Proximity Based Social Networking in Urban Environments: Applications, Architectures and Frameworks

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1 Introduction

An impressive growth of online social networking (OSN) is observed during the recent years and has flourished as never before in human history. On the other side of the world of technology, smart phones have been noted to be another success story in this new era. According to eMarketer [1], 1.75 billion people own a smart phone. This significant penetration of smart phones, together with the rapid emergence of social networking resulted in new consumer behavior and expectations. Large web online social networking sites ~~have~~ adapted to this new transition and social networking was stretched to mobile phones known as Mobile Social Networking (MSN) [2]. Popular online social networking sites such as Facebook and Twitter were not left behind and mobile applications have been introduced for their users [3, 59]. An important field of application of MSN has been highlighted by Kayastha et al. [4] known as Proximity-based social networking. These services take advantages of the additional features of smart phones such as the GPS and Wi-Fi to discover friends around or make new connections with physical proximate mobile users [5].

Proximity-based social networking (PBSN) refers to the social interaction of mobile users which takes into consideration location information primarily using geo-proximity as a main filter to determine who is discoverable on the network. The main activity on these networks known as "check-in", allows the users to share their real and current geographical location automatically in their posts. While studies has emphasized on how people are becoming more and more anti-social by using online social networking services and face-to-face interactions are decreasing [6], PBSN

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on the other side changes this perception of social networking. Cranshaw et al. [7] and Zhang et al. [8] endorse this fact by stating that PBSN as compared to OSN enables tangible personal social interactions blurring the distinction between online and offline social networks while OSN contributes to the isolation of people in the physical world. These statements illustrate that internet communication no longer has a negative impact on individuals as PBSN allows physical communications therefore decreasing level of loneliness.

PBSN services are practical to users allowing them to meet up with their friends in the surroundings or initiate new friendships with people around having similar attributes [9]. These networks have helped users to select restaurants or stores which have good reviews from friends. Therefore, this shows that PBSN is not only useful to users but it is equally important to promote businesses. Moreover, PBSN enable users to select routes based on the traffic information and set reminders at a specific place, for example, when a user reaches a grocery store, a reminder can be set so that the user remembers what he is supposed to buy based on his location.

1.1 Overview of Proximity Based Social Networking (PBSN)

The emergence of new technologies such as GPS, Bluetooth, Wi-Fi and broadband cellular networks has nurtured a new trend in social networking by offering location-based or proximity-based services to users. Proximity based services can be classified according to their functionalities and depending on how location information is being used. Three main types of location based services have been identified in existing literatures namely position awareness, location tracking and sporadic queries.

1. Position awareness also known as triggered PBSN services or simply push services, allow the location discovery of users, e.g. users can receive notifications about events taking place in their surroundings based on their current locations [10].
2. Location tracking applications, on the other side, track the locations of users using a GPS-enabled device by continuously pinpointing to the coordinates (longitude and latitude) and deriving the course direction of the users [11, 12].
3. Sporadic queries refer to services in which the user initiates the transfer of his location information to a service provider, e.g. a user can request the PBSN application to search for nearby hotels or restaurants based on his interests such as food tastes [13].

Generally, different components of the PBSN system work together and communicate with each other to offer the numerous services to mobile users. The main components of a PBSN system are the network infrastructure, service and application provider, data and content provider, positioning technology and mobile devices as illustrated in Fig. 1.

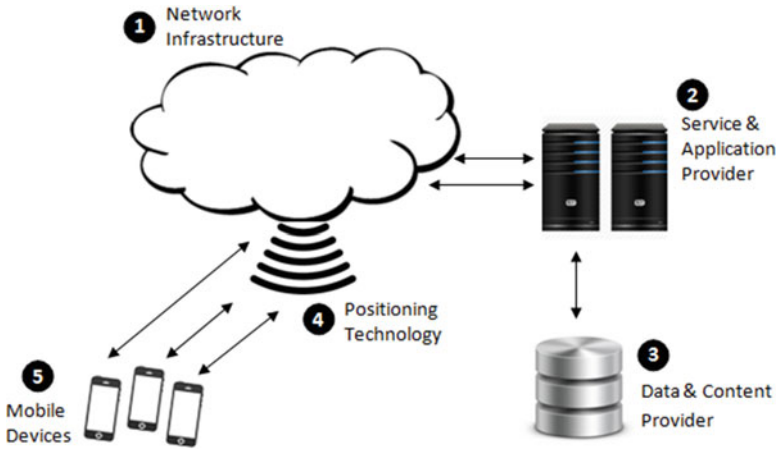

Fig. 1 PBSN components

1. **Network Infrastructure**
   The network infrastructure of a PBSN system refers to a wireless network using technologies such as Bluetooth, Wi-Fi or cellular networks to allow transfer of data between the service provider and the mobile users [4].
2. **Service and Application Provider**
   The service and application provider acts as a middleware between the data and content provider and the network infrastructure [14]. It will take the requests from clients through the wireless network and fetches the geographic information from the data content provider.
3. **Data and Content Provider**
   The content provider takes requests from clients, then processes and delivers the data to the users since service providers will not usually retain all information requested by users [15].
4. **Positioning Technology**
   The positioning feature provides the core services of PBSN system allowing the localization of mobile devices in the network by using different techniques such as GPS localization.
5. **User's Mobile Device**
   Any portable devices equip with proper communication technologies that allow reception of data from content providers and allow transfer of data to other users in the network.

1.2 Chapter Plan

In this chapter, a meticulous introduction to PBSN is presented outlining the different main components. The remainder of the study is organized as follows. In Sect. 2, the real-world PBSN application Foursquare is presented. Section 3 outlines an extensive categorization of the PBSN applications followed by a discussion of evaluation criteria used to measure PBSN systems in Sect. 4. Innovative PBSN applications in Urban Environments is presented in Sect. 5. Section 6 focuses on the different research challenges of PBSN before the concluding remarks in Sect. 5.

2 A PBSN Application: Foursquare City Guide

Foursquare City Guide, commonly known as Foursquare, is one of the most popular PBSN application, with more than 50 million monthly active users and around 105 million venues around the world have been mapped on the application [16]. Users check-in to a place on Foursquare when they are located there physically and inform other users in the network about their locations. Users are further encouraged to check-in at different places, by providing an innovative game-like service where the users are awarded for multiple check-ins by receiving points or badges. The user with the most number of check-ins at a particular place becomes the mayor of that place and may receive virtual and tangible rewards such as vouchers or free drinks. Foursquare adopted its own location detection technology: Pilgrim by using GPS and users' past check-in histories [17]. The Pilgrim technology refers to a decision-making engine, which determines the next destination of a user, where a user usually stops to hang out or the places he might be interested. It also recognizes when a user arrives in a new city and provides location recommendations of restaurants, bars or other places of interests.

2.1 Features of Foursquare

The main features of Foursquare relate to Check-ins, Tips, To-Dos, Things Done, Gaming and Venue Categorization as illustrated in Fig. 2. Check-ins are carried out in physical locations known as venues by the Foursquare users to share their locations. Users may also post tips about any venues to share information concerning any aspect positively or negatively, for example posting a good review on a specific meal in a restaurant or complaining about the service. Tips are also used to provide suggestions about the possible activities of that venue. The To-Do List feature allows the user to keep a list of the interesting places he may want to visit while the Things Done mark the items as done. Foursquare additionally employs gaming elements such as points, badges or mayorships to further attract users and to motivate them to use the check-in service at their most. A set of

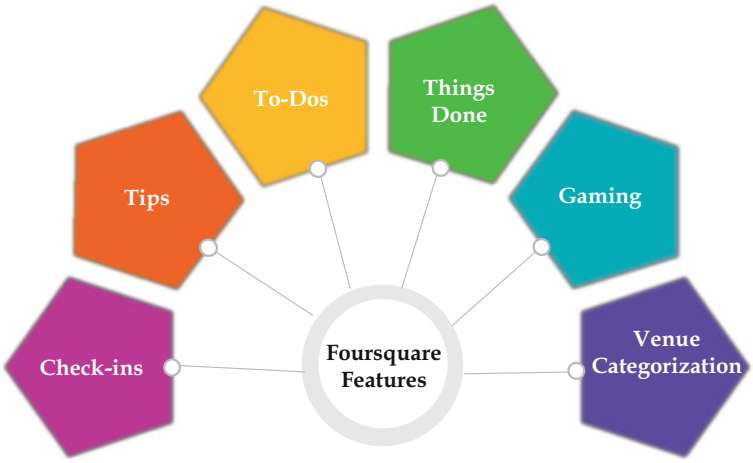

Fig. 2 Foursquare features

venue categories is maintained by Foursquare which allows users to search any locations according to their interests. The eight pre-defined venue categories are Arts & Entertainment, Colleges & Universities, Food, Great Outdoors, Nightlife Spots, Travel Spots, Shops, Home, Work and Others.

2.2 Foursquare Architecture

Foursquare relies on a client-server architecture and stores all the locations of the users in its database even if the users do not manually check-in to a particular location. The GPS in their mobile devices enable Foursquare to record their location histories. Based on this data, Foursquare cross-check which other users in the network that are located in the same place or in nearby locations. Suggestions can be sent to the proximity users to connect based on their tracked locations by Foursquare. As reported by Chen [18], the architecture of Foursquare comprises of five components as depicted in Fig. 3.

The Foursquare App refers to the client application on the mobile device of the user. The Foursquare App Server is the main component, which provides all the interfaces needed by the client server including the check-in service and third party applications. The Data Server allows the data storage using MongoDB and PostgreSQL while the Foursquare Offline Data Analysis system supports the data analysis and statistics of the users' check-in data. The Foursquare App Server, Data Server and the Offline Data Analysis system are deployed on Amazon Elastic Compute Cloud (Amazon EC2). On the other side, the map service provider used by Foursquare is Google maps, which allows the map contents to be visible on the Foursquare applications.

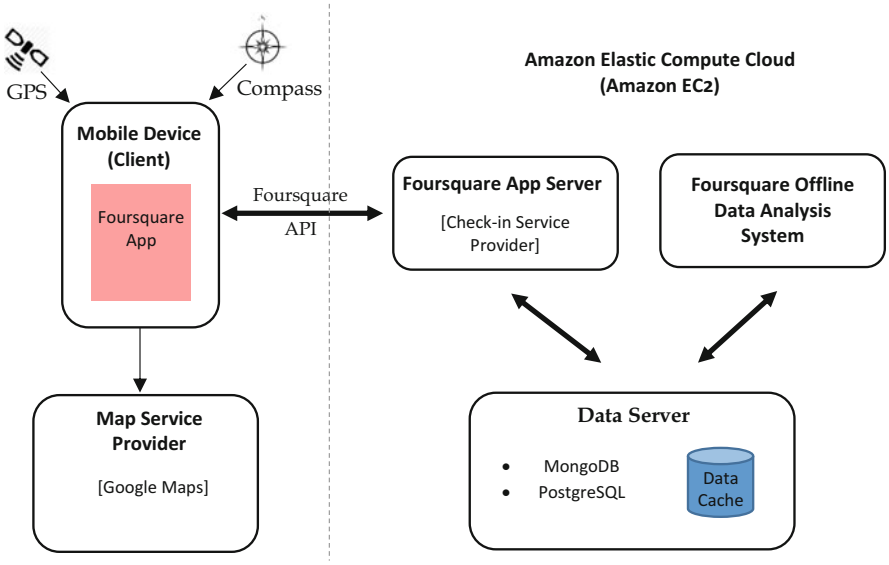

Fig. 3 The Foursquare architecture (Adapted from [18])

2.3 Uses of Foursquare

Other than sharing locations with Foursquare by check-in to different venues, Foursquare allows users to meet up with their friends or simply to find out where their friends are hanging out. Many users employ Foursquare as an entertainment purpose to win points, badges by checking-in and ultimately being the mayor of a particular venue by having the most number of check-ins in that location. Business also makes use of Foursquare to improve their services by working on the tips provided by their customers. Additionally, tips are exploited by the business, who are also Foursquare users, to promote any products or brands. It has also been noted that Foursquare can be used as an important feature in urban computing to carry out different research studies. For instance, the user activities in urban environments can be inferred by using the check-ins of the users in Foursquare [19]. Similarly, the popularity of locations in cities can be inferred from the analyzed Foursquare data and the users' movement pattern in the city streets can also be observed [20]. A recent study by Quercia and Saez [21] showed that location data from the Foursquare application can be used for crowdsourcing the land use of urban environments. With these data, the physical changes in a neighborhood is possible which can help to monitor the socio-economic deprivation of that neighborhood.

3 Categorization of PBSN Applications

Different types of mobile applications have emerged during the recent years helping people to locate each other and based on the location of users as a primary feature, different services are offered to them. Several attempts have been made in the past to give an overview of the different categories of PBSN applications. In light of the rapid adoption of smartphones and social media over the past years, new categories of PBSN applications have emerged providing users with more services. Hence, in this research, a new model of categorization has been derived based on four different criteria namely location, object, purpose and trajectory. Figure 4 illustrates the categorization proposed in this study:

The description of the categorization model is illustrated in Table 1 outlining the four categories:

The below sections give a detailed overview of the four categories of PBSN applications. For each category, around three sub-classes have been defined according to their application areas.

3.1 Categorization by Locations (Where)

In this category of PBSN applications, the responses of the applications are based on the changes of locations. The location information can be retrieved directly from the applications on a mobile device if location services are turned on, e.g. Location Services in iPhone allow some applications such as Maps and Camera to determine the user's location automatically using cellular data, Wi-Fi, GPS and Bluetooth [22]. The Where class of PBSN can be further be classified into several sub-classes as below:

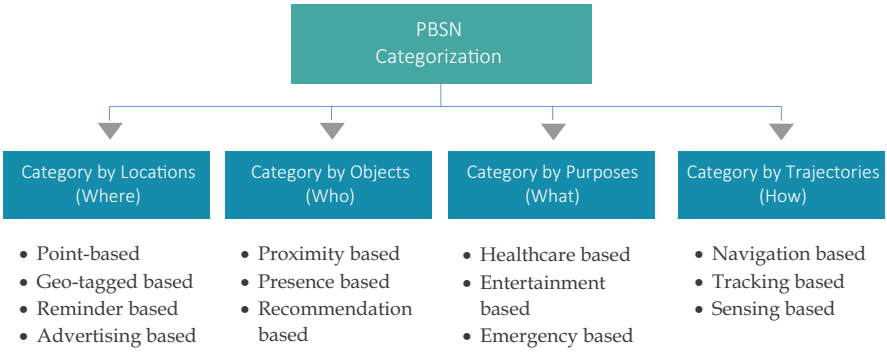

Fig. 4 PBSN categorization

Table 1 Description of categorization model of PBSN applications

Categories	Description	Example
Categorization by locations (where)	This category refers to applications where the location of users is the basis under which services are proposed to users	Check-in at a place
Categorization by objects (who)	It revolves around mostly the people in question such as discovery and recommendation algorithms which are integrated in PBSN applications to give further services to users in proximity	Friend finder applications
Categorization by purposes (what)	This category offers services in different application areas such as in health care, entertainment and emergency by taking into account the user's locations	Health care applications or location-based games
Categorization by trajectories (how)	This type of application refers to the different locations of a user in motion providing services	Road guide, tracking or fleet asset management

3.1.1 Point-Location Based

In this category, users can share their location using check-in posts allowing their friends to know where they are. Checking-in as outlined by Gao et al. [23] refers to an online activity which reveals the user's location with the help of social media acting as an interaction between the user and the real world. Facebook Places and Swarm (originated from Foursquare), categorized as point-location based applications, allow users to share their locations by checking-in to a particular place [24, 25].

3.1.2 Geo-Tagged Based

Bao et al. [26] introduced geo tagging services facilitating users to add a location label to different media contents such as text, photos or videos. For example in Facebook, if location services are enabled on a smartphone, the location is automatically shared when the user posts a status, clicks a picture or records a video and shares it on the timeline. Users can then view all the places they visited where photos were taken on a digital map. The same scenario applies for photo-sharing OSN Flickr [27] where photos uploaded from mobile phones having geographical data can be displayed on a map according to the location the pictures were taken. Color [28], a similar PBSN application, allows creation of photo and video albums with users located within 150 ft at social events such as parties or weddings.

3.1.3 Reminder Based

The services provided by this class of PBSN correspond to leaving self-reminders or notifications for friends at specific locations and when users are identified at the specific places, in other words, push notifications are sent by the applications installed on their mobile devices based on their locations. Some uses of such applications as outlined by Puttaswamy and Zhao [9] may correspond to leaving reminders for different events such as an updated location or time of a party, sending a shopping list when the user, his friends or family are near a grocery store. In addition, these applications can be also helpful when users want to keep a track of their running habits by setting reminders at specific points of their running tracks. Some applications such as Geobells are configurable such that notifications can be set either when arriving at a place or else whilst exiting [29]. The reminders can be viewed on a map and then swiped off once completed.

3.1.4 Advertising Based

Location-based advertising (LBA) applications correspond to adverts reaching customers directly when they are close to the advertisers' locations notifying users of the different sales going on or more interestingly on the new products based on the user's earlier collected tastes [30]. Early LBA applications, known as SMS-oriented, correspond to users receiving SMS adverts based on their locations suggesting them to visit a nearby local store or restaurant [31]. LBA services can be push-based where advertisements are sent based on the known vicinity of the users or pull-based LBA referred to as on-demand services. Customers make a request to receive some information and ultimately, they receive commercial messages, for example, finding the closest ATM machine [32].

3.2 Categorization by Objects (Who)

This category takes into consideration the responses based on the proximity changes of the objects, where in PBSN, the objects refer to the users. The below sections illustrate how these applications collect information from individual users and provide services such as discovery and facilitate interactions of groups of people in proximity.

3.2.1 Proximity Based

Proximity based applications use geo-proximity as a principal filter to determine users who are discoverable in the social network and enable physically proximate travelling users to interact with each other through their mobile devices.

Crocker [33] further identified three stages for connecting to this type of network namely the proximity network, where the nearby anonymous users can only be discovered, the elastic network and finally the social network. In the elastic network stage, users can interact with other people in the proximity network and build relationships with them without sharing too much information. Once a trust has been built, they enter the final stage, the social network, where the user's details are revealed, and stronger relationships are built. Yu and Han [34] focused on discovering groups of people who are most likely to share information by applying the CPMd algorithm for detecting the communities, for example Proxxi [35].

3.2.2 Presence-Based

Presence-based social networks applications focus on connecting users present in a certain place for a definite period of time such as a concert, wedding or sport event [33]. Users can discover each other within the time span they are in the proximity network and also have the choice to continue their friendship even afterwards. LoKast [36], short for "local-casting", is an example of such type of PBSN application and allows users to connect with group mediums starting around specific activities or events and then discover other users. They can then communicate with each other, share photos and videos thus enjoying their experiences around activities and events using their smartphones or other mobile devices. This type of PBSN application can be greatly used in business meetings to share useful information or reactions to live events happening.

3.2.3 Recommendation Based

Friend-finder applications help users to make new friendships but only if those users are in the same location or in nearby surroundings [33]. The recommended friends are based mostly by what they shared on their profiles and based on a matching algorithm these new relations are created. However, Burcea and Jacobsen [37] presented another view of such application where a user being notified when a member of his family or a friend is located in the surroundings. This algorithm is such that each user has a unique identifier MIN (Mobile Identification Number) associated with his mobile phone and if a user subscribes to the service, a corresponding location constraint such as MIN_1 or MIN_2 is created. Therefore, when two users are found in the same locality, the location constraint will be matched and thus notifications will be sent to each user.

3.3 Categorization by Purpose (What)

This categorization refers to what types of services that can be offered to users by using their location information where the responses are based on the purposes of the applications. These types of applications are designed for specific application areas such as healthcare, entertainment and emergency as detailed in the sections below.

3.3.1 Healthcare Based

Online social networking sites such as Facebook and Yelp are a common platform used for sharing health problems and seek health advices [38]. This was confirmed by a study carried out by Scanfeld et al. [39] who considered social networking sites such as Twitter as a medium for the informal sharing of health information and advices. However, Boulos [40] outlined that the users' needs are related to where they are and location information should be taken into consideration when advices about health information are given. CAALYX [41] is a user health monitoring platform which is used to closely monitor the health of elder people and try to help them in when they are in need. The autonomy and self-confidence of these people is increased by wearing a light device which can measure the vital signs, detect their falls and communicate in real time with their care provider in case of an emergency. A future work of CAALYX is to develop a geo-reminder system, which can help Alzheimer's patients with their short memory problems.

3.3.2 Entertainment Based

Entertainment features are usually embedded in popular PBSN applications such as Foursquare where there are virtual and tangible rewards when users check in. Points, badges or even mayorships can be won as virtual rewards for the check-ins recorded. When a user has the maximum number of check-ins at a particular venue for a certain period of time, the user becomes the Mayor of that location. Tangible rewards will correspond to some discounts at a coffee shop or free drinks or snacks at restaurants for users having significant number of points or for the mayor of that place [42].

Mobile Location Based Gaming (MLBG) is another growing trend among location-based services linking different games with new technologies such as GPS, Bluetooth, Wi-Fi and image recognition on smartphones [15] thus further bridging the gap between the physical and digital world. Sensors are used in the games applications to capture information about the gamers' current context and also their location which is used to deliver a gaming experience which changes according to their position, to what they are doing or even feeling. BotFighters [43] and PokemonGo [44] are popular location based gaming applications where the

locations of the gamers are used to provide interesting features in the games such as finding objects in the real world with reference to photos uploaded or locating friends using positioning techniques [45]. It is also known that Angry Birds will also include location-based features in the near future where locations such as coffee shops, bars, etc. will convert into playing grounds and players can compete with one another on a unique leader board tied to each location [46].

3.3.3 Emergency Based

Location information can be integrated into emergency-based applications to assist them in difficult situations. Twitter was used as an emergency service by De Longueville et al. [47] by analyzing the spatio-temporal dynamics of tweets activities during a major forest fire event in France in July 2009. The authors argued that the information gathered for this incident can support emergency planning, risk assessment and damage assessment activities in the future. Gomide et al. [48] analysed how the Dengue epidemic spreading in Brazil from 2009 to 2011 was reflected on Twitter, in other words, the tweets of users referring to Dengue were evaluated taking into consideration both time and location dimensions. They asserted the fact that Twitter can be used to predict Dengue epidemics spatially and temporally by means of clustering. Help me [49] is a specialized emergency GPS application based on location services where users can seek help from nearby smartphone users in crisis situations when there is no Internet connection.

3.4 Categorization by Trajectories (How)

In this category, the responses are based not only on the current locations but also the previous and future ones so as to offer users better services based on their routes. The below sub-classes give a better idea about these services.

3.4.1 Navigation Based

New interactive applications for social navigation have been emerged with the rising trend of embedded technologies such as GPS navigation and broadband internet access on mobile devices. Social Navigation Network [50], a framework for PBSN focusing on navigation where not only recommendations on where to go are given but also on how to get at a particular place. Users can mark locations on a map suggesting them two types of routes: walking or driving. On top of that, using the marked locations, users can indicate recommendations for not only locations to go, but also locations not to go by giving different ranks to locations. Onstar [51], an automatic vehicle location service, use the vehicle's GPS receivers together with the mapping guide to offer services in selected cars. Directions or other types of

assistance can be asked to a live OnStar representative by pressing the Onstar built-in button in the GM vehicle and if the vehicle is involved in an accident, the latter immediately contacts the driver to determine the help needed and then summons local emergency services as required.

Gaonkar et al. [52] introduced an alert-based location application to help and guide lost users. Since, internet maps will not help much in small areas such as a university camp, these location-aware alerts can help by enabling the user to view the pre-recorded walking directions from his current position to the desired location to find the way to their destination, for example their classroom.

3.4.2 Tracking Based

Popular applications such as Facebook, Twitter, Google and Foursquare use passive location tracking mainly for data mining purposes so as to improve their services [53] e.g. Google is known to track daily movements of users on a map to improve its search results. Many commercial applications such as Geofency [54] and Placeme [55] monitor the users' daily activities such as working hours, client visits, etc. Placeme allows a calendar view where a history of the locations visited can be viewed and notes can be added to each location. These tracking services can also be used to help preventing thefts of valuable items and to locate people such as lost children or pets. Some trucking companies used such applications to locate their trucks and in addition, to check the contents inside delivery trucks using an onboard wireless LAN. They claim that efficiency and customer service can be enhanced by making last minute delivery changes, which are based on truck invention and location. Route optimization for deliveries can be further improved by combining tracking with navigation services.

3.4.3 Sensing Based

Mobile location sensing allows not only collection of users' information but can provide location based services such as recognizing different activities of the users such as walking, running or driving or classifying several sounds associated with a particular context or activity such as using an ATM machine or being in a particular coffee shop [56]. Furthermore, combining the accelerometer data and location details from the GPS, the application can recognize the mode of transportation of a user, such as using a bike or car or taking a bus or the subway.

Personal sensing systems such as CenceMe [57] allows to predict the user's behavior including sitting, standing, using mobile phone, running, climbing, etc. by making use of human activity algorithms. The sensing presence can be added into online social networking applications such as Facebook, MySpace and IM such as Skype allowing for new levels of connections and implicit communication between friends in these networks. In addition, the CenceMe system also provides users with health related services by estimating the exposure to ultraviolet light and noise and

the number of steps taken to calculate distance travelled and number of calories burned. CitySense [58] relies on same protocols but the most popular places are sensed based on the number of check-ins. The popular places are noted on Google maps and thus are identified as the most happening places of the day or night. Over time, the preferences of the user can also be learnt, e.g. where the person likes to go or recommend people with similar tastes or even displays where a user's friends are.

3.5 Discussion

Based on the categorization model presented, Table 2 outlines a summary of the different categories discussed. The main features of each category are defined along with some examples of existing systems in which the features are applied. A short description on how the applications retrieve the locations of the users is also included.

4 PBSN System Evaluation

The efficiency of current PBSN systems has been measured against a set of criteria such as architecture, security and communication protocols. The different evaluation criteria that are used to evaluate PBSN systems are described below.

4.1 Architecture and Framework

There are different types of architectures for PBSN applications such as client-server, distributed, peer-to-peer (P2P) and cloud computing. However, distributed and P2P architectures are mostly used in such systems due to the absence of a fixed Internet connection. In a distributed architecture, servers and clients communicate with each other through a middleware providing and receiving services from each other [74]. A P2P architecture is more appropriate for such systems since the services are mostly intended for mobile users. Each peer may act as a server and a client in the absence of a centralized server and can be a source of information for some peers while at the same time retrieving information from others.

Based on the above-mentioned architectures, several frameworks have been designed and implemented for PBSN applications such as AllJoyn [75], HumHub [76], Elgg [77] and Anahita [78]. These help developers to design and implement such systems easily in which locations of users are automatically retrieved. The developers then have just to customize their applications according to their needs and requirements. Figure 5 presents the architecture of the AllJoyn framework.

Table 2 Categorization of PBSN applications

Categorization	Application areas	Features	Existing systems	Localization
Category by locations (where)	Point-based	– Push notifications are sent to users when they are located at particular places – Users can check-in using their mobile devices having GPS/Wi-Fi/Cellular Networks – Reviews, recommendations and comments from other users are obtained when users check in	– Swarm [25] – Facebook [3] – Twitter Twitter [59]	GPS in smart phones or tablets are used by these applications to retrieve the exact location of users
	Geo-tagged based	– Location label are embedded to media contents such as pictures or videos when posted online – Photos can be viewed on a digital map in the geographic context as created	– C-IMAGE [60] – Flickr [27] – Color Network Computing [28]	The geo tags can be added explicitly by the user or the tagging can occur passively when content is posted
	Reminder based	– Notifications or alerts can be set at a particular place so as when users are located nearby, the application reminds them of the action to be taken – Edge or the radius of the geo-fence can be specified defining how close the user is	– SmartNotify [60] – Task Trigger [61] – Geobells [29]	The app monitors the GPS information collected by the smart phone to trigger the alert when the user arrives at or leaves a destination
	Advertising based	– Advertisements are sent to customers based on their locations – On demand services or pull based allow users to opt for these advertisements	– Messiah [62] – Foursquare [63]	Different types of advertisements are sent to users based on their real-time location such as geo-aware ads, geo-fencing ads and geo-conquesting ads

(continued)

Table 2 (continued)

Categorization	Application areas	Features	Existing systems	Localization
Category by objects (who)	Proximity based	– Use geo-proximity to detect nearby friends – Allows meeting up and chatting with friends in same surroundings	– Foursquare [63] – Proxxi [35]	GPS or Bluetooth of mobile devices cross-check the position of a user with the locations of friends in proximity
	Presence-based	– When attending events such as a concert, business meeting or wedding, users can be in communication with each other through the application as a group – Information, photos and videos can be shared with each other	– iGroups [64] – Lokast [36] – Color [28]	The localization protocol ensures that only the persons within the location range are eligible for the service
	Recommendation-based	– Analyse and discover the social relationships between users in proximity to give location based recommendations – The suggestions are based on different other criteria as well such as interests or friends but focus remains on proximity	– Foursquare [63] – The Scoop [65] – Alike [66]	The profiles of mobile users are compared with other proximate users and recommendations are sent based on their matched profiles
Category by purposes (what)	Healthcare based	– Health advices can be given based on user's locations – Monitors health of patients taking into consideration their locations so as to alert required persons	– Caalyx [41]	The location information is taken into consideration when a user is in trouble and notices are sent to other people so as to locate him and help him
	Entertainment based	– Integrate current location information in gaming services – The exact location of the users is used as a feature in the games	– Geocaching [67] – BotFighters [43] – PokemonGo [44]	GPS of the mobile device tracks the location of the users

	Emergency based	– Can send current address, GPS coordinates and emergency message – This application can be for great help for elder people who live and travel alone	– Help Me [49] – OPLITOP [68] – SANA [69]	Spatio-temporal information of users is taken into consideration for such applications
Category by trajectories (how)	Navigation based	– Locations can be marked on a map to produce routes for users to follow – Telematic services or automatic vehicle location services are part of this categorization of PBSN	– GeoLife [70] – Social Navigation Network [50] – Onstar [51]	The locations are not retrieved at only one place but along routes, therefore a constant trace of the locations is taken
	Tracking based	– Locations of users are constantly retrieved from users even when they are not using the applications – Can be used in asset and fleet management	– PlaceMe [55] – Geofency [54] – PowerSpy [71]	Tracking devices using GPS can be integrated either in the mobile devices or in the vehicles and messages sent to the respective personals
	Sensing based	– Sensing occurs through ubiquitous devices for different activities of users and even for different sounds	– SenseDcity [72] – AndroSensor [73] – CitySense [58]	Different sensors on smartphones, such as accelerometer, digital compass, gyroscope, microphone, and camera are used together with GPS to retrieve locations and activities of users

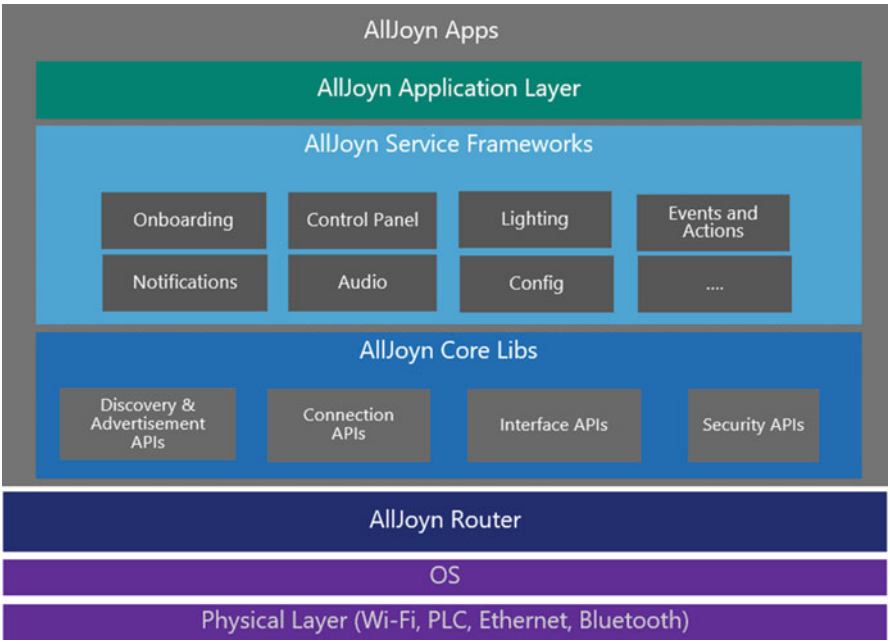

Fig. 5 AllJoyn framework [75]

4.2 Discovery Protocols

The discovery protocol is used firstly to access the users' attributes, then a proximity calculation is carried out based on the users' social coordinates. If the proximity between two users reaches a specific threshold, they can then discover each other. Eagle and Pentland [79] introduced BlueAware, a Mobile Information Device Profile (MIDP) 2.0 application, based on a central server device discovery and profile matching in which Bluetooth is used as the proximity detection protocol. MobiClique [80] is based on the same idea but however does not depend on a centralized server or even infrastructure connectivity but is mainly based on opportunistic connections between devices in proximity. When two mobile users are located near to each other and if their profiles are similar, both users are notified and then they can choose to have an exchange which can be a simple friendship or content distribution over an ad hoc network. The neighborhood discovery procedure depends on the radio technology of the device being used such as Bluetooth device discovery or WiFi SSID.

4.3 Profile Matching

Profile matching refers to the comparison of profiles and based on similar profiles, that is, two or more users having some attributes in common, these matched profiles can be used for recommendation purposes. Different profile matching algorithms were designed for PBSN systems but most of the recent ones focus on offering a secure profile-matching algorithm so that users do not have to compromise on the data shared on their profiles. Zhang et al. [8] proposed a fine-grained private matching protocol which enables finer differentiation among users having different levels of interest for the same attribute. Zhu et al. [81] designed a novel Privacy Preserving and Fairness-aware Friend Matching protocol in which the matching of profiles takes place only if the interests of both participants are common ensuring that no other extra information can be accessed from the protocol except the information that the user reveals.

4.4 Communication Protocols

Popular PBSN applications such as Foursquare rely on trusted cloud services allowing users to share their locations and communicate with each other in proximity. Recently, location based services have switched to Device to Device (D2D) communication using local-range technologies such as Bluetooth, WLAN and infrared known as Near LBS. Systems such as LoKast [36] and AllJoyn [82] also apply D2D communication in their implementations enabling accurate detection of nearby devices. D2D communication not only results in precise nearby devices detection but also enables excellent ad hoc communication and sharing. In ad hoc networks, the distance between devices are used to establish connection with each other and the peer-to-peer relationship based on proximity is used to continuously restructure the network into multiple clusters. In this model of ad hoc mobility, no fixed infrastructure is important to support communication.

4.5 Recommendation Algorithms

Recommender systems are known to be a success in OSN helping users to connect to friends whom they may know or simply connecting to new friends based on similar interests. The two most popular algorithms for recommender systems are content-based filtering and collaborative filtering [83]. While OSN has been concentrating on friend recommendations and tag recommendations only, PBSN considers location recommendations also [84]. Bao et al. [85] presented a location-based and preference-aware recommender system to facilitate the travel of users not only in their surrounding areas but also in a new city. Two models were proposed in

the system: online modeling where the personal preferences are learnt automatically based on the users' location histories and the social opinions and secondly, the offline modeling part where the location histories are extracted. Khalid et al. [86] proposed a novel cloud based recommendation framework which recommends venues at a finer granularity to address several issues such as data sparseness, cold-start and scalability.

4.6 Location Prediction

Location prediction is different from a location recommender system such that location prediction forecasts the next location that the users had been before or based on their location patterns. On the other hand, location recommendation focuses on recommending a new location to the user that the user had never been before. Location prediction can be applied on different applications such as mobile marketing, traffic planning and disaster relief [84]. Mahmud et al. [87] introduced a hierarchical ensemble algorithm using a combination of statistical and heuristics classifications for predicting the home or primary locations of Twitter users by considering their tweets and analyzing their tweet behavior. In addition to predict locations, the framework by Do and Gatica-Perez [88] forecasts also the applications that users will use in the next 10 min by using the contextual information extracted from the sensors of their smartphones. Their framework was based on a generic model comprising of commonly used prediction algorithms such as Least-Square Linear Regression, Logistic Regression, Random Forest, Markov Models and the Blending Model.

4.7 Security and Privacy

There are several threats associated with sharing of personal information online, however, PBSN users are more skeptical to share their locations on these applications as they are present physically and therefore the danger is greater. The users can be stalked, threatened or even sexually assaulted. Many commercial PBSN such as Foursquare, Lokast etc. employed different initiatives to help protect users' privacy by allowing the users to control the sharing of their information, for example by choosing the audience with whom they share their posts. However, it is clearly mentioned in their policies that once information has been shared these are no longer safe and third parties can have access [130].

Different privacy protection schemes have been introduced such as the use of anonymous identifiers or cryptographic keys when users in proximity communicate with each other [89, 90]. The data transferred is protected and can be received by only the persons having the shared keys. Others have adopted location-obfuscating techniques by hiding the exact locations of the users while some employed

encryption methods to protect the personal and location information of users [91]. These security measures allow users to have more trust in the applications and attract a larger number of users.

4.8 Overall Evaluation of PBSN Systems

A list of popular PBSN systems as from year 2005 is compared based on the above-mentioned criteria and details about how these criteria are used in each system are presented outlining the different techniques employed.

Based on the evaluation of the PBSN systems, it is observed that the centralized architecture is not commonly used, instead most of the systems employ the Client-Server and Peer-to-Peer architecture. Most of the PBSN systems makes use of cryptographic schemes to secure the data in the systems while some promote the use of secure identifiers. The most commonly used communication protocol refers to Bluetooth and GPS (Table 3).

5 Innovative PBSN Applications in Urban Environments

Urban environments have employed the implementation of intelligent infrastructure and advanced technologies to improve the services of the cities. Moreover, the vision of smart cities has been influenced by the widespread adoption of smartphones in such a way that GPS data is exploited to provide the citizens modern services. It has been observed that urban environments have adopted PBSN applications to facilitate the daily activities of the citizens or to attract tourists during their journey in the city. The different areas of the innovative popular PBSN applications are described below:

5.1 Collective Sensing Applications

Smartphones are no longer regarded as devices to communicate with each other but provide an extension of the users' personalities and a database of their interests. The embedded sensors in the mobile devices have allowed new advancements by retrieving data about people and their environments. Novel applications have emerged by using these features such that proximity and light sensors can be used to retrieve the context of the users while the accelerometer data can estimate the physical movements of the users [101]. As reported by Li et al. [102], it is possible to determine the activity of a person by continuously collecting audio from the phone's microphone. Furthermore, if the data of the accelerometer and the location estimates are combined, the mode of transport can be deduced [103]. Based on

Table 3 Evaluation of PBSN systems

Existing systems	Security and privacy	Communication protocols	Recommendation algorithms	Profile matching	Location prediction	Discovery protocols	Architecture	Frameworks
Identity Server [90]	Anonymous identifier (AID) using cryptographic hash function SHA-1	Bluetooth AID sharing service	N/A	Anonymous exchange of social networks	N/A	Discovery is based on AID generated	Peer-to-peer architecture	Restlet framework
MobiShare [92]	Two different servers are used to store users' information	Mobile cellular networks (3G/4G)	N/A	Based on profiles and distance of the users	N/A	Based on the public key of user and its threshold distance	Client-server architecture	JoyentCloud and Linode
Facebook Places [3]	Users control the audience to share their posts	Wi-Fi, Cellular Networks, GPS	Based on the check-ins and distance in km	Based on interests and places visited by users	Previous visit patterns	Location is automatically shared if location services are on	Client server	N/A
Foursquare [63]	Information is self-controlled by users	Wi-Fi, Cellular Networks, GPS	Push notifications Reviews or comments	Based on users' tastes and locations visited	Previous pattern visits and distance	Based on users' tastes	Client server	Scala/lift web framework
Place-Its [93]	Computation is done on the client's device	GPS, GSM and Bluetooth radio technologies	N/A	N/A	N/A	Set reminders are generated based on locations	Distributed architecture	Symbian Series 60 platform

EnCore [89]	Unique encounter ID and associated shared key using encryption/authentication codes	Bluetooth	A record of strangers' devices is kept to send recommendations	Based on shared attributes	N/A	Based on known friends, matched profiles or previously encountered devices	Peer-to-peer architecture	SDDR protocol
GeoSocialDB [94]	Privacy aware query processing is provided for recommendation queries	Users communicate by geo-tagged messages	Based on spatial and social preferences	N/A	N/A	Based on range distance	Distributed architecture	GeoSocialDB framework
E-SmallTalker [95]	One-way hashing of Bloom filters	Bluetooth	Based on common topics of users	Exchange of Bloom filters by the Content exchange components	N/A	Using the Bluetooth Service Discovery Protocol (SDP)	Distributed architecture	N/A
BlueAware [79]	No privacy measures employed	Bluetooth	N/A	Different weights are set on attributes	N/A	Using Bluetooth identifier (BTID) and timestamps	Centralised architecture	
OmniSuggest [86]	N/A	GPS	Hyperlink Induced Topic Search (HITS) approach	Using preferred venues	N/A	N/A	Hybrid cloud computing architecture	OmniSuggest

(continued)

Table 3 (continued)

Existing systems	Security and privacy	Communication protocols	Recommendation algorithms	Profile matching	Location prediction	Discovery protocols	Architecture	Frameworks
Bao et al. [85]	N/A	Data collected from Foursquare	Top-k ranked locations based on an offline and online modeling	Using a weighted category hierarchy-WCH	N/A	User's preferences are learned from their location history	Distributed architecture	N/A
Micro-Blog [52]	Users can control their own privacy preferences	Wireless networks such as Wi-Fi, cellular and GPS	N/A	Matching algorithm applied on micro blogs	N/A	Using a persistent TCP session locate users on map	Client Server architecture	Micro-Blog
CenceMe [57]	Users can control their privacy settings	Embedded sensors, Bluetooth, GPS	N/A	N/A	Based on user patterns	Based on previous visits	Threaded architecture	Java Micro Edition (JME)
MobiClique [80]	Entity's authentication support	Bluetooth connectivity	N/A	Syntactic pattern-matching	N/A	Depends on the radio technology used	Distributed architecture	Facebook API
Tribler [96]	Secure identifiers (PermIDs) using elliptic-curve cryptography	File Transfer Protocol (FTP) service	User-item rating matrix and standard collaborative filtering techniques	Using the Peer Similarity Evaluator module	N/A	Controlled by the BitTorrent protocol using Buddycast	Peer-to-peer system	BitTorrent

Existing systems	Security and privacy	Communication protocols	Recommendation algorithms	Profile matching	Location prediction	Discovery protocols	Architecture	Frameworks
Mobilis Group [97]	N/A	eXtensible Messaging and Presence Protocol	Based on current location and group memberships	N/A	N/A	The XMPP Service Discovery extension	Centralized architecture	Mobilis
Road Speak [98]	Asymmetric cryptographic key pair (using PKI)	Using 3G-based cellular over a voice communication system	N/A	Based on time, location and interests	N/A	Based on groups and location	Centralized system	Vehicular Social Networks (VSN)
VENETA [99]	Commutative encryption scheme	Bluetooth	Based on mutual friends	Based on age and gender	N/A	Based on matched friends	Decentralize architecture	Java microedition
Clements et al. [100]	N/A	Geo-tagged photos retrieved from Flickr	Based on preferences of landmarks	Gaussian kernel convolution	Based on travel behavior	N/A	Centralised architecture	Flicker API

the collective sensing features, different classes of applications have been emerged in urban environments such as monitoring real-time traffic including braking and honking [104]. Additionally, the road conditions such as potholes or bumps can also be detected by using the embedded sensors such as accelerometer, microphone and GPS as described by Nericell [105]. Environment pollution monitoring such as EcoSensor is also possible with PBSN applications allowing the monitoring of air pollution through mobile sensors [106] and the NoiseTube project, which is used to monitor noise pollution by using microphones in the mobile phones to measure the noise level in the current location.

5.2 Mobile Guide

PBSN applications can be used as mobile guides in the city streets as a replacement to traditional maps and paper guides. The geo-positioning features of the smartphone in addition to its portability allows the mobile guide PBSN applications to provide real-time information to visitors and are easier to reach tourists. Furthermore, the mobile guide applications offer search features, pull and push notifications to the users based on their locations and also reviews and recommendations by previous users [107]. As outlined by [108], learning about new cultures and history of the cities is one of the main reason of travelling and PBSN mobile guide applications engage visitors in an entertaining way to learn about the places they are currently visiting. Pica et al. [109] proposed the GeoGuide application which allows the overlaying of images, sounds and videos to allow visitors discover and learn the history of buildings or even view the landforms of the cities before the existence of the current infrastructures.

5.3 Assistive Technology

Urban cities have witnessed a rapidly changing population where the distance between family members is increasing resulting into a higher degree of isolation among older people. To improve the living conditions of this group of population, different assistive technologies have been introduced to support them in their daily life and to provide care facilities [110]. While these solutions can be expensive and require large computational cost, PBSN applications, inspired by human cognition, can offer the assistance by making use of the retrieved context data. Similarly, assistive services can be provided to visually impaired persons to facilitate their pedestrian experience in the city streets [111]. The proposed system provides guidance in real-time and is responsible for obstacle detection as well as interaction facilities with the users.

5.4 Crowdsourcing

Crowdsourcing applications allow users to contribute to complex problem solving in a transparent manner by making use of the multi-sensing capabilities of the smartphones [112]. The PBSN crowdsourcing applications are known to be more beneficial by using the temporal dimension in addition to the location coordinates. As outlined by [113], these innovative applications were helpful in emergencies such as finding a lost child in the city or a disaster relief. To find the child, several pictures have been uploaded by visitors in that area during a certain timeframe and by using data analytics, the police looked out for the lost child by using the uploaded pictures. For the second case, an infrastructure in a city was damaged and no way was available to assess the damage using the remaining infrastructure. To help reconstruct the disaster site, citizens shared its pictures, which were helpful in speeding up the rescue efforts in a more effective way.

6 Research Challenges

Numerous PBSN systems have been designed or implemented in different application areas to help people in their daily lives. However, it is noticed that there are still many issues and challenges involving these applications. The main challenges of PBSN platforms are described below.

6.1 Security and Privacy

Popular PBSN applications are known to provide self-controlled privacy settings for users to protect their information online. However as outlined by Chang et al. [114], hiding information does not really mean that a flawless privacy protection is provided since locations of users can be deduced from different sources, e.g. based on friendships of users and moreover, when users are tagged on friends' posts, locations are automatically exposed. A study carried out by Krishnamurthy and Wills [115], showed that leakage of personally identified information (PII) of users is occurring in many OSN sites to third parties aggregation servers. TaintDroid [116] was implemented to study the behavior of 30 such third-party applications and the study concluded that two-thirds of the applications examined exhibit suspicious handling of sensitive data, and that 15 of the 30 applications reported users' locations to other advertising servers. Several attempts such as encryption and cryptography approaches have been proposed to further protect location information but it is also known that many attacks can be made on such encryption protocols to decrypt and have access to the information such as spoofing attack or man-in-the-

middle attack. In addition, securing data in a peer-to-peer environment is even more challenging in the absence of a centralized server for communication.

6.2 Anonymous Profile Matching

Many studies on profile matching of PBSN have based their algorithms on fine-grained privacy protocols to primarily secure the privacy of the users and in addition to present them with finer detailed profiles that are matched on different levels of their interests. Since in this case, the privacy of users is related to both the privacy of their profile information and the results of their profile matching, therefore anonymous profile matching should be done. Liang et al. [117] addressed this challenge by introducing two protocols with full anonymity namely the Comparison-based Profile Matching (eCPM) and the Predicate-based Profile Matching (iPPM). These two protocols enabled users to anonymously request messages and respond to the requests without disclosing any personal information. However, in the current system, partial information about the user is revealed. Deep investigation and further research is needed in this area so as to improve the matching algorithms by integrating full anonymity measures and in addition, users should be aware of the information that is being used for this feature.

6.3 Trust Management

Trust between users in online social networking sites following a centralized architecture, is based mostly on the real life social relationships such as college friends, family members or even colleagues. For PBSN services, the level of trust between the users will be different since people communicate with each other without any prior interactions before. Since communication will be based on a peer-to-peer architecture, trust management will be more challenging because of an absence of a central server and in addition the mobility of the users. As outlined by Cho et al. [118], defining and managing trust in mobile ad hoc networks, the interactions between the composite cognitive, social, information and communication networks must be considered. MobiTrust [102] is a novel trust management model for PBSN where it is based on a fully decentralized and self-managed system. The computation of trust is based on three functional factors such as user profile similarity, reputation and history of friends. Trust management plays an imperative role in defining the success of PBSN applications where both the location and identity of users have to be protected. Further works must be done to establish trust relationships among the users and also between the users and the system.

6.4 Data Analytics

Location based services are the new trend in social networking and the market is currently expanding to meet its customers' needs and to further improve its services, the business models are concentrating deeply on data analytics. Several platforms are used to monitor social media and some of them focus on the analysis of location-based social data, e.g. or the Foursquare Merchant Dashboard [63]. The data analyzed can be used in several areas such as for advertisements and marketing purposes and also to study the usage patterns of users for example, the platform KitLocate [119] uses data to forecast the user's next actions. However, it should be noted as for other research challenges outlined, data analytics also raises a privacy issue for users as the information are usually publicly available on the Internet.

6.5 Analysis of Topological Characteristics of Social Networks

Due to the popularity and huge acceptance of PBSN applications, it is vital to further study the statistics and dynamics of these networks to better design the future applications or to improve the existing ones. Analyzing the topological characteristics of such networks is challenging since it involves crawling large graphs of data and highly dynamic ones. In addition, it becomes more challenging since the networks change quickly over time through the addition of new edges, therefore changing the underlying social structure. As future directions, studies should be carried out to understand the content patterns of these networks and to derive new algorithms for discovering people, recommendations and advertising based on the preferences of the users.

6.6 Link Prediction Problem

A common computational problem with the social network is the link prediction problem. Many studies have been carried out to improve the current link prediction services by analyzing user mobility patterns. For instance, Liben-Nowell and Kleinberg [120] studied an array of measures such as graph distance, common neighbours, etc. that can help to lead to the most accurate link predictions. Scellato et al. [121] argued that effective link prediction on location-based services is possible by focusing on the friends-of-friends and on the place of friends of a user. However, when there are millions of users, these are quite sparse, therefore designing an accurate and efficient prediction algorithm is quite challenging. Gao and Liu [84] outlined that the best way to combine PBSN services with location prediction efficiently is still an open research problem. Therefore, further investigation is required so as to improve the link prediction problem using geometric data

together with spatial-temporal data. As outlined by Bliss et al. [122], the prediction algorithms should be designed in such a way so as to prevent decay of links over time and deducing the inconsistencies in flow rates.

6.7 Privacy Context Based Communication

Different types of context-based services have been implemented making use of the location information and daily activities of users ranging from discovering nearby friends applications to sharing recommendations or content and gaming applications. While offering several benefits to users, at the same time, these applications expose users' to different risks. EnCore allows secure event-based communications, but in spite of the strong security and privacy guarantee, different types of attacks can take place, e.g. attackers can act as peers and participate in the communication [89]. Other ways that the security of EnCore can be bypassed consist of attackers tracking a device if it remains in continuous communication with another device over Bluetooth or if users have shared some explicit information such as nicknames, attackers are able to link the communication or posts shared. Other challenges of communication in context aware services as outlined by Li et al. [123] include of a quick discovering method, efficient channel allocation, power control and interference management.

6.8 Adaptabilities

Adaptability is one of the fundamental characteristic of wireless services and mobile applications in the current trend of PBSN. It refers to the ability how the PBSN applications gracefully abide with changes in circumstances. Context information is normally used to provide adaptability in the mobile network [124]. The adaptation provides a proximity based selection of services, automatic reconfiguration in the settings of the application or of the contextual information and also a set of actions during a context change. From previous studies, it is noticed that designing such algorithms can be quite challenging to ensure adaptability in PBSN applications since the network is quite large and very dynamic [125]. Adaptive applications need to match the main three domains: user preferences, device capabilities, and application requirements. Much research must be done in this area to better support PBSN systems. Matching approaches in PBSN applications must be based on semantics so as they are able to adapt to different situations.

7 Conclusion

In this chapter, a comprehensive review of PBSN was carried out outlining the different types and components of PBSN systems. An innovative categorization model of PBSN applications has been presented namely Categorization by Locations, Categorization by Objects, Categorization by Purposes and Categorization by Trajectories. Each category has been further classified into sub-classes and examples of each has been provided after providing a systematic discussion. A thorough evaluation of PBSN is done based on important criteria such as security and privacy, discovery protocols and architectures. It is observed that even though PBSN is a novel application in the social networking area, several new aspects have been emerged in addition to the features of OSN applications since location is taken into consideration. For instance, the architecture is different since the mobility of the users have to be considered in addition to the computation cost and battery life of the mobile devices. The development and evaluation of these proximity applications are subjected to a new direction in the field of social computing giving rise to innovative research directions. We have observed that location privacy is very crucial for these applications and static privacy as provided for OSN applications cannot be applied in PBSN but the dynamic situations of the users should be considered. This survey is concluded with a discussion of research challenges in Proximity Based Social Networks. The research challenges will be helpful in the design of future PBSN applications so that important features such privacy-preserving techniques, communication and adaptabilities are taken into consideration. This detailed study on PBSN applications will also support future researches in the implementation of new algorithms for PBSN frameworks.

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