



# Context Management Architecture for Ambient Networks

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**Abstract**—Future wireless networking beyond 3G will provide nomadic users with context-aware, adaptive services. Context-awareness including context information coordination and management may increase system productivity as well as provide an efficient approach for personalizing network services. Ambient networks are aimed at enabling the co-operation of heterogeneous networks on demand, transparently to the potential users, and without the need for pre-configuration or offline negotiation between network operators. Context-aware networking enables new types of applications and services in ambient environments. This paper discusses the approach taken by authors to incorporate context-awareness into ambient networking concepts.

**Index Terms**—Ambient Networks, Context Coordination, Context Management, Context Sensitive Communication, Contextware.

## INTRODUCTION

Context information is any information that can be used to characterize the situation of an entity, where an entity can be a person, place, physical, or computational object. Traditionally, context-aware applications were designed to collect and use relevant context information. Most of these applications use small pieces of contextual information and none of them are specially compelling. It is believed that future wireless networking beyond 3G will provide nomadic users with context-aware, adaptive services [1], [2]. We propose a new approach, wherein the network entities collect the relevant context information and adapt to it i.e., *protocols, not applications adapt themselves based on context information*. Context-aware communication and context information management [3] may bring significant

improvements in performance and scalability of services rendered to mobile users. Autonomic management and communication of context information, unique to an end-user, at network-level will reduce the amount of human interaction. As human attention is generally seen as the ultimate bottleneck in networking and computing, context-awareness offers an opportunity to increase system productivity in a substantial way, as well as to provide an efficient approach for personalizing network services.

Ambient Networks (AN) [4], [5] comprise several different kinds of networks, starting from personal area networks (PAN) ending to satellite networks. Network context acquisition, representation, storage, dissemination, and transfer negotiation and management are not possible with today's networking technology. Ambient networks thence aim at enabling the co-operation of heterogeneous networks on demand, transparently to the potential users, and without the need for pre-configuration or offline negotiation between network operators. Context-aware networking enables new types of applications and services in ambient environments. But the lack of a standard framework and support from the network for the provision of contextual information hinders the widespread of context-aware applications and the rapid development of the field of context-aware computing. ANs aim to support a common framework for context awareness across all functions in the Ambient Control Space (ACS) in order to adapt service availability and service delivery in heterogeneous networks and dynamic environments.

This paper mainly discusses the approach



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taken by authors to incorporate context-awareness into ambient networking concepts. The rest of the paper is organized as follows. Concepts related to management of context information in ambient networks are discussed next. This is followed by a discussion on the role of contextware and its requirements. Then, the context provisioning architecture is discussed in detail. Context level agreement and quality of context concepts are also discussed following the architecture. The last section concludes the paper with remarks on future research.

## CONTEXT MANAGEMENT IN AMBIENT NETWORKS

In this section, we define context management and its importance in an Ambient Network [6].

Context information in the context of ambient networking can be stated in simpler words as, the information that is required to make an ambient network context-aware. Basically, two types of context information need to be considered: (i) User-related information (for example, user location, identity, available devices, preferences, etc) and (ii) Network-related information (for example, network identity, network resources, available QoS, security level, access-types, etc). This depends on whether context clients are end user's applications or other Functional Areas (FA) of the ACS. Here, a context client could be any process, application, or service that needs context information to enhance its operation. An ambient network's control plane is known as the ACS and it's sub-divided into FAs that include a network's control and management functions.

As discussed in the introduction section, the lack of an infrastructure for the provision of wide range of context information makes it harder to use them. In fact, proprietary systems have to be developed from scratch, for each application, for the collection and modelling of other types of context information. Therefore, a new approach is introduced, in which, the network entities collect/have access to relevant context information and adapt to it, instead of applications collecting context information and basing their behaviour on it. For

instance, the multimedia routing entity, making use of information about the devices available to a user, could adjust the behaviour of its routing protocol to direct the streams to the most appropriate device (for example, to a plasma screen instead of a PC monitor). This network-centric approach provides a consistent support from the network for context management.

One of the key characteristics of an ambient network is that it is extremely dynamic. Unlike conventional networks, the information that can be used to characterize the situation of an entity changes frequently. It is therefore necessary to keep track of this information and to manage it. Network-related context information is necessary to manage the interactions between the heterogenous networks forming an ambient network and the adaptation of the network topology resulting from network composition. Therefore, making an ambient network "context-aware" requires both, the existence of an appropriate architecture for Context Information Management as well as appropriate relationships between it and the FAs that will be composing the ACS.

Also, context management is important to enhance the user experience during the communication. Context information can be used to make networks more receptive to users' needs and enhance the users' experience by making the communication easier and richer. Any communication that takes place according to the situation of the entities and components of the environments and coordinates this process based on entities' requirements is termed to be a context-sensitive communication (CSC).

## CONTEXTWARE

The role of contextware in ANs is discussed in this section. The term contextware is introduced by the authors and it is used as a synonym of "architecture for context management" [3], [6], [7]. The two main roles of contextware in ANs include (i) Management of a set of Context Information Bases (CIB) within and across domains [7] and (ii) Coordination of different FAs of the ACS [7].

A CIB solves the task of collecting,

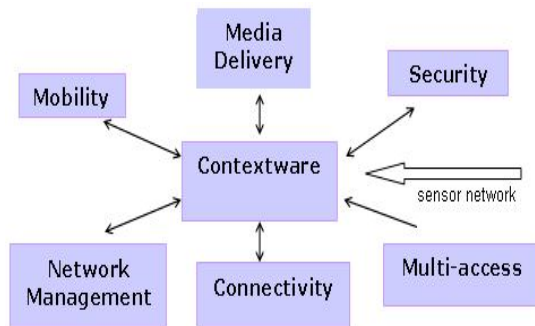


Fig. 1. The coordination-of-information-exchange role played by contextware

processing, and disseminating context information from and to the AN entities in a generic and not application- or device-specific format. It also manages the sharing of context information between different domains. Therefore, each CIB should contain up-to-date and valid context information, which is also required for the operation and decision making of other FAs. For example, a CIB could maintain information to decide if an entity should perform handover or not, should compose with another or not.

Contextware coordinates the information exchange between different FAs of the ACS by collecting the information relevant to each subscribed context client and redistributing it to the interested entities, through the associations maintained in the CIBs. This role is illustrated in fig. 1. In addition, it also collects and distributes information such as environmental, physiological, and spatial context information which is not available in FAs.

The presence of contextware functionality helps to make the interactions between the different context sources and clients simpler and more efficient. It acts as a mediating unit and reduces the number of interactions (for example, from 'full mesh' to 'finite'), and thus improves the performance. Contextware also provides information at different levels of abstraction. Basically, contextware is mainly concerned with the important information, which is of interest to most of the subscribed context clients. Therefore, information that is specific to a certain FA and is of no use by other FAs of the ACS shall not be managed. In addition to providing up-to-date context information, contextware plays a proactive role by sending notifications when updates in context information are available. This

feature is essential for rapid adaptation of the network to a change in its context.

## CONTEXTWARE REQUIREMENTS:

The main contextware requirements are discussed as follows.

### 1. General Requirements:

- **Context Support in Ambient Networks:** This is the basic requirement wherein an ambient network shall support a common framework for context awareness across all functions in the Ambient Control Space.

- As discussed, the framework should include support for collection, processing, management, and dissemination of context information enhanced with context level agreement negotiations and support for conflict resolution.

- Main sub-requirements include context support in Ambient Control Space functions, context support in ASI<sup>1</sup> [8], and context support in ANI<sup>2</sup> [8].

### 2. Context Sensitive Communication Requirements:

- CSC must be capable of providing non-intrusive automated connectivity and information exchange in context aware environments and in specific, ambient networks.

- An ambient environment should be capable of creating, modifying, and adapting sessions, and maintain persistency to the contextual preferences of the sessions.

- Main sub-requirements include mobility management, communication coordination, technology transparency, dynamic association between entities, and communication personalization.

### 3. Functional Requirements:

- **Requirements on context ontology:** Common context ontology is required to be able to process, compare, and match the contextual information of different Ambient Networks' context-sensitive entities.

- **Requirements on Context Information Base:** As up-to-date context information concerning both the network and the users is necessary to make an AN context-aware, the

<sup>1</sup> ASI – Ambient network Service Interface, an interface towards user/application plane

<sup>2</sup> ANI – Ambient Network Interface, a network level interface used for network composition

process of managing a CIB is vital. A CIB will need to support the main features of context information, which may belong to different entities, have various degrees of reliability, may require intermediate processing, may be highly volatile, etc. A sub-requirement on CIB includes managing Quality of Context (QoC) [3], [6]. This sub-requirement will influence the CIB design, making sure the appropriate parameters (such as trustworthiness, probability of correctness, etc) can be associated with context information.

- **Requirements on Context Associations:** For context sinks and context sources to have the same view on what, how and when context information should be exchanged between them, there is a requirement on the establishment of associations between sources and sinks. A context association has first to be established and then managed.

- **Requirements on Context Level Agreements:** A context-aware AN must support context level agreements (CLA) [3], [6]. A CLA negotiation function must support: criteria of reaching an agreement, auto-generation of policies for context exchange, functions for evaluation of satisfaction of exchanged context information, methods of guaranteeing the negotiated agreement, and privileges and priorities in case of conflicts or violations. A CLA has several other sub-requirements towards its contents, trust models, arrangements, templates, and validity.

- **Requirements on Context Support in ASI:** The ASI must be able to listen to context clients' (applications) requests, negotiate and send network context information in a similar way as in ACS functions. The ASI is also required to support functionalities related to negotiation and establishment of context association.

#### 4. Non-Functional Requirements:

- The main non-functional requirements on contextware include efficiency, scalability, robustness, auto- and self- reconfigurability, privacy and security, and cost effectiveness.

## CONTEXT PROVISIONING ARCHITECTURE

From the discussed concepts and requirements, an architecture for context management in ANs is proposed and its features are discussed in this section. The

architecture includes creating, exchanging, and handling context information, and is enhanced with context level agreement (CLA) [9] negotiations forming therefore what we refer to as context provisioning. This architecture would satisfy the requirements to make an ambient network context-aware.

An ambient network's main aim is to support a common framework for context awareness across all functions in the ACS in order to adapt service availability and delivery to heterogeneous networks and dynamically changing environments automatically. This common framework should support collection, processing, management, and dissemination of context information enhanced with context-level agreement negotiations and support for conflict resolution. Also, this network facility introduces an important aspect in the design of an ambient network. User specific information, such as terminal capabilities as well as preferences shall be easily communicated across networks in order to always achieve the required result. Other terms related to ambient networking that are used in the architecture include ASI, ANI, and ARI<sup>3</sup> [4], [8].

The Ambient networks project assumes that the exploitation of network context information as basis for control decisions is a central component of future networks. Therefore, an open and generic system that provides context information to functions inside and outside the ACS is specified, rather than having all FAs working on specific methods to derive required network information. The overall architecture of context provisioning is developed around the existence of two main context-specific Functional Areas, one interfacing other FAs of Ambient Networks and the other implementing the core internal operations required in the context provisioning system. These two functional areas are called Context Co-ordination FA (ConCord FA) and Context Management FA (CM FA) and are elaborated in the following sub-sections. The contextware architecture puts these FAs into a wider ambient network context and is

<sup>3</sup> ARI – Ambient network Resource Interface, a network level interface to access network side resources

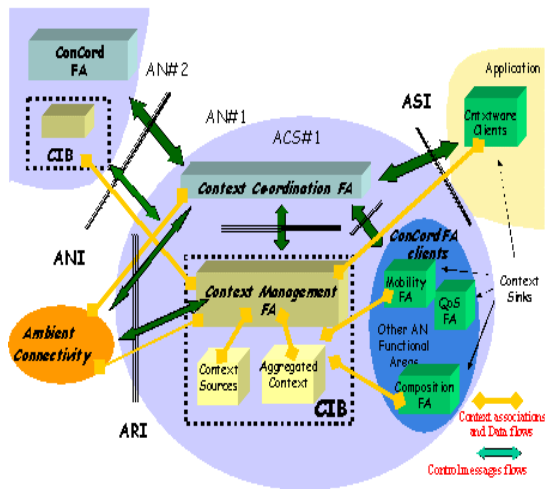


Fig. 2. Contextware architecture – Contextware FAs in a wider AN context

illustrated in fig. 2.

### CONTEXT CO-ORDINATION FUNCTIONAL AREA:

The FA's main aim is to co-ordinate information exchanged between different FAs in ANs. It is believed that most of the FAs would benefit from the availability of context information i.e., to improve their operation [8]. Therefore, information relevant to each entity should be collected and re-distributed, and this takes place through the maintained Context Information Bases (which come under CM FA). Each CIB contains up-to date context information and was previously discussed in the "Contextware" section.

The ConCord FA is the first point-of contact for any context client. For instance, context clients request context information, negotiate type and quality of context, and investigate possible conflicts with the ConCord FA. The Context Coordinators also negotiate Context Level Agreements [9] between domains in order to enable cross-domain exchange of context information. CLAs are further discussed in the next section. The envisaged functions implemented by the ConCord FA are discussed next and are illustrated in fig. 3.

- **Subscription Management:** This function aids in establishing the right associations between context sources and context clients. Though it is normally called by end-user services through the ASI, it could also be called by network services (to specify particular context information they are

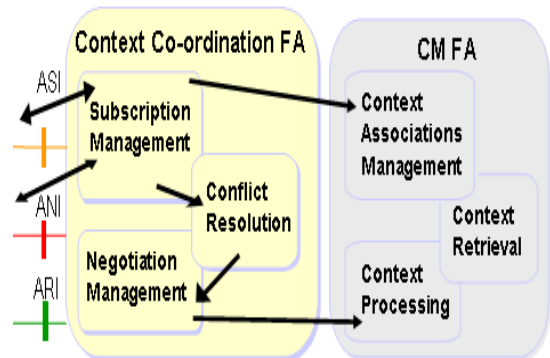


Fig. 3. ConCord FA's functions and relationships

interested in). After processing, for example, the client could be allowed to access the necessary information by invoking the CM FA and creating an association by calling the Context Association Manager.

- **Negotiation Management:** Its main duty is to negotiate between entities requesting context information and context providers. The process of negotiation could be required for mainly two reasons. Firstly, the requestor may not be allowed to access all requested information or the information requested may not be available at the expected level of quality, and secondly, the requestor could ask for information that is not readily available. To negotiate these cases, this function could either be called by the Conflict Resolution function or it could call the Context Processing function. It also may cooperate with Negotiation Management functions in other ANs

- **Conflict Resolution:** This function's main feature is to identify and manage possible conflicts that arise in the exchange of information between administrative domains. It may call the Negotiation Management function if, for example, some negotiation needs to take place to resolve conflicts. Also, it is called by the Subscription Management function to confirm that a subscription request has no conflicts.

### CONTEXT MANAGEMENT FUNCTIONAL AREA:

The CM FA is devoted to manage a set of CIBs within and across domains. This would involve operations such as collection, description/modelling, and dissemination of context information to the interested entities, as well as managing the sharing of context information between different domains i.e.,

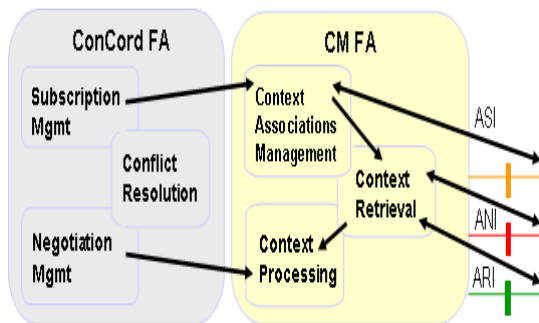


Fig. 4. Functions implemented by the CM FA and their relationships

cross-domain management. This FA is initiated through the ConCord FA and is also responsible for scheduling interactions between context sources and context clients, monitoring these interactions, re-allocating channels of interaction (in case of context changes), and finally aggregating and composing context according to clients' requirements. The envisaged functions implemented by the CM FA are discussed next and are illustrated in fig. 4.

- *Context Associations Manager:* This function's main purpose is to manage associations between various context clients and different context data, and notify the subscribing clients of any changes. The Context Associations Management function includes (i) Registering/De-registering entities in the AN space, (ii) Managing associations between contextware clients and sources, (iii) Grouping/Re-grouping context sources associated with contextware clients, (iv) Managing context information access: indexing, persistent subscription, scheduling, etc, and (v) Publishing of context and client notification. This function calls the Context Retrieval and Context Processing functions to fulfill the agreed context associations. It may also co-operate with Context Associations Management functions in other ANs. This is an important function as component performance depends upon the correctness and freshness of delivered information.

- *Context Retrieval:* This function is essential as contexts in ANs vary significantly in changing situations. Significant methods to lookup, fetch, search, and index context information in the AN space are provided by the Context Retrieval function. This includes (i) Context information monitoring, (ii)

Indexing of context/network schema for context, (iii) Network storing and backing up context, (iv) Context usage monitoring for context managers and services, and (v) View management of context information. This function is called by the Context Associations Manager and Negotiation Management functions. It can retrieve context information from other ANs through the ANI, while the ARI would be needed to retrieve information on available network resources. Indexing is an important method since component performance depends upon the speed of retrieving context information and responding accordingly.

- *Context Processing:* The purpose of this function is to manipulate raw context information based on knowledge from the Context Associations Management function. The Context Processing function is Context Association agnostic and is invoked by the Context Retrieval function, when necessary. The methods provided by this function include (i) Aggregating context information, (ii) Composing of context, and (iii) Filtering and semantic searching. Also, when needed, the Negotiation Manager in the ConCord FA may call this function.

## CONTEXT LEVEL AGREEMENT & QUALITY OF CONTEXT

Context Level Agreements (CLA) are required for the establishment and enforcement of policies governing the kind of context information that is allowed to be exchanged between different parties. For example, any context client can negotiate CLAs with the ConCord FA. CLAs can be negotiated between functions in an AN and also between two different ANs to allow inter-AN context information utilization. CLAs can even be negotiated dynamically, and in this case, the Context Management Functional Areas of each ambient network through their respective ConCord FAs make requests for context information held by other ANs. Also, CLAs need to be established prior to information sharing if the sharing occurs through the Context Coordinators of the different ANs. The CLA functional requirements were previously discussed in the "contextware requirements" section.

Context information can be uncertain or



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incomplete by its nature. This specific aspect might eventually influence both the way control functions are enforced and context information is actually utilized. Contextware networking services are dependent on the availability of context information, which must be provided at the right time and place (i.e., the availability of a distributed CIB). These parameters pertaining to context data give rise to the idea of Quality of Context. It is essentially any metric that describes the quality of information used as context information, such as precision, probability of correctness, trust-worthiness, resolution, and validity period. Basically, QoC management is a part of the CIB design and QoC Information requirement is a part of CLAs' content.

## CONCLUSION

To conclude, exploiting context information can make ambient networks simpler, more efficient, and more powerful, thus simplifying the management of the networking infrastructure for network operators while providing end-users with value-added services and an enhanced communication experience. This vision of simplified and yet powerful networks is the essence of Ambient Networks.

Context-sensitive communication poses not only new opportunities for end-users and application designers, but also calls for fundamental change(s) in our thinking about communication and networking infrastructures. An ambient network with CSC is basically self-aware through programmable sensing of user- and network-side contexts; the self-awareness in turn allows the networking infrastructure to compute itself in a way that is user friendly and cost efficient. We see our work as a corner stone of network self-organisation that will lead to needed advances in re-configurability, truly cross-layer optimized protocol stack, and self-management of networks and services.

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