

# Applications, Architectures, and Protocol Design Issues for Mobile Social Networks: A Survey

*Mobile social networks that can define behavior of people, devices, and systems are surveyed in this paper. Applications and architectures are discussed as are related literature and research.*

By NIPENDRA KAYASTHA, DUSIT NIYATO, *Member IEEE*, PING WANG, *Member IEEE*, AND EKRAM HOSSAIN, *Senior Member IEEE*

**ABSTRACT** | The mobile social network (MSN) combines techniques in social science and wireless communications for mobile networking. The MSN can be considered as a system which provides a variety of data delivery services involving the social relationship among mobile users. This paper presents a comprehensive survey on the MSN specifically from the perspectives of applications, network architectures, and protocol design issues. First, major applications of the MSN are reviewed. Next, different architectures of the MSN are presented. Each of these different architectures supports different data delivery scenarios. The unique characteristics of social relationship in MSN give rise to different protocol design issues. These research issues (e.g., community detection, mobility, content distribution, content sharing protocols, and privacy) and the related approaches to address data delivery in the MSN are described. At the end, several important research directions are outlined.

**KEYWORDS** | Community detection; content distribution; context-aware data transfer; mobile social networking services and applications; network architecture and protocol design;

security and privacy; social networks; wireless communications and networking technologies

## I. INTRODUCTION

The notion of social network and its application has recently gained much attention from the researchers in many fields. The reason is that all entities (e.g., people, devices, or systems) in this world are related to each other in one way or another. A social network not only defines the behavior of these entities but also helps to understand different relations among them. In principle, a social network is a structure of entities (e.g., individuals, organizations, and systems) that are connected to each other through one or more interdependencies. These interdependencies could be shared values, physical contacts, financial exchanges, commodity trades, and group participations [1]. Recently, the concept of social networks has been used in the context of information and communication technologies to provide efficient data exchange, sharing, and delivery services [2]. A social network defines the structures and ties among the users in which the users and system can use the knowledge about the relationship to improve efficiency and effectiveness of network services.

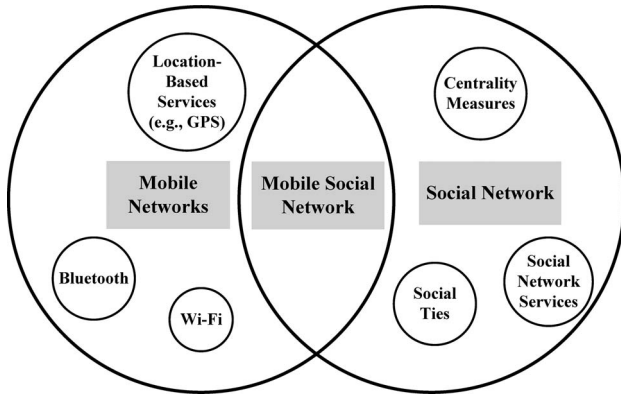
Today, mobility has become an integral part of our human society. However, mobility results in random behavior of users, making it difficult for data exchange, sharing, and delivery services. Fortunately, understanding social behavior and the interdependencies among mobile users, and their movement patterns can be helpful for such

Manuscript received November 3, 2010; accepted September 6, 2011.

N. Kayastha, D. Niyato, and P. Wang are with the Nanyang Technological University, Singapore 639798 (e-mail: nkayastha@ntu.edu.sg; dniyato@ntu.edu.sg; wangping@ntu.edu.sg).

E. Hossain is with the Department of Electrical and Computer Engineering, University of Manitoba, Winnipeg, MB R3T 5V6 Canada (e-mail: ekram@ee.umanitoba.ca).

Digital Object Identifier: 10.1109/JPROC.2011.2169033



**Fig. 1. Mobile social network at the intersection of mobile network and social network.**

services [3]. As the mobile devices are carried by people, the knowledge of social behavior and structure can be one of the key information for designing and providing efficient and effective data communications services (e.g., in terms of routing and data dissemination, bandwidth and computing capacity allocation, storage and power consumption) [4].

Mobile social network has been introduced by combining the concepts from two disciplines, i.e., social network (from social science) and mobile communications networks (Fig. 1). This presents a new research area related to content publishing, data exchange, sharing, and delivery services. In a broader sense, a mobile social network is a mobile communications system which involves the social relationship of the users. In such a network, mobile users can access, share, and distribute data in a mobile environment by exploiting the social relations. Due to the ubiquitous availability of mobile devices (such as smart phones), a mobile social network can fully take advantage of human interaction and physical mobility to achieve efficient and effective data delivery services. A mobile social network can be established on any existing centralized or distributed mobile network given that the interdependency of mobile devices can be exploited using social network analysis methods for providing better quality of service (QoS).

This paper presents a comprehensive survey on mobile social network (MSN). The outline of paper is shown in Fig. 2. First, a brief overview of MSN is provided and its different types are discussed (Section II). The major applications of MSN are reviewed (Section III). The architectures of MSN for different data exchange, sharing, and delivery services are also presented. Next, the issues related to the design and analysis of MSN are presented and the related works in the literature are reviewed (Section VI). At the end, several major open research issues are discussed and future research directions are outlined (Section VII).

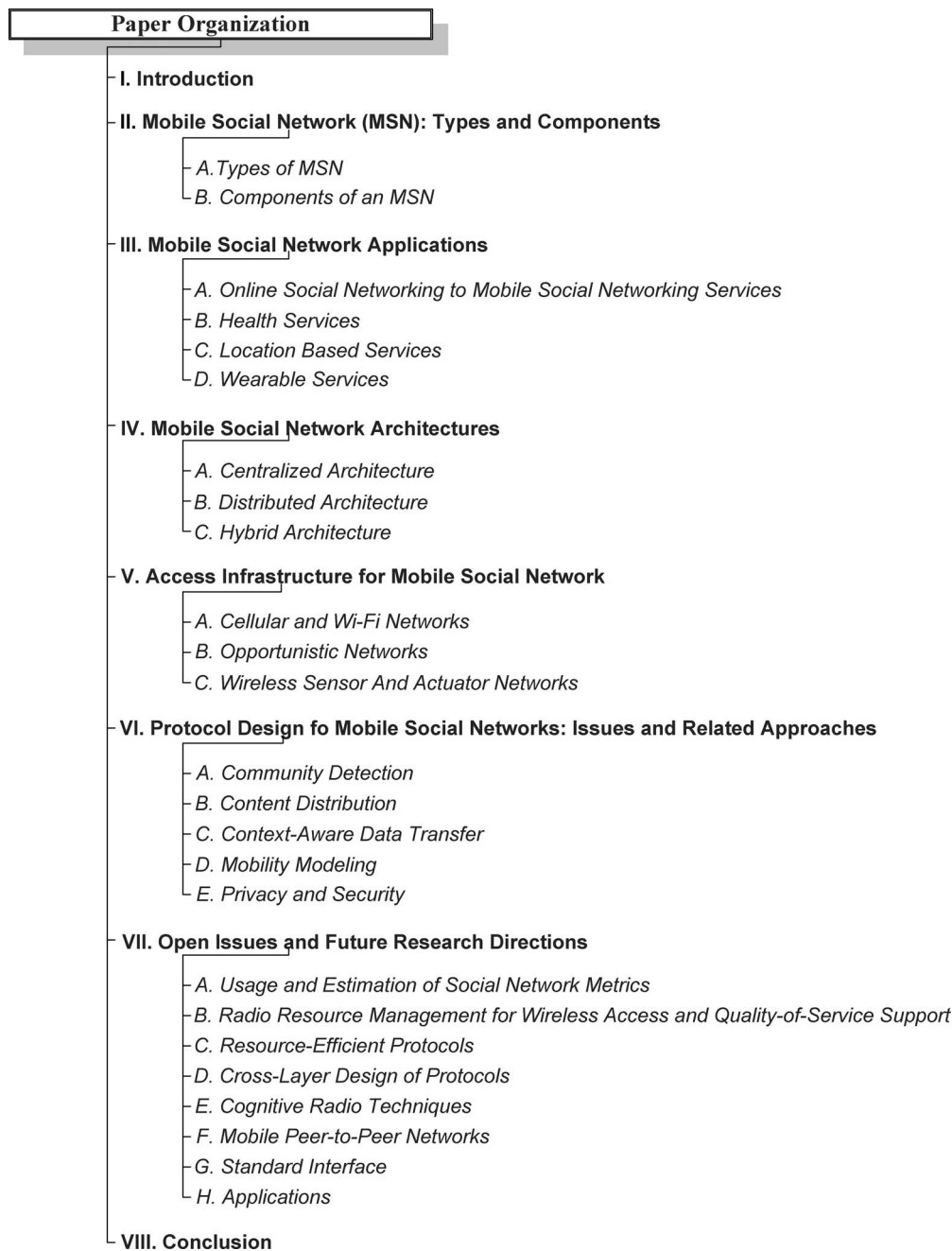
## II. MOBILE SOCIAL NETWORK (MSN): TYPES AND COMPONENTS

In this paper, we consider the MSN as a heterogeneous network where mobile users carrying mobile devices interact and share user-centric information with each other using socially aware algorithms to achieve better QoS. Therefore, MSN is a user-centric mobile communications system in which the methods of social network analysis (SNA) can be applied to analyze the structure and ties among mobile users with the objective of improving the efficiency of publishing and sharing information. Specifically, in the MSN, the mobile users not only transmit data, but also provide constant feedback to improve the services [5]. This feedback is basically the social relationship among mobile users which could be provided by mobile users themselves or could be analyzed from the mobility pattern. Mobility can be used as an additional information to analyze the social relationship among mobile users. This constitutes the major difference between the MSN service and a classical social network service (e.g., Facebook, Hi5, etc.). The social relationship can be defined by using different social network metrics. These social network metrics provide new insights and understanding of social relationship and the interdependencies within the network.

### A. Types of MSN

The MSN has evolved to meet the requirements of data exchange, sharing, and delivery services. Nonetheless, the MSN can be broadly classified into two types, i.e., web-based MSN and decentralized MSN [2], [6], [7].

1) *Web-Based MSN*: Web-based MSN uses social network services (e.g., Facebook, Myspace, and micrologging websites) or mobile portal websites (e.g., m.4info.com) for acquiring information through mobile devices [7]. The mobile users can communicate with web-based applications through Internet given the availability wireless connectivity. There are numerous web-based MSN applications for mobile users to support and provide these services. For example, “iPhone Facebook App” [8] is a mobile application which allows mobile users to interact with web-based “Facebook.” Similarly, “WhozThat” [9] application (prototyped for music recommendation) utilizes the context-aware content of online social network to obtain the identity and interest of a particular user. “Google Latitude” [10] is another web-based socially aware mobile application that helps mobile users to locate a particular person who has decided to share his/her location. These types of web-based MSN use simple wireless protocols to transfer the mobile users’ identity and bind it with different contextual information such as users’ interest, location, activity, etc. Generally, web-based MSN is based on a centralized communications structure.



**Fig. 2. Organizational layout of the paper.**

2) *Decentralized MSN*: In a decentralized MSN, a group of mobile users is formed to disseminate data among them without connecting to a centralized server. Such connectivity is best defined by opportunistic contacts where users exchange and share information whenever they come in contact using wireless technologies such as Bluetooth or Wi-Fi. With this type of MSN, the data are generated by mobile users, and these users interact with each other on the basis of their common interests thus forming a social group to disseminate the data [11]. For example,

“EyeVibe” [12] is a video and chat community on mobile device where users can share/transfer videos within the mobile community.

### **B. Components of the MSN**

As shown in Fig. 3, the MSN consists of three major components, i.e., content provider(s), mobile user(s), and network infrastructure(s).

- *Content providers*: The content provider can be a fixed dedicated server (e.g., news server and

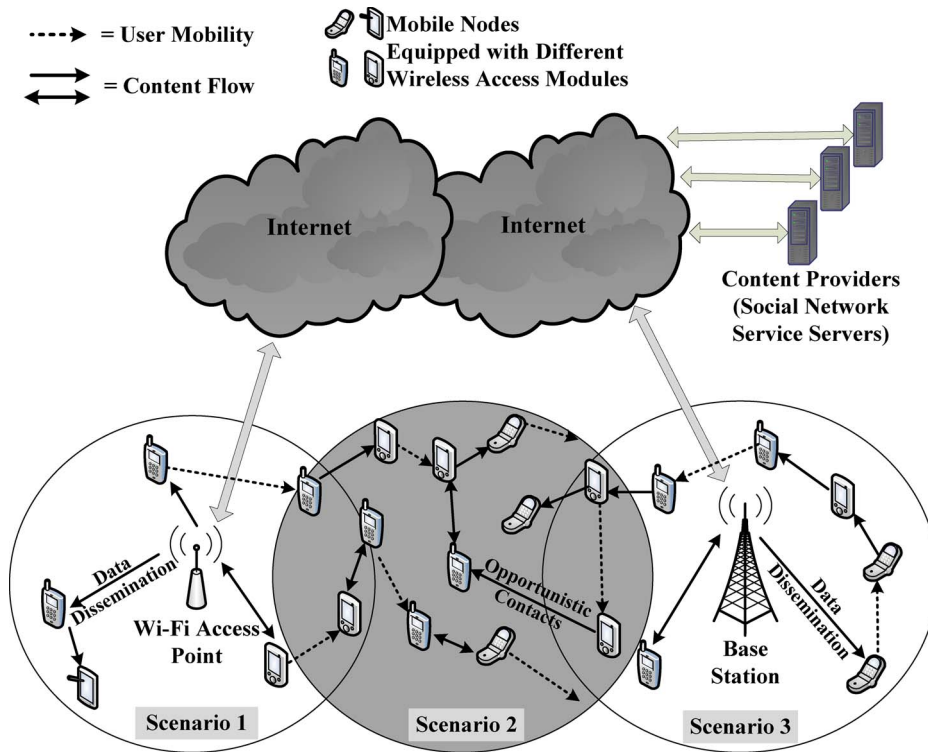


Fig. 3. Components of MSN.

web-based MSN server) connected to the Internet which injects its content or data to a group of mobile users through the network infrastructure.

- *Mobile users/devices*: Mobile devices (e.g., mobile phones, PDA, or any human assisted devices) may have different wireless interfaces (e.g., Wi-Fi, cellular, and Bluetooth). Mobile users can receive data from content providers. Also, a mobile user can create and transfer the data to other users through network infrastructure.
- *Network infrastructures*: A network infrastructure is used to transfer data from a source (e.g., content provider) to a destination (e.g., mobile user). Two major types of network architectures can be identified in this context, namely, centralized and opportunistic network architectures. A centralized network (e.g., Wi-Fi and cellular networks) generally belongs to the network operator which could be the same as or different from the content provider. An opportunistic network (e.g., *ad hoc* network or delay-tolerant network) can also be used to transfer data when the centralized network structure is not a viable choice (e.g., not available or expensive to use).

In the MSN, data can be a message, a packet, or collection of messages which may contain updates, alerts, or routing information. The data dissemination process

can be unicast, broadcast, or multicast depending on the nature of the applications and service. Also, data flow can be unidirectional or bidirectional depending on the protocols and the social metrics considered to disseminate data among the mobile users.

### III. MOBILE SOCIAL NETWORK APPLICATIONS

The use of MSN is increasing as the human society is becoming more dynamic in nature. In general, the main objective of the MSN applications is to increase the closeness of social relationship among mobile users by using wireless and mobile communications technology [13]. Note that the social behavior and relationship can be analyzed by using the centrality measures such as the betweenness centrality, degree centrality, and closeness centrality (which will be described later in this paper). Also, based on experimental studies, it has been observed that the MSN is typically a scale-free network which exhibits the “small-world phenomenon” [14]. In simple terms, it means that any two users in the network are likely to be connected through a short sequence of intermediate acquaintances. Various MSN applications have been introduced which take advantage of this characteristic. In this section, we introduce some of the MSN applications.

### A. Online Social Networking to Mobile Social Networking Services

One of the main reasons that online social networking services such as Facebook, MySpace, Orkut, and Hi5 have gained popularity is the increase in people's interest in forming virtual social network. Knowing people and becoming friends are the key motivations for these online social networking services. The MSN services add freedom of movement for users which provide ease of use and seamless connection to social world. Mobile phone can be used with advanced services [such as global positioning system (GPS), sensors like accelerometer, touch technology], and, hence, many new services are being introduced by the social networking service providers. Recent research studies have shown that it is possible to provide corresponding functionalities of social networks even more effectively using mobile phones while preserving the usability and satisfaction of users [15]. The extension of the popular online services (e.g., Facebook, MySpace) to mobile devices accounts for wide popularity of mobile social networking services. However, for successful implementation, many issues regarding usability, availability, and most importantly, the privacy and security issues need to be resolved.

### B. Healthcare Services

As people are becoming more health conscious, a new trend is emerging in the form of healthcare services to help their members with various physical and mental ailments. In this regard, the MSN can be used to exchange information and provide virtual portal for discussions in healthcare area. Today there are free web-based social network applications such as PatientsLikeMe [17] and CaringBridge [18] that connect its members to share treatment and symptom information in order to track and to learn from real-world outcomes. CaringBridge is also available for iPhone and iPod Touch users. The MSN can extend the scalability of such services by providing easy access during emergency situation. mCare service [19] is another such healthcare service which uses the underlying principles of social networking to provide efficient service for both patients and doctors. As a result, the patients can search or request help from different panels of doctors. For people with severe mental illness and life altering diseases, such healthcare services can provide continuous support and guidance for the caregiver. For instance, in [13], a general MSN architecture for patients with severe mental illness is proposed. In this work, the MSN is used to locate patients and help them whenever they are lost or confused about their locations. The proposed architecture has both client and server interfaces to be used in cellular network. With a GPS-enabled device, a user can access MSN to provide location information. This MSN is able to identify the caregiver within a distance from the target patients if they need help. Similar architecture is implemented in [20] which

could be used to help the families with development-delay children. In this MSN service, location-based service (LBS) modules are used to assist volunteers to obtain the location and services needed by the families with development-delay children. With this architecture, the information could be circulated to find the nearest volunteer among the family social groups. With advancement in mobile phone platform and incorporation of new sensors, the MSN-based healthcare services will continue to grow.

### C. Location-Based Services

LBS is another prominent field of application for the MSN. An LBS provides information specific to a location to mobile devices using GPS or using signal triangulation of cellular towers. This location-based information when combined with social network can provide the MSN users with a variety of contextual services such as finding location of people or friends, nearest banking cash machine or restaurant, recommending social events and even location-based advertisements and games. Of the many LBSs, Google Latitude [10], Loopt [21], Gypsi [22], Whrrl [23], Mobiluck [24], Foursquare [25] are some of the popular location-based mobile social networking services. These services basically help users to connect and share their location information with other people in their network and also provide additional information about position (e.g., Loopt, Google Latitude, and Mobiluck), related photos and videos (e.g., Gypsi), users' real world experiences (e.g., Whrrl) in the form of updates or gaming experience (e.g., Foursquare). Almost all the applications except Google Latitude (i.e., web based) have mobile versions which are supported by mobile platforms such as Apple's iPhone, Google's Android, Blackberry, and Nokia's Symbian-based phones. An important issue regarding these services is the privacy where users should be given proper security levels to show/hide their location information to individuals or particular groups.

### D. Wearable Services

Wearable computing can augment the real and virtual world social interaction. A wearable network comprises mobile devices which can be worn on the body and is used in behavioral modeling, health monitoring, and entertainment development. The MSN can provide necessary integration of social contextual data with the Internet required by wearable network to automate daily tasks [26]. Wearable devices can give a touch of feel and sensation to people by mimicking the human emotions. For instance, "Hug Shirt" [27] can provide virtual hug which can give the real feeling of being hugged by exerting pressure and heat to person wearing it. "Hug Shirt" is sensor/actuator device which interacts with normal bluetooth enabled mobile phones to send hugs from MSN services. Similarly, "Patches" [28] augments the virtual poke function of popular "Facebook" service by literally giving



the physical feeling using touch and heat sensors. “iBand” [29] can be used to exchange, store, and display user’s information by doing simple handshaking. The device has an infrared transceiver and motion sensor to detect the handshaking gesture which is activated only when the user’s hand/wrist is in a precalibrated handshaking orientation. Wearable services provide a whole new meaning to the MSN services where mobile devices can be anything that can be worn on a body and provides a sense of closeness to users.

In the following sections, the network architecture and network protocols, which efficiently and effectively support aforementioned applications, will be presented.

#### IV. MOBILE SOCIAL NETWORK ARCHITECTURES

To support different data exchange, sharing, and delivery scenarios, different MSN architectures can be developed. In this section, we describe different MSN architectures and different network access options for the MSN.

##### A. Centralized Architecture

In a centralized MSN architecture, a centralized server is used to exchange, share, and deliver data between content provider and mobile users. This is a client–server structure in which the mobile user is the client and the centralized server of the content provider is the server. The content created by the content provider is injected to the mobile users via the server. The mobile users can also update and share the content with other users in the MSN via the centralized server. Fig. 4 shows a centralized MSN architecture. The protocols required by the mobile users and the centralized server are also indicated. The data flow can be via third party application or content provider using Internet services. In this case, third party application may have different services (e.g., map, social networking, and video sharing services). Almost all of the mobile applications used to access the online social networking sites (e.g., Facebook) are based on this centralized architecture.

A centralized architecture forms the basis for web-based MSN where the mobile users depend on content

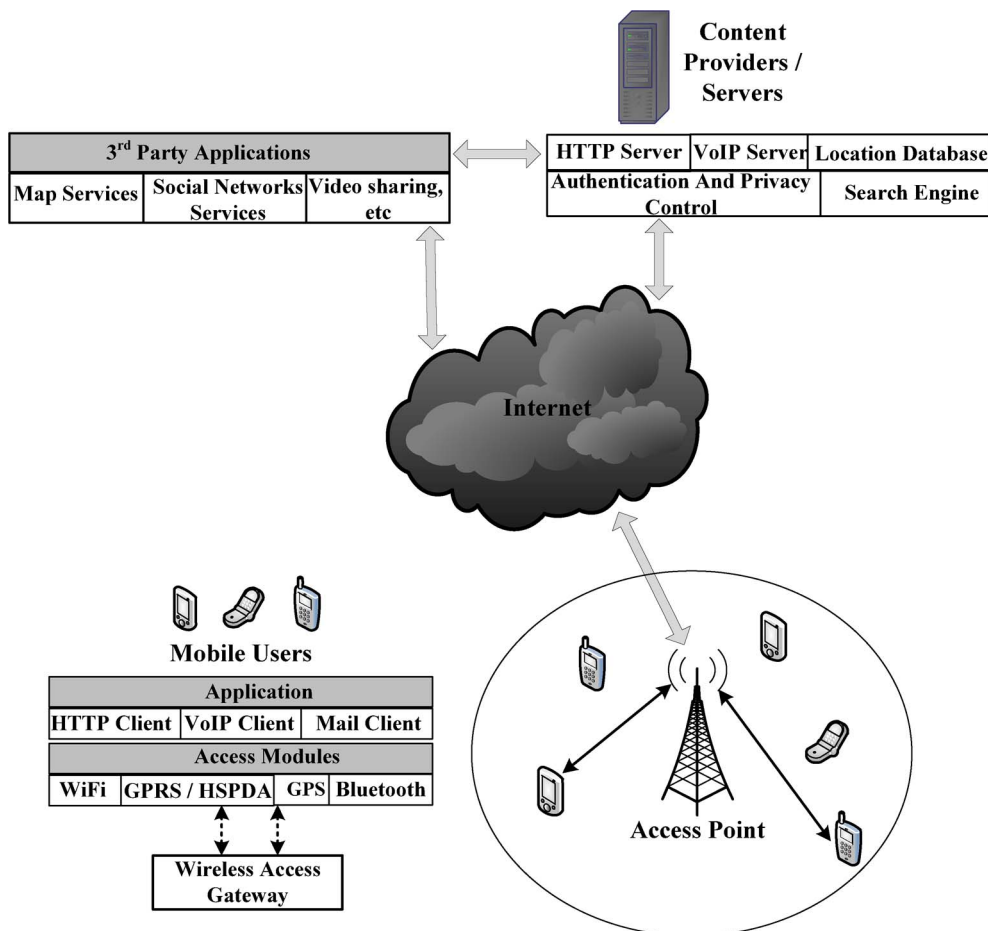


Fig. 4. A centralized MSN architecture [6], [30].

providers updates (e.g., Facebook server). Designing efficient and effective MSN architecture has always been the focus of the research community. For example, in [30], a general architecture capable of supporting both indoor and outdoor positioning of mobile users in the MSN is proposed using Wi-Fi and cellular networks. The proposed architecture uses mash up (i.e., interconnection of various online social web services) of web services and hence can be easily integrated with the available networks. In [31], a mobile social computing middleware called “MobiSoC” is introduced to provide a common platform for capturing, managing, and sharing the social state of physical communities. The middleware service runs on a centralized sever providing simple application programming interface (API) for mobile clients which can interact with the services over the Internet. Similarly, in [32], the middleware framework called “RoadSpeak” is proposed for vehicular social networks to provide virtual chat groups for people driving on the road. The idea is to facilitate better communication among people who are physically present in the vicinity but are unable to communicate directly. This overlay middleware runs on a centralized server to manage the profile and activity of the mobile users. The advantages of a centralized architecture include the simplicity of service implementation and the high efficiency of centralized control. However, similar to a client–server structure, a centralized MSN architecture may have a single point of failure and may experience congestion at the server when a large number of mobile users access the services at the same time.

## B. Distributed Architecture

In a distributed MSN architecture, the mobile users communicate directly using the existing network technologies (e.g., Wi-Fi and Bluetooth) on the basis of encounter/re-encounter (i.e., opportunistic contacts) among them [2]. The mobile users interact with each other on the basis of their common interests and mobility patterns thus forming groups of distributed MSNs (as shown in Fig. 5). The data flow in this distributed architecture can be via other mobile users as well as access points (e.g., as the relay node). However, a centralized server is not required.

Distributed MSN can work based on existing software [2] or based on dedicated middlewares [6], [31], [33]. These dedicated middlewares are able to provide all the necessary functionalities including storing the interests, identifying the other users, sharing data, and possibly expanding the MSN. For example, in [6], a middleware for dynamic group creation and management for social networking in a mobile environment is introduced. This social network middleware is implemented based on a peer-to-peer network which works as a personal-area network (PAN) to provide a communication environment for mobile users (i.e., peers). The mobile users can communicate directly with each other without any centralized server. Similarly, “MobiClique” middleware [33] is developed for

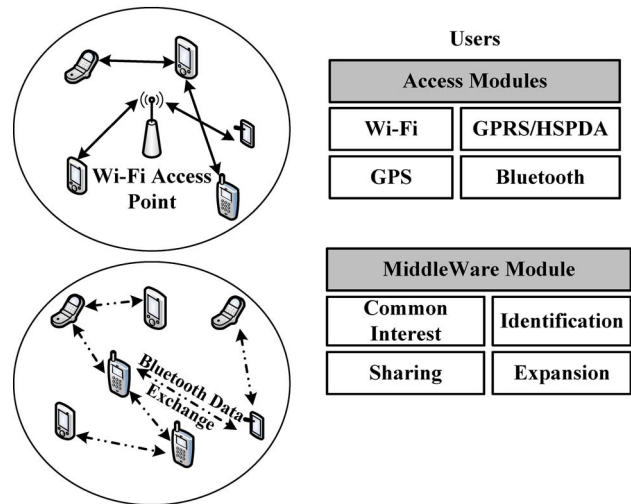


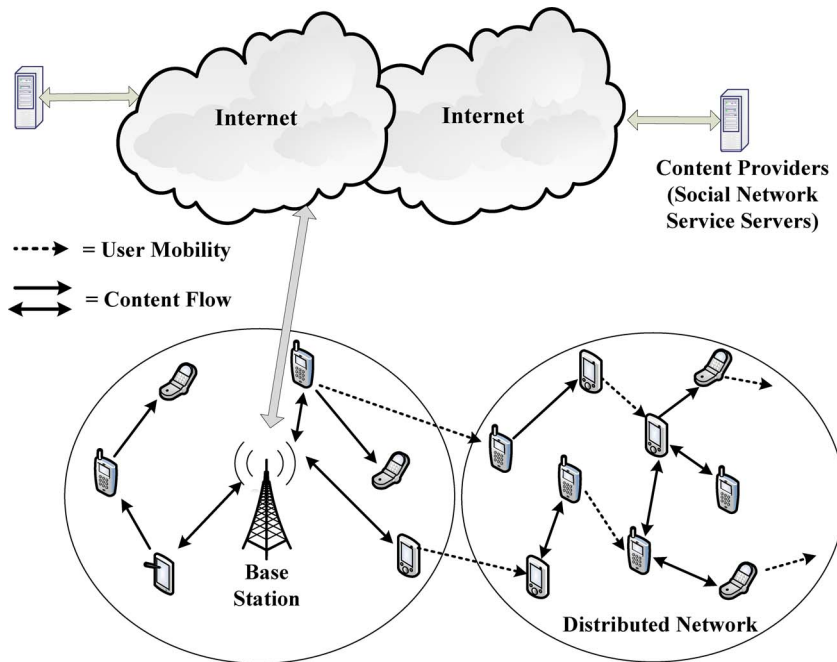
Fig. 5. A distributed MSN architecture.

the MSN. With this middleware, mobile users form *ad hoc* communities using store-carry-and-forward technique. “MobiClique” helps mobile users to maintain and extend their virtual social network beyond their physical world through opportunistic encounters. However, opportunistic contacts introduce the issues of community detection, routing, content distribution, and delivery delays.

## C. Hybrid Architecture

In a hybrid architecture, the mobile users can access data from the content provider (as in a centralized architecture). Also, the mobile users can use a distributed architecture to communicate with other users (as shown in Fig. 6). In this case, the mobile users will contact the content provider when the centralized network structure is available (e.g., users in a Wi-Fi hotspot). However, data from other mobile users sharing the same interests can be exchanged and delivered when they encounter/re-encounter each other.

In this hybrid architecture, the network selection (i.e., from centralized to distributed or *vice versa*) to transfer data is an important issue. In addition, the new mobile phones are equipped with both cellular (i.e., GSM or CDMA antenna) and short-range (i.e., Wi-Fi or Bluetooth) communication capabilities. This feature can be exploited for a hybrid MSN architecture. For example, in [34], a hybrid MSN architecture is introduced for a mobile transient network using multimode devices. A multimode device can communicate with the content provider via cellular network and simultaneously use an *ad hoc* network (using Wi-Fi and Bluetooth radio interfaces). This hybrid architecture is based on intelligent agents which utilize the social relationship among users sharing the same interest to cooperatively retrieve and share the



**Fig. 6. Hybrid MSN architecture.**

remote data. While the cellular network can guarantee the performance of data delivery, using an *ad hoc* network can reduce the cost.

In [35], a hybrid middleware platform based on Jini Surrogate Architecture (JSA) specification [36] is proposed to support the development of social networking applications in the MSN. The proposed middleware enables a smart phone with *mobile service provisioning* (i.e., ability to host a device service) for both local and remote users in the MSN. The JSA is based on Java's Jini service-oriented middleware, which allows resource-constraint devices (e.g., smartphones) to participate as service providers (device service) in a Jini environment (i.e., distributed system of client and service). Due to the limited computational and network capabilities of mobile phones, an intermediary machine called surrogate host (SH) is placed between a device (e.g., smartphone) and its Jini clients to perform service registration, discovery, and consumption. The SH serves as a container which manages one or more surrogates that represent the service running on a mobile device (i.e., device service). The device service first registers its surrogate (i.e., its service) with the SH which upon activation registers the service as a Jini service with the Jini's decentralized lookup service (LUS). The LUS provides the necessary service objects and localizes the service for the service requester. Thus, the JSA uses lookup service as a centralized architecture to register different services, whereas upon registration, the service requester interacts with device service in a

decentralized manner. Connectivity between a device service and its surrogate is performed over IP, Bluetooth, or HTTP using an interconnect protocol, which overcomes the addressability and accessibility problem associated with communicating with devices on mobile third-generation (3G) networks. In [35], the JSA middleware has been modified with discovery mechanism and surrogate-to-surrogate communication protocol to facilitate information exchange between service requesters and service providers. Furthermore, a caching mechanism is added to SH to increase scalability and availability. The data caching in SH increases scalability since many simultaneous client requests can be served and caching frequently accessed data ensures smooth availability of the data. Also, a context-aware framework is added to the middleware to manage and provide specific information to the users.

## V. ACCESS INFRASTRUCTURE FOR MOBILE SOCIAL NETWORKS

The MSN has emerged with a basic need of accessing the online social network applications where people are connected to share data using mobile devices. Data communications and networking is the key component to achieve this goal. The traditional networking protocols can be modified by exploiting the mobility pattern and social relationship of mobile users to improve the performance of data delivery service in MSN. Different



network infrastructures can be used in the MSN, e.g., cellular/Wi-Fi networks, opportunistic networks which includes delay-tolerant networks [37] and disconnected delay-tolerant MANETs [38]–[40], and wireless sensor networks [41].

1) *Cellular and Wi-Fi Networks*: Of the many wireless communications technologies, cellular and Wi-Fi technologies are the most popular. Since cellular networks support seamless communications among mobile users, researchers are interested in understanding the behaviors and relationship among mobile users in cellular networks. For example, cellular networks can be considered as a hidden social network [42]. They are able to support user-generated content (UGC), LBS, and call logs. This information (specially history of call data records) can be used to identify the social relationship among users to build the MSN. For example, in [43], the call-detail records of a cellular network are used to predict and identify the social relationship of users on one-to-one granularity. For this, affinity probability model [44] together with reciprocity index [1] is used for quantifying the strength of social tie among users and their communication partners. The affinity model measures the similarity between probability distribution which can be used to quantify the strength of social ties among the users in the cellular network. On the other hand, reciprocity index defines the action of returning similar acts. The reciprocity index is used to study the frequency of call and relationship between the caller and callee in a period of time (i.e., how many times caller **A** calls callee **B** and *vice versa*). Since the social relation is dynamic in nature and changes over time, the call log data is mapped over time series by affinity model. For predicting the strength of social tie, an autoregressive integrated moving average (ARIMA) model is used. It is shown that the proposed prediction method can achieve almost 95.2% accuracy in predicting socially close and near member in a cellular network.

In addition, a cellular network can act as a backhaul network on which the MSN can be overlaid. Cellular networks provide the most popular network infrastructure to support web-based mobile social networking services (e.g., Facebook and MySpace). Wi-Fi networks can support the same services as those in cellular networks with higher data rate but in smaller coverage areas.

2) *Opportunistic Networks*: Opportunistic networks [45] (e.g., delay-tolerant network (DTN) [46], disconnected delay-tolerant MANET (DDMT) [47]) are characterized by prolonged disconnection, partitions, unpredictable and unstable topologies. That is, the nodes in the network are sparsely connected and due to their mobility, there is no fixed topology or connection between the source and the destination. These characteristics are common in human community where people are in constant movements. Therefore, opportunistic networks provide suitable infra-

structure for the MSN [48]. Packet routing and forwarding are the key concerns in opportunistic networking due to the intermittent connectivity and long disconnection duration [49]. As a result, special routing scheme such as *mobile-assisted routing* is used (i.e., *store-carry-and-forward*). The concept of store-carry-and-forward allows the intermediate nodes (i.e., between source and destination) to store messages when no forwarding opportunity exists. The intermediate nodes then exploit any future contact opportunity with other mobile nodes to transfer the messages closer to the destination [50]. However, mobile nodes make independent forwarding decisions when they meet by estimating the probability of encountering the destination [51]. In an opportunistic networking scenario, the mobile nodes can form the MSN which can exploit the social information and mobility of these nodes to achieve better routing and data dissemination performances.

Table 1 summarizes some basic social network metrics used in the MSN, and Fig. 7 shows examples of these metrics. Note that the links (or edges) shown in Fig. 7 can represent not only the physical connection, but also the logical social relation. These metrics can be estimated by analyzing users' mobility parameters (e.g., frequency and duration of contacts).

3) *Wireless Sensor and Actuator Networks*: A wireless sensor and actuator network interconnects low-cost and battery-limited sensor nodes with short-range transmission capability. Wireless sensor and actuator networks have been adopted in many applications due to their flexibility [52]. Sensor nodes can capture and process physical phenomena and then transmit the sensory data to the destination (e.g., data sink), and the actuators can provide with necessary actions. Since the MSN is user centric, a wireless sensor and actuator network can be used to collect and exchange information about users' behavior. Sensors can provide contextual information about various real-world aspects for further enriching the understanding of context and social relation. The actuators can provide necessary actions depending upon the collected information, for example, the use of wearable services as described in Section III-D.

The main issue in integrating a sensor network with the MSN is how to interpret the data between mobile users. As the collected data vary in attributes and context, data management and mining stand as an important challenge. One solution is to use semantic web as discussed in [52]. Semantic web provides a common platform over the existing application for providing data integration from sensor network for query processing. "CenceMe" [41] is another mobile sensor social network, which can sense the presence and state of people using different sensors (e.g., GPS, accelerometer, and microphone). Then, this information is shared with other people through web portals (e.g., Facebook).

Table 1 Social Network Metrics

Social Metrics	Description	Importance
Betweenness Centrality [16]	Indicates the bridge node or edge between two adjacent nodes or clusters. (e.g., node 8 in Fig. 7)	Determines the links between communities
Closeness Centrality [16]	Indicates the node which has shortest path to all other nodes. (e.g., nodes 4 and 5 in Fig. 7)	Determines the most efficient path and visibility of the network
Degree Centrality [16]	Indicates the number of connection (direct or indirect) to other nodes in the network. (e.g., node 1 in Fig. 7)	Identifies the most active node in the network
Similarity [38]	Indicates the grouping of nodes depending upon common contacts or interest.	Used to disseminate information among clusters of nodes
Tie Strength [39]	Indicates the characteristic (i.e., strength) of link between two nodes. (e.g., using frequency and duration of encounter)	Identifies the weak and strong connections among nodes

## VI. PROTOCOL DESIGN FOR MOBILE SOCIAL NETWORKS: ISSUES AND RELATED APPROACHES

The MSN can be overlaid on any existing heterogeneous network. Due to the unique characteristics of the MSN, many issues arise, i.e., community detection, optimal bandwidth allocation, forwarding node selection, data diffusion and distribution, content sharing protocols, and

privacy. In this section, these different protocol issues for the MSN and the related approaches are reviewed.

### A. Community Detection

Community detection mechanism is used to discover unknown clusters or groups of mobile users sharing the same social behavior or interests. This detection can help to improve message forwarding efficiency among

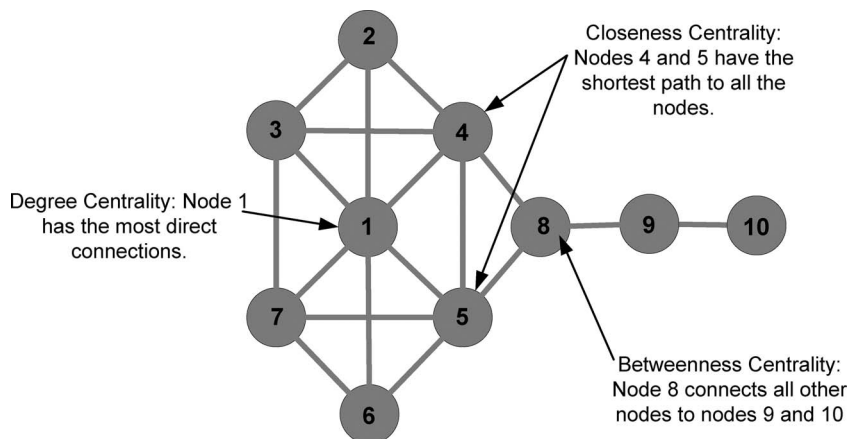


Fig. 7. Metrics for social network analysis.

distributed and intermittently connected mobile nodes. Community detection is closely related to the idea of graph partitioning in graph theory which divides any given network into approximately equal size groups irrespective of node similarities. However, the objective here is to identify groups from an unknown network structure that either have an inherent or an externally specified similarity among nodes. Community detection algorithms help to identify these unknown communities [53], [54]. However, for the MSN, the community detection is complicated due to the node mobility. The nodes are mobile in nature, and hence, detailed and deeper social information (e.g., closeness, modularity, reciprocity, tie strength, etc.) are required for extracting communities from a vast group of random individuals. Also, in the MSN, the number of communities and the size of communities are unknown. In this regard, the measure of the connection between the nodes will play an important role in detecting the communities in the MSN.

The social communities are formed by either defining the relations personally or detecting certain patterns from data traces. Two major approaches are widely used, i.e., *self-reported social network* and *detected social network*. The *self-reported social network* follows the terminology introduced in [55] which is based on a user's declared interests or friendship relation defined in *Facebook* social network. The users willingly participate and thus provide the relevant social information to form social communities based on their common interests, relations, or objectives. Alternatively, in a *detected social network* [53], a community is detected based on the collection of encounter/re-encounter traces or patterns (i.e., which can be intercontact time, location and mobility pattern, contact frequency, and duration, etc.). There are numerous real-world human mobility and connectivity traces such as MIT reality mining project [56], Infocom project [57], Cambridge project [58], and SASSY project [59] that are used in numerous research literature (e.g., [37], [39], [78], [77], and [94]) to reproduce synthetic MSN. These data sets are then used to determine the underlying community based on certain pattern or behavior. Such detected social network, however, may fail to detect some strong social ties to other users that they seldom encounter (e.g., distant relatives) [60].

Although self-reported and detected approaches are different in terms of structural and role equivalence, and distribution of node betweenness [61], the performance in terms of data delivery ratio is observed to be similar [59]. However, a *self-reported social network* incurs lower data delivery cost than that of a *detected social network*. This is due to the fact that if a mobile node already knows the social relation, it is easy and more efficient to build the routing tables. Recent studies have shown that, for opportunistic networks, better routing algorithm (i.e., in terms of lower delivery cost) can be developed if the mobile nodes use predefined social profiles (i.e., *self-reported*

*social network*) instead of running a dynamic method to detect communities [62]. The social profile is collected from questionnaire forms completed by Infocom 2006 conference attendees [57]. The attendees are asked to fill out different social properties such as nationality, affiliation, city and country of residence, and topic of interests. Once the social structure is determined using the aforementioned approaches, various community detection algorithms can be applied to segment the network into smaller communities. Now, we present the existing community detection algorithms in the MSN.

1) *Community Detection Based on Heuristic Measures*: Due to the importance of the connection between nodes, the MSN can be characterized by a directed weighted graph. In a directed weighted graph, the weights (integer or non-integer) are assigned to the ties among the mobile nodes, which can be used for community detection in the MSN. For instance, Girvan and Newman [63] proposes a divisive algorithm that utilizes the betweenness metric to extract the community from a cluster of nodes. The betweenness metric can identify the bridge node between two groups. In particular, the value of betweenness metric will be large for the link (i.e., betweenness edge) which connects two groups. Recursively removing these large betweenness edges will partition the network into small communities of different sizes. The only drawback is that it fails to quantify the strength (good or bad) of the formed community. Following this, Newman and Girvan [64] propose a *modularity metric* to measure the goodness of the community detected using algorithm in [63]. The modularity metric measures the density of links inside the community as compared to the links between communities. Higher modularity value inside the community indicates that the community division is a good one. However, both the algorithms exhibit high computational cost, hence making it unsuitable for very large networks. In its simplest and fastest form, both algorithms have the worst case runtime of  $O(m^2n)$  on a network with  $m$  edges and  $n$  vertices, or  $O(n^3)$  on a sparse network [64].

Similarly, another divisive algorithm [65] is proposed where a local measure called edge clustering coefficient is used to remove the edge joining communities. The edge clustering coefficient [66] is the ratio of number of triangles that a given edge participates to the total number of possible such triangles. The clustering coefficient is low for those edges connecting the communities and hence the algorithm proceeds by removing the edge with the least clustering coefficient. The runtime of this algorithm is found to be of  $O(m^4/n^2)$  which is better than that in [63] and [64]. Another faster algorithm using the modularity measure is proposed in [67] using agglomerative hierarchical method. In contrast to the divisive method, the agglomerative hierarchical method repeatedly joins communities together in pairs by adding the edges joining them. At each step, the join should result in the greatest

increase (or smallest decrease) in modularity measure which is optimized using greedy optimization. The progress of the algorithm can be represented as a “dendrogram,” which is a tree that shows the order of the joins. The worst case runtime of the algorithm is of  $O(n(m+n))$ .

The algorithm proposed by Clauset, Newman, and Moore (CNM) [68] is an adaptation of the agglomerative hierarchical method [67], which is one of the fastest algorithms for detecting community in large-scale networks (i.e., network size of 400 000 nodes). The algorithm greedily combines nodes/communities to optimize the modularity gain by using the special data structure to store and retrieve information required to update modularity. The runtime of algorithm is reduced to  $O(md \log(n))$ , where  $d$  is the depth of the dendrogram describing the community structure. Similarly, in [69], a variation of the CNM algorithm is proposed which unfolds a complete hierarchical structure for the network. The proposed algorithm is divided into two phases that are repeated iteratively. The first phase finds the natural partition of the network using modularity value and the second phase finds the global maximum of modularity where the newly combined communities are treated as a single node. The weights of the links among the new nodes are calculated by summing the link weights of the nodes in the corresponding two communities. Both phases are iteratively performed until there is no increase in modularity value. The proposed algorithm works extremely fast and allows community identification of very large networks containing millions of nodes. A recent work by Saravanan *et al.* [70] enhances the fast unfolding algorithm [69] by using structural property for community detection. The structural property shows that a particular behavior predominant in a group of individuals. For this, the community detected by using fast unfolding algorithm is again split into smaller size communities using a graph theory algorithm. These smaller size communities are then analyzed and labeled based on their behavior patterns. The behavior pattern can be based on usage pattern, location pattern, or interest pattern. The structural properties help to map these behavior patterns into suitable labels for each distinct group. The effectiveness of this algorithm is evaluated empirically using a large database.

Although modularity gives a good measure of the community partitioning, it has some resolution limit. The modularity optimization fails to detect community smaller than a certain size which is known as the resolution limit [71] of a pure modularity optimization approach. To overcome this, Raghavan *et al.* [72] proposes a simple label-based propagation algorithm (LPA) for identifying the communities in the network. The proposed algorithm uses only the network structure and requires neither optimization of a predefined objective function (such as modularity) nor prior information about the communities. A unique label is given to each node at first and the labels are propagated through the network. Each node then

updates its label by choosing the label which most of its neighbors have (i.e., maximal label) and eventually joins that community. A random label is chosen if all are maximal labels. As the node propagates through the network, densely formed groups of nodes form an agreement on their labels. Then, the nodes having the same labels are grouped as communities. As all the nodes are given label only in the beginning and the algorithm breaks ties randomly, the proposed algorithm can create different community structures in each run. Jaccard index [73] is used for comparing the similarity between social profiles of different nodes. LPA is a simple, yet efficient and accurate community detection algorithm with fastest runtime of  $O(m)$ . Recent work by Leung *et al.* [74] provides extensive analysis of LPA [72] and extends the algorithm for real-time community detection by incorporating different heuristics. By simple tweaking of the parameters, the extended algorithm can detect communities with higher accuracy than the modularity optimization algorithms.

An important fact is that the nodes in a community can be linked to many other nodes in another community. The community detected by the aforementioned methods can be overlapped depending upon the individual social connection. Thus, for detecting such overlapped communities, the communities can be considered as a union of smaller complete subgraph ( $k$ -clique) that may share common nodes [75].  $k$  is the number of nodes in a  $k$ -clique which is defined as the union of all  $k$ -cliques that can be reached from each other through a series of adjacent  $k$ -cliques. Two cliques are said to be adjacent if they share  $k-1$  nodes. At first, the cliques are identified and then the clique-clique overlapping matrix is formed whose row and column represent the cliques and the corresponding element represents the number of common nodes between two cliques (Fig. 8). The diagonal element is the size of the respective clique. The  $k$ -clique is extracted by erasing all nondiagonal elements smaller than  $k-1$  and erasing all diagonal elements smaller than  $k$ . The rest of the elements are replaced by value of 1 as shown in Fig. 8. Both weighted network analysis and  $k$ -clique are proposed for community detection which rely on a centralized server and complete network information. Nonetheless, for self-organizing networks (i.e., detected social networks), these centralized community detection algorithms need to be modified for distributed environment. A similar algorithm for detecting a time-varying MSN is proposed in [76]. The  $k$ -cliques community is redefined on the basis of contact duration by extracting the nodes which have “heavy interaction” (i.e., if the contact duration exceeds certain threshold) within the community. The global time stamp, intercontact time, and contact duration among the mobile devices carried by human are the information used in this algorithm. A summarized history of the contact duration is maintained to find the nodes with “heavy interaction.”

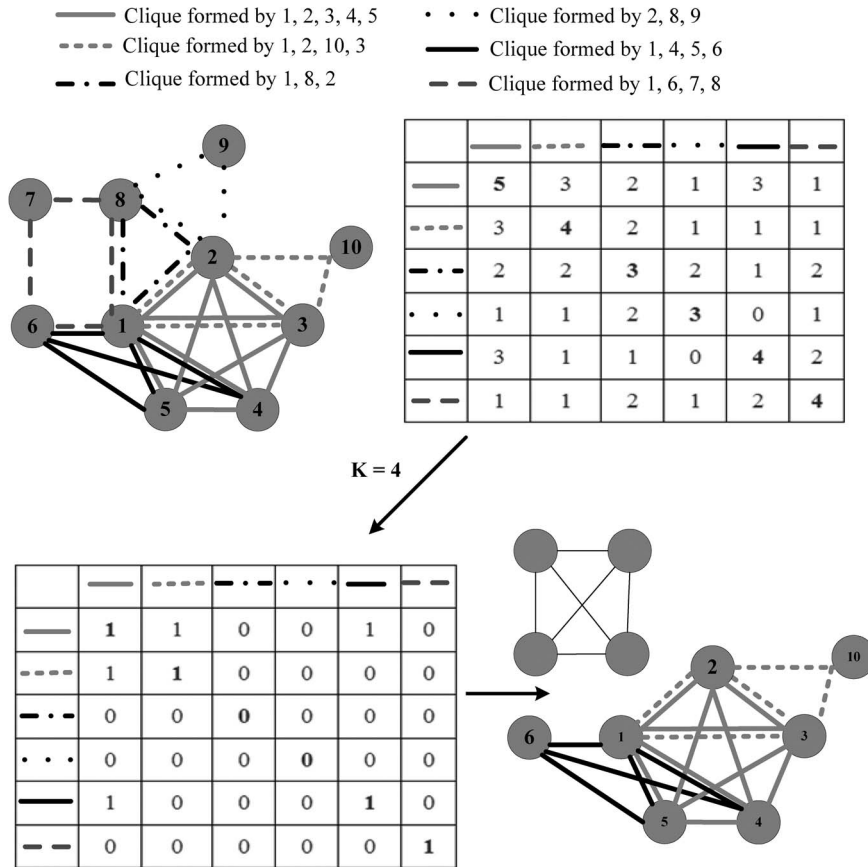


Fig. 8. Extraction of  $k$ -clique community at  $k = 4$ .

Hui et al. [77] proposes three distributed community detection algorithms, namely, SIMPLE, K-CLIQUE, and MODULARITY. It is proved that these algorithms can achieve up to 80% accuracy compared with the centralized  $k$ -clique algorithm. These algorithms use contact duration and number of contacts among mobile nodes to correlate and categorize the nodes in the cluster. Similarly, in [78], “Bubble rap” algorithm is proposed that uses weighted network analysis [79] and  $k$ -clique [75] algorithms for community detection, and the contact threshold (i.e., the duration during which the nodes comes in contact) for extracting the  $k$ -clique community. The data sets of reality mining project [56] are used to verify their results. It is found that community detection shrinks (i.e., less independent community) as the value of  $k$  increases. The authors also use the Bubble rap algorithm for detecting community and forwarding information in distributed community using the methods in [77] (i.e., called as DiBuBB). The degree centrality metric is used for forwarding data in the distributed network.

Tables 2 and 3 provide a summary of different heuristic algorithms used for community detection based on the heuristic and social concept used, and computational efficiency.

2) *Community Detection Based on Influence Maximization:* For better message dissemination, the message can be forwarded to certain influential nodes in a community which have large influence (i.e., connection) on other nodes in the network [80]. A classic example is “word-of-mouth” effect wherein certain people recommend a product to their friends, who in turn recommend it to others, and so forth, creating a cascade of recommendations. This concept is formally known as *influence maximization problem* whose objective is to find a small  $S$ -subset of  $K$  nodes (i.e., seed nodes) in a social network that can maximize the spread of influence in the network. Basically, a node can be classified as a member of a group which contains maximum number of its influenced nodes. In the MSN characterized by intermittent connectivity and delay in data delivery, the influence maximization problem can be used to find the specific influential nodes to forward the data.

The concept of influence maximization was first studied in [81] to find influential customers for marketing using social context. In [82], this influence maximization problem is formulated as an optimization problem and is proved to be NP-hard. Three cascade models, i.e., the independent cascade model, the weight cascade model, and the linear threshold model, are considered in [82]. A



Table 2 Community Detection in the MSN Based on Heuristic Measures

Publication	Proposed Algorithm	Social Concept Used	Computational Efficiency	Remark
Grivan and Newman [63]	Divisive algorithm that uses betweenness metric to partition the network into smaller communities	Betweenness Metric	Slow with worst-case runtime of $O(m^2n)$ on a network with $m$ edges and $n$ vertices, or $O(n^3)$ on a sparse network	Uncertainty about the community partition
Newman and Grivan [64]	Divisive algorithm that uses betweenness metric to partition the network and modularity metric to quantify (good or bad) the detected community	Betweenness and modularity metric	Slow as [63]	Introduced the modularity factor for community detection
Radicchi <i>et al.</i> [65]	Divisive algorithm that uses edge clustering coefficient to partition the network	Clustering coefficient	Runtime of $O(m^4/n^2)$ which is of better than [63], [64]	
Newman [67]	Uses agglomerative hierarchical method and modularity factor to detect community	Modularity metric	Runtime of the algorithm is $O(n(m + n))$ which is faster than [63], [64], [65].	Introduced agglomerative method for detecting community
Clauset <i>et al.</i> (CNM) [68]	Adaptation of the agglomerative hierarchical method which greedily combines nodes/communities to optimize the modularity gain by using the special data structure	Modularity metric	Fastest algorithm based on agglomerative method with reduced runtime of $O(md \log(n))$	Fastest and most popular algorithm that can include larger network for community detection
Blondel <i>et al.</i> [69]	Variation of CNM algorithm [68] which unfolds a complete hierarchical structure for the network.	Modularity metric	Faster than CNM	Algorithm works extremely fast and allows community identification of very large networks containing millions of nodes
Saravanan <i>et al.</i> [70]	Enhances the fast unfolding algorithm [69] by using structural property for community detection	Structural properties (e.g., behavior)	Fast	

greedy algorithm (GA) is presented which is applicable for all three models. The GA guarantees that the influence spread is within 63% of the optimal influence spread. The

basic idea of the GA is to find the number of  $K$  nodes in the social graph (referred to as seeds) such that under given influence cascade model, the expected number of other

nodes influenced by the  $K$  seeds (referred to as the influence spread) is the largest. It is also shown through experiments that the GA can significantly outperform the classic degree and centrality-based heuristics which are commonly used in the sociology literature as estimates of a node's influence [1] in influence spread. However, the main disadvantage of GA is its high complexity. Finding a small seed set in a moderately large network (e.g.,

15 000 nodes) could take days to complete on a modern server machine.

Following the work of Kempe *et al.* [82], many other efficient greedy algorithms are introduced such as “cost-effective lazy forward (CELF)” scheme [83], “NewGreedy” and “MixedGreedy” [84] with slight improvement in terms of performance. Various methods such as using submodularity property (in CEFL), removing

**Table 3** Community Detection in the MSN Based on Heuristic Measures (Continued)

Publication	Proposed Algorithm	Social Concept Used	Computational Efficiency	Remark
Raghavan <i>et al.</i> (LPA) [72]	Uses only the network structure and labeling technique for identifying the communities in the network	Similarity metric used to find the nodes with same label	Efficient and accurate community detection algorithm with fastest running time of $O(m)$	Simplest yet effective algorithm that neither requires optimization of a pre-defined objective function (such as modularity) nor prior information about the communities
Leung <i>et al.</i> [74]	Uses different tweaking of heuristic measures to LPA [72] for real-time community detection	Same as in [72]	Faster than the modularity optimization algorithms	
Palla <i>et al.</i> [75]	Uses ( $k$ -clique) approach that considered community as a union of smaller complete subgraph community to detect overlapping communities.	Community can be formed from combining multiple small communities with common nodes		Initially designed for binary graph (unweighted network) but could be used in weighted network as well
Chan <i>et al.</i> [76]	Uses $k$ -clique algorithm to find nodes with “heavy interaction” (nodes with higher contact duration) for community detection in time-varying MSN	Node centrality (one with higher contact duration) for detecting the community		Distributed community detection algorithm for time-varying MSN
Hui <i>et al.</i> [77]	Uses contact duration and number of contacts to correlate the nodes	Relationship between nodes, which is defined based on duration of encounters		Distributed community detection algorithm
Hui <i>et al.</i> [78]	Uses the weighted network analysis [79] and $k$ -clique algorithm to detect the community	Degree centrality, which uses frequency of contact for community detection		Framework for detecting community in decentralized networks

the noncontributing edges that do not help in information propagation (in NewGreedy), and combination of NewGreedy and CELF as MixedGreedy algorithm are used to develop faster greedy algorithms. In addition, a new degree discount heuristics algorithm called “DegreeDiscount” [84] is proposed which uses degree of nodes to increase influence spread. The DegreeDiscount algorithm performs faster than existing GA. The influence spread of DegreeDiscount is significantly better than the classic degree and centrality-based heuristics and is found to be close to the influence spread of the greedy algorithm. These results provide a new perspective that investing in heuristic to improve influence spread will be more promising than trying to improve the running time of the greedy algorithms. However, a heuristic approach does not have any provable performance guarantee. Similarly, more recent work such as [85] proposes a new algorithm called community-based greedy algorithm (CGA) for finding top- $K$  influential nodes in a large MSN. The basic independent cascade model is extended to include the edge weight for the MSN. CGA exploits the community structure of the social network by applying a dynamic programming algorithm for selecting communities to identify the influential nodes. Also, it uses information diffusion among nodes to partition the network into small communities. Experimental results based on large real-world MSN show that the CGA performs much faster than any other state-of-the-art GA (e.g., Mixed-Greedy, NewGreedy, CEFL, and GA) for finding the influential nodes.

Table 4 provides a summary of different greedy algorithms used for community detection based on proposed algorithm, social concept used, and computational efficiency.

## B. Content Distribution

Content distribution is a challenging issue in the MSN due to the sparse connectivity and limited mobile resources. For smooth content distribution in the MSN, the underlying principle is to find the appropriate forwarding nodes/links to increase the delivery efficiency and reduce the delay. Apart from this, some of the important factors to be considered for content distribution in the MSN are bandwidth utilization, mobility, time, and duration of encounters, message duplication, and the freshness of the content available to the users. Due to diverse architecture and network topology, the MSN nodes can also use opportunistic contacts for data dissemination. In other words, users of the MSN may receive updated content simply by exchanging information with other mobile nodes in a delay-tolerant manner without connecting to the network infrastructure. For opportunistic contacts, the mobile nodes should be able to form desirable social communities. In this regard, for the MSN, community detection plays an important role in content distribution. Many approaches based on social network analysis (e.g., closeness, tie strength, and mobility pattern) and optimization approach

(such as optimizing certain utility function) can be used to distribute the content among the mobile nodes in the MSN. Now, we review the works related to content distribution in the MSN.

1) *Content Distribution Based on Social Patterns*: The occurrence of opportunistic contacts entirely depends upon the probability of encounter/re-encounter with other nodes. To identify these encounters, social patterns of mobile nodes can be exploited for predicting future contact between users [4], [37]. Social patterns can be measured in the form of users’ connectivity pattern, contact duration, social behavior, and interests. The social patterns influence not only users’ interest but also their willingness (i.e., selfish behavior) to share the content [86]. For example, in [87], social pattern such as frequency and time duration of the contact (i.e., tie strength) is used to identify the contact pattern of the nodes to form required social group for opportunistic contacts. The knowledge of the contact pattern of the mobile nodes helps to increase the message delivery ratio and eventually decrease the delivery delay. A dynamic social grouping algorithm is used which measures the tie strength between two or more nodes to form groups. The routing of message takes place using probabilistic routing scheme. The probability of delivery (i.e., delivery ratio) of each node or of the group is maintained and if the node or group encounters another node or group with higher probability of delivery, the message is forwarded to that node or group. This allows the routing algorithm to ensure an effective routing by identifying the node or group which is currently in contact with the source of message (e.g., base station).

The information related to social patterns can be regarded as added benefit to opportunistic contacts which can be measured as capacity available for content updates [86]. However, this added capacity can improve the performance of content distribution. Recent work in [86] provides a tractable model for quantifying such capacity for content updates in the MSN. It is shown that this added capacity can be obtained by solving a convex optimization problem where the optimal operating points can be realized using social connection such as users’ contacts and interests. It is shown that realizing these capacities depends entirely on how the content providers allocate the updates to the forwarding nodes which in turn depends upon the content generation rate, node contact rates, node interest, and sharing behavior. Similarly, in [88], the effect of relational ties among mobile users on the bandwidth usage, content dissemination, and expansion of the network is investigated. It is shown that the bandwidth usage by the mobile users can be reduced significantly if users forego contact with people they meet frequently and instead utilize the contacts with people they meet rarely (i.e., preserving the weak ties). Weak ties help to preserve the necessary link to disjoint communities, thus indirectly increasing the speed of content distribution.

Table 4 Community Detection in the MSN Based on Influence Maximization

Publication	Proposed Algorithm	Social Concept Used	Computational Efficiency	Remark
Kempe <i>et al.</i> [82]	A greedy algorithm (GA) is used to find $K$ nodes in the social graph such that the expected number of other nodes influenced by the $K$ nodes (referred to as the influence spread) is the largest.	Does not use social metric	High computational complexity	For influence maximization, an optimization problem is first formulated which is proved to be NP-hard.
Leskovec <i>et al.</i> [83]	Uses greedy algorithm with submodularity property to find $K$ influential nodes for community detection	Submodular property	Faster than GA	Improved version of GA
Chen <i>et al.</i> [84]	Propose three algorithms called NewGreedy, Mixed-Greedy, and DegreeDiscount heuristic algorithm to find influential nodes for community detection.	Degree metrics	DegreeDiscount runs faster than MixedGreedy than NewGreedy	Provides a new perspective that investing in heuristic to improve influence spread will be more promising than trying to improve the running time of the greedy algorithms
Wang <i>et al.</i> [85]	Community-based Greedy Algorithm (CGA) which uses community structure of the social network by applying dynamic programming algorithm for selecting communities to identify the influential nodes	Community structure	Fastest greedy algorithm	Suitable for large real-world MSN

The importance of weak ties is also studied in [89] to improve the performance of delay-tolerant networking, peer-to-peer file sharing, and virus infection prevention. Note that weak and strong ties are defined as the relations with small and large values of betweenness metric, respectively.

Due to the intermittent connectivity and uncertainty of future encounters, most of the message forwarding protocols split or replicate the message to increase the probability of successful message delivery. For example, in [37], flooding concept is used to disseminate the data in the

detected community. Social centrality measures are used to identify the nodes with higher number of social links (called “broker”) for community detection. A socially aware overlay network of “brokers” is then constructed over the community for publish/subscribe services. Upon receiving the data, the broker floods data into the community. However, the message flooding incurs a heavy traffic load in the network which unnecessarily overloads the bandwidth usage, energy and memory consumption. Moreover, the overlay scheme may not be feasible in opportunistic networks. This issue is important in the



MSN which uses opportunistic contact to exchange message with their social peers where message delivery delay exists due to intermittent connectivity. Thus, message duplication can have a propagating effect on the bandwidth usage and memory usage. In [90], a simple message duplication reduction algorithm is proposed that uses the mobility predictability property of the users in the MSN. The proposed algorithm uses the concept of graph and spanning tree to reduce message duplication. By allowing the message forwarding nodes with the same message to interact with each other, the node which has the earliest probability of encountering the destination is only allowed to retain the message. The rest of the forwarding nodes discard the message, thus ensuring that only one copy of the message is delivered to the destination node. The proposed algorithm however incurs larger memory usage as it uses graph to store the information of nodes and edges.

Selfish behavior is an important issue, where people want more by giving less in return. In the MSN, the selfish nodes would simply drop every message they receive except those destined to themselves. However, with proper incentives, these selfish nodes can be motivated to carry and forward the message despite their behavior. A recent work by Mei *et al.* [91] presents a forwarding protocol which can accommodate these selfish nodes for content distribution. Simply hiding certain information such as message content and sender information provides the incentive for the selfish nodes to remain truthful in the network. By exploiting the selfish behavior of these selfish nodes, the proposed protocol propagates the message to the rightful destination. Since the forwarding nodes do not have the information about the message content, sender and destination node, the selfish node in fear of losing information accepts to relay the information. This process continues until the message reaches the destination node. As the relaying selfish nodes do not deviate from their duties, the proposed protocol achieves the Nash Equilibrium to ensure that the node will forward the message given that other nodes do so.

Table 5 provides a summary of content distribution algorithms based on different social patterns.

2) *Content Distribution Based on Mobility Pattern and Control*: Mobility is an important factor in the MSN since the mobile devices are carried by people. Moreover, with careful study of their encounter/re-encounter, one can predict the mobility patterns for a given period of time which can be utilized to effectively distribute the contents to the destination. However, it is not necessary that these encounters lead to social connection [2]. In fact, a social group or connection is formed if the encounter patterns are consistent and repeatable. Nazir *et al.* [2] argue that the mobility patterns can be predicted by maintaining the record of time and duration of encounters. This information can be used to improve the content delivery services by reducing the delivery delay. The underlying concept is

that the mobile users are not always connected and eventually their predictable mobility patterns can be utilized to effectively distribute the contents to the destination. In addition, it is noted that the average time of encounter is also important which determines the size of content to be exchanged. This implies that for content delivery, the time and duration of contact is more important than the probability of encounter/re-encounter. Similarly, Costa *et al.* [40] present efficient message routing (called, “SocialCast”) for publish/subscribe network using colocation and movement patterns of the users. The colocation metric together with mobility pattern can be used to predict the availability of nodes such that the appropriate forwarding node can be selected for data dissemination.

Also, by controlling the mobility of the users based on certain criteria, the mobile nodes can be directed toward the destination node for effective information dissemination. For example, in [92], a scheme is proposed to direct unconnected mobile nodes toward connected mobile nodes in the MSN. Since the cooperative users (i.e., connected nodes) are connected to the main server through base station, the noncooperative users (i.e., unconnected nodes) can use these cooperative users as the relays to obtain connectivity. The users’ location information is periodically updated to the server and hence the server sends command to the unconnected nodes to move in the direction of the connected nodes. An attraction force function is used to define the moving path of unconnected nodes. The results show that the ratio of connected nodes can be improved significantly with this mobility control scheme. Similarly, in [93], a simple connection scheme is introduced to exploit mobility in web-based MSN. The moving nodes (mates) are connected to at most one static node. The static node maintains the contact history of the moving nodes. The routing is performed by the source node which selects the static or moving nodes closest to the destination.

Table 6 provides a summary of different content distribution algorithms based on mobility pattern and control.

3) *Optimization-Based Approach for Content Distribution*: Most of the content distribution schemes proposed so far rely on utility-based criteria to optimize data dissemination. Usually, the utility is associated with certain social metrics for evaluating the effectiveness of the proposed algorithms. For instance, in [94], an optimal solution for content update is proposed to distribute new content as fresh as possible from content provider to the mobile users. The content injected by the content provider propagates within the network through the encounter of mobile users. In this case, the old contents will be replaced with new contents during opportunistic contacts. A utility function (social welfare) is defined which is a decreasing function of content age. The objective is to determine the optimal bandwidth allocation which can maximize the utility. The content updates can be provided by the content



Table 5 Content Distribution in the MSN Based on Social Patterns

Publication	Proposed Algorithm	Social Patterns	Remark
Cabaniss <i>et al.</i> [87]	Uses probabilistic routing scheme to forward message to the node or group which is currently in contact with the source of message	Using frequency and time duration of contact to find contact patterns	Simple scheme to ensure effective message delivery with less delay
Ioannidis <i>et al.</i> [88]	Uses weak ties for content distribution into otherwise disjoint communities	Mobile user contacts to find the relational strength	Weak ties not only helps in faster content distribution but also in expansion of the MSN by connecting disjoint communities
Yoneki <i>et al.</i> [37]	Uses flooding concept to disseminate the data in the detected community	Social centrality measures are used to identify the nodes with higher number of social links	The message flooding increases the probability of content distribution but incurs a heavy traffic load in the network due to message duplication.
Kawarabayashi <i>et al.</i> [90]	Uses graph and spanning tree concept to reduce the message duplication during content distribution	By exploiting mobility predictability property of the users, the node which has the earliest probability of encountering the destination is only allowed to retain the message.	Simple algorithm but requires larger memory usage as it uses graph to store the information of nodes and edges
Mei <i>et al.</i> [91]	A forwarding algorithm is proposed for selfish nodes where certain information such as message content and sender information are hidden forcefully.	Exploits the selfish behavior such that a selfish node in fear of losing information accepts to relay the information	The proposed protocol achieves the Nash Equilibrium to ensure that the node will forward the message given that other nodes do so.

provider and optimization of content distribution is an important issue. In [95], the problem of content distribution in a publish–subscribe MSN is considered from content providers’ perspective. The objective is to maximize the number of mobile users having fresh data. An optimization model based on constrained Markov decision process is developed to obtain the optimal policy for content distribution. The idea is to hold the new content and allow the mobile users to forward content for a longer

period of time within the network. In practice, content provider and network operator can be different entities, and they interact to distribute the content in the MSN. However, the objectives of content provider and network operator are different. The content provider tries to minimize the cost of bandwidth and minimize delay. On the other hand, the network provider’s interest is to maximize the revenue from selling wireless access services to content providers. In [96], a coalition game model among the

content providers is formulated to minimize the cost of wireless connectivity and maximize the revenue of network provider. A controlled coalitional game is developed where the network operator allocates bandwidth to wireless connections used by the content providers. Subsequently, the content providers form coalitions to share wireless connections. The results show that the content providers can benefit by forming coalitions.

The work in [97] provides a general utility-based framework for opportunistic networking which exploits the context information about the users' social behavior to find the appropriate forwarding nodes. The data dissemination is based on the tradeoff between the utility of the data object (content) and the cost of resource consumption which are calculated locally. Based on these measures, any encountering node can select the content to be transferred so that the total utility is maximized under limited resource. Similarly, the work in [4] provides social-oriented policies for optimizing content availability using a system called "ContentPlace." "ContentPlace" follows the simple concept of social behavior in which mobile users form a group according to their interests and social ties. Basically, each user advertises the interested data objects which they

want upon making contact with other nodes. A utility value is assigned to each data object which is computed based on the needs of the social communities in which the node resides. The data object is made available if its utility value is high, thus the process optimizes the content availability. Also, in [38], a utility-based routing scheme (i.e., SimBet) is introduced to find the best forwarding node in an opportunistic network. Social network metrics such as betweenness and social similarity are used to calculate the SimBet utility which is used to select the node that provides the maximum utility for carrying the message. These metrics are then used to detect the community ties in the network. This SimBet routing scheme is extended to simBetTS which uses the centrality measures (i.e., betweenness and social similarity) and tie strength to calculate the best forwarding nodes [39].

Table 7 provides a summary of different content distribution algorithms based on the optimization approach.

### C. Context-Aware Data Transmission

Context awareness refers to having the knowledge of the situation in which a device is being used. Context awareness can be incorporated in the MSN. Different

Table 6 Content Distribution in the MSN Based on Mobility Pattern and Control

Publication	Proposed Algorithm	Mobility Patterns	Remark
Nazir <i>et al.</i> [2]	Uses time and contact duration of social encounters for predicting the mobility pattern in the MSN for efficient content distribution	Mobility pattern can be predicted for a given period of time depending upon time and contact duration.	Social groups can be formed by studying and deducing the consistent/repeatable social encounters.
Costa <i>et al.</i> [40]	An efficient message routing (called, "SocialCast") is presented for publish/subscribe network for content distribution using colocation and movement patterns of the users.	The colocation metric together with mobility pattern is used to predict the availability of forwarding nodes.	
Chelly and Malouch [92]	Introduces an algorithm for directing an unconnected user toward a connected user using location-based service in the MSN	Attraction force function, which defines the attraction between nodes, is used	Targeted coverage for the node is needed to build a connection tree
Chaintreau <i>et al.</i> [93]	Uses underlying online social network services for exploiting mobility behavior to enhance the performance of the MSN	Uses link traces from online social network	Proves that opportunistic contact between nodes can be used to construct social relation

Table 7 Optimization-Based Approaches for Content Distribution in the MSN

Publication	Proposed Algorithm	Optimization Criterion	Remark
Ioannidis <i>et al.</i> [94]	Global utility function (social welfare) is defined as a decreasing function of content age, and maximizing this utility provides optimal bandwidth solution for scalable content distribution in the MSN.	Finds the optimal bandwidth allocation for downlink which maximizes the utility function (social welfare)	Addresses the optimality and scalability of dynamic content distribution in the MSN
Niyato <i>et al.</i> [95]	Content distribution policy of a content provider is optimized for maximizing the fresh content in the MSN	Maximizes the number of mobile users having fresh data	Highlights the content distribution from content providers' perspective
Niyato <i>et al.</i> [96]	Uses a coalitional game model to investigate the decision making of the content providers and network operators for optimizing the content distribution	Minimizes the cost of wireless connection for content provider and maximizing the revenue for network operators	Addresses rational cooperation among content providers and network operator for content distribution
Boldrini <i>et al.</i> [97]	A general utility based framework is proposed for opportunistic networking which exploits the context information about the users' social behavior to find the appropriate forwarding nodes.	Utility is a function of the data object (content) and cost of resource consumption.	The proposed framework is general enough to be customizable to any definition of utility, and to consider any set of resources.
Boldrini <i>et al.</i> [4]	A social-oriented policy for optimizing content availability using a system called "Content-Place" is proposed.	Optimizes the content availability by using utility of data object which is computed based on the needs of the social communities in which the node resides	
Daly and Haahr <i>et al.</i> [38]	A utility based routing scheme (i.e., SimBet) is introduced to find the best forwarding node in an opportunistic network.	SimBet utility is calculated based on social network metrics such as betweenness and social similarity which is used to select the node that provides maximum utility for carrying the message.	

analyses would be required to obtain the context awareness (e.g., pattern, trend, and fact analysis [98]). With context awareness, mobile users can adapt their behavior according to the circumstances. This learning process can

be used to serve different types of use cases [99]. For the MSN, this concept can be used to improve the QoS and simplify the service implementation. In addition, a context-aware framework in the MSN can provide intelligent

reasoning and understanding for users which are required to support user discovery, message processing, routing, and privacy protection. Context-aware mobile social network applications such as *whozthat* [9] are already available—this is a music jukebox that plays songs depending upon the taste of individual standing close to it by integrating social networks like Facebook with mobile device. CenceMe [41] is a mobile application that can sense the presence and state of people to provide context-aware information about user actions by extracting data using smart phone sensors.

The work in [100] provides a completely new vision of context-aware world by combining inputs from mobile, social networking services, and sensing data to create a contextual picture surrounding a user or a group of users. Basically, sensor networks are integrated into the MSN to provide a more comprehensive context-aware world in the form of SocialFusion. SocialFusion is able to provide necessary location information (by using mobile devices), user's action (by using sensors such as accelerometer, microphone, camera, and digital compass), and user's social behavior (by using online social networking services such as Facebook). For this, multistage architecture and distinct classes of data (namely mobile data from smartphone, sensor data from sensor networks, and social networking data from online social network like Facebook) are defined to integrate and extract meaningful contextual information from the raw data. However, collecting, managing, and mining such voluminous data raise many issues in terms of collecting and managing diverse data streams, mining the data for context-aware recommendation, and preserving security and privacy. These challenges have been addressed, and a possible solution is provided for implementing this system. Nevertheless, the concept presented in the form of SocialFusion opens more possibilities and applications toward the vision of context-aware MSN.

Similarly, in [101], context awareness is used in the semantic web-based open agent framework. The agent can understand the context-aware data (i.e., to know the context for which the data are being used). Different contexts can be considered in this framework (e.g., infrastructure-based context data, application-based context data, personalized and social context data). Semantic web is used to interpret the meaning of the context-aware data needed for the MSN. The proposed framework can improve efficiency, usability, and interoperability of the MSN. In [102], a social relation-aware routing protocol (SRRP) is proposed. This protocol exploits the social context between users to calculate routing metrics (e.g., forwarding nodes and replicating nodes). The users' context interest is added to the routing table which can be used to estimate the likelihood of accessing the content by other users. This likelihood information together with link error rate is used to calculate the utility of the route. Then, an optimization technique is applied to maximize the utility which is a function of data delivery ratio and network overhead.

Table 8 provides a summary of the existing works on context-aware data transmission in the MSN.

#### D. Mobility Modeling

Mobility models represent and emulate the movement characteristics of mobile users. They are used for simulation and evaluation of the performance of new algorithms and protocols in mobile wireless systems [103]. Therefore, to obtain accurate evaluation results for the MSN, a realistic mobility model is required, which should consider the social relationship of mobile users. Such mobility models are available for *ad hoc* networks [103]–[105]. Also, there are some real scenario traces such as [56]–[58], which are used to provide proper data training sequence for simulation. These traces provide important real-time data such as intercontact time, contact duration, and contact distribution which can be used to provide MSN-like scenario. Moreover, these real scenario traces are environment specific (e.g., in college or conferences) and are also limited in number of participants (i.e., not scalable). Since the MSN includes a variety of users which grow and differ in their social behaviors, it may exhibit different scenarios depending upon their surroundings. In this case, the mobility patterns in the MSN should take the real human mobility patterns and behaviors into account so that effective routing and data dissemination protocols can be developed.

Virtual social simulated environment (VSSE) [106] is the closest state-driven simulation model which provides real-life simulation environment for the MSN. The proposed model uses a popular Internet-based virtual world entertainment called second life (SL) [107] as a simulation environment. SL can reproduce day-to-day human activities of average people using their avatars (i.e., graphical representation of users in virtual world). VSSE uses SL Bots (i.e., computer controlled SL agent) and message exchange protocol to allow external users (i.e., as avatars) to participate in the simulation. Both SL Bots and the protocol are used as an interface to integrate the avatars into VSSE by allowing avatars equipped with mobile device (i.e., developed in SL) to exchange message with the closest SL Bots. The message management in SL Bots is controlled by the VSSE using multimodal presentation markup language 3-D (MPML3D) which is also used to connect VSSE to SL server. To produce real-life like dynamic behavior, the proposed simulation environment mimics the users' behavior and the moving pattern in the form of their avatars.

Similarly, the work in [108] presents a versatile mobility model called small world in motion (SWIM) that is able to generate different mobility scenarios such as conference, campus, city that differ not only in size but also in shape and cardinality of the communities therein. The mobility pattern of SWIM follows a simple intuition that people prefer going to popular and close place where they can meet lots of people. It is shown experimentally



Table 8 Context-Aware Data Transmission in the MSN

Publication	Contextual Information Used	Contextual Integration	Remark
Beach <i>et al.</i> [100]	Uses context-aware information related to location, users action and users' behavior	Contextual data are integrated using multistage architecture (SocialFusion) and distinct classes of data.	Versatile system that integrates mobile technology, online social networking services, and sensing technology to create state-of-the-art context-aware framework
Rana <i>et al.</i> [101]	Uses infrastructure-based, application-based, personalized and social context data	Uses semantic web-based open agent framework and semi automated concept to understand the context of content so that the content can be adaptively transmitted to the appropriate mobile users	Introduces a framework for reasoning and understanding user needs in the MSN
An <i>et al.</i> [102]	Uses similarity of context interest among mobile users	Uses a context-aware routing protocol that adds contextual information to the routing tables to obtain the best forwarding and replicating nodes	Simple technique which achieves higher delivery ratio with lower network overhead

that the synthetic traces (i.e., statistical data such as inter-contact time, and contact duration) generated by SWIM are almost the same as the real data traces such as Infocom [57] and Cambridge [58]. Also, it is shown that the SWIM can be used to accurately predict the protocol performance on real networks. For this, Bubble rap [78] (i.e., a community-based forwarding protocol for the MSN) is used to compare its performance on both real and synthetic traces. It is found that SWIM with its synthetic traces can successfully provide a scenario to accurately predict the performance of complex socially aware algorithms like Bubble rap. These mobility models such as VSSE and SWIM provide a new sense of direction and easiness to construct desirable and scalable MSN. However, these types of mobility models should be tested and validated extensively to each scenario to exactly reproduce a real MSN.

### E. Privacy and Security

Most of the MSNs are capable of accessing the users' physical location, preference, and social relations. There-

fore, the privacy and the security related issues for mobile users in the MSN become crucial [109]. Due to its profound scope and unique degree of sensitivity, privacy implementation is not an easy task. Moreover, since human interfaces are involved in the MSN, the granularity of privacy concern may differ from user to user. Sensitive information (e.g., location, relation, and interests) for one user might not be the same for others. A generalized privacy policy is hard to implement in that sense. One possible solution could be to provide context-aware privacy protection which will dynamically adapt privacy requirements according to the users' context [110]. Also, it is unclear whether the added privacy setting will enhance the performance of particular algorithm or application due to possible increase in overhead. However, a recent study shows that adding privacy enhancement features in social network routing for opportunistic network has less impact in terms of performance [110]. The proposed privacy scheme [i.e., statisticulated social network routing (SSNR)] intentionally changes the copy of sender message by adding or removing nodes. This introduces a degree of



confusion in the network such that it cannot be identified whether the message is originated from the sender's social network. However, the data sets (i.e., Reality Mining data set MIT [56] and SASSY data set [59]) used to evaluate this scheme may not represent the true MSN environment, even though the initial results are promising. For better privacy analysis, real mobility models should be used to identify the scope and sensitiveness of the privacy requirements depending upon the contextual reference of users. However, implementing context-aware algorithms in social routing still needs further research. Depending on this, we categorize privacy issues based on the importance of information to be shared.

The most security-sensitive mobile social networking service is the one which provides LBS that shows users' location to users' friends or friend of friends. Location information helps people to be in connection; however, it also discloses actual location of the users, which might not always be used in a proper way. In order to address this problem, numerous privacy-aware proximity detection methods are proposed [111]–[115]. Privacy-aware proximity detection service determines closeness between two or more mobile users without disclosing their exact location to other users or the service providers. For example, a centralized solution for maintaining the privacy of user is developed in [111]. The proposed scheme converts a user's actual location into the transformed location which is used to determine the proximity to other transformed locations using distance preserving mapping. Although the proposed scheme helps to ensure user's location privacy, apparently it is not so secured since the mapping function can be easily derived if desired. Similarly, Longitude [112] also provides a centralized solution for maintaining the privacy of the user location using spatial cloaking followed by modular transformation prior to sending their location to the server. Spatial cloaking technique generalizes the user's actual location into an arbitrary region. The modular transformation provides extra level of privacy by preventing the disclosure of location information. However, this type of prevention can introduce false proximity detection.

Hide and Crypt [113] is another privacy preserving solution for LBS which uses spatial cloaking to encrypt the user's location before sending them to the central server. The maximum and minimum distances between these cloaked regions are calculated by the server. This calculated distance is then used to identify the proximity of each user with his/her friends. The location information and vicinity region are first mapped into a spatial region (which can be a grid). A secure two-party computation (SMC) protocol is used to check the overlay of mapped location of one user location over the mapped vicinity of other users. However, the central server always has the information of users' cloaked regions, thus still resulting in vulnerability in privacy. Also, in this type of proximity detection approaches, there is an increase in communication cost for accurate proximity detection.

In [114], a centralized proximity detection method called FriendsLocator is presented which provides strong privacy guarantee. For this, a grid-based adaptive position-update policy is implemented which can also optimize the communication cost. Basically, the proposed scheme maps user location into four cells of a grid. The location information is encrypted using one-to-one encryption function which is shared among the available users. The central server checks for matching encrypted coordinates among the group of four cells to identify user's proximity with other users. However, all of the mentioned privacy-aware proximity detection services [111]–[114] lack flexibility in user preference (i.e., user's interest) and dynamic-shape vicinities. That is, the distance proximity does not guarantee that nearby users share the same interest which might be the deciding factor for closure. Also, dynamic-shape vicinity is more likely to define exact proximity of the user rather than using static, circular shaped, user-location-centered vicinities. For example, if two users located on the opposite banks of a river are classified as being in proximity, then the generated proximity might not be useful since it might be difficult for users to meet each other. That is why proximity detection method should support both user location privacy and dynamic-shape vicinities.

VicinityLocator [115] is an example of such proximity detection which detects proximity by checking the inclusion of one user's location inside another user's vicinity region, and offering users control over both location privacy and accuracy of proximity detection. The vicinity region is an area around a user's location which also defines a user's scope of interest in this client-server system. The vicinity regions can be drawn manually or automatically generated based on the shapes of the nearest spatial objects. The user maps his/her location into a granule and finds all granules contained in his/her vicinity, which can be shaped arbitrarily. The proposed privacy service uses both spatial cloaking and encryption to encrypt user's location and vicinity which will be sent to the central server for further processing. The novelty of the proposed scheme lies in providing proximity estimation by the central server without knowing any spatial data related to user's location. For this, the server checks the proximity by testing for the inclusion of an encrypted location granule within a set of encrypted vicinity granules of a different user. By allowing users to update their locations only when leaving particular vicinity, the overall communication cost can be reduced.

In [116], a privacy design method for commercial mobile social network applications (i.e., for Apple App Store) is studied. It is shown that both feedback and control of information construction and accessibility are vulnerable. This is due to the mash up among various social networking sites which expose personal information flow to the attackers. In addition, the method to control the information flow in these MSN communities is also

important to protect the mobile user privacy. Taking these issues into consideration, Cai *et al.* [117] suggest a granularity control method for publishing information or sharing resources in the MSN. Different granularity levels are introduced for mobile users' information which is able to control level of information flow depending upon relationship between the requestee and the requester. This relationship can be defined by various metrics (e.g., degree of separation between two members of the social network, actual geographical distance, common interest and membership in event or groups, and usage). Controlling the source of information flow can minimize any possible misuse. However, the risk still exists, since personal information is exchanged through wireless links. In [118], the friendship relation among mobile users is investigated as it can be a pitfall for privacy in the MSN. Specifically, the effect of disclosing the friendship among users on the privacy is analyzed. It is shown that there is a need to hide the friendship relation to avoid the attacks. The implementation of this privacy enhancement scheme is developed for the MSN.

In [119], a method of information encryption using identity servers (ISs) is introduced for the MSN. This encryption scheme associates a unique anonymous identity (AID) to the mobile device request. In this case, whenever there is a request for data transfer, only the encrypted AID is exchanged between the mobile users which can be decrypted using the centralized identity server. Any attacker trying to eavesdrop on the communication cannot decrypt the anonymous identity. However, this scheme requires Internet access for authentication and verification which might not be always feasible in the MSN. Integrating the identity server into existing cellular systems might be a possible solution, but the operational cost will increase.

## VII. OPEN ISSUES AND FUTURE RESEARCH DIRECTIONS

Although different challenges in the MSN have been addressed in the literature, there are still many challenges. Also, there are opportunities to improve the efficiency and effectiveness of the MSN to accommodate new applications and services. In this section, several open issues and possible research directions are outlined from the perspective of architecture and protocol design for the MSN.

### A. Usage and Estimation of Social Network Metrics

Social network metrics can be estimated and used for data delivery (e.g., [37] and [39]). However, the usage and importance of social network metrics may differ depending mainly on the applications and data delivery services of the MSN. There are a variety of social network metrics (e.g., betweenness, bridge, closeness, clustering coefficient, and cohesion) for social network analysis [1]. These

metrics have to be properly applied to different MSN. For example, clustering coefficient may be suitable for cluster formation, while betweenness is suitable for packet forwarding. In addition, the mapping from physical mobility parameters (e.g., duration of contact and the amount of data to be transferred between encounter) to the social network metrics (e.g., betweenness and closeness) needs to be investigated.

### B. Radio Resource Management for Wireless Access and QoS Support

Bandwidth allocation in the MSN can be optimized to achieve the best performance [94], [96]. However, the impact of social relation on the radio resource management of different wireless systems has not been investigated. In addition, existing optimization formulations ignore the QoS requirements of the MSN applications. For example, in voice-based MSN [32], packet loss and delay have to be maintained below the target levels. Due to the lack of any centralized control, radio resource management and QoS support become more challenging in the MSN with distributed architecture.

### C. Resource-Efficient Protocols

The MSN is basically formed by different mobile devices which exploit the social network metrics for better network performance. However, these mobile devices are resource-limited in terms of memory, buffer, computational intelligence, and power supply [4]. These limitations bring the constraints which should be considered for protocol design for the MSN. Efficient usage of the resources (e.g., energy-efficient community detection) in mobile devices for routing and information sharing is of paramount importance. There is a tradeoff between conserving these resources and guaranteeing effective and uninterrupted services in the MSN.

### D. Cross-Layer Design of Protocols

One of the approaches to improve the performance of data delivery in the MSN is to optimize the wireless and mobile networking protocols. Cross-layer design has been used to optimize the performance of protocols across different layers (e.g., physical, medium access, network, transport, and application layers) [120]. Since the protocols in different layers can utilize the information about social relationship to optimize their performance, a cross-layer design approach can be adopted to achieve globally optimal performance. For example, community detection in application layer can be jointly optimized with the content distribution (e.g., routing) in network layer.

### E. Cognitive Radio Techniques

Cognitive radio techniques can be used for flexible and efficient wireless access in mobile communications environments [121]. For improving the data communication among mobile users in the MSN, cognitive radio

techniques can be used which exploit the social relationship in the MSN and also the mobility pattern of the users. It has been shown that collaboration among cognitive users is beneficial in terms of reducing cost and improving performance [121]. The MSN can be formed among cognitive users utilizing licensed spectrum to support existing or new techniques for data distribution.

### F. Mobile Peer-to-Peer Networks

Mobile peer-to-peer network is a self-organizing system of resource-limited nodes without hierarchical structure or centralized control [122]. Mobile peer-to-peer network services include file transfer and VoIP communications. The knowledge about users' social behavior can help to understand a peer's relationship and its interdependencies. As mobile devices are carried by people, knowing their mobility patterns and relationships will be useful for finding the appropriate relaying nodes in a peer-to-peer network. Thus, a distributed MSN can be overlaid over this mobile peer-to-peer network. Context-aware data distribution in the MSN can be utilized by mobile peer-to-peer network.

### G. Standard Interface

Interoperability becomes an important issue when multiple MSN need to interact and communicate with each other. Standard protocol, signaling, and interface for exchanging information of social relationship and data delivery among different MSN would be required to ensure seamless services. This standard protocol is important not only for data distribution, but also for context awareness and privacy in the MSN. Also, the interoperability between mobile and desktop platforms would be important [123].

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### H. Applications

The MSN is expected to be common in our daily lives [37] and many applications of the MSN can be envisioned (e.g., public safety, vehicular communications, and emergency networks). For example, social relations of vehicular nodes can be used to improve the performance of data transfer in vehicle-to-vehicle (V2V) communication networks. Also, there is a need for customization of MSN by taking the application specific requirements (e.g., QoS) into account. At the application layer, there are challenges in developing services and applications for MSN. The applications have to be optimized considering the uncertainty in the underlying wireless access network. Also, it is essential that applications scale up for a large number of users.

### VIII. CONCLUSION

The MSN is an evolving paradigm which would change the way people communicate and exchange data. MSN offers user-centric services in which mobile users who are parts of the MSN not only utilize but also improve the services of the MSN. In the MSN, information about social relationship among users can be used to optimize data exchange, sharing, and delivery to meet the requirements of the services and applications. In this paper, we have presented the basic concepts of the MSN. Major applications of the MSN have been summarized. Different architectures for the MSN have been introduced. With the emphasis on data communications and networking, the network access infrastructures related to the MSN have been described. The major issues related to protocol design for the MSN and the related approaches from the existing literature have been reviewed. Finally, several research directions have been outlined. ■

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## ABOUT THE AUTHORS

**Nipendra Kayastha** received the B.E. degree (with distinction) in electronics and communication engineering from Nepal Engineering College, Bhaktapur, Nepal, in 2004 and the M.E. degree in information and communication technologies from Asian Institute of Technology, Bangkok, Thailand, in 2008.

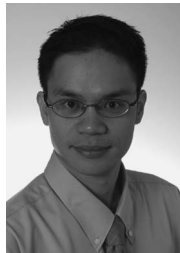
His research interests are in data communication and protocol design for new and emerging areas such as mobile social networks, smart grid, and femtocell. He is a Project Officer with Center for Multimedia and Network Technology, Nanyang Technological University, Singapore.



**Dusit Niyato** (Member, IEEE) received the B.E. degree from King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand, in 1999 and the Ph.D. degree in electrical and computer engineering from the University of Manitoba, Winnipeg, MB, Canada in 2008.

He is currently an Assistant Professor in the School of Computer Engineering, at the Nanyang Technological University (NTU), Singapore. His research interests are in the area of radio resource management in cognitive radio networks, mobile social network, and mobile cloud computing.

Dr. Niyato serves as an Editor for the IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, *Wireless Communications and Mobile Computing (WCMC) Journal*, and *Journal of Communications and Networks (JCN)*.



**Ping Wang** (Member, IEEE) received the B.E. and M.E. degrees from Huazhong University of Science and Technology, Wuhan, China, in 1994 and 1997, respectively, and the Ph.D. degree from University of Waterloo, Waterloo, ON, Canada, in 2008, all in electrical engineering.

Since June 2008, she has been an Assistant Professor in the School of Computer Engineering, Nanyang Technological University, Singapore. Her current research interests include quality-of-service (QoS) provisioning and resource allocation in wireless communication network, mobile social network, and cloud computing.

Dr. Wang was a corecipient of a Best Paper Award from the 2007 IEEE International Conference on Communications (ICC). She is an Editor of the IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, the *EURASIP Journal on Wireless Communications and Networking*, and the *International Journal of Ultra Wideband Communications and Systems*.



**Ekram Hossain** (Senior Member, IEEE) received the Ph.D. degree in electrical engineering from the University of Victoria, Victoria, BC, Canada, in 2001.

He is a full Professor in the Department of Electrical and Computer Engineering, University of Manitoba, Winnipeg, MB, Canada. He was a University of Victoria Fellow. His current research interests include design, analysis, and optimization of wireless/mobile communications networks and cognitive radio systems. He is an author/editor of the books *Smart Grid Communications and Networks* (Cambridge, U.K.: Cambridge Univ. Press, 2012), *Green Radio Communication Networks* (Cambridge, U.K.: Cambridge Univ. Press, 2012), *Dynamic Spectrum Access and Management in Cognitive Radio Networks* (Cambridge, U.K.: Cambridge Univ. Press, 2009), *Heterogeneous Wireless Access Networks* (New York, NY: Springer-Verlag, 2008), *Introduction to Network Simulator NS2* (New York, NY: Springer-Verlag, 2008), *Cognitive Wireless Communication Networks* (New York, NY: Springer-Verlag, 2007), and *Wireless Mesh Networks: Architectures and Protocols* (New York, NY: Springer-Verlag, 2007).

Dr. Hossain serves as an Editor for the IEEE TRANSACTIONS ON MOBILE COMPUTING, the IEEE COMMUNICATIONS SURVEYS AND TUTORIALS, IEEE WIRELESS COMMUNICATIONS, and an Area Editor for the IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS in the area of "resource management and multiple access." He has several research awards to his credit which include the University of Manitoba Merit Award in 2010 (for research and scholarly activities) and the 2011 IEEE Communications Society Fred Ellersick Prize Paper Award. He is a registered Professional Engineer in the province of Manitoba, Canada.

