An information model for the provisioning of network connections enabling customer-specific End-to-End QoS guarantees

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***Abstract*—The growing significance of international collaborations in research, education, and business fields has raised the demand for the assurance of the quality of the network connections which the projects and applications are realized upon. A large spectrum of examples with diverse requirements is found in areas such as GRID- and Cloud computing, eLearning, and video-conferencing. The consequences of these diverse project and application requirements culminate in the urgent necessity to provide an End-to-End (E2E) guarantee for any customer-specific or user-tailored combination of service-specific Quality of Service (QoS) parameters.**

The quality of the overall network connections provided to users obviously directly depends on the quality of the involved connection parts. This means that already during the setup negotiation process the quality of the available connection parts has to be considered. Especially for international connections it is common that multiple independent service providers (SPs) realize different connection segments. This means in turn, that during the information exchange about available connection parts not only the technical challenges have to be solved, but also preferences and restrictions of the involved provider domains must be considered.

In this paper we present a novel information model for the description of such connections. In the proposed model, a multi-domain view is derived from the single-domain perspectives of each considered SP. This model serves as a pro-found basis for an end-to-end routing algorithm which considers multiple user specific QoS parameters in parallel. The proposed model also accounts for the typically very restrictive SP information policies.

Keywords-network description; multi-domain information model; multi-QoS support

I. INTRODUCTION

As an answer to the growing demand for network connections with guaranteed End-to-End (E2E) Quality of Service (QoS), multiple dedicated national and international research projects have been established. Currently, the Dynamic Circuit Network (DCN) [1] cooperation led by Internet2 can be referred to as the most advanced of all of these projects. Among others, projects like OSCARS [2], DRAGON [3], Phosphorus [4], and the Géant-developed AutoBAHN [5] are involved in this cooperation. All these projects are focused on two primary aspects: (a) technologies for dynamic circuit switching within a single administrative domain and (b) interoperability between the developed management systems as well as between the networking technologies used in these domains.

Despite all achievements of these projects, their main drawback is the consideration of only a single QoS parameter – the bandwidth of the E2E connection. Support of further QoS parameters like jitter is planned for the future but not implemented yet. However, international research cooperation and many other large scale projects require E2E guarantees for more than just a single QoS parameter. Moreover, the combination of the required QoS parameters will vary with the application area of the network connections. For instance, in order to distribute raw experimental data of the Large Hadron Collider (LHC) [6] project, additionally to the bandwidth also the high avail-ability of the connections has to be guaranteed. In the GRID cooperation DEISA [7], more than a dozen European supercomputing centers must be interconnected with guaranteed bandwidth as well as low jitter. Currently, no automated establishment of connections considering combinations of multiple QoS parameters is supported by the established connection services and this issue is neither tackled by the currently ongoing research projects. Therefore, the establishment of connections with multiple customer-specific and user-tailored QoS parameters re-mains a subject of manual connection planning and setup. For the above mentioned LHC and DEISA projects such connections and their respective required properties are realized based on manually planned *Géant E2E Links* (also referred to as *GÉANT Lambda*) [8, 9]. Due to the massively increasing demand for such high-quality links, a higher degree of automation is absolutely critical to ensure sufficient scalability.

In order to guarantee certain quality parameters, e.g. service high availability, a thorough management of the connection service itself as well as of the underlying infrastructure is an obvious prerequisite [21]. The relevant management aspects are very well understood when only a single administrative domain is involved. *IT Service Management* (ITSM) frameworks like the IT Infrastructure Library (ITIL) [10] and the New Generation Operations Systems and Software (NGOSS) [11] specify several measures in order to guarantee the quality of the customer-faced service: At least permanent monitoring of the achieved quality is required. Furthermore, measures for *Incident & Problem Management* should be defined in order to fix possible problems quickly and efficiently.

However, when considering multi-domain network connections, the management aspects are mostly limited to network technology specific solutions, e.g. the well-known monitoring in SDH networks [12] and OAM for Ethernet [13], which is still under development. Even the more generic multi-domain solutions, like the E2E Monitoring System (E2Emon) for Géant E2E Links, are currently limited to a project-specific combination of QoS parameters [14].

In this paper we argue that the user- and customer-tailored requirements for connection service can be only truly fulfilled, if they are already considered during the ordering process. This means that the routing algorithm which is used to define the service parts provided by multiple SP domains have to take into account both, the E2E user requirements and the quality which can be guaranteed for connection parts by the Service Providers (SPs) realizing them. Consequently, for the operability of routing algorithm it is essential to have an information model for the precise description of the connections avail-able within a single administrative domain as well as of the connections interconnecting neighboring domains. In order to provide customer-tailored services, our model explicitly supports associations between connections and the customer-specific combination of the required QoS parameters as well as the required management functionality. Moreover, as service providers (SPs) often can realize the same connection with different QoS values, our model supports the exact specification of the available alternatives. The proposed model can be used with both currently used information exchange models – direct communication between SP domains on the one hand and indirect communication via an information broker on the other hand.

The remainder of this paper is structured as follows: In the next section we discuss the related work which has motivated as well as influenced our model. In Section III the focus of our model as well as the related user requirements and SP constraints are discussed. Section IV then presents the single-domain view of our model, whereas Section V discusses the inter-domain view and Section VI details the multi-domain view. After discussion the relevant connection properties in Section VII, a complete UML representation of our model is presented in Section VIII. We conclude by giving an outlook to our ongoing work in Section IX.

II. Related Work

Several information models have been designed for the planning and description of the currently predominant real world network connections services. Although being well understood and having been expanded by scientific research, none of these models does cover multi-domain routing in conjunction with user-tailored combinations of multiple QoS parameters yet.

Even well-established real-world routing approaches, such as OSPF [23] and BGP [24], are based on information models with only a single metric restriction.

Computer networks with multiple QoS parameters can be represented as graphs with multiple values associated to its edges (known as *multi-weighted graphs*). The algorithm described in [18] shows *better-than-the-brute-force* results for path finding. The distinction between the parameters is accomplished by utilizing the position in a value vector; thus, it cannot be applied to a user-specific combination of QoS parameters or their combination. Also global knowledge is needed by the algorithm, which cannot be guaranteed in a multi-domain environment.

Also, major movements in the ITSM research area have been achieved in the last years. In this context two de-facto standards influenced our work:

a. The IT Infrastructure Library (ITIL) [10] – a best practice guideline – defines service management processes, but it does not provide any specific information model for available services; it furthermore cannot be extended to suit inter-organizational environments easily.
b. Within context of NGOSS [11] – a framework sup-porting SPs to manage their business –the Shared Information & Data Model (SID) [19] is defined. Unfortunately, by supporting only bidirectional relationships to other SPs, it cannot be used to provide a global view in complex real-world multi-provider environments. Similar to SID, also the Common Information Model (CIM) [25] focuses on the description of relations between service and underlying network technologies.

Existing multi-domain service models like the MNM service model [20] and its recent extension for the support of Concatenated Services [22] are intended to describe the service composition of already established service instances. However, it cannot describe the "interplay'' between SPs during the initial instance provisioning phase.

In order to support the customer-specific and user-tailored combination of QoS parameters, a novel information model has to be designed. This information model has to support multiple QoS parameter and shall be applied to the provisioning of multi domain service instances which fulfill and guarantee the end-to-end customer and user quality requirements.

III. Focus, Prerequisites and Constraints

Our work focuses on the development of an Information Model for provisioning of Concatenated Services (CS), which are – regarding their planning and operation – the probably most challenging type of Point-to-Point connections. The following properties are characteristic for CS [15]:

a) **User perspective:** a guarantee for the E2E quality of the connection and its management is required;
b) **Service composition:** the E2E service is composed of horizontally (i.e. at the same network layer) concatenated connection segments, which are realized by different SPs;

c) **Organizational relationships:** all SPs involved in the service's provisioning are independent organizations and are considered equal partners.

A detailed requirements analysis for CS is presented in [15]. In this section we only present a short outline of the most important requirements, challenges, and design criteria.

We derive the requirements primarily from the **user demand**. The instances of CS can be used in various types of user specific applications, which in turn will require varying connection characteristics. This means that support for different QoS parameters as well as for their combination is needed.

Furthermore, in order to guarantee assured service levels, the management aspects of the connection – e.g. continuous monitoring of the achieved quality – must be supported. Moreover, the connection management re-quested by the user – like the run-time adjustment of required quality levels for various QoS parameters – must not be neglected. In both cases the multi-domain management of E2E connections has to rely on the management of all involved connection parts.

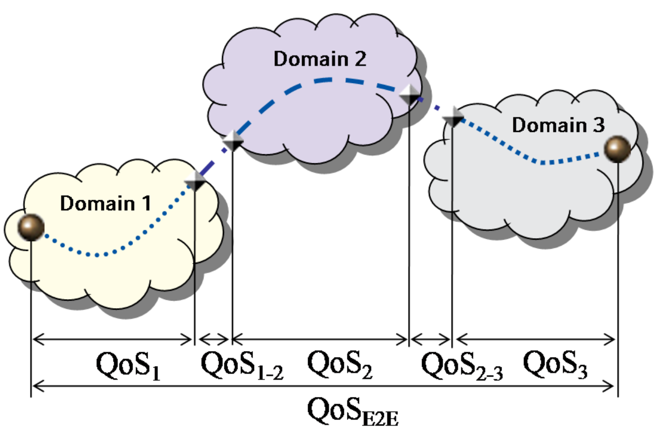

Figure 1 Composition of E2E connection quality

The **service composition** influences how the overall quality of an E2E connection is derived from the quality of each of the involved service parts. In this regard, especially the often-neglected fact has to be recalled that the overall E2E quality is not solely influenced by the quality of connection parts provided within a single administrative SP *domain*, but also by the quality of – typically very short, but highly relevant – connections between those domains (see Figure 1). The consideration of domain inter-connecting parts remains a big challenge since – caused by the organizational boundaries – each SP domain generally knows and manages only its own network equipment and the services implemented upon.

Before we analyze the aspects of the organizational relationships and domain boundaries in more detail, we discuss one more challenge caused by the service composition. The functions – referred to as *aggregation functions* – which are used to derive the E2E quality from the quality of involved connection parts, might differ between the various connection properties. For instance, for bandwidth it is the *min*-function, for delay it is *add*, and for more complex parameters like the common maintenance window it is an *intersection* of time ranges. Consequently, a generic approach to associate the aggregation functions to the corresponding QoS parameters must be defined.

Finally, the **administrative boundaries** of SP domains relate to very restrictive information and management policies. For the definition of an information model used across SP domains these constraints are especially important. Generally, information like the domain-internal network topology, the used technology and equipment, available capacity as well as utilization are considered as highly sensitive by most SPs. This means in turn, that the information model has to abstract from this sensitive information. However, at the same time it must still contain enough information to allow for the efficient computation of a path satisfying all required connection proper-ties.

IV. Information Model: Single-Domain View

After thorough discussion in the research community, it is now common understanding to design the network description for inter-domain routing in the granularity of the SP domain abstraction level. The reasons lay predominantly in the very restrictive SP information policies as outlined above. Our model supports this established point of view.

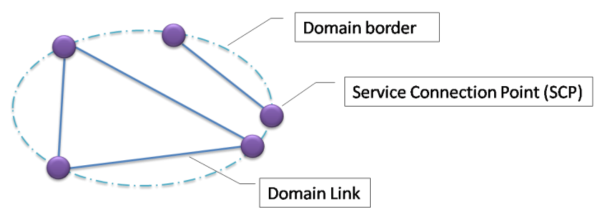

Figure 2 Abstract network topology of a single domain

In our model, so-called *Domain Links* are connections within a single domain. Domain Links end at the SP do-main boundary by definition (see Figure 2). Because from a SP perspective all Domain Links are services, their end-points are referred to as *Service Connection Points* (SCPs). At the abstraction level of the network infrastructure, each SCP corresponds to one or more UNI/NNI[1] interfaces.

For SP networks it is very common to have multiple resilient paths between edge routers (see Figure 3). This is often done for the sake of improved network robustness and load balancing. These alternative paths can have different characteristics. Consequently, our information model supports the description of multiple alternative properties associated with the same Domain Link.

[1] User-Network Interface (UNI) and Network-Network Interface (NNI) are used to refer interfaces interconnecting SP with users or with neighboring SPs correspondingly.

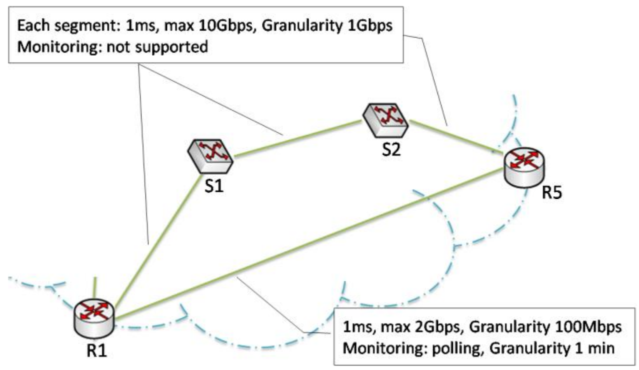

Figure 3 Alternative routes with different properties

In order to tackle this issue, we re-use the two-level approach specified in the ITU-T recommendation G.805 for description of optical transport networks [16]. We chose this description model because it foresees the association of multiple alternative properties to the same connection. In a graphical network representation specified in the mentioned ITU-T recommendation the multiple technical connection properties can be associated with a single connection. In the recommendation these are only technical parameters that are needed to interconnect the segments, like e.g. multiplexing of different channels. We propose to apply a similar representation to describe alternative service properties realized on top of networks. In the two-level specification of a connection, the principal connection possibility between two SCPs is specified as a *Compound Link* (see Figure 4).

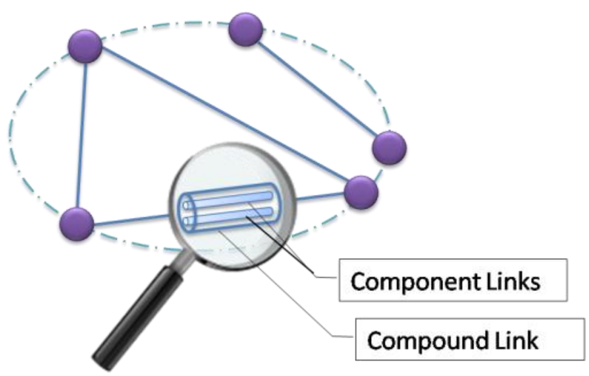

Figure 4 Two-level connection specification

No connection properties are associated with Compound Link; instead, every Compound Link should contain one or more *Component Links*. For any eligible connections, the appropriate QoS parameters and their values as well as the supported management functionality and its respective parameters are always associated with these Component Links.

V. Information Model: Inter-Domain View

Interconnections between neighboring SP domains are referred to in our model as *InterDomain Links*. Apart from several aspects and realization techniques, like e.g. *patch panels*, the description of InterDomain Link properties can be performed in a fashion similar to the Domain Links (see Figure 5).

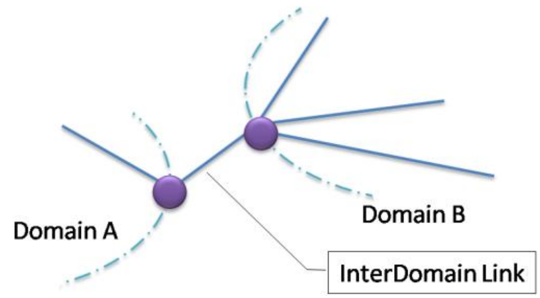

Figure 5 Abstract network topology of SP connections

However, besides such minor technical differences there are also organizational issues with have much greater impact. Whereas the entire network infrastructure of a Domain Link is controlled and managed by a single service provider, the interconnected SPs usually only have a view at their own portion of the InterDomain Link. Thus we are forced to assume that each single SP is unable to compute all possible properties of an InterDomain Link alone. To give a simple example, it is possible that an InterDomain Link is realized as an optical connection over multiple glass fibers and that several receivers on both sides of the connection are damaged. Especially if only ISO/OSI layer 1 monitoring is possible, each SP will be able to recognize merely its own erroneous connections and exclude only those from the calculation of available connections and properties.

In order to resolve this situation, we propose a two-level information exchange for InterDomain Links:

1) The neighboring domains have to exchange information about existing physical connections. In this case each physical connection will be described as a separate Component Link with its physically realizable properties. In order to match the *Partial Views* of involved SPs at the same InterDomain Link, we propose to associate an ID with each Component Link. The uniqueness of those IDs needs to be guaranteed only between the two involved domains. Based on the IDs of Component Links, the aggregated view at the InterDomain Link can be derived (see Figure 6).
2) Based on the infrastructure related view, a consolidated description can be calculated. This information can be shared e.g. with an information broker without breaking the security and privacy concerns mentioned above.

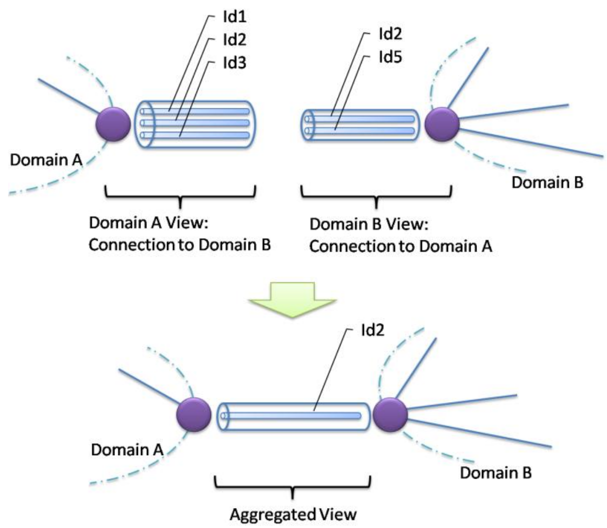

Figure 6 Derive InterDomain Link aggregated view

VI. Information Model: Multi-Domain View

The *min* function is an obvious example for a trivial aggregation function, it could be applied, e.g. for band-width. Also all qualitative QoS parameters have a trivial aggregation function, e.g. the Boolean AND operation. In the case of trivial aggregation functions, obviously no E2E information is required to derive possible E2E properties. However, in the case of non-trivial aggregation functions, direct or indirect (via e.g. sub-total value) in-formation about properties of all available considered segments is required. Thus, our information model also has to support non-trivial aggregation function

For the link path planning purpose we propose to use a Multi-Domain view at the available connections which is composed of information from multiple SP domains. In order to construct such a view, we propose to first gather the local views from the relevant SP domains. SP views at the Domain and InterDomain Links – as they were de-scribed in sections 4 and 5 – can be correlated based on the globally unique IDs of SCPs (see Figure 7).

For the more general case of large open provider cooperation we propose to use URIs as the globally unique SCP-IDs. The globally unique domain part of URIs might be also used to distinguish between the SPs owning the SCP. At the same time URIs allow SPs flexible extensions and changes in the organization of their own network infrastructure and/or its representation. Especially in the case of tight provider cooperations, simply structured IDs can be used, e.g. composed of only two parts: Domain- and Local-IDs.

Based on the derived multi-domain view of the service parts available in different SPs, a routing algorithm can be used to find the path fulfilling the E2E user requirements.

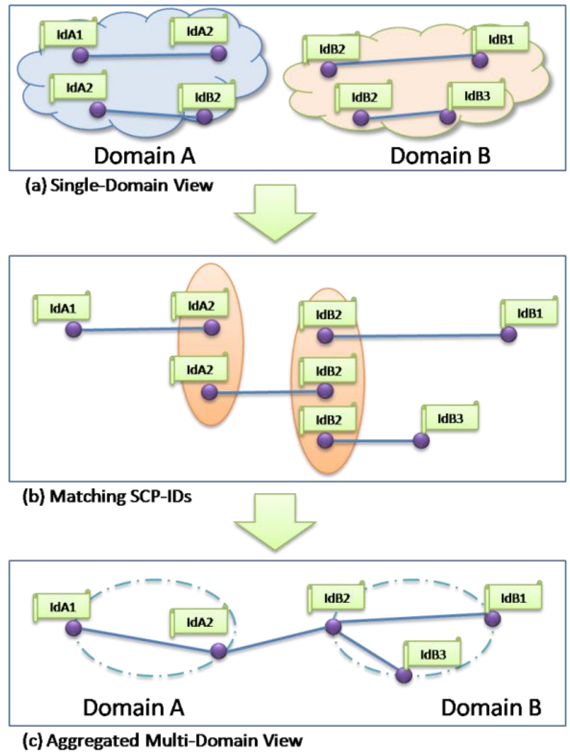

Figure 7 Deriving Multi-Domain view from SP views

VII. Connection properties, their description, and their distinction

In our model, as *connection properties* we define sup-ported QoS parameters and available management functionality. As stated in the first section, our goal is to sup-port E2E connections crossing multiple administrative domains with guaranteed and customer-specific combinations of QoS parameters and management functionality. This means that in order to derive an acceptable multi-domain path, only customer-specific combinations of required properties have to be provided for available Domain and InterDomain Links.

We propose to model *Properties* as an aggregation of the relevant qualitative and quantitative QoS parameters as well as of management functionality. Every supported property has to be identified via an associated globally unique ID. For the assignment of IDs to different proper-ties we suggest to use a registration tree. Using registration trees has several advantages, including a) the guarantee of unique semantics in multiple domains, b) guaranteeing for an easy extension to support further necessary QoS parameters and management functionality later on, and c) the possibility to assign functions to operate on properties. Especially this last aspect is very important in order to achieve a similarly fashioned property treatment. Further, whereas it is sufficient to specify which qualitative QoS parameters are supported, for quantitative QoS parameters it is essential to also provide the values it can assume.

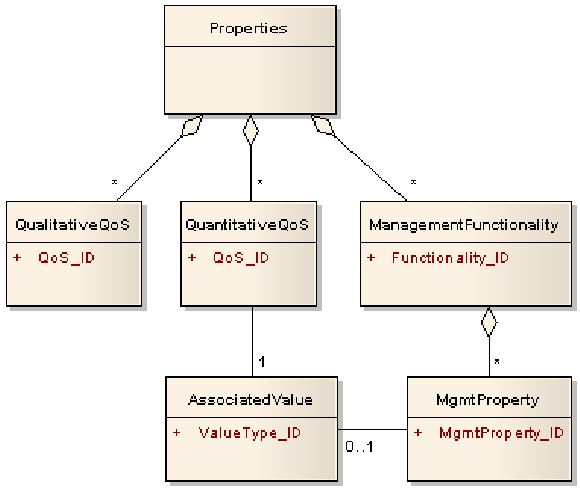

Figure 8 Modeling Connection Properties

The UML diagram modeling connection properties accordingly mentioned concepts is depicted in Figure 8. The relationship between parameters and values that parameters can take is specified as an association between the classes QUANTITATIVEQOS and ASSOCIATEDVALUE. Similarly, the supported management functionality has to be specified in more details through its properties. For instance, the management functionality "Monitoring" of a network infrastructure can be realized with the following properties: a) based on hardware generated "traps" or b) via periodically "polling" of the current hardware state. Only in the second case also the "polling interval" value has to be specified. This is reflected in the cardinality of the association between corresponding classes.

The ASSOCIATEDVALUE class depicted in Figure 8 only contains a single member variable – a globally unique ID to distinguish between different derived classes. In Figure 9 two derived classes are presented, which can be used to describe a single fixed value or a value range of a single property (in this case a QoS parameter or a management functionality property). Further derived classes can be considered, e.g. for the description of upper or lower bounds.

We argue for this methodology for the description of associated values based on the necessity to reduce the (vast) amount of graph edges (Compound and Component Links) that have to be considered during the routing calculation. Moreover, the usage of an ID to distinguish between derived classes will guarantee easy extensibility with further necessary derived classes. As the global uniqueness of VALUETYPE_ID has to be guaranteed between multiple domains, we again propose to use a registration tree as the basis for this ID.

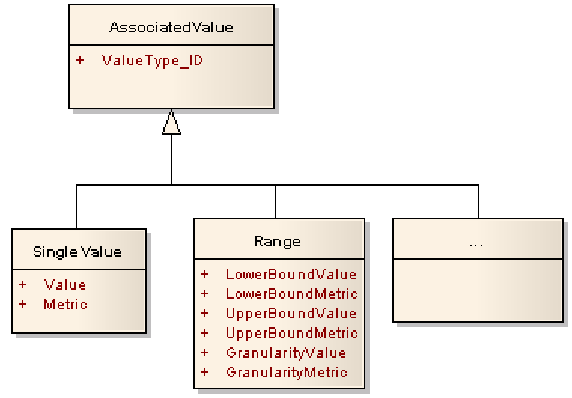

Figure 9 Derived Classes for Associated Values

VIII. PUTTING ALL TOGETHER IN A UML MODEL

As discussed in section 6, the Multi-Domain view on the existing possible connection can be only derived from Single-Domain views. Figure 10 presents a UML model designed for the representation of a Single-Domain view and reflecting all the previously discussed decisions.

The classes DOMAIN, SCP, COMPOUNDLINK and COMPONENTLINK correspond to objects and relations described in section 4. Additionally, each SP domain has a globally unique DOMAIN_ID. The member variable DSM_ADDR is used to store the communication address of a SP domain. In combination with the Domain-Domain association "Connected with", the DSM_ADDR can be used as an entry point for an inter-domain communication. This is only relevant if the provider cooperation is open and/or highly dynamic, and not all SPs have direct relationships or knowledge of each other.

In the class COMPONENTLINK, the member variable COMPONENTLINKTYPE_ID is used to distinguish between Domain and InterDomain Links. Furthermore, two types of information provisioning about InterDomain Links are supported – a single SP can provide information for the whole InterDomain Link or only its partial view at the connection. As discussed in section 5, we propose to use the partial views only for information exchange between neighboring SP domains. In all remaining cases we propose to use an aggregated view on the InterDomain Link.

The class COMPONENTLINKPART is only necessary for the description of partial views. The COMPONENTLINK_ID member variable of this class is used to find counterparts from neighboring SPs. Also only in this case the property of the whole InterDomain Link has to be calculated from properties specified for partial views.

For the specification of connection properties for Domain and InterDomain Links (in all its variations) the class LINKPROPERTIES is used. This class only slightly extends the model presented in the section 6. The member variable SERVICE_ID can be used to distinguish between various supported connection services, e.g. between ISO/OSI layer 2 and layer 3 connections. The second member variable UNCERTAINTYTYPE_ID can be used to reflect the probability that a connection with the specified properties can be established. Especially in the case when connection are manually planned, this field can reflect whether the required infrastructure is already in place or still should be bought, installed, and configured.

The class TIMEPERIOD is only needed if the planning of future connections should be supported. In this case a sort of "time fragmentation" is reflected through multiple time periods the component links with specified connections properties are available. In the case that no future planning is needed, the specification of time periods can be omitted.

In order to support Multi-Domain Management, the MULTIDOMAINMANAGEMENTFUNCTIONALITY class is specified and associated with the DOMAIN class. The purpose of Multi-Domain Management, e.g. E2E Monitoring, is the integration of Single-Domain connection management into the management of the whole E2E service instance. Furthermore, such a description allows SP domains to either specialize on or to omit the realization of diverse Multi-Domain management functionality. Such specialization and functionality sharing concepts have proven their practical relevance many times, e.g. in the DNS system.

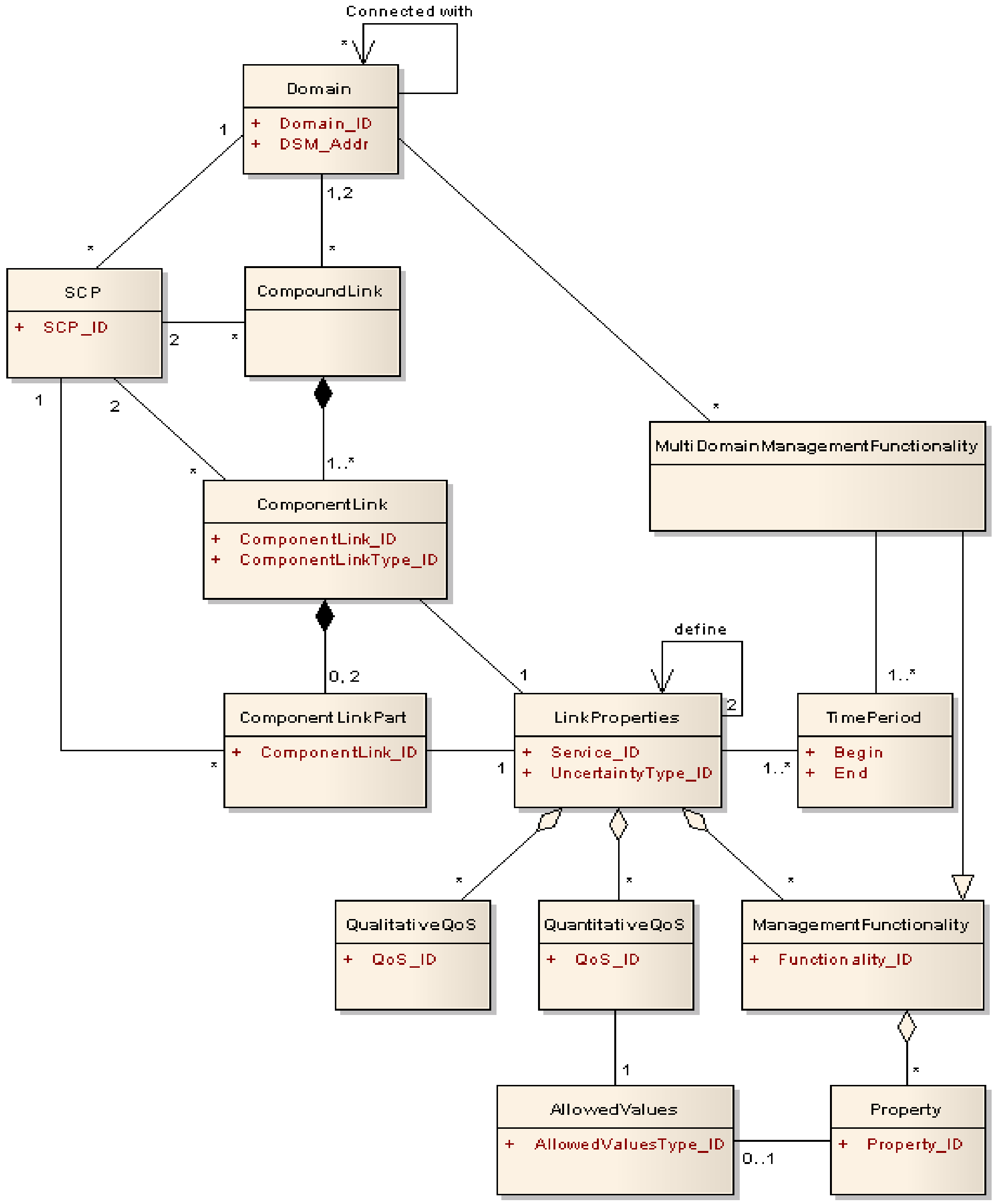

Figure 10 Available Connections and their Properties, Single-Domain View

IX. Outlook

In this paper we presented an information model for the provisioning of Concatenated Services. Based on this model, we will refine an inter-domain routing algorithm considering both end-to-end customer requirements and SP constraints. Furthermore, several suggestions for the general treatment of QoS related operations have been outlined; however, the solutions for some of these challenges still have to be found. We furthermore plan to investigate how the management processes for Concatenated Services can be established.

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