On the definition and relevance of context-awareness in Personal Networks

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***Abstract*— Personal Networks (PNs) enable users to be connected with their devices and services at any time and any place. Context-Awareness will further enrich PNs. This paper shows some examples, presents definitions of Context and Context-Awareness for PNs, and introduces a high-level architecture for Context-Awareness that is tailored to PNs.**

I. Introduction

Imagine yourself travelling back home after a conference visit. Just before leaving the hotel, your mobile phone switches to ”holiday mode”, and the e-book you buy in the lobby is automatically paid from your private bank account. When you get into the taxi, the taxi driver asks you to confirm that your destination is the airport. The navigation system of the car communicates with your personal devices, and tells the driver to drop you off at terminal C.

During the trip to the airport the taxi passes some tourist sites, and you take a couple of pictures with your digital camera. Your phone automatically sends them to your family PC at home. There is a small traffic jam and you decide to start reading the e-book with your e-book reader. The e-book reader switches to a larger font size in order to increase the reading comfort in a (slowly) moving car.

When you arrive at the airport, your mobile phone shows the e-bill of the taxi trip, and asks for confirmation. After you temporarily override the phone's ”holiday mode”, the e-bill is paid by the company. The phone shows the directions to the correct check-in desk, while encouraging you to hurry up as you are slightly delayed. Once checked in, it appears that the flight is delayed on departure. So, the phone directs you to a shop that, it thinks, you might like. Upon touching a product's RFID tag with your RFID reader, your Personal Digital Assistant (PDA) loads a web page with more information about this particular product. The PDA also informs you that the product is cheaper in a store near home.

Just before entering the plane, the mobile phone is automatically turned off. Once the seat belt signs are switched off you start using the laptop for writing some e-mails. The laptop finds out that there is a wireless hot spot available in the plane, connects to it, and informs you about the Internet connectivity pricing. You reject the offer. On the long flight back home you compose several e-mails off-line, since your cellular phone must remain turned off.

When leaving the plane, your phone is turned back on. It starts querying the laptop for pending outgoing emails and thus sends the messages composed in the plane. After picking up the luggage you drive back home in your own car. The phone notices that you are the driver, and automatically connects to the car audio installation. From your driving style, it also senses that you are a little tired, and therefore tunes your car radio to your favorite Internet broadcasting station. Your family is aware of the car's current location, and knows that you are almost back home!

This scenario shows a glimpse of what one can do with a Context-Aware Personal Network, which this paper is about. In Section II, we briefly introduce Personal Networks (PNs), and give an overview of context-awareness. In Section III, we first present definitions of context and context-awareness in PNs. Next, we highlight the context-awareness examples from the usage scenario in the introduction of this paper. Finally we present a high-level architecture for context-awareness in PNs.

II. Background

A. Personal Networks

Local communication is slowly but surely becoming part of people's everyday lives. In the various private domains of the user (home, car, office, workplace, etcetera), clusters of networked devices (local networks) appear that share content, data, applications, and resources with each other. They communicate with the outside world by means of a common gateway, such as the Residential Gateway [1].

When people are on the move, they carry an increasing number of electronic devices. Some of them have access to the public mobile network. Others have not, but might be capable of connecting to other devices in the personal operating space, forming a temporary ad-hoc Personal Area Network (PAN). This can be done using recently developed Wireless PAN (WPAN) technologies such as developed in IEEE 802.15.

At the same time, mobile telecommunication has become a commodity and third generation (3G) services such as Universal Mobile Telecommunications System (UMTS) are now widely available. The next generation of mobile communication technology (4G) is expected to support interactive multimedia services, service portability, and global mobility. This recently led to the idea to use 4G technology to connect all local networks belonging to a single user with each other and with his PAN, seamlessly, at any place and any time, and thus creating a so-called Personal Network (PN) [2]. Instead of a single device or even a PAN, the complete PN will then become the center of personal communication.

Our definition of a PN does not imply that a PN must contain a PAN consisting of several devices. The PAN can also be a single device. It is also possible that the PN does not contain a PAN at all. For instance, when the user is at home, the PN can very well contain just the home network and the in-car network, or just the home network alone.

Another important notion here is the fact that a PN will not be an end-user service *per se*, but merely a service enabling platform that makes current services easier to use and more widely available to the user, and opens the way to many new (context-aware) applications [3], [4]. The PN user does not care about the architecture of this service enabling platform, e.g. if it is distributed or centralized. The user only desires user-friendly and cost-effective access to the devices, services and content in his PN. Until now, most of the work done on PN architecture has been focussed on a distributed model where all functionality needed for the realization of PNs is implemented in the local networks alone. However, we think that such architectures are not commercially viable on the short term, because a successful introduction of PNs is dependent on the amount of currently existing devices that can be seamlessly incorporated into a PN. These devices cannot be manipulated easily. We therefore assume most PN-specific intelligence to be present in a single server system, and any additional intelligence in the various local gateways and in (few) end devices.

The PN server system can be an always-on PC somewhere in the user's local networks, for instance, the Residential Gateway. However, we propose to locate this functionality with a third party, called Personal Network Provider (PNP) [5]. The PNP is then responsible for the flawless operation of the PN and the integration of services offered to and by the PN. There are three deciding arguments why a PNP will guarantee seamless working of the PN. First, PNs are expected to enable many new services and improve their usability. In theory, users can maintain a business relationship with every device and service provider, individually. However, this would require much effort and it does not guarantee end-to-end service management. The second argument is a consequence of the increasing complexity of integrating and constantly growing number of networked devices. Most users do not want to be bothered with installing and configuring the services and devices in their PN. The PNP can hide the complexity of installation, configuration, and maintenance of the PN from the user. Finally, the realization of PNs needs technology (such as MobileIP Home Agent servers or Simple Traversal of UDP through Network Address Translation (STUN) servers) to be put somewhere in the public network. The business case for such investments can only be positive for a party whose core business is realizing PNs and providing PN services. A schematic view of a PN is given in Figure 1. The cloud in the middle represents the public infrastructures involved in creating a PN. The PN itself is drawn as an overlay that hides the underlying network and business complexity from the user.

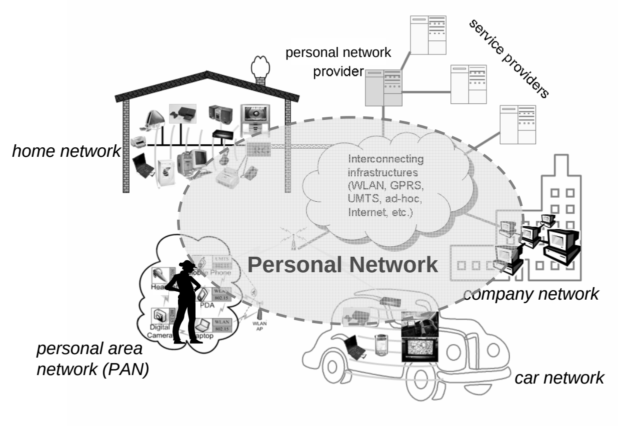

Fig. 1. A Personal Network (PN) is a personalized overlay over multiple network domains.

B. Context-Awareness

1) What is context?: Without naming it context, one of the first publications about the use of context came from Want *et al.* [6] and dates from 1992. However, Schilit and Theimer [7] were the first to introduce the concept of *context* and *context-awareness*. Since then, the research topic context and context-awareness received much attention by researchers. Recently, the research focus has shifted from the definitions of context and context-awareness to the development of context sources and the application of their output (see, for instance, [8]).

An important contribution to the definitions of context and context-awareness has been delivered by Dey *et al.* in [9]. They provided an overview of the existing definitions of context and context-awareness, and they introduced their own definition, which we base our definition on in the next section. Furthermore, they categorized context and features of context-aware applications, making it easier to catalogue context-aware applications.

According to [9], many definitions of context (e.g., [7], [10]–[12]) are definitions by example, i.e., the definition is a list of some types of context such as location, time, and identity of the user. Other definition of context ([13]–[16]) are just synonyms for context such as ”the situation of the user” and ”the state of the applications surrounding”. The final group of definitions is more specific than the synonyms, though above the level of definition by example. Pascoe [17] describes context as the subset of physical and conceptual states of interest to a particular entity. Dey [18] initially defines context to be the user’s physical, social, emotional or informational state. Later, Dey *et al.* [9] define context as any information that can be used to characterize the situation of an entity, where an entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves. They further define *location*, *identity*, *time*, and *activity* as the primary context types for characterizing the situation of an entity.

2) What is Context-Awareness?: Context-awareness is often defined in relation to an application or computational service. Dey *et al.* [9] reported that the first work [7] mentioning context-awareness defined a context-aware application as an application that adapts itself to context. Hull *et al.* [16] and Pascoe *et al.* [17] defined context-awareness computing to be the ability of computing devices to detect and sense, interpret, and respond to aspects of a user’s local environment and the computing devices themselves. Dey *et al.* [11] first limited context-awareness to the human-computer interface. Later, Dey *et al.* [18] defined context-awareness to be the work leading to the automation of a software system based on the context of the user. Finally Dey *et al.* [9] defined a system to be context-aware if it uses context to provide relevant information to the user, where relevancy depends on the user’s task. This is the definition which the definition of context-awareness in PNs will be based on in the next section.

Researchers have also categorized the aforementioned adaptiveness into different categories. These categories can often be mapped on the context-awareness categories proposed by Dey *et al.* [9], i.e., *presentation* of information and services, *automatic execution* of a service, and *tagging* of context to information for delayed adaptiveness.

III. Context-Awareness in PNs

PNs can be greatly improved by making them context-aware. But what is context and context-awareness from the point of view of PNs? Dey *et al.* presented a generic, though workable definition for context and context-awareness for a system. Consequently, we will base our definitions on these.

A. What is Personal Network Context?

As presented in SectionII-A, PNs consist of a set of inter-connected and scattered devices. Hence, the environment in which the user resides is not necessarily that of the PN devices. Moreover, each PN device may have a different environment in which it resides. Inherently, we define context in PNs as:

Personal Network Context is any information that can be used to characterize the situation of the PN user, his PN devices, his environment, and the environments of his PN devices relevant to the operation of the PN and the interaction between the PN user and his PN.

Jacobsson *et al.* stated in [19] that a PN can be viewed in three abstraction layers, i.e., connectivity abstraction level, networking abstraction level, and service abstraction level. The connectivity abstraction level shows the devices from the point of view of the link layer, the medium access control (MAC) layer, and physical link layer. The network abstraction layer shows the PN devices from the point of view of the network and transport layer. Finally, the service abstraction level shows the PN devices from the point of view of services and applications. We add a new abstraction level, i.e., the presentation abstraction level, which can be seen as the PN/user interface over which interaction between the user and his PN takes place. Information that characterizes the situation of a PN device can be information about any of its abstraction levels. For instance, information of a PN device on its connectivity abstraction layer can be ”the physical link quality is low”.

Our definition of PN Context does not mention the inter-connecting networks. The reason for this is that we look at the inter-connecting networks from the point of view of the connectivity and network abstraction layers of the PN devices. In other words, each PN device interfaces to available networks via its network interface(s). Via its network interface(s) each PN device can discover the situation of the network it attaches to.

B. What is a Context-Aware PN?

In the previous section, different definitions of context-awareness have been presented, of which Dey’s definition is more general, though specific enough to be workable. We base our definition of context-awareness on Dey’s definition and state that:

A Personal Network is said to be context-aware, if it adapts to the Personal Network Context in a way relevant to the PN user, where relevancy depends on the PN user’s task.

Taking the abstraction layers of a PN into account, a PN can be made context-aware by making the devices adaptive to PN context at their different abstraction layers. Table I shows examples of context-awareness of a device in each of its abstraction layers.

Abstraction layer	Example of adaptiveness
Presentation	Font of GUI dependent on movement (e.g., larger font in case of movement)
Service	Availability of a service based on the location of the user
Network	Changing traffic route based on security alarms
Connectivity	Selection of link layer technology based on pricing (e.g., in case of two hot spots with different pricing)

TABLE I
EXAMPLES OF ADAPTIVENESS OF PN DEVICES AT THEIR DIFFERENT ABSTRACTION LEVELS

C. Analysis of the use case

The introduction of this paper presented a PN usage scenario comprising several examples of context-awareness. These include:

- Your mobile phone (and the rest of your PN) is aware of the fact that your are leaving the hotel, heading for home, based on your agenda and the current time. Consequently, your PN is automatically switched to ”holiday mode”.
- As you are now in ”holiday mode” your purchases will be paid from your private bank account, unless you override as you will do when paying the taxi bill. Also, the pictures taken with the digital camera will be sent to the PC at home.
- Your PN is aware of the fact that you step into a taxi and tells its driver that you are heading for the airport, and that you want to be dropped off at terminal C.
- Your PN is aware of the fact that you are reading your e-book and that you sit in a moving car. Consequently, it increases the font size in order to increase your reading comfort.
- Your PN is aware of the location of the desk where you have to check in and shows you the right direction based on your current location.
- Your PN is aware of the time at which you have to check in and encourages you to hurry up based on the current time and your location.
- Your PN is aware of the fact that your plane is delayed and concludes, based on the current time, that you have some time left for shopping.
- Your PN knows your favorite shops and directs you to one of them based on your current location and the fact that you have some time left for shopping.
- Your PN is aware of the fact that you are interested in a product and checks for prices of that product in stores near home.
- Your PN is aware of the fact that you are entering the plane and therefore switches your mobile phone off. It furthermore informs your mobile phone about the location (your destination airport) at which it should turn itself on.
- Your mobile phone is aware of the fact that you arrived at your destination airport and is automatically switched on.
- Your PN is aware of the fact that you are driving your car and it connects your mobile phone to the car audio system.
- Your PN is aware of the fact that you are tired and it tunes your car radio to your favorite Internet broadcasting station.

The above-mentioned examples show how context-awareness can increase the added value of PNs. At the same time, the examples show that there is a need for uniform distribution and usage of context information. In other words, the diversity of PN devices and their geographical dispersion make it necessary to develop a context-awareness architecture that is tailored to PNs.

D. Architecture for Context-Awareness in PNs

Researchers have proposed several context-awareness architectures is order to ease the deployment of context-aware services. Dockhorn Costa *et al.* [20], [21] have defined a services platform architecture for context-aware applications, giving emphasis to the configurability and extensibility of the platform’s generic functionality. Strimpakou *et al.* [22] have introduced the Context Management Subsystem (CMS) which provides context consumers with an uniform way to access context information. Siljee *et al.* [23] present a context architecture for service-centric systems, claiming that the architecture provides separation of concerns while developing context-aware service centric systems. In this section, we introduce a high-level architecture for context-awareness, which is tailored to PNs. We realize that this architecture is not yet as well developed as the many (non-PN specific) context-awareness frameworks that can be found in the literature. However, to our knowledge, this is the first time that an architecture is published that is specific to PNs based on a PNP-centered architecture.

The architecture is shown in Figure 2. The Context Factory is the central part of the architecture, which is operated by, for instance, the Personal Network Provider (see also Figure 1). The Context Factory consists of a Context Server in which context information is stored. Furthermore, it consists of a Context Rules Server which contains the collection of rules that state what actions to be taken by whom based on the context information stored in the Context Server. The Context Factory also contains a Context Collector which is responsible for collecting external context, i.e., context that is not (necessarily) provided by the PN devices. An example of such context is an externally provided weather forecast, or the actual departure times of relevant planes. Finally, the Context Factory contains a Subscription Manager that handles the subscription of the PN devices. Through the Subscription

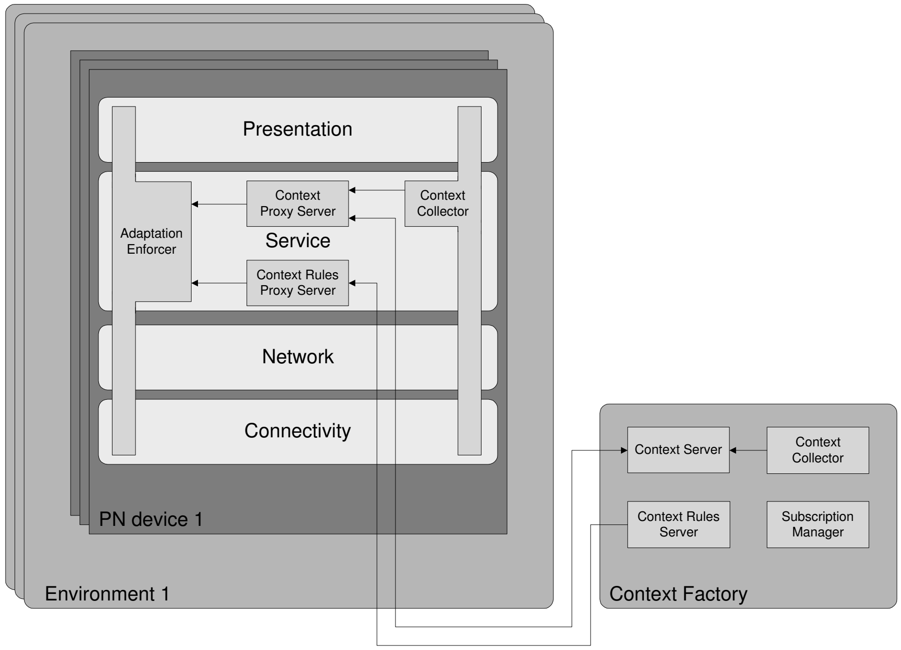

Fig. 2. Architecture for a Context-Aware PN

Manager, each PN device subscribes to particular context information, which it then will receive regularly. The PN devices also inform the Subscription Manager about the context information that they will make available for the Context Server in the Context Factory.

Each context-aware PN device contains the context-awareness entities depicted in Figure 2, namely a Context Collector, a Context Proxy Server, a Context Rules Proxy Server, and an Adaptation Enforcer. The entities are located at the Service level of the PN devices, but the Context Collector and the Adaptation Enforcer can interact with the other abstraction levels of the device. The Context Collector collects context information from the PN device at its different abstraction levels. For instance, through APIs, the Operating System knows which link layer technologies are available for connection at the Connectivity layer. PN devices can also be connected to external context sources (e.g., ZigBee temperature sensor) that do not have IP networking functionality. The output of these context sources can be made available for the PN by letting them appear as an output of a service at the service layer of a PN device, and, subsequently, collecting them by the Context Collector.

The Context Proxy Server contains local context information provided by the context collector, as well as context information retrieved from the Context Server in the Context Factory and to which the PN device is subscribed. Based on the subscription to the Context Factory, the Context Proxy Server is periodically synchronized with the Context Server in the Context Factory.

The Context Rules Proxy Server contains the rules that define the usage of context information. A context rule can for instance be ”If WiFi hot spot is insecure then remove from list of available hot spots”. The Context Rules Proxy Server is synchronized with the Context Rules Server in the Context Factory. More specifically, the Context Rules Proxy Server retrieves the context rules for which it contains the appropriate context information from the Context Rules Server in the Context Factory.

The Adaptation Enforcer is responsible for enforcement of the adaptation to context by the PN device in all its abstraction layers. It resides in the Service layer, but is able to interact with the remaining abstraction layers through available APIs.

E. The mood page

Maybe the most important research issue is the user perception of the many possibilities that context-awareness in PNs offer. There is a great danger that users perceive actual implementations as ”mostly annoying” and ”never doing the thing that I really want”. However, a truly context-aware PN is also aware of the mood and habits of the user, and always adapts its services to his implicit wishes. This requires a great deal of (real and artificial) intelligence at the Context Factory. On the short term, however, a designed context-awareness system cannot cover for expected behavior that in all circumstances pleases the owner of a PN. This requires a user interface that is capable of more than just overriding suggestions by the system, namely, immediate user interaction to control complex behavior of the PN. As such, it keeps the owner of the PN in control. We have dubbed this user interface "Mood Page". In the Context-Awareness architecture, Mood Page is located on the presentation layer as an abstract interface for all layers below. It presents a number of user roles (meeting, private, holiday, etc.) that define presets of the behavior of the Context-Aware PN, the personal devices, the services offered, and the related connectivity. The user can pro-actively select the role according to his mood, and may also fine-tune the impact of a particular role.

IV. Conclusions and further work

In this paper, we discussed Context-Awareness in Personal Networks. Through a user scenario we showed examples of the benefits of making PNs context aware, and we explained how context and context-awareness in PNs can be defined. Furthermore, we introduced a high-level architecture, which we believe will help with the implementation of context-awareness into PNs. Two important conclusions can be drawn from this architecture. First, introduction of context-awareness into PNs requires that the general PN architecture of [19] is extended with a Presentation layer. Second, context-awareness in PNs encompasses more than the context-awareness of the individual PN devices. It also relates the context of the various PN devices to each other, to the PN user, and to other sources of context outside the PN. One can actually speak of the context of the PN as a whole, and the PN's awareness of it, next to the context-awareness of the various individual PN components.

Several issues remain for further research. For instance, we have chosen a centralized context-awareness architecture, where communication about context takes place between the PN devices and the central Context Factory on a regular basis. A suitable communication platform for the aforementioned communication must be selected or developed. The same applies for suitable formats for context descriptions and context rules. Also, an intermediate proxying rule of the various gateways (Residential Gateway, car gateway, etc.) in context-awareness should be examined. One of the biggest challenges is the trade-off between increasing the synchronization time-intervals and making recent context information available to the PN devices. Guidelines for determining the appropriate synchronization intervals must be developed.

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