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# Architecture for dynamic management of QoS policies for heterogeneous Internet environments

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## Abstract

*In heterogeneous Internet access network environments (UMTS, WLAN, WIMAX, WLAN DVB-T, DVB-H), there is a challenge for automated configuration and adaptation of policies aimed at management of Quality of Service (QoS) guarantees and resource usage. The paper is focussed on a QoS policy management architecture, which allows interaction and adaptation of QoS policies of different actors (network operator, service provider and user) using a scalable policy repository. Design issues of such an architecture are discussed, emphasising on policy information models for dynamic resource, transport and measurement adaptation in heterogeneous network environments, modular and extendable ontology driven policy repository design, as well as flexible management interfaces for policy specification.*

## 1. Introduction

In heterogeneous Internet access network environments, QoS policies can be used to adapt and optimise dynamically services and QoS parameters within different communication layers dependent on the capabilities of the particular access networks and the specific business goals of users, service providers and network operators.

For efficient operation of heterogeneous Internet infrastructures considering users with multiple access network interfaces, it is critical that resources and services for QoS-aware applications are intelligently managed and dynamically adapted based on QoS policy specifications and automated learning of network and device contexts [1].

Derived from Service Level Agreements (SLAs), QoS policies are applied to enforce the automated resource, parameter and service (re-) configuration at managed

devices and entities according the specific objectives of the policy actors.

The dynamic management of QoS policies in heterogeneous environments is motivated by the need to automate the adaptation of QoS parameters and mechanisms of applications and routers considering complex relationships, such as particular network characteristics and device contexts, the specific objectives of the policy actors and their hierarchical dependencies, SLAs and other issues.

The focus of this paper is architecture for dynamic QoS policy management in heterogeneous network environments, aimed to support automated policy specification, adaptation and enforcement, using ontology driven policy repository and context learning approaches. The architecture, designed in European IST project NETQOS [2], [3], is enhancing the IETF QoS policy framework with policies of different kind of actors (users, service providers and network operators) for dynamic resource and QoS adaptation in heterogeneous network environments, as well as with context learning and automated policy adaptation facilities. The interaction of the components is based on ontology driven policy and context repositories including related information for QoS management in heterogeneous network environments.

The modular ontology oriented design allows a high degree of autonomy, flexibility, and agility of the components and repositories included in the policy management architecture. Flexibly configurable Graphical User Interface (GUI) is used to specify policies according specific scenarios for dynamic QoS management of heterogeneous networks.

This paper is organized as follows. In section 2, policy and ontology research is evaluated. Section 3 is focused on the design of the dynamic QoS policy management architecture. Section 4 discusses the modular ontology and policy repository design. Section 5 presents flexible GUI design for resource configuration policies. Section 6 concludes this paper.

## 2. Related research

### 2.1. QoS Policies for heterogeneous network environments

Policies are defined as a set of rules to administer, manage and control access to network resources by applications and users (see RFC, 3198 [4]). Policies are designed using specific policy information models and generic (core) policy characteristics (see, RFC 3060 [5], RFC 3460 [6], RFC 3318[7]). Policies, specifying conditions and actions, can express the specific business goals and objectives of policy actors (network operator, service providers and users) based on the contracted SLAs between them.

The IETF policy management architecture is based on interactions of a policy management application, a policy repository, a policy decision manager and policy enforcement points.

The idea behind the more specific QoS policy concepts is to allow automated configuration of resources of managed entities, such as traffic limit for the routers and protocol parameter updates. QoS policy rules are derived from the contracted Service Level Agreements (SLAs) between policy actors.

In IETF framework, QoS policies of network operators are based on IntServ and DiffServ provisioning technologies and applied to network devices (see, RFC 3644[8]). They are specified based on the Common Information Model (CIM) [5], Policy Core Information Model (PCIM) [6] and QoS Policy Information Model (QPIM) [8].

QoS policies for heterogeneous Internet environments can be defined by the policy actors to consider different kinds of SLAs (for intra- and inter-domain networks), business scenarios and goals.

Examples for policies aimed at management of resources in heterogeneous environments are:

- Optimisation of the traffic allocation (redirection) between heterogeneous access networks [9];
- Dynamic service discovery and customization considering network capabilities and context information [10];
- Intelligent network selection for mobile users and QoS-aware applications in heterogeneous Internet environments based on QoS parameter constraints, user-centric and network-centric approaches [11];
- Automated resource configuration, provisioning and adaptation based on user, service and access network characteristics (profiles) [12].

Policy definitions are related to specific scenarios. To support formal specification and flexible policy refinement, ontologies are used.

### 2.2. Ontology requirements for QoS policies

Ontologies, providing key terms, inference rules and semantic interconnections, allow a common vocabulary to access information in policy management systems. Ontologies can be used for formal semantic specifications of QoS policies in different scenarios, as for instance:

- QoS based dynamic service selection [13];
- SLA defining the contracts between users, service providers and network operators [15]; [16];
- Autonomous service discovery [17];
- QoS monitoring and measurement [18];
- Formal context description [14];
- Service adaptation based on network and device ontologies [19];
- QoS call control [20];
- Policy refinement using ontologies [29].

Recent research is aimed to integrate the different QoS ontology efforts, deriving requirements for unified QoS ontology design based on existing QoS concepts [21]. Ontologies are usually exchanged in XML [22] and RDF/XML [23] language constructs built from higher level ontology languages, such as OWL (Web Ontology Language) [24] and SWRL (A Semantic Rule Language) [25]. The background is to use such ontology languages for policy specification in order to allow formal semantic specification and machine reasoning. Using ontology languages, the policy is defined by concepts (taxonomies), relations, functions, axioms, and instances. Comparison of ontology languages is given in [26]. The OWL language, standardised by the World Wide Web Consortium (W3C), has strong industry support and is widely used for policy oriented services. For instance, based on OWL-S, policies for support of dynamic QoS adaptation are defined [27].

OWL in connection with a policy management system is used for Internet call control [20]. Dependent on the application, there are different OWL versions, such as OWL full (complete language), OWL DL (full language used with reasoning systems) and OWL Lite (used for simple constraints and a class hierarchy).

The benefit of the usage of ontologies for dynamic policies management in heterogeneous environment is the possibility for flexible integration of different kinds of ontologies in a large, modular, expanding and scalable policy framework. To reduce complexity, support interoperability, standardised solutions, enhanced machine reasoning, re-usage and adaptation of existing ontologies, OWL can be preferred for policy definitions in heterogeneous environments.

### 3. Architecture for QoS management in heterogeneous network environment

#### 3.1. QoS policy framework

The QoS policy framework includes policy models for heterogeneous networks, aimed at automated (re)configuration of resource, transport and measurement facilities dependent on the preferences of policy actors (users, service providers and network operators) considering the capabilities of the networks. The QoS policies are derived from the Service Level Agreements (SLAs) between the policy actors and can be dynamically adapted considering them.

Such SLA contracts can allow the usage of multiple access networks, alternative routing paths and adaptable QoS levels for applications dependent on the preferences of the given actors. Example scenarios and policies supported by the architecture are given in table 1:

Scenario	Policy description	Managed entity
Traffic balancing between heterogeneous networks	Dynamic (re)configuration of bandwidth resources at routers dependent on the capabilities of the networks and network context (for instance, congestion)	Routers included in the infrastructure
Resource adaptation of QoS-aware applications in case of handover	Automated adaptation of resource reservation strategy of QoS aware application dependent on the preferences of policy actors, capabilities of the networks and network context.	Application resource requests
Optimisation of QoS measurements	Reconfiguration of QoS measurement strategies for particular network dependent on monitored context, events and services	Measurement scenarios and tools
Transport reconfiguration in case of failures and congestion	Dynamic reconfiguration of transport protocol parameters in case of failure, congestion and other events	Transport protocol parameters

Table 1: Example scenarios and policies

Policy actors can specify preferences for their applications, i.e. which access networks have to be used depending on performance objectives, as for instance cost, reliability and QoS guarantee. Considering hierarchical dependencies of the policy actors, the policy parameters can be automatically optimised. Learning procedure and context information can be used for top-down and bottom-up policy adaptation.

#### 3.2. Functional design

The architecture is aimed at automated (re-) configuration of QoS mechanisms on different layers in heterogeneous network environments based on policies defined by actors. The architecture allows that the actors specify QoS policy (as autonomous, hierarchical or dependable policy kind), which can be dynamically adapted and improved based on context information (monitoring data, events) and learning algorithms.

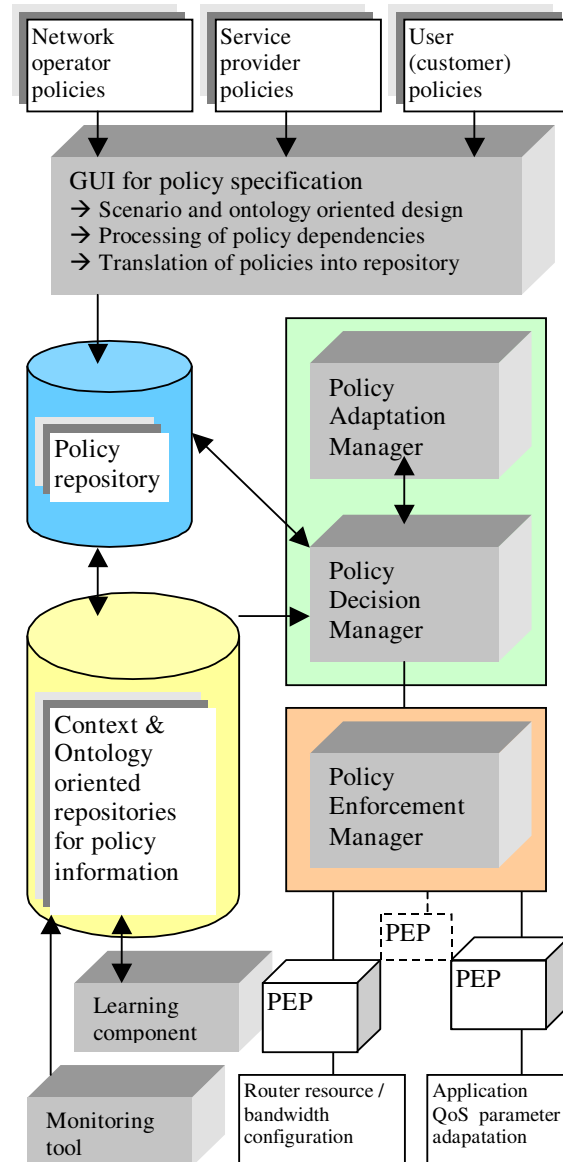


Figure 1: Functional design of the architecture

The interaction of the components is based on the ontology driven policy repository and context

information. In order to support interoperability and dynamic policy parameter update, the architecture includes a policy repository derived from extendable ontologies describing network capabilities, SLA, QoS requirements, profiles of policy actors and other policy information. For dynamic management of QoS policies, following components are involved (see figure 1):

- Policy specification GUI (called also Application Preference Manager) for policy specification considering dependencies of the actors;
- Policy Adaptation Manager performing automated policy adaptation based on context and learning information;
- Policy Decision Manager deciding to adapt (change) or to enforce a policy;
- Learning component including algorithms for learning of context information in order to support policy adaptation;
- Policy Enforcement Point (PEP) interacting with the managed entities (access routers and applications) for automated policy configuration;
- Policy Enforcement Manager triggering the automated policy configuration supplying the policies to the PEPs;

The interactions of the components are coordinated by the Context Manager using the context (measurement data and events) obtained by dedicated Monitoring tool and Learning facilities.

The dynamic management of QoS in heterogeneous environments is enhancing the IETF QoS policy framework in following aspects:

- Different policy actors are assumed and their dependencies are used for automated policy adaptation.
- Automated policy configuration considers not only the network devices as managed entities, but also applications and protocols.
- Learning component is a new facility, supporting automated policy adaptation in operational network environment.
- The QoS policies are specified for heterogeneous environment using ontology driven policy repository.

#### 4. Ontology driven policy repository

Because of the complex policy information domains for management of QoS in heterogeneous network environments, ontologies can be applied for policy specification. Using OWL [24], the ontology can be created by defining “classes” representing concepts and “properties” expressing relationships between classes.

The modular ontology design (see, figure 2) is the conceptualisation of the QoS policy information domain for heterogeneous network environment. The selected ontology classes are defined at a high level of abstraction.

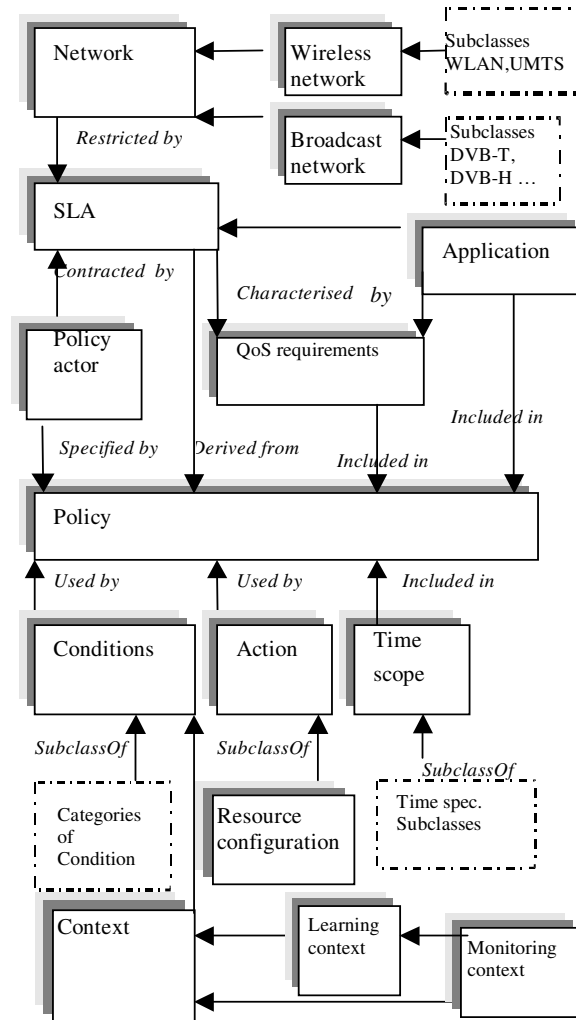


Figure 2: Modular ontology design

A given QoS policy (for instance policy for resource adaptation in heterogeneous network environments) is represented as an instance (in OWL an individual) of the policy class. A detailed policy specification is described by:

- Policy identification and type;
- Policy conditions;
- Policy actions (resource, transport and measurement configurations);
- Time scope;
- SLA reference, to which the policy is related;
- The policy actor defining the policy;
- QoS requirements included in the policy;

- Application profile involved in the policy.

The modular ontology design includes classes and subclasses, which can be extended flexibly dependent on requirements of the heterogeneous infrastructure and business goals. The main ontology classes used for formal policy information presentation are:

- Service Level Agreements (SLAs) based on subclasses describing QoS contracts between policy actors;
- Policy actor ontology including profiles of users, service providers and network operators;
- Network description ontology (containing as subclasses QoS capability description of heterogeneous networks);
- QoS requirement classes;
- Application ontology (i.e. application profile characteristics);
- Context ontology .containing subclasses presenting events, learning context and monitoring data.

For enhanced interoperability and cost efficient development, there is a challenge to reuse and enhance ontologies developed with similar purposes in standardisation efforts and further research, for instance ontologies for SLAs (see, [15]), network descriptions (see, [19]), QoS ontology (see, [21]).

The ontology driven specifications are translated to XML language constructs [22] and relational data bases, such as My SQL.

## 5. Flexible policy management interface

The policy management interface (called preference manager in the context of NETQOS project) allows the policy specification by the actors. The interface supports the modular definition, translation and storage of the policies in the repository using ontology descriptions. Further functions are aimed at control of the interactions and the dependencies of the policies of the different actors.

Ontology driven policy specification and modelling can be based on customizable Graphical User Interface (GUI). Such GUI can be developed using specific ontology tools, such as Protégé [28]. The GUIs for policy management are designed to support the specific policy scenarios. Policy repository functions included in the GUIs allow performing of operations for entering, changing, deleting of policies, as well as browsing of policies using the policy repository.

An example is given for a GUI implementing resource adaptation policy for QoS-aware applications considering the capabilities of the heterogeneous networks. The general policy description part allows the specification of user profile, policy identification

and QoS/SLA, which characterise the basic policy properties. The definition of the policy parameters is related to further ontologies describing application profiles, QoS requirements and network capabilities.

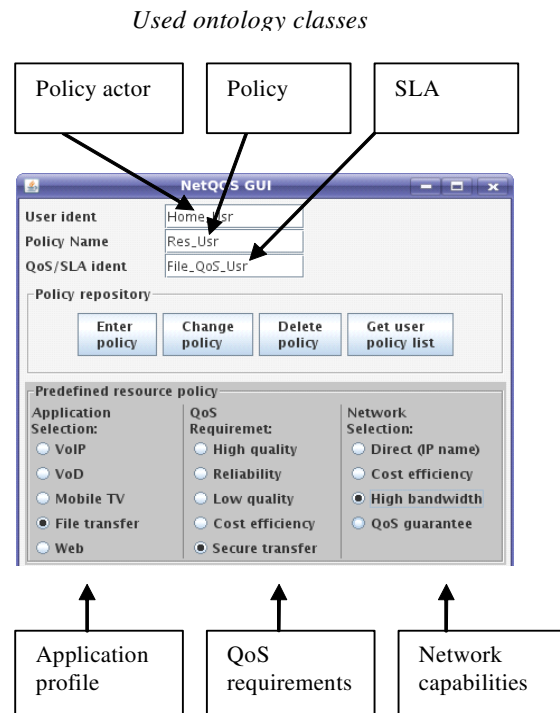


Figure 3: GUI parameters of resource adaptation policies

The ontology driven GUI design is shown in figure 3, where the relationships between GUI fields and designed ontologies are shown.

The policy actor selects the application profile (VoIP, VoD, Mobile TV, File Transfer, Web), for which the resources should be dynamically adapted and automatically reconfigured considering the QoS requirements of the policy actors and network capabilities. QoS requirements, such as “HighQuality”, “Reliability”, “LowQuality”, “CostEfficiency” and “SecureTransfer” for a given application are mapped dynamically based on the relationships of the ontology classes to different bandwidth configurations of the applications for the given network.

The system allows the user to prefer an access network for a particular application directly by using the IP address or based on criteria (cost efficiency, high bandwidth, QoS guarantee).

Based on the resource adaptation policy, the QoS requirements of applications are mapped to concrete bandwidth requirements of the particular access networks dependent on their type (DVB-H, UMTS; WLAN, WIMAX).

## 6. Conclusion

The paper presented an extendable architecture for management of QoS policies in heterogeneous network environments, which will allow new business scenarios considering automated translations of SLAs to QoS policies, learning and dynamic policy adaptation based on modular and unified ontology design. Future work is aimed at ontology driven configurable policy management GUIs, which are able to support new policy information models for heterogeneous networks using scalable and modular policy repositories with low cost access.

## ACKNOWLEDGEMENT

This work is supported by the project NETQOS [12] funded by the European commission.

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