Triggering Multi-dimensional Mobility in Ambient Networks

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Abstract— **Increasing heterogeneity in our networking environment requires a generalised approach for mobility management in order to gain from the vast amount of information available everywhere in the system and to make best use of the diversity in communication technologies. In this paper we enlarge the notion of mobility to cover multiple dimensions with a single general model. We present architecture for the handling of triggering events, which form the input for handover decisions and other mobility actions in the context of Ambient Networks. Based on the triggers classified according to various criteria, we have developed a handover decision entity, which computes the variety of triggers and evaluates the necessity of handover execution in different mobility dimensions.**

Index Terms—**Ambient Networks, handover management, heterogeneous networks, mobility management, trigger**

I. Introduction

THE environment in which mobility takes place is becoming more pervasive. Mobility exposes the users to heterogeneity and dynamics on different levels, e.g. access technologies, networking and trust domains, device capabilities and user contexts. The challenges faced by mobility include how to cope with this changing communication landscape, how to maintain communications in a heterogeneous networking environment that also includes legacy technologies.

Different kinds of events may trigger mobility management actions. Traditionally, changes in radio link specific conditions have been considered as triggers and currently IEEE working group 802.21 is standardizing the L2 triggers of different wireless technologies. [1] IETF DNA (Detecting Network Attachment) working group considers L2 events in combination with Layer 3 events, like IPv6 protocol messages, useful as mobility triggers. [2] Broadening the scope we think that context-dependent, security-related, upper-layer requirements and other system-, application- or user-dependent events may lead to mobility actions as well. To cater for all these events, we need general and coherent mechanisms to enable mobility triggering and to identify related events on different protocol layers in a distributed system. [3] The authors are not aware of any existing triggering framework, which could handle this broad scope.

As illustrated in Figure 1, trigger sources include at least the following:

- Users (humans)
- Service providers
- Operating system, including:
  - applications
  - protocol stack(s)
  - resource manager(s) (e.g. for hardware status)
- Policy & preferences database
- Local Ambient Control Space
- Remote Ambient Networks

The Ambient Networks project [4] is developing a future networking architecture, which aims to enable the cooperation of heterogeneous networks belonging to different technology or operator domains. The architecture introduces a common control space (ACS) for all networks, which comprises of several functional areas (FA) allowing the diversity of implementations. [5] Mobility management is an integral part of the Ambient Networks architecture, including the means for triggering and managing the mobility of various mobile entities able to move in multiple dimensions. The triggering framework will be a key enabler for seamless mobility by collecting a large number of triggers and hints in order to perform accurate and justified handovers maintaining user communication undisrupted. The framework will be flexible and can be used by other mobility functions as well.

The rest of the paper is organised as follows: Section II introduces our high level view on multi-dimensional mobility. Section III describes the triggering architecture in general giving an overview of the approach. Section IV explains how collection of various triggers is being designed. Section V

This paper describes work undertaken in the context of the Ambient Networks project which is part of the EU's IST programme. In total 41 organizations from Europe, Canada, Australia and Japan are involved in this Integrated Project, which will run from 2004-2005 in its first phase. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the Ambient Networks Project.

introduces the criteria used for classification of triggering events, while section VI describes an approach for making handover decisions based on classified triggers. Section VII concludes the paper also indicating some future work.

II. Mobility Dimensions

Before describing the triggering architecture, we introduce the notion of mobility for which the triggers have been investigated. Instead of considering mobility only as a physical movement or as a change of network point of attachment, we have taken a fundamentally broader view. In Ambient Networks, mobility may take place in different dimensions, which are independent of each other. However, mobility may often take place in several dimensions simultaneously, even in a coupled manner. We have identified seven dimensions, which can be considered as orthogonal to each other. Figure 2 illustrates examples in four of these dimensions.

- **Physical location:** A mobile entity[1] moves between access points within the same radio access technology (traditional mobility),
- **Access technology:** A mobile entity moves from one radio access technology to another (e.g. vertical handover),
- **Address space:** A mobile entity moves between networks/devices, which use different address space (e.g. IPv4 ⇨ IPv6, public ⇨ private),
- **Security domain:** A mobile entity moves between networks/devices/environments, in which trust or security are enforced differently (e.g. public ⇨ secured Virtual Private Network),
- **Provider domain:** A mobile entity moves between networks/devices operated/owned by a different provider (e.g. roaming),
- **Device properties:** A mobile entity moves from one device to another, hence the system properties of the host device may change dramatically (e.g. inter-device handover),
- **Time:** A mobile entity does not move spatially, but on-going communication is suspended for a while and resumed afterwards (e.g. if a user wants to pause the connection for a while, or to allow a temporary loss of connectivity).

Some of the triggering events relate only to a single mobility dimension, while others may require mobility actions to be performed in several dimensions. In this high level view, a mobile entity always has a "coordinate" in each dimension. Whenever movement in a certain dimension takes place, the respective coordinate changes. Mobility management mechanisms can be seen as functions updating one or more of these coordinates.

[1] Mobile entity should not be considered as a physical host, but as an abstract notion of an object able to communicate and move between networks and devices, quite similarly as *entity* in [6].

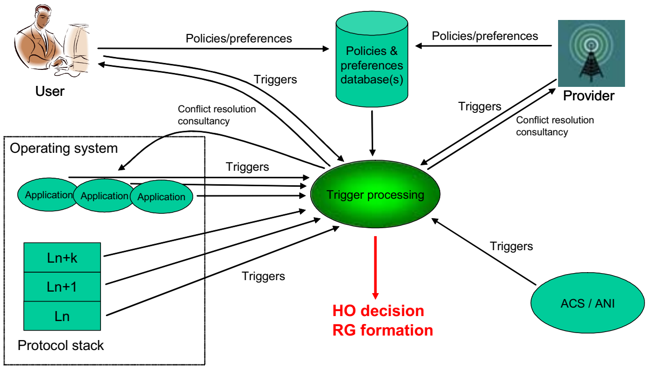

Fig. 1. Possible sources of mobility triggers.

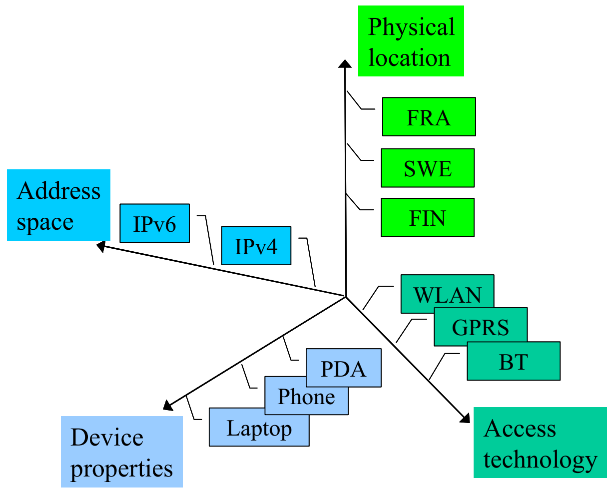

Fig. 2. Mobility may take place in various dimensions orthogonal to each other. Four of the seven dimensions illustrated.

III. Overall Triggering Architecture

In AN context, the triggering architecture has two main tasks:

- collecting and transporting triggers from various sources, and
- arbitration of conflicting triggers to result in a possible handover decision and/or routing group formation.

The Trigger processing entity shown in Figure 1 is implemented in the Ambient Control Space (ACS), partly in the Triggering Functional Area (later referred to as Triggering FA or TRG FA), partly in the Handover Management Functional Area (later referred to as HO FA). Both are depicted in Figure 3. This figure also shows how ACS offers communication to external functions via three interfaces:

- **Ambient Service Interface** (ASI) interfaces towards service infrastructures and allows applications and services to issue requests to the ACS.
- **Ambient Resource Interface** (ARI) provides control mechanisms ACS can use to manage the resources residing in the connectivity plane.
- **Ambient Networks Interface** (ANI) is a horizontal interface interconnecting different ACS.

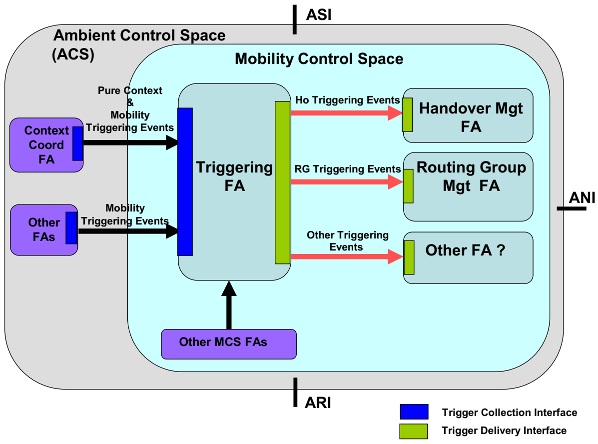

Fig. 3. Triggering Architecture.

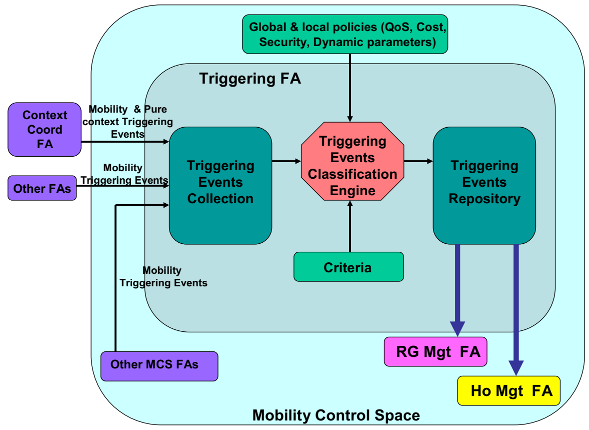

Fig. 4. Triggering Functional Area.

Triggering FA handles triggers originating from other Functional Areas (such as the Context Coordination FA, which collects contextual information), and other sources (such as the mobility protocol states and link-layer information). The HO FA, in turn, uses the collected triggers and rules stored in the policy database to resolve whether a handover is needed and which mechanisms to use, after which it proceeds to actual handover execution. Another identified user of the triggering information is the Routing Group Management FA, but further discussion on routing group management is out of the scope of this paper.

IV. Collection of Triggering Events

Triggers for handovers are handled in three main ACS functions (see Figure 4), which are the Triggering Events Collection (TEC), Triggering Events Classification Engine (TECE) and the Handover Decision Engine (HDE), which is described in more detail in section VI. TEC and TECE handle the collecting, classifying and storing of incoming triggers, which HDE fetches from Triggering Events Repository (Collecting triggers also requires a temporary storage, the TER, for the received triggers) for further processing. HDE solves possible conflicts between the triggers and makes decisions on handovers. It signals the Handover Execution (HE) function, which performs the actual handover. When receiving a trigger, the trigger processing classifies and timestamps the trigger. Triggers also have a lifetime, after which they are removed from the TER. The repository is more like a buffer than a database, as new triggers may be received at any time, even before the previous one has been processed.

The trigger collection process has to gather locally generated triggering events from the mobility control space (MCS). These triggers include e.g. those generated by mobility protocols (router advertisements, etc). This makes necessary that the Triggering FA has to coordinate and develop mechanisms in conjunction with other FAs within the MCS to compile triggers that could be relevant for the HO decision process. In addition, the collection process has to request (or receive) to (from) the Context Coordination FA (ConCord FA) the necessary mobility context information to perform the decision that will lead to realize optimum handover operations.

For the handover decision process, not only policies or mobility related context information should be taken into consideration, but also context information that does not belong to the mobility control space. This type of information that we regard as "pure" context information, such as a neighbouring device capabilities or geographical location is extremely useful for deciding whether to perform a handover.

In addition to gathering the triggers, the triggering events collection function need to define a relative timestamp and lifetime for the triggers. This will ensure that the gathered triggers are used in correct order for rules evaluation and are still valid in the appropriate context situation.

The gathering of triggering events requires the definition of interfaces between the involved FAs. However, depending on the type of the trigger and its importance to attain the goal of seamless handover, there could be a combined implementation to gather triggers.

A basic set of rules for gathering the triggers for performing HO decision could be defined as the following:

- There are some types of mobility triggers that need to be acted upon immediately (real-time) in order to perform a smooth handover operation.
  - If the trigger is a real-time class trigger, it can be collected directly from source (FA)
- There are other types of mobility triggers which are not time sensitive (non real-time) that could be gathered periodically or on demand.
  - If the trigger is a non real-time class, it may be collected from ConCord FA
- Policies and Agreements that could be considered as triggers could be gathered first at call/session setup
- Other non-mobility context triggers would be collected from the ConCord FA.

V. TRIGGER CLASSIFICATION

Triggering events originate from several different sources, as illustrated in Figure 1. Exploration of communication standards, research papers and past projects, mobility scenarios of AN project [7] and discussions with specialists in various areas revealed a couple of hundreds of different events that might be considered useful as mobility triggers. Certainly even more such events exist and will be emerging in the future. Mobility management mechanisms cannot efficiently handle such an amount of triggering events. That is why grouping and classification of the events is desired. Independently of the communication technology used, it is possible to group similar or related triggers together. Such grouping was performed for the identified trigger events. After that, the handling of the events is much simpler, even if there are still around 30 different event groups. However, the number of groups aims at guaranteeing sufficient diversity for event separation and classification. The event groups contain triggers related to changes in network topology, available accesses, radio link conditions, user actions and preferences, context information, operator policies, QoS parameters, composition and routing events, security issues, etc.

To enable development of mechanisms for handover decision, all trigger groups were classified based on criteria presented in Table 1. For each particular mobility case, the classification allows identifying and concentrating only on those events that are deemed necessary to monitor and react. For example, reception of a *forcing* event *via ASI* indicates an explicit handover command from user or application. For each case it is possible to select a suitable set of classification criteria for identifying those trigger events that comply with particular user and operator preferences or policies. After that, any developed handover decision logic can rely on a suitable set of triggers selected according to the classification. In many cases, mobility in different dimensions will be initiated based on different sets of triggers, and suitable handover mechanisms can be selected accordingly. Classification function must also consider causal relationships between some triggering events in order to avoid generating a number of transient triggers based on the same physical event, like a single link break.

VI. HANDOVER DECISION CONCEPTS

The trigger classification is mainly used by the handover management functional area. Current state of the art focuses mostly on vertical handover based on very limited number of triggers (mainly signal quality). In order to perform a handover that takes more triggers, rules and policies into account we propose a new concept for the handover decision, which utilises dynamic production rules. As depicted in Figure 5, this FA is divided into several functions.

First is the *Handover Decision Engine* (HDE) which is responsible for the production of the handover rules. The rules encode knowledge about a certain domain in simple condition-action pairs. Working memory initially represents

Table 1 Classification criteria for triggering events.

Criteria	Classes	Description
Event source	**ACS**	An event is received from the local Ambient Control Space, i.e. from any of the Functional Areas (FA) in the local ACS. Further sub-classification could be done based on the FAs
	ANI	An event is generated in some other AN, and is delivered to local ACS via Ambient Network Interface (ANI)
	ASI	An event is generated on higher layers and received via Ambient Service Interface (ASI)
	ARI	An event is received via Ambient Resource Interface (ARI)
Event type	**Predicting**	An event that does not imply the need for a handover yet, but might be a hint of the need for handover in near future and consequently allow anticipation.
	Triggering	An event that alone may lead to a handover. Other concurrent or earlier events may affect the handover decision and procedure.
	Forcing	An event that mobility management has no way to optimise or negotiate. This forces a handover execution. Otherwise communication will be interrupted
Event frequency	**Periodic**	An event occurs periodically with a constant time interval.
	Asynchronous, on-demand	An event may occur at any time, but is generated on-demand due to a request by the system.
	Asynchronous, self-generated	An event may occur at any time in a self-generated manner
Event Persistence	**Volatile**	An event may occur and disappear in the sense of a transient event
	Non-volatile	Once the event occurs, it stays in the same status and doesn't disappear.
Event Time constraint	**Real-time**	An event that must be raised within a certain timeframe
	Non real-time	An event that can be raised at any time without time constraint

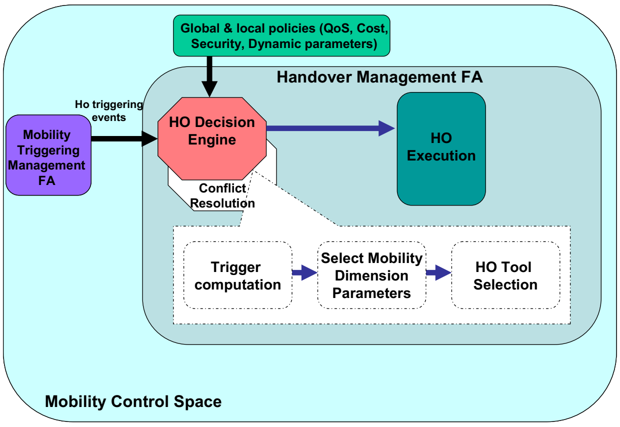

Fig. 5. Handover Management Functional Area.

the input to the system, but the actions that occur when rules are implemented can cause the state of the working memory to change. Creation of production rules means to fill in the basic rule (see below), the events that have been gathered, weight them and evaluate the rule. As this is a process that repeats itself but with a different type and amount of triggers, it is very dynamic depending on the movement characteristics of the mobile entity. Usually, dynamic rules based systems operate with rules that utilize low update frequency conditions (conditions: e.g. policies) and high update frequency conditions (events: triggering events).

Consequently, the general type of rules to be applied has the following form:

IF (conditions) THEN action:perform handover (1)

If we take into account the frequency update of the conditions which is different for triggers of class Triggering, Forcing and Predicting and the local and global policies. We have a more complete form of rule which is:

[ON (events:T, F) AND (events:P) AND] IF (conditions) THEN action:perform handover (2)

The produced rules are applied after there has been some modification on the conditions caused by a change in context or the reception of a trigger. When the number of these events is plural, it could appear that several rules give a contradicting action. We can say that there is a decision contention relation between two rules if the following holds,

$$\text{If } \alpha(r1,r2) == \text{TRUE} \tag{3}$$

Where $\alpha(\ )$ is the decision contention relation and r1 and r2 are the rules in contention or have inconsistencies between their action (THEN clause). When the expression (3) exists then:

$$\delta[\alpha(r1,r2)] \rightarrow \{r1|r2\} \tag{4}$$

where δ is the resolution operator that selects r1 OR r2, but not both.

Contention resolution is the second function of the handover management FA. In order to realize contention resolution, we studied two processes. The first one is based on applying weights to the events and conditions of the produced rules. The second one is based on precedence levels that are applied to the rules depending on the time, user preferences or operator policies.

The third function is responsible for the handover execution. By use of trigger classification and after contention resolution, the handover decision engine will be able to indicate one or more mobility dimension in which the handover takes place. In order to execute the handover decision, a handover tool has been defined. It is a set of elementary handover mechanisms that can be used to describe a generic handover. Examples of handover tool mechanisms are authentication, forwarding, buffering, and context update. It is the selection and the sequencing of the elementary handover parts that construct a specific handover process. This approach allows meeting specific service requirements, to optimise network resources and to support various handover types (inter-interface, inter-device, inter-technology), handover mechanisms (planned, unplanned, network-initiated, network-controlled...) and handover specific features (flow redirection). The handover tool will cover both existing and future kinds of handovers.

VII. Conclusions

We have introduced an approach for utilising triggering events from everywhere in the system and ambience as input for decisions on mobility management in the context of Ambient Networks. We are not aware of another approach as general and technology independent. We have enlarged the notion of mobility to cover multiple dimensions with a single general model and presented an architecture for triggering mobility in multiple dimensions, including a design of two main functional areas. Both functional areas are involved in a general handover process making use of the criteria defined for collecting and classifying triggering events. We have also proposed a rule based logic for resolving handover necessity according to the classified triggers.

Specifying a distributed triggering framework includes many challenges, which are still to be addressed. Those include, for example, practical implementation of trigger classification mechanisms, scalability and performance of the trigger collection and distribution mechanisms, as well as the feasibility of the rule based handover decision logic. In future work we will enhance the conceptual model by developing the interfaces and protocols for communication between the entities in the architecture, as well as define the delivery mechanisms and format of trigger information. Feasibility analysis and tests in a real environment will follow.

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