Towards Automized Interconnection of Networks: Composition and Dynamic Negotiation of SLAs

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Abstract. The world of telecommunications shows clear trends towards increasing dynamicity; new types of networks, new types of applications, and also new types of businesses and business relations. At the same time, and partly due to the increase in dynamicity, operators and service providers, as well as other new type of players such as access aggregators seek to find new innovative architectures, methods and technologies to decrease the cost of operating and managing networks and services. This increase in OPEX is due not only to the increasing dynamicity but also due the ever increasing number of applications. This paper provides background and overview of the underlying issues, which then is used in order to describe concepts and technologies that could play a fundamental role in addressing and resolving those issues, both from recent as well as ongoing research. The paper ends with some conclusions, and with an outlook of issues that needs further studies in upcoming research activities.

Keywords: Architecture, management, composition, SLA, negotiation, stratum, ambient networks, governance, automization.

1 Background

In the area of telecommunications such as cellular systems, as well as within data communications like the Internet, different networks interconnect in a way that requires substantial manual work. Not only does it require the setup of network nodes to configure a huge amount of different parameters concerning for example routing, traffic management, and policies, but also the negotiations of a business agreement and the SLA (Service Level Agreement) that governs the interconnection of the networks. As this consumes lot resources, it becomes increasingly difficult to handle and

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scale the operations and management of networks when the business and technology environment becomes more and more complex and dynamic.

During the last couple of years we have seen a tremendous growth in applications and services, and we also see trends in that we get more options regarding what access network technologies that can potentially be used at different locations, for example Turbo-3G, WLAN, and WiMAX. This has also resulted in new types of business players such as access network providers or roaming brokers.

Looking ahead there are no signs that the increased dynamic nature of networking and business will slow down. What this means is that the current procedures for internetworking needs to be more cost-efficient and scalable, as well as the ability to cut lead times for deployment of new functionality. Generally this speaks in favour of automizing many of the procedures that today require manual work.

Though the focus in the descriptions above has been on the network operator side, the possibility of automizing the interconnection of networks is uttermost a matter of improving the end user experience, and ensures that consumers have access to up-to-date and the latest developed applications and services.

This paper describes approaches to address the needs of automization of the procedures to interconnect networks that have been undertaken mainly in the research community. It also describes the most recent results and findings from work in EU-funded projects, notably 4WARD (www.4ward-project.eu), Ambient Networks (www.ambient-networks.org), and ONE (one-project.eu).

Section 2 describes important issues in internetworking which motivate to drive research beyond current state-of-the-art. Section 3 describes composition and negotiation concepts, as well as how to control and support the process of composition. Section 4 describes a use case to show how the pieces fit together, and finally Section 5 provides conclusions.

2 Issues in Current Operations and Management of Internetworking

As Ronald Coase argued in 1959 [1] that private negotiated arrangements are frequently superior to regulated arrangements in multiple fields. This has been also the case in current IP interconnection models. This has led to the existence of multiple models for the interconnection charging models as reported in [2], where different interconnection models between carriers and the negotiated services are described.

It should be noted that just for the configuration of these agreements that are performed off-line and are not done dynamically some manual configurations (or ad-hoc configurations) are still required to configure border routers in the different domains (e.g. configuration of neighbors in the BGP routers). Therefore, the procedures to negotiate a new private agreement and its configuration have a cost that could be reduced by means of the automization of all these procedures.

Moreover, considering the current trends in the evolution of the traffic ([3]), it is more or less clear that there is a huge increment of the end users' demand of new multimedia applications that require better network performance, different traffic profiles (i.e. the asymmetry of the traffic patterns is changing) or guaranteed Quality of Service (QoS), such as on-line gaming, video streaming or videoconference.

Therefore, new networks able to provide more capabilities in terms of bandwidth, network guarantees (end-to-end QoS parameters), etc. are foreseen in Future Internet scenarios. Moreover, in these scenarios, the cooperation between service providers and network providers will be also required in order to provide carrier class services across Internet. This has an important operational cost in today's networks, since as shown in [4], there are multiple solutions to provide QoS guarantees that are not only technology dependent but also vendor dependent and that, therefore, require the specification of ad-hoc solutions due to the lack of well-known interfaces and protocols.

In order to assure the success of Future Internet, all these advanced capabilities aware networks must be able to interwork in an efficient way from both the technical (the capabilities should be maintained across different domains and the agreements should be done and configured automatically) and economical point of view (operational costs must be reduced). In this context the concept of composition is interesting since as explained in the next section, it allows the automized internetworking across different domains.

3 Concepts and Technologies Supporting Automized Internetworking

3.1 Overview

The first more significant step to provide an overarching framework for the dynamic interconnection of networks was formulated and described by the Ambient Networks project. It was coined Network Composition, and in its core there is a process that describes how the Ambient Control Spaces of two Ambient Networks interconnects to form a Composition Agreement. As an extension to this work, a study was performed in 3GPP to describe Network Composition in the context of 3GPP, and how it could be useful and beneficial for the development of business and technology based on a 3GPP network architecture [5]. An interesting observation from this study acknowledges that Composition Agreements needs to be based on what is called a Framework Agreement, pointing to the fact that not "everything" can be automized, e.g. regulatory and legislative aspects needs to be settled prior to the essential business negotiation.

In the 4WARD project, a what can be called a "network algebra" has been defined which out from the Nth Stratum concept [6] describes how strata can be composed and where such composition of strata would be under the control and supervision by a Governance function. The Nth Stratum concept systemizes and generalizes the idea behind Network Composition as defined by Ambient Networks into a set of generic operations. In addition, the Nth Stratum concept also provides support for service composition, thus aiming at a unified approach to composition of network functionality.

3.2 General Composition Principles

Composition in networking can be divided into three categories: Protocol composition [7], Network composition [8], and Service composition [9, 15]. In other words, composition in networking can be realized at three levels: protocol level, network level and service level.

Protocol composition deals with the composition of algorithms and message exchanges to build a protocol between sender and receiver. Protocol composition also deals with the combination of simple protocols to form a more complex protocol.

Network is a set of communication entities (nodes) and a set of links and associated protocols used between them. Network Composition deals with the interconnection of networks and how to compose the functionalities represented by the communication entities.

Service is defined by a set of service primitives at an interface, and is indeed independent of how that service is provided by underlying protocol or network. Service composition is thus a matter of composing the service primitives of the services to be composed.

Protocol composition can occur in design-time or in run-time, and which is also the case of Service Composition. Network Composition generally takes place during run-time. Throughout the rest of the sections below, the focus is mainly on Network Composition, but also with examples and discussions around Service Composition.

3.3 Network Composition in Ambient Networks

In the Ambient Networks project, a new framework to dynamically establish cooperation between entities called Network Composition [10, 11] was developed. Cooperation between networks requires basic interconnectivity between cooperating entities as control plane functionalities and such interconnectivity does not always exist, thus it needs to be established on the fly. The composing networks exchange their offers and requests on capabilities, resources and different kinds of services to find out whether there are sufficient incentives to compose. The Network Composition process consists of the following phases; *Media Sense, Advertisement & Discovery, Security and Internetworking Connectivity Establishment, Composition Agreement (CA) Negotiation* and *CA Realization.* These phases are not always executed in a one-way fashion, thus the process could have different forms depending on the use case for where the process is applied.

There are four composition types according to which networks can compose; 1) Network Interworking, 2) Control Delegation, 3) Control Sharing and 4) Network Integration. These types are defined based on how the composed resources are managed after a composition. In Figure 1, two Ambient Networks AN1 and AN2 have composed and a new virtual network AN12 is created. Resource *r1* is contributed according to the *Control Delegation* type, where AN1 delegates the resource control to AN2, i.e., after the composition, from management point of view, *r1* could be seen as the resource of AN2. Resources *r2* and *r3* are contributed according to *Control Sharing* and their management is the responsibility of a new resulting network AN12. Resource *r4* follows the *Network Interworking* composition type, where AN1 has granted usage rights of it, but AN2 retains its full management and control rights. The *Network Integration* type is the case where the composing networks are not visible from outside anymore after the composition, thus they can be seen as a new network.

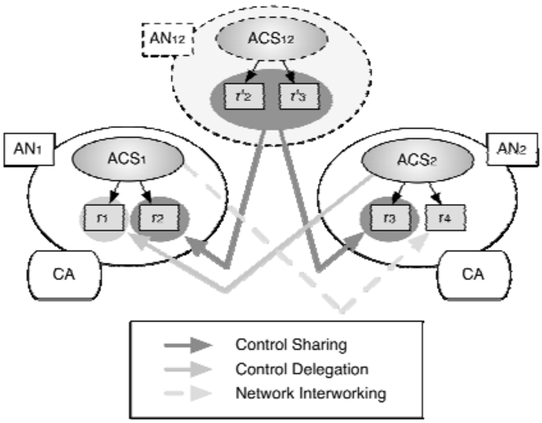

Fig. 1. Network Interworking, Control Delegation and Control Sharing composition types

Network Composition is thus about how to manage and use resources according to the agreed CA. Once the networks are composed and the CA is created, then the SLAs could be negotiated based on the CA, which basically defines how the resources could be used in the SLAs as illustrated in Figure 2. For the SLA creation, the involved entities and the used interfaces could be different compared to the CA creation. A SLA renegotiation could occur without that the related CA is changing. Thus, Network Composition between two networks can be seen as an enabler to automatically create SLAs between networks, i.e. connectivity and other networking resources based on which SLAs are negotiated are setup by Network Composition. Compared to how SLAs are used nowadays, the CA could potentially include much more technical and business details, since it is not only about services, but also more generally about resources. And this is one reason why there could be more content-wise richer SLAs that could also be temporary and created on the fly.

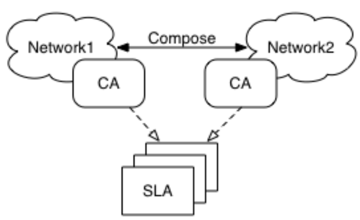

Fig. 2. The relation between CAs and SLAs

3.4 Composition Principles in the Nth Stratum Concept

The Nth Stratum concept was first described in [6], and then further developed and detailed in [12]. A stratum is defined as a distributed function which has an internal and an external view. The internal view of a stratum comprises a set of logical nodes and a medium ensuring the data transfer between the logical nodes. A logical node models a piece of the functionality as defined for a stratum. The external view of a stratum comprises the Stratum Gatewaying Point (SGP) through which a stratum interconnects with other strata of similar type, and the Stratum Service Point (SSP) through which the services of a stratum are offered to other dissimilar strata. Figure 3 presents a stratum with its internal view and external view.

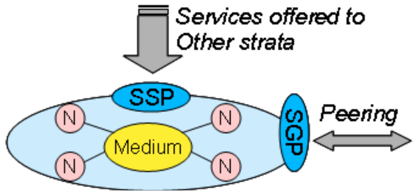

Fig. 3. Stratum with its internal and external views

The Nth-stratum framework also defines an architecture comprising vertical, horizontal strata, and abstract strata [6]. A functioning network is composed of a set of horizontal strata and vertical strata. Horizontal strata provide the connectivity and eventually additional services such as QoS, mobility or security support. Vertical strata comprise one Governance stratum and one Knowledge stratum ensuring the management and control of the horizontal strata. Abstract strata (not further described in this document) are defined in the framework as modular design patterns used to constitute horizontal and vertical strata.

Stratum is a powerful concept to model an administrative domain and how such domains can be composed. As presented in [6], horizontal strata are managed by the Governance and Knowledge strata. That means that these horizontal strata and associated Governance and Knowledge strata should be under the same administrative domain. A domain is characterized by the following properties: (i) all the components inside the domain belong to just one administrative entity, (ii) different policies can be applied inside the domain (iii) the domain provides a set of services to the end users and to other domains, (iv) the domain is autonomous in the sense that it is able to negotiate agreements with other domains. Taking into account the external reference points provided by each stratum, the SSP and the SGP, it should thus provide a clear interoperable framework.

The composition of strata belonging to different administrative domains requires a negotiation between their Governance strata (as explained in the next section). Interoperability between domains such as QoS class definition should be also resolved during the negotiation between Governance strata.

The Nth-stratum framework currently defines six generic operations: stratum instantiation, strata concatenation, strata merging, strata slicing, strata aggregation, and stratum split [12]. These strata operations can be used to control or manage the composition or decomposition of networks and services. *'Stratum instantiation'* operation instantiates a stratum over physical network, e.g. we apply IP over a set of nodes in order to form an IP network. *'Strata concatenation'* operation (maps to the Network Interworking and Control Delegation composition types) concatenates two strata, e.g. we interconnect two IP networks by border routers. *'Stratum merging'* operation (maps to the Network Integration composition type) merges two strata to form a single stratum, e.g. the merging of two IP networks to form a single IP network. *'Strata slicing'* operation (maps to the Control Sharing composition type) is basically a virtualization operation, e.g. the allocation of an IP-based VPN. *'Strata aggregation'* operation aggregates the resources of two or more strata in order to provide a summarized representation of the resources and services available across the aggregated strata, e.g. to aggregate the routing tables in several IP networks. *'Stratum split'* operation splits a network into two networks, e.g. the division of one IP network into two separate IP networks.

Following the Nth Stratum model, the following composition types are considered:

- **Service Composition:** strata of different nature can compose via their SSPs in order to provide a specific service. This type of composition was not studied and defined in Ambient Networks.
- **Network Composition:** strata of the same nature compose in order to extend a specific service entity to another network environment. In this case, both strata negotiate and implement the agreement through the SGP.

3.5 Governance for the Control and Supervision of Composition

The Governance Stratum is in charge of managing the operation and configuration of the Horizontal Strata, according to the specific policies defined by the network administrator. The Governance stratum is supported by the Knowledge stratum that provides the functionalities related to the maintenance and monitoring of network status, including what services/resources are available in each of the horizontal strata.

Since the Governance stratum is in charge of managing the network domain, it is the main responsible for the orchestration of the composition process. In particular the following functionalities related to the composition are foreseen:

- Management of the CA including the SLA(s): the Governance stratum is responsible for the negotiation of the agreement (via the SGP of this stratum) and of the admission control process that should be triggered when a new service request is received.
- The policies as well as the network status from the Knowledge stratum, form basis for accepting or rejecting the CA. The configuration of these policies can have associated a non-dynamic operation that are required as part of the Framework Agreement where specific regulatory constraints are considered.
- Once the CA has been accepted, the Governance stratum is in charge of triggering the configuration of the Horizontal strata; this includes the authorisation of information coming from other domains that, for security reasons, must be filtered in the borders of the domain.
- The Governance stratum will also ask the Knowledge stratum to monitor the fulfilment agreement and, if an alarm is received, the Governance will take the actions required to maintain it by means of configuring the appropriate network resources.

An important step beyond the current state of the art is the interworking between domains that could implement different functionalities and services, such as for example network operators implementing the traditional transmission functionalities and service providers (providing, for example server farms to provide their services).

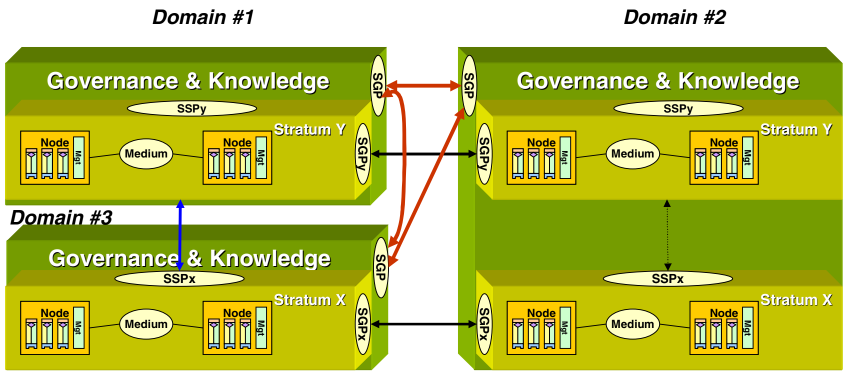

Fig. 4. Interoperability of different domains

In Figure 4 Domain #1 and Domain #3 have completely different functionalities (e.g. Domain #1 could be just an Information network with a set of nodes that are in charge of distributing the information while Domain #3 is in charge of providing transport capabilities). In this case, if Domain #2 aims to use Domain #1 services, the following interaction are foreseen:

1. Domains #1 and #3 have an agreement negotiated by means of the Governance capabilities to allow Domain #1 the usage of the services provided by Domain #3 through the SSP. The configuration of this agreement results on the composition of the services available in domains #1 and #3, which is implemented as a strata aggregation or merging, depending on the type of agreement.
2. Domains #2 and #3 have an agreement to assure the Interconnection (network composition implemented through a strata concatenation operation) for the capabilities located in the stratum X. This agreement has been negotiated through the SGP of the Governance strata (red line between domains #2 and #3) and triggers the configuration of the SGPs located at the strata X to allow the interaction between these two domains.
3. Domains #1 and #2 have an agreement to interconnect the capabilities located at strata Y. This operation follows the strata concatenation process.

In this way, Domains #1 and #2 can offer a service to, e.g. end users. This illustrates how the 4WARD Architecture Framework allows both the configuration of network and service composition allowing the implementation of multiple business agreements. The 4WARD Architecture Framework allows the Interconnection at different levels between two different domains; providing the basis for the assurance of end-to-end services. This interconnection is possible thanks to the existence of management functionalities (Governance and Knowledge) and interdomain interfaces (SSP and SGP).

This is an important achievement from both the technical and the business point of view, since in the current IP Interconnection market only two types of horizontal agreements are being considered: peering (two operators agree on processing the traffic that starts and ends in these domains) and transit or hub (a transit domain, usually a Tier-1 carrier provides connectivity to any domain). There have been other initiatives, such as the IPX promoted by the GSM Association to design the agreements at also the service level, but this framework assumes the vertical integration of the operator, without providing enough flexibility to configure all the possible scenarios (with a lot of players) foreseen in the Future Internet.

3.6 A Meta-model for the Negotiation of Compositions

By applying the Open Negotiation Metamodel (ONM, [13]) to the CA Negotiation phase of the composition process, we allow for an automated and flexible negotiation process. This metamodel have been developed in the European IST project ONE [14]. It is designed as a tool supporting system designers in creating specific and customized negotiation models.

ONM defines all elements of a customized negotiation model and their relationships, essentially by capturing the semantics of an e-negotiation domain [14]. It covers two aspects: 1) the *negotiation information*, focusing on the *subject* of the negotiation and the negotiable *issues* depending on the business context and, 2) the *negotiation process*, defining the mechanism under which the interaction between parties takes place (the communication *process*, and *rules* governing the process).

The ONM allows designing processes for specific negotiation types but generic with respect to the actual negotiation context (such as network protocol aspects).

Figure 5 shows the core concepts of the ONM. Every *negotiation* involves *participants* (maps to Governance stratum) that negotiate towards *agreements*. The participant is represented by software where its behavior is defined by the explicit set of actions defined by the negotiation process and constrained by the negotiation rules (acceptance and rejection policies). Every *negotiation* comprises a number of *subjects* (maps to resources), which in turn contain *issues* (negotiable characteristics of such resources), which in turn are resolved by the *agreements* the *participants* are trying to reach.

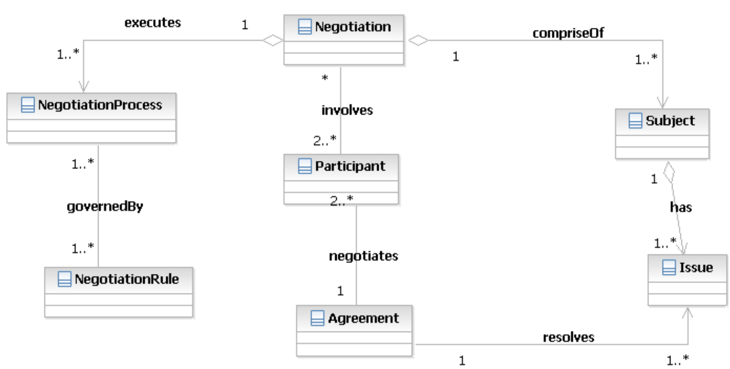

Fig. 5. Negotiation MetaModel Overview

The left part of Figure 5 shows the negotiation protocol part. Each *negotiation* executes a *process* which is governed by *rules*. The *process* will implement the behavior of the negotiation [13], and the exact messages of the negotiation protocol. The *rules* will govern this behavior according to the requirements of the negotiation information and protocol. For this article, we assume that a policy-based management system (inherent to the Governance stratum) will provide the rules according to the context of the involved networks (and their administrative domains). ONM defines a specification language to define different CA templates and specific negotiation processes that can be used in conjunction with the Governance stratum capabilities.

4 Use Case, Putting the Pieces Together

The use case is depicted in Figure 6 below, and which we believe would be relevant to solve through network composition using the model of strata as to address issues of scalability in regard of management and also ease of use.

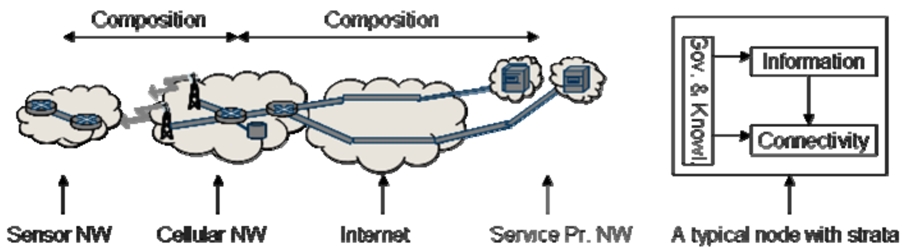

Fig. 6. The use case, with involved networks, and the strata in a node

We can here think of small sensor type of networks at the very edge, and which may well be counted in millions globally, providing some type of measurement data, e.g. weather related data. Those networks are connected via a cellular network, which could provide an aggregation and filtering service, to a service provider type of network (located somewhere on the Internet) consisting of servers which further aggregates, filters, processes, and stores the measurement data received from all the sensor networks at the edge.

The networks consist of network functionalities modeled as strata deployed across the nodes in each of the networks. Figure 6 shows a simplified view on what strata that may run in one node (real networks would consist of more horizontal strata). Governance and Knowledge strata have already been presented above. The Connectivity stratum provides connectivity services, and the Information stratum manages measurement data (this latter stratum only needs to run in nodes which manages the measurement data). The gatewaying type of nodes that needs to be present in each of the networks implements the SGP of each stratum. Notably the SGP of the Governance stratum can basically implement and execute the network composition process. Via the Knowledge stratum, the Governance stratum can find out which services/resources are available within the network and which thus can be advertised to another network (subject to policies). To establish the security association, as well as serving needs for compensation, SIM-based credentials can be used (at least between the sensor and the cellular networks). To establish the CA, ONM is applied and where specifically the services/resources related to the measurement data are negotiated. As for compensation, the owner of the sensor network may get a discount on the voice services, and the cellular network could be compensated by getting some share of the income from ads being generated by the service provider.

Please also note that generally all the strata in the connecting networks are being composed, and thus not only the Governance strata, but their respective composition processes will be firstly under some control from the Governance stratum (and subject to policies), and secondly be a simplified version compared to the full composition process executed between the Governance strata.

In this use case, all the strata will be composed according to the strata concatenation operation.

5 Conclusions

In this paper we have described how concepts from the Ambient Networks, ONE, and 4WARD projects can be used in an integrated way to provide a solid foundation to dynamically interconnect networks. Nonetheless, though significant and mostly theoretical results have been achieved so far, there are issues left for further study, and notably further studies for how to model service composition is needed, as well as through experiments evaluate performance and scalability aspects.

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