Generic object-oriented information models for reconfigurable communication subsystems in beyond 3G mobile systems

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Abstract. Global consensus on the beyond 3G mobile era sketches a heterogeneous system that combines different wireless access systems in a complementary manner and is vested with reconfiguration capabilities that enable the flexible and dynamic adaptation of the network infrastructure to meet the ever-changing service demands. For protocol stack reconfiguration to become commonplace, a language suitable for modeling, expressing and circulating metadata essential to reconfiguration, including reconfigurable device capabilities and semantic properties of reconfigurable protocol stacks, is necessary. We outline related standardization initiatives in the mobile domain, summarize existing work in reconfiguration architectures and identify key shortcomings that hinder the advent of ubiquitously reconfigurable systems. Further on, we outline the major limitations of existing standards for the representation of capability information pertaining to protocol stacks. To support reconfigurable communication systems, we identify essential metadata classes and introduce an associated object-oriented UML model. We elaborate on the design rationale of the UML model, presenting and discussing the alternative metadata representation standards and suitable encoding formats. Finally, we demonstrate the suitability of our UML model by using it to describe the standardized protocol stacks of 3G cellular network elements.

Problem statement

The wide disparity in the technical characteristics of network devices suggests that reconfigurable wireless systems will need a common set of mechanisms capable of identifying and triggering reconfiguration actions on the network infrastructure and/or the mobile devices. Fundamentally, this calls for *a common vocabulary for describing the architecture of a reconfigurable system*, discovering the feasible reconfiguration options and, finally, selecting the change to be applied upon it.

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Related work and motivation of research

SDR Forum has defined a Software Radio Architecture (SRA) for mobile devices based on a variant of the CORBA CCM specification. SRA defines OMG IDL interfaces for installing and using waveform (i.e., software radio) applications within a single device and a set of (CCM) XML profiles to describe the hardware/software components of an SDR system, their properties and their interconnections (i.e., metadata about its software architecture). These XML profiles concern (SDR) component packaging and deployment issues and are bound to a specific deployment setting. Therefore, they cannot express important deployment invariants (e.g., protocol inter-dependencies). Most importantly, XML lacks the semantics that ensure unambiguous descriptions, thus falling short of applications where preservation of semantic integrity is sine qua non. Such applications include the unanticipated on-the-field assembly of protocols in a protocol stack that satisfies the inter-dependencies of all its constituent protocols and can provably realize the services it is intended to.

CCM treats a component and all its possible implementations as a specific named collection of features described by an OMG IDL component definition or a corresponding entry in a CORBA Interface Repository, i.e., a CCM component is assumed to comply with some well-defined behavior. However, the CCM standard does not prescribe a particular association between a CCM component and a formal semantic descriptor of that behavior, nor does it define any mechanisms to establish such an association at development-time and/or at runtime. Without an unambiguous definition of component behavior semantics, independently developed component implementations may be semantically incompatible, thus undermining the interoperability of CCM applications such the dynamic assembly of protocol stacks implemented with SRA technology.

Based upon SRA but without its dependencies on CCM, the PIM/PSM specification developed by the OMG Software-Based Communication (SBC) group also overlooks the semantic aspects arising in multiple protocol stacks and communication standards. These semantics depend solely on the different valid ways that individual protocol layers can be combined in a protocol stack; unfortunately, the PIM/PSM proposal is based on the original SRA model and provides no such modeling instruments.

The (now joint) Parlay/OSA initiative has been a major step forward towards flexible mobile service provision but did not anticipate the case of reconfigurable systems; Parlay/OSA considers the network functionality as immutable and defines technologically agnostic (i.e., OMG IDL, W3C WSDL) interfaces for accessing it. Although their logical architecture does not preclude it, the case of communication systems capable of dynamically adapting their internal instrumentation (e.g., their protocol stack) and behavior whilst operational is beyond their current scope.

To summarize, the semantic aspects of reconfiguration, particularly in applications where independently developed protocol layers with various inter-dependencies must be assembled into a set of protocol stacks that is guaranteed to function as intended to, are generally overlooked by existing initiatives.

Current standards for equipment capabilities

3GPP standards

The 3GPP network management specifications define the Network Resource Model (NRM), a protocol-independent model describing information objects that represent 3GPP network resources (e.g., an RNC network element). A generic NRM defines information object classes and interfaces independent of any protocol solution set (e.g. CORBA/IDL, CMIP/GDMO) and network domain (e.g. UTRAN, GERAN), thus providing the largest subset of information object classes that are common to all NRM instances to be defined by 3GPP (e.g., Core Network NRM, UTRAN NRM). The generic NRM specifies logical interfaces for a network management agent to retrieve the attributes of a network element, to navigate any containment relations to information objects contained therein and to manage subscription to particular events of interest so as to receive future notifications concerning those events. The 3GPP UMTS NRM specification builds on the generic NRM and extends it with additional information object classes modeling the functional entities located in UMTS network elements (e.g., RNC function) along with their possible containment configuration (e.g., RNC functions contains zero or more Iub functions).

OMA standards

The Open Mobile Alliance (OMA) User Agent Profile (UAProf) specification is concerned with capturing classes of device capability and user preference information for the purpose of customizing content delivery. UAProf achieves interoperation to standards for Composite Capability / Preference Profile (CC/PP) distribution over the Internet by leveraging mechanisms standardized by W3C for capability description and negotiation, namely:

The Resource Description Framework (RDF) standard for the definition of the UAProf data (i.e., information) model.

The Resource Description Framework Schema (RDF Schema) specification for the definition of the User Agent Profile vocabulary.

The Composite Capability / Preference Profile (CC/PP) specification as a high-level structured framework for describing capability and preference information using RDF.

The capability and preference information is represented as collections of properties (i.e., attribute-value pairs) that are classified into one of several components, each of which represents a distinguished set of characteristics. The current UAProf specification includes (but is not limited to) the following components:

HardwarePlatform, describing the hardware characteristics of the device (e.g., device type, model number, display size, input and output capabilities, etc)

SoftwarePlatform, describing the application environment, operating system and installed software of the device (e.g., operating system vendor and version, MexE support, list of audio/video encoders, etc)

BrowserUA, describing the HTML browser application.

NetworkCharacteristics, dealing with network properties and settings (e.g., supported network bearers, etc).

WAPCharacteristics, pertaining to the WAP capabilities supported by the device (e.g., WML script libraries, WAP version, WML deck size, etc).

PushCharacteristics, dealing with the push capabilities supported by the device (e.g., supported MIME types, maximum size of push message sent to the device, etc)

Profile attributes may have composite and/or multiple values and the final value of each profile attribute is resolved according to the resolution semantics prescribed for that particular attribute in the UAProf specification. The latter is reused in the 3GPP Mobile Station Application Execution Environment (MExE) specification for 3G mobile terminals.

Limitations of existing standards

From a modeling viewpoint, the generic NRM specification supports arbitrary type attributes and containment hierarchies, and the granularity of the event detection and notification mechanism is adequate for basic object-level events (e.g., a change in the attribute value of an object). Unfortunately, the generic NRM is of little practical value in describing the reconfiguration capabilities of 3GPP UMTS network elements, as it lacks a precise definition for object classes and attribute types pertaining to reconfiguration in a 3GPP UMTS network context.

The UAProf schema was designed to express immutable device capability information in strata above the network layer, where a sufficient level of abstraction from underlying network technologies is the de facto working assumption. Network and/or link layer properties (e.g., multiple RAT capability) tend to be technology specific and thus, are either unsupported or insufficiently addressed by the current UAProf specification. Although it is possible to express capability information for reconfigurable protocol stacks in suitable UAProf extensions (i.e., UAProf components) that can be integrated in the current UAProf schema relatively easy, the applicability of these solutions is hampered by the flat component model of UAProf. In the current UAProf standard, nesting of components within components is not possible, practically ruling out the representation of inherently hierarchical structures, which are fundamental building blocks of software architectures and commonplace in reconfiguration applications (e.g., protocol graphs).

Design rationale in modeling reconfigurable protocol stacks

Stratification (i.e., layering), the basic structure mechanism for protocol stacks, renders each protocol layer impervious to the functionality within other protocol layers. The functionality embodied in a protocol layer offers a particular set of services to higher protocol layers and expects a particular set of services from protocol layers. Typically, the specification of some protocol’s functionality includes only the offered services and the associated Service Access Point (SAP) primitives to invoke them; semantic information and functional dependencies to the set of services expected from other protocol layers is considered well-known and omitted from the specification.

An important issue concerns the specification of a suitable (abstract) model for reconfigurable software architectures – particularly protocol stack architectures. The software architecture of a computing system refers to its structure, which comprises software components, their externally visible properties and the established relationships among them. The introduction of reconfigurable mobile systems will require a suitable object-oriented model to describe their internal software architecture and structure in an implementation agnostic way. Such a 'reconfiguration vocabulary' provides the unified view required to define the capabilities of reconfiguration systems and to develop reconfiguration algorithms independent of implementation technologies.

Functional requirements of protocol stack reconfiguration

To support out-of-the-box reconfiguration, a reconfigurable protocol stack must be based on a modular (i.e., component-based) architecture and support structural hierarchies of arbitrary depth through component composition. Furthermore, it must adhere to an information model for reconfiguration-related metadata that describes the reconfigurable (software) architecture, its constituent components and their properties (e.g., usage semantics and component inter-dependencies) using what effectively constitutes a *reconfiguration ontology.* Hence, a reconfigurable protocol stack must be adaptable at two levels:

The base level that includes the software implementations of protocol functionality.
The meta-level comprising the (abstract) specifications of protocol functionality.
Thereupon, we propose that reconfigurable protocol stacks are built upon abstractions of (protocol) behavior specifications and implementations of those specifications.

Reference points for protocol stack reconfiguration

Reconfiguration of communication personalities and protocol stacks entails a certain degree of exchange functionality manifesting at a certain reference point. When reconfiguration is about switching between different implementations of the same protocol, the exchange reference point is virtual in the sense that it exists between an abstract specification of the respective protocol's functionality and all of its available implementations – as opposed to being an actual reference point in the protocol stack architecture. When reconfiguration entails changes to the stratification of protocol instances in a communication device, then the exchange reference point lies in the reconfigurable protocol stack realm, specifically at the boundaries of adjacent protocol instances (Fig 1).

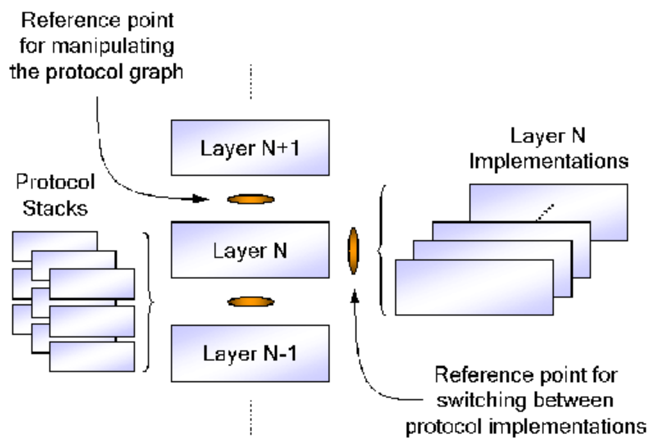

Fig 1. Essential reference points in protocol stack reconfiguration.

Metadata support for compositional definitions

Observing that different standards may reference common protocols but stratify them in different ways, we realize that the analysis granularity must support modeling of (protocol stack) standards independently of modeling of (protocol) specifications – and vice versa. To support discovery and resolution of protocol interdependencies, we postulate that protocol definitions include navigable associations to the services provided and required by each individual protocol, where each service is defined by an unambiguously identified (possibly formal) descriptor.

An object-oriented model for reconfiguration metadata

Metadata classes

`Product`, the root abstract class in our model, specifies an 'exchangeable' item that is identified through a textually represented name (e.g., by querying a name registry service). To align our model to the W3C Semantic Web work and its Resource Description Framework (RDF) that considers anything that can be identified via a URI as a resource, we include a (URI-convertible) URL attribute that provides a unique identifier of each individual `Product` instance as a Semantic Web resource.

`Service` is a subclass of `Product` that refers to some precisely defined functionality and has a textual description property. A `Service` instance provides an unambiguous placeholder for a service definition accompanied by a textual descriptor that might be associated with arbitrary formal semantics, provided those semantics have a textual representation (e.g., OMG IDL, ITU SDL). It is not particularly important that a unique formal format is employed for the service descriptor, since adaptation mechanisms may be used to identify the appropriate handler for each available format (e.g., for syntax validation purposes). However, it is paramount that the service descriptor identifies the service *unambiguously* – an issue that is further developed in the subsection entitled "Metadata encoding".

`Specification` is a subclass of `Product` with additional (textual) attributes (author, version, release, description and summary) that represents behavioral and/or functional specifications (e.g., the specification of a session protocol). It is meant to provide a first-class abstraction for standards developed and published by authoritative bodies[2], like the UMTS standards developed by 3GPP (e.g., the GPRS Tunneling Protocol (GTP) specification). Currently, such specifications are recorded in various human-readable formats (e.g., the IETF Request for Comments (RFC) text format). The lack of a common machine-interpretable format for specifications published by different standardization bodies rules out the possibility of having those specifications parsed and interpreted by a computational agent (e.g., one in control of a reconfigurable protocol stack). `Standard` is a subclass of `specification` that provides a generic container for related specification instances, to facilitate modeling of specifications that reference other specifications, possibly published by a different authoritative body (to the one publishing the standard). For example, the 3GPP UMTS IP Multimedia Subsystem (IMS) is a standard that leverages specifications developed and published by a different authoritative body (i.e., the IETF SIP specification). We stress that, through the `Specification` and `Standard` classes, inheritance-based and composition-based modeling of communication standards is possible, thus allowing significant modeling flexibility. `Implementation` is a subclass of `Product` that refers to a software artifact that may realize multiple specifications. It is meant to model the real-life software implementation of a specification's associated functionality but may also represent functionality that is not associated to a particular specification (e.g., utility functionality). Given that an implementation may be developed in different programming languages and supporting technologies (e.g., C, C++,.NET) and packaged in various deployment formats, the `DeploymentArtifact` class and its sublcasses are used to model the different deployment artifacts (

Fig 2) an implementation may have.

`Binding` is an association class that provides a first-class abstraction for an association between a `Service` instance and a `Specification` instance. Its design purpose is to model a particular stratification of `Specification` instances in the context of a `Standard` instance. To facilitate the reuse of `Binding` instances, a `Binding` instance may be referenced by multiple `Standard` instances. During processing of a `Standard` instance, a computational agent may discover the referenced `Binding` instances

[2] The term authoritative bodies is not restricted to public bodies vested with specification development authority but includes all legal entities (e.g., private enterprises, physical persons) with a legitimate right to develop and publish the specification for a product or service.

by navigating the `binding` association(s) of the particular `Standard`. The purpose and use of the `Binding` class is demonstrated in subsequenet sections.

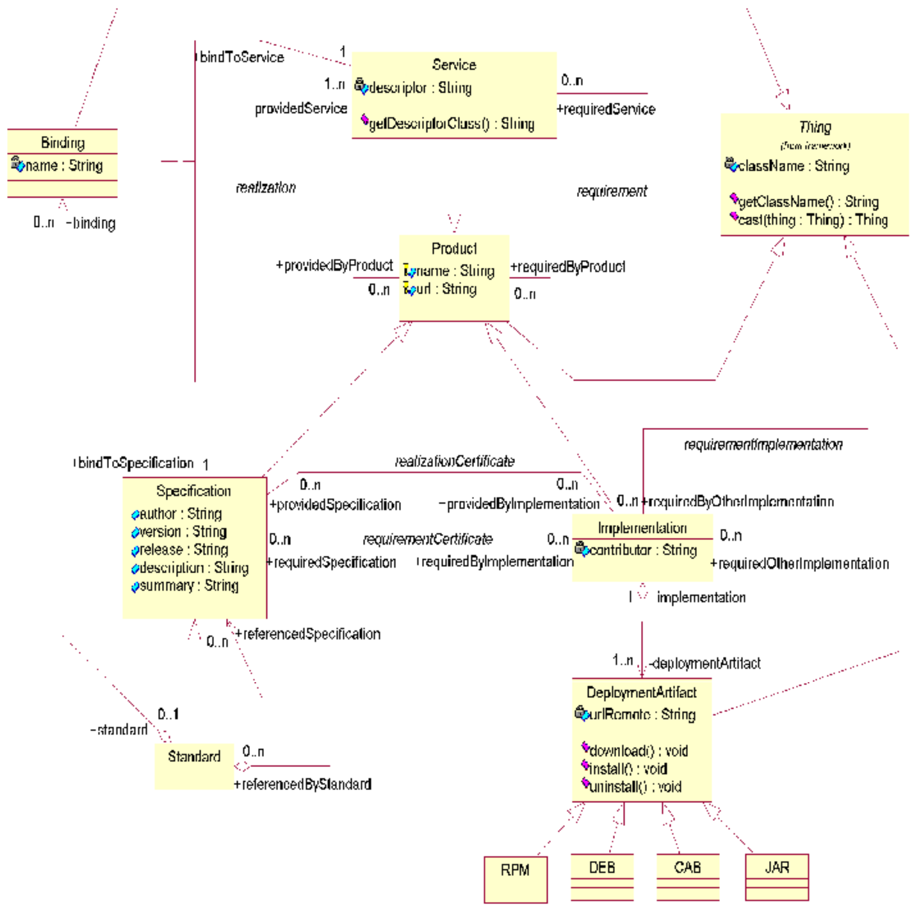

Fig 2. The object-oriented UML model for reconfiguration metadata.

Metadata associations

A `Specification` instance may depend on multiple services much as it may render multiple services. Similarly, a particular implementation, in addition to the set of services that its associated specifications collectively require and realize, may depend on additional services to function properly and may realize additional services. Because they apply to specifications and implementations alike, these concerns are expressed through a pair of associations between the `Product` and `Service` classes named `requirement` and `realization`, respectively. This degree of modeling flexibility with regard to required and realized services facilitates arbitrary implementations (e.g., from third parties) that do, however, comply to a specification. Finally, the `requirementImplementation` association can be used to model an implementation depending on other implementations to function properly.

It is not mandatory that an `Implementation` instance be associated a `Specification` instance; it might as well be an implementation of utility functionality not subject to standardization yet required by other implementations. Thus, the case of an `Implementation` unassociated to a `Specification` instance is considered valid. Typically, the association between a `Specification` instance and an `Implementation` instance is handled through the `realizationCertificate`, `requirementCertificate` (multilateral) associations. The former signifies that the `Implementation` instance realizes the behavior of a set of `Specifications` and the latter marks its dependence upon a set of `Specification` instances.

Metadata encoding

Considering that reconfiguration metadata will be subject to processing and exchange in different administrative domains, it should be represented in an instrumentation-independent format that promotes interoperability. Two W3C standards, XML and RDF are considered as prime candidates for this task. XML is easier to use and manipulate, but RDF has a far greater capacity for expressing semantically rich information. Most importantly, only RDF is capable of unambiguous representation, as the RDF Model Theory on which it is based defines an explicit unique interpretation of any RDF data Consequently, a particular piece of information can be represented in RDF in exactly one unique way, while in XML many different representations with the same underlying meaning are possible. This advantage of RDF comes at the cost of being more verbose and significantly more complex, making it less attractive for the vast majority of users and developers.

In our approach, all reconfiguration metadata are represented in RDF, while the vocabulary used in the RDF representation is a combination of the standard RDF vocabulary and an extension vocabulary defined in an RDF Schema document, all using XML as the serialization format. The extension vocabulary is named RCM and is derived from an isomorphic mapping of the introduced UML model to an RDF Schema document. Reconfiguration metadata are expressed in the RCM vocabulary that integrates seamlessly to the standard RDF vocabulary through the RDF namespace mechanism. The primary reason for choosing RDF is its ability for unambiguous representations. Furthermore, RDF models can be serialized in XML, an interoperable, machine-interpretable textual format that is easily circulated across different administrative domains.

Support for reconfiguration option discovery

The process by which an intelligent agent discovers the possible combinations of known communication personalities and associated protocol implementations that render an integral and usable system is termed reconfiguration option discovery. Thanks to the graph model theory foundation of RDF, one can query an RDF graph of reconfiguration metadata for entries with particular properties and get unambiguous results. W3C has developed the SPARQL query language that establishes the definitive grammar for querying an RDF graph for statements matching a given pattern. Through formulation and submission of appropriate SPARQL queries, an intelligent agent can navigate a knowledge base (i.e., a RDF graph) of reconfiguration metadata and thus support reconfiguration option discovery. Regarding protocol stack reconfiguration, the application of SPARQL facilitates the discovery of the set of services required at a particular protocol strata as well as the set of specifications and/or implementations providing those services. The use of RDF and SPARQL greatly simplifies the consistency checking of reconfigurations, thus preserving the protocol stack's semantic integrity across reconfigurations.

Application scenarios: 3G network elements and protocol stacks

Application of the reconfiguration metadata model in 2G/3G protocol stacks

In this section we use the introduced reconfiguration ontology to model the protocol stratifications in the user plane of the packet switched domain of the GPRS and UMTS access networks (Fig 3). The (tentative) list of services in Table 1 servers mostly illustration purposes; alternative identification and naming of service entities (e.g., in further detail) is possible. Fig 4 provides a simplified form of the RDF graph for the reconfiguration metadata pertaining to the Fig 3 protocol stacks.

Table 1. Analysis of 2G/3G user plane protocol stacks and identification of Service classes.

Providing Specifications	Service	Requiring Specifications
RF	"Layer_1"	MAC, FR
AAL5, FR	"Layer_2"	IP, BSSGP
BSSGP	"Layer_2_BSSGP"	LLC
LLC	"Layer_2_LLC"	SNDCP
MAC	"Layer_2_MAC"	RLC
RLC	"Layer_2_RLC"	PDCP, LLC
IP	"Layer_3"	UDP
UDP	"Layer_4"	GTP

IP	"Layer_Tunneling"	IP, GTP
PDCP, SNDCP	"Layer_Convergence"	IP

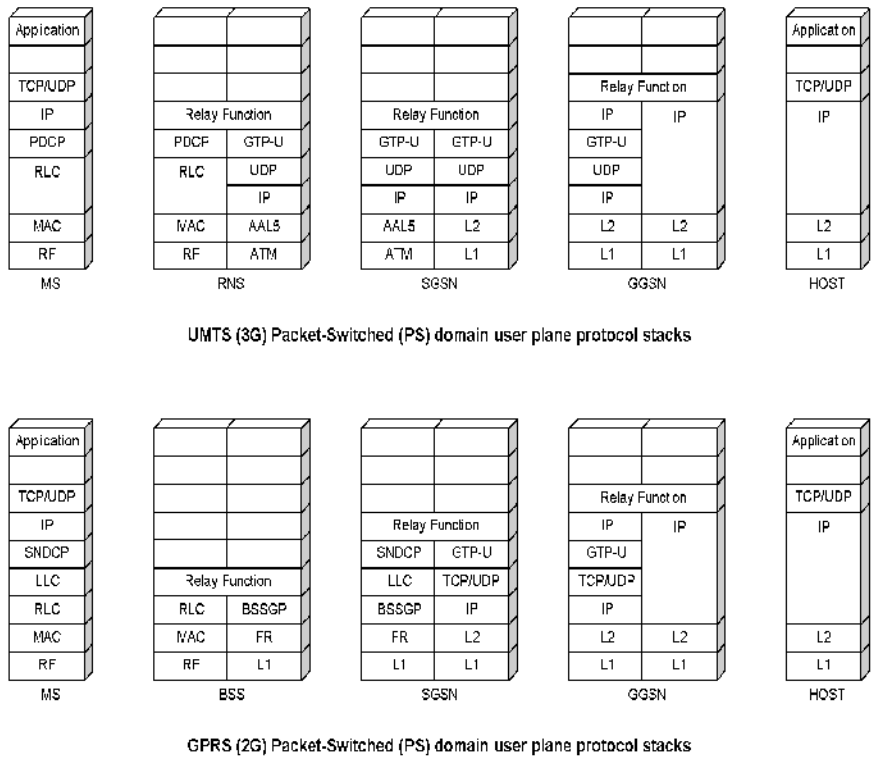

Fig 3. User plane protocol stacks for the 3GPP GPRS and UMTS cellular access standards.

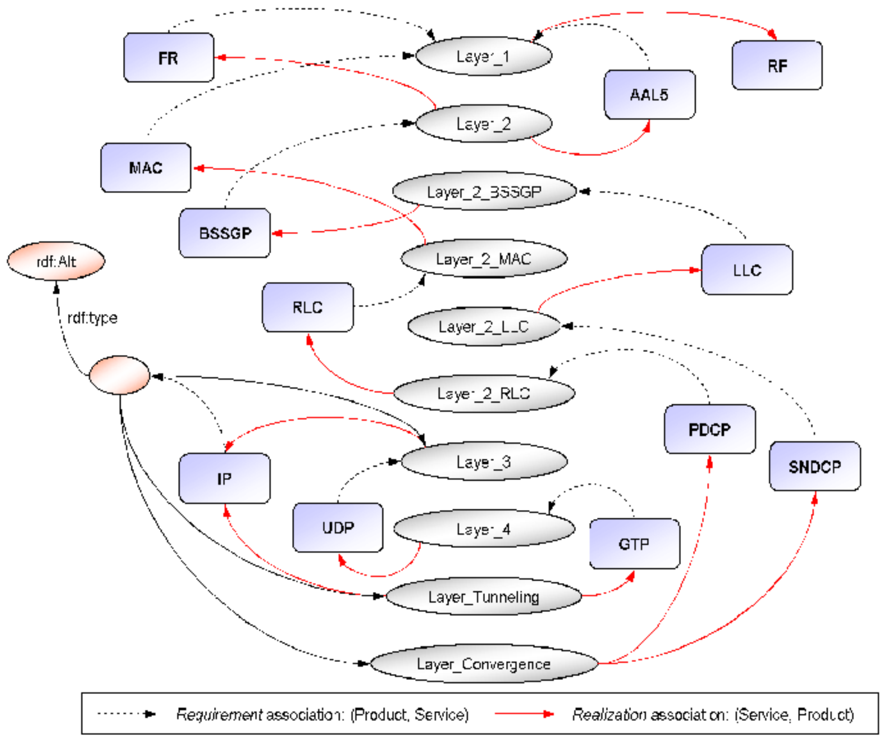

Fig 4. Simplified RDF graph for reconfiguration metadata pertaining to 2G/3G protocol stacks.

A communication standard may include several protocol stacks each with a specific stratification of protocol instances. Different communication personalities may employ some protocol instances in common but stratify them in radically different ways, thus requiring additional metadata classes and/or associations to capture and express the stratification differentia among them. For example, let's consider the user plane protocol stack of the Serving GPRS Support Node (SGSN) and Radio Network Controller (RNC) network elements in the 3GPP UMTS cellular network. The SGSN and RNC exhibit significant similarities in their protocol stacks, referencing the same protocols (e.g., GTP, UDP, IP, etc) but stratifying them differently, depending on the particular interface (Iu-PS, Gn, Iub, Iur, etc) the protocol stack concerns. While reconfiguration option discovery based on requirement and realization associations supports the identification of all valid alternative stratifications, it cannot contribute to the decision regarding which particular alternative to employ in a given situation. To support switching between entire communication personalities and their associated protocol stacks, it is required to explicitly model the differences in the involved protocol stratifications (if any) and record them in the reconfiguration metadata knowledge base.

The `Binding` class in our metadata model undertakes this role, by modeling a specific association between a `Service` instance and a `Specification` instance. Each `Binding` instance associates a `Service` to a `Specification` and applies in the context of all `Standard` instances referencing it. The primary purpose of the `Binding` class is to restrict the applicable `Specification` instance for a `Service` instance, effectively guiding reconfiguration option discovery through a specific edge in the RDF graph of the reconfiguration metadata. During processing of a `Standard` instance, an intelligent agent may discover the `Binding` instances contained therein in order to narrow the set of valid `Specification` instances for a specific `Service` and to select the appropriate `Specification` instance among multiple alternatives.

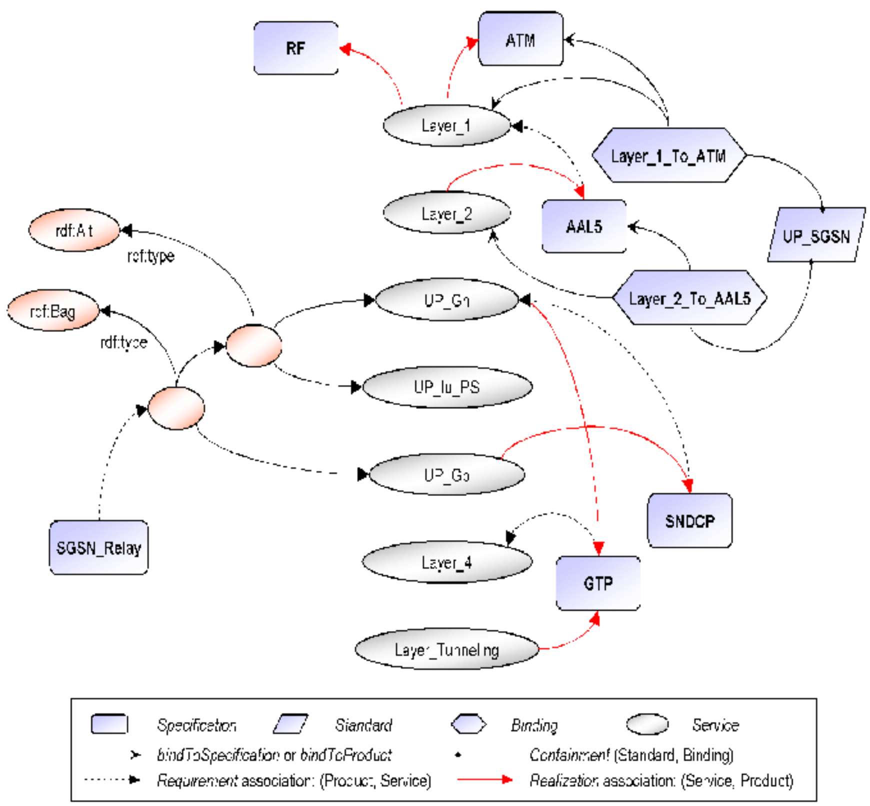

Fig 5. Simplified RDF graph for reconfiguration metadata pertaining 2G/3G SGSN network element.

Modeling and representation of the SGSN UMTS network element

We now illustrate modeling of the user plane protocol stacks and their associated dependencies for the SGSN network element for its Iu-PS, Gb and Gn interfaces, as follows:

Each of the standardized SGSN user plane interfaces (i.e., "Iu_PS", "Gb" and "Gn"), is modeled as a `Service` instance (prefixed by "UP"). The protocol specifications providing each `Service` instance are indicated through `providedByProduct` associations.

The SGSN network exposes different logical interfaces and their associated protocol stacks to different network elements (e.g., HLR, RNC, GGSN). The SGSN user plane relay functionality is modeled as a Specification instance named "SGSN_Relay" that depends on the "Gn" service and either one of the "Iu_PS" and "Gb" services. This realistically models the packet switched domain user plane architecture of a SGSN network element that interfaces to a GGSN network element over the Gn logical interface and may also interface to an RNC network element over the Iu-PS interface and/or a BSC network element over the Gb interface.

The collection of user plane protocol stacks of the SGSN network element are modeled as a `Standard` instance named "SGSN" that contains at least one "SGSN_Relay" Specification instances. This caters for SGSN network elements with multiple simultaneous interfaces to both RNC and BSC network elements (i.e., a 2G/3G SGSN).

A protocol stratification that is specific to the SGSN network element is modeled as a distinct `Binding` instance between a `Service` instance and a particular `Specification` instance. In the SGSN case, the stratification of the IP protocol over the AAL5 protocol in the Iu-PS interface is modeled as a `Binding` between the "Layer_2" Service and the "IP" `Specification`. In a similar manner, the stratification of the AAL5 protocol over the ATM protocol in the Iu_PS interface is also modeled as a `Binding` between the "Layer_1" Service instance and the "ATM" `Specification` instance.

According to the above formulation, each "SGSN_Relay" instance will be dependent upon either of the ("Gb", "Gn") and ("UP_Iu_PS", "Gn") Service pairs. By modeling the SGSN as a Standard instance that contains "SGSN_Relay" Specification instances, it is possible to support both the Gb and Iu-PS interfaces by multiple "SGSN_Relay" instances. Fig 5 shows the RDF graph for the SGSN protocol stack in a simplified form.

Reconfiguration option discovery must be generic so as to support inter-standard and intra-standard reconfigurations with minimal runtime adjustments. Our model effectively supports that capability through the `Standard` and `Binding` classes. If `Binding` instances contained in a `Standard` instance are treated as invariants to be preserved during reconfiguration, then reconfiguration is classified as an intra-standard reconfiguration, i.e., a reconfiguration affecting only those parts of the protocol stack that the respective standard allows. If, however, `Binding` instances are ignored by reconfiguration option discovery, then reconfiguration is an inter-standard reconfiguration, i.e., a reconfiguration that may radically modify the current communication standard, possibly resulting in a different communication personality, perhaps even one not described by a `Standard` instance.

Conclusions and directions for future work

Consensus on the vision of mobile systems beyond 3G mandates system support for the reconfiguration of individual protocol layers, entire protocol stacks and communication personalities (e.g., cellular, ad-hoc) through common procedures. That poses major challenges in all aspects of reconfiguration research, from designing an expressively sufficient model for reconfiguration metadata to engineering the functionality that supports reconfiguration of protocol stacks within operating network equipment. The work presented herein identified the essential classes and associations to support the envisaged reconfiguration capability for protocol stacks, regardless of what its supporting functional architecture is. The basic merit of our information model is its support for unambiguously specifying the associations that may occur between the services realized throughout an arbitrary stratification of protocols and the specifications and/or implementations (of protocols) requiring and/or providing those services, however complex those associations may be. This includes associations with requirement and realization semantics that are essential to the preservation of the protocol stack's integrity across reconfigurations. Not being tied to a specific reconfiguration architecture (e.g., SRA), the introduced reconfiguration ontology may also serve as a common language to describe reconfigurable protocol stacks in a uniform way that promotes the interoperability of the different architectures supporting reconfiguration. In this respect, the contribution of the present thesis is twofold: At a research level, it identifies the pivotal aspects of reconfiguration, enumerates and classifies its manifestations, and, points out the relation to software architecture research. At a technical level, it provides a minimal yet expressive object-oriented UML model for reconfiguration metadata that can be employed to describe the capabilities of reconfigurable protocol stacks for beyond 3G systems. The higher complexity associated with the choice of RDF as our model's realization technology is the price to pay for semantic univocality – although collateral benefits, such as seamless plug-in to the Semantic Web infrastructure and setting the foundation of a reconfiguration knowledge base to support the development of self-aware, cognitive adaptive systems, probably offset the cost in the long run.

References

1. V. Gazis, N. Alonistioti, and L. Merakos, "A generic model for reconfigurable protocol stacks in beyond 3G", IEEE Wireless Communication Magazine, vol. 13, no. 3, 2006.

2. V. Gazis, N. Alonistioti, and L. Merakos, "Metadata design for reconfigurable protocol stacks in beyond 3G”, Kluwer Wireless Personal Communications Magazine, vol. 36, no. 1, pp. 1–28, 2006.
3. V. Gazis, N. Alonistioti, and L. Merakos, "Toward a generic Always Best Connected capability in integrated UMTS/WLAN mobile networks (and beyond)", IEEE Wireless Communications Magazine, vol. 12, no. 3, 2005.
4. V. Gazis, N. Alonistioti, and L. Merakos, "A generic architecture for Always Best Connected UMTS/WLAN mobile networks”, International Journal of Wireless and Mobile Computing (IJWMC), δεκτό προς δημοσίευση.
5. V. Gazis, N. Alonistioti, N. Houssos, M. Koutsopoulou, S. Gessler, and J. Quittek, "Intelligent network provisioning for dynamically downloadable applications in beyond 3G mobile networks”, Kluwer Journal of Network and System Management (JNSM), vol. 14, no.2, pp. 221–241, 2006.
6. N. Houssos, K. Kafounis, V. Gazis, and N. Alonistioti, "Application-transparent adaptation in wireless systems beyond 3G”, International Journal of Management and Decision Making (IJMDM), vol. 6, no. 1, 2005.
7. N. Houssos, V. Gazis, and N. Alonistioti, "Enabling delivery of mobile services over heterogeneous converged infrastructures”, Kluwer Information System Frontiers Journal, vol. 6, no. 3, 2004.
8. D. Wisely, H. Aghvami, S. L. Gwyn, T. Zahariadis, J. Manner, V. Gazis, N. Houssos, and N. Alonistioti, "Transparent IP radio access”, IEEE Wireless Communication Magazine, vol. 10, no. 4, 2003.
9. S. Panagiotakis, M. Koutsopoulou, N. Houssos, V. Gazis, and N. Alonistioti, "An advanced service provision framework for reconfigurable mobile networks”, International Journal of Mobile Communications, vol. 1, no. 4, 2003.
10. Σε βιβλία:
11. N. Alonistioti, S. Panagiotakis, M. Koutsopoulou, V. Gazis, and N. Houssos, "Open APIs for Flexible Service Provision and Reconfiguration Management”, in Software Defined Radio: Architectures, Systems and Functions, M. Dillinger, K. Madani, and N. Alonistioti, Eds.: John Wiley & Sons, Ltd, 2003, pp. 165-189.
12. S. Panagiotakis and V. Gazis, "Adaptive Protocols”, in Software Defined Radio: Architectures, Systems and Functions, M. Dillinger, K. Madani, and N. Alonistioti, Eds.: John Wiley & Sons, Ltd, 2003, pp. 73-92.
13. Σε συνέδρια:
14. V. Gazis, N. Alonistioti, and L. Merakos, "Metadata design for introspection-capable reconfigurable systems", in Lecture Notes in Computer Science: NETWORKING 2004, Networking Technologies, Services, and Protocols; Performance of Computer and Communication Networks; Mobile and Wireless Communications, Vol. 3042. Springer, Athens, Greece (2004) 1318-1325.
15. N. Houssos, V. Gazis, M. Koutsopoulou, and N. Alonistioti, "Middleware platform support for the realization of advanced business models in beyond 3G environments”, in proceedings of the 8th International Workshop on Mobile Multimedia Communications, Munich, Germany, 2003.
16. N. Houssos, V. Gazis, and N. Alonistioti, "Application-transparent adaptation in wireless systems beyond 3G”, in proceedings of the 2nd International Conference on Mobile Business (M-Business) Vienna, Austria, 2003.
17. N. Houssos, F. Foukalas, V. Gazis, K. Kafounis, and N. Alonistioti, "Adaptability issues in reconfigurable environments”, in proceedings of 2nd ANWIRE workshop on reconfigurability, Mykonos, Greece, 2003.

18. V. Gazis, N. Houssos, M. Koutsopoulou, S. Pantazis, and N. Alonistioti, "Towards reconfigurable 4G mobile environments”, in proceedings of the 2nd ANWIRE workshop on reconfigurability, Mykonos, Greece, 2003.
19. V. Gazis, N. Houssos, N. Alonistioti, and L. Merakos, "Service provision and reconfiguration management in 4G mobile networks”, in proceedings of the IEEE 5th International Conference on Mobile Wireless Communication Networks (MWCN), Shangri-La Hotel, Singapore, 2003.
20. V. Gazis, N. Houssos, N. Alonistioti, and L. Merakos, "Generic system architecture for 4G mobile communications”, in proceedings of the IEEE 57th Semiannual Vehicular Technology Conference (VTC), Jeju, Korea, 2003.
21. V. Gazis, N. Houssos, and N. Alonistioti, "Reconfiguration management In 3G/4G mobile environments: Requirements, process and architecture”, in proceedings of the SDR Forum Technical Conference, Orlando, Florida, USA, 2003.
22. V. Gazis, N. Houssos, A. Alonistioti, and L. Merakos, "On the complexity of Always Best Connected in 4G mobile networks”, in IEEE 58th Semiannual Vehicular Technology Conference (VTC), Orlando, Florida, USA, 2003.
23. N. Houssos, V. Gazis, S. Panagiotakis, M. Koutsopoulou, and A. Alonistioti, "Advanced business models and flexible service provision for reconfigurable mobile systems”, in proceedings of the SDR Forum Technical Conference, San Diego, California, USA, 2002.
24. N. Houssos, V. Gazis, S. Panagiotakis, S. Gessler, A. Schuelke, and S. Quesnel, "Value-added service management in 3G networks”, in proceedings of the IEEE/IFIP 8th Network Operations and Management Symposium (NOMS), Florence, Italy, 2002.
25. N. Houssos, V. Gazis, and A. Alonistioti, "A flexible management architecture for the support of advanced business models in 3G mobile service provision”, in proceedings of the 1st International Conference on Mobile Business (M-Business), Athens, Greece, 2002.
26. V. Gazis, N. Houssos, N. Alonistioti, and L. Merakos, "Service provision evolution in mobile communication networks”, in proceedings of the EU-China Post Conference on Beyond 3G Beijing, China, 2002.
27. V. Gazis, N. Houssos, A. Alonistioti, and L. Merakos, "Evolving perspectives on 4th generation mobile communication systems”, in proceedings of the IEEE 13th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Lisbon, Portugal, 2002.
28. N. Alonistioti, N. Houssos, S. Panagiotakis, M. Koutsopoulou, and V. Gazis, "Intelligent architectures enabling flexible service provision and adaptability”, in proceedings of the Wireless Design Conference (WDC), London, UK, 2002.
29. S. Panagiotakis, V. Gazis, M. Koutsopoulou, N. Houssos, Z. Boufidis, and N. Alonistioti, "Roaming issues for service provisioning over 3rd Generation mobile networks”, in proceedings of the Advanced Technologies Applications and Market Strategies for 3G (ATAMS), Krakow, Poland, 2001.
30. K. Molnar, Z. Nagy, S. Panagiotakis, V. Gazis, N. Houssos, and M. Koutsopoulou, "Location features in the MOBIVAS project”, in proceedings of the Mobile Location Workshop (MLW), Espoo, Finland, 2001.
31. M. Koutsopoulou, V. Gazis, and A. Kaloxylos, "A novel billing scheme for UMTS networks”, in proceedings of the International Symposium on 3rd Generation Infrastructure and Services, Athens, Greece, 2001.
32. M. Koutsopoulou, C. Farmakis, and V. Gazis, "Subscription management and charging for value added services in UMTS networks”, in proceedings of the Vehicular Technology Conference (VTC), Rhodes, Greece, 2001.

33. M. Koutsopoulou, N. Alonistioti, V. Gazis, and A. Kaloxylos, "Adaptive charging accounting and billing system for the support of advanced business models for VAS provision in 3G systems", in proceedings of the IEEE 12th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), San Diego, California, USA, 2001.
34. N. Alonistioti, V. Gazis, M. Koutsopoulou, and S. Panagiotakis, "An Application platform for downloadable VAS provision to mobile users", in proceedings of the IST Mobile Communications Summit, Galway, Ireland, 2000.