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Mobile social network in proximity: taxonomy, approaches and open challenges

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Abstract

Purpose – Recent smart mobile devices are capable of letting users produce various digital content, and share/upload the content to many social network services (SNS) directly via wireless network connections. The phenomenon has increased the number of people using mobile SNS applications. Although the applications have become more popular, mobile users have been restricted in the virtual communities of online SNS and are not aware of the social opportunities available to them in real-time surrounding. While they spend most of their time accessing online SNS, they have missed many opportunities to interact with others for new friendships, business opportunities or information sharing. Consequently, a new breed of mobile social network (MSN) system has arisen to assist mobile users to interact with proximal people and perform various social activities. Such a proximal-based MSN environment is termed a Mobile Social Network in Proximity (MSNP).

Design/methodology/approach – Developing an MSNP system needs to address a number of issues and challenges, such as heterogeneity, content/service discovery, privacy and trust, resource management, and so on. This paper identifies and describes these challenges, and reviews a number of related solutions from existing literature. In the follow up, this paper addresses a number of open challenges in the MSNP domain.

Findings – Although various works have been proposed to enable and overcome challenges in MSNP, there are still many unsolved open challenges in terms of identification, content management, social-aware discovery, trust in public environment, adaptation, quality of service and the development of MSNP. We have addressed these challenges in this paper as future research directions in the MSNP domain.

Originality/value – This paper provides an original literature review in MSNP and identifies a number of open challenges as research direction in the MSNP domain.

Keywords Survey, Mobile social network in proximity, Mobile web services, Ubiquitous content sharing

Paper type Literature review

1. Introduction

Accessing social network services (SNS) such as Facebook[1], Twitter[2] or Google+[3] has become a common daily activity for Internet users. On average, a Facebook user

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accesses Facebook's services for over 7 hours per month, and with around 80 per cent usage traffic being derived from mobile applications (ComScore, 2012). Recent smart mobile devices, such as smartphones, tablets and handheld media players, are capable of letting users produce various digital contents, and share/upload the content to many SNS directly via wireless network connections. This has increased the number of people using mobile SNS applications.

While mobile SNS applications have successfully become the most popular applications for mobile users, mobile users have been restricted in the virtual communities of online SNS and are not aware of the proximal social opportunities available to them, such as real-time opportunities to interact with others in proximity for new friendships, business opportunities or information sharing (Borcea *et al.*, 2007). Consequently, proximal-based social network systems (Pietiläinen *et al.*, 2009; Tsai *et al.*, 2009; Allen *et al.*, 2010; Sapuppo, 2010) have been proposed to enable a new breed of mobile social network (MSN) functions, which can assist mobile users to interact with proximal people and perform various social activities such as searching for new friends who have common interests, exchanging content of common interests and establishing conversations. In this paper, such a proximal-based MSN environment is termed a Mobile Social Network in Proximity (MSNP).

MSNP is a next-generation technology that changes the way human communicates. Currently, many countries in the world are establishing free urban wireless network infrastructures (ABC News Australia, 2013; Taipei City, 2013; Tourist Information Tartu and Tartu County, 2013). Once the network infrastructure has been completed, MSNP can be seamlessly deployed in every corner. People can easily share and retrieve information from one another in proximity using their mobile devices on the go. MSNP provides many benefits to its users in social opportunities and commercial business opportunities. Moreover, the decentralised MSNP can also provide a flexible system that assists emergency or disaster rescue needs. Hence, MSNP is one of the important research topics in mobile computing.

An MSNP should not be seen as a replacement of existing SNS but as its complement (Pietiläinen *et al.*, 2009). MSNP leverages online SNS with a proximal mobile wireless network connection by providing location-based social networking opportunities. It can be applied in various social scenarios such as:

- *Opportunistic content sharing*: MSNP allows mobile user to discover/share the downloaded application in proximity so that the needs of Internet bandwidth can be reduced (Bianchi *et al.*, 2012).
- *Commercial Advertising*: In the Internet of Things (IoT) domain, MSNP enables opportunistic trading (Guo *et al.*, 2013), in which the trading request advertisement can be disseminated opportunistically to MSNP participants without the need of Internet connection.
- *Gaming*: In the commercial domain, MSNP has been applied in the popular gaming platforms such as Nintendo 3DS and Sony Playstation Vita that enable players to interact with players (friends/strangers) in physical proximity, thus enabling new social relationships (Bakht *et al.*, 2012).
- *Disaster recovery*: The European-funded MSNP framework – Haggle (Nordström *et al.*, 2014) – has been applied in disaster recovery area to support fast communication establishment.

Enabling MSNP faces numerous challenges in heterogeneity, discovery, privacy and trust, resource management, etc. In the past few years, a few number of MSNP-related literature surveys have been proposed. Kayastha *et al.* (2011) contributed a MSN survey in the domain of architecture and protocol designs. The authors have summarised a large number of MSN approaches including proximity-based MSN, distributed/decentralised architecture-based MSN and opportunistic network-based MSN. However, their discussions did not emphasis on the major challenges and promising approaches for the decentralised proximity-based MSN, which is the focus of our work. The works contributed by Karam and Mohamed (2012) and Bellavista *et al.* (2013) focused on the review of emerging middleware technologies that enable MSN. In Karam and Mohamed, 2012, a number of proximity-based MSN middleware frameworks have been discussed. However, the authors did not differentiate the taxonomy of the middleware frameworks. Moreover, challenges of proximity-based MSN were not covered. Different to the definitions by Karam and Mohamed (2012), Bellavista *et al.* (2013) defined MSN as a composition of social network and opportunistic network, in which participants are capable of performing temporal social interaction in proximity. Their work focused on providing the taxonomy of MSN middleware approaches together with minor summaries of a few existing frameworks, regardless of a thoroughly analysis of promising technologies for enabling the environment and the involved challenges. Finally, Vastardis and Yang (2013) focused on how the MSN systems process the social network relationship and properties to form the social groups. Their study addressed how distributed MSN participants can manage the message routing based on the social relationship in the large score mobile *ad hoc* network (MANET) manner. Different to their study, in our work, we do not consider a large score MANET as one of MSNP environments because in our definition, MSNP occurs in a fairly close range in which the messages only deliver within a single hop range (direct peer-to-peer [P2P]).

Different to previous related works, this paper provides a different angle of the MSNP review in which the focus is on the schemes that enable decentralised MP2P-based MSNP. We discuss the specific challenges and related solutions in MSNP that were not addressed in the existing related studies. The review consists of how the existing technologies enable MSNP systems, and how they overcome the challenges in MSNP. A comparison is provided to summarise how different frameworks realise MSNP. Afterwards, a number of unsolved open challenges in MSNP are described as future research directions.

The remainder of the paper is organised as follows: Section 2 summarises the background and identifies the features of MSNP. Section 3 describes the network models of MSNP. Section 4 reviews approaches for enabling MSNP and challenges that have been solved by existing MSNP approaches. Section 5 provides the information of open challenges and research directions in the MSNP domain. Section 6 summarises the work provided in this paper.

2. Background of MSN in proximity

MSNP is derived from MSN (Kayastha *et al.*, 2011) and location-based social network (LBSN) (Zheng, 2011; Lindqvist *et al.*, 2011; Shankar *et al.*, 2012). The main difference among them is the physical geographical coverage. MSNP emphasises on the proximal social interaction in which the social content or information is shared with the mobile device user's nearby participants in a fairly close range using the short-range wireless network communication technologies. MSNP provides the opportunity for people to establish new social interaction with strangers in real-time public environment, in which people who do not know each other in proximity, but probably should, gain the opportunity to know each other (Sapuppo, 2010).

The fundamental notion of MSNP derives from two works: MobiClique (Pietiläinen *et al.*, 2009) and local social network (LSN) (Sapuppo, 2010). As MobiClique did not specifically give a name to such an environment, and the name LSN does not encompass the important elements – that is, *mobile devices* and real-time *proximal mobile network connection* – to highlight them and to distinguish the environment from generic MSN and LBSN, we use the term MSNP.

MSNP has two basic principles:

(1) *Decentralised operation*: MSNP operates in a mobile P2P (MP2P) network, in which participating mobile devices do not rely on intermediate entities to assist their communications (Sapuppo, 2010). Such a requirement avoids the single point of failure, and the communication between participants can partially work without Internet connection.

(2) *Leveraging existing social networks*: MSNP applications link to their users' SNS to enable common profile exchange capability (Pietiläinen *et al.*, 2009; Sapuppo, 2010) or to share online content by providing uniform resource locator (URL) links. Hence, MSNP applications are capable of performing common interest matchmaking and content recommendation for their users.

Based on the two principles, we define:

> Mobile Social Network in Proximity (MSNP) is a wireless software application environment in which participants in the environment can use heterogeneous mobile applications to share information and perform computational social network application activities without necessarily assistance from central management service.

In the past several years, numerous works were proposed to enable proximal-based mobile social networking. Most of these works were tightly coupled systems. As mentioned by Kayastha *et al.* (2011), in general MSN, a standard interoperation interface has become an issue. Existing works lack common protocol and interfaces to seamlessly exchange information on social relationships, and data retrieved from different MSN. A standard is required not only for data exchange but also to support context awareness and privacy and trust control. Hence, to support such a need, a loosely coupled MSNP solution is required. In the following sections, numerous frameworks designed for enabling MSNP will be reviewed. A key focus of our review falls in analysing whether the frameworks are compliant to loose coupling while achieving their primary objectives. Firstly, we discuss the fundamental architecture models of MSNP.

3. Network models of MSN in proximity

MSNP can be categorised into three network models: centralised, semi-decentralised and decentralised. Although it has been mentioned that MSNP is based on decentralised operation, the centralised model has been included as the compliance of discussion, and to justify why the centralised model was not considered as a feasible option for MSNP in existing works (Pietiläinen *et al.*, 2009; Sapuppo, 2010; Chang *et al.*, 2012).

3.1 Centralised models

As Figure 1 shows, centralised models utilised portal-like central services to support users to discover and to interact with other participants based on the information retrieved from miscellaneous SNS. To discover proximal participants, a centralised model facilitates a location tracking service (e.g. global positioning system, Google Maps)[4] to continue tracing each participant's current location. Benefiting from a broad range of distributed resources, centralised models are capable of providing high performance and effective services to mobile users. However, centralised models have a number of drawbacks such as the bottleneck problems and the location tracing approach requiring users' devices to frequently send the current locations to the central server, which tends to consume a lot of the battery life of the mobile devices.

A centralised model has the following advantages and disadvantages:

(1) Advantages:
- *Efficient discovery and matchmaking processes*: A centralised model benefits from the support of the powerful central server to process data. It is very efficient in performing the matchmaking process for users to discover and establish new social networks based on their location information and common interest profiles.
- *Easy maintenance*: Because mobile-side applications are simple client-side software, it is much easier to maintain and to perform the version update of the system when compared to the pure MP2P-based decentralised model.

(2) Disadvantages:
- *Less control in user privacy*: A centralised model requires users to upload their data to the central repository. Existing SNS such as Facebook have provided various privacy settings for users to control who can see their content. However, some users have concerns about how the central repository service provider protects their data against malicious hackers or repressive governments (Stuedi *et al.*, 2011). Additionally, people may have no incentive

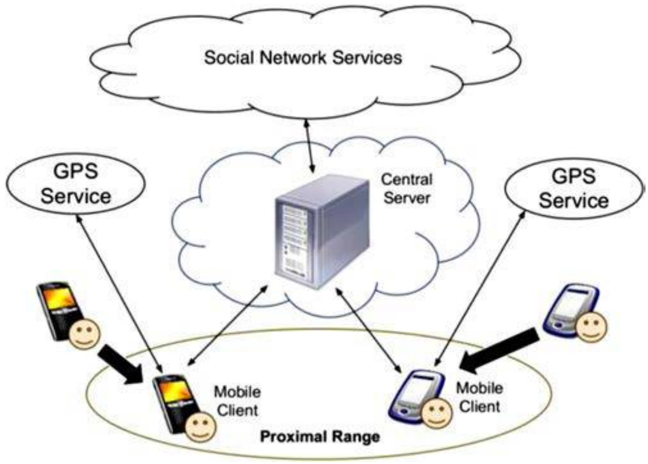


Figure 1.
MSNP based on the client–server model

to expose their current location information to a centralised server. However, they may be willing to let people who are in proximity to discover their device because they can have already see each others (Bakht *et al.*, 2012).

- *Single point of failure of server-side leads to the failure of the entire MSN*: Further, the dynamic nature of mobile users leads to unstable Internet connection. When a mobile user loses his/her connection with the remote central server, the proximal MSNP discovery mechanism will fail because the process is entirely relied on the remote central server.
- *Always-on data transmission channel*: A centralised model usually requires the mobile client application to retain its communication channel between itself and the remote server to let the server track the mobile user's position. Such an always-on data transmission channel consumes a lot of the battery life of a mobile device.
- *Communication latency*: Centralised model requires all the communication to be performed via the remote central server, which can cause high latency and limit its usefulness for real-time interaction (Bakht *et al.*, 2012).

3.2 Semi-decentralised model

A semi-decentralised model consists of partial centralised nodes and a MP2P network. The semi-decentralised model can be further classified into two models: a super peers model [see Figure 2(a)] and a central repository model [see Figure 2(b)].

A super peers model (Tsai *et al.*, 2009; Kern *et al.*, 2006) requires at least one active participant to assist participants' discovery process. As Figure 2(a) shows, two pre-connected super peers – S1 and S2 – act as brokers to assist two groups of users located in different wireless local area network discover one another. Peer A, B or C is capable of requesting or advertising SNS content with Peer D, E or F via S1 and S2.

A central repository model (McNamara and Yang, 2008; Yang *et al.*, 2008; Brooker *et al.*, 2010; Sapuppo, 2010) utilises static central servers to assist MSN participants to discover their proximal peers based on certain criteria [see Figure 2(b)]. The central server is either implemented in a particular location (e.g. Jini-based model; Brooker *et al.*, 2010) or is accessible via the Internet as a global broker (Sapuppo, 2010). Participants' social activities are still operating in the direct MP2P network.

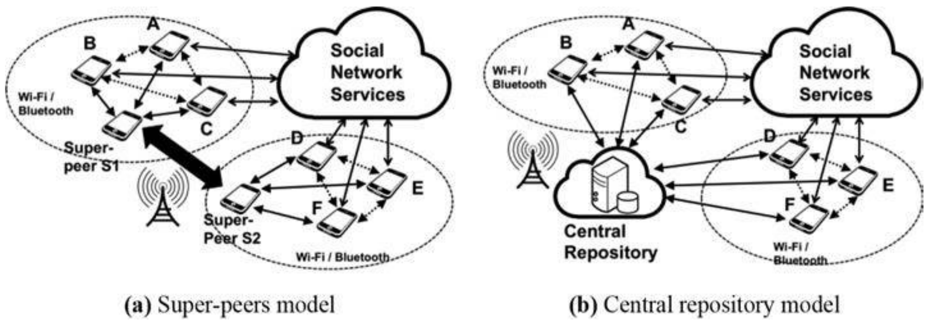


Figure 2.
MSNP based on semi-decentralised models

A semi-decentralised model has the following advantage and disadvantage:

(1) Advantage:
- *Reduced burden*: The burden of the central server is greatly reduced because either the super peers or registry servers are used for discovery only. Other social activities are done by P2P or distributed to other entities.

(2) Disadvantage:
- *Single point of failure*: A super peer model will fail if an environment does not have a super peer, which is powerful enough to handle all the discovery processes. A static repository model will also face similar problems.

3.3 A decentralised model

A decentralised model aims to overcome the limitations of the centralised solutions by utilising the MP2P network approach. As Figure 3 shows, each participating peer is equipped with a common decentralised MSNP application. The application associates with its user's SNS to share content to proximal peers when they meet each other in proximity via short-ranged wireless network connection and semantic metadata exchange. The MSNP applications can establish social group interaction based on users' common interests based on their pre-fetched SNS profiles.

Existing decentralised model are still in their early stages. Pietiläinen *et al.* (2009) and Xing *et al.* (2009) focused on how to enable the SNS activities in MP2P network environments. Others have focused on how content can be shared. Uttering (Allen *et al.*, 2010) provides the user interest profile modelling mechanism and also introduced a formal strategy to decide how the content can be proactively pushed to the friends/contacts who have potential interest in the content. MobiSN (Li *et al.*, 2012) supports ontology-based semantic models to enable content sharing using a semantic content matchmaking scheme. The approach enables user interests' content routing in a decentralised model based on user profile similarity measurement strategies. However, Uttering and MobiSN did not provide a generic architecture or framework for enabling the model.

Further, most existing decentralised model solutions described above are tightly coupled, which have limited the flexibility and scalability. Ideally, participating in MSNP should be flexible. Users can use the application by their own choice just like participating in a popular online content-sharing network such as BitTorrent[5].

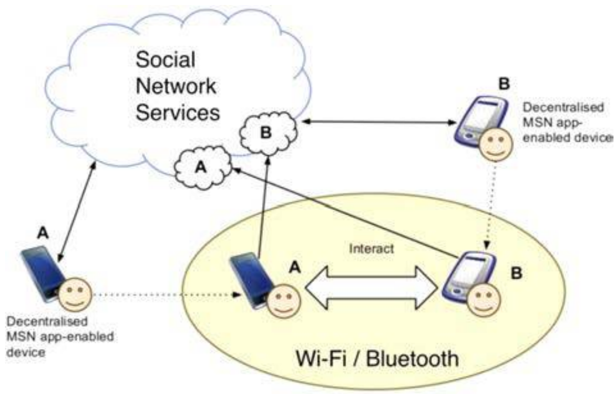


Figure 3.
MSNP based on the decentralised model

Moreover, developers should also have the flexibility to implement their own applications to interact with such MSNP environments.

A decentralised model has the following advantages and disadvantages:

(1) Advantages:
- Participants in decentralised model have full control over sensitive materials such as their profiles. They can decide where the data is to be stored (e.g. in their own cloud storage) and with whom and how the data are shared.
- A decentralised model-based MSNP can potentially avoid a single point of failure. Activities can still be performed partially in a decentralised model-based MSN even when the Internet is not connected.
- Reduce the need of Internet connection. Because data transmission among proximity is possible, it can eliminate the cost of using mobile Internet.

(2) Disadvantages:
- *Resource-intensive*. The model can be resource-intensive when the message-driven service-oriented solution is applied. The service discovery processes can also face latency issue.
- *Complexity*. Development is more complex compared to a centralised model.

4. Enabling MSN in proximity

Enabling MSNP involves a number of fundamental challenges. This section reviews these challenges and their corresponding solutions provided by existing related researchers. Although these works provide proximal-based social interaction, some of them are not necessarily following the definition of MSNP. We address these works to make completed comparisons with works that follow MSNP definition.

4.1 Identification

4.1.1 Challenge. The decentralised MSNP faces a challenge in managing unique identification of participants. Because participants in MSNP are free to join and leave, it is a crucial task to validate the identification of them without a central server to govern the identification of participants.

4.1.2 Promising approaches. While some relevant works (Buchegger *et al.*, 2009; Datta, 2010) assumed that a unique identification is allocated to each participant who joins the network, some researchers have specified more completed solutions. Au Yeung *et al.* (2009) utilised Web ID, which was based on the format of uniform resource identifier, e.g. http://msnp.org/b-card#johan. The work based on Extensible Messaging and Presence Protocol (XMPP)[6] (Lubke *et al.*, 2011) mentioned that XMPP offers the possibility for identification in a format similar to email, e.g. user@server.org/resource. Finally, Seong *et al.* (2010) applied OpenID[7] to ensure the Identification (ID) redundancy issue will not occur in the network. An OpenID is an email address that can be used to login to numerous associated online services such as YouTube[8], Gmail[9], Flickr[10] and Facebook. OpenID appears to be a feasible option for MSNP. However, all the discussed identification approaches in this section still require a third-party service to validate the identification. Most existing works have not propose a purely P2P-based strategy. This topic remains as a future research direction in MSNP.

4.2 Content provisioning and management

4.2.1 Challenge. Sharing content is a basic activity in MSNP. A content advertiser can provide various contents to participants based on their interests. However, continuously providing content from mobile device via wireless network can quickly drain the battery life. Hence, an energy-efficient content provisioning strategy is needed.

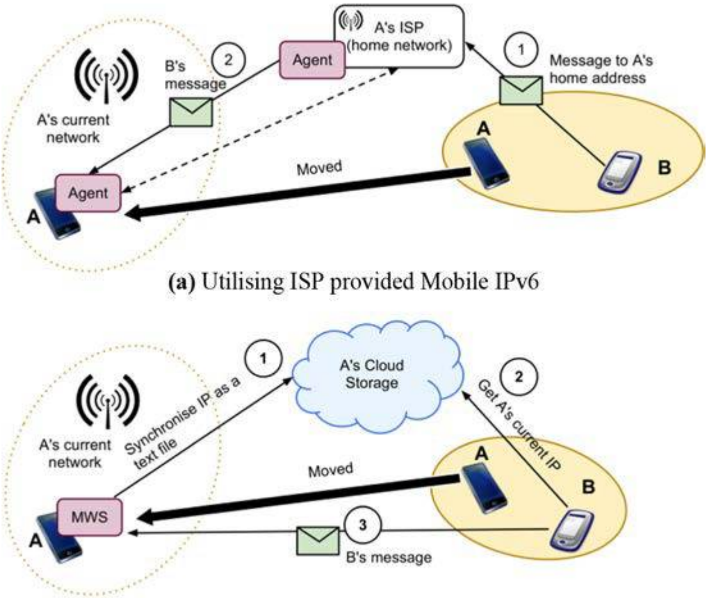
4.2.2 Promising approaches. In the decentralised MSNP, content can be replicated in numerous existing participants to reduce the transmission of the original content provider. For instance, in a semi-decentralised environment, super peers can provide storage to assist participants to distribute their updated content (Sharma and Datta, 2011). Recently, cloud resources were utilised in various networked applications to reduce the burden caused by data transmission. Users' content can be stored in any trusted cloud storage (e.g. Amazon Simple Storage Service or Dropbox) by the user's own choice (Au Yeung *et al.*, 2009; Seong *et al.*, 2010). A simple URL can be provided in the corresponding metadata to redirect a client to the content stored in the cloud storage. For example, the AMSNP project (Chang, 2013) is based on decentralised online social network solutions that utilise distributed cloud storages to store large-size content such as images, videos and audio. Each participant's device communicates with proximal participants using metadata-based messages. If a participant's device has been requested for a particular content, it will respond with metadata, which describes the URL of the corresponding content in the participant's SNS space or cloud storage. Afterwards, the requester can retrieve the content from the cloud storage without requiring heavy data traffic between the requester and the provider.

4.3 Mobility

4.3.1 Challenge. In MSNP, content can be discovered and shared whenever the content provider and content requester are in proximity. However, when a content file is transmitting, there is a chance that either the content provider or the content requester has moved out from his/her current network that leads to the failure of file transmission. One potential solution is to switch the communication to mobile Internet. However, in many cases, a mobile device is unable to obtain a static Internet protocol (IP) address from its carrier, which leads to unstable communication.

4.3.2 Promising approach. A common solution for the mobile IP issue is to apply a proxy to broker the messages (Chang, 2013).

Figure 4(a) illustrates a scenario in which two MSNP peers – Peer A and Peer B – are in physical proximity with a Wi-Fi connection, and they have established a connection by exchanging service description metadata (SDM), which contains the IP address of each other. In this scenario, Peer A's IP address is a static mobile IPv6 address (also known as a "home address"). Afterwards, Peer A moves to another location with a 3G/4G connection. Peer B intends to retrieve content from Peer A. Because Peer A's Internet Service Provider (ISP) has provided Peer A with a mobile IPv6 solution, Peer B's request message can still reach Peer A because in the mobile IPv6 environment, data intended to reach Peer A's IP is actually received by the broker server of Peer A's ISP (Step 1). The broker server will forward the data to Peer A via software agents [agent in Figure 4(a)] that maintain the communication channel between Peer A and the broker server of Peer A's ISP (Step 2), which is also known as communication within a "home network".



(a) Utilising ISP provided Mobile IPv6

(b) Utilising Cloud storage service

Figure 4.
IP mobility support in MSNP

Ideally, mobile IPv6 can resolve the IP mobility issue. However, at the time of writing this paper, most mobile devices in the market do not have static mobile IPv6 addresses. To overcome this limitation, a possible approach is utilising cloud storage services to dynamically synchronise the device's IP address [see Figure 4(b)]. This approach serves a similar solution as a mobile IPv6 solution. Each participant in an MSNP has its own cloud storage (e.g. Dropbox) by its own choice. Figure 4(b) illustrates a scenario in which Peer A and Peer B were in the same network and exchanged their SDM with each other. To let Peer B maintain communication with Peer A when Peer A moves to another network, they will perform the following steps:

- Peer A obtains a new dynamic mobile IP address; it synchronises its new IP address as a text file to its cloud storage.
- Peer B retrieves the text file that describes Peer A's IP address from Peer A's cloud storage.
- Peer B identifies Peer A's current IP address from the text file, and then sends its request to Peer A.

Although it is possible to utilise cloud storage services to share IP addresses of mobile devices, in some cases, the user's current network environment may not support a public IP that can receive incoming request message from external network. In such a case, a proper proxy service for brokering request messages is needed to overcome the mobility-related issues. For example, by utilising network address translation with transmission control protocol (TCP)/user datagram protocol (UDP) hole punching technologies, devices in mobile IP network can maintain their communication via a rendezvous server (Srirama and Liyanage, 2014).

4.4 Heterogeneity

4.4.1 Challenge. An ideal MSNP environment enables heterogeneous devices and platforms to discover and interact with each other towards share various content such as photo, video, text, public social profiles, and so on. Such an environment requires a standard communication protocol.

Imagine an MSNP environment with a variety of mobile device users. Each user intends to use their MSNP application to interact with one another. However, as each MSNP application is implemented in different technology, the opportunity of discovery and interaction between mobile users is much less. For example, a user who is using an MSNP application based on JXTA (Juxtapose) will be unable to communicate with a user who is using the Universal Plug and Play-based[11] MSNP application because the way they perform discovery and describing service/operation are different. Moreover, when the environment grows, the number of operation types and content types increases. To fulfil the need, semantic annotation may be applied to describe the operations provided by each participating device. However, due to the heterogeneity issue, the semantic discovery mechanism is difficult to be implemented.

4.4.2 Promising approaches. A few MSNP frameworks have applied web service standard technologies to overcome the heterogeneity issue. In semi-decentralised model-based frameworks, SocioNet (Pernek and Hummel, 2009) applied web services as the common interface to improve interoperability. In decentralised model-based frameworks, RESTFul web service technologies have been used in AMSNP (Chang *et al.*, 2012; Chang *et al.*, 2013) to enable a loosely coupled MSNP environment. It is also possible to extend other service discovery technologies to enable a loosely coupled environment. For example, Srirama *et al.* (2013) have composed a number of platform natural service discovery technologies to support a platform-independent semi-decentralised P2P discovery environment.

Although a number of approaches summarised above have been proposed to improve the interoperability of MSNP based on web service standards, these works have not considered that the classic web service standard-based protocols are still considered as heavy-weight approaches to resource constrained mobile devices. The application developers need to be aware of that, in reality, mobile users intend to save as much energy as possible. There is a need for developing a lightweight energy-efficient standard-based MSNP protocol. In recent years, a number of promising standard protocol stacks have been proposed for resource constrained machine-to-machine communication in the IoT scenarios. For example, in the physical layer, IEEE 802.15.4 ZigBee[12] and Bluetooth Low Energy[13] provided an energy-efficient data transmission approach. In the application layer, the Constrained Application Protocol (CoAP)[14] can replace the traditional HTTP protocol to reduce the message size. Additionally, W3C's Efficient XML Interchange (EXI)[15] standard can reduce the payload message size. By applying the energy-efficient standard protocol stacks, it is possible to realise an energy-efficient loosely coupled MSNP environment. However, such approaches have not yet been investigated by existing standard-based MSNP projects.

4.5 Content discovery

4.5.1 Challenge. Content discovery is a challenging task in MSNP when a new participant may not have any knowledge about the other participants. If the new participant performs a manual searching in a high-population environment, the user may receive a large number of search results, regardless of their interests. The user may soon lose their incentive to participating in MSNP because of irrelevant search results.

4.5.2 Promising approaches. For a tightly coupled solution such as MobiClique, which utilises Facebook's user profiles to establish relationships between participants, it is not applicable to participants who do not have a Facebook account. Au Yeung *et al.* (2009) applied friend of a friend (FOAF) documents to support friendship discovery. Each device contains a FOAF document to describe the social relationships of its user. However, the FOAF approach does not benefit a new participant who does not have any friend in the environment. A highly distributed decentralised social network – SuperNova (Sharma and Datta, 2011) – has adapted super peers to assist new participants in the network. Super peers are active participants who intend to assist new participants in their early stages to find new friends/subscriptions by disseminating their profiles. Eventually, a super peer will gain reputation by performing such assistance and may further gain commercial benefit. Each super peer can provide different kinds of services. Some super peers provide a user list, which allows a new participant to discover the existing participants who have common interests or who can provide some content of interest to the new participant. Some super peers are recommenders who intend to actively recommend new friends/subscriptions to the new participant based on the participant's interests.

The preceding description provides the conceptual approach for content discovery based on existing decentralised social network systems. The fundamental challenge is how to realise the discovery mechanism in MSNP. A common approach is to utilise the distributed hash table (DHT) technique (Xing *et al.*, 2009; Buchegger *et al.*, 2009; Datta, 2010). In a classic P2P network, each participant maintains its DHT, which contains information about the other participants, such as their network addresses, provided services or even some text messages (Buchegger *et al.*, 2009). Besides these static description-based approaches, Seong *et al.* (2010) and Li *et al.* (2012) have applied semantic technologies to enhance the discovery process.

To discover content in MSNP, one needs to first identify whether the content provider's mobile services can respond to the required content. Such information is not clearly described in DHT, and the requester needs to retrieve the provider's web services description language (WSDL) (and related documents such as semantic service description document web ontology language-description logics (OWL-DL) and XML schema) to identify whether the provider's service can respond with the required content or not.

In SNS such as Facebook, a user may enter a number of keywords to search for a particular content provider. However, the efficiency of the keyword-based search is restrictive (Srirama *et al.*, 2008). When the environment grows, a keyword-based search can result in a large number of matched services. Manual browsing to select a feasible service from such a list is not ideal for mobile application users. To overcome such a problem, researchers (Toninelli *et al.*, 2011; Chang, 2013; Rana *et al.*, 2010) have applied semantic web technology to improve the discovery process in MSNP to autonomously discover and filter search results. Although the XML format-based semantic technology may affect the performance of content discovery process, Steller and Krishnaswamy have proposed mTabeaux (Steller *et al.*, 2009) to improve the performance of semantic document processing for resource constraint devices. The main strategy is to perform partial semantic reasoning based on the inference algorithm.

An alternative strategy to improve the service discovery is to utilise proactive service discovery scheme based on the user preference prediction (Chang *et al.*, 2011). For example, by utilising the context-aware prediction scheme, a system can compare the current contexts to historical records to compute which query requested by the user has the highest probability. Each query recorded by the system has its associated semantic service type. By predicting the highest probable query, the system is capable of identifying what semantic service type is interested by the user in current environment. Hence, the mobile application is capable of performing proactive service discovery and filtering autonomously regardless the user's manual input.

4.6 Trust

4.6.1 Challenge. Imagining a decentralised MSNP environment which consists of a large number of mobile content providers who intend to advertise content to proximal participants. Because there is no centralised service to govern the environment, identifying malicious content providers becomes a critical trustworthiness challenge. Overall, most existing MSNP approaches did not address trustworthiness. Without a proper strategy for trust, people will hesitate to use MSNP. Trust in mobile P2P environment has been studied in past survey (Cho *et al.*, 2011). A variety of approaches have been discussed in the survey. However, the challenge falls in MSNP environment is the latency issue. To apply the trust strategy, a participant is usually required to retrieve and process a large number of trust or reputation related data, which will lead to the high overhead issue.

4.6.2 Promising approaches. Reducing data transaction is a common strategy to improve the processing speed of trust in decentralised MSNP. Wu *et al.* (2009) have proposed a group-based reputation scheme for semi-decentralised environment. In their approach, a super peer manages the reputation rating data of a group of mobile peers with a similar movement speed. The super peer is selected based on the peer's performance. Although the approach can explicitly resolve the transaction overhead issue, in the public environment-based MSNP, users may not be willing to let their devices act as super peers because the high frequency of data transaction can quickly drain the battery life of their mobile devices.

M-Trust (Qureshi *et al.*, 2010) reduces reputation data transaction by selecting recommenders based on the confidence of the candidate recommenders. When a new peer joins the network, it collects the reputation rating data from other peers to establish an initial reputation data list. Based on the rating list, the new peer identifies the most reliable recommender to provide its trust rating of a particular service provider. A disadvantage of M-Trust is that the system will directly remove a trustworthy peer's recommendation (reputation rating) when the peer is disconnected from the current network (either due to network switching or due to the time to live of its recommendation expiring). It would be ideal to provide a strategy to let M-Trust retrieve updates from recommenders in a different network, but this has not been addressed.

Similarly, TEMPR (Waluyo *et al.*, 2012) also improves the trust processing speed by utilising the selective recommender approach. Distinguished from M-Trust, the TEMPR scheme computes direct peers' (candidate recommenders who can directly interact with the requester) trustworthiness based on two scores:

(1) the direct peers' trustworthy rating from other unknown peers; and

(2) the direct peers' untrustworthy rating from other unknown peers.

Once a set of trustworthy direct peers is identified, the requester peer can request them for a service provider peer's reputation rating. The trustworthy direct peers can also use the same approach described above to identify the trustworthy recommenders in their own groups of connected peers who are the indirect recommenders of the initial requester peer. Hence, TEMPR can reduce unnecessary message transactions.

The trust scheme proposed by Chang *et al.* (2014) is an extension of TEMPR, designed specifically for decentralised MSNP. The major difference is that the work proposed by Chang *et al.* (2014) does not assume strangers' mobile application will always forward messages to assist other participants for the trust processes. Hence, a requester who intends to identify a provider's trustworthiness has to obtain the reputation rating data by either directly invoking the data provider (if the data provider application provides the corresponding web service operation) or by retrieving the data from the data owner's cloud storage (based on the URL links described in the data owner's SDM). In their approach, each participant has a backend cloud storage. Each MSNP participant can synchronise its reputation rating data to its public accessible cloud storage. The corresponding URL link of the reputation rating data is described in its service description metadata. Hence, when a requester performs the service discovery process by retrieving other participants' service description metadata, it will obtain the corresponding URL links of each participant's reputation rating data. Furthermore, to enhance the trustworthy service discovery process, the authors have proposed schemes that compose the reputation-rating data derived from friends and FOAF and the credibility (the reputation rate given by the public) for FOAF-based and public-based trustworthy service discovery processes. The fundamental strategy of the reputation rating is based on how expatriate the participant is as a content requester and provider in MSNP environments, and the average rating value of the participant given by the other participants in the past.

4.7 Adaptive resource management

4.7.1 Challenge. A specific challenge of decentralised MSNP application is resource management, which derives from the fundamental mobile network topology. Tightly coupled systems can apply specific communication protocols to support the best performance of their systems. Conversely, when loose coupling is required, in which the MSNP participants utilise standard message-driven protocols such as simple object access protocol (SOAP) and OWL to communicate (Toninelli *et al.*, 2011), the participating mobile devices will face resource intensive challenges derived from disseminating and processing a large number of standard formatted documents.

4.7.2 Promising approaches. To reduce the resource usage of mobile devices, Pernek and Hummel (2009) utilised a remote centralised server for MSNP participants' discovery processes. Such an approach potentially faces the single point of failure issue. Instead of relying on a central repository server, the decentralised social network platform – Contrail (Stuedi *et al.*, 2011) – utilised the cloud services to offload the communication tasks to the runtime established cloud services. Such an approach can reduce the burden of mobile device processes and also avoid the single point of failure issue. However, in MSNP, distributing tasks to cloud is not always an effective solution because utilising cloud service consumes extra costs such as network latency, price of using the service, etc. In some cases, retaining the communication within local wireless network is better when both performance and cost are considered, especially when there are only a few MSNP peers involved. Conversely, when there are many MSNP peers involved, it may be more effective to distribute more tasks to the more powerful cloud services. It would be helpful if there exists a system that can adapt to different situations when dealing with change in the number of MSNP peers. While most existing decentralised MSNP frameworks did not deal with adaptive resource management, Chang *et al.* (2012) introduced the AMSNP framework, which is capable of dynamically changing its approach at runtime to adapt to these situations, while a particular MSNP peer performs MP2P social network activities.

AMSNP framework utilises an enterprise service bus architecture to enable the resource-as-a-service design in which local components of mobile device and remote cloud services are managed as web service resources. Therefore, in the AMSNP framework, resources can dynamically launch/connect and terminate/disconnect at runtime without relaunching the base MSNP application. The fundamental part of AMSNP that supports resource awareness mechanism is the business process execution language (BPEL) workflow-based adaptive task reconfiguration component. The component combines the fuzzy set model and the cost – performance index model to determine the best approach and components used for the task at runtime. Hence, the AMSNP framework can perform its MSNP tasks more efficiently.

4.8 Comparison of MSNP frameworks

Table I summaries and compares the existing MSNP middleware frameworks. Note that works such as Uttering (Allen *et al.*, 2010) and MobiSN (Holanda *et al.*, 2012), which were proposed for resolving specific challenges in MSNP, are not included in this comparison because they are not the complete frameworks.

The comparison is based on the following criteria, denoted by the columns in Table I:

- Architecture (Archi.) represents the base model of the framework. The three basic MSNP models are: client–server, decentralised (DC) and semi-decentralised (Semi-DC).
- Proximal discovery (PD) is the means by which participants discover one another in their proximity.
- Auto match (AM) denotes how the system enables autonomous content discovery and filtering based on user profile or context.
- Trust (Tru.) specifies whether the system support trust control.
- Reducing latency (RL) represents whether the system provides a strategy to reduce latency in the bootstrap and service discovery phase.
- Resource-aware (RA) denotes whether the system supports a scheme to adapt dynamic changes at runtime to effectively select the most appropriate approach for social network activities.
- Loose coupling (LC) denotes whether the system supports loosely coupled interoperability for heterogeneous mobile devices and applications.

An ideal MSNP framework should support the following capabilities:

Table I.
Comparison of MSN frameworks

Work	Archi.	PD	AM	Tru.	RL	RA	LC
MobilisGroups (Lubke *et al.*, 2011)	Client – server	Centralised	Manual Location Profile	No	No	No	XMPP
Smart Campus Project (Yu *et al.*, 2011)	Client – server + Minor DC	Bluetooth	Manual	No	No	No	No (OSGi)
SPN (Yang *et al.*, 2008)	Client – server + Minor DC	Bluetooth	Manual	No	No	No	No
Jini-based MSN Project (Brooker *et al.*, 2010)	Semi-DC	Jini	Manual	No	No	No	No
SocioNet (Pernek and Hummel, 2009)	Semi-DC	Bluetooth	FOAF Profile	No	No	No	Web Service
MobiSoft (Kern *et al.*, 2006)	Semi-DC	JXTA	FOAF RDF	No	No	No	No (Tracy2 + JXTA)
MoSoSo (Tsai *et al.*, 2009)	Semi-DC	JXTA	Manual	No	No	No	No
Spider Web (Sapuppo, 2010)	Semi-DC	Bluetooth	Manual	No	No	No	No
Proximiter (Xing *et al.*, 2009)	DC	OLSR	Manual	No	No	No	No
Mobi Clique (Pietiläinen *et al.*, 2009)	DC	Bluetooth	Social Profile	No	No	No	No
Cloud Semantic MSN (Rana *et al.*, 2010)	DC	Mobile Agent	Semantic	No	No	No	No
Yarta (Toninelli *et al.*, 2011)	DC	SLP	Semantic	No	No	No	RDF
AMSNP (Chang *et al.*, 2013)	DC	Zeroconf	Semantic	Yes	Yes	Yes	RESTful WS

- Decentralised, which can avoid single point of failure issues.
- Autonomous discovery to support a mechanism to improve the service/content discovery result.
- *Trust*: An MSNP system should support trustworthiness to help users interact with people who are not in their contact list.
- *Loose coupling*: To enhance the interoperability of a heterogeneous platform.
- *Latency reduction*: A loosely coupled MSNP system faces latency challenges. The system should provide a proper strategy to reduce the latency of the message-driven service/content discovery.
- *Resource awareness*: In different resource and environmental condition, a MSNP system should be able to perform its tasks by using different approaches. Different approaches require different resource usage. An MSNP system should support resource awareness, which adapts to dynamic changes.

A purely centralised framework such as MobilisGroups potentially harbours the risk of single-point-of-failure. Some centralised solutions (Yu *et al.*, 2011; Yang *et al.*, 2008) support minor decentralised communication capabilities by utilising the Bluetooth technology when the central server is not available. However, such a solution is insufficient because by simply utilising Bluetooth-based discovery, it can result in high latency especially when the environment grows.

Most existing works also lack support for heterogeneous platform interoperability. As Table I summarised, most frameworks were proposed in the form of stand-alone technology. Within these frameworks, some have applied standard service-oriented technologies. MobilisGroups has utilised internet engineering task force (IETF) XMPP, which is a popular centralised standard communication protocol. Yarta utilised standard protocol – Service Location Protocol (SLP)[16] – for proximal mobile P2P discovery, and it also applied standard semantic discovery technology based on Resource Description Framework (RDF) to realise autonomous discovery.

Within these frameworks, Yarta is the closest framework to achieve the basic capabilities described previously. It is capable of avoiding a single point of failure, and it supports heterogeneous platform interoperability and autonomous discovery. However, Yarta has not provided a strategy to reduce latency caused by applying standard semantic discovery technology in a MP2P network. The evaluation result of Yarta's prototype has indicated that this is an issue. Further, Yarta has no support for resource awareness in which the discovery and interaction scheme should adapt to the resource changes and environmental factors.

Overall, most existing works did not address trustworthiness, which is an important aspect of MSNP because MSNP allows users to interact with new people who are not in their existing contact list.

The AMSNP project took a different track from the other existing frameworks by filling the gap in the subjects of loose coupling, reducing service discovery latency, supporting lightweight trustworthy service discovery and providing a strategy to enable system to reconfigure its resources and task for MSNP activities at runtime to adapt to dynamic changes.

5. Open challenges and research directions of MSNP

Although various works have been done to enable MSNP, there are still many unsolved challenges. We describe these challenges in this section as future research directions in the MSNP domain.

5.1 Identification

As described previously in Section 4.1, OpenID can be used to support identification in MSNP. One concern in such an approach is that in reality, users can always apply multiple OpenID accounts. It is difficult to identify the trustworthiness of an OpenID. The similar problem also exists in online trading services such as eBay[17]. Users of eBay can always apply multiple accounts and use some accounts to perform dishonour actions. For example, a buyer may not pay his/her order, or a seller may not send out the ordered item to the buyer. Such dishonoured users may have been using fake contact profiles. Hence, when other people are aware of their dishonest activities, the dishonoured users can simply delete/terminate their accounts. Other users will never be able to find the dishonoured users. The identification problem can be more complex in decentralised MSNP because there is no central management service governing the environment. Therefore, there is a need to propose a feasible identification support in MSNP.

While the P2P trading system – BitCoin[18] – has shown its success, researcher in the MSNP domain can try to adapt the similar framework to support the identification scheme of MSNP. For example, it may be possible to compose the frameworks that based on BitCoin (e.g. Bitgroup[19] or BitMessage[20]) to realise a platform independent MSNP identification system.

Beside the purely software-based identification strategies, MSNP can also adapt the emerging technologies from IoT for identifications. For example, utilising radio frequency identification together with EPCGlobal[21] network services, each MSNP participative device can provide unique identification and also can be validated.

5.2 Content management

As described previously in Section 4.2, a MSNP participant can utilise cloud storage services to support data provisioning. Such an approach heavily relies on cloud services and has potential risks derived from the reliability issues of existing cloud services. In October 2012, both Amazon and Google's cloud services failed due to memory leaks (Williams, 2012a). Google's cloud service failure also caused a chain effect in which both Dropbox (cloud storage service) and Tumblr (micro-blogging website) were affected (Williams, 2012b). In fact, such a single point of failure issue always exists in distributed computing, but it appears that when this happens in cloud service system, it causes more serious problems. This remains an in-progress research domain.

5.3 Content discovery

It was mentioned in Section 4.5 that utilising the context-aware user preference associated proactive service discovery for MSNP scheme could improve the service discovery performance. However, such a strategy requires a fair amount of context information associated service discovery and interaction records to predict the user preferred service type. For a user who has none or only a few records, the scheme is unable to predict the user preferred service type with regards to the context information of the user's current environment. One possible solution is to utilise the context associated service interaction records from the user's social groups such as friends or FOAF based on some similarity measurement between the user and his/her friends' profiles. However, a proactive service discovery scheme that relies on social-driven information will incur additional data retrieval cost at runtime, which can increase the overall service discovery makespan. A proper solution to overcome such an issue requires further investigation.

5.4 Trust in public environments

In trustworthy service discovery process of MSNP, when the reputation rating data comes from the public, it is inevitable that the requester has to retrieve all the available reputation rating data from all the available proximal MSNP participants. The transaction cost can also be high when the environment consists of a large number of proximal MSNP participants. An alternative solution is to use cloud utility services to enhance the overall performance of trustworthy service discovery. However, utilising cloud utility is not a straightforward task in this case. Dynamic factors such as unmeasurable number of proximal MSNP participants and their FOAF in the public reputation-based scheme means that it is preferred that the trust approach should be defined at runtime. Therefore, it is ideal to support an adaptation mechanism in MSNP when applying cloud services in this 5 scheme.

5.5 Resource awareness

Content provisioning is one of the main objectives in MSNP. Ensuring the quality of service (QoS) for content providers in MSNP is a crucial challenge. Although existing approach such as the AMSNP framework (Chang *et al.*, 2012) has provided a corresponding solution for adaptive resource management. It does not address how a content provider can provide a high-quality long-live communication in an environment with unstable network connectivity, or when the content provider's device is running low in power. A potential solution is to establish a private cloud service terminal between content provider and consumer dynamically. However, such a solution involves more advanced runtime task reconfiguration techniques. It requires further investigation in the mobile cloud computing domain.

5.6 Development

Currently, there is still a lack of proper complete software package/library of MSNP application programming interface (API) for developers. Standalone technology-based API restricts the application bound with a specific software platform. Its scalability is much lower than a standard-based API. When a standalone technology-based API is used, developers have to implement a corresponding application for each platform in which the development cost will increase. Although some works reviewed in this paper have applied web service standards to introduce loosely coupled service-oriented solutions, the complexity of the message-driven web service standards also caused latency issues. Therefore, there is a need to develop a feasible standard precisely for MSNP, so that a more feasible MSNP API can be implemented. For example, developers can apply IoT technologies such as the technologies mentioned in previous section, (e.g. CoAP and EXI) to support energy efficiency and also fulfil loose coupling. The evaluation by Colitti *et al.* (2011) has shown how much CoAP can outperform HTTP in energy saving. Tamayo *et al.* (2012) has shown the efficiency of EXI as compared to JSON, compressed XML and normal XML. Wang *et al.* (2013) has provided an early design of Bluetooth with IPv6/6LoWPAN stack for service provisioning from resource constrained devices. We are looking forward that developers can apply these standard-based protocol stacks towards developing a promising energy-efficient MSNP framework.

6. Summary

This paper provides a review in the MSNP domain. The paper first introduced the needs of MSNP. In the follow up, the background of MSNP and its roots have been described. Because the primary media used in MSNP is mobile devices such as smartphones, the dynamic nature of mobile communication brings about many challenges of MSNP in terms of network model design, identification, content provisioning and management, mobility, discovery, trust and resource management. We have reviewed a number of existing approaches and solutions with regards to each challenge. Finally, we have presented a comparison of existing MSNP frameworks to summarise the outcomes of existing works.

Although various works have been proposed to enable and overcome challenges in MSNP, there are still many unsolved open challenges in terms of identification, content management, social-aware discovery, trust in public environment, adaptation, QoS and the development of MSNP. We have addressed these challenges in this paper as future research directions in the MSNP domain.

Notes

1. www.facebook.com
2. https://twitter.com
3. https://plus.google.com
4. http://maps.google.com
5. www.bittorrent.com
6. http://xmpp.org
7. http://openid.net
8. www.youtube.com
9. https://mail.google.com
10. www.flickr.com
11. www.upnp.org
12. www.ieee802.org/15/pub/TG4.html
13. www.bluetooth.com/Pages/Bluetooth-Smart.aspx
14. https://tools.ietf.org/html/draft-ietf-core-coap-18
15. www.w3.org/TR/exi/
16. www.ietf.org/rfc/rfc2608.txt
17. www.ebay.com
18. https://bitcoin.org/
19. www.bitgroup.org
20. www.organicdesign.co.nz/Bitmessage
21. www.gs1.org/epcglobal

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