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Issues of advanced mobility management in Ambient Networks

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***Abstract*—This paper discusses the challenges of providing mobility in next generation networks. We elaborate on the features that will be required for mobility solutions in heterogeneous, ambient networking environments and contrast this with the features provided by existing solutions developed for the more traditional networking scenarios. The key challenge is managing cross-domain and cross layer interactions inherent in the Ambient Network scenario. The following paper illustrates how the coordination of such interactions benefits from a coherent control plane with a well-defined interface to access the mobility functionality and the resources they control.**

Index Terms—Handovers, multi-access, multi-domain, global mobility , mobility endpoint [*]

Introduction

Ambient Networks [1] is a multi-national collaborative project within the European Sixth Framework Programme, targeted at investigating the networking aspects of mobile systems beyond today's 3rd generation standards. An overall theme of the Ambient Networks project is to develop the future mobile systems that must encompass a much wider variety of business environments and networking scenarios enabled by the emerging radio technologies. Ambient Networks aim to integrate different access technologies and support diverse applications in a multi-provider environment, requiring that mobility solutions should operate in a heterogeneous network and a cross a range of business models. In addition, minimal assumptions are made about user devices, requiring a solution that can operate on terminals with differing capabilities. This leads to a multi-domain environment where none of the existing mobility solutions is sufficient.

The mobility solution can be subdivided into a number of key subareas.

Global Mobility Management handles mobility of an endpoint across multiple domains, and is also concerned with maintaining reachability, and connectivity of active sessions. *Local Mobility Management* and *Advanced Handover Management* deals with moving endpoint, rerouting and updating state to reflect the new location of the endpoint. This state might include authentication and QoS attributes among others that could be transferred from the previous point of attachment. *Advanced Location Management* implements the tracking of a mobility endpoint. This is particularly important for paging a dormant mobile node and to implement location aware services and applications. It is closely related to the reachability of a mobility endpoint. *Mobility Context Management* refers to the use of more complex context information to support handover decisions and mobility management mechanisms.

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In the remainder of this paper the challenges for each of the above mentioned mobility sub-area are discussed separately and compared with the state of the art solutions.

Global Mobility

Global Mobility Management handles the reachability of a mobile endpoint. Typically this is accomplished by the registration of a global identifier and by the indirection of the communication to the topologically correct locator of the peers. There are many well-known proposals and solutions for this basic operation. The challenge for Ambient Networks is to develop a solution that operates efficiently in a heterogeneous multi-domain environment. There are different addressing realms, security domains (i.e. home and enterprise networks and public wide area networks) with their own security infrastructures, and administrative domains with their own policies. These domains are often connected through middle-boxes such as Network Address Translators (NAT) and Firewalls. In fact, firewalls and NATs could be considered as belonging to the security infrastructure of a domain. Functions at the IP-layer support ubiquitous connectivity but do not provide sufficient co-ordination or control mechanisms to coherently handle the multi-domain heterogeneity. Mobile IPv4 and Mobile IPv6 work well within their own problem space but do not interwork with each other efficiently. Similarly newer schemes such as HIP [2] and I^3 [3] have their own set of assumptions, constraints and benefits. Assuming a single global mobility scheme that works across multiple domains and layers is truly a noble goal but may turn out to be an ambitious one, and one that is too restrictive for the emerging wireless ecosystem.

The heterogeneity of the networking environment leads to a set of contradicting requirements. Meeting all of them with a single protocol seems to lead to suboptimal and complex solutions if not some of the previous design premises are not revisited. An IP-address identifies an interface of a device, but not a node or a session or an end user. However, a session may move within a node from one interface to another in a multi-interface terminal and at the same time change a security policy and address domain. Clearly an IP-address alone is not expressive enough. We need to reconsider what entity is moving and how to identify it in a way that allows different levels of security assurance and conformance, i.e. anonymity and privacy, but also supports redirection of the communication.

The Ambient Networks project has chosen to approach this problem by studying a layered naming and addressing solution that encompasses all layers from the user and application down to the topological location of an interface. Separation of the identifier from the routing locator at various layers provides many advantages for mobility management. The use of identifiers and names (i.e. upper-layer identifiers) are a fundamental part of any mobility scheme. An identifier maps to an identity. An identity is unique and something that can be verified, but an identifier may vary between contexts (e.g. an IPv4 and an IPv6 address may point to the same network attachment point). This consideration also applies to the locators.

The context of the communication determines what kind of identifiers should be used. It could be an application layer identifier, such as a FQDN, a NAI or a SIP URL or a session identifier. The type of the identifier implies what directories or registers should be used, and how to bind the name to the lower-layer identifiers. Common practice today is to use IP-addresses, ports and protocols to identify the transport layer session. Thus, the transport identifier is dependent of the underlying IP layer, due to the use of the IP address as part of the identifier. This layering violation restricts the design of mobility and multi-homing solution unnecessarily. Hence, the Ambient Network solution is exploring the use of transport layer identifiers. This may lead to a naming scheme between the application layer and the network layer facilitating transport layer transparency from changing address spaces at the IP-layer.

Two-way functions to map parameters between different classes of domains are required for multi-domain mobility. An example of such function could be a mapping of addresses between different types of addressing domains. This mapping function

builds on top of the underlying protocol layer functionality; it might include e.g. tunnelling or translation mechanisms, which in turn, may involve several steps and communication between several network entities.

Discovery of the available domains is a precondition of multi-domain mobility. Typically this is also based on identifiers. The network could provide the discovery function but there are cases where the terminal itself is best positioned for the domain discovers. For example, discovery of a new network prefix in IP-layer advertisements is a way to discover mobility within an addressing domain whilst discovering a Network Address Identity during authentication process is a way to discovery mobility with respect to the network provider.

Cross-layer and cross-domain coordination within a user device and in the network requires a consistent view on the resources involved with the mobility event. This is achieved by introducing a common control plane with standardized **Ambient Network Interface, ANI,** as a means to connect and execute the functions across the domains see figure 1.

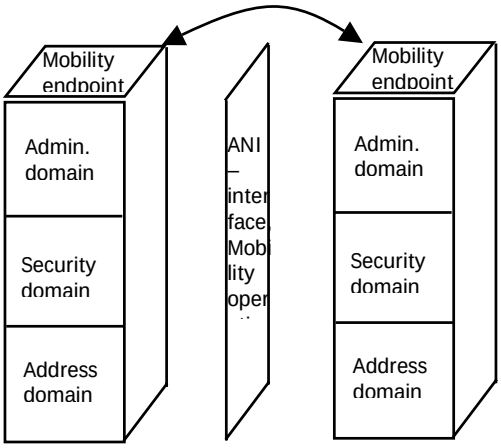

Fig. 1. Mobility domains and ANI

Local Mobility and Handover Management

Local Mobility and Handover Management handles mobility of an endpoint within the local network to which the mobility endpoint is attached. The boundaries of the local network are usually determined administratively, allowing each operator to optimise the behaviour of the network according to their own local policy and service offerings. This mechanism has been successfully deployed for many years in cellular and other wireless networks. In addition, this topic has been addressed in various research projects (BRAIN [5], MIND[6]) and standardisation groups (Mobile IP [7], Seamoby[8]) with the of introducing handover functions in IP networks as well as enhancing the handover process itself by providing loss-less, fast re-routing and context transfer procedures.

Even though numerous activities have been carried out to further develop and optimize the handover process, to accommodate the requirements of the Ambient Network scenario, it is necessary to further investigate local mobility and handover management from a different conceptual point of view. Whilst some recent research work dealt with performance enhancement of the handover process, the Ambient Networks approach is to develop a broader architectural concept that considers handover as a set of well-defined steps instead of a monolithic service offered to the mobility endpoint, effectively providing a toolbox of handover and context transfer techniques that can be applied as and when needed based on the type of handover and operator requirements Some of the challenges posed by Ambient Networks are outlined below.

The initial issue is related to a question about what is moving. The notion of a 'mobility endpoint' refers to a diverse range of things, which goes far beyond a human user carrying a mobile device:

- Session or flows: where endpoint represents the information exchanged between application instances on communicating endpoints
- Aggregates: where multiple entities that are moving are grouped together into a single endpoint, for example, nodes in a moving network or multiple flows belonging to a single session.
- Middleboxes: where changing a service node / device along the data path can be modelled as a handover event, with the middlebox acting in the role of endpoint.

This diverse range of endpoints requires a flexible and extensible solution to local mobility and handover management that can operate across multiple domains. It also introduces some new handover types that must be supported by the mobility solution. These include:

- Inter-interface: between interfaces on a multimode terminal (i.e. move a web browsing session from the cellular to WLAN interface)
- Inter-device: move an application (and associated set of sessions) from one device to another (e.g. headset to laptop)
- Inter-point of attachment: move an interface between different base stations or access points in the network. The handover or context transfer mechanism that can be used will depend on the relationship between the old and new points of attachment, e.g. cross administrative domain.
- Inter-middlebox: change the middlebox that the data path is running via.

Since the Ambient Network approach provides a toolbox of different solution parts that can be plugged together as needed, the core approach can be adapted to suit the needs of a particular endpoint and/or handover type. The framework within which these solutions will operate has the following features:

- Timely Sequence: the handover process is a sequence of different steps with trigger generation, initiation, decision, execution and post processing rather than an atomic process
- Modularity: Each step comprises of a set of tools that can address specific problems in the handover process, i.e. there is not one function, which can solve all problems in the handover process
- Configurability: The individual steps of the process can be configured by some administrative entity or by the mobile endpoint that is served. Therefore the process supports the 'plug and play' concept, where individual function are selected based on the type of mobile endpoint, received triggering event and possible other criteria
- Location Independency: The decision engine may reside centrally on a single node or may be even distributed over different Ambient Networks, assuming that some other network may have additional information and/or authorization privileges.

The flexibility and modularity of the Ambient Network concept enables a number of new handover and local mobility management features. These include:

- Candidate Network Selection and Handover Redirection

A well-known problem associated with handover management is that of candidate network selection. This is where the mobility endpoint is presented with a number of options as to the target network to which to handover, and must make a decision about which network to use. In the most basic case, this decision may be based on information such as signal strength. More complex cases allow the terminal to make decisions based on information about the base station and associated capabilities.

Handover redirection extends the concept of candidate network selection to allow the network to redirect a mobility endpoint to an alternative target location if the alternative target location is better able to service the handover request and the requirements of the mobility endpoint. For example, a mobile terminal selects a target access point, AP, based on user and application policy, and the network decides that an alternative AP is better suited to service the needs of the terminal. This may be the case when only a single AP in the network is broadcasting beacon messages (so it is the only AP the terminal can see), but in actual fact there are multiple APs in the network, and the network selects an AP to redirect the terminal to based on load balancing and other local network policy.

In order to support handover redirection, the target network must be in a position to determine that the decisions it makes with respect to the target network are at least as good as, if not better than, the decision the endpoint makes for itself. In addition, the

information considered by the network should be scoped in some way (i.e. does the network only consider local information, or also discover information about other networks that the terminal is in range of). Ambient Networks will support this functionality by providing a flexible way for the terminal and the network to exchange information regarding decision policy (so the network knows what the desirable characteristics of the target network would be from the terminal perspective).

- Enhanced Context

Context Transfer refers to the action of transferring state between nodes along the old and the new path to the current location of the mobility endpoint. The problem of context transfer is well documented, and solutions have been developed within a number of standardisation bodies.

However, each of these approaches provides solutions for a fairly restricted scenario. Within Ambient Networks, the number of different options for mobility endpoints and types of handover immediately requires a flexible and generic context transfer solution that is able to work in multi-technology environments, and potentially cross administrative boundaries. For example, different context transfer procedures may be needed at different stages of the handover process dependent on what is moving, and what the underlying capabilities of the link layer technology are. The exact role of context transfer at different layers of the protocol stack can be negotiated between the networks as part of the Ambient Network composition procedure.

Advanced Location Management

Through advanced location management, the network can associate topological location to a mobility endpoint and predict its location for subsequent actions, such as the selection of the proper handover type, e.g. fast handover, session handover with or without session re-invitation. Advanced location management includes location tracking that supports the collection of geographical and topological information about the whereabouts of the mobile entity. Note that physical closeness does not always translate to topological adjacency and it does not imply that the entities are neighbors in the networking sense. This has significant implications for the mobility management decisions and actions. Functions as paging of a dormant mobility endpoint and location prediction belong to the advanced location management services. Utilizing information such as velocity, available PAN entities, device battery level and movement patterns, can optimize selection of possible mobility events and target handover candidates. Advanced mobility management requires coherent interplay between the mobile entity and the network supporting it. Moreover advanced location management and its usefulness depend on the quality and granularity of the information that the mobility endpoint is willing to reveal to the servicing network.

Current paging solutions are dependent on the link layer technology and network structure, e.g. in a cellular system, the paging procedure for dormant mode terminals consists of listening to location indications that depend on the routing area and cell identity beacons, which in turn are dependent on the network topology. The Ambient Network scenario requires the facility to be able to page across heterogeneous network technologies. For instance, a multi-interface terminal may switch its wide-area interface into a power saving mode, but keep its short-range Bluetooth-interface active. In such situation, the device may be paged over the wide-area interface, or alternatively the terminal may be considered to be not dormant at all, i.e. incoming calls would be always routed through the active short-range radio interface.

A mobility event may lead to a handover where the new location is not stable but alternates between a number of other targets, i.e. handover leads to a ping-pong phenomenon. In such situations, the location information can be used to find out the potential access networks and access routers nearby. Updating the potential access networks and routers in the location management system with the state of the mobile end point paves the way for smooth handovers.

Mobility Context Management

We assume that the future terminals, applications and networks will be able to provide a versatile set of information about themselves, their surroundings and the situation where they are used. For instance a moving Ambient Network could indicate its location, direction and velocity, users could express their wishes and preferred services through a set of preferences that could cover attributes such as QoS, pricing and preferred, alternative access methods. Already SIP [4] protocol provides means for the end user to express a number of alternative contact means. In Ambient Networks, it is assumed that setting of the preferences will be automated. The preferred alternatives could be learnt from the past user behaviour or based on the current on going sessions and their patterns. The user and the application context information, that could be either static or dynamic, should be structured for efficient mobility management.

An example would be a case where a moderate bit rate audio/video stream to a handled device is automatically forked into a separate video and audio streams for a big screen hi-fi home theatre system once the end user reaches his or her home. The session and related connection splitting is based on the nature of the session and reachability of alternative target handover candidate devices to which the session is authorized to handover. In order to execute such a handover without end-to-end negotiation, session re-establishment and end user action, the use of advanced context information would be beneficial. Splicing and merging of communications via “middle-boxes” is one alternative tool for applications to facilitate resolving heterogeneity on “upper layers” as well as dynamic service composition for ongoing communications. Middle-boxes can be applicable for the session transfer, splitting of the session for each device and codec transformation. Based on the context information, a mobility event could insert a middle-box, or initiate change of the application level session attributes.

The mobility control space needs access to the **Context Information Base**, **CIB**, within the network that is responsible for maintaining user policy and context information, and that is updated by mobility triggers from the mobility events. The mobility control space could act proactively or on demand basis depending on the decision logic and the state of the context information.

The mobility context management receives context information from all communication levels; from physical to application. Based on this and other supplemental information, such as terminal capacity, type and number of interfaces, network topology and availability, the mobility context management guides the handover process decision process.

Particularly the use of mobility context management to implement inter-address space mobility, inter-trust-domain mobility and aggregation of mobility are areas of further research.

Conclusion

Ambient Networks can be regarded as an approach to solve the complex mobility requirements in next generation mobile networks. Our work assumes IP-connectivity, but develops a control plane overlay to provide a mobility solution that is able to cope with the challenges of cross-layer and cross-domain interactions. The fundamental characteristic of the solution is the modularity and adaptability of the mobility management process to suit the operational environment where it is being used. For example, handover is regarded as a series of different stages with specific tools that are deployed based on context information, the type of received trigger event, the type of mobility endpoint and user/operator preferences.

For all aspects of the mobility management solution, the set of functional areas that interact with each other need to be identified, and the managed entities belonging to the Ambient Network control space must be defined. Once this work is completed, the mechanisms to negotiate which parts of the toolbox should be utilized can be developed, providing the means to adapt mobility management “on-the-fly”.

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