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Components and Concepts of the Ambient Networks Architecture

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***Abstract*— This paper presents an internetworking architecture for cooperative networks that is currently under development within the IST's Ambient Networks project. Its architectural approach builds on the establishment of a common, distributed control plane facilitating the interoperation of heterogeneous networks. This shared control space is structured as a modularized framework that allows dynamic, plug-and-play adaptation of control functionality, as well as generic interfaces that abstract the control specifics of configurable networks, resources and services.**

Introduction

One of the main goals of the IST's "Ambient Networks" project ([1], [2]) is to enable seamless interoperation between heterogeneous networks. Ambient Networks aims to establish this interoperation through a common control plane distributed across the individual, heterogeneous networks. This new control plane functionality can be an integral component of future network architectures. To allow existing, legacy networks to interoperate with future networks, this common control plane functionality can also "wrap around" legacy control functionality, encapsulating and abstracting from these networks' individual control idiosyncrasies. The migration path to enable already deployed, legacy infrastructure to participate in the advanced internetworking capabilities provided by the Ambient Networks architecture is a first-order priority for the project.

Figure 1 illustrates the logical organization of the control space. It consists of a collection of control functions that cooperate to implement specific control functionality. These control functions exist within the overall control space framework. Besides offering common, required functionality, the framework structure also enables modularization of the control space. This modularization enables operators to adapt their networks' control functionality to their specific needs, while maintaining global interoperability, even with other networks that do not implement the same subsets of control space functionality. A second advantage of a modularized control space is dynamic, plug-and-play integration of new control space functionality during the lifetime of a network. This improves evolvability and adaptability of deployed infrastructure.

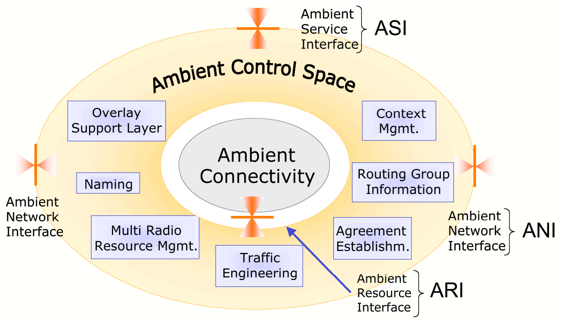

Figure 1: Control Space Modularization and Interfaces

Figure 1 also illustrates how the common, distributed control space encapsulates both legacy and future internetworking infrastructures and provides generic interfaces that are independent of specific network architectures. Network entities interact with the new control space through three different interfaces. Higher-layer applications and services use the Ambient Service Interface (ASI) to access a subset of the control space functionality. This subset includes functions like naming, location and context management, inter-domain management and traffic engineering. Connectivity resources interact with the control space through the Ambient Resource Interface (ARI), for example, to access multi-radio resource management, mobility and trigger processing. Finally, the Ambient Network Interface (ANI) facilitates communication between the control spaces of different networks, creating the shared, common control space that enables the advanced internetworking capabilities the Ambient Network project aims to achieve.

One key example of a novel internetworking capability is the concept of composition. Composition is the dynamic merging of multiple networks through the cross-network interface (ANI.) During a composition, the involved networks dynamically negotiate the terms of their interoperation across the ANI, such as service agreements. The result of a successful composition operation – depending on the specific negotiation – can be a new entity that appears to others as a uniform network and may itself participate in additional composition operations.

It is important to note that this document describes the early stages of an internetworking architecture that is under active development. Therefore, the details of several aspects of the control space only exist at a conceptual level at this point. Also the set of control functions mentioned within Figure 1 will be defined within the individual work packages and work on them is not complete.

Control Space Interfaces

This section discusses the three interfaces to the common control space, the Ambient Network Interface (ANI), the Ambient Service Interface (ASI) and finally the Ambient Resource Interface (ARI) in more detail.

In principle, these interfaces share common structure that consists of a generic, common part independent of the specific control space functions and several parts that depend on the presence of specific control space functions.

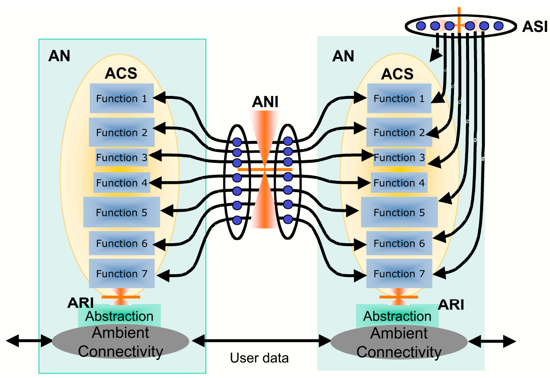

Figure 2: Internal Structure of the Ambient Network Interface.

Ambient Network Interface

The Ambient Network Interface (ANI) is the interface through which individual networks communicate. It enables common functionality and advanced capabilities by facilitating communication across the control spaces of different networks.

As illustrated in Figure 2, the ANI consists of multiple logical channels that handle the signalling associated with individual control space functions; for example, internetwork mobility mechanisms. Additionally, the ANI includes a common channel that enables shared functionality, for example, per-channel negotiation of signalling protocols.

The ANI is modular; similar to the control spaces it connects. It can dynamically incorporate new signalling channels for new control space functionality, and it can support new signalling protocols.

Ambient Service Interface

The Ambient Service Interface (ASI) is the upper-layer interface to the control space. It is accessible from any entity (*e.g.*, end-user applications, management applications or control applications) outside the control space, assuming the necessary access permissions.

The ASI comprises two parts. The first part is an interface to the subset of control space functions that are of relevance to external, higher layers. These functions allow external entities to interact with the control space; for example, to allow a content provider to create a media distribution service or for end-users to signal context updates such as resource availability or terminal properties. The second part of the ASI is a generic mechanism similar to the ANI that, for example, enables discovery of available interfaces and functions.

Another similarity between the ANI and ASI is abstraction of the internal structure of the control space and its functionality. Users of the ASI remain unaware of the internal structure of the control space. This decouples the internal structure of the control space from its external protocols, allowing radically different implementations of the same functionality within different networks. This again enables the common control space to operate uniformly across heterogeneous networks.

Ambient Resource Interface

The Ambient Resource Interface (ARI) is the interface between the control space and the resources of the underlying connectivity plane, as shown in Figure 2. This generic model can support many different network resources, including routers, switches, quality-of-service enforcement points, firewalls, split-connection proxies or legal-intercept devices. The ARI is involved whenever connectivity resources must be controlled, for example, for quality-of-service management.

To avoid polluting the control space abstraction with domain-specific knowledge of underlying connectivity resources, the ARI encapsulates the details of specific connectivity resources. It presents a uniform abstraction of the connectivity plane to the control space, maintaining the domain-specific knowledge of connectivity management at a lower layer.

Control Space Framework Functions

The common control space described in the sections above also includes framework functionality that is not specific to particular control tasks. This framework functionality includes both abstractions and common functionality. The next sections will outline the current control space functionality.

Connectivity Abstraction

Operating on an abstraction of specific connectivity resources instead of the resources themselves allows the control space to remain independent of specific connectivity technologies. This simplifies the control space and allows it to support heterogeneous infrastructures more easily. The ARI translates control messages from their generic form into the specific instantiations required for a given connectivity infrastructure. When controlling legacy networks, the abstraction includes both user-plane connectivity functions as well as legacy control functions that are not already present in the common control space.

Session Abstraction

Besides abstracting from the technologies used in specific connectivity planes, the control space also operates on abstract sessions instead of including support for different session metaphors directly. The common session abstraction of the control space includes the session endpoints and the characteristics of the communication channel between them.

Conflict Resolution Mechanism

Control space functions are self-contained modules that issue control decisions without first coordinating them with other functions in the control space. Some of these decisions may lead to conflicts, because they interfere with concurrent decisions of other control functions. The control space thus includes explicit mechanisms that detect and resolve such control conflicts and facilitate consistent decisions according to network operators' policies and preferences.

Resource Registry

This function manages the connectivity resources together with their specific access control characteristics with the control space.

Message-Passing Mechanism

Due to the modular nature of the control space, different configurations of functions can exist within the single control space of a particular network. It is thus beneficial to decouple the communication needs of the control functions from the presence of particular functions in the control space. The control space thus includes a generic message-passing mechanism that is an indirect information exchange of messages between control functions. Those messages are based on the communicated information elements rather and do not depend on the functions themselves.

Control Space Functions

Besides the control space interfaces and its common functionality outlined above, the control functions to operate and manage particular network aspects form the a third set of components that is part of the overall control space architecture. As mentioned before, the modular structure of the architecture allows dynamic deployment of these functions on demand.

The Ambient Networks project is currently investigating many different control space functions in its individual work packages. A first collection of identified functions and the descriptions of the individual function's scope are provided in the following paragraphs.

Naming and Addressing Framework

The Ambient Networks architecture introduces several new namespaces. Besides splitting user-plane locators and names, similar to many other next-generation architectures, it differentiates between the identities of legal entities (persons or organizations), network identities, persistent service or data object identities and session identities for groups of flows. Besides detailing the specific requirements for each of these namespaces, the naming framework will also include functionality to allocate and deallocate entities in these namespaces and map entities between namespaces.

Multi-Radio Resource Management

Multi-radio resource management manages all available radio access resources. These may potentially belong to several radio access technologies. It maps individual communication needs to one or several radio accesses. Typically, each radio access technology will contain its own, locally responsible management entity. The shared multi-radio management will mainly provide coordination between the different radio access technologies. One of its tasks is deciding on the assignment of radio resources to a session; another one is controlling handover between different radio access technologies in cooperation with the mobility mechanisms.

Composition

Composition control is one of the key functions of the control space. This functionality coordinates composition-related network control and management aspects, for example, to control composition processes based on existing policies, current network state and inputs from other functions.

Quality-of-Service

Quality-of-service functionality provides dynamic control in ubiquitous mobile environments in a technologically independent way. It allows networks to delegate and share control over the overall network resources, including functionality such as QoS-aware handovers. The QoS functionality will adapt to advanced scenarios that include multi-connected networks and multiple paths between two networks.

Congestion Control

Congestion control mechanisms operate

both at the connectivity level and at the control space level. This functionality allows both user plane and control space mechanisms to obtain information about network conditions. This may incur cooperation with related functions, such as quality-of-service, mobility or traffic engineering. Congestion control information may be used by other functions, such as routing.

Locator Management

This function manages the allocation of locators to network endpoints. It maintains information required for translating identifiers into locators and manages forwarding state in the network.

Trigger Processing

This function decides upon the execution of mobility management functions. Other control space functions initiate mobility management functions by generating specific triggers that will initiate the execution of the requested functionality.

Context Transfer

This function transfers mobility management state when during mobility events. It ensures consistent transfer of distributed state.

Routing Group Formation

When endpoints exhibit similar mobility patterns, this function coordinates the formation of routing groups to optimize routing and mobility management.

Overlay Control Space

This function controls the establishment, maintenance and release of service-specific overlay networks. These overlay networks are tailored to the specific needs of media delivery services. The overlay control space determines the topology of the overlay network during its establishment phase and reconfigures existing overlays when changes to the underlying physical resources make this necessary. During the lifetime of an overlay, this function manages data routing as well as adaptation of media content.

Context Management

The context management function manages a set of context information bases within and across different control spaces. The function is responsible for scheduling and monitoring interactions between context sources and clients and reallocates channels of interaction in case of context changes.

Context Coordination

The context coordination function coordinates the exchange of information between different control space functions. It collects information relevant to each function and redistributes it to other relevant entities through the respective context information base.

Agreements

Agreements functionality includes agreement establishment, verification, enforcement and dispute resolution. The agreement establishment function is responsible for conveying agreement information to other functions. It also obtains policies for agreement negotiation and handles trust related data (e.g., public key certificates.). During an agreement negotiation, the function maintains communication between the involved networks, but it can also establish communication with another network to obtain trust information.

Management

In the area of management, the control space includes functionality for distributed inter-domain management. Specific aspects of these mechanisms deal for example with traffic engineering. One key focus of the management mechanisms lies on self-configuration and automatic coordination within one network and across domain boundaries.

Conclusion

This paper presents an internetworking architecture for cooperative networks that is currently under development within the IST's Ambient Networks project. Its architectural approach builds on the establishment of a common, distributed control plane facilitating the interoperation of heterogeneous networks. This shared control space is structured as a modularized framework that allows dynamic, plug-and-play adaptation of control functionality, as well as generic interfaces that abstract the control specifics of configurable networks, resources and services.

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[2] "Ambient Networks - Research for Communication Networks Beyond 3G", Norbert Niebert, Hannu Flinck, Robert Hancock, Holger Karl, Christian Prehofer, IST Mobile Summit, June 2004