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Wireless Social Networks: A Survey of Recent Advances, Applications and Challenges

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ABSTRACT With the ubiquitous use of smartphones and other connected pieces of equipment, the number of devices connected to the Internet is exponentially growing. This will test the efficiency of the envisioned 5G network architectures for data acquisition and its storage. It is a common observation that the communication between smart devices is typically influenced by their social relationship. This suggests that the theory of social networks can be leveraged to improve the quality of service for such communication links. In fact, the social networking concepts of centrality and community have been investigated for an efficient realization of novel wireless network architectures. This work provides a comprehensive introduction to social networks and reviews the recent literature on the application of social networks in wireless communications. The potential challenges in communication network design are also highlighted, for a successful implementation of social networking strategies. Finally, some future directions are discussed for the application of social networking strategies to emerging wireless technologies such as non-orthogonal multiple access and visible light communications.

INDEX TERMS 5G networks, centrality, community, social networking.

I. INTRODUCTION

A recent estimate reveals that on average, every third individual uses more than two devices connected to the internet [1]. The internet traffic involves the daily transfer of about 40 Exabytes of data [2]. This large data volume is commonly attributed to the widespread use of smart devices such as smartphones, tablet computers, smart TVs and smart-watches that are integrated with the Internet.

The need to share information has always been one of the key aspects of human survival. People meet with other individuals in their social networks to share their first-hand experiences and activities of common interest. This has led to the well-explored field of sociology, which is the study of human social behavior. Today, the ubiquitous Internet connectivity facilitates people to remain updated about the world around them. This Internet-based surge in social networking poses an important question: can we use strategies derived from sociology to improve the performance of future wireless communication systems? A straightforward reply is yes, because the social networks we inhabit are related to the nature of the information that we consume [3]. In particular, our economic and information systems have become reliant on the structure of information such as people's preferences, interests, and hobbies [4]. Inspired by this phenomenon, many researchers have investigated the use of social networking features for improving the underlying communication technology, e.g., the proposal of context-aware wireless communication protocols [5]. Thus, the social network characteristics need to be studied for their judicious utilization in wireless communications.

Over the past decade, several authors have explored different aspects of social networks in wireless communications. Kayastha *et al.* [6] reviewed the application of social networking to mobile networks. They indicated that social networks can provide health-based services along with location-based and behavioral monitoring services. Later on, Zhu *et al.* [7] investigated the effects of social networking characteristics on the performance of delay tolerant wireless

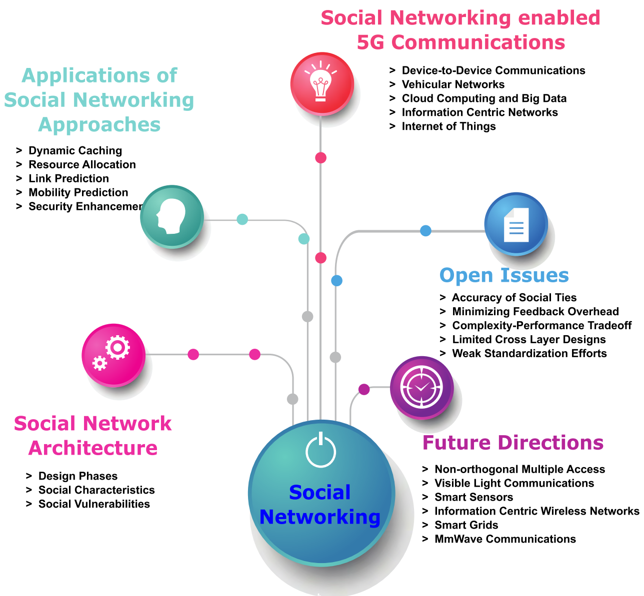

FIGURE 1. **Roadmap of social networking approaches for 5G and beyond. The applications of social awareness in wireless networks are shown together with some research challenges for its successful incorporation into the communication network design.**

networks. The authors identified some positive contributions of the social characteristics such as assistance in message transmission, especially during node mobility, to improve the network's routing performance. The same authors also identified other negative behaviors, such as selfishness and misbehavior of nodes, which can compromise the network security. An overview of social-aware routing protocols from 2007 to 2012 was provided by Wei *et al.* [8]. Similarly, Singh *et al.* [9] performed a brief survey of network developments from the socio-5G perspective, whereas, Li *et al.* [10] established a new paradigm for analyzing the performance of device-to-device (D2D) communication by exploiting socially aware characteristics. They quantified the gains that can be obtained from social-aware D2D communications over the conventional D2D communications. For vehicular networks, Lequerica *et al.* [11] have reviewed various studies on social networking approaches to cope with the issues of routing and message transmission.

The proposed work is different from the aforementioned surveys in that we focus on providing detailed applications of social networks and the associated challenges for its practical implementation. A roadmap of social networking approaches for 5G communications is provided in Figure 1. Specifically, the major contributions of this work are listed as follows:

1) A comprehensive discussion on the architecture of social networks and detailed classification of different social characteristics along with major vulnerabilities have been discussed.
2) Case studies of various applications of social networking have been provided. Some of these applications include message forwarding, dynamic caching and security enhancement.
3) Social networking solutions for 5G wireless networks including the Internet of thing (IoT) communications, cloud computing, vehicular communications, and the associated open issues are described.
4) Detailed discussion on the applicability of social networking approaches on some broader areas of communications, such as non-orthogonal multiple access (NOMA), visible light communication (VLC) and smart grid communication, has also been provided.

The remainder of the paper is organized as follows. In Section 2 detailed architecture of social networking has been given along with a discussion on some social characteristics and their vulnerabilities. Section 3 provides potential applications of social networks. Section 4 provides details of the recent advances in the envisioned 5G technologies from the perspective of social networking. In Section 5, some of the open research challenges are presented. Then, Section 6 provides a discussion on some broader perspective of social communication. Finally, Section 7 concludes this work. In addition to this, a list of commonly used acronyms is provided in Table 1.

II. SOCIAL NETWORK ARCHITECTURE: AN OVERVIEW

Social awareness is the study of contextual information and enables communicating devices to formulate efficient protocols for their communication. As this is a relatively recent area of research, the design of the associated network architecture continues to be investigated in the literature. A simplified architecture consisting of six phases, i.e., sensing, analysis, knowledge, communication, cooperation, and coordination & collaboration, is illustrated in Figure 2 and is explained below.

At the physical layer, intelligent sensors are installed in the devices to obtain raw data from the environment [12]. At this stage, the devices are unaware regarding the existence of each other in the network. However, a set of devices may have a particular task and the collected data will be a representation of their similar interest. For instance, smart bulbs in a room will collect information regarding the room luminosity, whereas, a smart thermostat will collect the data on temperature and humidity in the room. Similarly, a smart entertainment system will collect the information related to users' experience and their viewing/ listening habits. The collected data from sensors is analyzed to obtain useful information by utilizing technologies like machine learning or data mining [13]. The information obtained from the environment can now be used for improving human-to-human, man-to-device, and device-to-device interaction. At this level, the devices are somewhat aware of the situation and communication conditions.

After processing the obtained information, the devices are ready to plan on how to obtain knowledge regarding a given problem. Previous experiences can also be leveraged by the devices to acquire new information. After gaining a significant amount of knowledge about their surroundings, the social devices can now start communication with

TABLE 1. List of acronyms.

Acronym	Full form
ARIMA	Autoregressive integrated moving average
ATM	Adaptive trust management
BS	Base station
CBSTM-IoT	Context-based Social Trust model for the Internet of Things
CCRCN	Content-centric residential community network
CALA	Continuous action set learning automata
D2D	Device-to-Device
DONA	Data-Oriented Network Architecture
DHT	Distributed hash tables
DRU	Discovery resource unit
DSSoT	Dynamic social structure of things
FIB	Forwarding information base
FST	Firefly spanning tree
GSMA	Group special mobile association
HAP	High altitude platform
IaaS	Infrastructure as a Service
ICN	Information centric network
IoT	Internet of things
LBR	Low bit rate
LRS	Lookup based resolution system
LED	Light-emitting diode
LTE	Long-term evolution
MANETs	Mobile ad hoc networks
mmWave	Millimeter wave
NBR	Name-based routing
NDN	Named data networking
NDO	Named data objects
NFV	Network function virtualization
NetInf	Network of information
NOMA	Non-orthogonal multiple access
NRS	Name resolution system
OBD2	On Board Diagnostics 2
OFDMA	Orthogonal frequency division multiple access
ONSIDE	OpportuNistic Socially aware and Interest-based DissEmination
PaaS	Platform as a Service
pCoCe	Probabilistic control centrality
PoC	Proof-of-concept
PURSUIT	Publish-subscribe internet technology
REK	Reputation Experience Knowledge
ReViV	Rebroadcaster selection mechanism for Video streaming for VANET
RpR	Recommendations plus reputations
RSC	Route stability clustering
RSU	Road side unit
SaaS	Software as a Service
SIC	Successive interference cancellation
SIoT	Social IoT
SoCast	Social-aware video multiCast
SOR	Social on road
SPC	Sociological pattern clustering
SPRING	Social-based Privacy-preserving packet forwardING
SPRINT	Social PRedIction-based routing in opportunistic NeTworks
SUMO	Simulation of urban mobility
TACIoT	Trust-aware access control system for IoT
TRIAD	Translating relaying internet architecture integrating active directories (TRIAD)
UAV	Unmanned aerial vehicle
VANET	Vehicular ad-hoc networks
VLC	Visible light communication
VPC	Virtual private community
Wi-Fi	Wireless fidelity
WIMAX	Worldwide interoperability for microwave access

other objects of interest in the network [14]. For instance, a smart lighting system can inform the smartphones in case of any anomalies in the electric power or malfunctioning of the system. The ability to communicate with other objects in network open new opportunities to ensure cooperation between various devices. The exchange of information and resources and between devices happen at this level. Based on our previous example, a lighting system in a house may not be able to directly make contact with the smartphone a user who is far from home. Therefore, it can use the resources of wireless fidelity (Wi-Fi) to send its messages via the internet. Lastly, at coordination and collaboration stage, a social network harmonizes all the activities that need to be incorporated in order to work like a well-oiled machine. Later, these activities are given proper sequencing through collaboration among devices to perform effectively [15]. To achieve a common goal, devices use trusted social relationships which facilitate them to make proper decisions. Social-aware routing protocols and data dissemination schemes can be formulated here based on the information gained during the initial phases.

The above-mentioned functionalities can easily be incorporated in the latest devices which is one of the reasons for the dramatic popularity of social network theory in recent years. Presently, the devices are equipped with high-speed processors, large storage and wireless interfaces. With the help of short-range technology like Bluetooth and Wi-Fi, portable devices can now easily create ad-hoc networks to conveniently communicate with each other. Of late, research efforts to improve mobile communication have made great strides. Technologies like mobile sensing [16], [17], mobile ad-hoc networks (MANETs) [18], mobile computing [19] and mobile cloud [20] have surfaced which utilize opportunistic network approaches. The development of these fields, in parallel with the development of social networking, will immensely improve the performance of future networks.

Another important aspect of incorporating social behaviors into devices comes from the fact that most of the mobile devices are being used by humans. Smartphones are being carried by the people to their homes and offices. The mobility of these smartphones indicates the mobility pattern of the people. This mobility determines the properties of various social relationships as the people spend time with people whom they trust and have strong social ties. It is quite possible that people from the same community often contact each other for sharing information. This information can be extremely helpful for the devices as they can make decisions and design routing protocols for forwarding of data. Based on these social behaviors, the devices can also use prediction models to optimize their performance and save resources when no contact opportunity is available.

A. SOCIAL CHARACTERISTICS

Since most of the network entities are connected to each other in one way or another, therefore, the importance of social networks has risen exponentially [6]. Social characteristics not only define the relationship between devices but also illustrate the common interest and goals [21], [22]. We now discuss some of the key characteristics of social relationships,

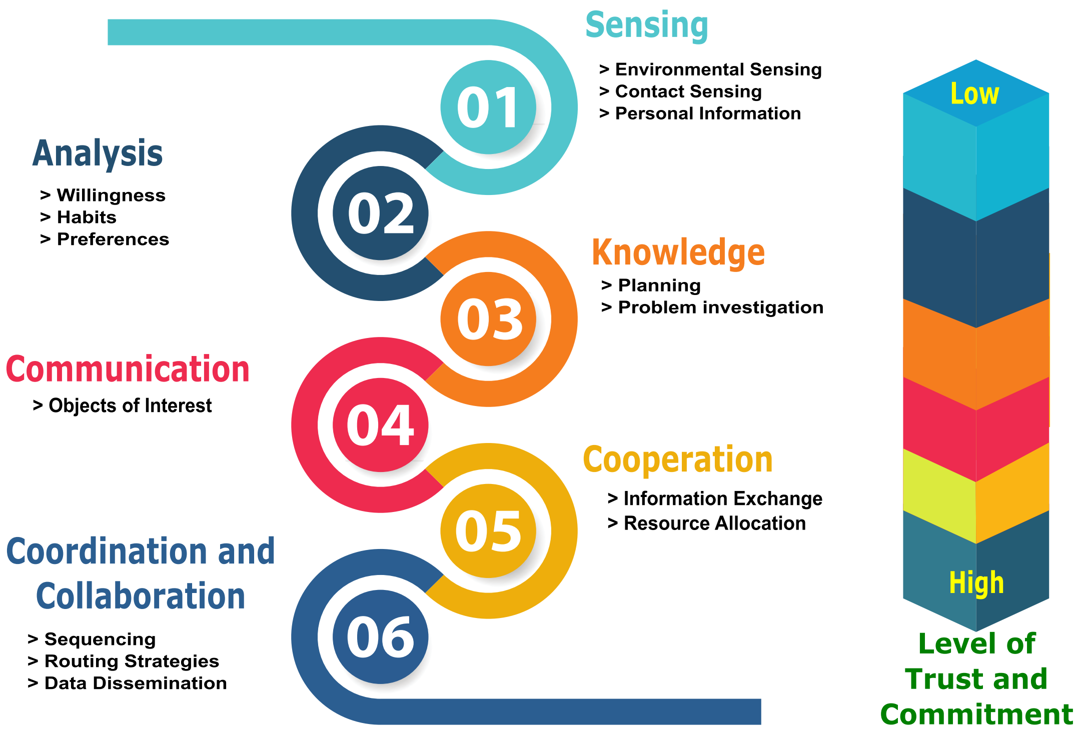

FIGURE 2. The six design phases of a social network architecture. These phases are numbered in an increasing order of trust required between the communicating devices.

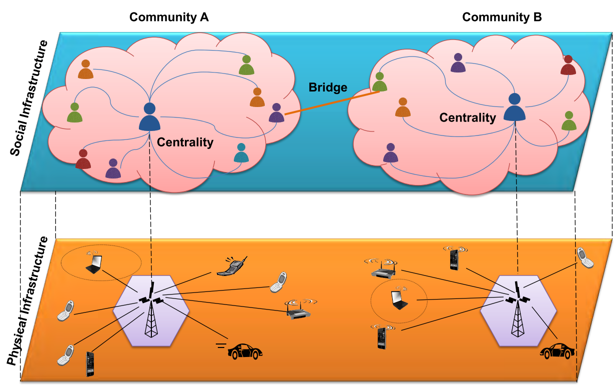

FIGURE 3. A typical mapping of physical infrastructure to a social network. The two access points of a cellular network, with their respective associated users, can be viewed as two social communities A and B. The set of users act as community members.

as shown in Figure 3, that are essential for the realization of the next-generation wireless network.

A social tie is a basic notion that indicates how closely two devices are related to each other. For humans, it is observed in activities and altruistic behavior of humans [24]. Similarly, in mobile networks, it is identified by how strong the two devices are connected. Based on these ties, a community is formulated between a group of people that share a common interest and demonstrate similar behaviors [25]. In the case of mobile networks, it may represent a cluster of devices located within a geographical proximity or having the same content. The communities are generally connected through a set of bridging nodes. A bridge is a connection between communities which is used to exchange information among adjunct communities. In general, every community has a pre-specified number of nodes for establishing a connection with the neighboring community.

Two nodes communicating frequently may have a significantly large contact history [26]. Thus, it can be intuitively concluded that these nodes have a strong social relationship. In contrast, the nodes that contact seldom to each other are considered to have a weak social connection. The social contacts can be characterized by multiple factors such as the contact frequency (which is the number of times contact was made between two or more nodes), contact interval (which is the reciprocal of contact frequency) and duration of contact (which is the average time during which the contact remained established). Another important characteristic is the social similarity of nodes. Social similarities can be found by using the contact books or records of the nodes in a network [27]. The nodes that most often discuss a particular issue or topic can be deemed as socially similar to each other. In other words, it can be defined as the closeness of two nodes that is determined from the intersection of their respective areas of interest. A trust value which is the expectation value of confidence that a node can put in the network. In simple words, it is the amount of trust that a node can put into the actions of a specific node. In addition, confidence value also relates to the trustworthiness which is the statistical probability of evaluated trust value. Both of these values are

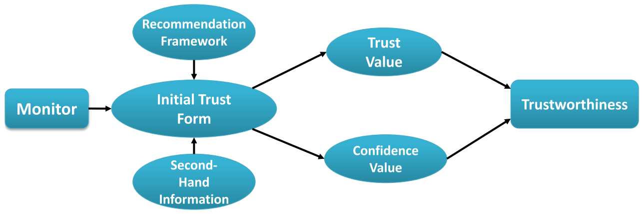

FIGURE 4. Trustworthiness framework for determining the commitment and trust of devices [23].

calculated using a trustworthiness mechanism which is shown in Figure 4.

Centrality refers to the ability of devices to connect to other devices. A central user in the network can easily establish a connection with other network entities. One of the most common ways to measure centrality is by Freeman's degree [6].

The basic idea behind centrality is to gauge the effect that inter-node distance has on the communication between these nodes. Specifically, a node is more likely to communicate with its nearby neighbor than with a node located farther away. There are broadly three classes of centrality as shown in Figure 5. These are known as closeness centrality (which is described by the distance to reachable nodes), betweenness centrality (which is defined by the set of shortest paths from one node to the others), and degree centrality (which is the importance assigned to a node based on its ability to act as a bridge between different communities). The nodes may try to cooperate with each other, e.g., by relaying each other's data. Its examples can be found as dissemination of contact and relaying of data. A node in the network may be more willing to help a particular set of nodes than helping the others. This inclination towards a particular group can be because of the attached incentive in the form of allocation of some resource such as power or bandwidth, which would not be available otherwise.

B. SOCIAL VULNERABILITIES

Here, we provide some of the most discussed vulnerabilities in the literature on social networking. Due to the anonymity of nodes, it is quite possible that the malicious nodes provide false information or dishonest recommendations about themselves [28], [29] to increase the trust values. This is one of the easiest ways to spread wrong information about a node in the network which can be exploited in future communication. Moreover, a good node, if compromised, can become a malicious entity while an incompetent node can become a competent subject to different changes in the network. The on-off attack in social networking is indeed the exploitation of this behavior of nodes [30], [31]. It means that a malicious/compromised node can act as a competent node for some time while it can act badly for other times. This strategy is usually adopted by nodes to stay undetected in the network while silently damaging the resources of the network.

Another commonly known attack is self-promotion attack in which a device provides bogus good recommendations regarding itself [32]. This results in building their good reputation among other devices. It also causes frequent selection of these devices for the provisioning of trusted services to other devices. However, these devices in actual provide low-quality services which affect the network performance. A node can act as good or bad in the time domain, but it can also show conflicting behavior in the user domain. Particularly, a malicious node can behave differently for different sets of users. This results in the conflict of opinions made by two sets of nodes whereby one set has a high recommendation value and the other set has a low recommendation value. In the Sybil attack, a node can take several IDs at the same time [33]–[35] which it can use to its advantage. More specifically, a node can use fake IDs to act as another node in the network. In this way, it can gain the trust of nodes that actually may not recommend it. Moreover, it can share the blame on other competent nodes resulting in damaging other nodes' social reputation.

Reputation lag in networks is the interval between generation of sensing report and determination of trust rating based on the mentioned report. During this time, an adversarial device can contribute towards sending false information regarding trust recommendations. Hence, this time lag can be misused by a device to provide corrupted services while quality services can be provided during sensing time to remain hidden. A malicious device can also launch an opportunistic service attack when it observes that its reputation in the network is falling. One of the reasons for this fall can be the provisioning of bad services by the devices. In this case, the adversarial device can start providing good services to the network for a brief period of time. When obtained a sufficient level of reputation, it can again start manipulation of data by colluding with other malicious devices [36]. In addition to this, a compromised node can exploit the relationship register to remove its previous bad record [35], [37]. If a node can easily register itself as a newcomer in the network then it can repeatedly exploit the system by exiting the network and returning a new node. This heavily damages the trust management flow of the network. Based on the above discussion, we now provide a detailed classification of social attacks in Table 2, with respect to non-cooperative or cooperative attacks and their direct or indirect impact on the network.

C. SUMMARY AND INSIGHTS

In this section, we have delineated some of the basic concepts of the social networking theory that are helpful to understand the remainder of this work. After showing a stepwise approach to design a social network of wireless devices, we have highlighted the fact that the level of trust, at each step, increases as devices move from the sensing phase to the collaboration phase. We have also identified the key characteristics of these social networks including social ties, social similarity and centrality. Figure 3 has shown the mapping of a typical physical infrastructure of wireless devices to a social network composed of different communities. Finally, we have highlighted some key vulnerabilities of social

TABLE 2. Classification of various attacks.

Attack	Single	Group	Direct involvement	Indirect involve-ment	Non-cooperative	Mis-behaving	Compro-mised
Bad mouthing attack	✓			✓	✓	✓	
On-off attack	✓		✓		✓	✓	✓
Self-promotion attack	✓			✓	✓		
Conflicting behavior attack	✓	✓		✓		✓	✓
Sybil attack	✓	✓	✓	✓	✓	✓	
Exploitation of reputation	✓			✓		✓	✓
Opportunistic service attack	✓	✓		✓	✓	✓	
Newcomer attack	✓		✓	✓	✓	✓	

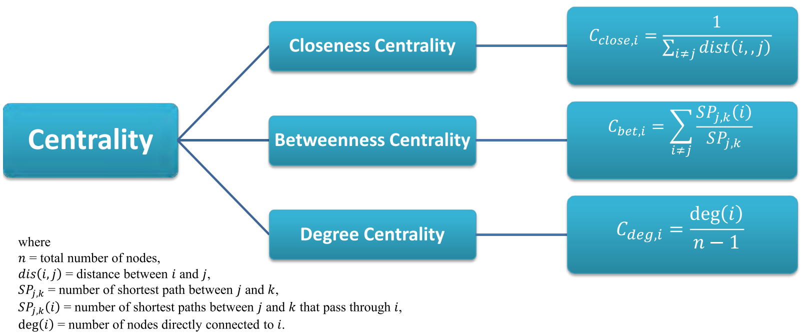

FIGURE 5. Classes of centrality and their closed-form expressions.

networks in terms of self-promotion attack, conflicting behavior attack, and Sybil attack. These vulnerabilities require research attention and long-term solutions for an optimal utilization of social networking approaches in 5G networks.

III. APPLICATIONS OF SOCIAL NETWORKING

We now discuss some of the recent advances in the application of social-aware networking to wireless communications, as shown in Figure 6. More specifically, we have categorized the social networking literature based on how the information extracted from a social relationship can be leveraged to improve the quality of service in a wireless link.

A. DYNAMIC CACHING USING SOCIAL NETWORKING

Efficient content delivery has gathered much attention in the recent years as it can significantly reduce the network traffic [38], [39]. Based on the recent research efforts, the content-caching technologies can be classified into the following two categories:

1) End Caching - Caching is performed at end devices only.
2) Network Caching - Caching is performed on the devices inside the network.

For content delivery networks, the network caching holds considerable importance and has been studied in detail over the past few years. However, the edge caching is relatively new and comparatively difficult to implement. In particular, recent developments show that the content can be cached at highly function mobile edge devices [38]. Future networks are expected to be dynamic and flexible in a way that the end users will be able to receive not only content from the original server but also from the nearby mobile caching devices. As expected, this approach would reduce the end-to-end as well as content access delays and would also be helpful in reducing the traffic volume in the network. In this regard, some other recent developments are listed below:

1) RECENT ADVANCES ON SOCIAL-AWARE DYNAMIC CACHING

Owing to an increase in the demand of content in future networks, various strategies have been proposed to move the content near the end user [40]–[42]. Bastug *et al.* [40] explored the option of using small cells for caching, while in [41] and [42], the content itself was proactively downloaded by specific end users. These end users then distribute the content to other users via D2D communication. Bastug *et al.* [41] optimize the problem of load balancing in backhaul and in small cell connections. They also propose machine learning algorithms to heuristically find a solution to the problem under minimum iterations. In a similar work, Bastug *et al.* [42] use a prediction approach to find the most popular content within communities. The content is then stored at the base station (BS) of the small cells in a greedy approach.

To extend the above works, Siris *et al.* [43] introduced the aspect of mobility of users in the popularity prediction model. In particular, the proposed scheme determines whether an

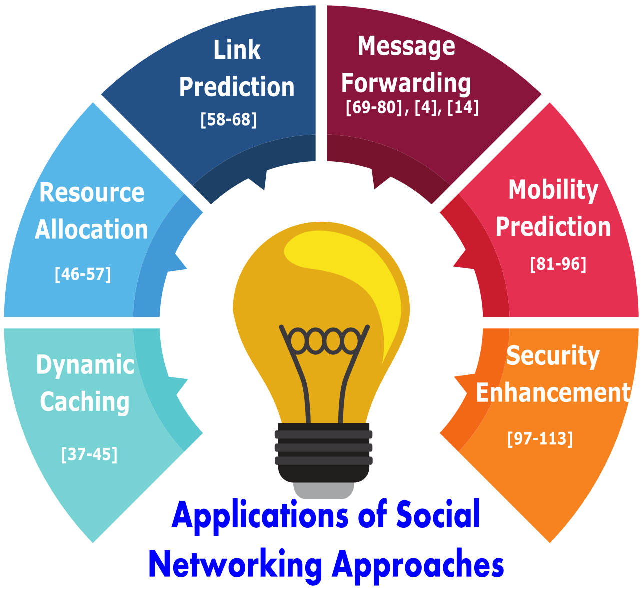

FIGURE 6. **Applications of social networking approaches. These applications consist of dynamic caching, resource allocation, link prediction, message forwarding, mobility prediction and security enhancement.**

item should be saved at a particular BS of the small cell. The prediction model exploits the inter-arrival time of request generated within a community for a particular object. The authors proved that the performance under joint mobility and prediction model surpasses that of only mobility or only prediction. Due to the random nature of users' demands, it is generally difficult to model the content requests. In this regard, tools from stochastic processing can be used to model the uncertainties of content requests. With this intent, Tadrous and Eryilmaz [44] utilize probability distributions for modeling content requests uncertainties in proactive caching of content. Caching policies were also derived by the authors to show that lower bound can be achieved. Another technique to produce efficient caching was introduced in [45] for personalized content pricing schemes. An optimization problem was formulated and consequently, a sub-optimal solution based on an iterative algorithm was derived to separate the proactive download decision from price allocation strategy.

Huang and Cai [46] devised a caching mechanism by exploiting the social characteristics of the smart devices in the network. A welfare maximization scheme was formulated and solved by using the transformation method. The authors also demonstrated that both the BS utilization and network capacity can be significantly increased by exploiting the social characteristics of the intelligent network nodes. Wu *et al.* [47] designed a context-aware caching system, which employed a performance optimization routine based on the device capacity and real-time network conditions. Although the authors performed experiments in London City to verify their design, they asserted that their design was equally applicable to other major metropolitan cities like Shanghai, Paris, and New York City. Machado *et al.* [48] analyzed the spatio-temporal features of human mobility in New York City to investigate its impact on content dissemination. They also proposed a dynamic caching framework based on the analyzed spatio-temporal characteristics and social factors and verified their design through field trials.

2) CONCERNS AND LIMITATIONS ON DYNAMIC CACHING

Although edge caching appears to be a promising approach, yet the devices may not be completely willing to cache the data that they do not require. In other words, there can be a tendency of selfishness among different devices. Existing works assume the cooperative behavior of the devices, however, it may be possible that devices do not cooperate without any real incentive. Some incentive mechanisms have been proposed, still, the nature of incentive and its requirement may vary based on the type and size of the content.

Another concerning issue is the security of cached data. Proper mechanisms for security classification of cached content need to be defined. Moreover, there is a need to certify who would have the access to the cached content. All of these factors would require consideration the prior implementation of the social-aware content caching.

B. RESOURCE ALLOCATION IN SOCIAL NETWORKS

In order to meet the requirement of high data rates for new applications, wireless communication has been continuously evolving. Thus, for a reliable communication between two end users to incorporate increasing the number of users in the network, orthogonal multiple access techniques were proposed. Some relatively new systems like the worldwide interoperability for microwave access (WiMAX) and long-term evolution (LTE) systems use orthogonal frequency division multiple access (OFDMA). OFDMA divides a single bit streams into multiple streams, which are transmitted over orthogonal subcarriers. Although the OFDMA subcarriers improve the spectral efficiency, it may not be enough to cater to the demands of future networks. For an optimization of the resources, it is critical to have a clear view of the characteristics of the resources, the physical topology of the network and the status of entities in the network.

In addition, the resource allocation must be performed in a dynamic manner, allowing the resources to be released in case of a link or node failure. Moreover, the reconfiguration time of the system must also be taken into account to provide much-needed elasticity in resource demand. Keeping in view the importance of the resource allocation and its ability to impair the functionality of a wireless network, we now provide a discussion on the recent advances in social-aware resource allocation.

1) STATE-OF-THE-ART FOR SOCIAL-AWARE RESOURCE ALLOCATION

Resources can be efficiently managed by using social aspects of the network such as interactions, interests, and activities. Using this information, social utility functions and distributed game-theocratic approaches can be formulated. Semiari *et al.* [49] propose a context-aware framework to determine the strongly connected users in the network. The solution provided by the same authors has been found to be efficient when social similarities exist. Semiari *et al.* [50] dealt with the problem of joint allocation of resources for BS using millimeter and micrometer waves. Additionally, Namvar *et al.* [51] and Zhang Namvar *et al.* [52] performed resource allocation for small cell BS and for device offloading techniques, respectively.

Shah and Fapojuwo [53] investigated the impact of social-awareness in an OFDMA network. Two optimization problems were formulated to address the problem of resource allocation whereby devices directly communicate with BS during the first hop which can be extended to another hop in order to communicate with another device. The solution was compared with conventional resource allocation schemes to prove the usefulness of the proposed scheme. Li *et al.* [54] introduced a social community-based resource allocation technique by leveraging the properties of centrality and community. The proposed allocation scheme demonstrated better performance as compared to other contemporary schemes. However, the centralized nature of this scheme puts an excessive burden on BS and may introduce a single point of failure. Zhao *et al.* [55] maximized the overall throughput of the considered network by using a clustering approach. They selected the cluster head and cluster members by taking into account not only the geographical closeness between the nodes but also their social attributes. Subsequently, they used a matching algorithm employing a one-to-many bipartite graph for a fair allocation of the cellular channels. Their proposed scheme was shown to increase the throughput by 50% and 5% when compared with heuristic and stochastic algorithms, respectively.

In another related work, Zhao *et al.* [56] proposed a many-to-one matching algorithm with manageable complexity in which the user pairs and resource blocks interactively converged to a point of stability. Floréen *et al.* [57] showed that their proposed scheme outperforms the context unaware, one-to-one matching, and Gale-Shapley (GS)algorithms by 63%, 20%, and 11%, respectively. Zhang *et al.* [58] analyzed the results of an online interaction between users for improving the network performance. In [59], a resource allocation framework was developed for a media cloud. In particular, Tran *et al.* [60] used the backward induction method to obtain Stackelberg equilibrium. It was shown that each player in the game can achieve maximum revenue by exploiting the social features.

2) CONCERNS AND LIMITATIONS

Dynamic resource allocation has several drawbacks. For instance, most of the resource allocation based techniques consider perfect knowledge regarding the devices in the network. This knowledge is including that the channel state and distance are collected from the devices deployed in the network. By exploiting this information, it is possible that some malicious devices may gather more resources than they require. Hence, reducing the available resources for other needy devices. Future social network solutions need to jointly consider the resource allocation and trustworthiness of nodes for justified allocation of resources.

C. LINK PREDICTION AND SOCIAL NETWORKS

Link prediction is essential for characterizing the link-level performance of wireless networks. Link prediction works by detecting the missing or newly added links in the network. It can also help to identify the links that have a high probability of contact which is very beneficial for opportunistic networking [61]. Typically, the link is predicted using a link prediction score and this score is obtained using one out of the two methods stated below:

1) *Supervised Link Prediction:* In this approach, a classifier is constructed which predicts whether a link exists between two devices using previously learned characteristics of the network topology.
2) *Unsupervised Link Prediction:* This approach generates the link prediction score using real network characteristics like a number of neighboring devices and number of paths, etc.

As explained earlier, the supervision of network behavior can become tedious due to dynamicity and scalability of future wireless networks. Thus, we now focus on unsupervised link prediction, which is considered more suitable for wireless networks. As shown in Figure 7, there are two subcategories of unsupervised link prediction, i.e., neighbor-based link prediction and path-based link prediction. For generating the link prediction score, the neighbor-based approach locates the neighbor of each node, thus using only local information. In contrast, global information is used for generating a score with the path-based link prediction method.

1) RECENT ADVANCES ON LINK PREDICTION SCHEMES

Recently, many studies have focused towards using social characteristics like ties, bridging, and community, to solve the common problems in wireless networks. Due to this reason, the problem of link prediction has gained significant research interest [62]–[64]. In this domain, one of the initial works was done by Valverde-Rebaza and de Andrade Lopes [65]. They combined community information (social behaviors and interests) with network topology to predict links for Twitter. It was unveiled that the proposed solution can efficiently predict the future links in asymmetric large-scale networks. Similarly, Li *et al.* [66] found that centrality approach can also be used to improve the link prediction accuracy. It is because most of the time, devices like to connect with similar devices and prefer a central node. Using maximal entropy random walk, they proposed a centrality based link prediction method.

Based on the above-mentioned works on link prediction, Liu *et al.* [67] used social ties between neighboring devices in order to find the node connection likelihood. They pointed out that among other social characteristics, social ties

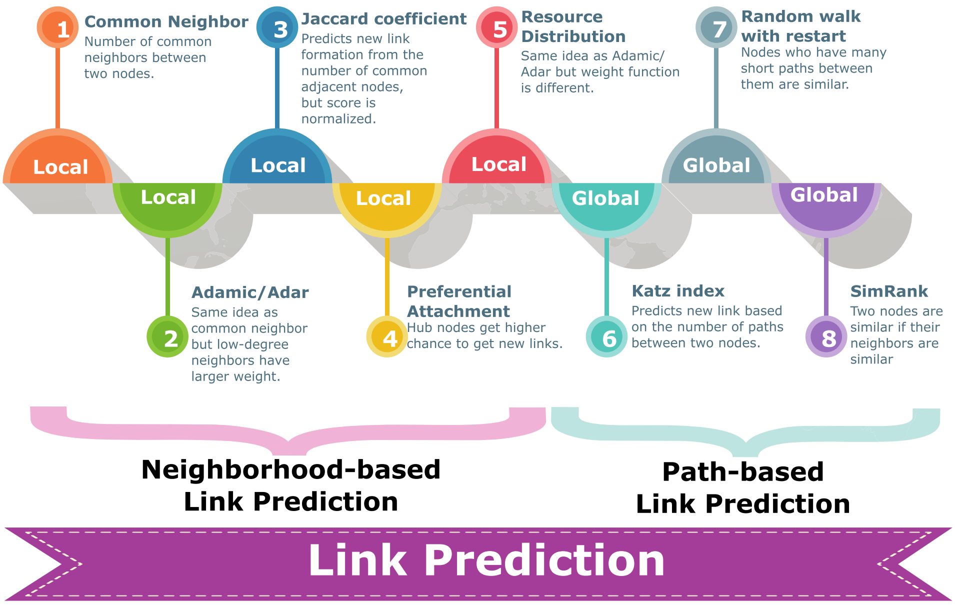

FIGURE 7. Link prediction techniques based on node similarity score.

are more appropriate to improve link prediction accuracy. Qiu *et al.* [68] proposed a novel event-driven model to observe network processes in real time. These observations are then used to better predict the future link connections. Some other studies like [69] investigate complex approaches like homophily (togetherness) and social balance to find social patterns in the network. In another work, Moradabadi and Meybodi [70] developed a link prediction algorithm namely, continuous action set learning automata (CALA). Specifically, the authors try to develop a feedback environment and formulate link prediction as a noisy optimization problem. To solve this problem, different combinations of environment feedbacks are obtained at different periods which have shown to be helpful in learning the true value of the link.

Similarly, Gündüz-Öğüdücü and Çataltepe [71] provided a time series based forecasting approach for prediction of the link. This method works by examining the changes in past nodes similarities which is then used to predict recurring or new links. It was concluded that the proposed method improves the performance as compared to benchmark methods. Lebedev *et al.* [72] apply efficient top-k routing algorithms to solve the link prediction problem. The article compares the top-k shortest path results with the state-of-the-art baseline methods and it was shown that the top-k similarity measure outperforms the classical Adamic/Adar and Jaccard measures.

2) CONCERNS AND LIMITATIONS

Using global and local information for link prediction has its disadvantages. In particular, the global information regarding paths cannot be available under all conditions. Moreover, for large-scale networks, it may introduce significant delays while simultaneously choking the resources of the network. On the other hand, local information requires less information exchange and has lower communication overhead. However, the local information based link prediction would underperform for the mobile networks.

Overall, the future efforts must be focused towards hybrid solutions. The social networks need to be equipped with decision-making algorithms allowing a smooth transition from neighborhood-based link prediction to path-based link prediction.

D. ROUTING AND MESSAGE FORWARDING WITH SOCIAL NETWORKING

Delay tolerant and opportunistic networks have recently gathered much research attention as they do not require the construction of new infrastructures [73]. Let us consider an opportunistic network where a source S wants to transfer message M to a receiver R. Since the direct path from S to R is missing, the message will have to be transferred through intermediate nodes. One of the easiest ways to transfer this message to R is through epidemic forwarding. In epidemic forwarding, each node that receives the message forwards it to the other connected nodes. Although it reduces the end-to-end message delays, yet the consumption of network resources increases significantly. Moreover, epidemic routing can cause congestion in a large scale network which may halt the functionality of the network.

It is evident from the above explanation that the intermediate node selection is important for efficient and reliable routing of messages. Therefore, the design of routing schemes that have the high probability of delivering the message to the destination has been extensively studied in the literature. We now provide a comprehensive explanation on some of the recent message forwarding techniques for social networks.

1) LITERATURE REVIEW OF ROUTING METHODS FOR SOCIAL NETWORKS

The social networking structure offers unique opportunities to exploit the network characteristics due to its implementation at three levels i.e. 1) individual 2) community 3) entire network [74]. Nodes in a particular community have more choices to communicate with each other than the nodes of different communities. One of the pioneering works was done by Hui and Crowcroft [75] to use the community-based relationship for the routing of messages. Subsequently, the same authors proposed three algorithms in [4], namely, K-CLIQUE, SIMPLE, and MODULARITY. These were based on the contact graphs in a distributed community rather than utilizing a conventional centralized community-based approach. Bulut and Szymanski [76] proposed a method to strengthen the virtual link between devices to form a friendly community. The friendship community is a subset of the community that experience link quality better than the pre-specified threshold. Some other works consider the relationship between communication wherein inter-community based forwarding decision mechanisms were proposed [77].

To liberate the devices to communicate independently, Daly and Haahr [14], [78] introduced community independent schemes. These schemes use the betweenness centrality to formulate a utility function which reduces the load on central devices. Moreover, few other studies consider embedding contextual information to route the messages [79]. The mobility of human beings has also been used to find the best path for routing the messages. For instance, Yuan *et al.* [80] use Markov chain technique to estimate the mobility patterns of people to estimate centrality and strength of social ties. The aforementioned protocols use unicast routing to forward the message to the destination. In contrast to these protocols, multicast routing can also be used to improve the routing performance [81]–[85]. However, one of the main concerns of these multicasting protocols is the frequent changes in the number of group members with time, as devices may join or leave the group independently [83].

2) CONCERNS AND LIMITATIONS

The majority of the recent studies uses unicast socially aware algorithms to improve the performance of networks (see e.g. [4], [14] and references therein). However, from a social perspective, only a handful of multicast algorithms have been developed [86]–[89]. It is therefore interesting to investigate how social-aware multicast routing protocols can be used to improve upon the performance of unicast protocols. Additionally, it is also interesting to see how social-aware any-cast algorithms can be used to improve the performance of wireless networks.

E. SOCIAL NETWORKING AND MOBILITY PREDICTION

One of the most important features of wireless nodes is that they can be deployed at any place without disrupting the normal operations of the existing network. Nodes can also join or leave a wireless network, thus changing the topology of the network. This type of change, which rarely occurs in the network, is called weak mobility. Wireless networks are generally good at handling weak mobility by frequently updating the information of their neighbors. However, nodes can only perceive a change in their surroundings at the start of their active period. This results in a considerable delay in packet transmission when the change occurs in the network topology. The performance worsens even more when a change is encountered in multi-hop networks. Still, the delay introduced by weak mobility can be tolerable since the modification rarely takes place in the network.

In contrast to weak mobility, frequent failure of nodes and their physical movement fall within the gambit of strong mobility. In some cases, nodes may be attached to a moving vehicle/ person or they can be moved by external forces like water or air [90]. A strong nodes mobility can cause some of the following major problems:

1) It deteriorates the quality of the wireless link, resulting in increasing the packet retransmissions.
2) The mobility of nodes can introduce significant packet delays due to frequent changes in the route.
3) Due to the mobility of the nodes, the process of neighbor discovery can produce considerable communication overhead.
4) The mobility can increase the collision between packets, as the neighborhood information may lead to inconsistencies due to nodes joining/ leaving the network.

Overall, it is essential to predict the mobility patterns of the nodes using contextual/ learned information. In this regard, explanatory discussion on some of the recent studies for social networks is provided in the coming subsection.

1) MOBILITY PREDICTION FOR SOCIAL NETWORKING

In order to mitigate the scanning overhead in the future networks, Wanalertlak *et al.* [91] provide a mobility prediction tool for the efficient hand-off. Based on the previous information regarding users the authors make use of hand-off tables which are fed into a prediction software namely auto-regressive integrated moving average (ARIMA). This strategy returns the likelihood of the user to hand-off to a nearby access point. The social platform called Foursquare has been used to leverage the information to predict the mobility pattern of the user. The authors collected the data for one month across different venues and build a time-stamped data set to formulate linear regression and M5 tree. However, the authors do not provide specific applications of their proposed prediction model. Besides this, the mobility of users has been characterized for urban environments in [92]. The authors, in addition to social information, gain benefit from the physical information of the network to eventually formulate a probabilistic model on real-life data of mobility

TABLE 3. Summary of mobility prediction techniques.

Reference	Input Parameter	Technique	Prediction Efficiency
[98]	Previously visited location	Markov chain model	High
[99]	Previously visited location	Density joinable cluster & Markov chain model	95%
[100]	Time series of locations	Cross correlation	Directly proportional to the series length
[101]	Time information along with visited locations	Viterbi decoding and supervised learning	High
[102]	Sequence of locations	Hierarchical triangular mesh and Markov chain model	Low
[103]	Sequence of regions	Association rule along with pattern extractions	Average
[104]	Node's online connections	OpportuNistic Socially-aware and Interest-based DissEmination (ONSIDE) algorithm	Average
[105]	Node's social connections, contacts history,	Social PRedIction-based routing in opportunistic NeTworks (SPRINT) algorithm	High
[106]	Real time mobility traces of nodes,	Recent Weighted Average Method	High

traces of users. A brief summary of different mobility prediction techniques along with their prediction efficiency is presented in Table 3.

In a similar way, Bapierre *et al.* [93] predict mobility based on joint information from temporal (location of nodes) and social features (e.g., the location of friends with respect to the node). Through simulations, the same authors try to validate the accuracy of mobility patterns. The idea of social assistance among BSs was proposed by Yi *et al.* [94] to efficiently estimate the cellular network. Here, a social graph was created where the edge represents the spatial correlation of traffic between the BSs. In this way, the most critical BSs are identified to subsequently perform the prediction of traffic. It was found that prediction with fewer than 20% errors can be ensured using the proposed scheme. Tsiropoulos *et al.* [95] optimize the performance of downlink resource allocation by utilizing the popularity of end users. A sub-optimal solution was provided by heuristically solving the optimization problem which was then verified using synthetic data.

Ning *et al.* [96] proposed a cooperative service access system for vehicular networks and quality optimization method. Initially, the authors investigate and construct the social relationship between vehicles on the road. The authors then propose a trajectory-based time prediction algorithm to minimize the effect of the unstable network topology. The simulation results indicate that the proposed scheme is more effective than other baseline algorithms. Yuan *et al.* [97] studied the mobility patterns by incorporating anomaly detection, location prediction, and time-aware interdependency between devices. The experimental results demonstrate that the proposed algorithm outperforms the baseline schemes proposed in the previous literature.

2) CONCERNS AND LIMITATIONS

A few social-aware mobility prediction solutions have been proposed in the literature, however, they do not cover all types of scenarios. For instance, the mobility prediction model developed for vehicles on the highway may not be suitable for predicting mobility in a dense urban environment and vice versa. Moreover, future networks are also expected to incorporate high altitude platforms (HAPs) which would consist of several unmanned aerial vehicles (UAVs). The velocity of UAVs is higher than the vehicles on the road which warrants new mobility prediction schemes. Moreover, the mobility pattern of UAVs would be in three-dimensions, and therefore, two-dimensional mobility models could not be applied on UAV social networks. Future research works on the social network must focus on these aspects of mobility prediction solutions.

F. SECURITY ENHANCEMENT USING SOCIAL NETWORKING APPROACHES

Inevitably, the impact of the security in social relationships is quite significant. While most of the studies consider that nodes in the network are randomly deployed and grouped into the source and destination pairs [107]–[110], some studies have proposed social models for securing the large-scale networks [111]–[115]. The following subsection discusses the recent developments with respect to ensuring the security of social networks.

1) RECENT DEVELOPMENTS TO SECURE SOCIAL NETWORKS

It is well-established that the social ties indicate the willingness of devices to share resources and information. In cooperative or relay assisted communication, it is commonly assumed that the intermediate relay is trusted [111], [112] which may not be a practical approach. It is because a relay can belong to another network or may be a compromised device. To partly address this issue, Vastardis and Yang [116] recommended using social trust degree for relay selection. Subsequently, few studies have used social ties to provide link security in cooperative networks [113]–[115]. More specifically, Tang *et al.* [113] analyzed secrecy outage probability of a cooperative network from a social perspective.

Similarly, Ryu *et al.* [114] proposed a cooperative transmission strategy. They considered that the relay can act as a potential eavesdropper based on the social trust degree mechanism. Huang *et al.* [115] provided a jamming mechanism and power allocation strategy based on the social characteristics of devices. To adopt a more realistic approach, they considered that the channel state information of devices in unavailable at the transmitter. These studies, even though, evaluate social ties on the basis of either relaying or jamming operations, yet a more dynamic scenario, where both relays and jammers cooperate exploiting social trust is largely missing in the literature.

Secrecy capacity analysis for large-scale networks was performed by Zheng *et al.* [117] by using social relationships. Particularly, they derive the secrecy rate and secrecy throughput based on the social ties between source and destination. Chen *et al.* [118] exploit the social layer information for jamming the transmission of eavesdroppers. They leverage the social reciprocity along with social trust to improve the secrecy performance of the network. In order to extend their previous work [119] for cooperative networks, Wang *et al.* [120] used contact duration to propose admission policy in the network. Ergodic secrecy rate using these social characteristics was also evaluated without the knowledge of CSI.

2) CONCERNS AND LIMITATIONS

Establishing secure end-to-end communications between two legitimate devices is one of the most critical issues in wireless communications. Some factors contributing to the unsafe transmission of messages are an uncoordinated access of the medium, a centralized routing mechanism, and unreliability of neighboring devices. Although the social perspective in communications can strengthen the authentication aspect of link security, it has its inherent vulnerabilities, as discussed in the previous sections. For example, the information collected for employing trustworthiness can be exploited by a malicious user to obtain access to the data on other devices. Providing security, in this regard, is significantly difficult due to the availability of global state information in the network. Which device should have access to this information and what degree of access should be provided to these supervisory entities must be determined in order to materialize the social networking potentials.

G. SUMMARY AND INSIGHTS

This section has identified some application scenarios of social networking concepts in wireless communications. Specifically, social networking approaches can be used for dynamic caching, resource allocation, link prediction, mobility estimation, message forwarding, and security enhancements. Resource allocation and dynamic caching applications have been largely focused on optimizing the utility function under a context-aware framework. On the contrary, the link/ mobility prediction and message forwarding applications of social networking mainly rely on event-driven models. Social networking approaches have also been reported to improve the security of wireless devices, but these studies are limited to a specific layer only. The proposed security solutions would require considerable refinements to make full use of the cross-layered architecture of wireless networks.

TABLE 4. Some variations of the *5G vision*, as proposed by different stake-holders [123].

Key Players	5G Vision
5GNOW	- Universal filtered multi-carrier - Unified frame structure - Abandon synchronism and orthogonality
5G Forum	- Intertwining heterogeneous networks - Commercialization by 2020
5G Training	- Personal mobile Internet, D2D - Architecture and key technologies - Disruptive technology direction
5GPP, METIS	- Scalable and sustainable - Multi-tenancy - Softwarization of 5G
Samsung Electronics	- Extensive cloud computing - Enhanced multimedia experience - Internet of things
NOKIA Solution Networks	- Sufficiently accurate channel models - Augmented reality and tactile Internet - Heterogeneous deployment
DOCOMO	- Everything connected wirelessly - Extensive and enriched content
Huawei	- Network deployment scenario - Diverse application and services - Massive capacity and connectivity
Qualcomm	- Improved user experience - Connecting industries and devices - Enabling novel services
Ericsson	- Affordable and sustainable - Networked society

IV. POTENTIAL SOCIAL NETWORKING SOLUTIONS FOR 5G COMMUNICATIONS

Social networking approaches have the potential to exploit the social characteristics of networks to improve their performance. Lately, the research community has focused its attention towards using the social aspects of wireless networks. Thus, in this section, we discuss some recent developments in key enabling technologies of the 5G communication, from the perspective of social networking. Let us first understand the requirements of 5G communications as it will help us in analyzing some recent studies.

A. 5G-ENABLED WIRELESS COMMUNICATIONS

The wireless communication networks have been significantly improved over the past decade due to focused research efforts. The combined effect of increased scalability, hyperconnectivity, and application-specific requirements are helpful in triggering the next evolution of wireless networks (i.e. the 5G networks) [121]. It is also envisaged that 5G technology will bring the magnitude of the decrease in energy consumption and round-trip latency while increasing the data rates, connectivity, and coverage. As shown in Table 4, the key vision of 5G is different for top market players, which makes it difficult to shape standards for 5G technologies. Still, the standardization efforts are more active today than before and the first standard for 5G is envisioned to get mature by 2020. Group special mobile association (GSMA), along with its partners from industry and academia, is working on blending several research activities to meet the major requirements of 5G communications [122]. These requirements are listed below:

TABLE 5. Application of social awareness to D2D communications [10].

D2D Task	Community	Ties	Bridge	Centrality
Peer discovery	Encounter patterns & peer discovery	Beacon rate adjustment	-	Communication demands & proactive beacons
Mode selection	Community interests & community density	-	Inter-community demands	Bottleneck detection & cellular preferential
Resource allocation	Communication demands & community-oriented sharing	Security and privacy & communication demands	Dissemination based bottleneck prediction	Resource based bottleneck prediction
Interference management	Distributed coordination & resource partition	Spectrum allocation & relay selection	-	-

KEY REQUIREMENTS OF 5G COMMUNICATIONS

The future networks are going to revolutionize our lives by leveraging large-scale connectivity of heterogeneous and smart devices. To materialize this vision, following key requirements have been established for 5G systems:

- *High data rates:* In order to provide somewhat acceptable performance for future applications (e.g., virtual reality, augmented reality, video streaming, etc.), the 5G technologies would have to support data rates up to 10 Gbps.
- *High scalability:* To support fronthaul network decomposition through network function virtualization (NFV), high scalability of networks is essential.
- *Low latency* Future applications like video games, tactile Internet and sophisticated car alert systems would require lower latency which cannot be supported through existing infrastructure. Therefore, 5G must support 10 times less round-trip time as compared to existing LTE systems.
- *Higher reliability:* 5G communications must be able to provide uninterrupted service to a massive number of devices.
- *Perceived availability of network:* The network coverage needs to be available for 99.9% of the time so that the network is available anywhere, anyplace and anytime [122].
- *Minimization of security threats:* The massive connectivity of devices may have catastrophic effects if a malicious user executes network attacks. It is, therefore, needed that 5G communications incorporate effective and light-weight security protocols to protect user privacy and to avoid network failures.
- *Increased battery life:* Due to rapid depletion of energy sources, green technology would be an essential part of future communications networks. Hence, a 5G system must support energy efficient methods and standard bodies need to incorporate this feature while making policies [122].

Based on the above discussion, it can be concluded that the exact concept of 5G communication is still vague. However, the 5G requirements can act as potential guidelines towards the realization of 5G systems. In this context, social networks can play a pivotal role in optimizing the performance of large-scale 5G networks. In light of this vision, we now analyze some recent studies on wireless social networks.

B. SOCIAL NETWORKING IN D2D COMMUNICATIONS

With the densification of cellular networks, the users in close proximity would be able to communicate directly without any involvement of BS. This communication approach between devices is called direct D2D communications. Due to close proximity, the social networking approaches can be readily applied to D2D networks. For instance, community-based techniques can be used for optimal allocation of resource and interference management in the network. Besides this, a summary of other qualitative attributes and design aspects of social networking enabled D2D communication are given in Table 5.

1) SOCIAL-AWARE RESOURCE ALLOCATION FOR D2D COMMUNICATIONS

Recent studies in D2D communications have revealed that social behaviors of human beings can be used to improve the performance of D2D networks [124]. Zhao *et al.* [125] provided a solution for optimal resource allocation by using utility games within a social group. Orsino *et al.* [88] and Zhang *et al.* [89] investigated cluster based formulation for content dissemination and for channel sharing under various duplexing schemes, respectively. For energy efficient multicasting environment, the heuristic algorithm approach achieves a better throughput per unit energy consumption [87].

A two-step game model was provided Wang *et al.* [126]. Specifically, the authors noticed that D2D pairs can reuse the channels of cellular communities thereby resulting in optimal resource allocation. A firefly spanning tree (FST) based algorithm was provided by Chao *et al.* [127] which used received signal strength to formulate the tree. By adopting a similar methodology, Tang *et al.* [128] presented an uplink signal detection scheme. However, one drawback of this strategy is that the privacy of users was neglected while discovering neighbors.

2) INTERFERENCE MANAGEMENT USING SOCIAL-AWARE D2D COMMUNICATIONS

In some cases, the communication overhead for device discovery becomes very large due to dense deployment of devices. To address this issue, social networking based adaptive approaches can be used for discovering devices in nearby proximity. Specifically, Zhang *et al.* [52] vary the probing rate of device discovery based on the information of the social domain. While in [129], the wake-up schedule of devices is changed according to the probabilistically evaluated contact time of users. Thus, the lifetime of devices can be increased by appropriately adjusting the accuracy of device discovery. Community-based attributes can be exploited in massive D2D networks to ensure reliable transmission of data within the community and across different communities. With this motivation, Hasan and Hossain [130] used community-based attributes to configure the transmission power of devices.

3) TRUST-BASED SECURE COMMUNICATION IN D2D NETWORKS

Trust of each node is calculated with respect to particular metrics such as trust in the fast delivery of a service or the trust to deliver high quality or either trust for using as a relay. Trust is calculated by taking into consideration experience from direct interaction, knowledge from other devices and timing information. Each node maintains a trust table of all its neighbors and selects its relay node based on updated trust values in the device reputation table. Trust in a social network can be further divided into two classes; user based and device based social features [131]. Based on this observation, Ometov *et al.* [131] propose a weighted function that considers both classes of social features. The function's behavior is dependent on the way the weights are assigned. Higher weights can be assigned to either user-based social metrics or device based metrics depending on the requirements of a particular application.

Social relationships and trust are exploited by Social-aware video multiCast (SoCast) [132] to propose a social-aware video multicast system for D2D communications. SoCast exploits the social trust and social reciprocity parameters to stimulate cooperation between devices. Users can form groups to obtain missing packets from other clients and restore incomplete video frames, thus, improving overall video quality and user satisfaction. However, the element of trust was missing when groups are formed in [132]. Since social network approaches mainly rely on the trustworthiness of nodes, Mishra and Pandey [133] proposed a more sophisticated trust based relay selection scheme.

A privacy-preserving spatiotemporal scheme is proposed in [134]. Spatiotemporal matching is based on the location dependent information of D2D devices. Spatiotemporal profile of each device is maintained by keeping track of devices' whereabouts. Spatiotemporal matching of profiles of two devices can be used to determine the level of trust the devices have on each other. Devices with similar spatiotemporal profiles are more likely to stay within the transmission range longer. Liu *et al.* [135] investigated social-aware content caching mechanism in order to reduce downlink latency. By exploiting social characteristics, the authors selected important nodes in the D2D underlay cellular network to allocate files. Based on their previous work [135], the same authors proposed many-to-one and many-to-many file allocation strategies in [136]. The authors proved that the proposed scheme outperforms the benchmark schemes by reducing the downloading latency of the D2D-enabled cellular networks.

C. SOCIAL NETWORKING ENABLED VEHICULAR NETWORKS

In the present era, an increasing number of people are using private vehicles and cars on a daily basis. This increased use of cars has resulted in an exponential rise in fatalities due to road accidents. The danger of these vehicles have been recognized by modern societies and several solutions have been proposed to minimize it. In this regard, wireless communications provide a potential solution in the form of safe and reliable vehicular networks. It allows vehicles to share information on the road which may include traveler-related information, safety information to minimize the risk of accidents, and post-accident information for traffic jams and for accident investigation. This emerging field of communication has attracted the attention of researchers from all the domains including social networking. Some of the most prominent applications of the social network are appended below:

1) APPLICATIONS OF SOCIAL NETWORKING IN VEHICULAR COMMUNICATIONS

Network applications combining social networking and human factors can be naturally used for vehicular networks. A socialized vehicular network has common preferences, interests, and objectives. For instance, a group of people heading towards a football stadium to watch the same game can be expected to have the same interests which affect the vehicular connectivity [137]. Of late, mobile applications such as RoadSpeak and NaviTweet have been introduced to address drivers preferences [138], [139]. These applications are mainly devoted to providing infotainment and safety-related services. Another exciting aspect of incorporating social assistance in vehicular networks is that it can be used to reduce the traffic jamming conditions by predicting social behaviors of people [140]. In addition to this, people sharing same interests can discuss topics of mutual benefit [141] and form a community. Different communities can connect via intermediate helper vehicles which also act as bridges, as shown in Figure 8.

2) INCORPORATING SOCIAL BEHAVIORS IN VEHICULAR NETWORKS

Li *et al.* [27] proposed an efficient data dissemination scheme based on social similarity and local activity. However, two major concerns, as noted by Gillani *et al.* [142], in the social design of vehicular networks are (1) efficient integration of sensors with other technologies and (2) privacy of data. In this context, Lu *et al.* [413] proposed Social-based PRivacy-preserving packet forwardING (SPRING) protocol which exploits the efficient deployment of a roadside unit (RSU) at social points of intersection. However, the establishment of trust among drivers is still a critical aspect of vehicular networks and principles of admissions in a social group need

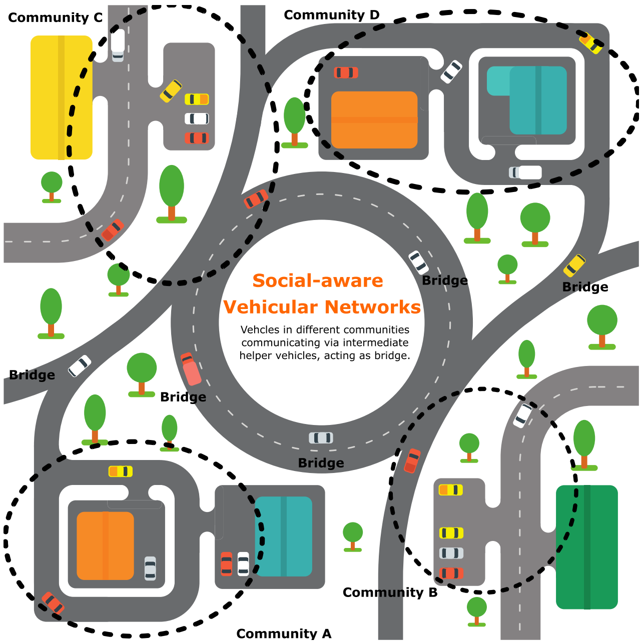

FIGURE 8. An illustration of social-aware vehicular networks. The figure shows four communities of vehicles: Community A, Community B, Community C, and Community D. Different communities of vehicles communicate with each other through intermediate vehicles called bridges. The main challenge is related to frequent changes in the number of community members due to the mobility of vehicles.

to be clearly defined [144]. Normally, the following factors should be considered:

- Formation of a social group.
- Evaluation of trust and its management [145], [146].
- Establishment of decentralized architecture.
- Flexibility in data exchange and its integrity [147].

Some other vehicular technologies focus on network analysis to ensure web-based portal to register the interested users [148]. Particularly, the importance of a node in the network can be evaluated by exploiting centrality metrics. This metric is then used to estimate social ties between the vehicles in order to register the incoming ones [148].

3) PACKET FORWARDING IN VEHICULAR NETWORKS USING SOCIAL-AWARENESS

Bradai and Ahmed [149] proposed a novel mechanism to provide efficient video streaming to the users based on dissemination capacity. Cunha *et al.* [150] proposed a new solution to select the best vehicle for rebroadcasting the messages while Stagkopoulou *et al.* [151] introduce a new metric namely probabilistic control centrality (pCoCe) to select the best vehicle for forwarding the messages. Maglaras and Katsaros [152] introduce new techniques i.e. route stability clustering (RSC) and sociological pattern clustering (SPC) to estimate the tendency of vehicles to take a particular route. Among other clustering approaches, Vodopivec *et al.* [153] performed a review of cluster-based vehicular networks. Other noteworthy context-aware social approaches to improve the support for vehicular applications were proposed by the authors of Hu *et al.* [154] and Yasar *et al.* [155]. A summary of the comparison of social networking protocols in recent years is given in Table 6.

D. SOCIAL NETWORKING AIDED CLOUD COMPUTING AND BIG DATA

With the rise of social media, the amount of data captured by organizations has been increased manifolds. This data can be collected in either unstructured or structured format. The creation of data (hereby referred as big data) is occurring at a rapid pace and this trend has received worldwide recognition [161]. Big data is quickly transforming business, finance, engineering, science, healthcare, and ultimately, the entire society. One of the major problems that practitioners and researchers are facing relates to slow development in cloud computing platforms for the analysis of data. One of the main advantages of social networking approaches is that they can be applied to both big data and cloud computing.

The cloud computing has several advantages like scalable data storage, integration of data service, parallel processing, virtualized resources, and security. Resultantly, various applications have been developed that leveraging the cloud platforms to efficiently manage the data for user access [162]. Despite some recent efforts, very few works exist in the literature where social networking approaches are used for cloud computing and big data analysis. In the following subsections, we discuss these recent works that apply social networking for scalable data management in cloud computing and for the analysis of big data.

1) SOCIAL NETWORKING FOR CLOUD COMPUTING

Scalable data management has always been one of the key motivations of the research community. In this context, cloud computing has proven to be an extremely useful paradigm. Cloud computing has mainly three paradigms namely, Software as a Service (SaaS), Platform as a Service (PaaS), Infrastructure as a Service (IaaS) [163]. Some of the attractive features of cloud computing are a low investment, elasticity, and transfer of risk. It can provide novel platforms by enabling distributed and ubiquitous availability of data.

The concept of cloud computing has generated a tremendous proliferation of data-driven applications. To manage this distributed data has been a key motivation of the database researchers for the last three decades. Much work has been put into ad-hoc and update-intensive workloads to improve the scalability of networks. However, these distributed systems were not successful due to the commercialization of parallel databases [164] which significantly grew in numbers [165]. Rapid variations in the data access patterns of applications need to be carefully evaluated and, therefore, the design of a single perfect data management system for cloud platforms is still an open issue.

Chard *et al.* [166] formulated a social cloud environment by combining the concepts of volunteer computing, cloud computing, and social networking. They proposed a

TABLE 6. Overview of social protocols for vehicular networks.

Reference	Challenge	Solution	Network Scenario
[143]	Formulation of incentive mechanism for security and privacy	Packet forwarding protocol SPRING	RSU at highly social interactive points i.e. V2I
[156]	Efficient treatment of data to ensure privacy of users	Packet forwarding protocol SPF	Social relay deployment for V2I communication
[157]	Trust and incentive-based user involvement	Packet forwarding protocol EVSE	V2I
[158]	Paradigm shift from centralized to distributed network architecture	Modeling using SocialDrive	V2V
[149]	Reliable dissemination of messages	Packet (video) forwarding protocol Rebroadcaster selection mechanism for Video streaming for vehicular ad-hoc networks (VANET) (ReViV) based on location and centrality metric	V2V
[159]	Treatment of data for effective dissemination of messages	Next hop forwarder protocol SCR based on social relations	V2V
[160]	Message dissemination and treatment of data	Packet forwarding protocol BEEINFO	V2V
[152]	Message dissemination	Packet forwarding protocol SPC/RSC	V2V

TABLE 7. Summary of social approaches in cloud computing and big data.

Reference	Challenge	Contribution
[184]	Presented the idea of combining Big data along with social networking	Analyzed the complexity of knowledge extraction when social networks are used to address Big data challenges
[185]	Improving data credibility and privacy	Provided practically executable network design and highlighted its applications in healthcare
[186]	Integration of Big data and social IoT	Social graphs approach for modeling of connected nodes
[187]	Review of the social perspective of Big data	Provided challenges and research issue for social big data
[188]	Introduced the concept of joint utilization of social networking and cloud computing	Proposed RFTRS scheme while using reputation and topological information of nodes
[189]	Service availability from the cloud for ad hoc networks	Presented the techniques to improve service availability whereby improving the efficiency of data forwarding
[190]	Providing mobile services using cloud computing	Proposed CloudMoV using IaaS and PaaS cloud and executed on Amazon EC2 and Google app engine
[191]	Efficient video streaming and cloud storage	Using CloudMoV proposed techniques to improve scalability and availability of data and pre-fetching intelligence
[192]	Allocation of tasks of big data mobile networks	Proposed trust based game-theoretic incentive scheme for task allocation
[193]	Reducing the workload of content-centric networks	Proposed social utility maximization game and find socially aware Nash Equilibrium point
[194]	Performance evaluation in terms of revenue and reputation	Developed a practical cloud system with the help of the CometCloud system

method where storage resources can be shared among friends. This model overcomes the restriction of sharing data among friends. However, it also assumes that the trust exists between users; which may jeopardize the security of data [146], [167], [168]. Of late, some incentive-based techniques have also been surfaced to promote the concept of social cloud computing [169]–[172]. This mechanism encourages devices to share their resource for providing data services to other devices. Bidoki and Kargar [170] proposed bee colony algorithm for sharing tourism-related data in the social cloud. Using an incentive approach, Chard and Caton [172] provide a crowd-sourcing infrastructure for social cloud network.

2) USING SOCIAL NETWORK FOR BIG DATA

Big data is the data analysis technique to support rapid analysis, storage and capturing of data. The data sources include numerous types of databases such as sensor data, mobile devices data and social media, etc [173]. In addition, the data need not be structured, rather the unstructured data that has no standard form can also be used. A typical data storage infrastructure for big data is in the form of clustered network attached storage [174]. Although the price of storage has significantly declined over the past years, it may still pose difficulties for small or medium-size businesses. However, despite recent advances, only a limited number of studies exist in the literature of big data that make use of the social characteristics of devices.

A brief summary of a few recent studies that investigate various aspects of cloud computing and big data from the social perspective is provided in Table 7.

E. SOCIAL NETWORKING ENABLED INFORMATION CENTRIC NETWORKS (ICNS)

Presently, internet communication is purely based on addressable hosts i.e. IPv4/IPv6 and these are rapidly exhausting leading to adopt the latest concept of naming content or data namely named data objects (NDO). This will, on one hand, eradicate the shortcomings of IP addresses but on the other, it will also be more susceptible to session termination, perturbations and other drastic anomalies in network operations.

ICN vision was primarily initiated by translating relaying internet architecture integrating active directories (TRIAD) [175] and has been progressively researched by various interested exploring groups namely data-oriented network architecture (DONA), named data networking (NDN), publish-subscribe internet technology (PURSUIT) and a network of information (NetInf) [176].

ICN architectures, generally, have an edge repository cache technique spontaneous within the network. As opposed to the contemporary internet which enables the senders to be in-charge of data transmissions, the content in ICN is receiver-driven technically. It consists mainly of two phases: first, the discovery is triggered by the consumer to find the content or its duplication, and the second is taking it back to the concerned consumer. There are two methods of content discovery: name-based routing (NBR) and lookup based resolution system (LRS) [177]. In the NBR, the consumer sends a content request packet (i.e., the so-called interest), hop-by-hop relaying by the packet forwarding nodes by looking up a name match into their forwarding information base (FIB) [178]. Whereas, with LRS, the content request corresponds to a resolution system, whose implementation is different in all ICN architectures. For instance, scalable and adaptive internet solutions (SAIL) protocol architecture defines a distributed name resolution system (NRS) that is based on hierarchically distributed hash tables (DHT). SAIL has been implemented as a hierarchical network and collects the publish messages and guides the layout (topology) manager for instilling compact path delivery.

1) CONTENT DISTRIBUTION TECHNIQUES USING SOCIAL-AWARENESS

Social networking approaches are a natural fit for the ICN and provide considerable improvements over the conventional TCP/IP-based networks. However, the work on the social perspective of ICN is very limited. Fleury [179] analyzed the interacting users to estimate the strength of the social relationship between them. Centrality measures such as PageRank [180] and Eigenvector [181] have also been used to improve the user interactions. Another important work is done by Bernardini *et al.* [182] who proposed socially aware caching for the ICN network. Mathieu *et al.* [183] noted that a content-centric network can employ short messaging services by introducing a fraction of complexity in existing networks.

In order to accommodate the demands of users, content delivery networks can exploit the social characteristics. In fact, some studies have proposed to use social characteristic evaluation models to further optimize the distribution of content on the Internet [195], [196]. For instance, Agarwal and Agarwal [195] analyzed Twitter's trending policies using an auto-regressive prediction method. Focusing on the geographic aspect of content-based networks, Scellato *et al.* [196] provided an efficient caching mechanism to store the most popular content on content delivery networks. Motivated by this, Nazir *et al.* [197] proposed a content delivery mechanism to extract time-based information and to estimate the contact period. Besides, distributed models, a central energy consumption model for content-centric networks can be used to make energy efficient caching decisions [198]. As a result, Fang *et al.* [198] proposed a game-theoretic strategy for making caching decision. A socially optimal configuration was found by deriving the Nash equilibria.

2) SECURING ICN USING SOCIAL NETWORKING

Kim *et al.* [199] introduced the concept of the virtual private community (VPC). VPC is an ICN based platform which facilitates users to communicate with friends and family without the need for a central server. Moreover, VPC does not require a centralized authentication server for verification of signatures. Kim and Lee [200] provided a proof-of-concept (PoC) where a selected group of members can download a list of content. Based on [199] and [200], Garroppo *et al.* [201] evaluated energy efficiency of a content-centric residential community network (CCRCN). To determine the energy footprint of the network, the same authors used an energy model. The energy model was constituted by the contents from the Internet, the power of gateways and the amount of exchanged content between the gateways.

F. SOCIAL NETWORKING AND IoT

The IoT has shifted the paradigm of device communication towards pervasiveness and heterogeneity, where a large number of connected devices generate information for particular applications [202], [203]. However, designing unique protocols to meet the demands of such a large number of devices is no simple task. The exchange of information needs to be efficient enough such that everyday objects can communicate/ interact using the minimum assistance of human beings. This has led to the introduction of the concept of virtual objects [204] that augments the abilities of real-world physical objects. As per [205], three phases can be identified enable physical-virtual world interaction:

- Information collection phase.
- Information transmission phase.
- Information processing phase.

1) ROLE OF SOCIAL NETWORKING IN IoT

Khan *et al.* [206] define SIoT as "A Social Collaborative Internet of Things is a new paradigm that has strong ties with Social Internet of Things and is defined as a platform of IoT where smart objects work together socially through recursive interactions of knowledge by establishing social relationships with their surroundings smart objects aiming to achieve common/shared goals in order to benefit humans". Based on this idea, Colom *et al.* [207] proposed a framework for load computing and devised a scheduling mechanism for allocating tasks to IoT devices. The scheduling is performed after a given device has computed the load of itself and its neighboring devices. Once the scheduling has been performed, the tasks are distributed among available devices.

TABLE 8. Overview of recent developments in Social aware IoT.

Reference	Challenge	Contribution	Network Condition
[215]	SIoT link selection problem	Performance analysis of social network of objects and adjustment of threshold for different numbers of users	Static
[216]	Performance analysis for cognitive Social IoT	Quantification of social relations for different characteristics of mobile nodes and managing irregularities of these social traits	Static
[217]	Modeling social network of objects and performance evaluation of web of things	Management of social network of objects with minimum involvement of humans	Static
[218]	Analysis of complex dynamics of SIoT devices	Explores dynamics and complexities of Social IoT and explore its application in disaster management scenario	Static
[140]	Implementation of IoT devices	Discussion on intelligent transportation systems station architecture functionalities	Mobile
[219]	Connection time prediction in SIoT	Proposed social on the road (SOR) for the case when number of users in the network changes and connectivity is irregular	Mobile
[220]	Architecture for SIoT	Performed simulations with Open Street Map, on board diagnostics 2 (OBD2) and simulation of urban mobility (SUMO) trace for various emergency applications	Mobile
[221]	Efficient resource utilization	Proposed light-weight query mechanism with the help of "Fission Computing"	Static

Kasnesis *et al.* [208] designed two ontologies to handle the social relationship of devices followed by investigating use case scenario of social IoT. Hussein *et al.* [209] provided a social structure namely dynamic social structure of things (DSSoT) to evaluate the devices' short-term needs based on their situation. The algorithm consists of two phases (1) identification phase (2) goal detection phase. The performance of the system was evaluated in terms of complexity and data growth rate. A list of recent development with respect to efficient forwarding of messages in SIoT is provided in Table 8.

2) TRUST-BASED TECHNIQUES FOR SECURING IoT

As one of the aims of IoT is to autonomously make decisions for different services and applications, therefore, the importance of trust for SIoT cannot be neglected [210], [211]. A trusted platform can maximize the probability of the transfer of information and minimize the risk of eavesdropping. To build a trusted platform for SIoT, various factors need to be incorporated e.g. knowledge, experience, and reputation. Some other protocols for trust management in SIoT are adaptive trust management (ATM), recommendations plus reputations (RpR), trust-aware access control systems for IoT (TACIoT), context-based social trust model for the internet of things (CBSTM-IoT) [32], [212]–[214].

G. SUMMARY AND INSIGHTS

This section has provided the recent developments in 5G communications with respect to social networking. The introduction of social characteristics in 5G communications has completely altered the perspective of wireless communications. At present, studies are being conducted to improve the performance of D2D communications, vehicular communications, ICN & cloud computing networks, and IoT. For D2D communications, social characteristics like social ties can be used relay selection and beacon rate adjustment. Similarly, social centrality can be used BS for allocation of resources among D2D and cellular users. In the domain of social-aware vehicular communications, solutions like SPRING and ReViV have been proposed to improve security and message dissemination, respectively. Centrality measures like Eigenvector and Pagerank have also been proposed for social-aware caching in ICN. Many investigations of social networking enabled IoT exist in the literature and proposals of fission computing and SOR have been given for static and mobile IoT, respectively. These studies indicate that social networking can be a promising approach for future 5G communications.

V. LESSONS LEARNED AND OPEN ISSUES

In view of this discussion, we now summarize some key challenges in the implementation of social perspective in existing and future wireless networks.

A. TRADEOFF BETWEEN COMPLEXITY AND PERFORMANCE

It is obvious that social-aware protocols require additional complexity and functionality in devices to perform as a community rather than as independent entities. Moreover, it has been proven that protocols which utilize a hybrid approach by combining multiple social metrics perform better than those using only one of these metrics [4], [14], [76]. Evidently, there is a tradeoff between the amount of bearable complexity and the performance of the network. This added complexity also brings additional delays which may not be desirable for highly mobile vehicles and intelligent transportation systems. Thus, there is a need to minimize the tradeoff between the performance and complexity of protocols.

B. STANDARDIZATION AND REDESIGNING EXISTING PROTOCOLS

The existing protocols and optimization techniques require to be redesigned for social networks. Dynamic protocols for scheduling, forwarding and queuing of messages and signals need to be designed in order to integrate social perspective with the existing protocols. For instance, in case of partial or completely unavailability of information about neighboring devices, what type of strategies must be employed for making an intelligent decision. Although some approaches using evolutionary algorithms have been investigated [86], [222], yet their efficient designing is still an unsolved issue. Standardization of these social algorithms is again a challenging issue which needs to be addressed for the successful implementation of social protocols in the network.

C. ACCURACY OF ESTIMATED SOCIAL TIES

The accuracy of how strong and weak social ties are depending on the global state information, which includes parameters such as the contact time and contact frequency. Most of the studies consider that this information is available *a priori* and it can be estimated perfectly. However, this is not the case in practical networks as the global state information usually requires the collection of a large amount of data which may not be feasible in ad-hoc networks [223]. Moreover, the data collection time is significantly longer and is not considered a feasible approach for time-varying environments. Some studies utilize self-reported techniques to acquire this information, but these techniques cannot be used to detect dynamic social ties. Hence, acquisition of accurate social relations under time-varying communication scenarios is still an open issue.

D. DETERMINATION OF APPROPRIATE METRIC

The forwarding decision in social networks is greatly dependent on the social relation of devices. Most of the social routing methods make use of either one or two social metrics to estimate the strength of social ties. However, in reality, using one or two metrics may not be enough as the topologies and environments greatly differ and are usually complex. Therefore, it is difficult to accurately estimate the social characteristics using only a few social metrics especially in the presence of highly mobile devices or in a frequently changing environment. Thus, more research efforts should be focused towards creating generic social metrics that can be applied to a wide range of environments. In addition, it is of high interest to investigate which types of social metrics are suitable for a particular application or scenario.

E. PEER DISCOVERY

One of the most neglected factors in social assistance is the discovery of peers and nearby devices. Note that the resources allocated for peer discovery are generally limited and therefore need to be utilized wisely. An illustration for resource allocation in LTE system is shown in Figure 9. Generally, peer discovery is done by sending beacons over control channels and based on the limited amount of information received by the connection-initiating device, it is difficult to estimate the feasibility of this connection from a social perspective. To partly address this concern some pre-association services can be utilized at the cost of a higher latency. However, the increased latency of pre-association schemes makes them

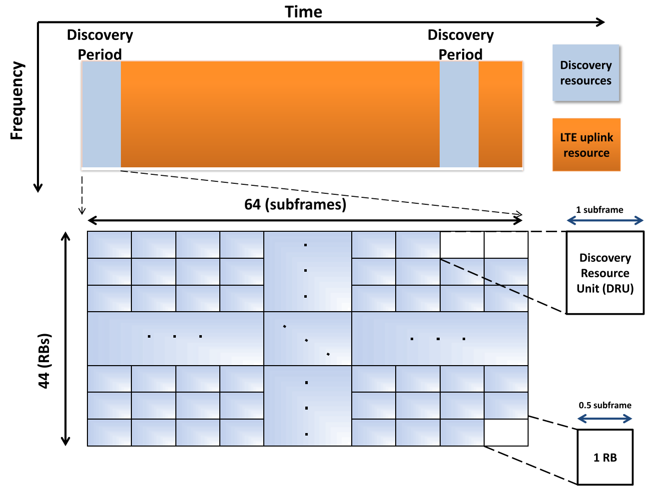

FIGURE 9. Device discovery resource allocation in LTE. The resources are dived into discovery resources and LTE uplink resources. Each discovery period consists of 64 subframes, wherein, one subframe forms a single discovery resource unit.

unsuitable for emergency applications. For these reasons, it is imperative to formulate a low latency and resource-efficient solution to enable social assistance in future devices.

F. REALIZING CROSS-LAYER DESIGN

One can perceive from the above arguments that social protocols are mostly MAC or Physical Layer based protocols. In addition, most of the studies consider a single layer to improve the performance of the system. The integration of these protocols with higher layers is an exciting prospect which requires a deeper investigation. Thus, more research efforts are needed to be directed towards realizing a cross-layer design for future wireless technologies such as IoT and VANETs.

G. MINIMIZATION OF FEEDBACK AND OVERHEAD

A significantly large number of network resources are consumed when connectivity needs to be maintained frequently. This connectivity comes at the cost of feedback overhead, which can consume both time and frequency resources. Replication-based services can also be used to improve the delivery ratio of the messages and, resultantly, improve the social ties. However, in a resource-constrained communication environment, replication based services use excessive power and bandwidth. This scenario gets worse when multiple intermediate devices are involved in the path from source to destination. The intermediate devices not only have to reserve resources for retransmissions but they also remain occupied until the successful transmission of messages.

H. SUMMARY AND INSIGHTS

In this section, we have highlighted the major open issues with respect to the implementation of social networking enabled 5G communications. Upon review of recent developments, we noted that the tradeoff between performance and complexity of incorporating social-awareness in wireless networks merits full clarification. Moreover, the standardization and protocol redesigning efforts are quite weak which will result in slowing down the evolution of social assisted wireless networking. Similarly, the research studies on cross-layered design and utilization of multicast protocols are limited and require the attention of the research community. Establishment of end-to-end security will be essential, especially with the deployment of ultra-dense networks. However, the security enhancement of social-aware 5G networks is still under-explored and require more research activity to develop advanced security techniques.

VI. EMERGING SOCIAL NETWORKS AND FUTURE DIRECTIONS

Based on the analysis of the above-mentioned studies, it can be inferred that social networking approaches have the potential to enhance the performance of future wireless networks. Here, we identify future prospects and possibilities for integrating the social networking approaches with emerging communication paradigms.

A. NON-ORTHOGONAL MULTIPLE ACCESS

NOMA has gained a significant amount of attention from the research community due to its promise of enhancing spectral efficiency and throughput of the users at the edge of the cell [224], [225]. All these benefits come with the prospect of minimum latency and power requirements. Moreover, the users within a cell can share the time and frequency resources by regulating their power ratio. This allows users with better wireless channel conditions to apply successive interference cancelation (SIC) technique to remove the messages for other users and subsequently decode their messages [226], [227]. The benefit of non-orthogonality in NOMA has been recently used in a number of wireless systems and applications. Also, NOMA systems generally perform better than OFDMA systems [228], [229], which signifies the usefulness of NOMA in future networks. Despite this importance of NOMA, the work exploiting social networking approaches for NOMA is almost non-existent. We anticipate that using social-aware strategies can further improve the user-fairness in NOMA. Moreover, by adopting social approaches in NOMA, the issue of trust management between resource sharing devices can be handled more effectively.

B. VISIBLE LIGHT COMMUNICATION

VLC has opened new avenues to realize ad-hoc and short-range communication [230], [231]. It is a low-bit-rate (LBR) communication system where light-emitting diodes (LEDs) act as senders and receivers using line-of-sight medium [232]. This cost-effective solution is considered to be most suitable for establishing sensor networks and consumer electronic networks. Moreover, VLC provides the flexibility of adding nodes on the go and has the capability of supporting various multiple access protocols. It can provide data speed up to 1Gbps in a normal setting and 4Gbps in a special setting which has motivated the works in [233] and [234]. From the security perspective, the VLC can be used to materialize the concept of ‘‘Protected Zones’’. It is because light cannot penetrate in walls which makes VLC more secure as compared to RF communication. Due to the visibility of communication, the receivers and senders are exposed at all the time and passive eavesdropping cannot take place [235]. The limited range of VLC is also considered beneficial for minimizing the interference [236]. Also, in contrast to RF communications, there are no side effects of the VLC on human health, especially for pregnant women.

Although numerous studies exist to improve the performance of VLC networks, yet the social networking perspective of VLC is mostly missing in the literature. Due to the ad-hoc nature of VLC, the social approaches are directly applicable to these networks. The social-aware VLC networks can perform better by analyzing the patterns of connectivity of devices. More specifically, the LEDs can be programmed to turn on and off based on the predicted behavior of devices in order to save energy and improve network lifetime. In addition, cluster-based VLC networks can work together by using centrality and social ties to better facilitate other devices in the network. An illustration of the socially connected VLC system is given in Figure 10.

C. SMART SENSORS

Sensors have the capacity to determine key parameters and to transfer the results to communications systems that can record and ultimately analyze the outputs instigating the requisite responses in a timely manner. Such sensors are well established for analyzing the production/transfer of items (perishable/non-perishable), recording characteristics, such as location, temperature, humidity and associated storage conditions, duration of movements, integrity of packaging, exposure to certain adulterants (chemicals, gases or pathogenic organisms) and finally determining the integrity of the item and its acceptability for use [237]. The close integration of such sensing systems with communications networks can provide vital information for producers, users and officials (e.g. quality assessors and government agencies) ensuring quality and global movement monitoring. Similar approaches are envisioned for monitoring healthcare [238] where discrete or arrayed sensors can record key physiological parameters (e.g. temperature, movement, glucose levels, or disease-related biomarkers) enabling both the patient and physician measure health and well-being and instigate appropriate interventions when necessary. The integrity of the communication systems are vital for recording the data, allowing appropriate checking, and updating the associated records (e.g. health records of a patient). Such approaches greatly facilitate timely medical interventions based on early detection of disease or where a patient requires close supervision [239] due to certain clinical conditions (e.g. diabetes, cancer, cardiac diseases). Such strategies can potentially provide much better clinical health monitoring,

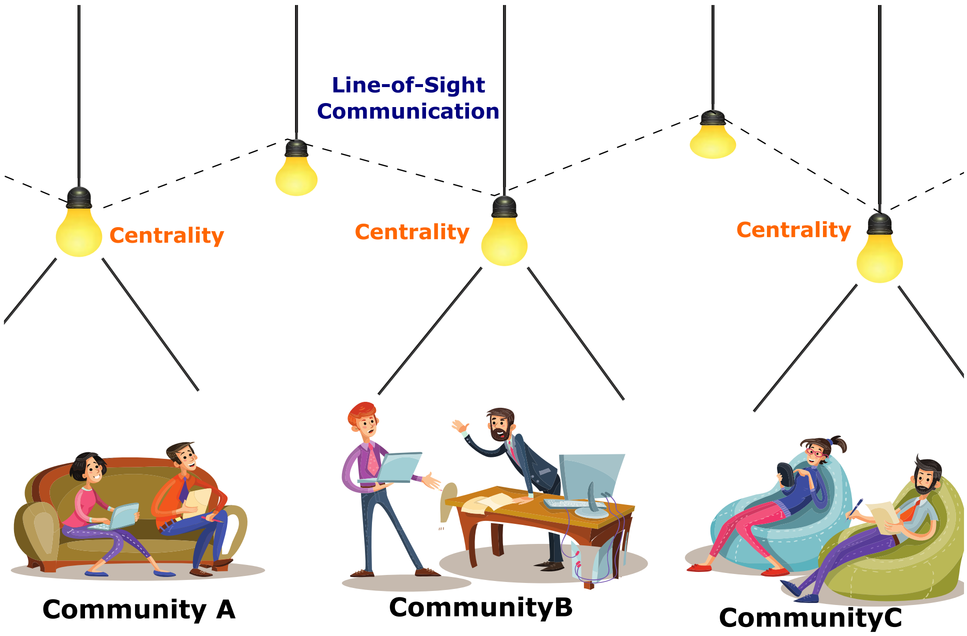

FIGURE 10. Demonstration of a socially connected VLC system. Three communities labelled A, B, and C each comprise of several connected devices like laptops and smartphones. Centrality is maintained by the light-sources and A, B, and C interact through line-of-sight links.

improve disease management, reduce the economic load of health provision for governments and, above all, provide a much enhanced 'quality-of-life' with people able to remain active and embedded in their own communities supported by effective technological advances.

Key items that need to be addressed relate to the maintenance of the integrity of the data, ensuring correct ethical usage and avoiding inappropriate exploitation. However, potentially much more can be achieved by integrating both sensing and communications systems. Given the huge involvement of people worldwide in such systems, the question arises as to how the activities of people 'online' can be used to determine their well-being. The nature of their activity profile, linked to sensing, may provide even more scope for disease monitoring particularly in relation to behavioral or neurological diseases. Since environmental conditions are of huge importance to some diseases (e.g. asthma), smart systems could provide much more effective help to sufferers in terms of awareness, and the need for interventions. There are many more scenarios where the integration of smart sensing systems with newly developing communications approaches can be highly beneficial but significant research is still necessary to optimize the sensing elements to supply the appropriate outputs in a cost-effective and timely manner with minimal human intervention.

D. INFORMATION CENTRIC WIRELESS NETWORKS

The aforementioned studies on ICN mainly focus on wired environments. However, the decoupling between publishers and subscribers can be utilized to increase the scale of communication. In this context, Amadeo *et al.* [240] analyzed the problem of energy efficiency in the content-centric network. They proposed to use personal mobile devices to temporarily cache the content and then distribute it in a multi-hop access network. Some of the potential benefits of content-centric MANETs are discussed in [241]. In a similar work, Shim and Kim [242] proposed a data aggregation strategy in ICN based wireless sensor networks. The same authors proposed to use IP-based communication architecture instead of ID-based ICN to reduce energy consumption.

A tree-based data aggregation scheme for ICN sensor networks was proposed in [243] and [244]. Jin *et al.* [245] provided a model to reduce energy consumption by exploiting the publisher/ subscriber paradigm. The proposed model not only reduces the energy consumed by sensor nodes but also satisfies the decoupling principles. Some studies have also proposed virtualization techniques [246], [247] in wireless ICNs. However, still, the work on social aspects of wireless ICNs is almost non-existent. Based on the discussion of potential applications of social networks in the above sections, one can predict that content dissemination can be further improved by using social characteristics of wireless devices in ICN. Thus, there is a need to design social models and incentive-based techniques to use the wireless content-based networks at their fullest potential.

E. SMART GRIDS

Smart grids are considered to revolutionize the energy infrastructure of the future smart cities. This technology aims to provide efficient, sustainable and cost-effective power generation solutions [248]. However, it is a challenging task to handle a large amount of data generated by smart meters to provide precise predictions. Commonly used data mining algorithms may not be applicable to provide accurate predictions for such a large amount of data. Social network relationships can help to effectively address this problem by digging a large number of hidden information [249].

Although a limited work [249]–[253] exists on exploring social aspects of the smart grid, yet these studies either review the advancement in smart grids or focus on predicting the monthly expenditure of consumers. Some learning techniques have also been developed better analyze the social relationship among smart meters [254], [255], however, the studies on security, grid management and demand response of social smart grid networks are absent. Also, the work on route management using social-aware communication between grid station and smart meters is missing. We expect that by solving these issues using social networking approaches, substantial gains can be obtained in terms of energy efficiency. Social aspects of smart grid communication can also help to improve the fault tolerance mechanism of the smart grid. Social ties can also be used by smart meters to monitor intermittent connectivity among meters. In case of any fluctuations or instability in connectivity, the neighboring meters can inform the main grid station to take further actions.

F. MMWAVE COMMUNICATION

Due to rapid growth in demand for data traffic, researchers have started exploring alternative procedures and methods to extend the bandwidth of wireless systems. In this regard, exploitation of millimeter wave (mmWave) frequencies (10-300 GHz) is considered to be a viable option to overcome the bandwidth limitations of existing networks. Due to small wavelengths of this band, large arrays of antennas can be used to provide higher directivity and improved signal strength at the receiver [256]. Higher directivity can be achieved by using beamforming approaches which also act effectively against path losses [257]. Also, this high capacity will allow connectivity of a large number of devices. Therefore, there is a growing consensus that mmWave communication will play a key role in the forthcoming generation of networks.

Although previously mentioned studies on mmWaves have laid a solid foundation, yet the application of social networking approaches in mmWave is still in its fancy. Moreover, exactly how much performance gains can be obtained, using social networking with mmWave communication, is still unknown. Lately, social schemes have been used to provide cell association services and dynamic clustering algorithms in dense networks [258]–[260]. However, the applicability of these techniques has not yet been exploited for a purely mmWave enabled cellular environment. In addition to this, social-aware protocols can be used to provide contextual information of devices which can minimize co-tier and cross-tier interference in mmWave cellular infrastructure.

G. SUMMARY AND INSIGHTS

This section has provided a discussion on some of the main communication domains that can benefit from adopting social networking approaches. These technologies include NOMA, VLC, smart sensors, wireless ICN, smart grid, and mmWave communication. Incremental incorporation of social networking approach in these technologies can constructively alter the perspective of academics and researchers on the design of the next generation of communication networks.

VII. CONCLUSION

We presented current state-of-the-art and the future developments of social networking approaches for 5G communications. Specifically, the paper offered a thorough discussion on the architecture, characteristics, and vulnerabilities of social networks. We have also focused on various applications of social networks for 5G technologies. This was followed by a discussion on recent developments in technologies such as D2D, IoT, cloud computing and vehicular networks. This study has identified that more work needs to be done to address the vulnerabilities in existing social networks. Also, there is a need to evolve universally acceptable performance metrics for social networking applied to communications. Finally, the current hardware limitations and lack of concentrated standardization efforts must be addressed for a successful incorporation of social networking in future communications technologies.

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