ToCo: An ontology for representing hybrid telecommunication networks

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Abstract. The TOUCAN project proposed an ontology for telecommunication networks with hybrid technologies – the TOUCAN Ontology (ToCo), available at `http://purl.org/toco/`, as well as a knowledge design pattern `Device-Interface-Link (DIL)` pattern. The core classes and relationships forming the ontology are discussed in detail. The ToCo ontology can describe the physical infrastructure, quality of channel, services and users in heterogeneous telecommunication networks which span multiple technology domains. The DIL pattern is observed and summarised when modelling networks with various technology domains. Examples and use cases of ToCo are presented for demonstration.

Keywords: Linked data · semantic web · ontology · hybrid telecommunication network · knowledge based system

1 Introduction

The rapid growth in telecommunication services has resulted in today's network infrastructure being increasingly heterogeneous and complex [1–10]. State of the art network physical infrastructure is extremely complex, consisting of *routers, gateways, bridges, router servers, switches, firewalls, NATs, etc.* For traffic control, there are *packet shapers, packet sniffers, scrubbers, load balancers, etc.* Many of these devices differ from each other in relatively subtle ways. To compound matters, there are a variety of operators and equipment vendors for telecommunication networks, e.g., *HUAWEI, SAMSUNG, THREE, O2, CISCO, ERISSON, etc.*, who each develop and construct their own mechanisms and own versions of *configuration, description documents, technical specification, and software systems* all for devices with a similar functionality. Current *standardisation documents* of networks are also problematic. Multiple solutions and standards exist with limited differences. For example, there is a significant number of competing IETF RFCs (the proposals for internet technical standard documentation) providing solutions to similar questions [11–13].

This growing complexity coupled with the increase in telecommunication services requires the construction of a suitably abstracted knowledge base which is universally accepted and machine interpretable [14, 15, 3–10]. Current knowledge bases for telecommunication networks management are problematic [2, 16, 17]. Most of them are defined for a specific protocol and focused on a single network layer. Consequently, when a situation arises which is out of the scope of the protocol or when the protocol is replaced or updated, then these knowledge bases are not appropriate.

Through the use of Semantic Web technologies, telecommunication networks can be described with all of their complexity and associated relationships. Thus allowing network administrators to operate at an abstract level removed from the technical details of configuration. Computer-processable semantics would also allow telecommunication network application developers to collect, reason about, and edit the network and the data transmitted.

In this paper we propose and develop an OWL formal-structured ontology – TOUCAN Ontology (ToCo) to describe the resources available in telecommunication networks with heterogeneous technologies. The ontology has 84 concepts, 39 object properties, and 54 datatype properties. To develop a well-structured and formal ontology, we propose a knowledge pattern to describe networks in various kinds of technology domain, namely a `Device-Interface-Link (DIL)` pattern, which forms the top-level of the ToCo ontology.

The contributions of this paper are threefold. The main contribution is the ToCo ontology. The domain definition of ToCo is introduced in Section 2. An outline and the key modules of ToCo are presented in Section 3. The second contribution is the `DIL` pattern based on which ToCo is built. `DIL` pattern identifies and provides an important insight into the abstract and recurring knowledge pattern in networks with different technology domains. With the `DIL` pattern, the ontology developing processes for networks will be made clearer and more efficient. The third contribution is the examples of ToCo, describing networks with various technologies, and the use cases in which ToCo is used (Section 4). This is followed by a conclusion (Section 5).

2 Background and Requirements

2.1 Background

This ontology development is part of an ongoing project – The TOUCAN project[1], which is a five-year EPSRC project exploring an technology agnostic, future-proof infrastructure and service management for networks with heterogenous technologies. The project is initiated by the University of Bristol, University of Edinburgh, Heriot-Watt University, and Lancaster University, with network experts in various technology domains (optical network, LiFi network, WiFi network, and computer network, respectively). One of the tasks of TOUCAN project is to use semantic web technologies to develop an knowledge base for networks with heterogenous technology domains.

[1] TOwards Ultimate Convergence All Networks (TOUCAN), Grant No. EP/L020009/1

When developing ToCo, the 7-step ontology developing methodology discussed in [18] was adopted, due to its iterative approach which is suitable for modelling an ever-changing domain such as telecommunication networks. The evaluation of ToCo is carried out through use cases and problem-solving methods, as in [18].

Ontologies that have been proposed for telecommunication network are numerous in the literature [3, 4, 19–21, 9, 6, 22, 5, 7, 8, 10]. The most popular ones are summarised below.

Network Description Language [23]: NDL is the first description language to describe computer networks. It provides several sub-ontologies that can be used for that purpose: a *topology sub-ontology* that describes the basic interconnections between devices, a *layer sub-ontology* to describe technologies, a *capability sub-ontology* to describe network capabilities and a *domain sub-ontology* for creating abstracted views of networks and a *physical sub-ontology* that describes the physical aspects of network elements, like a component in a device [23].

Ontology for 3G Wireless Network [3]: This ontology is proposed for wireless network transport configuration. It consists of two sub-ontologies, domain ontology and task ontology [3].

Mobile ontology [4]: Proposed for the SPICE Project, the Mobile Ontology has directed considerable effort towards ontology standardisation [4]. It is proposed as a scalable solution with several pluggable sub-ontologies: services, profile, content, presence, context, communication resources sub-ontology.

Ontology for Optical Transport Network (OOTN) [19]: OOTN is an ontology for optical transport networks based on ITU-T G.805 and G.872 recommendations. It is a computational optical ontology [19].

Ontology adopted in "OpenMobileNetwork" [21]: "OpenMobileNetwork" is a linked Open Dataset for Mobile Networks and Devices. It also developed an open source platform that provides semantically enriched mobile network and WiFi topology resource in RDF [21]. The ontology adopted is published online[2] and is efficient and mature for the description of mobile network topologies. However, that also limits the ontology to the specific scenario (describing WiFi topology). For example, it cannot describe optical backbone networks or LiFi.

2.2 Research gap

As stated above, the ontologies proposed for network management are numerous. However, they are designed for specific tasks. There is no single "best" approach for the domain of network management. They are not yet able to provide a universally accepted knowledge base for telecommunication networks with hybrid technologies. There are three main reasons for this:

[2] `http://www.openmobilenetwork.org/ontology/`

– First, many network description ontologies are proposed for some particular applications, rather than for the overall network resources.

– Second, the evaluation of ontology is problematic. Although many evaluation theories have been put forward [24, 25], few reports detail how to carry out the evaluation step by step. Generally speaking, for network description ontologies, there are two approaches to evaluation. One is to discuss with experts in the specific field, the other is to apply it in a real-world application. To the best of our knowledge, very few use cases have been carried out in practice. Thus, it is difficult to determine if one particular ontology is superior to any other.

– The final reason lies in the ever-changing nature of communication technology. For example, wireless communication technology changes generation almost every decade. New technologies keep arising, and it is difficult to develop a standard vocabulary to describe them.

3 TOUCAN Ontology

The ToCo ontology, available at `http://purl.org/toco/`, is constructed into 8 modules, namely, `Device`, `Interface`, `Link`, `User`, `Service`, `Data`, `Time`, `Location`. These modules and their key relationships are shown in Figure 1. The full ontology consists of 84 concepts, 39 object properties, and 54 datatype properties.

The namespaces used in this paper are written as the prefixes shown in Table 1. The ToCo has been formally published with a creative commons license[3]. The design and logic have been scanned and checked by ontology pitfall scanner (OOPS)[4].

The ontology is able to describe the physical infrastructures of the hybrid telecommunication networks, including devices, interfaces, and links in networks of all technology domains in current telecommunication system. Quality of communication service can also be described, such as bandwidth, data rate, package loss, delay, etc., to give a detailed representation for the performance of a certain link. Finally, concepts of services provided by the telecommunication networks, and the users being served, are also included, as they are part of the telecommunication system.

ToCo holds an inclusive view of the telecommunication networks: *"devices with interfaces through which can connect."* Ontology engineering is at its heart a modelling endeavour [26]. During the modelling process, networks with different access technologies are observed to have been repeating structurally similar knowledge patterns, termed here as the Device-Interface-Link (DIL) pattern[5]. The set of classes and relations that jointly form the Device-Interface-Link pattern are shown in Figure 2. ToCo is built around this pattern. The pattern is developed based on the minimal ontological commitment to make it reusable for applications in variety of network technology domains.

[3] `https://creativecommons.org/licenses/by-sa/4.0/`
[4] `http://oops.linkeddata.es/`
[5] Published on `http://ontologydesignpatterns.org/`

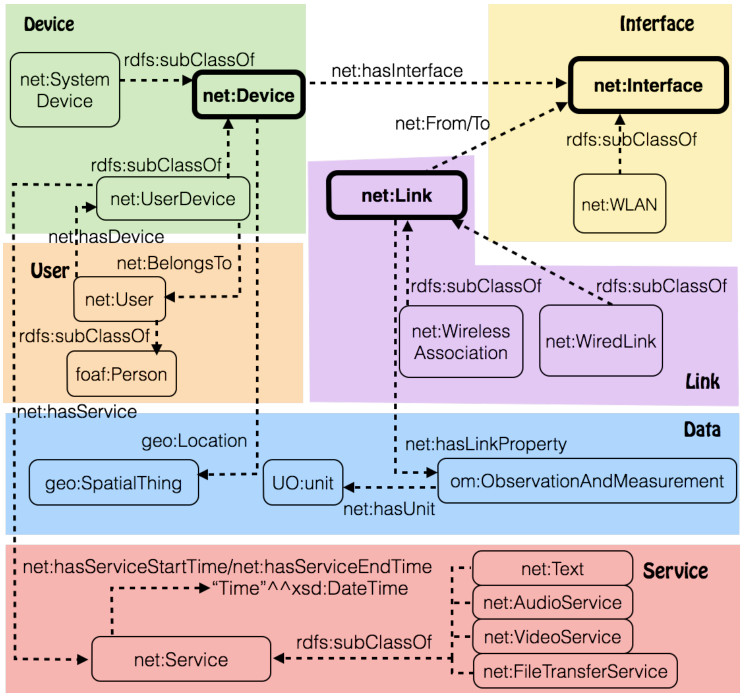

Fig. 1. The ToCo ontology, key concepts and relations, split by modules. The modules are divided by blocks with different colours. The central concepts are brought out by the DIL pattern.

The following section 3.1 describes the details of the `device`, `interface`, `link`, `user`, `data`, `and` `service` classes. Examples are given for each class to demonstrate its application, interaction with other classes.

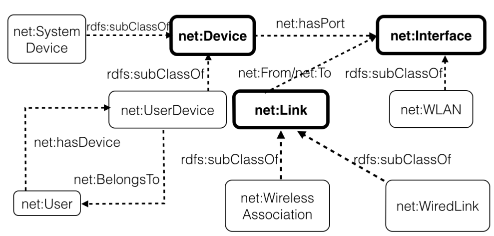

Fig. 2. The Device-Interface-Link Pattern (central concepts in bold).

ToCo can be seen from six perspectives:

Table 1. Prefixes and namespaces of the ToCo ontology.

Prefix	Namespace
net	`<http://purl.org/toco/>`
xsd	`<http://www.w3.org/2001/XMLSchema#>`
geo	`<http://www.w3.org/2003/01/geo/>`
foaf	`<http://xmlns.com/foaf/spec/>`
om	`<http://purl.oclc.org/net/unis/ontology/sensordata.owl/>`
UO	`<http://purl.obolibrary.org/obo/uo.owl>`
rdf	`<http://www.w3.org/1999/02/22-rdf-syntax-ns#>`
rdfs	`<http://www.w3.org/2000/01/rdf-schema#>`

A device perspective - focus on the devices in the network and their properties;
An interface perspective - focus on the interfaces on the devices, and their properties;
A link perspective - focus on a link, wired or wireless, between two interfaces, and its properties;
A user perspective - focus on a user of a user equipment, her information and properties;
A data perspective - focus on the data measured or observed out of a property;
A service perspective - focus on the service provided by the telecommunication system to users.

3.1 Ontology perspectives

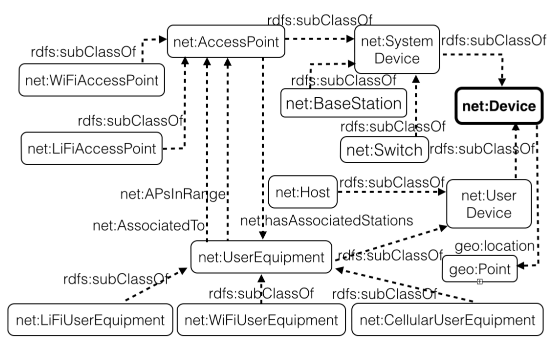

Fig. 3. Ontology view focusing on Devices.

Device A device (`net:Device`) is the device in the physical infrastructure of the telecommunication networks, with the ability of transmit and/or receiving signals in the form of electromagnetic wave (based on the frequency, could be microwave, millimeter wave, optical wave, etc.). Based on the function and role played in the telecommunication networks, devices can be divided into system device (`net:SystemDevice`) and user device (`net:UserDevice`). Moreover, the devices in networks of a specific technology domain are subclasses of the device (`net:Device`), for example, in wired network, there are hosts (`net:Host`) and switches (`net:Switch`); in LTE network, there are base stations (`net:BaseStation`) and user equipment (`net:UserEquipment`); in WiFi and LiFi networks, there are access point (`net:AccessPoint`), which can be further divided into WiFi access point (`net:WiFiAccessPoint`) and LiFi access point (`net:LiFiAccessPoint`). The ontology view of `Device` is shown in Figure 3.

Link Link (`net:Link`) is one of the most important concepts in telecommunication networks. The principal obligation of the telecommunication network is to establish a link and maintain the quality of the link. A link could be a wired cable (`net:WiredLink`), or a cluster of wireless connections (`net:WirelessAssociation`). Please note that `net:WiredLink` and `net:WirelessAssociation` are disjoint with each other, i.e., a link cannot be both at the same time.

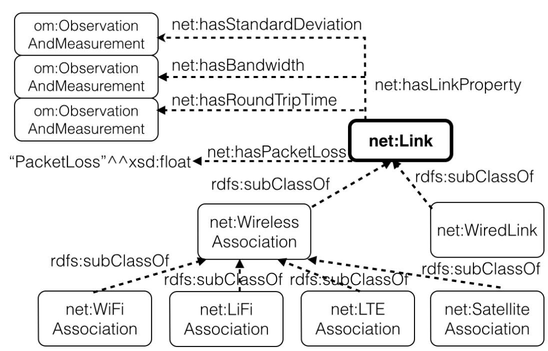

Fig. 4. Ontology view focusing on Links.

The properties of links determine the quality of a communication, for example, bandwidth (`net:hasBandwidth`), data rate (`net:hasDatarate`), transmit power (`net:hasTxpower`), receive power (`net:hasRecpower`), etc. An example of describing the bandwidth of a `Link` is shown below.

```
ex:link_1 a net:Link ;
 net:hasBandwidth ex:link_1_bw .
ex:link_1_bw a
 om:ObservationAndMeasurement ;
 net:hasValue "50"^^xsd:float ;
 net:hasUnit UO:0000325 .
```

It describes the fact that a link `link_1` has a bandwidth of $50MHz$. The ontology view of `Link` is shown in Figure 4.

Interface The important information for network routing is described as the properties of an interface, for example: IP address (`net:hasIP`), MAC address (`net:hasMAC`), antenna gain (`net:hasAntennaGain`), etc. The ontology view of `Interface` is shown in Figure 5.

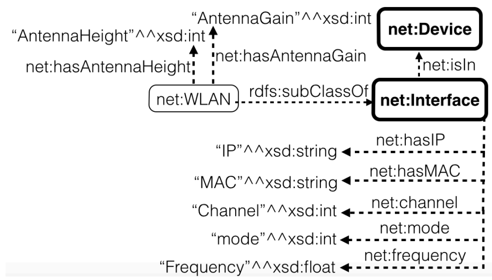

Fig. 5. Ontology view focusing on Interface.

User The user information in telecommunication networks is covered, e.g., `user id`, `name`, `join_date` `home_country`, `home_town`, etc. As the user is a human in real life, parts of the `foaf` ontology[6] is reused. The main relationship between `User` is with the `UserEquipment`:

```
net:User net:hasDevice net:UserDevice.
```

Some main concepts of `User` are shown in Fig. 6.

Data All the observation and measurement data, location and time information are described in the data module. General information, such as location, time, measurement, have previously been modelled by ontologies. Popular ontologies are reused here to describe the data. For example, the Units Ontology (UO)[7] is reused to describe the units of the data [27]. The SENSEI[8] observation and measurement ontology[9] is reused here to describe the observation results and measured data in telecommunication system. Location information are described with WGS84 ontology[10].

[6] `http://xmlns.com/foaf/0.1/`
[7] `http://purl.obolibrary.org/obo/uo.owl`
[8] A project of EU, `http://www.sensei-project.eu/`
[9] `http://purl.oclc.org/net/unis/ontology/sensordata.owl`
[10] `http://www.w3.org/2003/01/geo/wgs84_pos/`

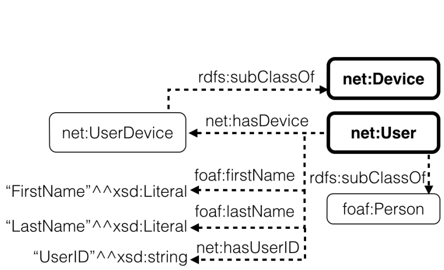

Fig. 6. Ontology view focusing on User.

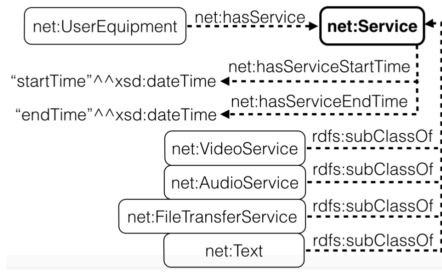

Fig. 7. Ontology view focusing on Service.

Service The service module describes the details of telecommunication services, e.g., voice session, video session, document transmission. Some concepts of the service module is shown in Figure 7.

4 Examples and use cases of ToCo

Examples are provided to demonstrate how networks within different technology domains are described with ToCo. From small-scale telecommunication networks such as vehicle-to-vehicle networks, smart home devices, to large-scale networks such as satellite networks can all be described with ToCo. The examples include: three network resource description examples for WiFi, LiFi, and computer network, respectively, two examples of network management task execution driven by ToCo, and a SDN flow description example.

4.1 Examples on Network Resource Description

To describe the information of a WiFi network, a simplified schema of a WiFi network is shown in Figure 8. The x-axis and y-axis denote the longitude and latitude of a planar graph. The circles with different colours represent WiFi access points (circles in blue) and user equipments like phones, laptops (circles in red), with the area of circles denotes the cover range of signal. If the centre of a red circle is in range of the blue circle, it means this user equipment is in the range of the WiFi access point. Some of the main triples are shown in the example in Listing 1.1.

```
ex:wifi20 a net:WiFiAccessPoint ;
    net:driver "nl80211"^^xsd:string ;
    net:hasWLAN ex:wifi20-wlan1 ;
    net:ssid "wifi"^^xsd:string ;
    net:stationsInRange ex:sta1, ex:sta2, ex:sta3,
        ex:sta4, ex:sta5, ex:sta6 ;
    net:hasAssociatedStations ex:sta1 ;
    geo:location ex:wifi20_location .
```

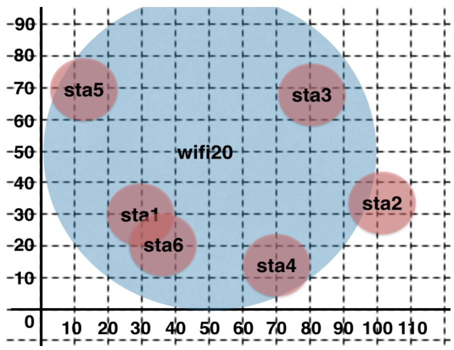

Fig. 8. The schema of a WiFi network with one access point “wifi20” and six mobile stations “sta1” to “sta6”.

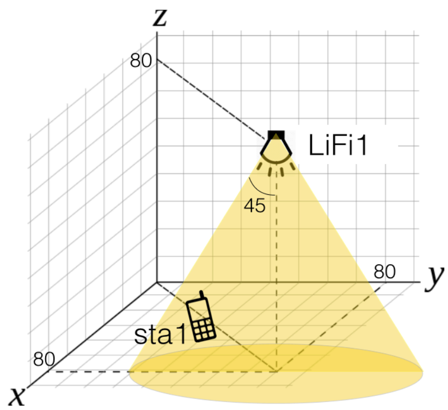

Fig. 9. A schema of a LiFi network with one access point and one mobile station.

```
ex:wifi20_location geo:alt  "0.0"^^xsd:float ;
    geo:lat "50.0"^^xsd:float ;
    geo:long "50.0"^^xsd:float .

ex:sta1 a net:WiFiUserEquipment ;
    net:hasWiFiWLAN ex:sta1-wlan0 ;
    net:hasName "sta1"^^xsd:string ;
    geo:location ex:sta1_location .

ex:sta1_h1 a net:WiFiAssociation ; net:from ex:sta1 ;
    net:to ex:h1 ; net:hasBandWidth ex:sta1_h1_bw .
ex:h1_sta1_bw a om:ObservationAndMeasurement ;
    net:hasUnit UO:0000325 ; net:hasValue "51.5"^^xsd:float .
```

Listing 1.1. Part of the RDF knowledge graph for a WiFi network. The knowledge of the stations in range, stations associated, location of a WiFi access point, and the bandwidth of the wireless link between the WiFi access point and a user device “sta1” is described.

Figure 9 shows a three-dimensional coordinate where a LiFi access point “LiFi1” and a user device “sta1” are located. The information of access point, such as, the half intensity angle, optical transmitted power, mobile stations in range, and location is represented in the Listing 1.2, as well as the information of the association between “LiFi1” and “sta1”, such as distance, bandwidth, incident angle, and radiance angle.

```
ex:LiFi1 a net:LiFiAccessPoint ;
    net:hasGainOfOpticalFilter "1"^^xsd:int ;
    net:hasHalfIntensityAngle "45.0"^^xsd:float ;
    net:hasOpticalTransmittedPower "0.3"^^xsd:float ;
```

```
    net:hasRespansivity "1"^^xsd:float ;
    net:stationsInRange ex:sta1 ;
    geo:location ex:LiFi1_location .

ex:sta1 a net:LiFiUserEquipment ;
    net:hasFieldOfView "90"^^xsd:float ;
    net:hasGainOfConcentrator "1"^^xsd:float ;
    net:hasLiFiWLAN ex:sta1_wlan0 ;
    geo:location ex:sta1_location .

ex:sta1_wlan0 a net:WLAN ;
    net:hasWirelessAssociation ex:sta1_ap1 .

ex:sta1_ap1 a net:LiFiAssociation ;
    net:hasDistance "9"^^xsd:float ;
    net:hasIncidentAngle "15"^^xsd:float ;
    net:hasRadianceAngle "27.5"^^xsd:float ;
    net:hasBandwidth ex:sta1_ap1_bw .
ex:sta1_ap1_bw a om:ObservationAndMeasurement ;
    net:hasValue "5"^^xsd:float ; net:hasUnit UO:0000325 .
```

Listing 1.2. Part of a RDF knowledge graph for a LiFi. The knowledge about the half intensity angle, optical transmitted power, mobile stations in range, and location of a LiFi access point is represented, as well as the knowledge of the association between "LiFi1" and "sta1", such as distance, bandwidth, incident angle, and radiance angle.

To describe a wired computer network, some examples of the triples are shown in the Listing 1.3. Knowledge about the interfaces, e.g., IP address, MAC address, and link information such as bandwidth are described.

```
ex:s1 a net:Swtich ;
net:hasInterface ex:s1_eth0, ex:s1_eth1, ex:s1_eth2 .

ex:h1 a net:Host ;
net:hasInterface ex:h1-eth0, ex:h1-eth1, ex:h1-eth2 .

ex:h1-eth0 a net:Interface ; net:hasIP "10.0.0.1" ;
        net:hasMAC "f6:8a:d8:0b:6d:e7" ;
        net:isIn ex:h1 .

ex:s1_eth1 net:hasLink ex:s1_h1 .
ex:s1_h1 a net:WiredLink ; ex:hasBandwidth ex:s1_h1_bw .
ex:s1_h1_bw a om:ObservationAndMeasurement ;
    net:hasValue "50"^^xsd:float ;  net:hasUnit UO:0000325 .
```

Listing 1.3. Part of the RDF knowledge graph of a computer network, describing the knowledge about the interfaces and links, e.g., IP address, MAC address, and bandwidth.

Another example relates to the software defined network (SDN). SDN is about making decisions on how a flow (or a connection) is transmitted across the whole network. Thus, `Flow` is the key concept in SDN. ToCo is able to describe the properties of the `Flow`, as shown in the Listing 1.4.

```
ex:s1 net:hasFlow ex:s1_flow1 .
ex:s1_flow1 a net:Flow ; net:idleTimeout 0 ; net:tableId 0 ;
        net:flags 0 ;  net:hardTimeout 0 ; net:priority 0 ;
        net:cookie 2 ; net:hasAction  ex:s1_flow2_action0 .

ex:s1_flow2_action0 a net:Output ; net:toPort ex:s1_port1 .
```

Listing 1.4. Part of the knowledge graph of a Flow in SDN. The information of a Flow is mainly described.

4.2 Examples on Network Management Task Execution with ToCo

With the knowledge base generated by ToCo, semantic queries can be designed to answer high level network management questions such as, "Which switch is host1 connected to?", "Find me the hosts in the network that are blocked from the others." or even more complicated one such as "Find me all the hosts connected to switch_1 and switch_3, if they are not host_3 or host_5," as shown in Algorithm 1.

```
SELECT ?port2 ?macAddr1 ?port4 ?macAddr2
WHERE {
  ?p1 net:isIn net:s1. ?l1 net:from ?p1; net:to ?p2. filter (?p1 != ?p2).
  ?p2 net:isIn ?h1. ?h1 rdf:type net:Host. filter(?h1 != net:h3). ?p2 net:hasMAC
?macAddr1.
  bind(strafter(str(?p2), "http://purl.org/toco/") as ?port2)
  ?p3 net:isIn net:s3. ?l2 net:from ?p3; net:to ?p4. ?p4 net:isIn ?h2.
  ?h2 rdf:type net:Host. filter(?h2 != net:h5)
  ?p4 net:hasMAC ?macAddr2. filter (?p3 != ?p4). }
  bind(strafter(str(?p4), "http://purl.org/toco/") as ?port4)}
```

Algorithm 1: SPARQL query to get all the hosts of switches "s1" and "s3" and their port number except the host "h3" and "h5".

The query in Algorithm 1 has been used in one project to build firewalls between customer selected hosts. For example, by passing the query result of Algorithm 1 to a firewall building function, we can build a firewall between switches "s1" and "s2", while the communication between hosts "h3" and "h5" (which are in the domain of "s1" and "s2" respectively) is not affected.

Another example for flow consistency detection in SDN is provided in Algorithm 2 [28]. To accomplish an autonomic network management system, the system needs to be self-aware. Thus, it should be able to learn what is happening inside, detect changes, decide what to do, and fix the problem itself. In SDN, flows are adopted to route packets to/from specific port. If a port accidentally fails, the flows related (the flows with instructions to send packet from/to this port) should be revised (stop sending packets to this failed port) correspondingly.

```
SELECT DISTINCT ?in_port ?to_port
WHERE {
  ?s a net:Switch; net:hasFlow ?f.
  ?f a net:PathFlow; net:inPort ?in_p; net:hasFlowAction ?a. ?a net:toPort ?to_p.
  ?p1 a net:Interface; net:isIn ?s; net:hasInterfaceName ?in_p; net:isUP ?isUp1.
  ?p2 a net:Interface; net:isIn ?s; net:hasInterfaceName ?to_p; net:isUP ?isUp2.
  filter (?isUp1 = "false"^^xsd:boolean || ?isUp2 = "false"^^xsd:boolean)}
```

Algorithm 2: SPARQL query for automatic flow update. A non-empty result returned by the query denotes that there are inconsistent flows.

4.3 Use cases

ToCo has been used in several applications for autonomic network management and disaster response. These use cases are: a network autonomic management system "SEANET" [28], a network policy-based management application "ReasoNet" [29], a shipwreck early detection use case "lost silence" [30], and "SARA" [31], a resource allocation application in post-tragedy situation.

SEANET [28] is a technology independent, knowledge-based network management system. The ToCo ontology and the DIL pattern are the key to the success of SEANET. It adopts the ToCo ontology as the language to build the knowledge base for telecommunication networks, and use SPARQL to query over the knowledge base. A technology-independent API is also provided by SEANET to implement autonomic network management tasks for customers without knowledge of semantic web or telecommunication network.

A policy based SDN network management approach "ReasoNet" [29] leads by researchers from Lancaster University, U.K., adopts concepts of ToCo to model their knowledge base on Ryu controller (a SDN controller). It can support network knowledge inference and integrity/consistency validation. Two popular control applications, a learning switch application and a QoS-oriented declarative policy engine, are presented to demonstrate the scalability which is comparable with current SDN network operation systems.

In lost silence [30], a methodology was illustrated to detect shipwreck incidents immediately (with the delay in the order of milliseconds), by processing semantically annotated streams of data in cellular telecommunication systems. In lost silence, live information about the position and status of phones are encoded as RDF streams, adopting part of the concepts of ToCo's `Device` module. The approach is exemplified in the context of a passenger cruise ship capsizing. However, the approach is readily translatable to other incidents. The evaluation results show that with a properly chosen window size, such incidents can be detected efficiently and effectively.

5 Conclusions

We developed the ToCo ontology, for hybrid telecommunication networks. ToCo is able to describe the devices, interfaces, and links inside the telecommunication system, and the measurement of the link properties (or in other term, channel QoS), without technology specificity. The information of users and services are also represented. ToCo also covers the main part of the SDN properties.

While modelling the knowledge in networks, an ontology design pattern, the `DIL` pattern, has been observed and summarised. It provides a simple and efficient insight into the structure of ontologies for all kinds of linked devices, making the ontologies modelling process efficient, by avoiding some repetitive work.

Eight physically separated modules are arranged in ToCo, focusing on different aspects, namely, `Device`, `Interface`, `Link`, `User`, `Service`, `Data`, the key modules of ToCo are `Device`, `Interface`, `Link`. The demonstrations conducted on four networks with different technologies have shown that ToCo is able to described these networks. Concepts from existing ontologies are reused, e.g., `foaf` for user presentation, `wgs84` for location.

ToCo is currently used in a number of projects. It is evaluated mainly based on the feedback from the projects. As the telecommunication network technologies are experiencing rapid developing, the ToCo ontology will keep evolving at the mean time. Now ToCo has been published via Github, thus it is open to public edition via Github pull requests, the authors are in charge of the edit inspection. We are open to more suitable approaches of the ontology publication and evolving in the future.

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