate	54 Mb/s
$P_{\text{trans}}^{\text{eNB}}$	46 dBm	SCR	16 bytes
Users–eNB distance	700-800 m	Payload size	512 bytes
Modulation and Coding Scheme	64–QAM	ETC, ACK	14 bytes
Transmission Time Interval	1 ms	PER	0.2
Rx power level	2 W	Idle and Rx power level	1.34 W
Video sequence	Foreman, QCIF, 15 fps	Tx power level	1.9 W

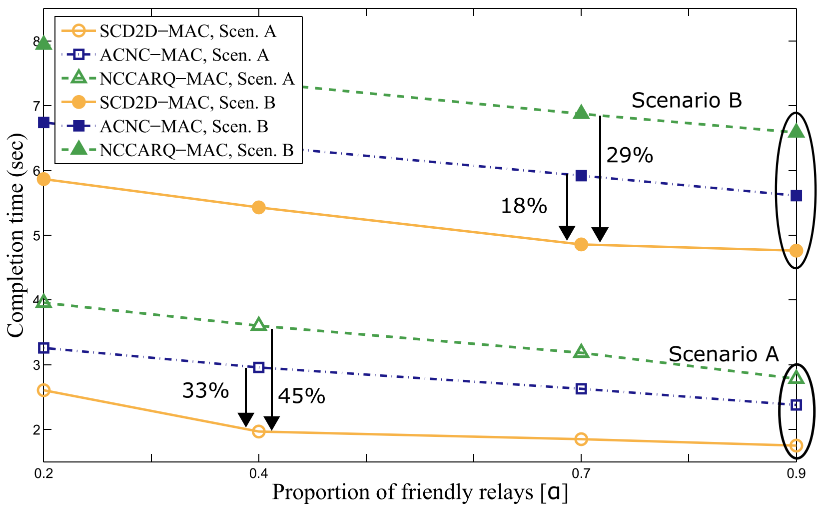

FIGURE 4. D2D content exchange completion time.

2) RESULTS DISCUSSION

In Fig. 4, the data exchange completion time achieved by the three protocols is depicted. The increase of the portion of friendly relays (α) improves the performance of all protocols, since fewer cooperation rounds are exploited by unknown users. However, ACNC–MAC and NCCARQ–MAC need significantly higher time to complete the exchange than SCD2D–MAC. Indicatively, for $\alpha = 0.4$ in scenario A, SCD2D–MAC achieves 33% and 45% lower completion time than ACNC–MAC and NCCARQ–MAC, respectively. Similarly, in scenario B, the decrease of completion time with SCD2D–MAC reaches 18% and 29%, for $\alpha = 0.7$. This differentiation can be explained by the fact that SCD2D–MAC restricts the set of relays, explicitly asking for the cooperation of friendly users only. Thus, each cooperation round serves exclusively the pair's D2D transmissions.

The influence of α level in D2D cooperation performance is also perceptible in Fig. 5, which depicts the energy efficiency levels achieved by the three protocols under comparison in both D2D content exchange scenarios. As α increases, the energy efficiency reduces as more relays are engaged in D2D cooperation, thus the total energy consumption in the D2D network increases. Due to this effect, even though the existence of more relays reduces the data exchange completion time in all cases, the energy efficiency does not follow the same trend. However, the multicast functionality of SCD2D–MAC enables the use of friendly relays only, improving the energy efficiency, comparing to ACNC–MAC and NCCARQ–MAC. For instance, in scenario A, for $\alpha = 0.2$, the energy efficiency of SCD2D–MAC is 18% and 35% higher than that achieved by ACNC–MAC and NCCARQ–MAC, respectively (Fig. 5(a)). In scenario B ($\alpha = 0.4$), the resulting improvement reaches 10% and 17%, as shown in Fig. 5(b).

The D2D energy efficiency performance is in accordance with the battery usage levels illustrated in Fig. 6. More specifically, the average battery drain for the pair and the relays increases alongside with α, as a higher number of friendly

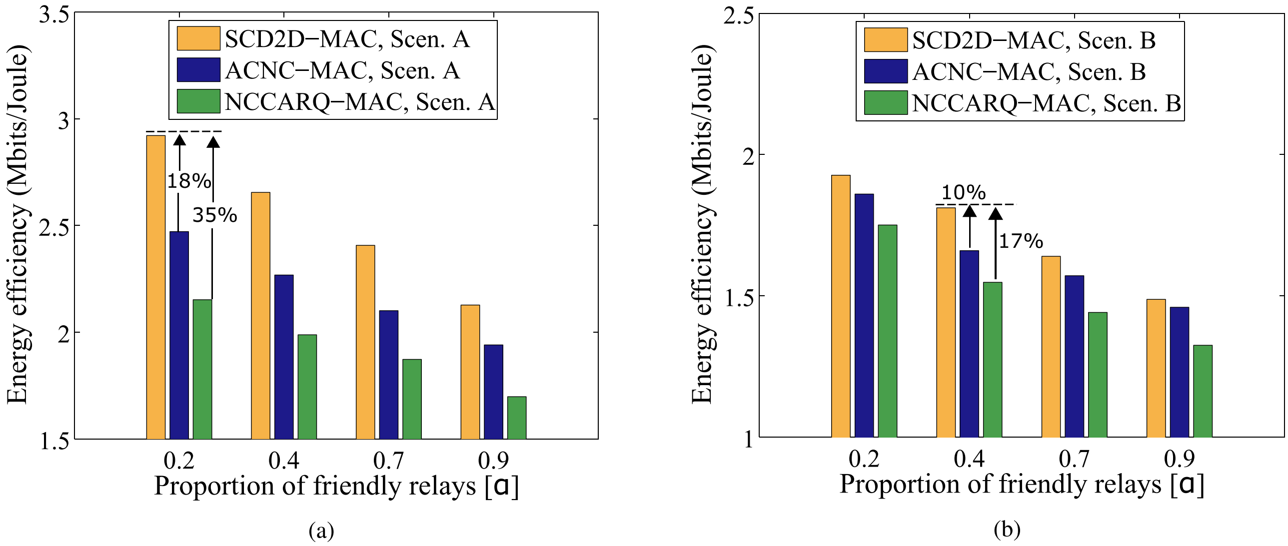

FIGURE 5. **Energy efficiency in D2D content exchange. (a) Scenario A. (b) Scenario B.**

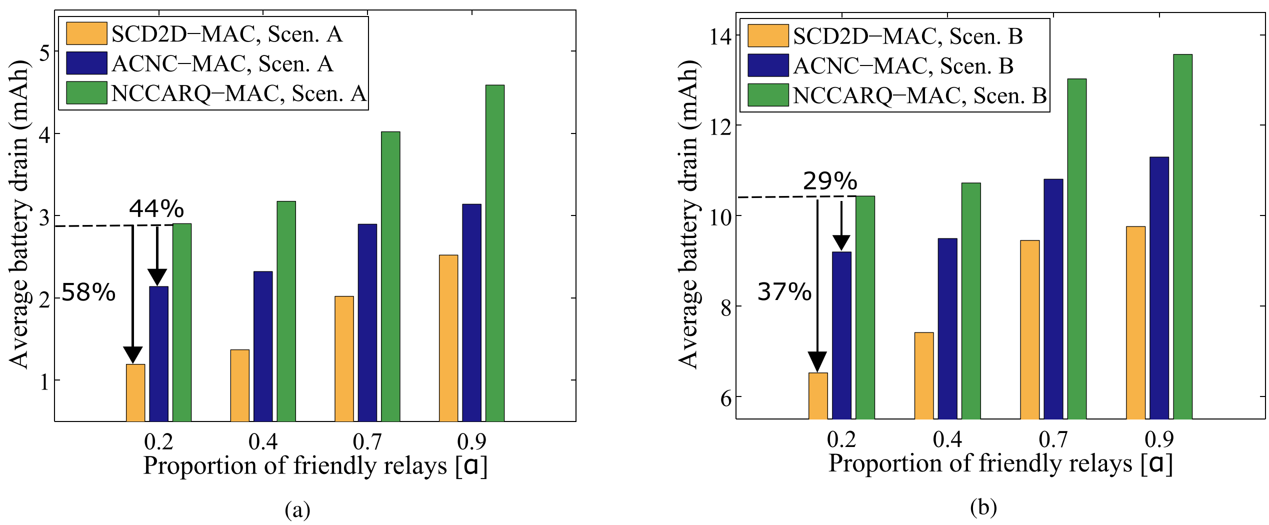

FIGURE 6. **Average battery drain in D2D content exchange. (a) Scenario A. (b) Scenario B.**

relays contend for channel access in order to support the pair's communication. However, the use of SCD2D–MAC results in lower total energy consumption, as only a portion of neighboring users are selected to act as relays, transmitting data packets that are useful to the pair and reducing the completion time. Particularly, for $\alpha = 0.2$, the battery drain with SCD2D–MAC is 44% and 58% lower than ACNC–MAC and NCCARQ–MAC in scenario A and 29% and 37% lower in scenario B, as depicted in Fig. 6(a) and Fig. 6(b), respectively.

We observe that the variation of friendly relays proportion affects the cooperation performance, regardless of the employed protocol. With SCD2D–MAC, when the density of users belonging to the considered pair's social circle increases, the D2D cooperation potential is reflected in the performance gains. The use of friendly devices and the prioritization of NC–capable relays results in faster data exchange, reducing the energy consumption of the involved mobile devices. In general, even though a social–unaware methodology detects the channel conditions that favor D2D cooperation, it cannot capture the users' social ties. The social structures may be favorable to D2D performance or hinder it, if ignored, as users tend to act altruistically for friends and selfishly for strangers. Additionally, the adaptation of D2D cooperation to the social context can also promote energy awareness, as the existence of social ties might affect the energy consumption levels during cooperation. Therefore, tackling the challenges of D2D cooperative communication imposes the consideration of the users' intention for cooperation.

V. PRACTICAL ISSUES IN INTEGRATION OF SOCIAL AWARENESS IN D2D COOPERATION

Promoting D2D cooperation among users with social ties is beneficial for the users' experience, in terms of data exchange completion time and battery drain. However, when the knowledge of social parameters is introduced in actual D2D cooperative networks, practical issues arise that may hinder opportunities for D2D cooperation and impact on D2D performance.

In realistic social–aware cooperative D2D networks, information of social domain about a possibly large number of users, e.g., in D2D data dissemination scenarios, is usually required, in order to obtain the users' social structures. This information can be transmitted to cellular infrastructure by the users' devices. During this process, additional signaling overhead in the cellular network elements that coordinate the D2D users is created. Without cellular network intervention, neighboring devices might have to exchange users' social information in an ad hoc manner, increasing the congestion in the D2D network. In any case, the benefits of social awareness in D2D cooperation should be studied in conjunction with the impact of additional network load that the transmission of users' social information induces.

To further harness the traits of using the knowledge of users' social ties in D2D cooperative structures, the network operators should provide practical incentives that can stimulate their mobile customers' interest in cooperation. However, motivating the users' participation is not trivial, as it requires observation of social characteristics and behavior in order to make the "remuneration" for D2D cooperation attractive. Although there exist approaches that integrate incentive mechanisms in D2D design, such as [29], it is usually assumed that all users are interested in the same type of payoff, e.g., monetary reward, improved QoS for some time period or various types of discounts in provided network services [30]. However, accepting homogeneity in users' interest may hinder the D2D cooperation opportunities, unless the usage of mobile devices' resources is compensated using assets tailored to users' needs. Therefore, the social context should be enriched with information about users' preferences that can help the operators devise targeted D2D cooperation proposals.

From the users' viewpoint, the introduction of social awareness in D2D cooperative scenarios raises privacy concerns. The acquisition of social characteristics of users in close proximity is of crucial importance in order to identify opportunities for D2D cooperation. Nonetheless, even though this information can help determine trust levels among users, improving the efficiency of D2D cooperative communication, the users might not desire to share personal data about the applications they use or their contact lists. Therefore, their consent to social networking information storing by mobile operators cannot be taken for granted and might be application dependent. For similar reasons, the extent of social trust among users, e.g., trust among friends–of–friends, needs to be properly specified for the formation of trusted cooperative structures. Special attention should be also paid to the design of users' data privacy policies in conjunction with proper encryption methods.

VI. CONCLUDING REMARKS

In this article, we have highlighted the main challenges of D2D cooperative communication, under the effect of users' social characteristics and the green context of social aware D2D cooperation. We have proposed a social–aware cooperative D2D MAC protocol that promotes the use of friendly users as relays and reduces the energy consumption of D2D cooperation. We also describe some practical concerns that arise when social awareness is incorporated in D2D cooperative networking. Our simulation results have shown that substantial gains can be achieved if D2D MAC protocols utilize the social information of the cooperating users. These results can provide useful guidelines for energy–aware cooperative D2D MAC protocol design and assist the development of social–aware green resource allocation and channel access coordination schemes for coexistent cellular and D2D networks.

ACKNOWLEDGEMENT

The statements made herein are solely the responsibility of the authors.

REFERENCES

[1] *Ericsson Mobility Report-MWC Edition*, Ericsson, Stockholm, Sweden, 2015. [Online]. Available: http://www.ericsson.com/ericsson-mobility-report

[2] A. Gupta and R. K. Jha, "A survey of 5G network: Architecture and emerging technologies," *IEEE Access*, vol. 3, pp. 1206–1232, 2015.

[3] L. Guardalben, T. Gomes, P. Salvador, and S. Sargento, "Improving MAC layer association through social-based metrics in mobile networks," *IEEE Commun. Mag.*, vol. 50, no. 6, pp. 91–98, Jun. 2012.

[4] A. Antonopoulos and C. Verikoukis, "Multi-player game theoretic MAC strategies for energy efficient data dissemination," *IEEE Trans. Wireless Commun.*, vol. 13, no. 2, pp. 592–603, Feb. 2014.

[5] A. Bourdena, C. Mavromoustakis, G. Mastorakis, J. Rodrigues, and C. Dobre, "Using socio-spatial context in mobile cloud offload process for energy conservation in wireless devices," *IEEE Trans. Cloud Comput.*, vol. PP, no. 99, 2016.

[6] Y. Li, T. Wu, P. Hui, D. Jin, and S. Chen, "Social-aware D2D communications: Qualitative insights and quantitative analysis," *IEEE Commun. Mag.*, vol. 52, no. 6, pp. 150–158, Jun. 2014.

[7] Z. Wang, X. Zhou, D. Zhang, Z. Yu, and D. Zhang, "SOCKER: Enhancing face-to-face social interaction based on community creation in opportunistic mobile social networks," *Wireless Pers. Commun.*, vol. 78, no. 1, pp. 755–783, Sep. 2014.

[8] E. Z. Tragos *et al.*, "Enabling reliable and secure IoT-based smart city applications," in *Proc. IEEE Int. Conf. Pervasive Comput. Commun. Workshops (PERCOM Workshops)*, Mar. 2014, pp. 111–116.

[9] R.-S. Cheng, C.-M. Huang, and G.-S. Cheng, "A D2D cooperative relay scheme for machine-to-machine communication in the LTE-A cellular network," in *Proc. IEEE Int. Conf. Inf. Netw. (ICOIN)*, Jan. 2015, pp. 153–158.

[10] E. Z. Tragos and V. Angelakis, "Cognitive radio inspired M2M communications," in *Proc. IEEE 16th Int. Symp. Wireless Pers. Multimedia Commun. (WPMC)*, Jun. 2013, pp. 1–5.

[11] L. Lei, Z. Zhong, C. Lin, and X. Shen, "Operator controlled device-to-device communications in LTE-advanced networks," *IEEE Wireless Commun.*, vol. 19, no. 3, pp. 96–104, Jun. 2012.

[12] T. Wang, Y. Sun, L. Song, and Z. Han, "Social data offloading in D2D-enhanced cellular networks by network formation games," *IEEE Trans. Wireless Commun.*, vol. 14, no. 12, pp. 7004–7015, Dec. 2015.
[13] B. Zhang, Y. Li, D. Jin, P. Hui, and Z. Han, "Social-aware peer discovery for D2D communications underlaying cellular networks," *IEEE Trans. Wireless Commun.*, vol. 14, no. 5, pp. 2426–2439, May 2015.
[14] Y. Cao, T. Jiang, X. Chen, and J. Zhang, "Social-aware video multicast based on device-to-device communications," *IEEE Trans. Mobile Comput.*, vol. 15, no. 6, pp. 1528–1539, Jun. 2016.
[15] Y. Zhao, Y. Li, H. Mao, and N. Ge, "Social community aware long-range link establishment for multi-hop D2D communication networks," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Jun. 2015, pp. 2961–2966.
[16] Y. Cai, D. Wu, and L. Zhou, "Green resource sharing for mobile device-to-device communications," in *Proc. IEEE Wireless Commun. Netw. Conf. (WCNC)*, Apr. 2014, pp. 3142–3147.
[17] Y. Li, S. Su, and S. Chen, "Social-aware resource allocation for device-to-device communications underlaying cellular networks," *IEEE Wireless Commun. Lett.*, vol. 4, no. 3, pp. 293–296, Jun. 2015.
[18] O. Semiari, W. Saad, S. Valentin, M. Bennis, and H. V. Poor, "Context-aware small cell networks: How social metrics improve wireless resource allocation," *IEEE Trans. Wireless Commun.*, vol. 14, no. 11, pp. 5927–5940, Nov. 2015.
[19] L. Wang, H. Wu, W. Wang, and K.-C. Chen, "Socially enabled wireless networks: Resource allocation via bipartite graph matching," *IEEE Commun. Mag.*, vol. 53, no. 10, pp. 128–135, Oct. 2015.
[20] A. Antonopoulos, E. Kartsakli, and C. Verikoukis, "Game theoretic D2D content dissemination in 4G cellular networks," *IEEE Commun. Mag.*, vol. 52, no. 6, pp. 125–132, Jun. 2014.
[21] Y. Jiang, Q. Liu, F. Zheng, X. Gao, and X. You, "Energy efficient joint resource allocation and power control for D2D communications," *IEEE Trans. Veh. Technol.*, vol. PP, no. 99, 2015.
[22] M. Zhang, X. Chen, and J. Zhang, "Social-aware relay selection for cooperative networking: An optimal stopping approach," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Jun. 2014, pp. 2257–2262.
[23] X. Chen, B. Proulx, X. Gong, and J. Zhang, "Exploiting social ties for cooperative D2D communications: A mobile social networking case," *IEEE/ACM Trans. Netw.*, vol. 23, no. 5, pp. 1471–1484, Oct. 2015.
[24] T. Han and N. Ansari, "Heuristic relay assignments for green relay assisted device to device communications," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Dec. 2013, pp. 468–473.
[25] *IEEE Standard for Information Technology–Telecommunications and Information Exchange Between Systems, Local and Metropolitan Area Networks–Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, IEEE Standard 802.11-2012, Mar. 2012, pp. 1–2793.
[26] E. Datsika, A. Antonopoulos, N. Zorba, and C. Verikoukis, "Adaptive cooperative network coding based MAC protocol for device-to-device communication," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Jun. 2015, pp. 6996–7001.
[27] V. Rodoplu and T. H. Meng, "Bits-per-Joule capacity of energy-limited wireless networks," *IEEE Trans. Wireless Commun.*, vol. 6, no. 3, pp. 857–865, Mar. 2007.
[28] N. Ding, D. Wagner, X. Chen, A. Pathak, Y. C. Hu, and A. Rice, "Characterizing and modeling the impact of wireless signal strength on smartphone battery drain," *SIGMETRICS Perform. Eval. Rev.*, vol. 41, no. 1, pp. 29–40, Jun. 2013.
[29] Y. Zhang, L. Song, W. Saad, Z. Dawy, and Z. Han, "Contract-based incentive mechanisms for device-to-device communications in cellular networks," *IEEE J. Sel. Areas Commun.*, vol. 33, no. 10, pp. 2144–2155, Oct. 2015.
[30] M. N. Tehrani, M. Uysal, and H. Yanikomeroglu, "Device-to-device communication in 5G cellular networks: Challenges, solutions, and future directions," *IEEE Commun. Mag.*, vol. 52, no. 5, pp. 86–92, May 2014.

EFTYCHIA DATSIKA received the B.Sc. and M.Sc. degrees in computer science from the Computer Science Department, University of Ioannina, Greece, in 2010 and 2012, respectively. She is currently an Early Stage Researcher with Iquadrat Informatica S.L., Spain. Her research interests lie in the areas of long-term evolution advanced networks and device-to-device communication.

ANGELOS ANTONOPOULOS received the Ph.D. degree from the Technical University of Catalonia in 2012. He has authored over 50 research papers on various topics, including 5G mobile networks, cooperative communications, radio resource management, network sharing, and energy efficient network planning. He has participated in several European projects and has been awarded by the Technical Chamber of Greece for Exceptional Graduate Performance. He received the best paper award at the IEEE GLOBECOM 2014 and the Best Demo Award at the IEEE CAMAD 2014. He was nominated as an Exemplary Reviewer of the IEEE COMMUNICATIONS LETTERS in 2015.

NIZAR ZORBA received the B.Sc. degree in electrical engineering from the Jordan University of Science and Technology, Irbid, Jordan, in 2002, and the M.Sc. degree in data communications and the M.B.A. degree from the University of Zaragoza, Zaragoza, Spain, in 2004 and 2005, respectively, and the Ph.D. degree in signal processing for communications from the Universitat Politècnica de Catalunya, Barcelona, Spain, in 2007. He led and participated in over 25 research projects, and authored five patents, two books, seven book chapters, and over 100 peer-reviewed journals and international conferences. His research interests are quality of service/experience, energy efficiency, and resource optimization.

CHRISTOS VERIKOUKIS received the Ph.D. degree from UPC in 2000. He is currently a Senior Researcher with CTTC and an Adjunct Professor with UB. He has authored over 95 journal papers and over 160 conference papers. He has coauthored over three books, 14 chapters, and two patents. He has participated over 30 competitive projects and has served as the principal investigator of national projects. He has supervised 15 Ph.D. students and five postdoctoral researchers. He is currently the Chair of the IEEE ComSoc CSIM TC. He received a best paper award in the IEEE ICC 2011, the IEEE GLOBECOM 2014 & 2015, and the EURASIP 2013 Best Paper Award of the *Journal on Advances in Signal Processing*.