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A Study of Opportunistic Networks for Efficient Ubiquitous Computing

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Abstract: Opportunistic networks support spontaneous interaction between mobile users carrying mobile devices with them. In this paper we discuss what makes opportunistic networks different to mobile peer-to-peer networks and mobile ad hoc networks; two network types that are closely related. We present a number of applications with a focus on data dissemination. It concludes with an overview of future research issues by naming a number of open and unsolved problems.

Keywords: Opportunistic, Ubiquitous, Mobile Computing, Adhoc

I. INTRODUCTION AND MOTIVATION

A major concern in ubiquitous computing (UC) is the purely natural and effortless interaction of humans with a intelligent environment for carrying out a certain task or simply to make life easier. Generally, interaction is bootstrapped with a user's personal, mobile device. Such a device may carry a digital representation in form of a user profile and a key pair that serves as a digital Identity. Examples of devices are personal digital assistants (PDAs) or mobile phones. The mobile phone plays an important role since it has conquered our everyday life and is ubiquitously available for the user.

More and more mobile phones and PDAs are equipped with short range wireless communication capabilities. In most cases, either Bluetooth or 802.11b Wi-Fi technology is integrated. The prevalent use of wireless connectivity is to synchronize personal data between a mobile device and a desktop computer (via Bluetooth) or have easy access to an organization' s network (via a 802.11 Wi-Fi Wireless Access Point) and further to the Internet. But in addition, with the integration of short-range wireless communication technology into these devices a new network type called opportunistic network and its corresponding applications based on spontaneous interaction and collaboration among devices and users is emerging.

Opportunistic networks are closely related to two other network types: mobile peer-to-peer networks and mobile ad hoc networks (MANETs).The latter operate mainly on the networking layer and provide novel types of infrastructure for all kinds of applications. Opportunistic networks may be considered the least emphasized of the three in the literature, but they provide unique and promising opportunities for the ubiquitous computing era. Opportunistic network applications take advantage of the fact that mobile, personal devices are able to discover and communicate with each other whenever they are nearby. Opportunistic networks help to make people physically aware of each other and second, opportunistic networks support data dissemination very similar to word of mouth communication among humans.

II. UNDERLYING IDEAS AND CONCEPTS

• **User vicinity exploitation**: An clear necessity for short-range communication to occur is the co-location of devices and thus their owners at a certain time and place. This vicinity sharing raises the opportunity for users to meet face-to-face and make personal contact. In addition, to some extent, the usefulness of an application increases, as nearby users share the same physical context and the likeliness might be high that these users share a common interest. For instance, users attending a pop concert have a similar taste in music. Their devices being close enough for communication may help to introduce the users to each other. This assumption might not be true for every encounter, for example, people meeting by accident on a public bus. But even in these kinds of situations, close vicinity enables getting to know new people with the help of the users' devices.

• **Profile based user interest expression**: After two devices have discovered each other, there needs to be a way to determine if it is beneficial for a device and thus for the user to communicate further. This is often achieved by employing a user profile on the device. A user profile expresses personal interests and knowledge. Nevertheless, a user wants to satisfy his interest and is committed to sharing his knowledge.

• **Data dissemination:** Whenever a user's knowledge that is stored on their device matches the interest of other user (by user profile matching), this knowledge is transferred from the former to the latter's device. Given a number of users with the same interest, we observe a data

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dissemination process. This process is additionally supported by the user's mobility, that is, users physically carry the data stored on their devices while they move around.

• **Open and unrelated user group:** Opportunistic network applications do not make any assumptions about their participating users. Thus, except for a few exceptions discussed later, users are unknown to each other, act independently and might pursue solely personal interests.

•**Unpredictable communication pattern:** Communication and information exchange takes place between mobile users that accidentally happen to be close-by. A user cannot rely on opportunistic network applications to satisfy his interest at all. Opportunistic networks help in providing best effort functionality. This restricts opportunistic networks to a certain kind of applications. The predominant use of opportunistic networks is the distribution of data by making use of human mobility and local, that is, one-hop, forwarding techniques. Information is stored on the device and passed further when an appropriate contact is met.

III. A DEFINITION FOR OPPORTUNISTIC NETWORKS

A. Opportunistic Network Definition

An opportunistic network is a network of wireless connected nodes. Nodes may be either mobile or fixed. Communication range between two connected nodes is within walking distance, that is, nearly between 100–300 meters. The network topology may change due to node mobility or node activation and node deactivation. The nodes provide the following functionality:

• Node discovery: A network node is able to discover other network nodes in direct communication range.

• One-hop message exchange: A node is able to send and receive arbitrary data in form of a message to or from any other node in direct communication range.

This definition indicates that in an opportunistic network there is an opportunity for nodes (devices) to recognize other nodes in physical proximity and to talk to them. Our view on opportunistic networks supports only one-hop message exchange due to a missing relation and a missing common goal among nodes.

B. Opportunistic Network Node Definition

An opportunistic network node consists of a device with short-range wireless communication capabilities. The device operates an opportunistic network application that uses a data sharing protocol for data dissemination. The data sharing protocol uses node discovery and one-hop message exchange mechanisms.

An opportunistic network node can be a mobile device carried by a human or a fixed device. This is reflected in the next two definitions.

C. Mobile Node Definition

A mobile node (or node for short) consists of a user arraying a mobile device that acts as an opportunistic network node.

D. Information Sprinkler Definition

An information sprinkler (abbreviated IS) is a fixed opportunistic network node within the network. It is a device placed at a dedicated location, thus it is not mobile and not under direct user control. The information sprinkler uses the same data sharing protocol as other opportunistic network nodes.

An IS can operate in a sprinkler mode, meaning information is only dispersed, or in a sink mode, meaning information is only collected, or in both modes together. An Information Sprinkler may also be connected to a backbone network. The backbone network may be a wired network that connects a set of Information Sprinklers and synchronizes their operation. For example, data that is collected at one Information Sprinkler is available at all other sprinklers shortly after.

- Vertical architecture**:** The definitions lead to a vertical architecture as depicted in Fig. 1 the Figure shows three Information Sprinklers and an optional sprinkler backbone. A connection link between nodes is indicated by a black dotted line. This link indicates that two adjacent nodes are close enough to exchange messages with each other. If they communicate at all after they have discovered each other depends on the application. There is no multi-hop communication support in opportunistic network. Thus, there is no direct message exchange between distant nodes.

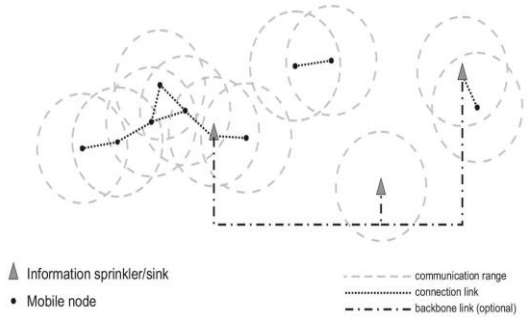

Fig. 1 Opportunistic network example

Communication ranges are depicted as dashed spheres. Note that in practice the communication range of a node is not an ideal sphere due to communication signal interference with the surroundings.

- **Differences To Mobile P2P And MANETS:** As mentioned in the introduction, opportunistic networks are closely related to mobile ad hoc networks and mobile peer-to-peer networks. Due to their inherent dynamic nature, all network types exhibit a number of self-organizing functionality. We will discuss this issue and compare it to opportunistic networks in the following two sections.

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- **Opportunistic networks vs. MANETS:** Since opportunistic network nodes are either mobile or fixed (cf. Information Sprinkler) and communicate over a wireless link, there is a relation to mobile ad hoc networks (MANETs).

The MANET Definition says:

E. Mobile Ad Hoc Network Definition

A mobile ad hoc network (MANET) is a self-configuring Network of mobile routers or hosts connected by wireless links—the union of which form an arbitrary topology. The routers are free to move randomly and organize themselves arbitrarily; thus, the network's wireless topology may change rapidly and unpredictably. Such a network may operate in a stand-alone fashion, or may be connected to the larger Internet.

MANETs are similar to opportunistic networks: both network types do not rely on a central component, for example, a central server. Their architecture is decentralized by definition and takes node mobility into account, that is, nodes connect and disconnect since they move in and out of communication range. Connection and disconnection may also happen because devices are turned on or off unpredictably. This is similar to opportunistic network. MANETs reside on the network layer and take special care about routing—an aspect that is deliberately left aside in opportunistic networks. Routing allows end-to-end communication of network nodes via intermediates. Since MANETs have been investigated in the context of military networks, emergency response, and mobile sensor networks, all applications considered have several assumptions in common that are a prerequisite for routing: All nodes expose a close node relationship. Nodes trust each other and share a common goal they want to accomplish.

In contrast, opportunistic networks are formed between unrelated nodes, and users might even be anonymous and therefore unknown to each other. This has an important impact on routing. Opportunistic networks solely expose a wireless one-hop communication scheme, where only directly connected nodes exchange messages if they benefit from the communication, for example, by learning about information they were looking for. This implies that opportunistic networks reside on the application layer.

F. Opportunistic Networks and Mobile P2P Networks

- **Peer-to-Peer Definition:** Distributed network architecture may be called a Peer-to-Peer (P-to-P, P2P) network if the participants share a part of their own hardware resources (processing power, storage capacity, network link capacity, printers, etc.). These shared resources are necessary to provide the service and content offered by the network (e.g., file sharing or shared workspaces for collaboration). They are accessible by other peers directly, without passing intermediary entities. The participants in such a network are thus resource (service and content) providers as well as resource (service and content) requesters (Servant-concept).

Opportunistic networks and peer-to-peer networks have the integration of client and server functionality into one node or peer in common. Looking at the most prominent P2P application, file sharing on the Internet, a P2P node consumes files from other nodes that match a search query and allows other nodes to access locally stored files. Similarly, the main purpose of opportunistic network nodes is to initiate collaboration. Thus, by providing information, opportunistic networks nodes take the role of a server, and, by consuming information of other nodes, they take the role of a client as well. Having stated this, opportunistic networks fall within the definition of peer-to-peer networks.

However, in P2P networks which do not rely on a central component (sometimes called pure P2P networks), peers build a so-called overlay network (managed in the application layer) for searching resources or content. Although peer relationship is basically not present on the Internet,P2P networks count on a cooperative behaviour of peers in order to maintain the overlay network structure.

Thus, individual peers forward search requests to adjacent nodes. This works well on the Internet, where online costs and peer energy consumption are not a predominant issue, and although nodes join and leave a P2P network at will, the size of the P2P network remedies this dynamic and unpredictable peer behaviour. Table 1 below summarizes similarities and differences between the discussed network types.

TABLE I

SELF-ORGANIZING NETWORKS

Network Type	P2P	Manet	Opp. Network
Layer	application	network	application
Routing/Msg. Forwarding	yes	yes	no
Focus Node Mobility	no	yes	yes
Network Size	high	low–medium	low
Community Dynamics	high	medium	medium
Node Relationship	low	high	low

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IV. OPPORTUNISTIC NETWORK APPLICATIONS

A. Active Collaboration (AC)

AC exploits the physical proximity of users. In addition to the exchange of digital information with users nearby, this allows for use of the device as a link to the user him or herself. Via nonintrusive user notification, such as for example, a subtle device vibration, users are made aware of each other. This may lead to face-to-face collaboration, for example, a conversation or pursuing a common goal in the real world. Active Collaboration has the advantage that the user's knowledge does not need to be stored on the device as a whole.

B. Passive Collaboration (PC)

PC collects and passes any kind of information from and to other users within communication range. This happens without any user interaction. Passive collaboration leads to autonomous information dissemination. In other terms, it is a form of digital word-of-mouth communication, for example, similar to the way rumours spread by word-of-mouth. Since user devices act without user control and interference, an incentive scheme might be crucial for application acceptance due to the fact that users share private resources (memory, battery, CPU). Otherwise, a user might not be interested in taking part in an application at all. In addition, depending on the application and the shared information, privacy preserving mechanisms may also be an important issue.

V. PRIVACY ISSUES

Recall that mobile nodes in an opportunistic network are carried by humans. Given that communication happens in a user's physical proximity and that the user's device will pass information or information needs without notice, this may conflict with users' privacy.

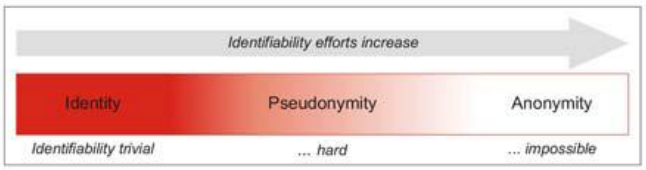

Fig. 2 Degrees of user identify ability

Privacy is the ability of a user to prevent information about her from becoming known to other users. In the realm of opportunistic networks it should be possible for a user to express an information need or offer a piece of information to others without linking back this action to the user. This requirement mainly depends on the application. An application that aims to bring people together (cf. active collaboration) needs one way to identify users and, therefore, to breach privacy, while pure information dissemination applications (cf. passive collaboration) may have a higher user acceptance, if privacy is protected. Privacy protection should be an integral part of opportunistic network applications.

In order to breach the user's privacy, data gathered has to be linked to the human being in the real world. This involves identifying the person.

A. Opportunistic Networks

There are three distinct degrees of classifying user identity:

- **Identity:** A user that communicates with others and reveals any piece of information that can be used to clearly identify him is said to work under his identity. Examples are the full name of a user.
- **Pseudonymity:** This is the ability to prove a consistent identity without revealing a user's real identity, instead using a pseudonym. This is very frequent on the Internet, for example in chat rooms or with electronic mail. Users are free to choose a nickname as a pseudonym and identify themselves with that.
- **Anonymity:** Anonymity is the ability to remain unidentifiable within a set. A user acts anonymously if it is impossible to reveal his identity. Different applications demand different degrees of user identify ability.

VI. CONCLUSION

Research in opportunistic networks is still in its infancy and raises a number of research questions. Since opportunistic network applications rely on a user profile, there needs to be an elegant and effortless way to fill this profile with useful data. Given the limited user interface of mobile devices, a user will probably not wish to type in his detailed taste in music by providing a list of all band names etc. The usage of user recommendation and trust mechanisms might be needed to avoid the dissemination of useless of deliberately incorrectly labeled data. But given the highly volatile nature of opportunistic network applications, that is, users might encounter each other just once in a lifetime, will trust mechanisms work? Finally, given an application is a success, this soon would ask for sophisticated and fine grained filtering mechanisms to keep the application useful by filtering out unwanted information.

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