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Exploiting Social Internet of Things Features in Cognitive Radio

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ABSTRACT Cognitive radio (CR) represents the proper technological solution in case of radio resources scarcity and availability of shared channels. For the deployment of CR solutions, it is important to implement proper sensing procedures, which are aimed at continuously surveying the status of the channels. However, accurate views of the resources status can be achieved only through the cooperation of many sensing devices. For these reasons, in this paper, we propose the utilization of the Social Internet of Things (SIoT) paradigm, according to which objects are capable of establishing social relationships in an autonomous way, with respect to the rules set by their owners. The resulting social network enables faster and trustworthy information/service discovery exploiting the social network of "friend" objects. We first describe the general approach according to which members of the SIoT collaborate to exchange channel status information. Then, we discuss the main features, i.e., the possibility to implement a distributed approach for a low-complexity cooperation and the scalability feature in heterogeneous networks. Simulations have also been run to show the advantages in terms of increased capacity and decreased interference probability.

INDEX TERMS Social internet of things, cognitive radio, spectrum management.

I. INTRODUCTION

Society is moving towards an "always connected" paradigm where the Internet user is shifting from persons to things, leading to the so called Internet of Things (IoT) paradigm. The IoT is expected to embody a large number of smart objects identified by unique addressing schemes providing services to end-users through standard communication protocols and to be composed of trillions of elements interacting in an extremely heterogeneous way in term of requirements, behavior, and capabilities.

All these objects will have to send/receive information to/from the Internet, most of the time by making use of wireless communications, contributing to spectrum overcrowding problems. Indeed, in the early 2000 the licensed-free ISM (Industrial, Scientific and Medical) band seemed to be an effective solution to accommodate emerging services but it is now overexploited and experiences serious coexistence issues.

Information upload on the Internet will then become more and more expensive and it will be necessary to find alternatives. The digital switchover of TV broadcasting services has induced a review of the Ultra High Frequency (UHF) spectrum usage, leaving free channels in each territorial area, the so-called "TV White Spaces" (TVWS) [1]. Huge debates are taking place within the wireless world among broadcasters, mobile operators, Internet service providers, and normative organizations about the possible utilization of the TVWS to deliver new services. From the technical viewpoint, new spectrum allocation techniques have been studied to exploit the TVWS, such as the dynamic spectrum access and Cognitive Radios (CRs). A good definition of a CR, according to Simon Haykin is "an intelligent wireless communication system that is aware of its environment with two primary objectives in mind, namely highly reliable communication whenever and wherever needed, and efficient utilization of the radio spectrum" [2].

A CR is a system employing technologies that allow for obtaining knowledge of its operational and geographical environment, established policies and its internal state, to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives [3]. The spectrum management rule of CRs is that all new users for the spectrum are secondary cognitive users (SUs) able to detect and avoid primary licensed users (PUs) by adjusting functional parameters, such as carrier frequency, transmission power, and modulation type. In 2012, the World Radio Conference decided that CRs are to be interpreted as a set of technologies and not as a radio communication service. For this reason, there is no need to change radio regulations, but just to ensure that CRs do not cause any interference or claim protection from authorized services operating in the same or in adjacent bands [4]. Once TVWS are identified, the national authority protects broadcasting services through several technical rules applied to the CRs and their operation in such white space spectrum.

Several studies on compatibility problems have been conducted [5] identifying the joint use of detection techniques [6] (i.e., spectrum sensing) and geo-location databases [7] as a possible way to enable harmless communications in the TVWS [8], [9]. Geo-location databases, if available, provides, for a certain location, the list of the free Digital Terrestrial Television (DTT) channels and the allowable maximum radiated power for transmitting without harmful interference to DTT users. In order to afford appropriate levels of protection to DTT service, it is necessary for the database to specify the maximum permitted emission levels for a CR across all DTT channels and in all geographic locations where the DTT service is being used. A major procedure in the depicted CRs scenario is the sensing, which is aimed at the continuous surveying of the status of the channels so that the relevant information can be used to drive the SUs towards a correct utilization of the shared spectrum resources. Several techniques have been proposed in literature [10], [11], which can be also cooperative and multi-band. Clearly, the complexity of the problem increases with the number of sensing devices and the need of near real time responses is a serious impairment to feasible and reliable solutions.

To achieve the required temporal and spatial accuracy, the cooperation of hundreds of devices to sense the spectrum in a certain area is mandatory in dynamic and crowded scenarios. The cooperation may be implemented involving only SUs, which are clearly those that benefit from an effective sensing procedure; however, in this case the resulting view of the channels status may not be accurate enough. Accordingly, it is important to find out other solutions where devices not directly interested in the usage of the CR resources still take part to the sensing procedures for the interest in the communities of devices they belong to. Such a cooperation among objects that belong to communities of friends is the principle that is behind the latest studies on the integration of social networking concepts into the Internet of Things paradigm [12], [13], which brought to the paradigm of the Social Internet of Things (SIoT) [14]. According to these studies, objects are capable of establishing social relationships in an autonomous way with respect to the rules set by their owners. The resulting social network has the potential to enable a faster information/service discovery, thanks to the possibility to navigate a social network of ''friend'' objects and a more reliable management of the information received by the other devices.

The synergy of the SIoT paradigm and of the CR technology seems to be the perfect answer to address the spectrum scarcity, which would not be solved considering only one feature alone. From one hand, the CR technology can lower the burden in overcrowded bands by allowing the devices to transmit as SUs in other bands; from the other hand, the SIoT allows the SU to have a complete and trustable vision of the spectrum usage, based on the concept that the many are smarter than the few [15] and enables to decouple the functions of sensing of the spectrum and transmission. Based on these considerations, the major contributions of the paper are the followings:

- Definition of a reference scenario, where SIoT are integrated for an effective utilization of the TVWS.
- Analysis of the requirements of the CRs, the role of the different nodes and the needs for a rapid and trustable diffusion of information related to the channels usage according to the social network among objects created with the SIoT.
- Evaluation of the benefits of the synergy between SIoT and CRs, which shows how it can reduce the burden of the spectrum and the interference probability.

The remainder of this paper is organized as follows. In Section II we summarize the basic concepts underlying the IoT and the CRsand provide a quick survey of the related works. In Section III and IV we describe the reference scenario and a simple use case. Section V presents the system performance and Section VI draws final remarks.

II. BACKGROUND

In this section, to better understand the proposed solution, we show the main features of the IoT paradigm and the main characteristics of the cognitive radios technology.

A. INTERNET OF THINGS

The Internet of Things paradigm integrates a large number of heterogeneous and pervasive objects that continuously generate information about the physical world. It is a worldwide network of interconnected objects uniquely addressable, based on standard communication protocols. By putting intelligence into everyday objects, they are turned into smart objects able not only to collect information from the environment and interact/control the physical world, but also to be interconnected to each other in order to exchange data and information through the Internet. IoT applications have to share features for the management of services and networks, leading to a horizontal approach; a common solution has been the introduction of the concept of the virtual object [16], which is the digital representation of a real world object (RWO), that augment the capabilities of the physical devices with additional functionalities and allow them to talk to each other at the same level and share their data with all the applications that needs them. Following the description in [17], there are three different phases with which the physical-virtual world interaction takes place: i) collection phase, which refers to the sensing of the physical environment and to the collection of real-time physical data; ii) transmission phase, which includes mechanisms to deliver the collected data to applications; iii) processing, managing and utilization phase, which deals with processing and analyzing information flow for the benefit of applications and services.

With reference to the goal of this paper, the transmission phase is what we are concerned about; when devices start to send and retrieve data from the Internet all at the same time, bandwidth issues arise. Indeed, the limited wireless spectrum available for cellular networks constitutes a major constraint in the widespread use of wireless technologies.

However, the IoT is still faced with a long and varied list of different issues; to cope with some of these issue, a new paradigm known as Social Internet of Things (SIoT), which proposes the integration of social networking concepts into the IoT solutions, is used in this paper.

B. COGNITIVE RADIOS

A CR is a system employing technologies that allows for obtaining knowledge of its operational and geographical environment, established policies and its internal state, to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives [18]. Several studies on compatibility problems [11], [19] have shown how the joint use of detection techniques (i.e., spectrum sensing) and geo-location databases can enable harmless communications in the TVWS. [20]. Signal power measurements have been performed in several European Countries on rural, suburban, and urban sites, providing a set of practical parameters upon which harmless unlicensed communication in the UHF TVWS is feasible [21].

The World Radio Conference decided in 2012 that there is no need to change radio regulations, but just to ensure that CRs do not cause any interference or claim protection from authorized services operating in the same or in adjacent bands [4]. Once TVWS are identified, the national authority protects broadcasting services through several technical rules that apply to the CRs and their operation in such white space spectrum [23].

The home wireless networking is booming thanks to the rapid progress of wireless technologies and adoption of broadband. Next generation smart homes consist of a wide range of devices that will have radio receivers to enable control, monitoring, and easy configuration. Since most of these devices operate in ISM bands that are becoming congested, leading to capacity and interference limitations, CRs can increase capacity to smart homes through secondary access to TVWS [24].

C. RELATED WORKS

The Devices to Devices (D2D) communication is emerging as a key technology enabling a direct communication among devices, bypassing the network infrastructure [25]. Comparing with conventional connections, the direct connections between proximity devices are more vulnerable due to limited computational capacity of mobile devices for security related computations, and autonomous security management, such as mutual authentication, key arrangement, and so on. D2D security architecture and further analysis security issues and requirements based on application scenarios and use cases have been explored in [26]. Research community is also considering D2D applications for vehicular communications [27] especially to address mobility issues in smart cities. The use of radio resources opportunistically through the exploitation of CR is expected to increase the efficiency and reliability in D2D and Device to Internet communications. Also vehicular ad-hoc networks (VANET) communications can benefit from the opportunistic spectrum usage with CR technology, using additional spectrum opportunities in TV bands according to the QoS requests of the applications. The performance of VANETs operating in TVWS has been evaluated in [28]. Actually, VANETs use the IEEE 802.11p standard [29] operating in the 5.9-GHz ISM band reserved for intervehicular and vehicle-to-roadside BS wireless communication, for safety and traffic information and monitoring systems in urban environments. There is insufficient spectrum for reliable exchange of safety information over congested urban scenarios through the use of cooperative spectrum sensing provided by cars, used to locate white channels in the ISM bands. Reference [30] provides guidelines for providing information about the availability of TV channels.

An intense research activity around the potential applications of CR technology in the IoT field is being produced in the last years. A recent work reviews various CR applications for IoT including public safety and disaster management, femtocells, and online multi-user gaming applications [31]. In [32], a new paradigm named cognitive Internet of Things (CIoT) to empower the current IoT with a brainİ for high-level intelligence, has been presented. Reference [33] surveys novel approaches and discusses research challenges, reviewing CR solutions that address generic problems of IoT (including emerging challenges of autonomicity, scalability, energy efficiency, heterogeneity in terms of user equipment capabilities, complexity, and environments) and presenting a general background on CR and IoT with some potential applications. CR brings several benefits to IoT:

- it enables an efficient spectrum utilization;
- it improves accessibility to various networks and services;
- it can autonomously adapt its operation to simplify the tasks;
- since CR devices communicate with each other in the form of collaboration among neighbor devices, the network can scale to much higher numbers of users.

However, there are still some key open research challenges to be addressed:

1) In the multi-hop CR scenario, there is the need to address the issue of neighbor discovery. In this context, the exposed transmitter and hidden receiver problems need to be solved.

2) CR have complex functionalities due to sophisticated algorithms. For this reason new solutions in order to bypass unnecessary functionalities must be designed.
3) Most of the works use simple ON/OFF models for PU activities. However, in reality there are many types of PUs due to heterogeneous networks.
4) After sensing procedures, the IoT assignment policy of radio resources needs to be efficiently performed.

In next section we show how the Social IoT paradigm and the CR technology cooperation can solve some of these issues.

III. PROPOSED SOLUTION

The main focus of this paper is the definition of a synergy between the Social IoT and CR technologies. In the following, we briefly review the main aspects regarding the Social IoT.

A. SOCIAL INTERNET OF THINGS

The idea to use social networking notions within the Internet of Things to allow objects to autonomously establish social relationships is recently gaining fast popularity. The driving motivation is that a social-oriented approach is expected to support the discovery, selection and composition of services and information provided by distributed objects and networks [13], [34], [35]. In this paper, without losing generality, we consider the social IoT model proposed in [14], which refers to the resulting paradigm with the SIoT acronym. According to this model, a set of forms of socialization among objects exist. The parental object relationship (POR) is defined among similar objects built in the same period by the same manufacturer where the role of family is played by the production batch. The objects can establish co-location object relationship (CLOR) and co-work object relationship (CWOR), like humans do when they share personal (e.g., cohabitation) or public (e.g., work) experiences. A further type of relationship is defined for objects owned by the same user (mobile phones, game consoles, etc.) which is called ownership object relationship (OOR). The latter relationship is established when objects come into contact, sporadically or continuously, for reasons purely related to relations among their owners (e.g., devices/sensors belonging to friends) and it is named social object relationship (SOR).

The main advantages of a SIoT approach is that the resulting social network can be shaped as required to guarantee the network navigability, so that the discovery of information is performed efficiently. Moreover, by leveraging the degree of interaction among friends, it is possible to achieve a high level of trustworthiness, in order to clear the uncertainty of the services received.

B. REFERENCE SCENARIO

In our vision, information about the spectrum usage and availability is considered as a sensing measure in the same way of other physical entities, such as humidity or temperature. Such information is then sent to the SIoT so that it can be used by any other object who needs it. Fig. 1 shows the reference scenario; every object in the real world has its own counterpart in the virtual world which host all the data sent by the physical object. At the virtual level, then the objects create their own relationship as it is the case for example of the OORs among the devices owned by the municipality (the traffic light, the camera, and the lamppost) or the SOR between the car and the camera.

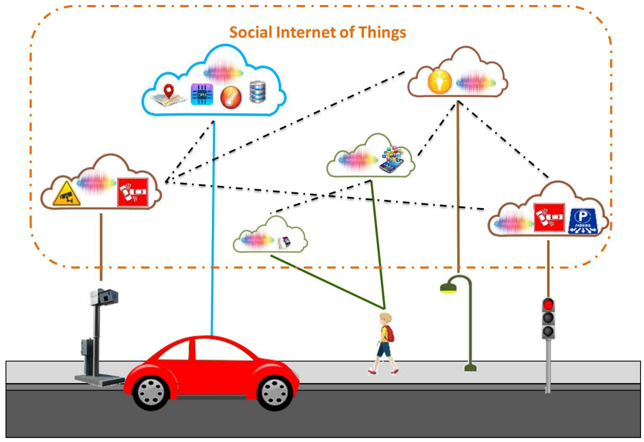

FIGURE 1. Reference scenario. Colored lines represent the connection between the physical and virtual world, while dashed black lines indicate relationships among virtual objects.

The SIoT is then in charge to analyze the information received to determine if any spectrum holes exists in a certain area, by combining all the measures; this approach enables to take decisions based upon a **greater number of devices** w.r.t. classic approaches seen in Section II-B, where devices need to be in visibility to each other to exchange information about the spectrum, leading to a more accurate evaluation of the spectrum. Moreover, there is then a **decouple** between objects which sense the spectrum and objects that use that information to transmit their data. In [36], a systematic tutorial on the key enabling techniques of the Internet of Spectrum Devices has been presented, including big spectrum data analytics, hierarchal spectrum resource optimization, and quality of experience-oriented spectrum service evaluation. Accordingly, even objects not interested to exploit the CR technologies can contribute to understand if there are any holes in the spectrum.

However, crucial points in this solution are the discovery of useful objects and the evaluation of the information provided by the other objects. The benefit of an IoT approach to CRs would be meaningless if spectrum information cannot be obtained in a timely manner. In the same way, without an effective trust management foundations, attack and malfunctions in the IoT will outweigh any of its benefit [37].

The SIoT can then solve both of these problem: on one side, this is due to the intrinsic capability of a SIoT network to come to a solution for a query and **quickly reach** the required object with a small number of hops, using object friendships [38]; on the other, the SIoT provides a level of **trustworthiness** of the information by taking advantage of the degree of friendship among objects; whenever a node needs information about regarding the spectrum, such information is weighted depending on the objects (and their relationships) that is providing it [39], [40].

With a complete view of the channels state, objects can exploit the white spaces in the spectrum to transmit their own data. However, it is important to **efficiently allocate** this channels so that devices can cooperate and broadcast their information without interfering with the PUs. Objects that share a social relationship, as it is the case of the objects owned by an user, are then more prone to also share the available channels so to avoid too many users to transmit on the same channel and then interference with the PU.

With reference to the open research challenges identified in Section II-C, the proposed solution is able to address all of them:

1) the evaluation of information provided by objects not interested in exploiting the CR technologies can contribute to understand if there is some hidden receiver; from this point of view, objects with a fixed position, having the precise view of a determined area, cover a crucial rule in identifying eventual obstacles that could mislead CRs during their sensing operations.
2) even if this is still an ongoing research issue, a SIoT platform, in the Cloud or in the Fog [41], will surely have the necessary computation capabilities to implemented algorithms that could not be implemented otherwise.
3) Independently of the PU activities, a collaborative SIoT approach is able to identify the availability levels of white spaces and to monitor accurately if any SUs is interfering with the PU
4) Relationships among nodes can be used to decide how the available channels have to be exploited among all the objects that want to use them to transmit.

In the following, we explain in details the advantages of the proposed solution.

C. DISTRIBUTED/LOW-COMPLEXITY COOPERATION

In CR, Cooperative techniques require the information exchange between the nodes, resulting in the increase in signalling overhead. For example, for cooperative interference coordination, all the transmitters need to convey their interference channel state information (ICSI) to a control node, often named Cognitive Engine (CE) [6], which is deputed to design the transmit beams and powers. To reduce the overhead, it is better to design the distributed or low-complexity cooperative techniques. From this point of view, each device should act as a CR to scan its environment, detect neighboring devices, and subsequently set itself. A dynamic self-configuring multi-hops topology considering a continuous cooperation between devices to uninterruptedly share real-time information on radio communications, frequency spectrum allocation, application requirements and so on is auspicable. From this point of view the IoT architecture can serve as a midleware to enable fast and precise updated information to the CR devices. Furthermore, in the SIoT devices profiles are available and the social relationships created through the SIoT among CR devices, can be used both to lower the computational burden and increase reliability in the detection process. Relying on SIoT, cooperative sensing can involve a huge number of profiled devices which can be characterized with a trust score to be used in the detection phase by opportunely weighting the contribution of each node. This would allow for minimizing the computational complexity of the sensing cooperative approach which increases with the number of node involved, by constraining the mathematical problem [42]. Therefore, it will be possible to perform cooperation with a larger number of devices reducing the impact of common problems occurring during sensing such as the hidden node margin [21]. On the other hand, an important challenge for the IoT is to find non-collision solutions to avoid wasting radio resources. CR can allow nodes detecting the radio environment, finding a solution to enable frequency space time reuse avoiding collision.

D. ENHANCED SCALABILITY IN HETEROGENEOUS NETWORKS

In near future, wireless services will be provided by heterogeneous networks, and thus the problem of spectrum scarcity will be severer. Spectrum sharing between heterogeneous networks to enhance scalability requires their cooperation. Due to different network structures and service types, it is necessary to design a novel scheme for inter-network cooperation, a new paradigm that can provide environment discovery, self organization, dynamic and efficient networking and communication. Considering the enormous amount of devices there are no tools that can solve this issue nowadays. Indeed, a large number of connected devices, as envisioned for the IoT, will create a major challenge in terms of spectrum scarcity. In this perspective, a joint use of IoT for exploiting the network resources availability in heterogeneous scenario through a coordinated approach and CR to allow for lessening the traffic load through local ad hoc transmission in the available channel opportunities could increase the feasibility of the paradigm.

IV. SAMPLE USE CASES

The traffic jam caused in urban or sub-urban scenario by a crash accident occurred represents a concrete use case showing the potentialities of the proposed approach. In the proximity of the accident site an user grabs with his smartphone 30 seconds HQ video of the scene with the intent of warning other users about the situation. In a current scenario the video is going to be uploaded to the internet through WiFi/cellular networks and downloaded by other users driving in connected cars if provided of infotainment systems or through their personal smart devices (tablets/smartphones etc.) [43]. However, users downloading the HQ video can rapidly deplete the available resources, leading to network congestion.

In this context, CR could be used to perform D2D transmission among smart objects by locally exploiting channel opportunities in the area of the accident. To obtain a trustworthy map of the spectrum, the SIoT considers relationships among devices. Moreover, it will efficiently distribute the network resources among groups of friends in order to minimize the probability of interference with the PUs.

Multi hop communications through the white spaces between vehicles stuck in line in the traffic jam could be set up using the information provided by the SIoT concerning devices position and possible relationships among them to distribute the video information. Common issues of CR approach, such as hidden node margin problems during spectrum sensing, could be overcome thanks to the information provided by the SIoT about reliability of the nodes based on device profiling and social relationships created among them.

V. ANALYSIS OF PERFORMANCE

A numerical evaluation has been conducted by using the Matlab® tool for a wide set of scenarios, to observe the achievable performance in terms of aggregate throughput needed by the objects to download a content from the IoT and the Receiver Operative Characteristics (ROCs) calculated with various degrees of collaboration between CR devices. To the best of our knowledge, this is the first work which is proposing some early results regarding the benefits of the CR technologies applied to the IoT scenario.

The cited performance analysis would need information about the position and mutual relationships of a large number of objects. This data is not available to date, as real applications have not been deployed yet. For this reason we resorted on the Barabási-Albert model [44], which is able to generate scale-free networks based on preferential attachment, where every link would represent a relationship between a couple of nodes. Starting with a small number of nodes, at each step, to the current network a new node is added with m edges (m is a parameter for the model) linked to nodes which are already part of the system. The probability p_i that a new node will be connected to an existing node i depends on its degree k_i, so that $p_i = k_i/(\sum_j k_j)$ leading to the name preferential attachment.

Additionally, we consider that the geographical distance of the nodes from the physical producer of the service follow an exponential distribution with different mean values, namely 5, 10 and 25 km. This models the location-based interest of the information, which is especially true in the Intelligent Transportation System (ITS) use case we are considering [45]. The resulting SIoT network has around 1000 nodes and 5k edges.

With reference to Fig. 2, we show all the different steps involved in the communication process. Evaluation of all these steps at the same time is indeed a difficult task, so the proposed simulations will analyze two different phases separately: firstly, we show how the aggregate throughput from the Internet can be reduced thanks to the proposed approach, i.e. after we obtain a clear view of the channel condition; secondly, we demonstrate how the channel information can be

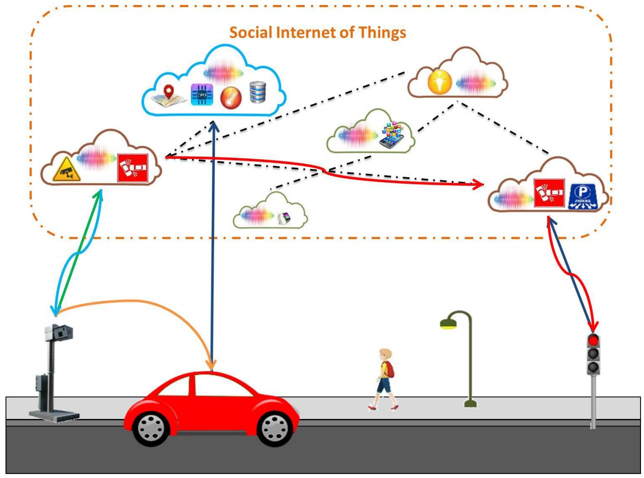

FIGURE 2. Communication scenario: green line represents the uploading of a service to the virtual counterpart, blue lines represent service requests, light blue lines indicate the information about the spectrum. Finally, orange line represents the delivery of the service through D2D communications while red lines through the SIoT.

improved when considering the trustable information coming from the friends of the SIoT network.

Whenever a service is produced by a node (the camera), it is then uploaded to its virtual counterpart in the SIoT (green line), so that the service can be available for every object that needs it.

As described previously, nodes interested in the service (the car and the traffic light) send a service request to the SIoT (blue lines). The virtual producer of the service, i.e. the virtual camera, calculates the white spaces available thanks to the collaborative sensing of other friends and send the information to the physical camera (light blue line).

Depending on the physical distance between the two nodes (i.e., requester and producer of the service), the SIoT could make use of the white spaces available and trigger a direct communication between them, without the use of any network infrastructure to delivery the service. In our setting, these D2D communications (orange line) happen whenever the distance between requester and producer of the service is lower than 2 km. If the distance is greater than 2 km, the service is delivered making use of the SIoT (red lines). Conventional D2D communications are implemented via LTE-Direct mode in case of cellular communications or via WiFi-Direct in wireless lan. In particular, following Qualcomm guidelines about LTE-Direct characteristic, 500m radius is the maximum that a D2D connection can reach [46]. On the contrary, Intel in its WiFi-Direct protocol claims that a reasonable value on D2D link on unlicensed bands is between 30m and 50m [47]. However, in both cases carrier frequencies around 2 GHz have been considered, which are significantly higher with respect to the spectrum in TVWS. In [48], a link budget analysis has shown how cognitive devices performing in TV bands can even exceed the distance of 2 Km. Also [49] presents a systematic approach to exploiting TVWS for D2D communications with the aid of the existing cellular infrastructure.

On the basis of these preliminaries, we proceeded by evaluating the effectiveness of the cognitive radio approach in reducing the burden on the limited wireless spectrum available. We suppose that a CIF (320x240 pixels) video stream was requested at the same time by a number of nodes.

If each node downloaded the video from the SIoT, this would call for a burden on the network, due to the aggregate throughput B needed to deliver the service to the nodes equals to

$$B = B_{unit} * N \tag{1}$$

where B_{unit} represents the throughput requested to deliver the service to a single device and N is the number of simultaneous requests. It is then obvious how the network can rapidly congest with numerous users and/or network demanding services.

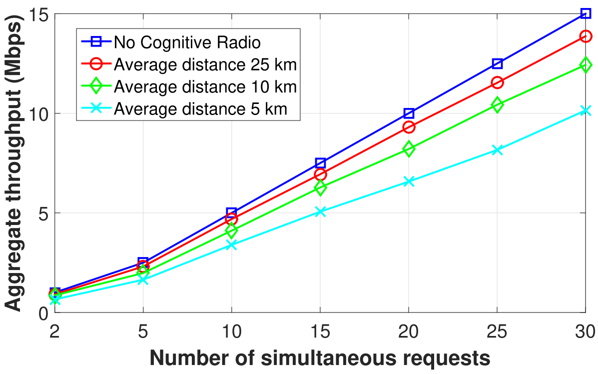

FIGURE 3. Aggregate throughput for different number of simultaneous requests for different value of the average distance of the devices from the provider of the service.

For this reason, whenever possible, the video stream is delivered making use of D2D communications, otherwise it is downloaded from the SIoT. Figure 3 shows the throughput needed to download the video from the SIoT for a different number of simultaneous requests and for different values of the average distance between the interacting objects. A smaller distance brings to a reduction in the aggregate throughput because there are more objects that can communicate using the white spaces obtained by the CR technology, leading to a reduction in the spectrum of up to 30%, when 30 devices request the same service simultaneously.

Another numerical evaluation has been conducted by using the alternative optimization technique based on genetic algorithms presented in [10], where each CR had a different weight factor based on its Signal to Noise Ratio (SNR). The optimal weights were recalculated using the old ones as an intermediate generation, therefore in most cases few iterations were needed to converge to the new weights for optimal detection.

The idea was to evaluate how the cooperation of CR devices to sense the spectrum in a certain area can improve by integrating the SIoT paradigm [14]. The resulting social network has the potential to manage the information received by the devices in order to discover the more reliable ones, that is the devices able to provide more accurate information. To do this, we would need information about the trustworthiness value of the objects in the SIoT. We then implemented the subjective algorithm presented in [39], where nodes have different level of trustworthiness among each other based on several parameters such as their past experiences or the type of relationship. To obtain such trustworthiness values, we run 5000 random transaction among the nodes, considering that 25% of them were malicious, i.e. they cheat whenever it is advantageous for them to do so. However, it is important to point out that the trust algorithm used in this paper is only needed in order to assign trust values to each object and then evaluate the spectrum information they provide; the definition of a trust algorithm is not the goal of this paper and any other trust algorithm based on the SIoT paradigm is acceptable and can lead to similar results.

We run the optimization tests on a framework with a variable number of CRs, namely 10, 20, 30, and 40 users, considering not only the SNR but also the trustworthiness of the information provided.

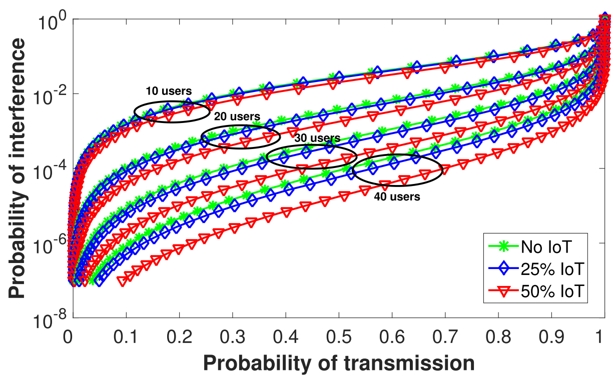

FIGURE 4. ROCs for the optimization of collaborating CR. Probability of interference vs probability of transmission.

Fig. 4 shows the transmission vs interference probability characteristics, which were calculated considering the spectrum information coming from the more reliable nodes, that in our case was 20% and 50% of the population, with a higher weight.

As can be seen from the results, the interference probability reduces accordingly with the increasing of the percentage of "reliable" devices. Furthermore, in this case, less iterations are needed to converge to the new weights for optimal detection.

VI. CONCLUSIONS

In this paper we have proposed the utilization of the SIoT (Social Internet of Things) paradigm for the sensing of the channel status to implement cognitive radio solutions. Indeed, the social network in SIoT enables faster and trustworthy information/service discovery exploiting the social network of "friend" objects and this is exploited in the analysed scenario. The main features are: the possibility to implement a distributed approach for a low-complexity cooperation and the scalability feature in heterogeneous networks. We have performed simulations from which we have demonstrated that with the proposed solution we can significantly reduce the need for congested Internet connections by using CR-enabled device to device communications, with a reduction up to 30%.

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