# A network computational model's for Software Defined Networking

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**Abstract.** In this paper we define a computational model for netowrk's programming languages that use Software Defined Network (SDN) paradigm. For this purpose, network's will be model as graphs, and a graph grammar semantic will be defined. Production's in the grammar will model actions that can take place in the network, and programs will be just a sequence of instruction's modifying a starting graph.
After graph grammar's definition, we will extend this grammar to a type graph grammar, and we will explain how this new grammar can be applied to create a type programming language for networks. Finally we will show how this computational model is well defined, by using it to create a compiler for a new network progamming language recently emerged called Nemo.

## 1 Introduction

Nowadays networks have became a crucial resource of any software application. Technologies for improving code crafting are emerging constantly. By contrast, network's have several issues to be solved. Some of this issues may be tagged as

- **Debugging problem's:** It is rather difficult to debug problems in network's using most known tools such as ping, traceroute, netstat, between others.
- **Changeability problem's:** changing traffic rule's, or security rule's in network may impliy modifying hundred, or even thousands code line's distributed in several devices around the network.
- **Deployment problem's:** most changes are made mannually in several devices, making human mistakes easier.

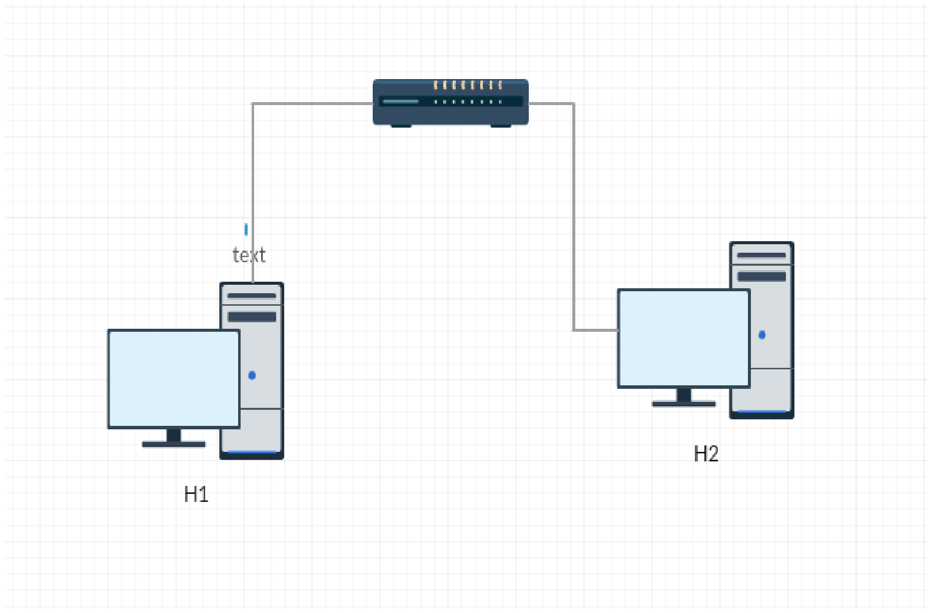
Is it possible to do better ?, Can software be of help in this task?, Is it possible to know when network change's will break something before applying them?.
We believe that all this question's have possitive answers, and the best way of solving this problem nowadays is using network's programming languages which are build over the Software Defined Networking (SDN) paradigm.
Multiple SDN's programming languages have emerged over the past year's (some examples of these are Pyretic, Frenetic, Nemo, etc.), having each of them different approaches to solve some of the problems described before. Some of the principal lack's of the network programming languages discipline nowadays are formal grammar definitions, verification, validation, testing, software metrics and quality assurance, betwen

multiple others.
Missing this properties makes harder to build some tools for network programming languages, such as compiler's, debugger's, coding enviorment's, etc. This limitation's makes the network operator's job difficult, even when using some of this programming languages.
The main contribution of this paper is presenting, as far as the authors know, the first network computational model based on the definition of a graph grammar. In section 2 we will define the problem to be solved with several examples and assumptions. In section 3 we will define the graph grammar, and we will extend this grammar to a type graph grammar in section 4. In section 5 we will use this grammar to show how we can solve the problems specified in section 2, and in section 6 we will check how the grammar can be used for building a simple compiler for the Nemo programming language. Finally, in section 7 we will give our conclusion and in section 8 we will introduce further work to be done.

## 2 Definning the problem

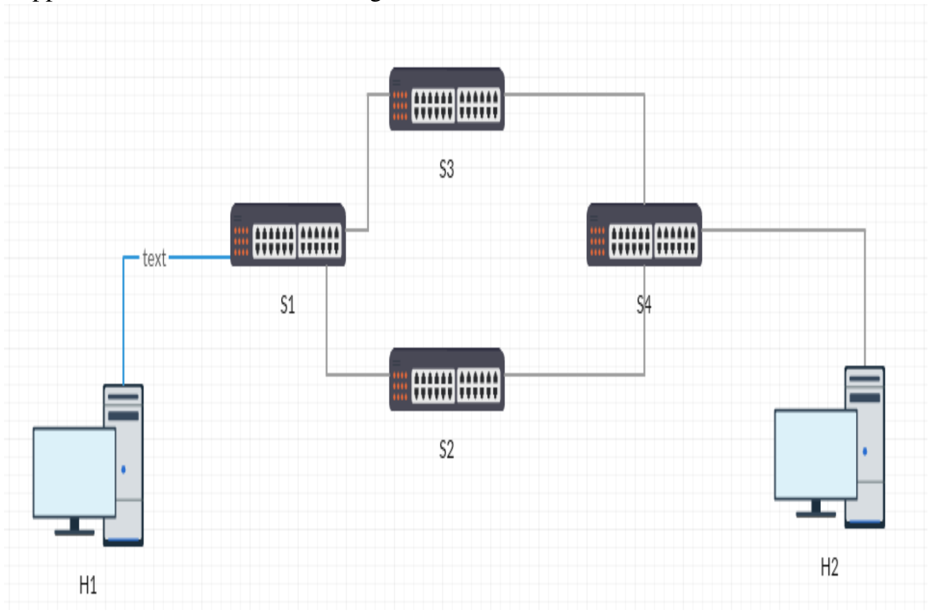
Let us remember that a program may be defined as a sequence of instruction's that executed perform a task in a computer or multiple computer's. Every program can be model as a Turing's machine or a finite lambda calculus computation, and despite of the model chosen, the operations are performed over a structure (usually this structure is a memory). In consequence, every network program is model as a finite sequence of operations over a structure.
Our first proposal is to define this structure as an oriented graph, since network's can be easily mapped to graphs, and also is perfect reasonably to think program's operation as graph's rewriting. After this reasoning, the second propose is to define a graph grammar in order to model all the network program's that may be written in any netowrk programming language.
In order to define the grammar production's, we will narrow to model programs that solve the following problems in networks where each device support's SDN:

***<u>First Problem:</u>***
Suppose that we have the following network:



where H1 want's to establish an ssh connection with H2, and let's assume that there are not forwarding rules in order to establish such connection's, and also H2 has not an ssh server client to fullfilled this connection.

***Second Problem:***
Suppose that we have the following network:



where H1 wants to establish a ssh connection with H2, using S1-¿S2-¿S4 path, and let's assume that there are not forwarding rules from S2 to S4.

Defining a graph grammar allows us to check easily some of the problems described before, particularly static properties, such as examples 1 and 2 (as we will shall see in following sections). However, dynamic properties (such as applying some load balancing policy when a queue start's to drop more than 50% of packets) are not easily checked by grammar production's. Some problems required to execute our program in a traffic network, however our approach is identifying problems in program's before they actually happen in the real network. In order to identify this class of problems, we propose an execution of some of the grammar production's in a simulator which will be inserted inside the language compiler. The program will then be executed in several simulation's, in order to check if the production applied to the actual graph is possible. For doing this, we will mapped the dynamic grammar production's to devs (a formal language specification for defining simulator's), and we will run a simulation using this formal specification.
Having defined the problem that we will be solving, let's define the primitive operations that we will used in our computational model.

## 3 Graph grammar

We start by defining the most basic grammar production's. These productions are the one's that allows us to modify the network topoloy:

- Node creation

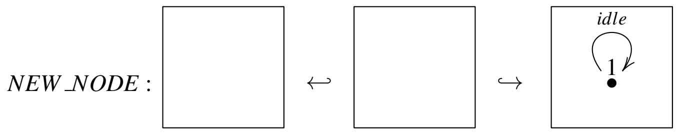


**Fig. 1.** Node creation

This production creates a new logical node (this means that the node could be either physic (which mean's it's a physical host with an assocciated address) or logic (this mean's a group of physical nodes, meanning that the address could be a CIDR).
It is important to remark that the created node is in an idle state, meaning that is not interacting with any other node in the network.

- Service creation

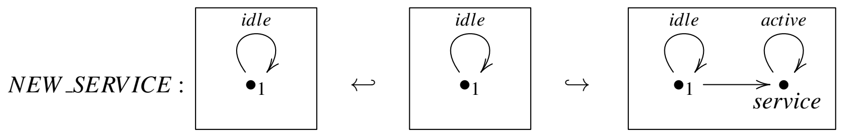


**Fig. 2.** Service creation

This is the production which defines new services in my node. Services are defined by the user, and they can be whatever service make sense in a node (also is important to notice that services in logical nodes, will not be the same as services in physical nodes). A service could be an Enum Type or something like that. Examples of a service could be ssh,http,https,sql,etc. (Note that physical services can be mapped to an active port).
Another thing to notice is that services will start in an active state, expecting to be used by the network. This state is going to be important in a future, because this state will define whenever is possible to use the service.
What would it be a service when we are talking in the logical node case?.

– Link creation

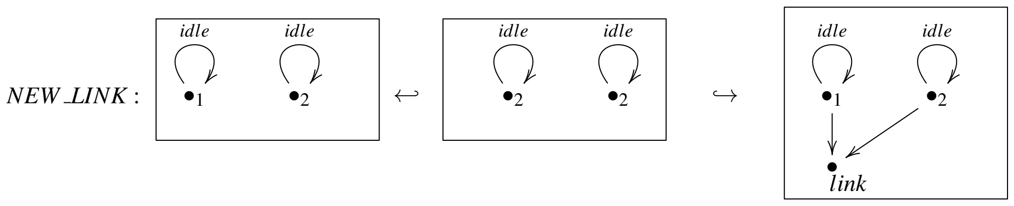


**Fig. 3.** Link creation

Here we define a new link between nodes 1 and 2. The only condition to apply this production is that both nodes must be in an idle state.
Note: Being in an idle state does not mean that they are doing nothing!. An idle state behaves likes a wildcard, meaning that from this state, multiply actions can be applied to the node.

– Link's property creation

*NEW_LINK_PROPERTY* :

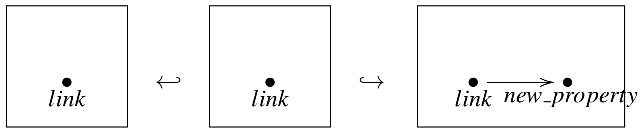


**Fig. 4.** Service creation

In this production we are allowing definition of link's property. This properties are going to be perhaps physical properties in physical links (for example, we can define here bandwith, average latency, perhpahs if it's either ethernet or wifi), and some other properties in logical nodes.
QUESTIONS:
1) What properties could be assigned to a logical link?
2) Can I always define properties in a node? (It really doesn't matter what is going on with that link in the network?. Perphas it happens something similar as nodes, that we need some 'idle' state, for example, an empty state).

So far we have defined productions that which are intended to be use between the interactions with the elements in the network. With the following productions, we will start using the productions listed before, in order to crate interaction between the elements in the network.

– Flow creation

*NEW_FLOW* :

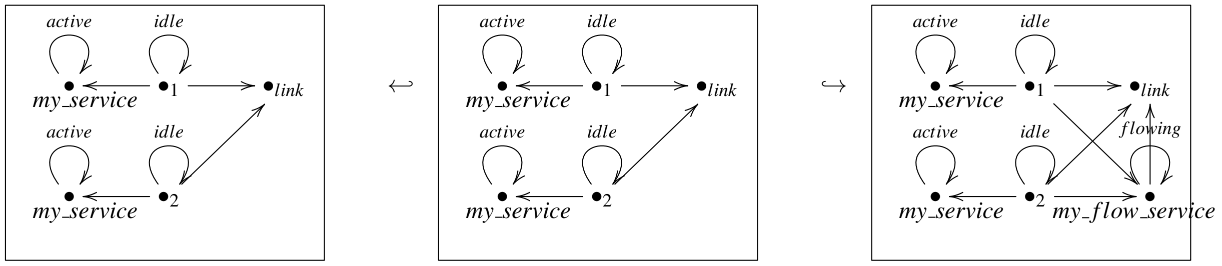


**Fig. 5.** Flow creation

In order to create a flow, I first need two things:

- I need to have a link between the nodes
- I need to have in both nodes the service which will be the content type of the flow.

Lets go through these rules one more time. The first rule is just telling us that, in order to be able to create a node, I need a connection between this node's (remember that this conection can be either logical or physical).
The second rule is telling us that, in order to create a flow of type X (lets say for example, that I want to create a ssh flow between this nodes), I need to guarantee that both nodes support ssh connections. This is represented as both nodes having a link to the service.
Finally, it's important to notice that a flow is associated betwen nodes and a link (this last one is going to be the place where it's flowing).

THINS THAT HAD TO BE THINK A BIT MORE:
1) Some rules may not be valid in this context ... How do I deny multiple ssh conections betwen same nodes? (Also, this sounds to me like a type condition, since another services may allow this behaviour, for example sql.)
2)

– Flow's properties creation

*NEW_FLOW* :

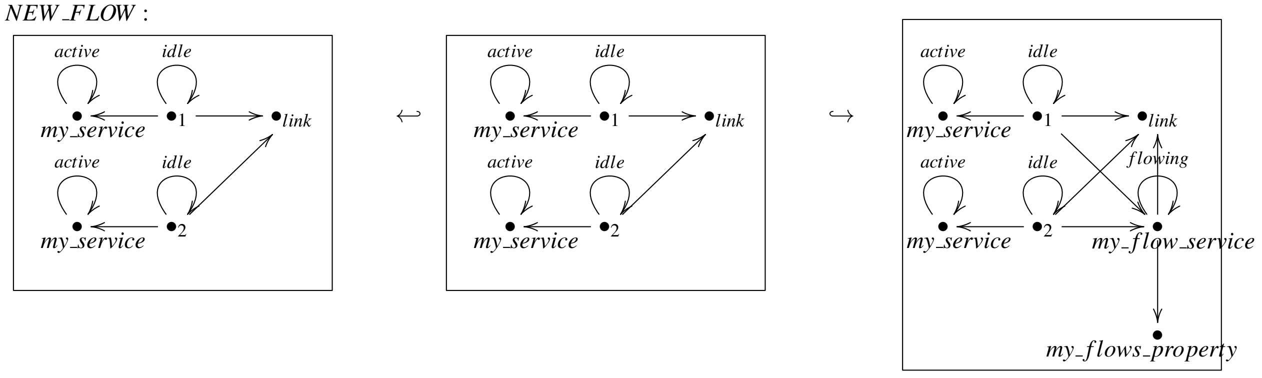


**Fig. 6.** Flow's property creation

This production allow's the creation of flow's properties.

QUESTIONS:
1) Can this properties be the actions associated in the nemo language ? Perphaps properties can be understood as premises that have to be guaranteed while the flow exist.
2) Some of this properties could be dynamic (this has sense, since flow is the rep-

resentation of dynamism in the network).

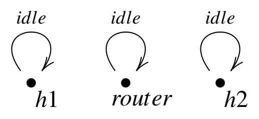
## 4 Graph instantiation

In this section we will focus in giving several examples of the usage of the grammar recently defined. The examples used in this section will be those defined in a previous document (REMEMBER TO REWRITE EXAMPLES HERE)
Lets first defined the first example, a network with two host and a router, which want to start a ssh connection.
There were two problems here:

- Neither of the host had ssh active
- Neither of the host were connected to the router.

Let's model our network, and see how the grammar defined before help us to detect problems in what we are trying to do.
This would be the network represented in our model:

$FIRSTEXAMPLE$



Having model our network, what we can check is that NEW_FLOW production can't be applied to my network (since there is no morphism between the left side of the production and this model). In this case, if I write a program for the situation described, we will have a compiler error, since there's going to be an instruction that cannot be done, and this is because the production associated with it cannot be executed.