# A Reference Conceptual Model for Virtual Network Function Online Marketplaces

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**Abstract.** Recently, we witnessed a shift in the Networking paradigm, with large part of the network control moving from hardware to software. This move has been accompanied by an increase of interest in declarative software models (conceptual models) for the domain. Moreover, novel architectures allow services to be deployed in multiple domains. These changes call for new business models to allow the commercialization of Virtual Network Functions (VNFs). This paper proposes the creation of an ontology-based reference conceptual model to support VNF Marketplaces, allowing VNF vendors and infrastructure providers to commercialize VNFaaS (VNFs as services). The proposed reference model has been engineered by using foundational ontology techniques (UFO/OntoUML), it has been formally validated by using model simulation techniques, and it has been implemented in OWL.

**Keywords:** Ontology-Based Conceptual Modeling, Virtual Network Function, Marketplace, UFO-S

## 1 Introduction

In the past few years, we have been observing a shift in the Networking paradigm, with large part of the network control moving from hardware to software in the context of an increased virtualisation of networks. This move has been accompanied by an increase of interest in declarative software models (conceptual models) for the domain [1]. Additionally, we have witnessed the migration of network services to profit from the growing adoption of distributed cloud computing technologies in 5G networks. In this setting, new business models are needed to enable the different market players to profit from these changes. Along with the changes in the business models, comes the need for novel platforms to support the development and commercialization of Virtual Network Functions (VNFs) and Network Services (NSs).

In this paper, we discuss the case of a VNF Marketplace to enable VNF vendors and infrastructure providers to commercialize VNFaaS (VNFs as services). This marketplace is based on the architecture of the 5G Exchange Hub [4], which consists of the interconnection of different testbed islands, allowing the orchestration and deployment of multi-domain NSs. In this marketplace, service developers may create new NSs through the combination of VNFs offered by different vendors and deployed at distinct sites, according to the requirements of the service being developed. In other words, we do not assume that the developer owns a particular infrastructure, but rather allow the services to be run in third-parties infrastructures, which are owned by infrastructure providers.

Our proposed business model requires that prior to the service development per se, a contract is established between the VNF vendor and the infrastructure provider, regulating VNF deployment. For that, the infrastructure provider must acquire a license to deploy, through a service agreement with the VNF vendor. For deploying the VNF, the infrastructure provider charges from the developer a deployment cost, which is defined with basis on how much the infrastructure provider spends with the VNF license, and the infrastructure running and maintenance.

The proposed marketplace is based on a Reference Conceptual Model to support the aforementioned business model, besides allowing NS developers to design and deploy NSs. This particular paper reports on an excerpt of this Conceptual Model, making explicit the involved market players (i.e. VNF vendors, infrastructure providers and NSs developer), and how a service is established between the different parties. In order to do that, we build our work on the basis of a Core Ontology of Services (UFO-S) [8]. UFO-S is a well-founded ontology based on the Unified Foundation Ontology (UFO), and by reusing it, we profit from its already established semantics. Furthermore, as demonstrated in [8], UFO-S is expressive enough to harmonize the different views of service found in the literature of Service Computing, Service Sciences and Enterprise Modeling.

We here claim that an ontology-based Reference Conceptual Model is more suitable than other kinds of conceptual models, such as ER and traditional UML models. Our main justification is that besides making the domain knowledge explicit, an ontology supports reasoning capabilities, i.e. the ability to navigate in the ontology model, finding answers to specific queries. Moreover, if there is a need to interoperate the marketplace with other systems (e.g. commercial portals from specific VNF vendors), ontologies are particularly advisable, especially if based on a foundational ontology, formalizing the real-world semantics behind the domain concepts.

Following the best practices in the area of Ontology-Driven Conceptual modeling [7], our proposed reference model has been engineered by using foundational ontology techniques (UFO/OntoUML). Moreover, it has been formally validated by using the OntoUML support for model simulation and anti-pattern detection, and it has been implemented in the description logics SHROIQ (OWL). The proposed model is then used to support the development of a proof of concept of the proposed marketplace and allows for a number of reasoning tasks regarding different aspects concerning its business model and its operation.

The remaining of this paper is organized as follows: section 2 presents UFO-S, the core ontology reused in this work; section 3 describes the Marketplace Reference Conceptual Model; section 4 discusses validation and codification of the proposed model, as well as the a proof of concept developed for the Marketplace; section 5 discusses some related works; and finally, section 6 presents our final considerations.

## 2 The UFO-S Core Ontology of Services

UFO-S [8] is a Core Ontology grounded on UFO [6] and as such, it is meant to capture a structure that is recurrent in several domains [3]. UFO-S accounts for a conceptualization of services independent of a particular application domain and is designed with the main goal of supporting meaning negotiation among different views on services held, for example, in Service Computing, Service Sciences and Enterprise Semantics. In our work, we use only an excerpt of UFO-S, and for the description of its remaining concepts, we refer to [8]. UFO-S is based on the UFO foundational ontology. For reasons of space, we are not able to present the definition of the categories comprehending UFO, and we thus also refer the reader to [6].

In UFO-S, agent is a category that represents the essential properties of any type of agentive object (e.g. person, organization, or software agent). Service provider is the role played by agents when these agents commit themselves to offer a service to a target customer community. As a role mixin, service provider can be instantiated by agents of different kinds, e.g., persons and organizations [6].

Target customer community is a collective representing the group of agents that constitute the community to which the service is being offered. The criteria for defining the target customer community membership are included in the content of the service offering. This may range from offerings with no restrictions to strictly targeted service offerings. The target customers are members of a target customer community and, therefore, have claims for the fulfillment of the service providers *commitments* when offering a service. The social relator aggregating the aforementioned commitments of the service provider and the corresponding claims by the target customers is named service offering.

After the service is negotiated, a service agreement is established, and the service provider becomes a hired service provider, while the target customer effectively is turned into a service customer. As in a service offering, a service agreement is composed of commitments and claims. However, in contrast to the service offering, a service agreement involves not only commitments from the hired service provider towards the service customer, but may also involve commitments from the service customer towards the hired service provider (for example, the commitment of providing a monetary compensation in case of service delivery). In any case, a service agreement should conform to the previous service offering, in a sense that the commitments established by the former should be compatible to the ones predefined in the latter.

## 3 VNF Marketplace Reference Conceptual Model

Figure 1 presents the concepts and relations that allow an `Infrastructure Provider` to deploy and commercialize a `Virtual Network Function (VNF)` developed by a third-party vendor, here named `Virtual Network Function Provider` (VNF Provider). A VNF is the role played by a `Software` when commercialized by a particular vendor (see the offers relation from `Virtual Network Function Offering` to VNF). A VNF instantiates a `VNF Type` (e.g. the Cisco ASA 5500-X Firewall is an instance of the Firewall type).

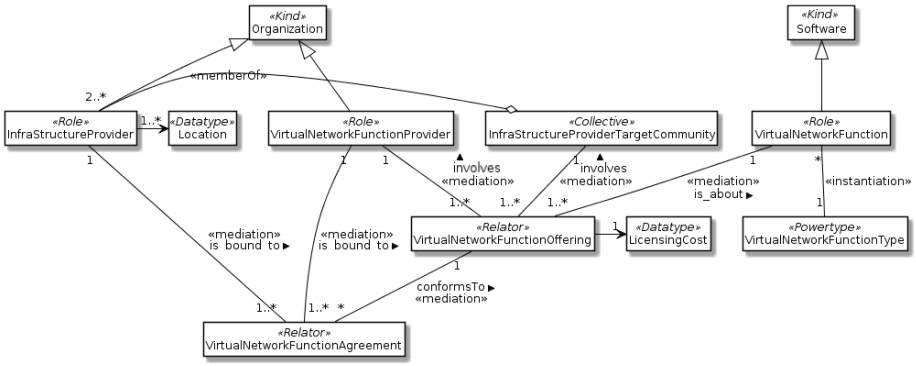


**Fig. 1.** Concepts involved in the contract between an Infrastructure Provider and a VNF Provider to deploy and commercialize a VNF

Both VNF Provider and Infrastructure Provider are roles played by `Organizations`. The Infrastructure Provider has a `Location` (this information is important to enable the NS Developer to select the best placement for a particular service). The VNF Provider represents the vendors of VNFs, while the Infrastructure Provider is the role responsible for actually deploying the VNFs that compose the NSs in the Marketplace. For that, a service agreement (in the sense of UFO-S) is established between the VNF Provider and the Infrastructure Provider, according to the concepts defined by UFO-S. Thus, first, a VNF Provider provides a service offering (again, in the sense of UFO-S) to a `Target Infrastructure Provider Community`.

The `VNF Offering` offers a particular VNF (e.g. Cisco ASA 5500-X Firewall), having a specific `License Cost`. If an Infrastructure Provider member of the target community is interested in the offering, a `VNF Agreement` may be established, conforming to such VNF Offering (see the UFO-S *conforms to* relation between the VNF Agreement and VNF Offering). Having established this VNF Agreement, the Infrastructure Provider gains the right to commercialize the deployment of such VNF in the Marketplace.

Figure 2 presents the concepts and relations that allow a service developer to acquire the right to *deploy* a particular VNF as part of a developed service. To enable the `Developer` to use the VNF as part of an NS, the Infrastructure Provider delivers

a service to the Developer, following the same service structure as the one described above. The Infrastructure Provider makes a `Virtual Network Function Deployment Offering` to a `Target Developer Community`, having a particular `VNF Deployment cost`. Note that the VNF Deployment Offering requires an existing VNF Agreement (refer to *requires* relation). This avoids that Infrastructure Providers commercialize the deployment of VNFs for which they have not yet acquired a licensing agreement. An interested Developer, member of the target community, may then make a VNF Deployment Agreement (`Virtual Network Function Deployment Agreement`) *conforming to* the VNF Deployment Offering, thus gaining the right to execute that particular VNF in a service developed through the Marketplace.

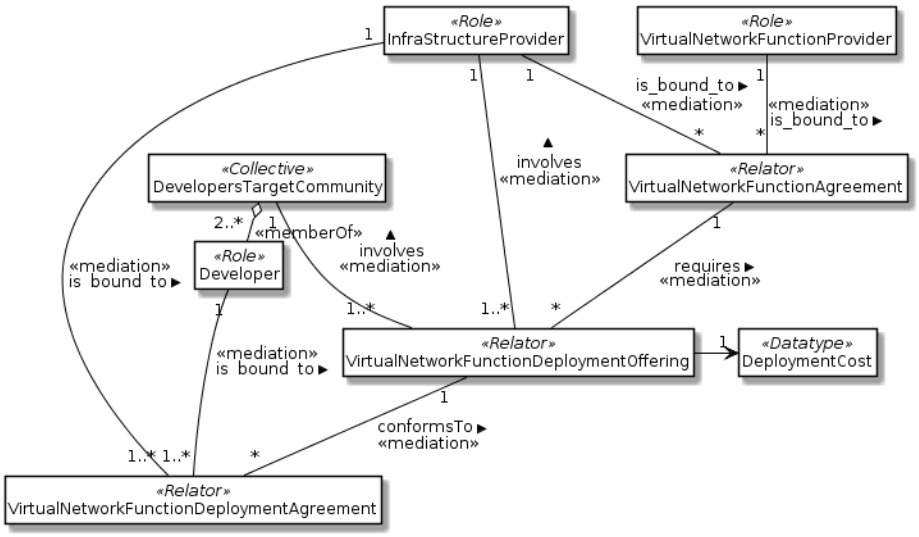


**Fig. 2.** Concepts involved in the contract between a Developer and an Infrastructure Provider to deploy a VNF as part of a developed service

Please note that the excerpts of our reference conceptual model presented in Figs. 1 and 2 are based on UFO-S. As previously stated, Core Ontologies are general enough to allow the creation of ontologies in more specialized domains. Thus, our reference model applies the UFO-S concepts described in section 2 by analogy. In other words, for all UFO-S described notions, we created concepts that are specific to the Marketplace domain. For instance, in Fig.1, the VNF Provider plays the role of UFO-S service provider (provides VNF Offering) and then the role of hired service provider (once a VNF Agreement is established), at the same time that the Infrastructure Provider plays the roles of target customer and service customer. In Fig.2, the Infrastructure Provider is the one that offers the service (see VNF Deployment Offering), hence playing the role of UFO-S service provider and then the role of hired service provider (once a VNF Deployment Agreement is established). Meanwhile, in the context of this last fig-

ure, the Developer plays the role of target customer and service customer. Moreover, our reference model shows two collectives based on UFO-S target customer community (namely, the Infrastructure Provider Target Community and the Developers Target Community), two relators based on UFO-S service offering (i.e. VNF Offering and VNF Deployment Offering), and other two relators based on UFO-S service agreement (i.e. VNF Agreement and VNF Deployment Agreement).

## 4 Implementation and Validation of the Reference Model

The Marketplace Reference Model proposed in the previous section has been developed according to domain-specific knowledge elicited from (and validated by) experts of the High Performance Networks Group of the University of Bristol. Besides that, the reference model has been implemented in the Description Logics SHROIQ (OWL) and verified using Protégé. Moreover, the derivation rules and integrity constraints complementing the model have been specified using SWRL rules (Horn Logic). Then, the ontology has been populated with instances. This allowed for the verification of *logical consistency* and *satisfiability* of the model.

With this implemented version of the model in Protégé, once the reasoner is turned on, some extra information is inferred about the individuals, based on the implemented SWRL rules. For supporting the Marketplace's functionalities, it is important to know, for instance, what VNF type a particular VNF Deployment Agreement agrees to deploy; and what are the possible Deployment Costs (related to the VNF Deployment Offering) associated to a specific VNF. This information (among other) may not be known by the way the Reference Model's concepts are directly related, thus requiring the creation of SWRL rules that enable such information inference based on the navigation of several concepts and relations.

Besides this formal verification, the model has been *validated* via visual simulation discussed in [7]. This strategy allows for systematically analyzing the mode instances generated by the simulator in contrast with the set of intended instances of the model developers. If the simulator generates unintended instances, it is necessary to constrain the model to avoid them; and, on the other hand, if some intended instances are missing, we need to verify if there are existing constraints that should be relaxed to allow for them. To employ this strategy, we have used the Alloy simulator of the OntoUML model-based editor [5]. Such simulator takes as input the OntoUML model and a set of OCL restrictions, generating as output the instances of the developed model.

Finally, an important validation is to understand if the model is able to adequately support the class of applications for which it was created, in our case, VNF Marketplaces. Figure 3 shows a screenshot of a proof of concept that we developed for a VNF Marketplace. The prototype was implemented with basis on the proposed reference model, which was taken as an analysis model to help shape the developed interface, functionalities and knowledge base. In this case, the implemented ontology was not used, since, as a design decision, we favored a widely popular architecture for single-page web applications, known as the MERN (MongoDB , Express , React , Node.js) stack. MongoDB is an open-source NoSQL database, which allows us to store data about the marketplace (e.g. available VNFs, NSs, infrastructure providers, etc.). Ex-

press and Node.js are being used in the server side of the marketplace, particularly to implement a RESTful API to persist and query application data stored in MongoDB. Lastly, we used React - a well known Javascript library developed by Facebook - to build the graphical user interface of the marketplace.

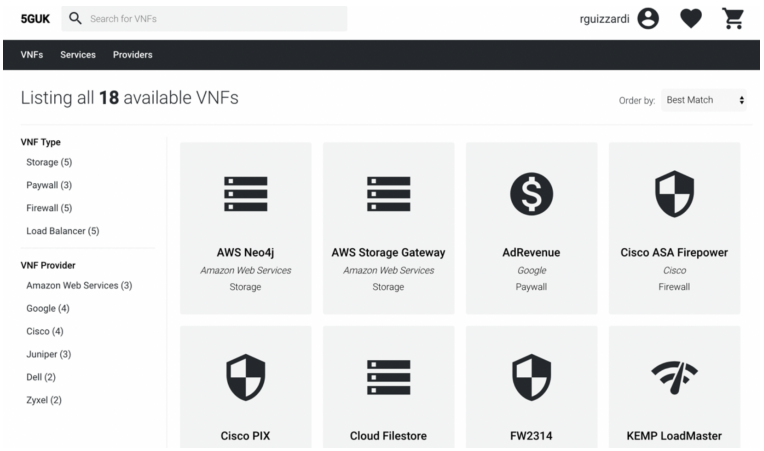


**Fig. 3.** Screenshot of the proof of concept homepage

## 5 Related Works

In the past few years, there have been a couple of initiatives proposing VNF Marketplaces in the sense discussed in this article. D'Oro, Palazzo, and Schembra [2] propose a VNF Marketplace to enable customers behaving as third-party sellers with their hardware and software resources providing VNFaaS (Virtual Network Functions as a Service). The paper describes the marketplaces architecture and propose a mathematical model to regulate the network flows. Xilouris et al. [9] describe the T-Nova approach, which includes a VNF marketplace to enable buying, composing, and deploying virtual services on the fly. In that paper, the authors describe some VNFs they have developed and how they may be combined with the assistance of the marketplace. Moreover, they discuss about VNF Lifecycles, Monitoring and Networking.

These works, however, despite discussing architectural and implementation aspects of VNF marketplaces, do not propose an explicit *reference model* for this domain. In fact, despite the recent interest in conceptual models in the area of computer networks (e.g., [1]), to the best of our knowledge, the proposal presented here is the first explicit, reusable, ontology-grounded Reference Conceptual Model for VNF marketplaces. We also highlight that, in both these existing works in the literature, the focus is on *scalability* issues, while our proposed reference model targets the marketplace *business model*. In particular, we do that by demonstrating that Network Services are indeed Services, in the sense of the term employed in Service Science and related areas, i.e., in a sense

that takes service to be more than mere *behavior* (service delivery) and function (the expected outcome of service delivery. Instead, this view essentially involves aspects such as *Service Offering* and *Service Agreement*. As such, besides these functional aspects, our model addresses the multiple aspects of contractual relationship management that are needed to make such a marketplace work. This is done here by systematically reusing the central pattern of the UFO-S Core Ontology of Services.

## 6 Conclusions

This paper presents a Reference Conceptual Model to support the development of a VNF Marketplace to enable VNF vendors, and infrastructure providers to commercialize VNFaaS. The proposed model has been developed using a well-founded approach for modeling, verifying, validating and implementing ontology-driven conceptual models. We believe that this model not only offers a solution to the immediate problem at hand, but it also contributes to demonstrate the practical usefulness of conceptual modeling techniques in the domain of Network Services and Functions.

Our proposed conceptual model mainly focuses on Service Design and Deployment via the appropriate configuration (binding) of VNFs and VNF types. As such, the model ignores the infrastructure providers deployment capacity. In a future version of this model (and its DL implementation), we should address this aspect, thus improving its reasoning capabilities for supporting network orchestration and management.

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