On Service Discovery in Mobile Social Networks: Survey and Perspectives

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Abstract

Mobile Social Networks represent a convergence between mobile communications and service-oriented paradigms, which are supported by the large availability and heterogeneity of resources and services offered by recent mobile devices. In particular, the service-oriented nature of MSN is in the capability of sharing resources and services among devices that lie in proximity and that opportunistically interact. Service discovery is thus of primary importance to sustain the most intimate mechanisms of MSN. Despite of their centrality, studies on service discovery in MSN are still in their youth. We contribute to frame the results achieved so far and to identify some possible perspectives of the research in this field, by giving a transversal review of the scientific outcomes in the different steps of service discovery, namely advertisement, query, selection and access.

Keywords: Service Discovery, Mobile Social Networks, Distributed Networks

1. Introduction

Mobile Social Networks (MSN) are build over concepts inherited from conventional Online Social Networks (OSN, such as Facebook, Google+ or Twitter) and wireless networks based on opportunistic communications such as ad hoc networks or delay tolerant network. Specifically, a MSN is a network of mobile devices (typically smart phones, smart watches, tablets etc.) that communicate opportunistically and that are carried by human users. Users exploit the devices to keep their social relationships with other users by means of (localized) communications with the devices of other users located nearby.

MSN are enabled by the tremendous diffusion of mobile devices in the planet. In fact, the average number of devices per-person exceeded 0.5 in 2013, which means that there are currently billions of mobile devices in the world [1]. These devices generally embed several network interfaces, including short-range (e.g. WiFi, Bluetooth or ZigBee [2]) and at long-range (e.g. GPRS, 3G and LTE). Short-range interfaces allow devices to communicate with each other without relying on any network infrastructure, while long-range interfaces guarantee broadband connectivity mostly everywhere. The devices are also equipped with advanced multi-core CPUs and dedicated GPUs, flash memories and external storage, and they embed a plethora of sensors such as accelerometer, gyroscope, GPS receiver etc. Such features make these devices ideal for the exploitation of a new form of distributed computing, such as the opportunistic computing [3].

As compared to OSN, MSN offer complementary opportunities to users, as they exploit the mobility of humans carrying the devices of the MSN. This fact has deep implications on the way these devices cooperate. In fact, people move according to objectives and activities arising from their social interactions [4]. The social interactions between humans are often called *social ties*, they can be tight, e.g. among friends or weak e.g. among strangers. The strength of social ties among people is a concept not easy to model; in [5] the author proposes a first definition of social tie resulting from the combination of different components such frequency, intimacy, recency and regularity. The strength of ties among humans reflects in some cases also on the amount of time spent together by them. For example friends, usually, share lot of interests, hence they tend to meet frequently and to spend lot of time together. Conversely, strangers with non-overlapping interests have few chances to stay in contact for long periods. Such all-human tendency of staying in touch with people with similar interests characterizes how people move by determining the topology of the MSN. Indeed, since people carry mobile devices in their pocket, the way the people move influences the communication opportunities among such devices. Since mobility strongly characterizes MSN, most of the works in literature focused on deepening the knowledge about relationship between social mobility and communications capabilities of MSN [6, 7].

More recently, the progress of knowledge on MSN opens to other research aspects that need to be explored and consolidated. In particular, the richness of resources (including sensors, hosted and self-generated data, connectivity etc.) of the devices forming an MSN raises to the problem of how to share and distribute such resources among users. A natural answer to this problem is in the organization of the MSN according to a service-oriented model, in which resources are made available in terms of services offered by the devices themselves. As a matter of a fact, a recent works [8] cites service discovery as a challenging open issue in MSN, and another works on opportunistic networking [3] describes the management of resources and services as an open research issue.

On the other hand, the development of service-oriented MSN is still in its infancy and relatively few works addressed this issue [9]. With this survey we reconsider these works along with a number of other works that treat service-oriented solutions for other networks sharing some aspects with MSN (for example pocket switched networks, ad hoc networks, or delay tolerant networks), and that can thus be analyzed into the context of MSN.

Differently than existing surveys on MSN, we thus focus specifically on the problem of introducing service-oriented features in MSN, and we discuss the implications and perspectives of the service oriented approaches in the framework of the specific requirements arising in MSN.

The rest of the paper is organized as follows. Section 2 describes the Mobile Social Networks, our reference scenario with some highlights on community detection algorithms and architectural aspects concerning the organization of the network. Section 3 introduces the relationship between the service-oriented model and the MSN, we classify the application services available in MSN within three categories, and we provide the big picture of the service discovery architectures. Section 3 concludes with a list of requirements for service discovery protocols in MSN. We then describe the service discovery as a process composed by four steps, namely the advertisement and query are described in Section 4, the selection step is described in Section 5 and the access step is described in Section 6. Section 7 states some research lines and perspectives on the service discovery and Section 8 draws the conclusions.

2. The Mobile Social Networks

As previously discussed, the mobility of people is a characterizing aspect of MSN which, in turn, is related to human sociality. In the rest of this survey we refer both to devices and to people carrying devices as the principle actors of MSN.

The human mobility can be characterized by three key-aspects: *(i)* common activities (e.g., we all go to work, go back home, travel toward office), *(ii)* visiting a limited number of locations (e.g., home, the office, a movie theatre), and *(iii)* traveling more often along short paths instead of long routes. On the other hand, homophily among humans introduces additional features in the way people (and hence devices) in MSN move and behave. In particular, humans tend to meet more frequently and/or for longer periods with other humans with whom they share similarities. As discussed in [4] "contacts among similar happen more frequently than that contacts among dissimilar people". For instance, race and ethnicity, sex and gender, age, religion and education are some notable aggregation factors that tend to cluster similar people together. A common way to model all these aspects is to group devices into communities and to profile them according to the interests of their users or according to other criteria such as time spent together, places visited or common acquaintances. The detection of communities can result helpful in order to study the effect of mobility on the effectiveness of different strategies for resources and information diffusion in MSN. In this section we give an overview of these aspects of MSN, before introducing the service-oriented approaches.

2.1. Communities in Mobile Social Networks

Human mobility is driven by several factors, among which, social interactions are predominant [10]. People that meet frequently for long periods have robust social ties, and they form *communities.* There is not a unique definition for the term community [11, 12], however it can be informally described as clustering of entities, e.g. people, that are closely linked to each other and have non-volatile social ties. Examples of communities are the employees of the same company that work in the same office, students attending the same lectures or members of a family. Communities are a useful tool for analyzing and exploiting the potentialities of a MSN, since members of a community are connected by similar interests, habits or mobility patterns. For example, classrooms attending to the same lecture may share interests for the university campus events or nightlife in the city where they live. Similarly, people commuting by train might be interested for the timetables, delays or the weather forecast at the destination. Not that, belonging to the same community does not necessary imply to be often in proximity, and communities composed by people that share the same interests but that have different mobility patterns are also admissible in MSN.

In general, algorithms and applications designed for MSN can exploit the existence of communities to optimize the diffusion of information, the routing and the discovery and access of services available in the MSN.

Since people in the same community spend time together, devices carried by people have great opportunities to communicate through short-range network interfaces. The community detection can be implemented with centralized [13, 14, 15] or with distributed [16, 17, 18] algorithms. The centralized algorithms need full knowledge of the whole network and of its ties, while in the distributed ones each device has a local view of the network, and it needs to detect the communities to which it belongs. The mobile and dynamic nature of the MSN leads us to consider the distributed community detection algorithms as the natural choice. Indeed, with distributed algorithms, the devices need to know the quality of encounters with other devices, in terms of:

- temporal metrics: measure of the temporal dimension of the device encounters. Some notable examples are the contact duration, the average inter-contact time, and the last time a device has been in contact.
- similarity metrics: measure of the similarity degree with the encountered devices. For example, the similarity function can measure the interests, the number of similar contacts or the similarity with the places visited.

Hui et al. [17] propose a family of community detection algorithms, namely SIMPLE, k-CLIQUE and MODULARITY. As a general principle, each device is maintaining a familiar set, in which encountered devices are imported when the cumulative contact duration exceeds a certain threshold. The community of each device contains all devices in the familiar set plus devices selected by the detection algorithm. If two devices have quite similar familiar sets, then they add each other into their communities. The two communities will merge in SIMPLE if they have more common devices than a threshold, in k-CLIQUE if the other device's familiar set contains at least $k-1$ devices of the root device's community and in MODULARITY if the familiar sets of the other device's community members, not included in the root device's familiar set, belong to the root's device community. One of the drawbacks of the SIMPLE algorithm is that it does not remove old contacts from the familiar set. In particular, once the cumulative contact duration for a device exceeds the threshold, it will never be removed. AD-SIMPLE algorithm [16] extends SIMPLE by adding a mechanism for ageing contacts and for deleting devices from the community. Another distributed community detection algorithm is presented by Li and Wu [19], as part of the community-based epidemic forwarding scheme called LocalCom. The detection algorithm is initiated by a self-selected device, called initiator. In order to use a broader definition than cliques, the notion of the virtual link is introduced and two devices are considered to be socially related if they share a strong connection with a common neighbor. Moreover, by adopting normalized cuts, devices are able to form communities in a distributed way. This is achieved by selecting the detected community with the smallest normalized cut value.

DRAFT [18] is a distributed spatio-temporal detection algorithm. It uses the cumulative contact duration to add or remove a device from a community. Moreover, it implements a decay mechanism to prune devices that no longer belong to a community. DRAFT takes three parameters: cumulative threshold, decay rate and length of the time frame, the combination of these parameters affects the cardinality of the communities detected by each device.

2.2. Distributed Mobile Social Network Architecture

MSN are mobile and dynamic in nature, people establish contacts according to their social activities, and, consequently, devices carried by people are able to interact only for short and intermittent periods. The network architecture required by MSN differentiates form the Online Social Networks (OSN). In fact OSN rely usually on a web-based centralized architecture. In this case, a cluster of replicated servers provide the back-end of the social network; the servers are supposed to always be on-line backed by ultra-fast and reliable network infrastructures. The (mobile) clients of the OSN connect to the servers by means of Wi-Fi or by long-range network interfaces such as LTE. In MSN such architecture is not feasible, hence we do not assume the existence of a stable network infrastructure that guarantees connectivity among every device; rather all the communications happen in an opportunistic way. More precisely, we refer to MSN based on a distributed architecture as shown in Figure 1. The

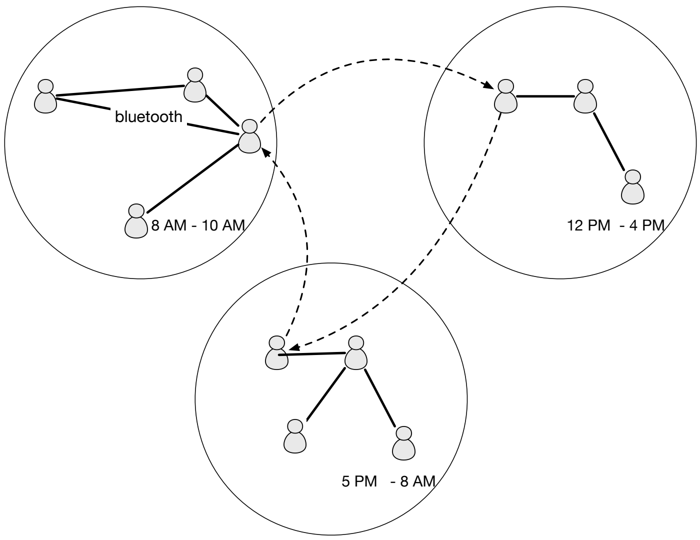


Figure 1: Snapshot of a distributed MSN.

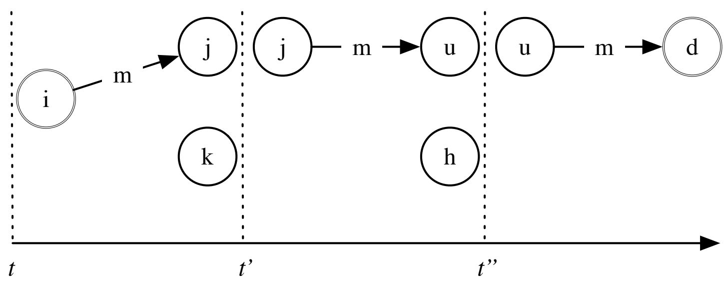
xw

figure shows the snapshot of a MSN along 24 hours. The snapshot shows the connections established by group of devices in different periods of the day. Some of them are connected directly by means of short range network interfaces (for example Bluetooth or WiFi Direct), other devices are (partially) disconnected.

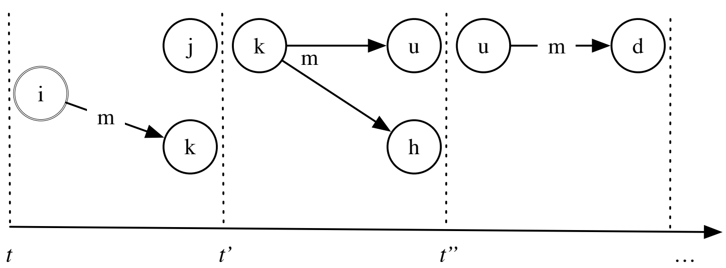
The key feature of distributed MSN is the total absence of centralized servers. Mobile devices are able to communicate and access the information only by connecting to other devices. Therefore, the network itself has to store and route data until the correct destination is found. Distributed MSN can be further divided into two different categories. In the first one, devices share contents directly or by using some deployed infrastructure (but not centralized anyway). In the second one (which is the most challenging), intermediate devices might be required to provided inter-communication between two devices (they are also named rely devices). Because no infrastructure is considered, the mobile devices themselves are designated to route or carry the messages until the final destination (the store-carry and forward paradigm) is found.

2.3. Routing and Data Dissemination in Mobile Social Networks

Routing and data dissemination are two complementary key-problems in MSN. The routing aims at delivering a message from the source to the destination, in this case the sender and the device receiver are known. Data dissemination aims at disseminating data produced from a provider to devices that might be interested in using such data, in this case the sender is known but the receivers are not known. In general, the goal of a routing protocol is to deliver a message quickly toward its destination, while the goal of a dissemination protocol is to diffuse efficiently a data among the interested devices. Figure 2 shows two simple strategies for routing and data dissemination.



(a) Routing message m from i to d.



(b) Disseminating message m from i.

Figure 2: Routing and data dissemination.

Figure 2a shows a simple routing strategy from device i to device d. Devices receiving the message m forward it to another device according a local decision, for example device j forwards m to u because u is often in contact with the destination d. Such decision is taken on the basis of a local routing policy. For example j delivers the message to u because u has the highest probability of encountering the final destination d.

Figure 2b shows a controlled-flooding dissemination strategy. Device i generates and propagates a message m among devices that are interested in receiving m; in particular i selects k at time t', k in turn, selects both u and h at time $t''$and, finally, u selects d. In this latter case, there is not a final destination, rather the message m is propagated until a certain rule applies (for example when it reaches its maximum hop count).

In MSN there are generally no stable end-to-end delivery paths. Therefore, delivering messages to a destination or diffusing a data towards interested devices becomes more challenging. Most of the existing solutions for routing and data forwarding adopt the store-carry-and-forward approach, which consists in storing a message locally to a device and carrying it until the destination or a *promising* device is encountered (i.e. a device that will hopefully meet the destination in the future, according to some metric). It is thus important to adopt a smart relaying selection and forwarding decision in order to reduce the latency of delivery. Based on a chosen strategy, policies for routing and data forwarding varies from epidemic replication of all the messages to every node like Epidemic routing [20], through to multi-copy and single-copy forwarding. Flooding-based protocols with unlimited replicas of messages cause high demand on network resources, such as storage and bandwidth and they cause congestion. However, multi-copy protocols typically aim to limit the number of replicas of the message in order to leverage a trade off between resource usage and probability of message delivery. On the other hand, single-copy strategies require routing algorithms to implement a next-best-hop heuristic that forwards the messages to those devices with a highest probability to deliver the message to its destination. Both of the problems are relevant for the service discovery (see Section 3.1) and in this section we briefly review existing solutions for them.

Routing strategies - Routing strategies can be further classified in community-aware or community-agnostic. In the first case, routing exploits the community structure (see Section 2.1) to select the relay node to forward the message [21, 22, 23]. If the destination belongs to the same community of the sender, than the message can be routed only among members of the community. Otherwise, the message is routed by considering all possible rely devices.

Community-agnostic strategies avoid detecting communities; rather they exploit social metrics to take the forwarding decision. Examples of metrics used are closeness centrality, betweenness or similarity. Mei et al. introduce SANE, a social-aware stateless algorithm for routing in Pocket Switched Networks [24]. According to SANE movements of individuals are driven by interests. Information is therefore disseminated among users with similar interests (*interest-cast* diffusion model). When two users meet, they first exchange their interest profiles. As soon as a user has a message to send to a destination, it forwards the message towards the user whose interests match with those of the destination. SimBet [25] is a prominent algorithm in this category based on the identification of the betweenness centrality and social similarity metrics. In this algorithm, an ego network analysis technique is used to estimate the values of the betweenness centrality and the similarity for each device. FairRoute [26] exploits the social process of perceived interaction strength based on the interaction strength between devices in a short term and long time scale. It forwards the message by the stronger social relation and uses assortative-based queue control to limit the exchange of messages to those users with similar social status. In social-greedy [27], a forwarding decision is made by the closeness and social distance. The closeness is calculated by the common attributes of the two devices. The more common attributes, the closer the two device.

Data dissemination – Data dissemination in MSN has some further challenges with respect to routing strategies. Indeed, the content providers and content consumers might never connect at the same time to the same part of the network. Therefore, data should be moved and replicated in the network in order to carry them to interested users.

Data forwarding can exploit traditional flooding-based strategies or other strategies such as those based on publish-subscribe paradigms or other social-aware approaches. With the publish-subscribe [28, 29, 30] devices interested in receiving some kinds of information (device consumer) diffuse a subscription in the network. All data matching with their subscriptions are forwarded to the consumers as soon as the providers generate data. Consumers and producers are not aware of their counterpart, in particular the consumer is only interested in receiving data subscribed, while the producer is not interested in delivering information to one specific destination. A notable example of publish-subscribe is the PodNet project [28]. It organizes contents in channels, which allow the users to subscribe and automatically receive updates for the contents they are interested in.

With the social-aware strategies, devices exploit the social relationships of the encounters to forward data. In DIFFUSE, Lin et al. [31] provide a solution for the data dissemination in pocket switched networks. The forwarding strategy is based on computing the contribution of each device, a parameter indicating the frequency and duration of contacts that a user has with other users. This parameter is used to select the relay node to which data is forwarded. PrefCast [32] targets on maximally satisfying user preference for content objects. To disseminate a suitable set of objects that can bring possible future contacts a high utility, a maximum-utility forwarding model is formulated in the protocol. Then, the paper proposes a dissemination algorithm that enables each user to predict how much utility it can contribute to future contacts and solve its optimal forwarding schedule in a distributed manner.

3. Service-Oriented MSN

The social nature of MSN leads people to form and maintain communities of similar. Communities are structures offering a great opportunity for people's devices to interact and exchange useful information. Devices can gather environmental data, download and share contents from the web, store multimedia contents and exploit sensing capabilities available on the device. Such information is continuously refreshed and updated according to the input of the end-users. When data available on a device are offered to the MSN, the computation paradigm may become service-oriented. In fact, every data can be exposed as a service offered to devices located in proximity or not directly connected but that are part of the same community. However, the service oriented paradigm cannot be applied *as-is*, rather MSN introduce several restrictions to such paradigm. The absence of a network infrastructure, the opportunistic nature of MSN and the human behavior typical of these networks draw a challenging but exciting scenario.

In particular, the problem of finding and accessing services (in one word, *s*ervice discovery) has been widely studied in many other contexts very close to MSN [33, 34]. We represent the service discovery problem as a loop composed by four steps, namely advertisement, query, selection and access as shown in Figure 3. We survey algorithms and strategies addressing each of these steps in sections 4, 5 and 6.

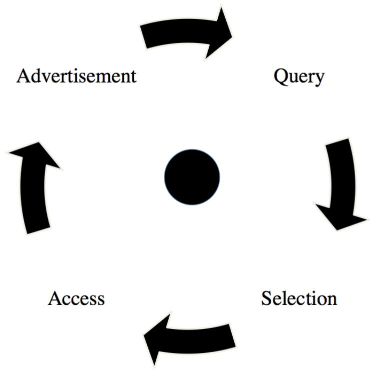


Figure 3: Service discovery process.

However, the existence of social relationships among users of MSN introduces aspects in service discovery that are largely unexplored. Some notables examples are the use of different routing and forwarding strategies to deliver a message, the combination of reactive and proactive discovery modes or the detection of communities to optimize the diffusion of messages. Section 3.4 discusses in detail each of these aspects.

3.1. Services and Applications in Mobile Social Networks

With the term service, we refer to every hardware and software resource provided by a device in the network. In this section we propose a spectrum of services potentially available in the MSN Figure 4 shows a non-exhaustive classification of application services in MSN.

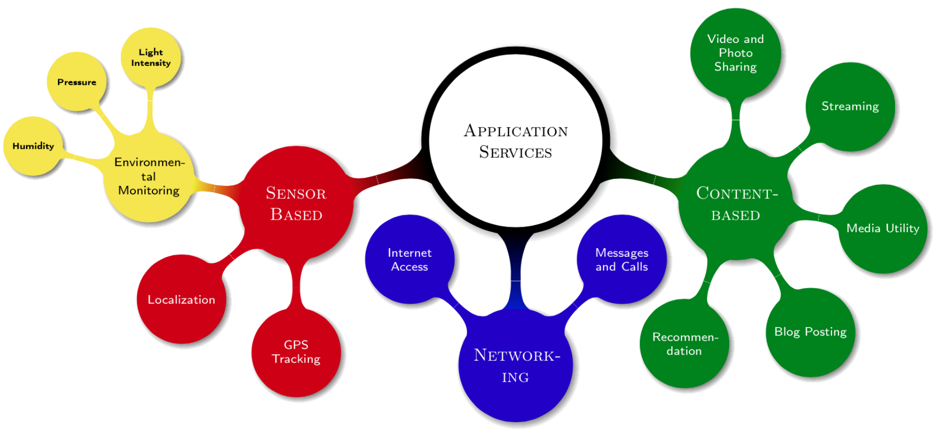


Figure 4: Classification of services in MSN.

Services are classified in three categories: content-based, networking and sensor-based. Content-based services are designed for sharing media contents with other devices; notable examples in this category are services for sharing video and photo, streaming of short videos, cooperative blogging platform [35], utility services for media contents such editing or compression of images, recommender systems for recommending places to visit (e.g. restaurants, pubs or others) [36].

The category of networking services does not only include the traditional services referred by [37, 38, 39] namely printer, fax, scanner and memory storage, but it also wraps services designed for sharing networking functionalities with mobile devices. Notable examples in this category are services for sharing the Internet connection [40] and services for enabling text messages or phone calls. The last category of application services we propose is sensor-based services. This category comprises all the services that exploit sensors installed on the device. When the sensing capabilities of a device are combined with the mobility and sociality aspects, the range of application services increases. Some notable examples are the opportunistic sensing and crowd-sensing [41, 42] platforms designed to gather information from mobile devices by exploiting sensors on the device itself.

Moreover, the way in which the application services are provided is something that distinguishes the MSN from other application scenarios. In particular, some services are meaningful only if they are geographically and temporally tagged. For example, during a social event like a concert, people can start exchanging comments and thoughts about the events in a shared virtual dashboard. The dashboard service is not provide by a server, rather all devices roaming around the event implement a distributed service that will exist until someone will keep using it. We define the way of creating and providing service on the fly *here & now*.

Real-world applications for MSN follow three main trends: social gaming, social discovery, and media contents. Concerning social gaming, in [43] the authors investigate the psychological elements affecting the user behaviors in mobile-social network games (M-SNG). The paper also mentions a large spectra of applications suitable for MSN. Some notable examples are the AGON platform, Zynga, Icy Tower ad Mafia Wars. Social discovery applications introduce a new concept of social networking that aims at discovering people who are nearby with similar interests. Such applications exploit short range interfaces such as Bluetooth and WiFi to detect devices carried by people running the same application. Some examples of social discovery application are Foursquare, Gowalla, Sonar and Banjo. With respect to the media content, we mention several applications for sharing different kinds contents such contacts, messages, clips and links. Some examples of such applications are Bluedating, Firechat, Bump and Aka-Aki also described in [9].

Another interesting area for MSN applications are vehicular networks [44, 45, 46, 47, 48]. The ICT market for cars is already big, and it's going to evolve drastically: big players like Google (Android Auto), and Apple (CarPlay) compete for the '*new OS*' for cars. We review [48] as a service discovery framework for VANET, in the same paper the authors list a number of applications that could be developed on top of their platform, most of these applications are in the area of vehicular safety, but other applications are related to infotainment and passengers comfort. A good introduction to the topic of Social Vehicular Network (SVN) is given in some recent works [49, 46, 44]. In [46] the authors develop an application called Verse to facilitate the social communications among vehicle travelers on highways. Verse enables passengers onboard vehicles to share the content information, such as travel blogs with pictures, among each other using impromptu wireless inter-vehicle communications.

3.2. Service Advertisements and Queries

In MSN devices play different roles, namely service provider, service client or service registry, moreover devices can play multiple roles simultaneously. The service providers announce of the existence of the services that they provide. This phase is achieved by propagating a service advertisement message to the devices that are met opportunistically in the MSN, this is commonly referred as proactive service discovery. The *service advertisement* is a compact data structure that summarizes the core features of the service, such as:

- the identifier of the service provider;
- the service interests that classify the service according to the functionalities it provides[1];
- the Quality of Service (QoS) features that describe how the service is provided; for example the estimation of the service competition time, the estimation of the length of the pending requests and other metrics useful to describe the performance of the service provider.
- input and output parameters that describe how to invoke the service and the kind of expected results.

The *service clients* are the devices that discover and access the services in the MSN. The clients propagate a *service query* in the network, this phase is commonly referred as reactive service discovery. The query is a message that describes the kind of service needed by a client. The query wraps a set of parameters that must be directly compared with an advertisement message, in particular a query may contain:

- the service interests that specific the kind of functionalities needed by a client;
- the QoS features that require a specific level of performance of the service provider;

Devices in MSN implement a distributed service registry. A service registry is a (set of) device(s) storing the service advertisements diffused in the network (Section 3.3 describes both the centralized and the distributed implementations). In particular, a device carries the service advertisements of the services it provides, as well as the service advertisements (provided by other devices) that the device received proactively or reactively. Since every device in the MSN is part of the registry, as soon as a device receives a query it checks if one of the advertisements stored locally matches with the query. If a match is found, than the device carrying the *answer* replies to the client with the service advertisement.

[1] There are well-known methods for service classifications, relying on syntactical or ontology-based techniques [50, 51]. These kinds of classifications is beyond the scope of this survey work.

3.3. Service Discovery Architectures

Service discovery architectures can be classified in: directory-based, directory-less or hybrid solutions [52].

The directory-based architectures assume the existence of a directory whose role is twofold:

- management of advertisements: devices providing one or more services store the advertisements in the directory;
- management of queries: devices looking for a service send the query to the directory. If the query matches with one or more advertisements, the directory replies to the service client with the matching advertisements.

The directory-based architectures can be implemented in a centralized or distributed way. In the centralized solutions (among them we cite some results [37, 53, 54]) there exists only one device acting as *directory* that is known in advance by every device in the network. This is the simplest solution, but these architectures are not designed to scale well in large-scale systems. Indeed, the directory is a single point of failure: if it is not available then the clients are not able to discover any service. In distributed solutions (an old but meaningful example is the Jini architecture [53]), a set of devices act as a distributed directory. Such pool of devices can implement methodology for synchronizing the advertisements stored locally or to split the advertisements inside the pool. A distributed directory can be implemented by statically configuring devices that implement the directory or by dynamically electing the devices [55]. In this last case, elected devices are those which ones have the best features for playing the role of directory [56, 57]. The distributed directories are more robust than the centralized ones, as several devices participate to the directory role.

The directory-less architectures, (some notable example are [58, 59]), are simpler than the directory-based ones. With directory less architectures the role of the registry is shared among all the devices in the MSN. As soon as a device receives a query, it checks if any of the advertisements stored locally matches the query. In this case, the device replies to the client, otherwise it propagates the query to other devices selected with a strategy. In a similar way, the providers diffuse the advertisements in the network with a proper strategy. Directory-less architecture are more suitable for MSN, since they do not assume the existence of always-on devices acting as directory. However, the strategy adopted by devices for querying and advertising is a crucial part of the discovery process, and simple solutions based on flooding or gossiping can revel too aggressive in terms of use of the network bandwidth, overheard of the protocol and energy consumption of devices. Section 4 describes the advertisement and query strategies available for service discovery in MSN.

When directory-based and directory-less are combined together, the discovery architecture is hybrid. In this case, the architecture supports the existence of a directory both centralized and distributed. Clients first query the directory; if no advertisements are found then clients query the whole network in a similar way to the process described for the directory-less ones.

3.4. Service Discovery Requirements

The features of MSN described in Section 2 impose several requirements to the service discovery problem described in this section.

Routing and multiple forwarding strategies. Discovering services in networks of mobile devices requires several steps, as shown in Figure 3. Each of the steps has specific goals that can be achieved by exploiting techniques coming from routing and data forwarding in MSN. In details:

- Service query: the goal of this strategy is to propagate a service query to devices that can potentially answer to the query in short time. The query strategy cannot rely on a registry that stores all or a subset of advertisements; rather, it has to explore the network to find devices that provide the service themselves, or devices that already know an advertisement matching with the query. For example, a device may have high probability to answer to a query if the person carrying the device already accessed to similar services matching with it.

- Service advertisement: the goal of this strategy is twofold. Primarily, it aims at diffusing advertisements in the MSN only to devices belonging to people that might be interested in accessing the advertised services. The advertisement phase is successful if people potentially interested in a service receive (at the right time) the advertisement required. In this case data forwarding strategies can be used because the set of recipients of the information it not known in advance (Section 4 surveys some available results). The diffusion of an advertisement might also be directed to a specific receiver (if the device that owns the advertisement knows the device to which deliver it). In this last case, the goal is to deliver quickly the advertisement to the destination. Here, the routing strategies are helpful to route the message towards its final destination.

  Secondly, the service advertisement strategy should avoid forwarding messages towards devices that already received them in the past from previous encounters. Indeed, flooding-based solutions may result too aggressive in terms of use of the network resources and energy costs, and the diffusion of advertisements has to find a balance between effectiveness of the diffusion and management of resources of the MSN.

- Service selection and access: given a service query, the selection strategy aims at ranking the service advertisements received during the query process in order to select the advertisement maximizing an objective function. Such function can be implemented in order to meet different goals: for example to reduce the energy cost, reduce the service invocation time and/or the service response time.

Discovery mode. Devices must support both the reactive and proactive discovery modes. With the reactive mode, a device propagates the query as soon as it needs to access to a service; with the proactive mode a device is proactively notified with some of the service advertisements during the occasional encounters with other devices. In a MSN it is important to adopt both the discovery modes in order exploit the occasional encounters with other devices to exchange service advertisements.

Community-based service discovery. Service discovery in MSN can exploit the community structure (see Section 2.1) in order to make more efficient the discovery phases previously described. In fact as discussed in [24, 60, 61] people with similar interests tend to stay in touch for longer period of times, with respect to people without overlapping interests. Such groups of similar people can be detected by means of community detection algorithms, that measure several metrics for identifying communities. Hence, service clients can propagate a query first among members of the same community in order to find people with matching interests. These people, in turn, might have high probability of answering to the query. Similarly, service providers can diffuse the advertisements inside their community in order to find people potential interested in the service.

4. Advertisement and Query

This section discusses the approaches for the dissemination of advertisements and queries in MSN. Some of the works here discussed are specifically designed for service discovery problem, while others are generically designed for data dissemination, but they can be applied to the dissemination of advertisements and queries. Queries and advertisements are messages that devices must disseminate in the network in a efficient way; the diffusion strategies presented in this section offer a plethora of alternatives, namely interest-based, flooding-based and social-based strategies.

Table 1 summaries the works presented in this subsections according to the following features:

- Forwarding rule: the strategy adopted by the reviewed works for the message forward;
- Mobility: the application scenario considered by the authors to evaluate the strategy. We distinguish between real-word scenarios (obtained with real-world mobility traces) from synthetic scenarios (obtained with mobility models);
- Community Detection: the algorithms used for detecting communities (if adopted in the strategy);
- Evaluation Metrics: some commonly used metrics used for evaluating the strategy.

4.1. Interest-based strategies

In interest-based strategies each device is associated with a set of interests representing the user profile, and each query or advertisement message is also described by a set of interests. The message diffusion strategy exploits only relay devices that have interests similar to the same interests of the message. To this purpose, these strategies adopt a similarity function whose goal is to measure the similarity between the interests of the message to be forwarded and the interests of the potential relay devices. The higher the similarity, the more likely the person carrying the device will use the information (query or advertisement) contained in the message. Examples of similarity functions are the Jaccard-index, the cosine similarity or the Hamming distance.

Figure 5 shows an example of MSN built around node 0 and it shows, with a color gradient, the similarity of interests among the nodes. To this purpose, we considered a network of 20 nodes, where the interests are distributed according to the Zipf distribution (skew parameter set to 0.5). In this network we computed

			Mobility Traces		Evaluation Metrics						
	Paper	**Forwarding rule**	**Real**	**Syntehtic**	**Community Detection**	**Delivery Delay**	**Delivery Ratio**	**Message Sent**	**Power Consumption**	**Fairness**	**Other**
Interest	[24]	similarity among node Interests	infocom 06	SWIM	not addressed	✓	✓	✓			coverage
	[65]	similarity among node Interests	PMTR	HCMM	Louvain algorithm	✓	✓	✓			coverage
	[66]	similarity among node Interests and energy awareness	SIGCOM	SLAW	not addressed	✓	✓	✓	✓	✓	effectivenes s, fairness
	[60]	FM: encounter time with the final destination IB: intetrest-based	infocom 06	SWIM	not addressed	✓					
	[30]	interest-based		CMM	Girvan-Newman			✓			Time To leave
	[62]	interest-based		CMM, RWP	not addressed		✓	✓			
	[68,69]	interest-based	infocom 06, MIT Reality, Cambridge	HCMM	AD-SIMPLE, DRAFT	✓		✓	✓		recall, gain
	[48,67]	interest-based		Road-Network Mobility	not addressed	✓	✓	✓			
Flooding	[71]	flooding-based		ad hoc simulation	not addressed	✓		✓			
	[72]	location-based		ad hoc simulation	not addressed			✓			number of clients that discover a provider
	[70]	flooding-based		ad hoc simulation	not addressed	✓		✓			
Social	[73]	general-purpose framework	infocom 06, MIT Reality, UCSD	not addressed	not addressed	✓	✓	✓			
	[29]	publish/subscribe	MIT Reality, UCDS, CAM, WirelessRope	not addressed	K-Clique, SIMPLE	✓	✓				
	[77]	centrality degree of nodes	infocom 06, MIT Reality, Cambridge, Hong-Kong	not addressed	K-Clique, Newman WNA		✓	✓			centrality and betweeness,
	[31]	contact duration	NUS, infocom 06 MIT Reality	not addressed	yes, assume the existence						number of nodes that can retrieve a copy of a data
	[63]	several utity functions: MFV,MLN,F,P,US		HCMM	based on the HCMM model	✓	✓			✓	

Table 1: Comparative tables of advertisement and query strategies.

the similarity degree between node 0 (our candidate) and the 20 nodes by means of the Jaccard index. In the figure, the colors of the edges and their thicknesses are proportional to the Jaccard index: the higher the similarity the higher the intensity of the color and the thickness. Even in this simple setting, we observe that there are some nodes which have a high similarity with the reference node 0, while other nodes have a weak similarity. This fact has been exploited by interest-based algorithms to optimize the selection of rely nodes for the dissemination of query and advertisement messages.

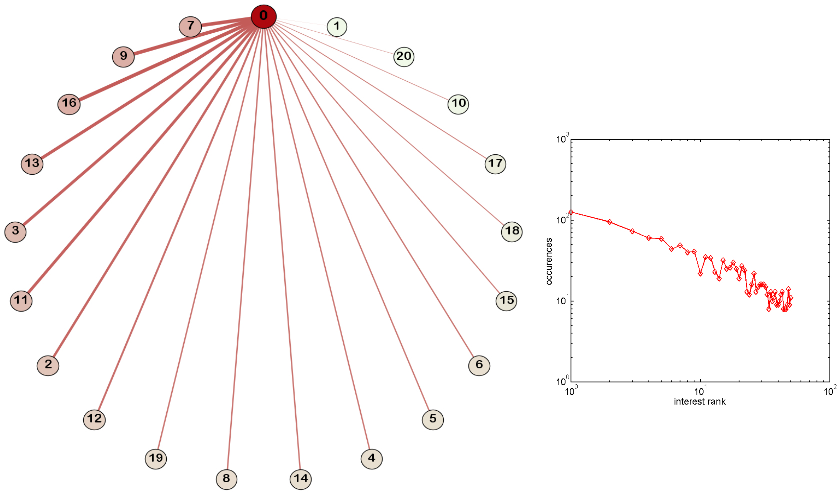


Figure 5: Similarity of interests among 20 nodes.

The authors of [62] propose a peer-to-peer service discovery protocol. They use a pull-based, (on-demand) query generation and propagation scheme, that merges two distinct overlay networks: one made by *interest* of devices, i.e. information about the *type* of content the devices are interested in, and one of *contacts* built with information about physical proximity between devices. Query are represented with a type (music, video, etc) and they are sent to all interested neighbors; these are discovered by previous messages received by the device and cached locally, or by propagation of interests using a gossip protocol. The authors study via simulation the hit-rate of the service discovery protocol and the influence of mobility and density of the network. The queries are based on a static set of topics without others metadata used in other works, however the paper does not address the case in which devices that share similar contents or services, i.e. how to deal with service selection.

The SocialCast [30] algorithm implements a publish/subscribe paradigm as in [63]. SocialCast relies on the observation that people with similar interests tend to meet more frequently with respect to people without overlapping interests. The data forwarding strategy is implemented by observing the mobility patterns of people and also the interests of devices running SocialCast. SocialCast adopts an interpolation function based on the Kalman filter, to predict the movement of people by tracking their previous movements. The SocialCast algorithms is implemented in several steps: *(i)* the dissemination of user interests, each device broadcasts the list of its interests to the ego-network. Then *(ii)* every device computes the utility function for all its interests and lastly *(iii)* every device checks the contents its carries with respect to the subscriptions of the devices, and eventually the contents are forwarded to the subscribers.

Mei et al. [24] focus on a forwarding strategy based on sociality of users in a MSN. This paper proposes the so-called interest-cast forwarding schema for the distribution of contents. The aim of interest-cast is to efficiently diffuse information to the highest number of interested devices (in particular the authors use the cosine similarity). The selection of interested devices is implicit and it builds on an assessment of the similarity of the interest of devices. Under this respect, the interest-cast service can be seen as a directory-less service in which the service selection is performed by the potential recipients of the content that filter the input content when they receive it. The assessment of interest-cast addresses the performance and overhead of the content diffusion, and especially focuses on the coverage, i.e. the percentage of relevant destination that hold a copy of the content within a time frame. The assessment is performed over real mobility trances and on synthetic traces built with the SWIM mobility model [64].

In [60] the authors describe a comparison between two forwarding strategies used to deliver a message from a source towards a destination in MSN. The paper presents two simple but effective strategies, namely FirstMeeting (FM) and InterestBased (IB). The first strategy is social-oblivious in the sense that it does not use any information related to the interests of the devices in order to take the forwarding decision. Conversely, the second strategy is based on the interest profiles of devices. With FM the source device, for example the one generating an advertisement for another device, always generates two copies of the message. One copy is stored locally while the second one is forwarded to device R, only if R is met before the final destination. Similarly to [24], the IB strategy relies on the assumption that people with similar interests tend to visit more frequently. With the IB strategy a device delivers a message to another device if the similarity between the interests is greater than a fixed threshold. The authors present a comparison between FM and IB by using two simulation scenarios based on real and synthetic mobility traces. The traces reproduce two realistic scenarios where the mobility of devices is affected by the interests of people carrying them.

The authors of [65] defines the BehaviourCast problem for the diffusion of information in MSN. BehaviourCast is based on four key-features. The validity: forwarding a message to a subset of the interested device, the effectiveness: forwarding the message in order to achieve total coverage of devices interested, efficiency: involving the smaller number of relying devices and the eventual termination: interrupting the forwarding of a message after a given time. The authors also propose two interest-based strategies solving the BehaviourCast problem, namely the basic InterestCast and the weighted InterestsCast. With the basic InterestCast, every device i executes an utility function that counts the total number of devices encountered and sharing the same interests of i. The authors argue that such basic strategy has no memory of past encounters, for this reason the authors propose an enhanced version, namely the weighted utility function. This last strategy is based on the Shannon's Entropy principle, it counts separately the number of encounters the device i had in the past with device j. The weighted utility function, hence, keeps track of the number of encounters with every single devices met. The authors simulate the two strategies proposed both with real and synthetic mobility traces and they compare the results obtained with respect to two similar works, ProfileCast and SocialCast.

The authors of [66] present PIPER an interest-aware social-based forwarding algorithm for MSN. PIPER extends the IPER algorithm by taking into account also the energy consumption of devices involved in the forwarding process. The IPER forwarding strategy combines together several factors in order to rank all the possible candidates for forwarding a message towards its destination. In particular, given the device i the IPER function combines the similarity between the interests of the device and the interests of the message to be forwarded, a dumping factor to determine the amount of reliance on opportunistic forwarding, the social rank of device i and the similarity between the interests of the advertisements and the interests of all the friends of device i. PIPER extends IPER by adding another parameter used for ranking a candidate forwarded, namely the battery level. The authors state that during the forwarding process, devices with low battery level should be excluded form the forwarding process in order to reduce as much as possible unattended battery depletion. In particular a device is highly ranked if one of the following conditions hold: its battery level is above a threshold, the person carrying the device is "linked with popular friends" and also if the set of friends of the person caring the device are also interested in the message. The paper also discusses the performance of PIPER with respect to IPER and a benchmark algorithm based on a Epidemic forwarding strategy with real an synthetic mobility traces.

In [48, 67] the authors propose a Service Discovery middleware for Vehicular Networks, that they call Cooperation as a service (CaaS). CaaS use a hybrid publish/subscribe mechanism where the driver (or subscriber) expresses his interests regarding a service (or a set of services) and where vehicles/drivers having subscribed to the same service will cooperate to provide the subscriber with the necessary information regarding the service he has subscribed to, by publishing this information in the network. CaaS adopts a Publish/Subscribe approach. In particular the authors assume that the network is peer-to-peer without an external infrastructure, the routing layer is organized with an overlay network to diffuse interest-based information, the routing is done using interests (CBR). The overlay is organized in two layer, they use CBR for intra-cluster communications; subscriptions of all members of the cluster are forwarded to a cluster-head and updated regularly to deal with the continuous movement of the nodes, note that they use more than a tree for each content and propose a specific protocol to deal with these forest of tree efficiently.

The authors of [68] propose SIDEMAN and its evolution termed CORDIAL [69]. Similarly to [30], SIDEMAN and CORDIAL exploit the similitude of interests among people in order to diffuse queries toward people that might answer with high probability, and to diffuse advertisements towards people that might be interested to such messages. In particular such algorithms are social and opportunistic in that they takes advantage of human behavior concerning locations and community membership. The two algorithms rely on a spatio-temporal community detection algorithm that identifies groups of people with high temporal correlation. In turn, such communities are exploited in order to diffuse advertisements and queries. The advertisement dissemination is realized by discovering and recognizing social communities and by a proactive diffusion of advertisements among people with similar interests. The service query is implemented by a controlled query propagation mechanism aimed at avoiding extensive use of indiscriminate flooding among people in the same community. SIDEMAN and CORDIAL adopt some strategies for reducing the overhead of the advertisement and query phases. More specifically, devices keep track of the communities visited along the time in order to avoid useless exchange of interests every time a community is detected. Moreover, the two algorithms adopt Bloom Filters in order to check in constant time if a device is interested in an advertisement or if an advertisement answers to a query.

4.2. Flooding-based strategies

Flooding-based strategies aim at maximizing the number of recipients of queries and advertisements messages but they do not use any social-based metrics to select the rely devices of messages. The main advantage of these solutions is the effectiveness and the simplicity of the diffusion strategy, but they may incur in a high overhead in terms of messages forwarded, network bandwidth and the devices battery depletion.

The authors of [70] present a service discovery protocol for MANET with low mobility of devices. The protocol is based on the reliable broadcast. Services are not described by id's nor by a service type, rather they are labeled with the input/output parameters. The parameters of the services available in the network are spread using a proactive exchange of the local tables stored locally by each device. Such tables contain a mapping between the service and the I/O parameters needed. Moreover, the protocol is supposed to be embedded with the neighbors discovery protocol of the underlying MANET. In this way, the services are advertised together with the discovery of devices found in proximity. Queries are diffused reactively by flooding the neighborhood, hence this happens as soon as a device needs to access to a specific service. The queries are described with a set of parameters, the authors propose a simple but effective solution for the composition of multiple services together. The use of parameters are described using a common taxonomy, that includes the possibility of hierarchies among parameters. The authors classify the queries within two categories, namely *exact* or *generic*. The protocol is evaluated via simulations by means of the NS-2 network simulator, statistics about the delay of service discovery and the amount of overhead of the protocol are studied. The interesting point, in our view is the use of more informative parameters description than simple id or type of service description. This enables service composition protocols and generic query of service providers.

In [71] the authors address the problem of service discovery in delay tolerant networks. The scheme adopts a proactive propagation of service advertisements, where each service provider announces periodically its own services to the entire network. The advertisement is composed by a list of keywords, and all the devices in the network cache the received advertisements and associate them to their latest time of reception. When a client looks for a service, it first checks into its local cache an advertisements. If there are no matches, then it starts a reactive service discovery by broadcasting a service query packet. Each device receiving the query looks for matches in its internal cache, hence the query can receive an early response even from intermediate devices. The client then selects the matching replies to its query based on the latest time of reception. The solution proposed [71] is evaluated by means of the NS-2 network simulator with an ad hoc mobility model, to assess the efficiency and the overhead of service discovery. Although this scheme does not consider sociality aspects in the advertisements and query distribution, its basic architecture of service discovery is also valid for MSN, and its mechanisms of diffusion of advertisements and service queries can be easily combined with knowledge about the communities and user interests to be adopted in MSN.

OLFServ (Opportunistic and Location-aware Forwarding protocol for Service delivery) [72] considers a scenario in which geo-localized devices in a mobile ad hoc network. The authors refer explicitly to an application scenario sparse, hence the network may become disconnected for some periods. It assumes that any device can advertise a service, by using a multicast-based scheme that limits the area of propagation of advertisement process. Service advertisements have an expiration time and they contain information about the position of the emitter (the service provider) and the geographic area where the service can be accessed. Furthermore, the service advertisements also include a list of potential recipients (service clients), although the paper does not discuss how this list is created and maintained. Beyond making public a new service, the purpose of the advertisement is also to make more efficient the access to the service by providing geographical information about the service provider. The authors evaluate the efficiency of OLFServ in distributing the advertisements against their rate of success (in terms of number of clients that find correctly a service provider).

4.3. Social-based strategies

Social-based strategies exploit information about users' social relationships to drive the dissemination of queries and advertisements. However, the human social relationships are difficult to capture and to measure, since they are influenced by many factors. According to Granovetter [5], "the strength of a tie is a (probably linear) combination of the amount of time, the emotional intensity, the intimacy (mutual confiding) and the reciprocal services which characterize the tie". Relationships among devices can be determined by using specific utility functions, such as contact duration among devices, inter-contact time or remaining inter-contact time or by means of well-known centrality metrics such as the betweenness centrality or the closeness centrality. Generally speaking, the social-based strategies are characterized by the capability of the strategy in discovering devices among which there exist non-occasional social ties. In turn, such devices are used to optimize the diffusion of information among social-linked devices.

Figure 6 shows the idea behind the social-based strategies. The figure has been obtained considering an MSN in which we detected communities by using the Modularity algorithm [17]. The figure shows the evolution of the detected communities over time, starting from the setup phase of the algorithm. The detected communities are denoted by different colors and the dimension of a node is proportional to the number of connections of the node with different communities. It is seen on the figure how the algorithm progressively enriches the information about communities: the first snapshot shows the communities found in the setup phase, the second refers to an intermediate stage, and the third shows the communities at the end of the simulation. Furthermore, the figure highlights (with circles of larger sizes) the presence of *hub* nodes, i.e. nodes with highly connected with different communities.

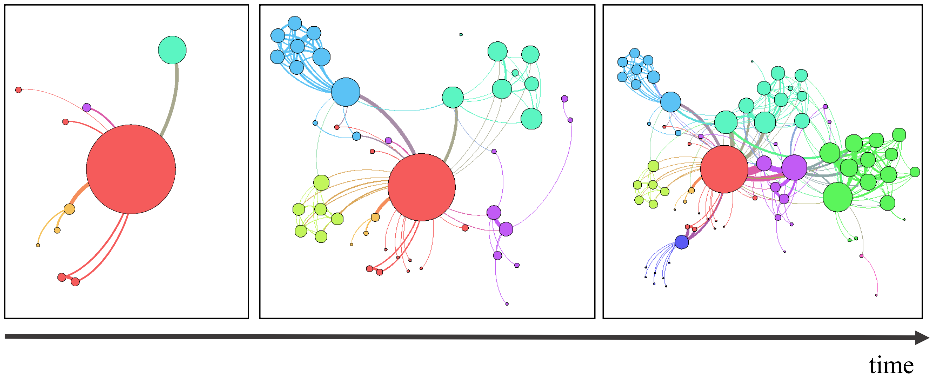


Figure 6: Communities in different temporal snapshots.

The authors of [73] describe a general forwarding algorithm for the diffusion of advertisement and query messages, namely Delegation Forwarding (DF). DF relies on a basic idea: a message is forwarded from the sender to an intermediate device only if the receiver is better than the sender with respect to a specific metric. The authors of DF does not define any new metric for taking the forwarding decision, rather they propose a general framework for deciding who should receive a message copy. The authors discuss the effectiveness of DF when implemented with some strategies:

- Epidemic [20]: a device forwards a message to all devices it is in contact with only if they did not have already a copy of it stored locally;
- Frequency [74]: a device forwards the message to another device if it has more total contacts with respect to the sender device;
- Last Contact: a device forwards a message to another device if it has contacted any device more *often* than the sender device;
- Destination Frequency: a device forwards a message to another device if it has contacted any device more *frequently* than the sender device;
- Destination Last Contact [75]: a device forwards a message to another device if it "has contacted any device more recently" than the sender device;
- Spray and Wait [76]: the message source s creates l replicas for the same message. If, along the time, s carries $k > 1$ replicas than if s encounters another device that has no replicas, then s forwards half of its replicas to the encountered node. Otherwise the Destination Last Contact rule is applied.
- SimBet [25]: the message source forwards a message to another device only if the SimBet metric of the encountered devices is higher than that the

SimBet metric of the source node. The SimBet metrics is basically a linear combinations of the betweenness and similarity graph metrics.

The BUBBLE Rap algorithm [77] implements a social-based forwarding strategy in delay tolerant networks. Users are given a global ranking and a local ranking, computed according to their *importance* in the network. The information (either service query or an advertisement) is first forwarded from the sender through users with higher global ranking, until the message reaches a user in the same community of the receiver. Then, the message is forwarded only among users in the same community according to the local ranking, until the information reaches its destination.

Socio-aware [29] is a publish subscribe strategy that relies on a overlay structure based on communities. Communities are detected by means of two algorithms proposed by the same authors [17]. The overlay structure assumes that devices can play different roles: the brokers, the subscribers and the publishers. The brokers have high centrality degree inside the community. The brokers receive all the subscriptions and un-subscriptions from other devices as well as the list of the centrality values form the devices in contact with a time stamp. The broker device evaluates the centrality values previously received in order to decide which device should take the role of the broker. If a change is needed, then the broker transfers the subscription list to the new broker with the highest centrality degree. Then, an update message is sent to all the brokers in the overall network. During the gossiping stage, subscriptions are propagated towards the community's broker. When a subscription reaches the broker, it is propagated to all other brokers, and then the broker checks its own subscription list. In the case there are members in its community that must receive the subscription, the broker floods the community with the information.

In ContentPlace [63] devices advertise the data objects they are interested in, and data objects that they carry around the network. Data objects are contents of different types, such as media content that are transferred with some communication channels. The protocol proactively exchanges information about the channels provided and subscribed by devices encountered along the time. Moreover, the protocol must decide on the basis of a utility function which data objects to replicate. The utility is a function of weights, the weights are function of groups, channels and the availability of the object in the network. The authors analyze via simulation ContentPlace with a number of different utility policies for computing such weights.

The paper [31] presents a forwarding schema by taking into account the time needed to transfer a piece of information (especially multimedia content). The authors observe that the time needed for such transfer could be not negligible, and that the transfer success is related to the duration of the contact time between the devices involved in the information transfer. In fact, typical forwarding schema for MSN may fail to forward the content if the transfer time is longer than the contact time between the sender and the chosen rely node.

5. Service Selection

Service Selection is another fundamental step of every service discovery protocol. After the advertisement and query steps, a device might receive a number of advertisements whose services provide the same or similar functionalities. In

[33] service selection is presented as the phase that comes after all the replies from a query are collected at the client and the right service provider must be selected among the alternatives. As discussed in [33], the most efforts in the literature focus on service advertisement and query, while the selection phase has not been studied in depth. In the following, we review how service selection has been studied so far by focusing on how to describe a service and how to implement the proper selection.

First, service selection is based on the evaluation of the properties of the service. In MSN different formalisms (languages) are used to describe service properties, they range from a simple key-value pairs, to XML or even more complex description. Moreover other formalisms are needed to describe user preferences and other context-information such as users-location or scope awareness. There is a constant trend in raising the complexity of these formalisms, moving away from simple keywords based service description and syntactic-matching of attributes, towards a semantically richer matching [70]. This, in turn, enables the use of very descriptive queries that perform most of the selection phase by carefully describing what are the real interests of a client. Most of the works on service discovery lack this point of view and study the query phase only as an information diffusion process; only few works measure metrics like the precision and recall of a query [78].

Second, as reported in [33] service selection protocols differentiates between *user's assisted* or *automatic* selection. In MSN, with pocket devices and mobile users, user's assisted selection might result not appropriate because users are typically not aware of the internal mechanism regulating the selection policy. Moreover, the MSN are supposed to implement an autonomic cooperation model, where user's intervention should be avoided as much as possible. Conversely, the automatic selection policies are more widely used and we expect that has noted previously, better description of user needs and context, will reduce the gap between the automatic and manual choice, with respect to overall user's satisfaction. For this reasons, we focus on the automatic service selection protocols. We therefore present a first attempt to classify the most interesting selection protocols along two categories: manual selection and automatic selection as shown in Figure 7.

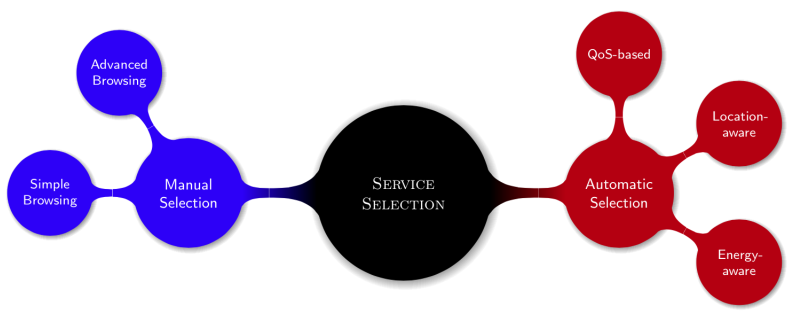


Figure 7: Service selection strategies.

A general-purposes service selection protocol is proposed in [79]. This selection protocol does not depend on any specific discovery protocol, rather it can be potentially applicable with any existing discovery protocol. The solution described in [79] implements a service selection based on dynamic attributes. Some notable examples of attributes are: "the size of the print queue or the computational load of the host that a service may be located on". Each client has a specific set of weights that measure the relevance, for that client, of the dynamic attributes. The weights are used to compute an overall score used to rank different service providers. Given the attributes and the ranking for a client, the service selection becomes mostly automated. In fact the selection is obtained by selecting the first providers in the ranked list of every client.

The authors of [80] propose several policies for the service selection. The policy proposed are: (i) Minimum Expected Value that minimizes the time required to receive the first response of the service invocation, (ii) the Random policy that selects randomly the provider, (iii) the Always First policy that selects the first suitable provider that is in contact with the client, if no such provider exists, the client waits to encounter it, (iv) the Atomic policy that selects the provider that offers a single service satisfying the request of the client.

The authors of [81] propose a cross-layer service discovery and service selection architecture. The solution proposed is based on the extension of two routing protocol for MANET, namely the DSR and DSDV by adding the service discovery and selection features. The SDL is defined as the Service Discovery Layer and the RLD is defined as the Routing Layer Driver. The SDL stores information about known servers in a service table. Table entries have five fields: service description, service location (e.g IP of the provider), minimum hop count from the current host to a service provider, optional routing protocol specific information provided by RLD (e.g., a list of available routes to the destination), and optional service-specific metrics supplied by a service provider (e.g., current load, CPU usage). The service selection is performed by applying a selection policy needs the client according to the information available in the SDL. The authors do not specify any policy, rather they propose a general-purpose framework for the service selection. Moreover, the authors propose a simple method for re-evaluating the SDL metrics and to re-select the provider as soon as the SDL metrics change significantly.

In [82, 78] presents a Location Aware Service Discovery Protocol (LADS), and a corresponding Service Selection Protocol (LASS). Both protocols assume that devices know their geographic location and their motion speed. The service discovery phase is based on a geographic scoped broadcast, i.e. only devices sufficiently close to the requester and not moving too fast, will receive the query and eventually send a reply. A node running LASS stops a query if it already forwarded k replies for the same query, the threshold k is chosen by the requester. Alternatively, a node running LASS stops the current reply if it does not satisfy a quality criteria, i.e. the distance/speed ratio of its service provider is worse than one already forwarded.

The authors of [83] propose two methods for the service selection. The methods proposed assume that every node in the network (the authors refer to nodes in a Wireless Sensor Network) know their position in advance. The first method is named Closest service selection and it selects the provider whose euclidean distance is the smallest among all the providers available in the network. The second method is named Nearby service selection and, given a threshold of the distance, it selects the provider whose distance is the nearest to the threshold.

In [84] the authors present a middleware for service selection in MANET, with a particular focus on emergency scenarios. The authors classify services in two complementary classes, namely comfort and safety-related services. The authors show that common service selection algorithms fail to distinguish the differences on the two classes. The solution proposed in [84] is a context-aware M2M middleware for service selection that incorporates client's realistic expectations, which are pre-defined in the middleware. The selection of comfort services is achieved by selecting the most popular services. The popularity is computed by considering the feedbacks reported by other clients, such feedbacks are un turn combined with the hop-count metric. The selection of safety-related services is achieved by selecting the most reliable providers, also in this case the authors of [84] adopt the hop-count metric.

In [85] the authors describe CoDA, a cost-based service discovery algorithm for Smart Environments. CoDA is based on a directory-based discovery architecture with a distributed implementation of the service registry. The network is configured with a number of service registries, and both the clients and the providers directly interact with the nearest registry in order to find a service or to announce a service. Despite of the kind of architecture, CoDA addresses the problem of which provider selects when multiple options are available. The solution proposed is to minimize the energy consumption required by a client in order to invoke the services available. The energy consumption is estimated by considering the distance between the client and provider in terms of number of hops, together with the energy cost of the path traversed. The lower the energy cost of the path toward provider x, the higher the probability that a client will select x as best option. CoDA considers different costs for the paths traversed by a client, such costs are defined according to the technology of the path. For example CoDA assigns different costs to wireless, wired or hybrid links.

In [86] the authors present a service discovery protocol with emphasis on security and trust. The authors explain that in a MSN, a content provider's may not be consistent with its description metadata, or the service provided may exhibit malicious behavior. Since a reliable central management party for supporting trustworthiness is not available, the environment requires a de-centralized trust solution letting each participant of MSN to manage the access control by itself. The proposed protocol is based on *reputation* of service providers. The idea is that each service provider could attach as metadata of a service, a list of past users of that service, this list works as a list of *recommended references* that save information about their past interaction with the service providers in a table of ratings. Before accessing a service, a requester could eventually contact the list of recommended references (nodes in the network) and check the ratings of the service, if more services are available this could be used in the selection phase to properly rank the service providers. This scheme could be attacked by a malicious provider that includes only references with high ratings for its services: the proposed solution is to maintain a list of friendly and trusted nodes and accept as recommended references only the ratings expressed by the requester trusted nodes. Moreover if a friend has given an high rating to a bad service provider, that node will be removed by the list of trusted friends. Note that the selection phase implicitly uses information about time, since the ratings are based on experiences that node have in accessing the service.

Finally, Table 2 compares the service selection strategies previously described with respect to three criteria:

	Paper	Selection Policy	Seletion in Query	Network Architecture
QoS	[79]	Relevance of service attribute	✗	Infrastructure-based
	[80]	Minimize response time, random selection, first choice, best-match policies	✗	Opportunistic network
	[81]	Description of the service, service location, minimum hop count	✗	MANET
Localization	[82,78]	Proximity of the provider	✓	MANET
	[83]	Closest provider and proximity provider	✗	Wireless Sensor Networks
Energy	[84]	Most popular provider and minimum hop-count	✗	MANET
	[85]	Minimize energy cost for the service access	✗	Infrastructure-based
Interest-based	[86]	Reputation of the service provider	✓	MSN

Table 2: Comparative tables of service selection strategies.

- selection policy: the policy used for the selection of the provider among QoS, Localization or Energy-based;
- Selection in Query: this feature describes if the selection strategy implements a pre-filtering mechanism in order to exclude in advance services that are appropriate for the service query;
- Network Architecture: the kind of architecture (either ad hoc network, WSN, DTN, etc.) considered by the authors;

6. Service Access

In the service access, the client requests the service to the provider chosen in the service selection phase and receive the results. In a MSN both the client requests and the responses of the provider may travel along the MSN using the available mechanisms. As there may not be a path constantly available between the client and the provider, the service access protocol should be tolerant to delays and disconnections. However, differently than the diffusion of advertisements and service discovery, the communications involved in the service access depend on the nature of the service. In some cases the service is stateless, thus service access protocol is limited to the exchange of a request and a response messages. In other cases instead, the request (or the response) may require the transmission of a large amount of data (think for example to a video streaming service). As a result, the phase of service access may be (even by far) the most expensive in terms of bandwidth and energy required. Despite this fact, only few works address this phase.

In particular, service access is discussed in some recent works [71, 87, 72, 88], although not specifically designed for MSN. Most of these works [71, 87, 72] implicitly assume services are stateless, that is, they can be delivered without memorization of the state at the service provider, and thus require a simple exchange of request and response messages. The work of [88] instead considers a wider scenario including services with state and stateless.

In particular, the service access scheme of [72] assumes a relatively simple service, which can be delivered by exchanging a single request and response message. This work focuses exclusively on the routing of these messages. In particular, it aims at optimizing the routing by using a different routing scheme than that the one used for service discovery. The proposed routing scheme exploits the information about geo-localization of the client and of the provider, and their estimated speeds to deliver the messages in the right place and (possibly) the right time.

The Time-Aware Opportunistic middleware (TAO) [87] addresses hybrid networks, defined as infrastructure-based networks with opportunistic extensions. Also its service access scheme (called TAO-INV, where INV stands for invocation) assumes relatively simple services, and it exploits request and response messages that are forwarded by using a "store, carry and forward" principle. Also in TAO the forwarding scheme for service access differs from the forwarding scheme adopted for service discovery, in the attempt to limit the cost of epidemic forwarding by reducing the number of copies of these messages that are generated in the network. Specifically, to increase the chance of fast delivery of a service request message, the routing scheme classifies the potential rely devices as good or bad based on the last date of contact with the service provider (the smaller is this date, the highest is the goodness of a rely device). To improve the reliability of the scheme, TAO-INV also forwards the message to some bad relay devices. Since the request message keeps the path traversed from the client to the service provider, the provider uses a reverse source routing scheme to send back the response.

Although [71] addresses resource/service discovery in delay tolerant networks, its results may also apply to service access in MSN. Differently than the previous works, the authors of [71] propose to merge the service query and request phases. In this approach, when a service query reaches the service provider it implicitly requests the service. In this case, the service response adopts an epidemic routing scheme, but when a copy of the response message reaches the client, the client immediately performs a network-wide broadcast to stop the further forwarding of other response message copies in the network in order to limit the overhead of the protocol.

In [88] the authors focus on service access (which is called service invocation in the paper) in disconnected ad hoc networks. The service access relies on a publish-subscribe mechanism, in which the clients publish a service description, and the providers subscribe for specific service descriptions. When there is a match, the service provider(s) transfer back the response by using again a publish subscribe scheme. In particular, the subscriber publishes a message with the identifier of the client, so that the client can subscribe for this message and receive the responses. Although there are presumably limitations in the parameters that the client can use to request a service, differently than the other methods, the scheme is not stateless and thus the response is not limited to a single message, but it can develop over several messages from the provider to the client. For this reason, this mechanism is associated to deadlines in order to let the provider clean its state of outdated subscriptions. Furthermore, the publish/subscribe scheme enable multiple providers to offer the same service to the client at the same time. This is partly a “desired” behavior of the protocol, as it enforces redundancy and reliability, but it requires a mechanism to limit the number of providers that connect to the client.

The entire mechanism proposed in [88] is also designed to be delay tolerant as the underlying network may be (temporarily) disconnected, and thus messages can be delayed. Furthermore, to manage situations in which the client and the provider become permanently disconnected during a service access, the authors propose to use keep the state of the session at the client-side, so that the client can recover by looking for an alternative provider.

Apart the work of [88], the other works focus only on the aspects of routing related to the messages involved in the service access. Furthermore, as they are not specifically designed for MSN, they do not introduce any optimization in data forwarding related to the social aspects of devices mobility, which, as observed in [24], brings significant advantages on the performance of the communication protocols. On the other hand, they observe that the interaction between the client and the provider requires different data diffusion mechanisms than those used to diffuse advertisements and queries. In particular, they all adopt routing schemes that tend to unicast-like communications by limiting the epidemic effect in the message forwarding.

Based on the latter observation, all the existing literature on general data diffusion schemes for social-based networks can be reconsidered for service access. As the review of such results is beyond the scope of the present survey, we limit here to mention [31, 89]. Specifically, [31] considers the contact time among devices and the time required to transfer the content in order to choose the best forwarding device to the destination. This can be particularly relevant in the access to services that have state and that require the transfer of large amount of data.

The optimization of the output bandwidth of a service provider in the context of a MSN is the focus of [89]. It formalizes a global optimization problem that aims at distributing the output bandwidth to several client by taking into account the freshness of the content transferred to the clients, in a model where the content continuously flushes from the provider to the clients.

Table 3 compares the service access strategies previously described with respect to the following criteria:

- network architecture: the kind of architecture (either ad hoc network, MSN, DTN, etc.) considered by the authors;
- stateful service: whether the service access protocol requires a service provider to keep a state. This is necessary when the service is complex and its access requires several interactions between the client and the provider;
- forwarding schema: the messages forwarding strategy adopted to access the services;
- use of sociality metrics: if the proposed approach exploits the human sociality to enhance the service access;

Paper	Network Architecture	Stateful Service	Forwarding Schema for Service Access	Sociality Metrics	Temporal Metrics
[88]	MANET	✓	publish/subscribe	✗	✗
[72]	MANET	✗	unicast / geo-localization of devices	✗	✗
[87]	Infrastructured with opportunistic extensions	✗	epidemic	✗	✗
[71]	DTN	✗	epidemic with limiting rules	✗	✗
[89]	MSN	✓	not addressed	not addressed	✗
[31]	MSN	not addressed	unicast	✓	✓

Table 3: Comparative tables of service access strategies.

- use of temporal metrics: the use of temporal metric such as contact duration or inter-contact time, to enhance the service access;

7. Discussion and Open Issues

There is a general tendency of MSN towards a service oriented organization, this is witnessed by the recent interest of the research for this aspect, as discussed in the above sections. This trend is motivated by the large availability and heterogeneity of services that will be offered by devices in the near future. There are, however, some barriers that still need to be removed.

The diffusion of discovery messages (queries and advertisements) represents a first main challenge to the introduction of service-oriented paradigms in MSN. The works surveyed in Section 4 provide a first attempt to solve this issue, but these solutions are still in their youth. We identify three areas of investigation for the dissemination of discovery messages, namely multiple forwarding strategies, understanding human mobility and end-user selfishness.

A first observation is that advertisements and queries are messages that require different diffusion strategies. In fact, as discussed in Section 3.4, queries should be distributed to devices that have the highest probability of finding an answer in short time. For this reason, the diffusion of advertisement messages may exploit rely devices that might be interested in accessing the service or that may easily meet other devices highly interested in these messages. The selection of rely devices with such properties can become more accurate by using community detection algorithms that combine temporal, spatial and social attributes. To the best of our knowledge, the distributed community detection algorithms suitable for MSN only address one of those attributes, giving rise to communities that only partially reflect the complexity of the human behaviors. In fact, algorithms that exploit only temporal or spatial metrics aggregate in communities people that meet frequently or that visit often the same places. However, disregarding weak temporal or spatial correlations among people, these algorithms may fail to connect devices brought by strangers (i.e. users that have social ties too weak to enter in a community) that instead may act as bridges among communities [65]. By means of more accurate community detection algorithms, a device ready to distribute a service query or an advertisement can better assess the potentiality of other devices as relays for its messages.

A second important aspect is how to exploit human mobility in the diffusion of queries and advertisements. Here the key is how to predict the human mobility based on the observation of the past encounters with other people, and how to use this prediction in the dissemination of discovery and advertisement messages. In particular, if a device k finds that h might answer to a query with high probability, then k may analyze its past encounters with h to predict when it will meet h again, and thus decide whether to wait for a meeting with h or to choose another rely device. Some recent works address the problem of understating human mobility pattern [90, 91], but these results are not integrated in the service discovery loop.

Third, the selfishness of individuals taking part to the discovery process is a natural but limiting feature of MSN. Most of the works surveyed in this work assume that all devices in a MSN collaborate to the service discovery process. However, in real scenarios, this assumption is a concrete barrier. People are skeptics with respect to unknown mobile applications that may cause an uncontrolled battery depletion, and that take autonomous decisions. Moreover, people might not agree in revealing personal interests and personal habits in order to detect communities or to propagate a query to a similar person. For these reasons, the service discovery process needs to be thought back to meet additional requirements such as energy awareness and privacy/security concerns. In particular, the strategy to select the target device to which forward a discovery message can be enhanced with the awareness of the energy consumption of the discovery process. Devices with low a battery level or devices with scarce computational resources could be temporary excluded from the service discovery. In addition, the strategies for service messages dissemination may introduce rewards to devices that cooperate.

Regarding the service selection phase, the works surveyed in Section 5 show that this phase is a fundamental but difficult step for SOA in MSN. In particular, we believe that the degree of interaction among users may have effects on the service selection strategies that do not clearly emerged yet. In the following, we discuss some possible research directions on this topic.

The dynamic nature of MSN, clearly steers the possible alternative illustrated in Table 7 towards protocols that perform an automatic selection of service providers. On the other hand, the most studied approach for service selection remains the selection of the nearest service provider. Clearly this is simplistic as, in other contexts, there are already protocols that optimize the selection not only with respect of QoS parameters, like access time, service load, etc, but more significantly with respect to *weights* or *reputation* (of providers) that are just a way to describe user preferences.

On the other hand, the alternative of manual selection is, in our view, inappropriate and impractical. Leaving the selection of the service providers (even based on a ranked list produced automatically) to the user could lead to paradoxical results: normal users do not know really the details of a ranking algorithm, nor understand the metrics that lead to a specific rank. Therefore, the only possible realistic user choice, is just selecting the first ranked service provider among the ones available. Thus, paradoxically reducing the manual selection to a slowed version of the automatic one.

On the other hand, the automatic selection (even based on the same ranked list mentioned above) may work only if the users trust it (i.e. if it really selects the best service providers). Note that this gives raise to quality of service issues in service access. A possible direction to tackle with these issues is to interact in a more informative way with the user, for example by exploiting information about users' preferences. This could be achieved by learning from the actions of the user, for example by monitoring premature interruptions of service access explicitly canceled by the user (could mean an incorrect selection), or by analyzing the behavior of users in the same communities or with similar interests. To the best of our knowledge, these aspects are still uncovered by the research in service discovery in MSN.

For what concerns the service access, most of the works are not specific to MSN (hence they do not exploit users' social ties), and they mostly address routing of service access messages. However, what emerges clearly is the need for communication strategies different from those used for service queries and advertisements. Another important observation is that very few works aim at exploiting opportunistically the evolution of the MSN during the access. This is particularly relevant when accessing services with state, which may require the transfer of a larger amount of data, and thus they may require the exchange of several response messages. In fact, devices' mobility in MSN may affect the QoS advertised or stipulated at service query time, the energy consumption of the service access phase, or it may even result in the interruption of a service due to network disconnections. As discussed in Section 6, these issues are only partly addressed in [88] in the case of service interruptions. On the other hand, mobility may also rise opportunities for improving the QoS of a given service, for example due to the availability of a new provider for the same service near the client. To meet these opportunities or to initiate recovery procedures in case the provider fails to meet the QoS requirements of the client, the service access phase may play a role in detecting changes in the way in which the service is currently delivered, and in triggering the mechanism already available in the service discovery and selection phases. However, so far these aspects did not receive much attention.

8. Conclusions

Social networking is gaining increased notoriety thanks to the widespread use of mobile devices, especially smart phones and tablets, whose pervasive presence constitutes the vast majority of devices at the edge of modern telecommunication networks. As a consequence, the mobile social networking paradigm, which combines social networks and mobile computing, has emerged. Mobile Social Networks are the most representative application scenario of this new paradigm. MSNs offer new opportunities for sharing contents and resources among devices carried by people, giving rise to a service-oriented model. In fact, every resource available locally on a device can be offered as a service that can be discovered and accessed. The advertisement, query selection and access operations are the typical steps of every service discovery framework. We survey in this paper the most recent results in literature concerning the service discovery, analyzed in the context of the MSNs. In particular we first survey MSNs by highlighting their mobility and sociality nature; then we introduce the service discovery problem and its requirements on MSN. For every step of the service discovery process, we present a qualitative comparison among results in the literature. We conclude this survey by presenting some research lines concerning the service discovery problem in MSN.

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