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THE APPLICATION OF FORMAL GRAMMARS THEORY AND E-NETWORK TOOLS FOR BEHAVIOUR ANALYSIS OF NFV INFRASTRUCTURE

Introduction

The main idea of Network Function Virtualization (NFV) technology is remote the network functions from physical devices and run them as a virtual abstractions. Due to NFV technology the services providers implement different network solutions (DPI, NAT, Firewall etc.) like software instead of hardware solutions. For today the different type of services such as infrastructure as a service (IaaS) and software as a Service (SaaS) are provided in this way. NFV applications work and implementation of virtual functions is possible only on high-performance networking platforms and servers [1, 2]. According to the series of ETSI recommendations [1-3] for stabile work and maintains the required level of quality of services the NFV architecture should includes thee key components: network functions virtualization infrastructure, virtual network function and NFV management and orchestration system [3, 4].

The efficiency of service provision in NFV infrastructure (NFVI) is greatly depend on administrative and management decisions that created by MANO systems. The forming of final management decision by controller is greatly depends on QoS requirements imposed to the NFVI for service providing. These requirements are laid down in the SLA and can be divided into two classes [1, 2]:

- Functional. The functional requirements determine the behaviour both virtual network infrastructure and separate computation nodes, such as virtual machines, vRoutes and vSwitches according that guarantees implementation of the required set of service.
- Non functional. The non functional requirements determine the private features of virtual infrastructure components. As a rule, the private features include the quantity characteristics: counters of actions and time counter, thresholds that lead to the changes in operation processes.

The analysis of practical NFV solutions showed that the mistakes that made on different stages of NFV realization process, such as assembling or logical errors in programming code, can lead to critical situation in the virtualized network operation: failure of services, denial of service, data theft take place in these situations. An analysis of the conformity of realization NFVI solution to specification requirements, as method that help to eliminate there type of errors is proposed to implement as a sub stage of realization process.

A lot of methods of analysis of communication network realization solution are existing today, but there methods have disadvantages as possibility to analyse only implemented network solution, restriction amount of founded errors [5], material and time costs [3]. Finding the solution that allows to eliminate these disadvantages during development process of NFV technology is an actual problem.

E-network as a tool for NFV infrastructure modelling

Mathematical modelling is one of the approach that give ability to perform behavioural analysis, especially the analysis of availability of functional and non-functional requirements [3]. The apparatus of E-network is proposed to use as a modelling tool [6]. Choice of E-network is caused by the following advantages: ability of parallel process modelling both synchronous and asynchronous nature, the management places existing, ability to use different level of models metallization, universal approach. Analysis and estimation of algorithmic features of E-network as reachability, boundedness, liveness, and persistence are used as a basic of behaviour analysis that evaluates compliance functional and non-functional requirement of specification, of NFVI solutions.

According to the E-network behaviour rules the transitions from one vertices-state to another vertices-state is carried out by labels translation. The theory of formal grammars is one of the methods of translation rules formalization. The regular formal grammars give ability to describe the chronological sequence of vertices-state activity due to symbolic formalization.

The regular formal grammars as a tool of behaviour analysis of E-network

The regular formal grammar [5, 6] that describes possible variant of E-network model behaviour is defined as follows:

$$G = (V_t, N, Tr, M), \tag{1}$$

where the set of terminal symbols V_t is a set of NFV infrastructure states, which are modelled by of analysed models $\{A, B, C \ldots Z\} \in V_t$, $A, B, C \ldots Z$ is a symbols that describe the vertices-state; N is non-empty finite set of non-terminal symbols, $V_t \cap N = 0$. The set of non-terminal symbols N consist from the next elements of models: $\{Tr, r(x), \text{","}\} \in N$, where management place r(x) includes the set of attribute, that affect to the transition rules, Tr is the symbol that identify the transition-state (T, J, F, MX, MY), "," is the splitting symbol, M is the initial symbols of language chain, the vertices-state corresponded to the initial makeup of E-network models.

The choice of P-type language caused by sufficient set of state space model and study the possibility of the formation of language chains (include the deadlock vertices-state).

P-type language is characterized by the following formalism: $L(C) = \{\alpha(\beta) \in \Sigma^* \mid \beta \in T^*$ and always exist $\delta(\mu, \beta)\}$ and can be defined as follows [7, 8]:

$$L(P) = (s_0\alpha \mid \alpha \in V_t, \delta(s, \beta) \in (N \cup V_t)^*). \tag{2}$$

P-type language chains generation is proposed to perform with help of next top-down construction algorithm that founded on mixing of language chains productions principles and rules of E-network labels translation [3, 5, 8]. The proposed algorithm includes following steps:

1. Determination of the set of alphabet symbols $\{V_t\}$ that belong to analysed E-network model.
2. Determination the set of initial symbols $[S_i], S_i \in \{V_t\}$ that correspond to the initial makeup of analysed E-network model.
3. Determination the set of final symbols $[S_f], S_f \in \{V_t\}$ that correspond to the variants of final makeups of analysed E-network model.
4. To set the potentially active transition-states for all $S_i : N, N \in (V_{nt})$. The type of each active transition is determined as T, J, F, MX, MY.
5. The concatenation of "pairs of symbols" are determined as $S_i S_{i+1}$. The concatenation possible only if $S_i \to S_{i+1}, N_i$ is active.
6. Implemented a series connection of pairs of characters. The concatenation possible only if $s_i, s_{i+1} \Rightarrow s_j, s_{j+1} \mid s_j s_{j+1} \in \{V_t\}$.
7. Completion of language chain $P(L)$ that belong to analysed E-network model. Do this operation recursively while $[S_f]$ not empty.

The pseudo code of proposed algorithm is shown below:

set str[ ] = {S1, S2,…, Sn}
if length.str[Si]=0 and $\mathrm{Si} \Rightarrow \mathrm{Sn},\ \mathrm{Sn} \notin \{\mathrm{N}\}$ **do**
Si=str_init[] length.str_init[]++
return str_init[]
else length.str[Si]≠0 and $\mathrm{Sj} \Rightarrow \beta, \mathrm{Sn} \mid \beta \to \mathrm{Sn},\ \mathrm{Sn} \in \{\mathrm{N}\}$ do

Si=str_fin[] length.str_fin[]++
return str_fin[]
end
for each state Si =init and Sj $\le$ *length.str[]* **do**
if $Si * Sj \to Sj+1; Sj+1 \Rightarrow \beta, Sn \mid \beta \to Sn,\ Sn \in \{V_t\}$
match $Sj+1$ as current vertices-state and find active transition-state Ta
if $Ta \in \{MY\}$ and L(P)[]>1 **do**
procedure COMPELER $L(P): Si \Rightarrow (*Sj, Sj+1 \to \beta, Sn) \| (*Sk, Sk+1 \to \beta, Sm) \mid Sn, Sm \in \{S_f\}$ $Sk, Sk+1 \in \{V_t\}$
if $Ta \in \{F\}$ **do**
procedure COMPELER $L(P): Si \Rightarrow (*Sj, Sj+1 \to \beta, Sn) \cup (*Sk, Sk+1 \to \beta, Sm) \mid Sn, Sm \in \{S_f\}$ $Sk, Sk+1 \in \{V_t\}$
else $Ta \in \{MX, J, T\}$
procedure COMPLETER grammar chain L(P)[], $L(P): Si \Rightarrow *Sj, Sj+1 \to \beta, Sn \mid Sn \in \{V_t\}$
Length.L(P)[]++
end
if $Sj \to Sj+1; Sj+1 \Rightarrow Sn \mid Sn \to e$, $Sj+1$=final vertices-state
procedure COMPLETER grammar chain L(P)[], $L(P): Si \Rightarrow *Sj, Sj+1 \mid Sn \in \{V_t\}$
return L(P)[]
else all grammar chain is found
return set of L(P)[]
end
end

An analysis of NFV resource allocation process by proposed method

As example proposed to analysed model of E-network that represents the process of resource allocation and reservation by MANO system. The main requirement is find the network channels that have appropriate bandwidth limits – the channel delay not be bigger than decelerate in SLA [2, 3, 5]. E-network model of channels search process is depicted on Figure 1.

The proposed E-network model include the next vertices-states:

SO:SQL req is initial state, orchestrator generates a set of requirements for communication channels, which corresponds to the SLA; the state *SO: alloc req* the generation of multiple orchestrator requests to the different; the state *NRC: search* the request to the network resource management module is obtained, the channels that correspond requirement parameters are chosen; the state *VNFM:search* is correspond to search of services, which can be accessed by certain communication channels; the state *NRC:req* is corresponds to the generation the answer by network recourse controller. The NRC answer include information about available communication channels *Ch(1…n)*; the state *Ch(1…n):find* models the start of procedure that determinates the communication channels with appropriate bandwidth limits. This state includes the formation of a query to the registry services and functions (*S&FR*) and start testing the changes of bandwidth (state *Ch:Monitoring*); the state *Ch:mem&check* models the entry the channel in the memory; the state *Ch:Drop* models the time interval when channel withdraw; the state *VNFM: VN monitoring* models the monitoring of network topology changes; the state *VNFM: resp models the process of sending response to the orchestrator*; the state *SO: des* corresponds to choose the management decision by orchestrator; the state *SO: resp models the path for service provision.*

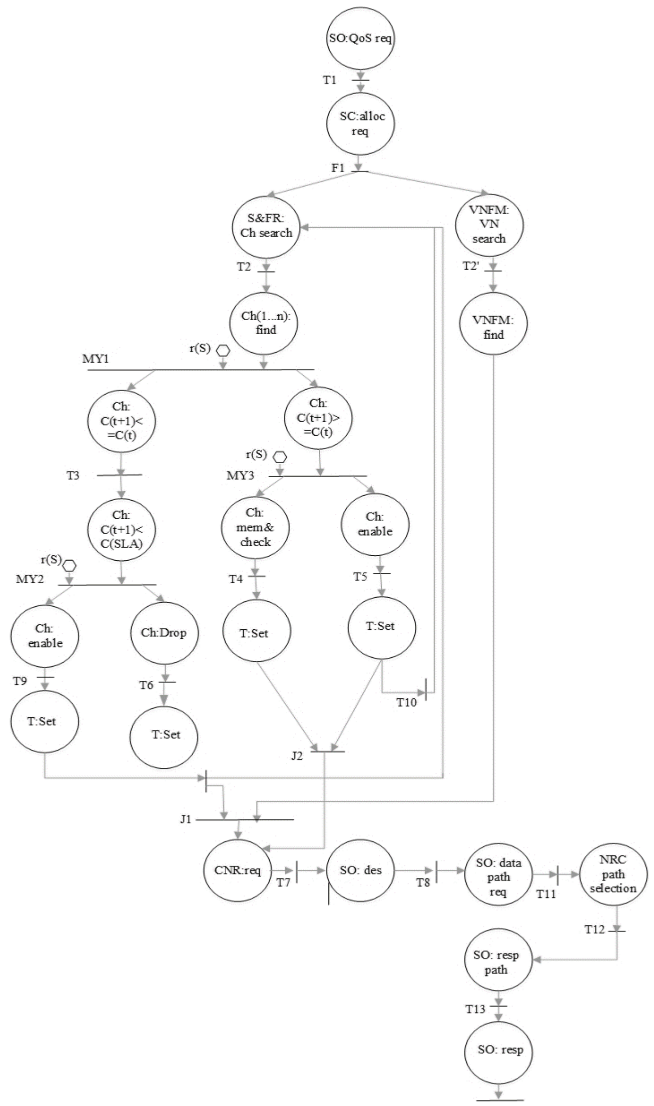

Fig. 1. E-network model of procedure for determining the communication channels that have appropriate bandwidth limits

Next steps represent the formalization and further analysis of process of orchestration of the virtualized resources of the network infrastructure according to the proposed P-type language generation algorithms:

1. The initial state of E-network model depicted on Figure 1 is *SO:QoS req* . The makeup that correspond the initial state is *Mo(1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)*

2. The final state of E-network model depicted on Figure 1 is *SO: resp*. The makeup that correspond the final state is *Mf(0,0,0,0,0,0,0,0,0,1)*.

3. The set of vertices-state of the E-network model {*SO:SQL req*, *SO:alloc req*, *NRC: search, VNFM:search, NRC:req, Ch(1…n):find, Ch: C(t+1)>=C(t), Ch:Drop*, *Ch:mem&check, Ch: C(t+1)<=C(t), Ch: C(t+1)<=C(t), Ch: C(t+1)<C(SLA), S&FR: N Monitoring, VNFM: VN monitoring, VNFM: resp, SO: data path req, SO: des, NRC: path selection, SO: resp path, SO: resp, T:set, Ch:Drop, Ch:enable*} is set of reachability states.

4. The P-type languages of the E-network model has the following output word-chains:

$L_1(P)=$ (*SO:SQL req*, *SO:alloc req*, (*S&FR: N Monitoring, Ch(1…n):find, C(t+1)<=C(t), Ch: C(t+1)>C(SLA), Ch:enable*)$\vee$(*VNFM: VN monitoring, VNFM: resp*),*T:Set, CNR:req, SO: des SO: data path req, NRC: path selection, SO: resp path, SO: resp*);

$L_2(P)=$ (*SO:SQL req*, *SO:alloc req*, *S&FR: N Monitoring, Ch(1…n):find, C(t+1)<=C(t), Ch: C(t+1)>C(SLA), Ch:drop, T:Set*);

$L_3(P)=$ (*SO:SQL req*, *SO:alloc req*, (*S&FR: N Monitoring, Ch(1…n):find, C(t+1)<=C(t), Ch: C(t+1)>C(SLA), Ch:enable*)$^N\vee$(*VNFM: VN monitoring, VNFM: resp*), *T:Set, CNR:req, SO: des SO: data path req, NRC: path selection, SO: resp path, SO: resp*);

$L_4(P)=$ (*SO:SQL req*, *SO:alloc req*, (*S&FR: N Monitoring, Ch(1…n):find, C(t+1)>=C(t), Ch:mem&check, T:Set*);

$L_5(P)=$ (*SO:SQL req*, *SO:alloc req*, *S&FR: N Monitoring, Ch(1…n):find, C(t+1)>=C(t), Ch:enable, T:Set*) $^N\vee$(*VNFM: VN monitoring, VNFM: resp*), *CNR:req, SO: des SO: data path req, NRC: path selection, SO: resp path, SO: resp*);

$L_6(P)=$ (*SO:SQL req*, *SO:alloc req*, (*S&FR: N Monitoring, Ch(1…n):find, C(t+1)>=C(t), Ch:enable, T:Set*) $\vee$(*VNFM: VN monitoring, VNFM: resp*), *CNR:req, SO: des SO: data path req, NRC: path selection, SO: resp path, SO: resp*);

$L_7(P)=$ ($SO{:}SQL\,req$, $SO{:}alloc\,req$, (*S&FR: N Monitoring, Ch(1…n):find, C(t+1)>=C(t), Ch:enable, T:Set)* $\vee$ *(VNFM: VN monitoring, VNFM: resp), CNR:req, SO: des SO: data path req, NRC: path selection, SO: resp path, SO: resp)*;

$L_8(P)=$ ($SO{:}SQL\,req$, $SO{:}alloc\,req$, (*S&FR: N Monitoring, Ch(1…n):find, C(t+1)>=C(t), Ch:enable, T:Set).*

The analysis of output word-chains shows that for the achievement of a final result lead only next output chain conditions $L_1(P)$, $L_3(P)$, $L_5(P)$, $L_6(P)$, $L_7(P)$. The output word-chains such as $L_2(P)$, $L_4(P)$, $L_8(P)$ indicate the occurrence of deadlock. The vertical-state *NRC: path selection* where deadlock may appear, this is possible in situation when the sequence $L_1(P)$ and $L_3(P)$ are performed rather then $L_5(P)$, $L_6(P)$, $L_7(P)$. The proposed E-network is non-saved. The appearance of cycles is one of the feature of proposed network. The power "*N"* in output word-chains (*S&FR: N Monitoring, Ch(1…n):find, C(t+1)>=C(t), Ch:enable, T:Set | S&FR: N Monitoring → CNR:req) u* (*S&FR: N Monitoring, Ch(1…n):find, C(t+1)<=C(t), Ch: C(t+1)>C(SLA), Ch:enable | S&FR: N Monitoring → CNR:req)* shows on this fact.

Conclusion

The popularity of NFV technology rapidly grows. But along with the many benefits and there is also a lot of problems. The problems primarily connected with places without the common mechanisms and standards in the formation and interaction of NFV architecture. There are for the new methods of analysis that take into account properties and features of NFV technology components need to be development. The proposed mathematical method of modelling based on E-network. Such approach allows to modulate the behaviour of NFV modules with different scalability include a parallels asynchronous process. As a method of behaviours analysis is proposed to use regular formal grammars, the P-type language was chosen. It was found that the formal grammars allow to resolve the problem of the definition of features such as reachability, liveness, safety and provides cycles detection.

The algorithm founded on mixing of language chains productions principles and rules of label translation in E-network is proposed. As an example, the process of recourse allocation and communication channels that characterize the appropriate bandwidth limits is consider. The analysis of resulting output word-chains $L_1(P)-L_8(P)$ shows that final state can be reach only in few behaviours scenarios $L_1(P)$, $L_3(P)$, $L_5(P)$, $L_6(P)$, $L_7(P)$. The scenarios $L_2(P)$, $L_4(P)$, $L_8(P)$ leads to deadlock.

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