Enhancing CIM with Linked Data Capability

Kosa R. Nenadić and Milan M. Gavrić

***Abstract* — In this paper the Common Information Model (CIM) modeling approach is analyzed from the Linked Data perspective. Due to the Resource Description Framework Schema extensions and constraints introduced by CIM in the IEC standards, the authors propose the enhancements that add Linked Data capability allowing the application of standard based reasoning tools on CIM documents. The paper contains the new approach for CIM-based network modeling using JSON-LD having the Linked Data principles applied.**

***Keywords* — CIM, Common Information Model, JSON-LD, Linked Data, OWL, RDF Schema, Semantic Web.**

I. Introduction

An energy company – utility will be in charge of monitoring and controlling millions of its own devices, and tens of millions of customer devices, directly or via an intermediate system, in the very near future [1], [2]. For such complex integration requirements, the ability of multiple systems to cooperate for a common purpose – interoperability is not a question of 'nice to have', rather it is a 'must have'.

In order to provide the interoperability, Common Information Model (CIM) is exposed as a ubiquitous common semantic data model for Smart Grid modeling. Definition of CIM as a complex vocabulary – ontology, that is an international standard, represents good ground for semantic definition of entities participating in Smart Grids, providing a way to overcome semantic heterogeneity. In report [3] the authors have identified that the power utility domain is not moving towards web data exchange as expected mainly due to its self-containedness inherited from the pre-smart grid era. In paper [4] the authors have showed that the semantic interoperability between legacy systems based on CIM has positive results. The main goal of this paper is to deal with the integration complexity by applying the Semantic Web technology to the typical CIM modeling approach making the CIM data usable on the Web 3.0.

The Semantic Web represents a Web of Data, where data and relationships among them are available in standard formats, accessible and manageable by various semantic web tools. In this way, collections of interrelated datasets a.k.a. Linked Data are created on the Web [5].

As for the CIM model maintenance, the Unified Modeling Language (UML) is chosen. The current CIM subsets are mostly modeled as Resource Description Framework Schema [6] (a.k.a. RDF Schema or RDFS) vocabularies, but there are some ongoing works in modeling CIM subsets using Web Ontology Language (OWL) [7]–[10].

RDF 1.1 [11] introduced JSON-LD (JavaScript Object Notation for Linked Data) [12] as its new, lightweight syntax for a serialization of Linked Data in JSON, capable of serializing any RDF Graph or RDF Dataset. Conversion of RDF/XML into JSON-LD is lossless as both formats serialize RDF graph. In the paper [13] the authors showed how CIM documents in JSON-LD syntax can be used in the modern Web. However, by simply converting documents containing RDF/XML serializations of CIM into JSON-LD documents, the power of JSON-LD would not be used to the full extent as CIM imposes a set of conventions that reduce Linked Data capability.

In the following section the typical CIM modeling approach is presented together with the recognized limitations. Afterwards, the enhanced CIM modeling approach is demonstrated using the real use case. The final section concludes the paper.

II. Typical CIM Modeling Approach

The IEC 61970-501 [14] describes the process of CIM UML representation mapping into Extensible Markup Language (XML) using the subset of RDFS. The mapping result is known as CIM RDFS. It defines a particular model of interest referred to as a CIM profile. The standard describes RDFS extensions as well. The IEC 61970-552 [15], specifies how CIM RDFS is used for constructing XML documents of Smart Grids' modeling information (a.k.a. CIMXML documents [15]).

The typical CIM modeling approach is illustrated in Fig.

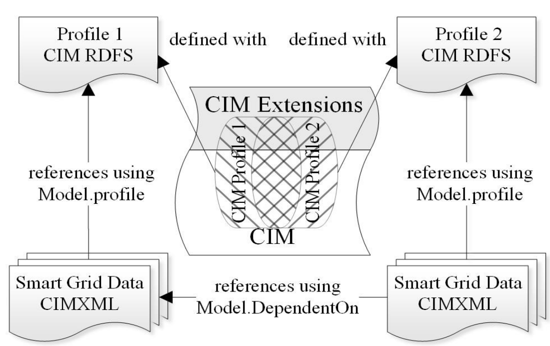

Fig. 1 Typical CIM Modeling Approach

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1, describing how CIM, CIM extensions, CIM profiles, CIM Profile RDF Schema and CIMXML relate to each other. A CIM RDF Schema for a CIM profile may contain only the CIM classes and properties of interest for that particular profile. However, a CIM profile may include needed extensions, namely classes, properties and/or associations with the profile CIM classes. Each CIMXML document may contain a description of a model. This description represents a header data containing a reference to the corresponding CIM profile and other CIMXML documents. FullModel class describes header data, of which Model.profile and Model.DependentOn properties are used to describe relationships shown in Fig. 1.

CIMXML introduces a convention where rdf:IDs originating from mRIDs are considered globally unique (i.e. across multiple CIMXML files). From a technical standpoint this is a constraint as the true unique identity of an RDF node is the concatenation of the local rdf:ID with the base Unique Resource Identifier (URI). Consequently, referenced resources are not dereferenceable in standard manner. Another constraint is that the namespaces in CIM documents are treated as Universal Resource Names (URNs), meaning that they are not dereferenceable as well. Further, although CIM Profiles are defined as vocabularies using CIM RDFS, vocabulary terms used in CIMXML are not referenced using fully qualified names belonging to these vocabularies but the overall CIM namespace. Instead, CIMXML header data ties the document to its vocabulary over Model.profile, meaning that CIM requires a custom tailored semantic reasoner in order to understand the underlying content.

A. CIM in UML

In order to address recognized constraints, the authors created a real use case relying on an extended CIM UML model (shown in Fig. 2 and Fig. 3) defined in an Enterprise Architect Project file (having the initial file obtained from the CIM Users Group official website [16]).

B. CIM RDF Schemas

CIM in UML is exported into XML Metadata Interchange (XMI) format, and used as a base for creation of the Substation and GeographicalLocation RDF Schemas

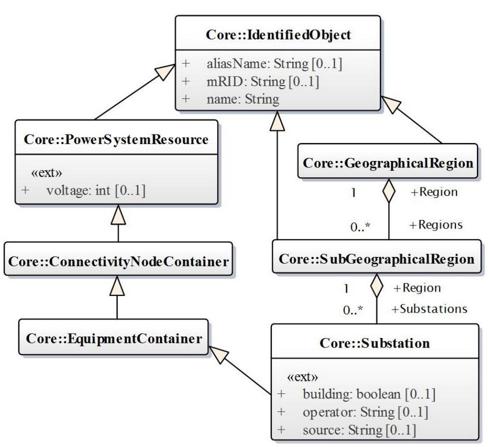

Fig. 2 Class Diagram of Substation Profile

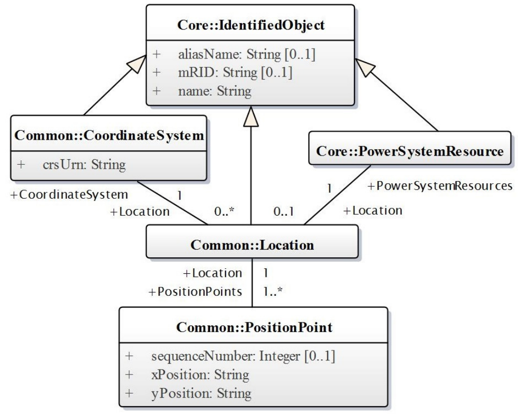

Fig. 3 Class Diagram of GeographicalLocation Profile in CIMTool (an open source tool that supports the CIM standards).

C. CIMXMLs

For the real use case data creation, the authors utilized Overpass turbo (data mining tool for OpenStreetMap) to extract the power station information. CIMXML models compliant with the created profile RDFSs are leveraging power station data of northern Italy (shown in Fig. 4) transformed from GeoJSON format using the custom built application.

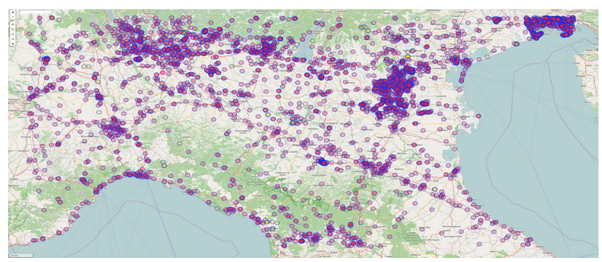

Fig. 4 Source Data Preview in Overpass Turbo

III. ENHANCED CIM MODELING APPROACH

The enhanced CIM modeling approach proposes the creation of separate ontologies for CIM, CIM extensions and model description. CIM and CIM Extensions ontologies are used as a base (i.e. common ontologies) for creation of CIM Profile ontologies that match the desired CIM Profiles RDF Schemas of the typical approach. On the other hand, Model Description ontology is used as is and describes model metadata. Each CIM JSON-LD document (i.e. CIMXML counterpart) in the proposed approach uses the appropriate ontology defined by the corresponding CIM Profile and Model Description ontology both expressed in JSON-LD syntax. CIM JSON-LDs are linked via Internationalized Resource Identifiers (IRIs) when one model references resources from another model. CIM Profile ontologies reuse terms of interest from CIM and CIM extension ontologies making their own terms equivalent to terms from which they originated thus creating the ontology mappings. CIM Profile ontologies may define specific restrictions for reused terms. Since some ontology terms may be reused in several CIM Profile ontologies those terms are implicitly equivalent.

A. RDF/XML into JSON-LD Transformation

CIM RDF Schemas of the Substation Profile, GeographicalLocation Profile and their corresponding CIMXMLs are transformed into JSON-LD using the RDF Translator [17]. Fig. 5 and Fig. 6 show excerpts of JSON-LD transformations of the Substation and Geographical Location models (ellipses are used for the omitted part of the code). Namespace definitions from RDF root element are transformed into JSON-LD terms within @context definition, while each RDF node is transformed into corresponding node object within default graph. Namespace terms defined within a JSON-LD document's active context, are used as a prefix in compact IRIs.

```
{   "@context": {... cim, ext, md, rdf, rdfs, xsd ...},
    "@graph": [{
        "@id": "#_c9bed68d-f616-fc7a-1c1f-d4c825ac7272",
        "@type": "cim:Substation",
        "ext:Substation.operator": "Enel Distribuzione",
        "cim:IdentifiedObject.aliasName": "Altavilla", ...
    }, ...
]}
```

Fig. 5 Excerpt of Substation Model

```
{   "@context": { ... cim, md, rdf, rdfs, xsd ...},
    "@graph": [{
        "@id": "#_78dff4b4-7e98-38a2-c470-17b49d63b90f",
        "@type": "cim:Location",
        "cim:Location.PowerSystemResources": "#_c9bed68d-f616-
fc7a-1c1f-d4c825ac7272", ...
    }, ...
]}
```

Fig. 6 Excerpt of Geographical Location Model

Although it may seem that both models reference the same substation identified with #_c9bed68d-f616-fc7a-1c1f-d4c825ac7272 as suggested by CIMXML convention, from a Linked Data perspective it is an IRI that is resolved relatively to the base IRI of a JSON-LD document. Base IRI is either defined using @base keyword in JSON-LD active context or relatively to the location of the document itself. Hence, the relative IRI is resolved differently in these two models as base IRIs are not explicitly set. In order to resolve a given relative IRI to the identical IRI, the relative IRI in both documents has to be dereferenceable to the same absolute IRI. The authors propose that instead of referencing resources using predefined convention, as in CIMXML, referencing should be compliant with the one defined in JSON-LD standard. In that way, an application of semantic knowledge in a CIM-based data model is introduced.

B. Defining Dereferenceable Ontologies

A CIM profile in the proposed approach is an ontology described using the RDF Schema plus a few OWL constructs (i.e. RDFS-Plus [18]). By this proposal, the subset of CIM that used RDF Schema classes and properties is extended with rdfs:isDefinedBy property. Also, a subset of OWL language constructs is included, namely owl:equivalentClass, owl:Class, owl:equivalentProperty, owl:ObjectProperty, owl:DatatypeProperty and owl:Ontology. Included OWL constructs allow more expressiveness than RDFS, but without introducing the complexity of OWL.

A CIM profile ontology uses a CIM ontology as a source ontology, meaning that each class and property defined in a CIM profile ontology defines equivalence with a common CIM ontology counterpart thus preserving the relation to CIM. In this way number of used CIM classes and properties is narrowed down when compared to the CIM as well as related intensional meaning is allowed for change. A comprehensive common CIM ontology is created from the initial .eap file and published under a defined CIM namespace, making it dereferenceable from other dependent ontologies. This is in contrast to the namespaces in CIM, where they are treated as Universal Resource Names. The rest of ontologies are also published under their namespace IRIs.

Class equivalence is achieved by using the owl:equivalentClass which states that two classes contain exactly the same set of instances [19]. Properties of the classes are not shared when owl:equivalentClass is used, as each class retains its properties [18]. Property (i.e. object property or datatype property) equivalence is achieved by using the owl:equivalentProperty which states that two properties have the same pairs of instances.

The Ext ontology in Fig. 7 contains terms that describe additional properties of CIM classes introduced in this real use case. A profile reuses the subset of terms of interest by using the Ext as a source ontology. Also, this ontology can be reused in other profiles where the intensional meaning of terms can be changed.

```
{   "@context": { ... owl, cim, cims, rdf, rdfs, uml, xsd ...
        "ext": "http://example.com/ext#"},
    "@graph": [{
        "@id": "http://example.com/ext",
        "@type": "owl:Ontology",
        "rdfs:label": "Ext Extension Ontology", ...
    },{ "@id": "ext:Substation.operator",
        "@type": ["rdf:Property","owl: DatatypeProperty"],
        "cims:dataType": "xsd:string",
        "rdfs:domain": "cim:Substation",
        "rdfs:isDefinedBy": "http://example.com/ext", ...
    }, ...
]}
```

Fig. 7 Excerpt of Ext Ontology

According to the described process, Model Description ontology is created. Fig. 8 shows an excerpt of a Substation Profile ontology.

```
{   "@context": { ...owl, cim, cims, rdf, rdfs, uml, xsd, ext ...
        "sp": "http://example.com/sp#"},
    "@graph": [{
        "@id": "http://example.com/sp",
        "@type": "owl:Ontology",
        "rdfs:label": "Substation Ontology", ...
    },{ "@id": "sp:Substation",
        "@type": ["rdfs:Class","owl:Class"],
        "rdfs:isDefinedBy": "http://example.com/sp",
        "rdfs:subClassOf": "sp:EquipmentContainer",
        "owl:equivalentClass": "cim:Substation", ...
    },{ "@id": "sp:Substation.operator",
        "@type": ["rdf:Property", "owl: DatatypeProperty"],
        "rdfs:isDefinedBy": "http://example.com/sp",
        "owl:equivalentProperty": "ext:Substation.operator", ...
    }, ...
]}
```

Fig. 8 Excerpt of Substation Profile Ontology

C. CIM JSON-LD Documents

The main advantage of CIM JSON-LD over CIMXML is that JSON-LD terms and compact IRIs are dereferenceable IRIs, their IRI values are also dereferenceable pointing to resources in the document itself or other CIM JSON-LD documents.

Apart from marking the affiliation of terms to ontology either by using IRIs, compact IRIs or setting the default vocabulary (@vocab) in a CIM JSON-LD instance, the CIM profile ontology when dereferenced allows an application with reasoning capability to check semantic compliance of the contained structured data. Further, the implicit relationship between the profile schema and the instance is achieved by defining a profile as an ontology – a vocabulary of JSON-LD document, instead of an explicit one as defined in the typical CIM approach when using FullModel's Model.profile property. Moreover, FullModel's Model.profile information is now a surplus. An example of CIM JSON-LD document representing a FullModel in a single file, is shown in Fig. 9.

```
{ "@context": {
        "md": "http://example.com/ModelDescription/1#",
        "sp": "http://example.com/sp#",
        "@base": "http://example.com/s/model", ...},
  "@graph": [{
        "@id": "#_c9bed68d-f616-fc7a-1c1f-d4c825ac7272",
        "@type": "sp:Substation",
        "sp:IdentifiedObject.aliasName": "Altavilla",
        "sp:PowerSystemResource.voltage": "132000",
        "sp:Substation.operator": "Enel Distribuzione",
        "sp:Substation.source": "www.terna.it", ...
    }, ...
]}
```

Fig. 9 Excerpt of Linked Data Substation Model

Each CIM JSON-LD document has an assigned unique identifier. It is assumed that a CIM JSON-LD document is dereferenceable against that unique identifier. Also, the default document base is set by defining the base IRI within the context and corresponds to the unique identifier. This is important for retaining the same absolute IRIs in a case of a document location change. Compact IRIs are used for identification of resources residing in other CIM JSON-LD documents as shown in Fig. 10.

```
{   "@context": {
        "md": "http://example.com/ModelDescription/1#",
        "glp": "http://example.com/glp#",
        "sm": "http://example.com/s/model",
        "@base": "http://example.com/gl/model", ...},
    "@graph": [
     {  "@id": "#_78dff4b4-7e98-38a2-c470-17b49d63b90f",
        "@type": "glp:Location",
        "glp:IdentifiedObject.name": "Location way/161867071",
        "glp:Location.PowerSystemResources": "sm:#_c9bed68d-f616-
fc7a-1c1f-d4c825ac7272", ...
    }, ...
]}
```

Fig. 10 Excerpt of Linked Data Geographical Location Model

IV. CONCLUSION

The typical CIM approach of power network modeling meets today's utility integration needs. It assumes application of CIMXML, an RDF subset, in describing Smart Grid data. The defined RDF subset introduces limitations on Linked Data capability leaving references non-dereferenceable making CIM data not suitable for data exchange on the Web. As Smart Grid evolves together with the applied technologies, the improvement of the existing and the adoption of a new business processes becomes inevitable. The authors propose a new approach for CIM-based network model and Smart Grid data definitions using JSON-LD that allows for linking documents relying on RDF technology. With this approach CIM data can be easily published online as documents and/or stored in any triple store exposing its endpoints thus allowing semantic reasoners to infer CIM knowledge on the Web obeying the Linked Data principles. The future work is aimed towards linking the CIM to other domains.

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