Formal Ontologies Meet Industry, Verona, Italy, June 9-10, 2005.

Using Ontologies to Simplify Wireless Network Configuration

David Cleary[1]*
Boris Danev[1]
Diarmuid O' Donoghue[2]

David.Cleary@ericsson.com
Voice: +353 9064 31579
Fax: +353 9064 31304

[1]Applied Research Labs, Ericsson Ireland,
Ericsson Software Campus,
Athlone,
Co. Westmeath,
Ireland.

[2]Department. of Computer Science, NUI Maynooth, Ireland.
Maynooth, Co. Kildare, Ireland.

Abstract

Today's global telecommunication infrastructure is growing in complexity, making it more difficult to manage and operate effectively. In this paper we examine the problems of simplifying configuration tasks and thus reducing operating expenditure (OPEX) for wireless telecom operators. Our approach is to use ontologies to capture networking information as well as the domain and expert knowledge needed for network configuration tasks. After semantically enriching the representation of the radio access network model, we will show how complex configuration tasks that manipulate the existing network models can be simplified. Furthermore we show how task complexity can be reduced by the use of formal ontologies.

1 Introduction

Since the early formalization of network management [14] as a discipline, many derivations and simplifications of the ideas have been proposed [4] [13] [17] [21]. For the most part these approaches have differentiated themselves by suggesting the use of “improved” syntactical protocols and processing models. This is an adequate (though not ideal) approach for two key areas, fault management and performance management. However when we talk about configuration management or provisioning, this approach proves to be inadequate. Configuration management relies on a full understanding of the network topology and state, such that a specific task can be addressed. Today, we rely on human and expert knowledge to fill this gap and configure our networks. This inability to create value added configuration applications stems from the lack of agreement on or the definition of, formal semantics needed for configuration activities.

Abstractly, network management can be thought of as an observer function, normally referred to as a *management station,* which communicates with probes, normally referred to as *agents,* in a piece of networking equipment. Different approaches in the cardinality, data abstraction and hierarchical nature of relationships often results in different software implementations.

If we look at the problems that are related to knowledge sharing, reuse and reasoning about information, we can see analogies within configuration management. In the wider research community much work is ongoing in this fledgling field. There are specific fields, even in computer science, which have successfully developed like knowledge based systems. The complexity of such systems prevents them from being used in general, and the lack of standardization, modelling, and reasoning tools undermines their future development. With the Semantic web initiative [2] ontology development regained life and attracted attention from the fast growing web community.

An ontology is a hierarchy of organised concepts, relations among them (in addition to *is-a* or *part-of*) and axioms to formalize the definitions and relations. Ontology based models allow reasoning through formal semantics, which can be understood by machines. We believe that ontologies have the potential to solve challenging problems in configuration management such as creating richer managed-object models of networks, while allowing more automation in detection of bad configuration and reconfiguration situations. This facilitates the creation of better business contracts between network elements and management stations to achieve a particular task through operator workflows [5].

At present, model manipulation in network management is based on manipulating data from network elements to facilitate the following [14] taxonomy of management. Network management models are generally based on a set of object-oriented models that raise the abstraction from physical resources to a higher level of abstraction that can be used by software management applications. These applications control the model by creating, modifying and deleting objects. The Managed Object Model (MOM) can be expressed in UML Class Models, with containment and association relations between Managed Objects being used to capture the interoperability of Managed Objects.

In the rest of this paper we will introduce the problem domain of configuration management in third generation wireless networks. Then we will give a brief overview of today's standard approach. Finally, our use of formal ontologies using a case study of reconfiguring a 3G radio network is presented.

2 Problem Domain

In this section we describe the key components in the 3G network architecture, focusing on the WCDMA radio access network (RAN). As it can be seen from Figure 2, UMTS is comprised of a Core Network (CN), which communicates with the radio access network (UTRAN) via a 3GPP standardized interface Iu. UTRAN itself communicates with the user equipment (mobile phone, PDA, etc) via the Uu interface.

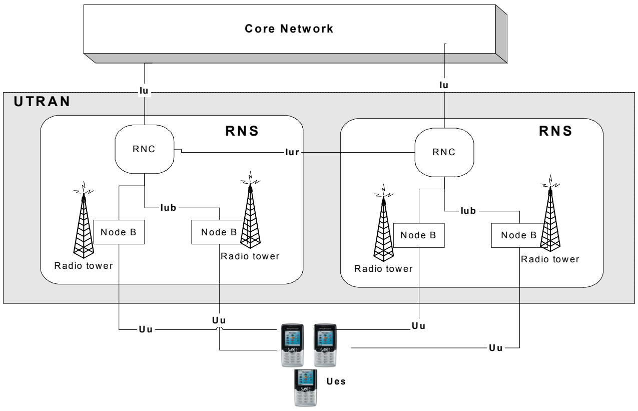

Fig 1: UMTS network architecture

CN is divided in circuit switched and packet switched domains. It covers all network devices responsible for switching of circuit-switched calls and routing packet data to external networks. For UMTS CN provides a platform for all communication services available to subscribers.

UTRAN (Universal Terrestrial RAN) is the UMTS radio access technology. It is composed of Radio Network Subsystems (RNS). The switching and controlling entity in the RNS is the Radio Network Controller (RNC). The RNCs control the allocation and the release of specific radio resources and are connected via the open interface Iur. Each RNC manages via the Iub standard interface a number of Node Bs. The Node B handles the radio communication with the user equipment (UE). UE can be any wireless device enabled to access the radio network, such as mobile phones, PDAs, etc. Consider the following operation on a typical network based on increase demand.

> *Given a metropolitan area with one radio network controller (RNC) and many radio base stations (RBS) in the North. The operator decides to expand the WCDMA network in the South. It starts putting new radio base stations in the South and parents them to the RNC in the North. During the expansion of the network, it becomes apparent that a new RNC will be needed in the South. The operator purchases a new RNC, installs it in the South and proceeds to move control (reparent) all RBSs located in the South to the newly installed RNC.*

The task involves two Radio Network Subsystems (RNS), one called source RNS and the other target RNS. Each RNS consists of an RNC (Radio Network Controller) and a number of Node Bs controlled by this RNC. The *reparenting* process consists of moving control of a Node B from the source RNS to the target RNS. This means creating control structures for the source Node B in the target RNS and deleting existing control structures in the source RNS without physically changing the location of the Node B.

Moving control from one RNS to another means building the standard protocol Iub, Mub and Aal2 links on the target RNC side. Each interface consists of a protocol stack. Reparenting Node B requires complex reconfiguration in three separate areas: ATM Transport Network, Radio Network and IP Network. This reconfiguration must be well planned and executed carefully following a big number of constraints represented in task workflows. Later in this paper, we will show how this reparenting task can be largely automated with the use of ontologies.

3 Current Management Models and Manipulation Techniques

From a configuration management perspective in the context of third generation radio systems, the information model that holds the information is accessible via a standardized CORBA interface [21] and not IETF's SNMP [23]. The Managed Object Model (MOM) is part of the management adaptation layer. The MOM is actually a UML model of the interface used by the network manager to manage a number of network elements. A central point in the MOM is the Managed Object (MO). The MO is an abstraction of some managed entity, such as a hardware resource, a mobile cell, or a communication channel. A manager controls an entity by creating, deleting, and modifying MOs that represent that entity. The main advantage of the MOM is that it follows the OO paradigm and thus is well structured and comprehensive. The management paradigm for all MOs is generic, irrespective of the entity that the MO represents. It is also possible to generate forms for all MOs by using the model information, making it possible to browse the model and to view and edit any MO.

Each network element has what is called a Managed Information Base (MIB). This is a container of MOs with concrete instances of Managed Objects, with relationships between them according to the rules in the MOM UML diagram. The Managed Object naming mechanisms consist of relative distinguished name (RDN), local distinguished name (LDN) and fully distinguished name (FDN). A MO's RDN is a name relative to a parent object, LDN is relative to the top object in local MIB and FDN is relative to the top object in particular domain. Managed Objects can be addressed with scope and filter parameters, which allow more than one MO to be addressed simultaneously. This is useful for performing searches of MOs with particular attributes or for performing operations on sets of MOs of certain types. MOs often have state, which is modelled in state attributes on the MOs in question.

3.1 Limitation of MOM in UML

Because of the informal semantics enforced in commercial UML modelling tools, expressing MOM structures in UML does not allow smart machine processing. When exploring the MOM in WCDMA, it can be seen that some knowledge is expressed in natural language. The list below gives two brief examples.

i) Specifying invariants on attributes in the MOM. E.g. *The Signaling ATM Adaptation Layer (SAAL) for use with ATM UNI specifies that congestion related attributes must be in a certain range.*

ii) Specifying constraints between attributes in the same MO. E.g. *SAAL for use with ATM UNI specifies that different congestion level attributes must follow a rule of type: 0<= congestionLevel1 <= congestionLevel2 <= 100.*

Extra constraints can be expressed in UML by using OCL (Object Constraint language) to annotate the model. OCL provides a syntax to specify invariants on classes and types, to describe guards and specify constraints on operations. This may lead to ambiguities, thus OCL relies on many primitives from the well-understood semantics of formal languages but the syntax is more human readable. Another issue with this approach is the runtime view or the mapping of the OCL constructs into instance objects.

As a result, consistency control needs to be performed separately from the model in many cases. This means that knowledge moves outside the model into another application. Interoperability of MOMs is difficult as they have proprietary aspects, thus it is problematic to exchange or integrate Managed Object information between vendors. Using UML and OCL limits us to modelling only the MOs that are common between vendors, thus it still does not let us represent vital semantic information.

4 A Ontological approach to Telecom Modelling

In this section we describe a new ontology-based modelling approach applicable to the wireless network configuration area. This approach tries not only to improve the current modelling, as expressed in the managed object models, but also strives to apply ontologies in modelling more complex configuration tasks that require domain and expert knowledge.

In order to achieve our modelling objectives, we designed an ontology centric management system for configuration applications. The overall architecture is depicted in Figure 2.

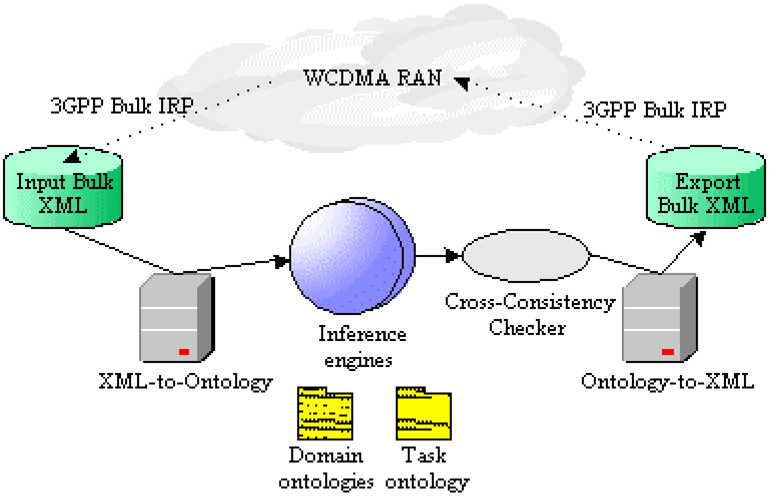

Fig 2: Ontology Centric Architecture

The architecture interacts with the current Network Management System and network resources via the 3GPP Bulk CM IRP standard [22]. The Bulk CM IRP provides an XML representation of configuration data for use by external network management applications. The Bulk XML configuration data is then used to build instances of the formal ontologies representing the domain and operational knowledge. These instances are supplied to the reasoning (inference) engine, the core of our ontology centric architecture. The inference engine's function is to control the configuration process by suggesting possible configurations and validating the consistency and integrity of user configurations against the knowledge base. After the configuration has been accomplished, a general consistency and integrity-checking phase is performed to ensure that the entire configuration is legal with respect to the knowledge base. Then the new configuration information inside the inference engine is converted again in XML according to the Bulk CM IRP standard for deployment on the real network.

4.1 Modelling Objectives

We consider ontologies as a possible solution to represent the network management domain model and integrate expert knowledge in configuration workflows, facilitating the engineering task. Central to our new approach are the following key objectives.

i) Our new formal representation will be based on current standard ontologies, thus facilitating model sharing and exchange as a key to solving the problem of interoperability.

ii) Our ontologies will allow for modelling of configuration task workflows, and thus incorporate expert configuration knowledge into our management application.

iii) The semantically enriched model will allow different categories of user interaction such as bulk unmanned background operation, Web portals, thick clients etc. . This is similar in thinking to 3-tier client server approaches, with the difference being that our network logic is enriched into the data tier.

iv) The models will help with consistency checking and validation at at run time, preventing errors, mis-configurations and inconsistencies.

v) As our modelling techniques are based on declarative techniques, issues like versioning can be easily handled with the interjection of rules.

vi) Perhaps the key benefit of this approach is that domain expertise in the Radio Access Networks (RAN) can be captured and reused across value added applications, independently of the OSS infrastructure and the presentation environment.

4.2 Modelling approach

After analyzing the problem domain, we found that the concepts encapsulated in the Managed Object Models are rather easy to express. There is no complex *is-a* inheritance hierarchy. All objects derive from class Managed Object and the hierarchy finishes there. The entire model is a complex type of "part-of" hierarchy, with cardinality constraints on the different parts of the model. Basically, it has containment relationships such as "Object A contains object B" or the inverse "B is a part of A", and association relationships used to define relationships between objects. The model is completely object oriented.

Description logic (DL) based languages support subsumption for classes, and are very helpful during modelling in detecting new *is-a* relationships between classes, thus avoiding errors in modelling new concepts. It is possible to use subsumption techniques for the part-of relationship, but there are issues with current tools, such as FaCT++ being potentially combinatory explosive when dealing with part-of hierarchies like medical anatomy ontologies. While being good at modelling, DLs do not seem to be applicable for reasoning/querying in large sets of instances and thus cannot be used as a run-time system for ontology-based applications based on the query-answer paradigm

Frame-logic based languages, on the other hand, also provide support for subsumption. [8] effectively reducing subsumption reasoning to query answering, but DLs remain in general more efficient[20]. The strength of F-logic languages comes from the fact that there are well-optimised implementations for query answering such as Flora-2 and Ontobroker, which makes them a possible run-time environment for ontology-based applications.

In the domain of telecom management there is a need for establishing business contracts in configuration or reconfiguration applications. We also need interaction rules to represent the behaviour of concepts and tasks from different MOMs. F-logic based languages have rules with well-studied semantics integrated into the language itself. For DL based languages such as OWL, the need for rules also exists, and there is currently a SWRL W3C recommendation, which integrates with OWL. However at the time of our investigation, no proper SWRL implementations were available.

There is a trade-off between the inference power of the language and the ability to catch modelling mistakes[6].

4.3 Manipulating Ontologies

Description logics [1] are a family of knowledge representation languages that can be used to represent the knowledge of a domain in a structured and formally well-understood way. OWL DL follows this modelling approach. Currently there are two optimized inference engines for reasoning about Description Logics, which are RACER [10] and FaCT++ [18]. They both are pluggable to many ontology-editing tools like Protégé. It is important to mention that an ontology editor is a graphical user interface to create ontologies, but not an inference engine. Most of the ontology editors use third-party inference engines to actually help with the modelling.

Frame logic (F-logic) [15] combines the advantages of the frame-based languages with the expressiveness and well-defined semantics from logics. It is a deductive, object oriented database language, which combines the declarative semantics and expressiveness of deductive database languages with the rich data modelling capabilities supported by the oriented data model. There are three well-optimised implementations of the F-logic paradigm that can be used for reasoning on languages based on F-logic. These are FLORID [16] which is a research prototype; OntoBroker [3]; and FLORA–2 [19].

To obtain the most value from representing information in ontologies, it is important to infer information or knowledge. There are two types of reasoning on ontologies: TBox (related to terminology) and ABox (query answering).

i) TBox deals with reasoning tasks: Subsumption of C by D concept. Satisfiability of C concept. Equivalence of C and D concepts. Disjointness of C and D concepts.

ii) ABox deals with answering queries over the knowledge base. There are two types of queries called ground and open queries. The inference task consists of checking if a fact is entailed by the knowledge base. An open query is a formula with free variables, and the inference task consists of finding the values of the variables from the knowledge base. Examples of queries are consistency checks, checks to see if something is an instance or a concept, retrieval of individuals and attributes, etc.

5 Case Study: WCDMA RAN Configuration

In order to demonstrate our ideas of using ontologies as a modelling paradigm for network concepts and relationships, we decided to take a configuration scenario from the WCDMA Radio Access

Network (RAN) as a case study - the *reparenting* task described in Section 2 above. Another interesting aspect of the domain is that configuration and reconfiguration tasks in the RAN require rather complex interactions between different network elements, which lead to a need for consistency checking and validation. Consistency checking tasks typically involve expert knowledge, presenting an excellent research topic on how to integrate this knowledge in some common modelling paradigm, with the goal of aiding the engineer during configuration or reconfiguration tasks. We chose to investigate our techniques of using ontologies for a specific *reparenting* reconfiguration task. Briefly, in this process we move control connections (and possibly the traffic connections as well) from a source node to a new destination.

We divided our formal ontology modelling into three logical parts. The first model captured the network information for the configuration task. The second model described the specific protocol that needed to be changed during the reconfiguration. Finally we represented the workflow needed to complete the task in a separated ontology.

5.1 Enriching The Network Model

In the first ontology we modelled the network and corresponding equipment adding semantic information, such as cardinality and complex relationships between entities.

A first modelling approach follows closely the UML Class model and looks like:

```
#ManagedElement[#logicalName=>xsd#STRING;
#hasIpSystem => #IpSystem;
      #mincard@(hasIpSystem) -> 1;
      #maxcard@(hasIpSystem) -> 1;
#hasTransportNetwork => #TransportNetwork;
      #mincard@(hasTransportNetwork) -> 1;
      #maxcard@(hasTransportNetwork) -> 1;
.
..
].
```

Fig 3: UML MO mapping to F-Logic

In this case the containment relationships between the IpSystem and TransportNetwork concepts to the ManagementElement concept, respectively (hasIpSystem and hasTransportNetwork) and their cardinality constraints are explicitly modelled using the appropriate F-logic primitives as shown in Fig.3.

The second possible modelling approach in Fig. 4 on the other hand does not model the containment relationships in an explicit way. The only way to test for containment between concepts is to use the reasoning power of the inference engine to infer the containment hierarchy.

```
#ManagedElement[#logicalName=>xsd#STRING;
      #contains => #IpSystem;
...
      #contains => TransportNetwork;
      #contains => #Equipment].
```

Fig 4: Containment Hierarchy

This modelling approach is very convenient when writing queries to retrieve data located down in the containment hierarchy. This is due to the fact that the user does not need to explicitly write the path to some object from another one situated higher in the hierarchy, but only to specify the types of the two objects and the containment relationship between them. However this approach presents a major drawback when modelling cardinalities. Capturing relationship cardinalities must be done using rules for every single containment relationship, while in the first approach it can be done with only one rule due to the explicit representation of the cardinalities.

5.2 Configuration task Ontology

Each task of a configuration process has two main subtasks. The first one is to get data for configuration and second is to create/update a particular managed object with this data. We identify three different sources of data for completion of a given task:

i) User supplied information. This information normally comes from detailed planning of the configuration task, and thus could not be automated. At this level, a human user supplies specific information, and the system can only work as an assistant.

ii) Information that could be inferred from the configuration context. This is derived from well-established business contracts between network elements taking part in the configuration. Any configuration data should respect these contracts. The system acts in this case as a suggesting tool and thus relieves the user from the burden of looking up information needed to complete his task.

iii) Information that comes from other (previous/next) tasks. In this case, we talk about implicit information; the system implicitly fills gaps, relieving the user from doing it manually.

```
#Task[#name => xsd#STRING;
      #directPre =>> #Task;
      #directPost =>> #Task;
      #status => xsd#STRING;
      #description =>> xsd#STRING]
```

Fig 5: Generic F-logic Task

A generic task is shown in Fig5 which comprises of a name, direct successor tasks, direct predecessor tasks, status and a description. Each specific task of a configuration process inherits from this generic task. Each task has a number of attributes that must be supplied; these closely map to the attributes of managed objects the task will create or update. Each task has an internal link to empty managed object(s). This is an explicit link between the MO and the task it is related to. It also has links to other task objects indicating which information or related managed objects are needed to complete the current task.

```
TransportTask[#atmPort =>
trans#AtmPort;
       #vp => xsd#STRING;
       #vci => xsd#STRING;
..
..
#atmTrafficDescriptorLink =>
trans#AtmTrafficDescriptor].
```

Fig 6: ATM Traffic Task

Fig6 expresses the configuration of a virtual path (VP) and a corresponding virtual channel (VCL). In order to complete the configuration, this task must use data from the AtmTrafficDescriptor concept. This is why there is an explicit link to that concept also. Its actual value is inferred from other tasks (in this case AtmTrafficDescriptor task) which will bind to the `#atmTrafficDescriptorLink` thanks to business contract rule.

5.3 Formal Rule

Finally in order to complete the modelling task, we created rules to establish the necessary business contracts between tasks in order to make the process consistent and compliant to the required configuration specification.

Basically we distinguish three types of rules; rules that are used to create new knowledge from existing knowledge, rules that are used to establish business contracts between concepts such as managed objects and tasks, and pure consistency checking rules such as cardinality constraint checking rules. The second type of rules could be also called inference rules. Here are examples from the current implementation:

i) *New knowledge derivation rules.* These rules are used to create new knowledge concepts based on already existing knowledge. (Concept uncle could be modelled as my father's brother, as long as father and brother are known concepts). The following rules create a new relationship "#pre" between two tasks and make the relationship transitive across tasks.

```
FORALL T1,T2 T1[#pre ->> T2] <- T1[#directPre ->>
T2].

FORALL T1,T2,T3 T1[#pre ->> T3] <- T1[#pre ->>
T2] and T2[#pre ->> T3].
```

Fig 7: Derived Rule

The first rule in Fig. 7 models a new relationship #pre between two tasks derived from the already existent knowledge about the relationship #directPre between the same tasks. The second rule models the well-known transitive property, namely if Task 1 has a relationship #pre to Task 2 and Task 2 has a relationship #pre to Task 3, this implies that Task 1 has a relationship #pre to Task 3.

ii) *Business contract rule:* These rules connect concepts in a way that satisfies some specific configuration requirement. They are not considered simply as checking rules because their role is to transfer information from one concept to another. We also call them inference rules.

```
FORALL Basestation,Controller,T,ID T[#baseID -> ID] <-
move(BaseStation,Controller,T) and T:ProtocolTask and
Basestation[#id -> ID].
```

Fig 8: WCMA Reconfiguration Rule

The rule described in Fig 8 infers the value of the #baseID attribute of the ProtocolTask *T* from the BaseStation #id when there exists a particular relationship (*move*) between a BaseStation, Controller and *T.* A direct consequence of this is that from a querying point of view, the user should not bother to know from where to retrieve the value of the attribute #baseID in a given configuration context. He just needs to query the owner of the attribute, in this case the BaseStation, and the rest is left to the inference engine to find its possible values.

iii) *Pure constraint checking rules:* These rules are most of the time used to constraint the domain model itself.

```
FORALL S check(S) <- EXISTS R1,R2,V1,V2
R1::#BaseStation[#id -> V1] and R2::#BaseStation[#id ->
V2] and equal(V1,V2) and S is "We can not have two
BaseStations with same identity".
```

Fig 9: Radio Network constraint

The rule in Fig 9 simply says that it is impossible to have two radio base stations with same identity in a sub-network if we assume a sub-network context.

By using the above approach we have seen that we can dramatically reduce the amount of human interaction needed for complex configuration operations. This ability to automate previously manual tasks creates a more robust environment for wireless operator. Tasks once the sole domain of human experts, due to the implicit knowledge needed to perform the tasks, can be carried out by less knowledgeable technicians. Our approach removes steps in the configuration workflow that were inherently prone to errors particularly in the area of the consistency of data values. A welcome side effect is also the reduction in the time taken to carry out complex tasks. With the help of formal ontologies we have significantly improved the workflow efficiency for reconfiguration of wireless networks.

6 Conclusion

In this paper we have shown the benefits of using Ontologies to help solve a complex real-world network configuration problems. Our approach of augmenting network management models with semantic knowledge coupled with workflows allows us to create new more powerful management applications. Finally we presented an example of our approach in the domain of third generation wireless network transport configuration. By adopting our techniques we are able to build more intelligent management application that reduces wireless operators operation expenditure by the use of formal ontologies.

7 Acknowledgements

We would like to thank **ontoprise®** GmbH for their support and assistance during our prototyping activities.

8 References

[1] F. Baader, Ian Horrocks and Ulrike Sattler, July 2003. Description Logics,

Handbook on Ontologies. International handbooks on Information systems.

Edition 2004.

[2] Tim Berner's Lee et al. 2001. The Semantic Web, Scientific American, May 2001

[3] S. Decker, M. Erdmann, D. Fensel, and R. Studer. Ontobroker: Ontology Based Access to Distributed and Semi-Structured Information. In *DS-8: Semantic Issues in Multimedia Systems*. Kluwer, 1999.

[4] Distributed Management Task Force http://www.dmtf.org

[5] Enhanced Telecom operations Map, TMF, GB91, version 4, March 2004.

[6] Jos De Bruijn, Dieter Fensel, Rubén Lara, Axel Polleres, Nov. 2004

OWL DL vs. OWL Flight: Conceptual Modelling and Reasoning for the Semantic Web.

[7] M. Genesereth: Knowledge Interchange Format. In J. Allenet & others (Eds.), *Proceedings of the Second International Conference on the Principles of Knowledge Representation and Reasoning (KR-91)*, Morgan Kaufman, pp. 238–249, 1991.

[8] Grosof, B. N., Horrocks, I., Volz, R., and Decker, S. (2003). Description logic

programs: Combining logic programs with description logic. In *Proc. Intl. Conf. on the World Wide Web (WWW-2003)*, Budapest, Hungary.

[9] Thomas R. Gruber. A translation approach to portable ontologies. *Knowledge Acquisition*, 5(2):199-220, 1993.

[10] Haarslev, V. and MÄoller, R. (2003). Racer system description. In *Proc.of the 12th Int. World Wide Web Conf. (WWW2003)*, pages 48 - 57. ACM.

[11] Andreas Harth, Stefan Decker. OWL –Lite reasoning with rules.

[12] Matthew Horridge, Holger Knublauch, Alan Rector, Robert Stevens

A Practical Guide To Building OWL Ontologies Using The Protégé-OWL Plugin and CO-ODE Tools

Edition 1.0

[13] The Internet Engineering Task Force Operations and Management Area http://www.ietf.org/html.charters/wgdir.html#Operations%20and%20Management%20Area

[14] ITU-T TMN Recommendation M.3400: TMN Management Functions, ITU-T, 02,00

[15] M.Kifer, G.Lausen and J. Wu. Logical foundations of object-oriented and frame based languages. Journal of the ACM, 42:741-843, 1995

[16] B. Ludaescher, R. Himmer¨oder, G. Lausen, W. Mayand C. Schlepphorst. Managing Semistructured Data with FLORID: A Deductive Object-Oriented Perspective. *Information Systems*, 23(8):589–613, 1998.

[17] Telecommunication Information Networking Architecture Consortium http://www.tinac.com

[18] Tsarkov, D. and Horrocks, I. (2004). Efficient reasoning with range and domain constraints. In *Proc. of the 2004 Description Logic Workshop (DL 2004)*, pages 41 - 50.

[19] Guizhen Yang, Michael Kifer FLORA: Implementing an Efficient DOOD System Using a Tabling Logic Engine. , Lecture Notes in Computer Science.

[20] Volz, R. (2004). *Web Ontology Reasoning with Logic Databases*. PhD thesis, AIFB, Karlsruhe.

[21] 3GPP SA5 Working Group TS 32.101 - Telecom Management Principles and High Level Requirements v 6.0.0

[22] 3GPP SA5 Working Group TS 32.611: Bulk CM Integration Reference Point (IRP).

[23] Feit S: SNMP: A Guide to Network Management, McGraw-Hill, 1995