DATA MODEL DEVELOPMENT FOR LTE ENODEB MANAGING IN THE OPENRAN RADIO ACCESS NETWORK

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The trends in the open eNoteB/gNB base station interfaces utilization for both 4G/LTE and 5G/NR technologies are relevant not only for network interfaces of the signaling (Control Plane) and user data (User Plane) planes, but also for management plane (Management Plane) interfaces. WG4 working group of OpenRAN Alliance has done important work on standardizing these management interfaces and developed the O-RAN.WG4.TS.MP.0 "Management Plane Specification" technical specification for managing Radio units (O-RU) of distributed eNodeB/gNB base stations. However, the issue of further standardization of configuring the distributed O-DU unit by the eNB/gNB base station in accordance with the operator's frequency-territorial plan during deployment on the site is currently open. A solution to this issue would allow for the unification of the EMS-RAN management system for OpenRAN network modules when using multivendor radio access networks for building 4G/LTE and 5G/NR networks. The 3GPP defines possibility of managing and orchestrating for 5G radio access network (RAN) using the NETCONF protocol and the YANG data modeling language as one of technical solutions for 5G Service-Based Management Architecture (SBMA). The article is devoted to the YANG model development of configuration data for eNodeB base station of OpenRAN network of LTE technology using NETCONF network protocol, as well as the development of sysrepo applications for applying configurations.

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Introduction

The trends in the open eNoteB/gNB base station interfaces utilization for both 4G/LTE and 5G/NR technologies are relevant not only for network interfaces of the signaling (Control Plane) and user data (User Plane) planes [1], but also for management plane (Management Plane) interfaces.

WG4 working group of OpenRAN Alliance [2] has done important work on standardizing these management interfaces and developed the O-RAN.WG4.TS.MP.0 "Management Plane Specification" [3] technical specification for managing Radio units (O-RU) of distributed eNodeB/gNB base stations. However, the issue of further standardization of configuring the distributed O-DU unit by the eNB/gNB base station in accordance with the operator's frequency-territorial plan during deployment on the site is currently open. A solution to this issue would allow for the unification of the EMS-RAN management system for OpenRAN network modules when using multivendor radio access networks for building 4G/LTE and 5G/NR networks.

The 3GPP defines possibility of managing and orchestrating for 5G radio access network (RAN) using the NETCONF protocol and the YANG data modeling language as one of technical solutions for 5G Service-Based Management Architecture (SBMA) [22]. Key technical specifications in this area are (see Table 1):

• TS 28.533 [4] defines a service-oriented SBMA architecture in which management services (MnS) are represented by various protocols, including NETCONF/YANG;

• TS 28.532 [5] defines general CRUD (Create, Read, Update and Delete) management operations and options for their execution by standard NETCONF protocol operations, for example, <edit-config> ;

• TS 28.541 [6] contains definitions of information Network Resource models for 5G RAN (New Radio interfaces), including 5G base stations gNB, Centralized Units (CU) and Distributed Units (DU), presented as YANG modules.

Table 1

Review of control tasks and protocols used [4]

Management Feature	Management Capability	MnS definition	Solution Sets
Network and network slicing management	NR Provisioning	CRUD operations/ notifications (3GPP TS 28.532 [5]) + NR NRM fragment (3GPP TS 28.541 [6])	RESTFUL
			NETCONF/ YANG
	5GC Provisioning	CRUD operations/ notifications (TS 28.532 [5]) + 5GC NRM fragment (3GPP TS 28.541 [6])	RESTFUL
			NETCONF/ YANG
	Network Slicing Provisioning	CRUD operations/ notifications (3GPP TS 28.532 [5]) + Network Slicing NRM fragment (3GPP TS 28.541 [6])	RESTFUL
			NETCONF/ YANG
		Network slicing provisioning service (3GPP TS 28.531 [7])	RESTFUL

Analysis of the execution options for general CRUD management operations for various solution sets (Table 1) will be determined by standard operations of the RESTFUL and NETCONF/YANG protocols.

The advantages of a management approach using a combination of NETCONF/YANG are:

• Interoperability – operators can manage equipment from different vendors within a single management environment;

• Automation – programmability of data models reduces the risk of manual configuration errors;

• Security – using SSH/TLS to transmit NETCONF messages ensures high security of management data.

Authors presented a developed model based on the YANG data modeling language, which allows for the practical configuration of eNodeB in to LTE network in accordance with the operator's frequency-territorial plan at all stages of the network life cycle.

1. Management of eNodeB base stations at different stages of the network life cycle

LTE mobile network and, correspondingly, the base station eNodeB of Radio access network (RAN) must be managed throughout its entire lifecycle – from deployment to dismantling (Fig. 1). The eNodeB lifecycle includes a structured process of planning, deploying, operating, and updating RAN parameters by configuring it to ensure efficient LTE network operation. The final stage of the eNodeB lifecycle involves removing the eNodeB from the LTE network and dismantling its configurations as part of a network resource upgrade.

During the development of the proposed configuration model, the following stages were considered as main stages of RAN LTE base station lifecycle, where eNodeB configuration is required in accordance with the operator's frequency – territorial plan:

• Deployment and commissioning of eNodeB base stations;

• Monitoring the status and configuration parameters of eNodeBs for subsequent optimization during network operation.

• Network optimization during operation to improve key performance indicators and service quality.

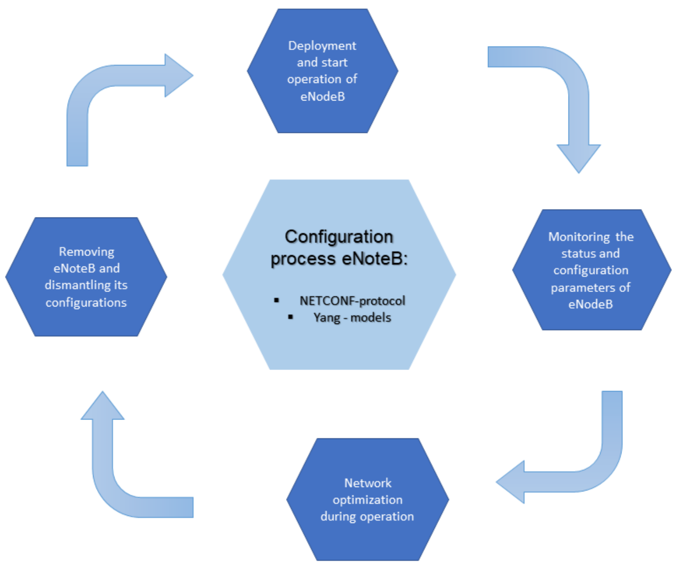

Fig. 1. Configuration process eNoteB from deployment to dismantling

The developed YANG model and applications enable management of eNodeB base stations at the following stages of the network lifecycle:

• during commissioning of the network deployment during the commissioning of the base station;

• during network optimization to improve key performance indicators for both the base station itself and the radio access network as a whole;

• during monitoring of the base station status and configuration parameters during operation.

At the stage of commissioning work for network deployment, when the Base station is put into operation, the operability of the eNodeB base station equipment is checked, its operating parameters are configured and its integration with the operator's network is ensured.

During the network optimization stage, when improving key performance indicators of the eNodeB base station, it is configured to improve coverage quality, increase cell capacity, connection reliability, and data speed.

During the monitoring stage of status and configuration parameters for eNodeB base station, in operation continuous remote monitoring of equipment's performances, collection of telemetry data, and analysis of key performance indicators are carried out to identify traffic anomalies for subsequent configuration.

Thus, the configuration of eNodeB base stations is a critical process that requires the development of a protocol for managing the configuration of LTE base station utilization, one of configuration data models of eNodeB base stations applying specialized software that defines the Network protocols stack of Radio access networks.

2. Capabilities analysis of NETCONF OpenRAN control protocol and problem statement

In accordance with the technical specification O-RAN.WG4.TS.MP.0 [3], O-RU units are controlled using the NETCONF network configuration protocol (RFC 6241) [8]. The NETCONF protocol is a multi-layer basic protocol for managing network units, replacing the outdated SNMP protocol (RFC 3411) [9].

As shown in Fig. 2, the NETCONF protocol [9] is based on either the SSH (RFC 4253) [10] or TLS (RFC 8446) [11] transport protocol and contains four layers:

1. **“Content” level** – management content containing configuration data or status data in XML format;

2. **“Operations” level** is a service part that designates the type of operation being performed, for example, <get>, <get-config>, <edit-config>, <copy-config>, <delete-config>, <lock>, <unlock>, <close-session> or <kill-session> for a given datastore:

– "Running" datastore – storage of configuration data previously successfully applied by the network unit and currently running;

– "Startup" datastore – storage of configuration data loaded by the network unit after it is turned on;

– "Candidate" datastore – storage of valid configuration data that does not affect the operation of the network unit and can be overwritten in other data stores: running or startup.

3. **“Messages” level** is a service part that forms the final message transmitted between the NETCONF client and the NETCONF server within the framework of the operation being performed and corresponds to the standardized model of the remote procedure call (RPC) (RFC 5717) [12], for example, requests <rpc> or responses <rpc-reply>, <rpc-error>, <ok> or notifications <notification>;

4. **“Secure Transport”** level – SSH/TLS transport layer protocol, ensuring secure data exchange over the network.

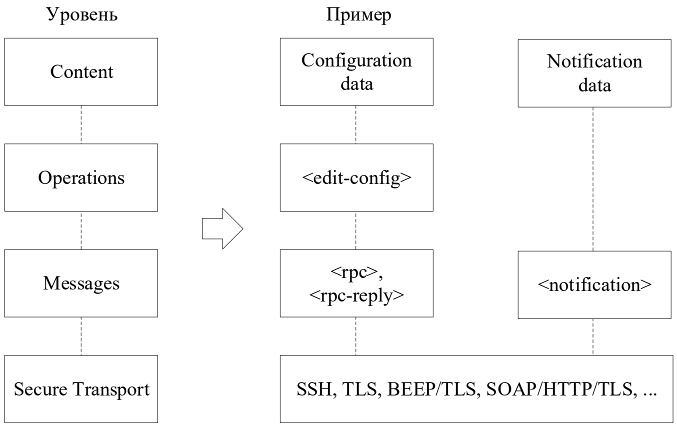

Fig. 2. Structure of the multi-layer architecture of the NETCONF protocol

The main advantages of NETCONF protocol using are the following:

– protocol openness, standardized by the IETF in the form of RFC technical specifications;

– separation of configuration data and operational state data;

– separation of configuration and configuration application operations;

– configuration of a network element in one or more transactions;

– selective data retrieval with filtering;

– streaming of notification data

– validation of configuration data before use;

– support for multiple data storage types, such as running, candidate, and startup;

– simultaneous opening of multiple sessions by one or more users;

– full or selective configuration of multiple parameters with a single <edit-config> operation;

– querying configuration data and operational state data with a single <get> operation;

– configuration application and rollback: commit and rollback, respectively;

– provide a high level of security and a wide range of authentication and cryptographic methods based on the properties of the SSH and TLS protocols [21].

A comparative analysis of existing control protocols for network units used by radio access networks 4G/5G is shown in Table 2.

An important aspect of the management standardization development in OpenRAN network is not only a messaging protocol development, but also management content unification itself based on the development of a configuration unified model and operational state data. For this purpose, NETCONF protocol uses the modern data modeling language YANG (Yet Another Next Generation, RFC 7950) [13].

Table 2

Network unit management protocols

Protocol type	SNMP	NETCONF	SOAP	REST
Developer of Standard	IETF	IETF	W3C	
Identification of the data object	OIDs	Paths		URLs
Data model	MIBs	YANG	WSDL	WSDL, WADL, text
Configuration operations	SNMP	NETCONF	XML schem	HTTP transactions
Data presentation	BER	XML	XML	XML, JSON
Transport protocol	UDP	SSH, TCP	SSL, HTTP, TCP	SSL, HTTP, TCP

To unify the management of O-RU units, OpenRAN Alliance has developed approximately forty of its own YANG data models of various types [14], and has also adopted YANG data models from IANA, IEEE, and IETF. As an example, some of main YANG models of OpenRAN Alliance are:

– Transceiver path configuration and status data models: o-ran-uplane-conf and o-ran-uplane-conf-option8;
– Performance measurement data model: o-ran-performance-management;
– Software management data model: o-ran-software-management;
– CPRI interface control and status data model: o-ran-processing-element;
– Synchronization control and status data model: o-ran-sync;
– RET servo drive control and status data models: o-ran-ald and o-ran-ald-port;
– File management data model: o-ran-file-management;
– Hardware data model: o-ran-hardware;
– Performance and characteristics data model: o-ran-module-cap.

The analysis revealed that the main advantages of YANG data models are:

– simple and understandable data modeling logic;
– hierarchical data structure;
– modularity and nesting of data;
– reuse of data types;
– use of structured data groups;
– increase in data volume through augmentation;
– formulation of data requirements and constraints for data validation purposes;
– management of data model versioning.

The models discussed above provide basic functionality management for O-RU units of eNodeB. However, in practice, radio modules from different manufacturers differ in so-called vendor-specific functionality. For this purpose, each manufacturer can use its own YANG – models as an add-on, such as vendor-specific-performance-management or vendor-specific-config-data.

3 Realization of LTE base station configuration management protocol

Using the above approach, the authors developed and implemented a structural diagram of the control software and a YANG model of the LTE eNodeB base station **softime-nodeb@2025-12-16.yang**, presented below on Fig. 3. The eNodeB base station, complete with one of type specialized software [15], was used as a prototype.

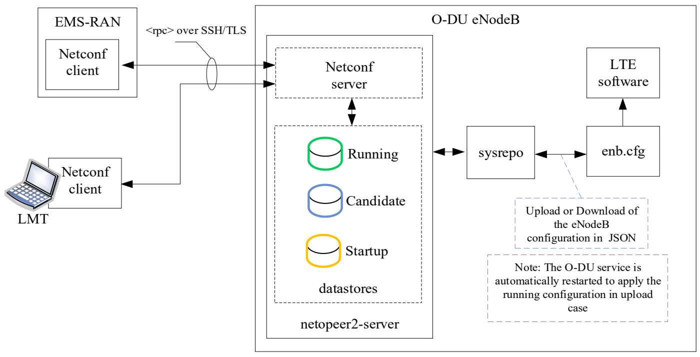

Fig. 3. Structural scheme of the control software for the LTE eNodeB base station

NETCONF server software includes three eNodeB base station configuration data stores: "candidate," "running," and "startup." The directions for copying and committing configuration data between these data stores are illustrated in Fig. 4.

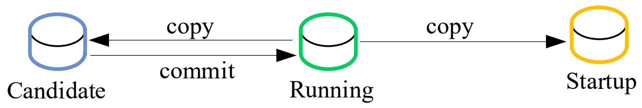

Fig. 4. Directions for copying and committing configuration data between datastores

Before making changes or copying data, it is possible to lock datastores to prevent other sessions from making data changes by parallel. To implement LTE eNodeB base station management via the NETCONF protocol, the following open-source software packages were used:

– netopeer2-2.4.1 (netopeer2-server application);
– sysrepo-3.6.11 (sysrepoctl and sysrepocfg applications – interfaces with the netopeer2-server application).

In the Linux operating system (OS), the NETCONF server is implemented as a systemctl service as netopeer2.service as shown in Listing 1.

```
# systemctl cat netopeer2.service
# /etc/systemd/system/netopeer2.service
[Unit]
Description=netopeer2 NETCONF server
After=network.targe

[Service]
#Type=notify
ExecStart=/usr/local/sbin/netopeer2-server -d -v2
Restart=always
RestartSec=10

[Install]
WantedBy=multi-user.target
```

Listing 1. Configuration of systemctl service by netopeer2.service

After installation and initial launch of netopeer2.service, the developed YANG model of the base station is loaded using the command "sysrepoctl --install softime-nodeb\@2025-12-16.yang -v3" in the Linux OS console, and the initial configuration of the eNodeB base station is imported from the enb.cfg file. To import the initial configuration, the authors developed sysrepo_reload application in the C programming language (designated as "sysrepo app" in Fig. 2), which performs the following actions:

1. Reads the original enb.cfg configuration file and converts it to JSON (JavaScript Object Notation) (RFC 8259) [16, 17] by removing macros and conditional statements (./json_util dump enb.cfg);

2. Converts configuration data from JSON to eXtensible Markup Language (XML) [18, 19, 20];

3. Adds a header to the XML data with the yang module name and the namespace: "<enodeb xmlns=\"urn:softime:nodeb:1.1\">…</enodeb>";

4. Validates the XML configuration data against the model, forming a lyd_node data node in the libyang context based on it;

5. Imports the configuration data as lyd_node into the "running" data store and applies the imported configuration to netopeer2-server application.

Restoring the NETCONF server configuration after restarting netopeer2.service or rebooting the hardware platform of eNoteB distributed unit (O-DU) is ensured by copying the configuration data from the "running" data store to the "startup" data store, for example, using the command in the Linux OS console "sysrepocfg --copy-from=running --datastore startup".

A sample example of the hierarchical structure of the developed YANG model of the configuration data of the eNodeB base station with specialized software is shown in Listing 2:

```
# pyang -f tree softime-nodeb@2025-12-16.yang
module: softime-nodeb
 +--rw enodeb
    +--ro enb_type?      enb_type
    +--rw enb_name?      string
    +--rw enb_id?        union
    +--rw com_addr?      string
    +--rw log_options?   string
    +--rw log_filename?  string
    +--rw mme_list* [mme_addr]
    | +--rw mme_addr          string
    | +--rw gtp_ext_addr?     string
    | +--rw s1ap_bind_addr?   string
    | +--rw qci_dscp_mapping* [qci]
    |    +--rw qci    uint16
    |    +--rw dscp?  uint16
    +--rw gtp_addr?      string
    +--rw cell_list* [cell_id]
    | +--rw cell_id                  union
    | +--rw tac?                     union
    | +--rw rf_port?                 uint16
    | +--rw n_id_cell?               uint16
    | +--rw root_sequence_index?     uint16
    | +--rw dl_earfcn?               uint16
    | +--rw ul_earfcn?               uint16
    | +--rw ncell_list* [cell_id]
    | | +--rw n_id_cell?         -> /enodeb/cell_list/n_id_cell
    | | +--rw cell_id            union
    | | +--rw dl_earfcn?         -> /enodeb/cell_list/dl_earfcn
    | | +--rw rat?               rat_type
    | | +--rw tac?               -> /enodeb/cell_list/tac
    …
    +--rw cell_default
    …
      +--rw drb_config* [qci]
        +--rw qci                   uint8
        +--rw ims_dedicated_bearer?    boolean
        +--rw rlc_config
    …
        +--rw pdcp_config
        | +--rw discardTimer?          uint16
        | +--rw pdcp_SN_Size?          uint8
        | +--rw pdcp_SN_Size_v1130?    boolean
        | +--rw pdcp_SN_Size_v1310?    boolean
        | +--rw statusReportRequired?  boolean
        | +--rw headerCompression
        |   +--rw maxCID?          uint16
        |   +--rw profile0x0001?   boolean
        |   +--rw profile0x0002?   boolean
        |   +--rw profile0x0004?   boolean
        +--rw logical_channel_config
          +--rw priority?                 uint8
          +--rw prioritisedBitRate?       int16
          +--rw bucketSizeDuration?       uint16
          +--rw logicalChannelGroup?      uint8
          +--rw logicalChannelSR_Mask?      boolean
          +--rw logicalChannelSR_Prohibit?  Boolean
```

Listing 2. Example of the developed YANG model of eNodeB base station configuration data

The conformity assessment of the developed softime-nodeb@2025-12-16.yang model and the configuration file of the specialized software "enb_full.xml" for eNB in XML format was performed and confirmed using the yanglint utility.

The conformity assessment of the developed softime-nodeb@2025-12-16.yang model and "enb_full.xml" configuration file of the specialized software for eNoteB in XML format ware performed and confirmed using by yanglint utility.

```
# yanglint -t data enb_full.xml softime-nodeb\@2025-12-31.yang -f json | jq '."softime-nodeb:enodeb"'.
```

To development of the YANG model were imposed following requirements:

– Full compliance of data structures with enb.cfg configuration file;

– Optimal model description by grouping data contained in multiple objects, such as cell_list and cell_default objects;

– Model parameters description of in description fields;

– Units measurement indication for model parameters and their permissible values/ranges of change in "range" fields;

– Indication of permissible values for string text parameters in the enumeration fields;

– Separation of parameters by operation type: read and write or read-only ("rw" and "ro", respectively);

– Separation of data into mandatory and optional (mandatory true or false, respectively);

– Key model parameters (key) contained in "list" node must be unique in enb.cfg configuration file across all base station configuration scenarios;

– specifying multiple key fields in the "list" node when one key field is not unique;

– establishing dependencies between different data, if necessary, when the value or mandatory presence of one data depends on other data in the model; for example, different sets of data for cell configurations in frequency FDD and time duplex TDD [23].

Command diagram explaining procedure of the eNodeB base station configuration change is shown in Fig. 3. To monitor changes in the "running" data storage, the sysrepo_subscribe_and_upload application was developed in the C programming language (designated as "sysrepo app" in Fig. 3), which performs the following actions:

– The sysrepo_app application subscribes to notifications about changes in the running datastore;

– Receives notifications about changes in the running datastore;

– Reads the current configuration from the running datastore;

– Converts data to JSON notation (RFC 8259) [17] and writes it to the enb.cfg configuration file, while saving (backing up) the previous configuration;

– Automatically applies the generated configuration file by restarting the O-DU unit service.

The sysrepo_subscribe_and_upload application is designed for the x86 CPU architecture and requires a minimal number of libraries, as shown in Listing 3:

```
# ldd sysrepo_subscribe_and_upload
    linux-vdso.so.1 (0x00007ffcb1eea000)
    libsysrepo.so.7 => /usr/local/lib/libsysrepo.so.7 (0x00007f1b191ce000)
    libyang.so.3 => /usr/local/lib/libyang.so.3 (0x00007f1b19026000)
    libjson-c.so.5 => /lib/x86_64-linux-gnu/libjson-c.so.5 (0x00007f1b19013000)
    libc.so.6 => /lib/x86_64-linux-gnu/libc.so.6 (0x00007f1b18dea000)
    libm.so.6 => /lib/x86_64-linux-gnu/libm.so.6 (0x00007f1b18d03000)
    libpcre2-8.so.0 => /usr/local/lib/libpcre2-8.so.0 (0x00007f1b18ca1000)
    /lib64/ld-linux-x86-64.so.2 (0x00007f1b192a5000)
```

Listing 3. The sysrepo_subscribe_and_upload application

An example of changing the configuration by sending a NETCONF rpc <edit-config> message, which provides for the following actions with the data in the datastore, is shown in Fig. 5:

– The "merge" action (nc:operation=”merge”, the default action) merges the provided data with the existing data in the corresponding yang model path. If the data does not exist, it is created;

– The "replace" action (nc:operation=”replace”) replaces the existing data in the corresponding yang model path with the provided data. If the data does not exist, it is created;

– The "create" action (nc:operation=”create”) adds data according to the yang model path only if it does not already exist. If it does exist, the NETCONF server returns an error message;

– The "delete" action (nc:operation=”delete”) deletes the specified data according to the yang model path. If the data does not exist, the NETCONF server returns an error message;

– The “erase” action (nc:operation=”remove”) – deletes the specified data according to the path of the yang model; unlike the “delete” action, if the data does not exist, the NETCONF server does not return an error, but simply reports successful completion.

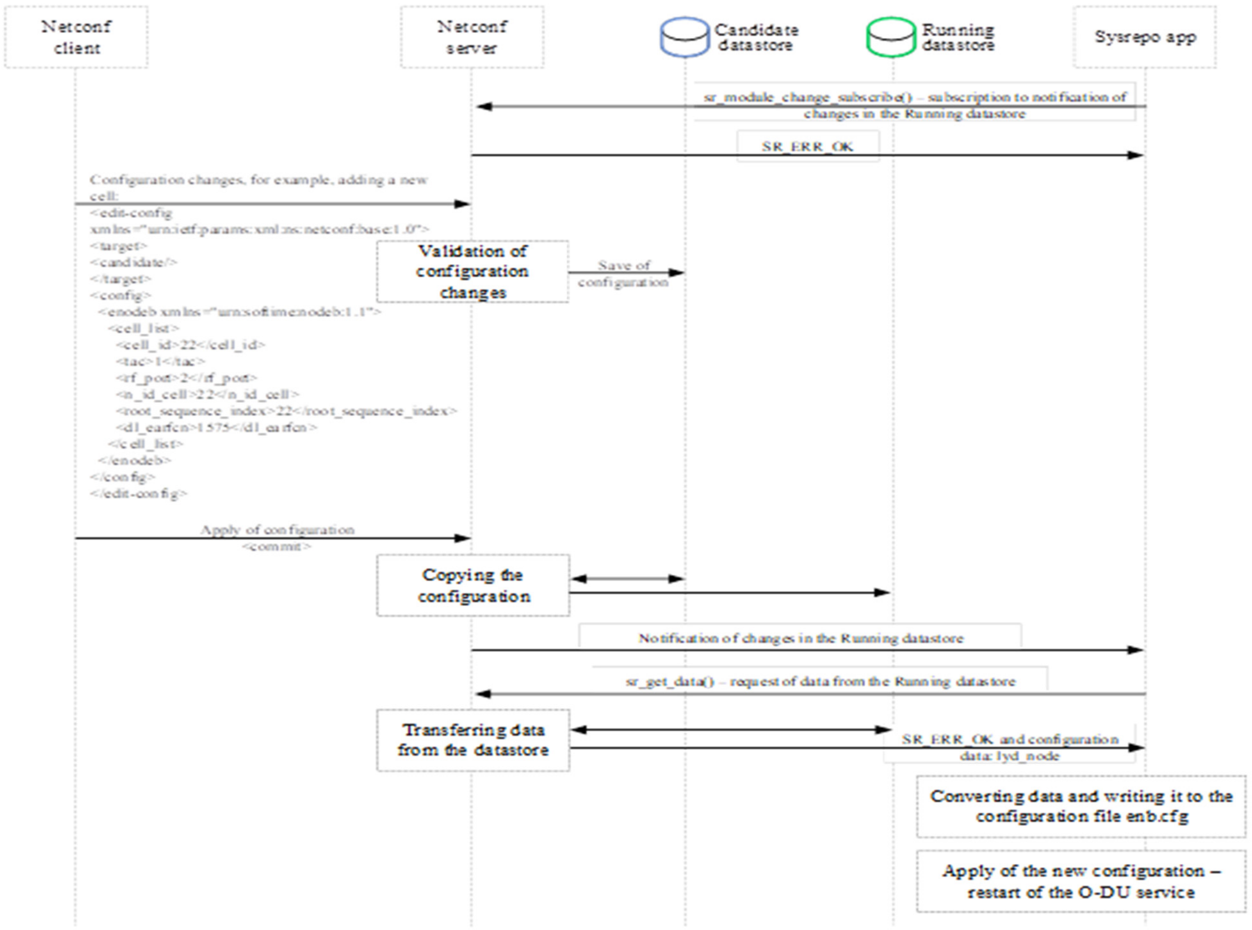

Fig. 5. An example of changing the configuration by sending a NETCONF rpc <edit-config> message

An analysis of the command diagram of the eNodeB base station configuration (Fig. 5) shows that as a result of transmitting the rpc <edit-config> control command and sequentially executing the steps by the sysrepo app application, the data is converted into the JSON notation format and the generated configuration file is applied by restarting the O-DU module service.

Conclusions

An analysis of the OpenRAN Alliance technical specifications revealed opportunities for implementing management of O-RU and O-DU units of the eNodeB base station in the management plane when using multivendor radio access networks for building 4G/LTE and 5G/NR networks.

The developed YANG data model for configuring the eNodeB base station with LTE technology, based on specialized Amarisoft software, enables eNodeB management and configuration.

The NETCONF server deployed on the eNodeB base station in the LTE network enables the use of the YANG data model for base station management, and the developed datastore status monitoring applications in the C programming language can be used to configure the LTE base station in accordance with the operator's frequency and territorial plan. The developed YANG model's compliance with the standard LTE network eNodeB configuration file using the Amarisoft protocol stack was verified in practice.

The open nature of the developed YANG model and the NETCONF network management protocol allows any developer to create new EMS-RAN management systems for Open RAN base stations.

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РАЗРАБОТКА МОДЕЛИ ДАННЫХ ДЛЯ УПРАВЛЕНИЯ БАЗОВОЙ СТАНЦИЕЙ eNodeB ТЕХНОЛОГИИ LTE В СЕТИ РАДИОДОСТУПА OpenRAN

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Аннотация
Статья посвящена разработке YANG – модели данных с использованием протокола NETCONF для конфигурирования базовой станции eNodeB в комплектации со специализированным программным обеспечением Amarisoft в сети радиодоступа OpenRAN технологии LTE, а также разработке приложений < sysrepo_reload> на языке программирования С в целях применения предложенных конфигураций. Конфигурирование базовой станции eNodeB сети радиодоступа OpenRAN требуется на различных этапах жизненного цикла сети LTE, которые рассмотрены в статье. В основу разработки YANG – модели данных используемой для конфигурирования базовой станции eNodeB положены возможности управления и оркестрирования сетью радиодоступа 5G RAN (Management and Orchestration), стандартизованные Партнерским проектом 3GPP и реализуемые посредством протокола NETCONF применяемого для внедрения технических решений на сервисно-ориентированной архитектуре SBMA (Service-Based Management Architecture). Представленные авторами листинги программ демонстрируют выборочный пример иерархической структуры разработанной YANG-модели конфигурационных данных базовой станции eNodeB со специализированным программным обеспечением Amarisoft. Разработанная YANG-модель и сетевой протокола управления NETCONF позволит лю-бому разработчику архитектуры сети создавать новые системы управления EMS-RAN базовых станций Open RAN.

Ключевые слова: *O-RAN, YANG, NETCONF, LTE, JSON, XML.*

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