Ontology for Knowledge Graphs of Telecommunication Network Monitoring Systems

Igor Kulikov[1](✉), Alexander Vodyaho[1], Elena Stankova[2], and Nataly Zhukova[3]

[1] Saint-Petersburg Electrotechnical University "LETI", Saint-Petersburg, Russia
[2] Saint Petersburg State University, Saint-Petersburg, Russia
[3] St. Petersburg Federal Research Centre of the Russian Academy of Sciences (SPCRAS), Saint Petersburg, Russia

Abstract. When Knowledge Graphs (KG) are used in practice, in particular for complex objects modeling, Semantic web recommends building KGs using existing common and domain ontologies as the base ontologies for modeling and extend them when developing new applications. In this work, detailed ontology for telecommunication networks (TN) monitoring system based on KG is discussed. The proposed ontology uses common ontologies and TN domain ontologies like Telecommunication Services Domain Ontology (TSDO) and TOUCAN Ontology (ToCo) as basic ontologies. To build the required ontology TSDO is extended on application level, in particular, new sub-ontologies for subdomains tasks solving are added. The case study of creation an ontology for TN monitoring system of a Cable TV operator is introduced. The developed ontology is described using Web Ontology Language (OWL).

Keywords: Knowledge graph · Dynamic network · Monitoring system · Domain ontology · Semantic web

1 Introduction

Typically, telecommunication network monitoring systems are designed to solve the following tasks [1]:

a) network performance monitoring;
b) emergency monitoring;
c) user account monitoring.

There are a considerable number of different available open source and commercial monitoring tools [2]. However modern TN have dynamic structure and used monitoring systems must be reconfigured when TN structure changes. Also, there are monitoring tasks that need usage of several TN models, i.e. topology model and billing model for

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solving them. Traditional monitoring systems cannot deal with these tasks without their re-design. For solving the tasks TN monitoring systems based on knowledge graphs were proposed [3]. This new approach allows efficiently solve monitoring tasks in practice. The article [5] presented the architecture of a monitoring system based on a knowledge graph, however, the issues of developing ontologies for KG building require additional study. This article explores the following aspects of ontology building:

a) definition of the problem and requirements to ontologies used for KG building;
b) design of the proposed ontology and its representation in OWL;
c) methods for the ontology integration and enrichment;

Also in the article an example for Cable TV operator sub-domain ontology for TN monitoring system is given.

2 Problem Definition

Based on the scope of the tasks solved by monitoring systems based on KG, the following requirements to the developed ontology are defined:

- TNs have complex dynamic structure, the main source of information about them is operational data received from the networks. Ontology must provide possibility of describing heterogeneous static and dynamic data about TN, including the network structure and state that are changing in time.
- TN operators business processes have high complexity, their execution require close interconnections between multiple information systems, including 3rd party systems. It is necessary to assure integration of the developed ontology with other ontologies that are used by TN operators.
- The majority of TN networks have peculiar features defined by target groups of subscribers, technical resources, etc. These features are essential for solving monitoring tasks. A possibility for ontology extension with specific data about TN must be provided.
- The developed ontology should allow use standard Symantec web toolset for building and executing SPARQL [4] requests and for logical inference. It must be possible to use existing methods for ontologies integration and enrichment.

The following standard ontology metrics are used for developed ontology evaluation: Axioms count, Logical axioms count, Declaration axioms count, Class/Data Property/Data Property/Individual count, DL Expressivity [33].

The proposed ontology is designed as a layered ontology that consists of the following levels: core ontologies level, domain ontologies level and application ontologies level [11, 19–22]. It is based on already existing ontologies. Ontologies integration is supported on the level of core and domain ontologies, ontology extension is assumed on application ontology level.

3 Related Works Analysis

Ontology is used as the vocabulary, where a set of classes and relations between these classes in a domain are represented. This representation has a formally defined and universally agreed structure [15–18]. The main purpose of developing ontology for KGs is knowledge sharing and reusing [12]. Ontology and its instances can be represented as a domain knowledge base. For TN domain, the ontology describes a set of network nodes, such as switches, routers, storage devices, and links between them.

3.1 Telecommunication Network Ontologies

There is a number of existing ontologies developed for TN domain, which can be considered:

- **Network Description Language.** Network Description Language (NDL) is used to describe sub-ontologies. There are a topology sub-ontology - describes interconnections between network devices; a layer sub-ontology - describes technologies; a capability sub-ontology - describes network capabilities; a domain sub-ontology - creates abstracted views of TN; a physical sub-ontology - describes the physical views of TN elements [7].
- **Telecommunications Service Domain Ontology (TSDO)** defines concepts, relationships to describe knowledge about telecom service domains and supports functional/non-functional property descriptions. TSDO is based on the semantic description approach (TelecomOWL-S) to telecommunication network services building which assumes extension of OWL-S [8]. This enables accurate description and matching of telecom network services with the annotated semantic information in an open and integrated network [9].
- **Ontology for 3G Wireless Network** [10]. This ontology is developed for wireless network transport configuration. The ontology includes two sub-ontologies: domain ontology and task ontology.
- **Mobile ontology** [11]: The mobile Ontology provides a possibility to restructure ontologies. It is a scalable solution with several pluggable sub-ontologies: services, profile, content, presence, context, communication resources sub-ontology [12].
- **Ontology for Optical Transport Networks (OOTN)** [13]: There is a low-level ontology for optical transport networks based on ITU-T G.805 and G.872 recommendations.
- **Ontology adopted in "OpenMobileNetwork"** [14]: There is a linked Open Dataset of Mobile Networks and Devices. This dataset is developed on an open-source platform that provides semantically enriched mobile network and WiFi topology resource description in Resource Description Framework (RDF). The ontology is published online.
- **TOUCAN Ontology (ToCo)** [26]. One of the modern structured TN domain ontologies.

3.2 Ontology Structures and Examples

Based on [11, 19–22] the ontologies can be allocated into three levels, the upper-level ontologies (or core ontologies), the lower-level ontologies (or domain ontologies), and the application ontologies. The upper-level ontology should be quite compact, as domain ontologies inherit its classes and properties [13, 25]. The most general classes of the particular domain ontology are placed in upper-level ontology. The upper-level ontology bridges the gap between different domains. The lower-level ontology can be considered as a domain-specific part of the vocabulary. In general, the lower-level ontologies are not exposed because they contain detailed information about the domain. Additional details about the domain are placed in application level ontology. In fact, an application ontology is not really an ontology, due to this type of ontologies is not shared and just represents a vocabulary for a specific application or system [23, 24].

There are two TN domain ontologies that are most interesting for designing the proposed ontology: TSDO and ToCo.

TSDO ontology is proposed in [9]. In this ontology semantics for Parlay-based services to describe telecommunication networks and the Internet is applied. An OWL-S-based semantic description approach for telecommunication network services description is presented, which is enabled by the telecommunication service domain ontologies to address the semantic interoperability between services. In the article [6] Xiuquan Qiao et al. introduce detailed description of Telecommunications Service Domain Ontology (TSDO) and methods of its modelling.

TOUCAN (ToCo) ontology is presented by Qianru Zhou et al. in [26] as ontology for telecommunication networks. The Device-Interface-Link (DIL) ontology design pattern is also described by authors in the same article. This development is a part of an on-going project which is addressing the convergence of telecommunication networks across multiple technology domains. Build around the DIL pattern, the ToCo ontology describes the physical infrastructure, users and quality of channels, services in heterogeneous telecommunication networks.

Reviewed approaches and domain ontologies provide the base for development of an ontology for TN monitoring systems based on knowledge graphs.

3.3 Ontologies for Knowledge Graphs

H. Paulheim [34] introduces the following KG definition: "A knowledge graph (i) mainly describes real world entities and their interrelations, organized in a graph, (ii) defines possible classes and relations of entities in a schema, (iii) allows for potentially interrelating arbitrary entities with each other and (iv) covers various topical domains".

KGs provides flexible mechanism for building TN models which can be used for solving analytical, management and prediction tasks [3]. TN models based on KGs can be built and re-built using algorithms with low computational complexity that allow use them for TN monitoring.

Ontologies define the vocabulary for knowledge graphs. Usage of ontologies for KGs allows describe heterogeneous static and dynamic data about TN using ontology classes, relations and attributes. Usage of ontologies also allows integrate information systems based on KG. Ontologies can be extended quite easy by adding new classes, relations and attribute. In addition, ontology-based KG design allows use standard semantic web toolset including SPARQL for data retrieving.

4 Proposed Ontology

4.1 Core Ontologies and Domain Ontologies Extension

The layered structure of the proposed ontology is shown in Fig. 1.

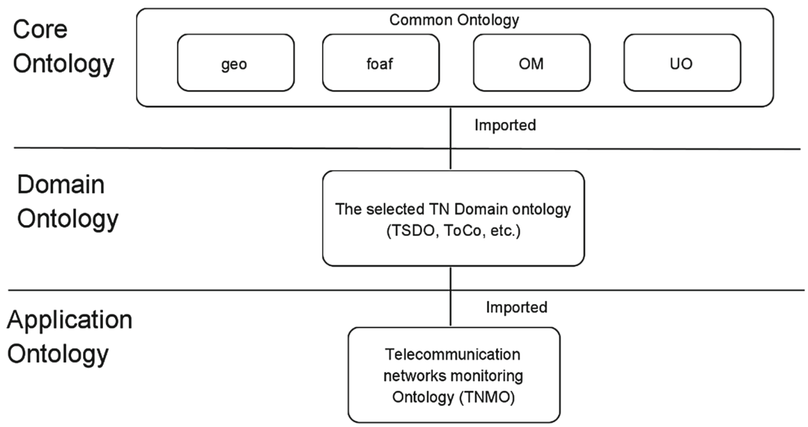

Fig. 1. The layered ontology for TN monitoring systems based on knowledge graphs.

There following core and domain ontologies are used for building the suggested ontology:

- Geo – Basic Geo (WGS84 lat/long) Vocabulary [27].
- FOAF - Friend of a Friend ontology [28].
- OM - Ontology of units of Measure (OM) [29].
- UO - Units of measurement ontology (UO) [30].
- TN Domain Ontology – any of the already developed TN domain ontologies, e.g. TSDO or ToCo.

The structure of the suggested ontology is multilevel and consists of core ontology level, domain ontology level and application ontology level. The set of common core ontologies are represented in the Fig. 1. On the domain level it is suggested to use TSDO or ToCo ontology. Domain ontologies are used as is. The core level ontologies are imported to the domain ontology. For the application level the new Telecommunication Network Monitoring Ontology (TNMO) is proposed.

For purpose of linking domain layer and application layer, the set of domain ontology entities are chosen for further linking with application ontology entities using object preferences mechanism. The following TN domain ontology entities are chosen as points for linking to TNMO:

- Device –any TN device;
- Link – wired or wireless TN link;
- Interface – any TN interface;
- Service – any TN service;
- Data – any data unit in TN (can be described by core ontology).

In TNMO the set of entities and links depend on the tasks solved by TN monitoring systems. Among the main subjects for monitoring in TN are:

- User actions;
- TN events;
- TN devices parameters.

TMNO oriented on solving the enumerated tasks is shown in Fig. 2.

To solve various monitoring tasks TNMO assumes import of different domain ontologies, thus, TNMO requires minimum redesign for adaptation to any domain task.

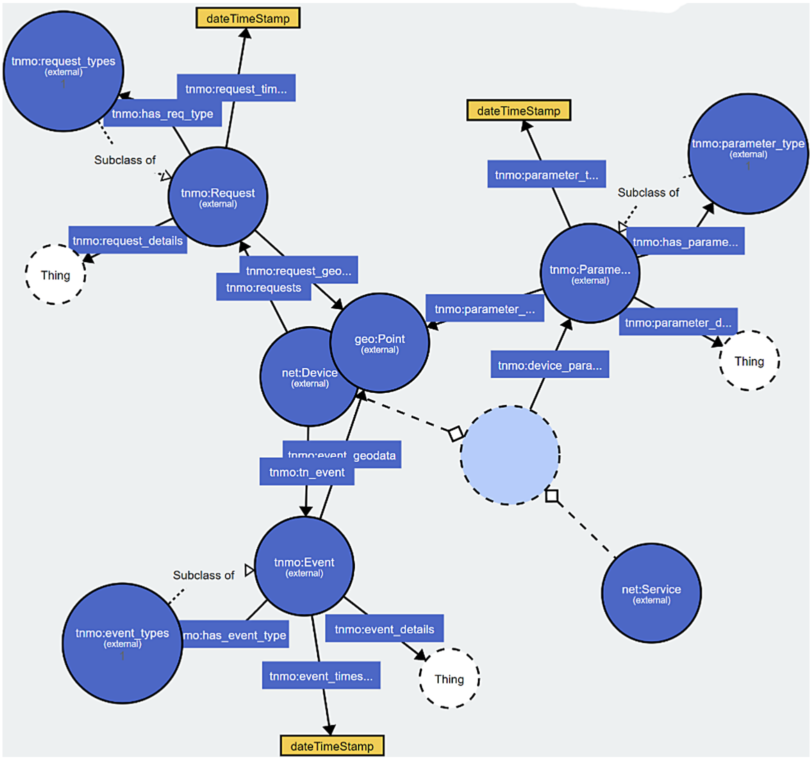

Fig. 2. TNMO ontology visualization

The description of the TMNO entities is given in Table 1.

Table 1. TNMO ontology description

Ontology entries	Entry type	Description
tnmo:Request	Class	Entity which contains detailed information about user request or actions
tnmo:Event		Entity which contains detailed information about TN event or failure
tnmo:Parameter_M		Entity which contains detailed information about TN devices monitoring parameters
tnmo:event_types		Defines the type of TN event or failure
tnmo:parameter_type		Defines the particular monitored parameter
tnmo:request_types		Defines the particular type of user request or monitored user action
net:Device		ToCo domain ontology entity: TN Device
net:Interface		ToCo domain ontology entity: TN Interface
net:Service		ToCo domain ontology entity: TN Service
net:User		ToCo domain ontology entity: TN User
geo:Point		GEO common ontology entity: geographical coordinates
tnmo:device_parameter	Object property	Specifies that connected entity defines an entry of TN devices monitored parameters
tnmo:event_details		Specifies that connected entity defines detailed information about TN event or failure
tnmo:event_geodata		Specifies the event geodata
tnmo:has_event_type		Specifies the event type
tnmo:has_parameter_type		Specifies the monitored parameter
tnmo:has_req_type		Specifies the user request or action type
tnmo:parameter_detailes		Specifies that connected entity defines detailed information about TN devices monitored parameters
tnmo:parameter_geodata		Specifies the monitored device geodata
tnmo:request_details		Specifies that connected entity defines detailed information about user request or action
tnmo:request_geodata		Specifies user device geodata
tnmo:requests		Specifies that connected entity defines an entry about user request or actions
tnmo:tn_event		Specifies that connected entity defines an entry about TN event or failure
tnmo:event_timestamp	Data property	Specifies the TN event timestamp
tnmo:parameter_tinestamp		Specifies the timestamp of monitored parameter
tnmo:request_timestamp		Specifies the user request or action timestamp

Application level ontology that was built for solving monitoring tasks is presented on Fig. 3, 4, and 5.

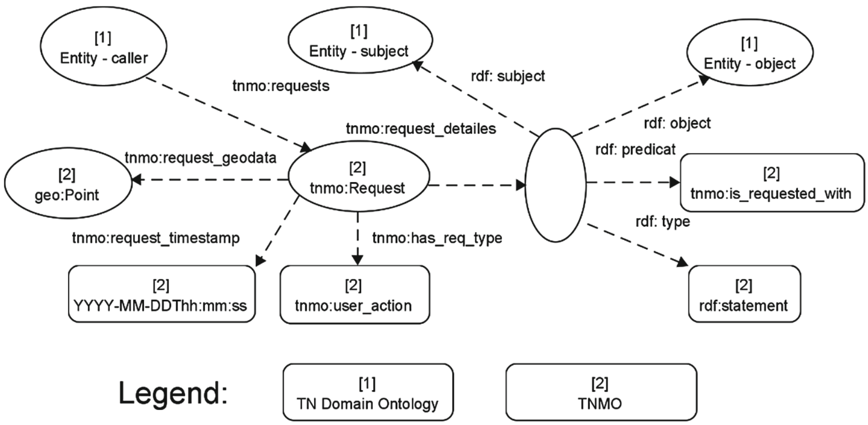

Fig. 3. Ontology for processing a user action in TN monitoring systems based on knowledge graph.

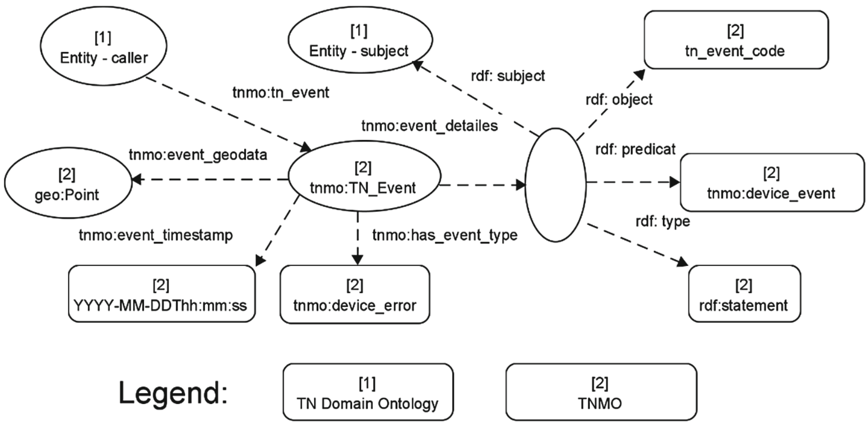

Fig. 4. Ontology for processing network events in TN monitoring systems based on knowledge graph.

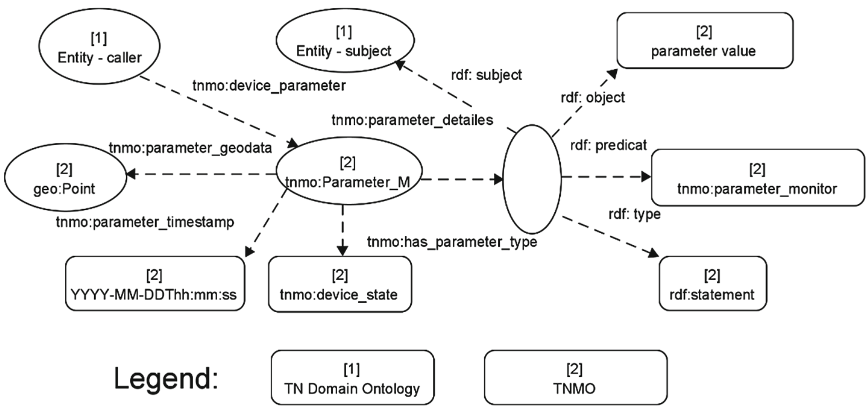

Fig. 5. Ontology for processing device parameters monitoring in TN monitoring systems based on knowledge graph.

4.2 OWL Representation

OWL representation of main classes of TNMO are below:

```
<!-- http://127.0.0.1/tnmo/Event -->
   <owl:Class rdf:about="http://127.0.0.1/tnmo/Event">
   <rdfs:subClassOf rdf:resource="http://www.w3.org/2002/07/owl#Thing"/>
   <rdfs:label>tnmo:Event</rdfs:label>
</owl:Class>

<!-- http://127.0.0.1/tnmo/Parameter_M -->
<owl:Class rdf:about="http://127.0.0.1/tnmo/Parameter_M">
   <rdfs:subClassOf rdf:resource="http://www.w3.org/2002/07/owl#Thing"/>
   <rdfs:label>tnmo:Parameter_M</rdfs:label>
</owl:Class>


<!-- http://purl.org/toco/Device -->
<owl:Class rdf:about="http://purl.org/toco/Device">
   <rdfs:label>net:Device</rdfs:label>
</owl:Class>

<!-- http://purl.org/toco/Service -->
<owl:Class rdf:about="http://purl.org/toco/Service">
   <rdfs:label>net:Service</rdfs:label>
</owl:Class>

<!-- http://purl.org/toco/User -->
<owl:Class rdf:about="http://purl.org/toco/User">
   <rdfs:label>net:User</rdfs:label>
</owl:Class>

<!-- http://127.0.0.1/tnmo/Request -->
<owl:Class rdf:about="http://127.0.0.1/tnmo/Reques">
   <rdfs:label>tnmo:Request</rdfs:label>
</owl:Class>

<!-- http://www.w3.org/2003/01/geo/wgs84_pos#Point -->
<owl:Class rdf:about="http://www.w3.org/2003/01/geo/wgs84_pos#Point">
   <rdfs:label>geo:Point</rdfs:label>
</owl:Class>
```

OWL representation of TNMO is available in the GitHub repository [32].

4.3 Ontologies Integration

TNMO can be integrated with different TN domain ontologies used by operators as shown in Fig. 6.

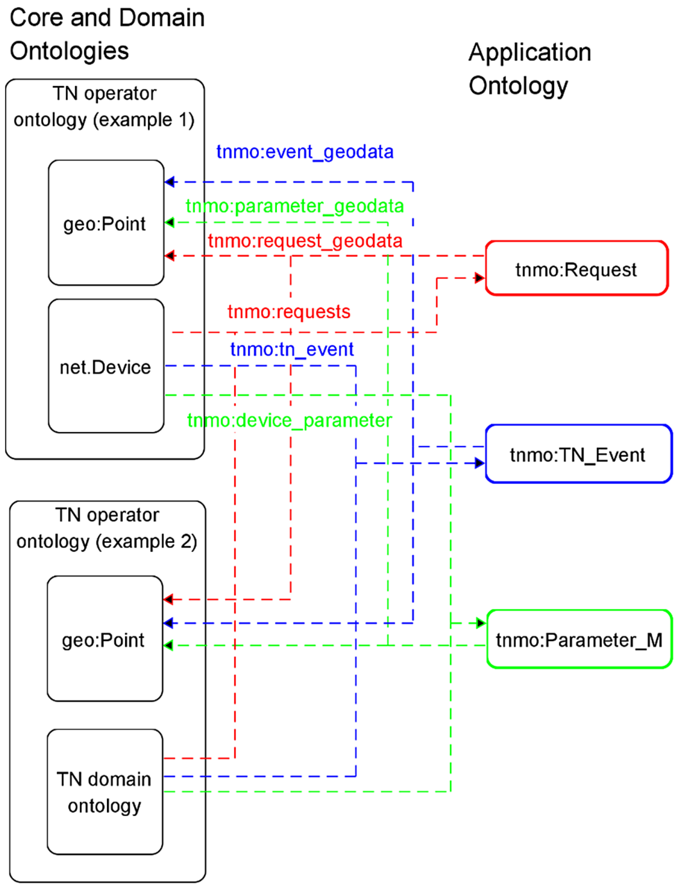

Fig. 6. Ontologies integration.

Integration of the developed TNMO application level ontology with other TN domain ontologies is based on using the similarity of the definitions of the subject area main entities (e.g. TN devises, users, services and interfaces). The ontologies integration methodologies are described in [35].

4.4 Methods of Ontology Enrichment

Ontology enrichment is the process of an ontology extending through adding new elements, relations and rules (Fig. 7). It is performed every time when the existing domain knowledge does not allow use data received from TN.

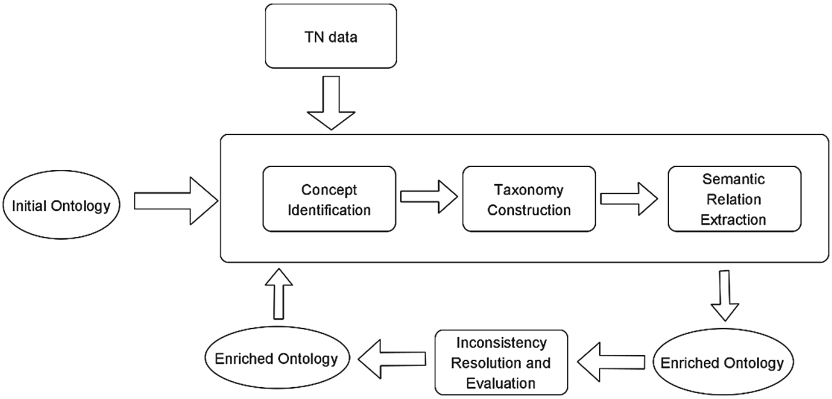

Fig. 7. Ontology enrichment method

Since new concepts and relations can be added during enrichment, the structure of the ontology can change [31]. Ontology enrichment cannot be full automated and remains typically a semi-automated procedure. It requires manual intervention of domain experts in order to review and accept or reject the system's proposals.

5 Case Study

5.1 Use-Case

Business Task: A TN operator uses a network monitoring system based on KG. A telecommunication network provides services, applications, and sells access to content. The operator defines a new requirement to extend the information about TN that is contained in the corporate knowledge graph (devices statistic, TN events and other monitoring data) with additional analytical data (geographical data, devices models, users tariff etc.). These parameters allow increase operativeness of TN issues and failures solving. To solve the task, the application-level TN monitoring ontology was developed and integrated with domain ontology.

Initial Data: The devices used are both stationary and mobile. The description of data used, data sources and data channels are presented in Table 2.

All this data must be collected, placed in the TN monitoring ontology and provided to the operator.

Task Detail: In the considered use case the following sub-tasks are resolved:

- Create TNMO based on domain ontology (ToCo [26]) for this case study;
- Check the developed ontology against requirements;
- Create knowledge representation of the monitoring data.

Table 2. The used data, sources and channels

Monitored parameter	Data source	Used data channel
Subscriber's service request	User action on subscriber device	Monitoring agent on subscriber device create and send to monitoring system the data pack with service request detail
Subscriber's device model	TN management system	This information is available in the KG as part of TN graph model
Subscriber's device geolocation	Subscriber's device geolocation service	Monitoring agent on subscriber device create and send to monitoring system the data pack with the device geolocation
TN device failure	TN device health checking system/TN monitoring system	Health checking system/Monitoring agent on TN device create and send to monitoring system the data pack with the failure detail

5.2 The TNMO Ontology

The suggested application level ontology is shown in Fig. 8.

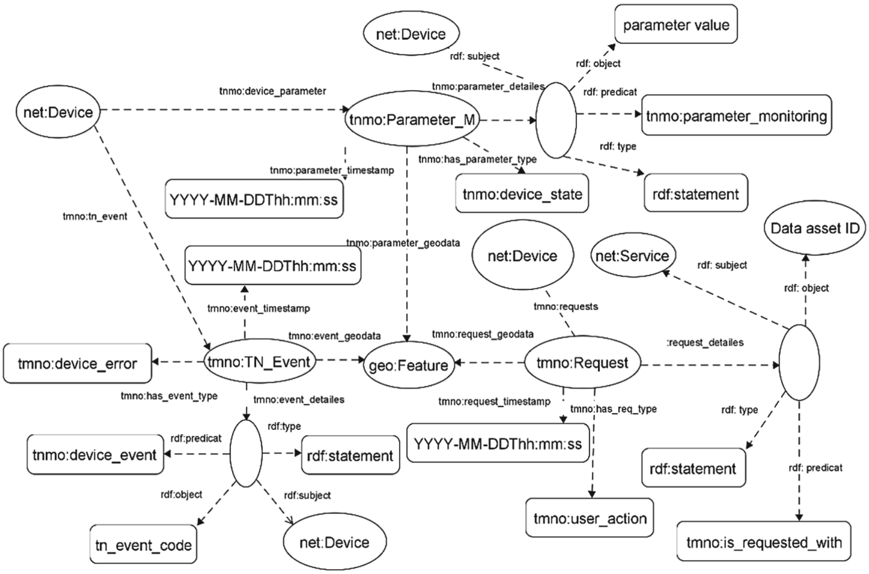

Fig. 8. The structure of the TNMO ontology.

This ontology is designed for solving the following TN monitoring tasks: collection data of user's actions and requests, TN events and failures and monitoring of TN devices parameters. The developed TNMO ontology is available on GitHub [32].

5.3 Ontology Metrics

The GEO core ontology, ToCo ontology and developed TNMO ontology metrics are shown in Table 3.

Table 3. Ontologies metrics

#	Ontology metrics	GEO	ToCo	TNMO
1	Axioms	28	725	128
2	Logical axiom count	2	303	57
3	Declaration axioms count	2	205	35
4	Class count	2	85	13
5	Object property count	1	41	13
6	Data property count		54	4
7	Individual count		1	6
8	Annotation property count	10	17	3

6 Conclusion

The new application level ontology for telecommunication network monitoring systems based on knowledge graphs is proposed in the paper. TNMO as application ontology is linked to domain ontology with specific object properties. For defining links, entities in domain ontology were chosen and object properties were defined in TNMO. The discussed ontology meets the formulated requirements, in particular, ability to describe heterogeneous TN static and dynamic data, ability of ontology enrichment. It also allows integrate TN monitoring system with other information systems, including 3rd party systems. The ontology is built according to the standards of Semantic web and can be extended or changed using standard methods and tools. The structure of the proposed ontology, method of integration with domain ontologies and method of the ontology enrichment are studied in the article. The main ontology metrics are provided. The case study of TNMO building for solving TN monitoring tasks is discussed. In the course of further research extending of TNMO and methods of its semi-automatic enrichment will be considered.

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