Multicast Simulation and Modeling in OMNeT++

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ABSTRACT
IP multicast is nowadays a common network technique for communication and data delivery between senders and a large set of receivers. It could be argued that multicast is not generally supported by ISPs yet it became a standard for media streaming, distributed computing, financial applications and many others [1]. There is a need for suitable modeling and simulation tools supporting multicast routing, distribution trees and visualization of multicast data flows. In this paper we report on our so called ANSA extension which expands INET framework in OMNeT++ environment.

Categories and Subject Descriptors
C.2.1 [**Network Architecture and Design**]: Network Communications and Network Topology—*multicast communication*; I.6.5 [**Model Development**]: Modeling methodologies—*OMNeT++, INET Framework and ANSA extension*;

General Terms
Design, Experimentation.

Keywords
IP multicast, ANSA extension, OMNeT++, INET framework.

1 INTRODUCTION
The main advantage of IP multicast is a scalable exchange of information among groups of users. Multicast reduces network resources usage in comparison with unicast, resp. broadcast that target one respectively all recipients on the segment. Media streaming, voice or video conferences, financial software or other real-time applications nowadays successfully employ multicast.

Multicast end-to-end operation depends on multiple factors:

- Hosts and multicast-enabled first hop routers need multicast group membership management protocols e.g. IGMP for IPv4 or MLD for IPv6. Those protocols allow for querying, reporting and leaving multicast group membership on a local LAN segment. Multicast groups are represented by special IP addresses – in IPv4 class D addresses and in IPv6 addresses with prefix FF00::/8.
- Routing between destination networks must be ensured preferably by fast exchange of unicast routing information by appropriate protocols such as OSPF, IS-IS, EIGRP on LAN and BGP on WAN.
- Multicast routing protocols help passing multicast data among destination networks. Multicast routing protocols use unicast routing information to build up and maintain multicast distribution trees and topology. Hence some of them such as DVMRP or MOSPF depend on (or even tight with) unicast routing protocols, whereas variants of the protocol PIM are independent by design.

Users sign on and off multicast groups very dynamically according to their needs. Multicast data could vary between small real-time packets with best-effort delivery and high volume traffic with reliable transfer. Simulation gives us opportunity to verify network design in a safe environment. Often we would like to test behavior of a network in the case of some failure scenario or trace a flow of multicast data between a source and receivers. Unfortunately, previous requirements and characteristic show how complex a general multicast architecture is and from how many different collaborating components it consists.

The motivation behind our research, which is overviewed in this paper, is to propose architecture and create a tool capable of the following:

1) Direct communication with network devices to pull/push running configuration and dynamic state from/into routers and switches.
2) Creation of a network model based on information acquired through direct communication or based on topology description.
3) Simulation of multicast routing and data delivery using created model including visualization of distribution trees and end-to-end multicast investigation.
4) Formal verification and analysis of multicast communication models with optional recommendations how to "repair" running configuration according to the results.

This paper outlines some of the concepts behind ANSA (Automated Network Simulation and Analysis) project. Our contribution comprises of external tool for converting miscellaneous configurations into unified form named ANSA Translator. Another contribution are source codes of new simulation models named ANSA Router and ANSA Switch extending INET framework in OMNeT++ environment for multicast group management support.

This paper has the following structure. The next section provides a quick overview of existing tools and simulation models for

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multicast networks. Section 3 discusses our ANSA extension in details. Section 4 gives notes on the implementation and presents a simple test scenario. Section 5 summarizes this paper and proposes future work.

2 STATE OF THE ART

Nearly every major manufacturer of routers and switches developed its own tool for run-time monitoring, managing and visualization of multicast communication. Those tools could be either a part of more general application (e.g. HP Network Node Monitor [2]) or stand-alone software (e.g. Cisco Multicast Manager [3]). Both variants are implemented as servers communicating with other devices via SNMP using proprietary MIBs to get all necessary information – unicast and multicast routing tables and routing protocols, CAM tables with multicast MAC addresses assigned to ports and multicast group memberships. Unfortunately, these proprietary tools are difficult to deploy in a multi-vendor environment because they are not universal. Some IP-based multicast support is also built in a few discrete network simulators used in computer science such as NS2 [4] or OPNET [5]. Nevertheless those implementations lack or have limited support of tracing data flows, IPv6 multicast routing or visualization of multicast distribution trees.

Current status of multicast routing according to our knowledge in OMNeT++ 4.2 and INET 20111118 framework is as follows. Right now models of hosts (e.g. variants of `StandardHost`) and simple routers (e.g. `OSPFRouter`) are among available nodes representing network devices in INET. All of them are using `networkLayer`, `routingTable` and `interfaceTable` modules to process and handle L3 communication. Empty `igmp` module is prepared inside the package `inet.networklayer.ipv4`. Currently, there is no implementation of multicast routing table. Only one available option now is the statically configured unicast routing table in `*.mrt` file with multicast addresses mapped to outgoing interfaces. Multicast group management or any multicast routing protocols are also missing. Situation is quite similar for IPv6 simulation models (e.g. `networkLayer6`, `routingTable6`, `Router6`, etc.).

We want to take best features from existing tools and simulation models described above, combine them together and add what is missing. Our main goal is to give OMNeT++ community new source codes of models that will support multicast simulations.

3 DESIGN

In this section we explain parts of our ANSA extension, briefly describe their functionality and underlying design principles.

The first part consists of a translator from a vendor specific running configuration language to an universal configuration in XML form and its component to get relevant current state of existing network devices via SNMP. The second part discusses our own models of ANSA Router and ANSA Switch with the integrated unicast and multicast routing support.

3.1 ANSA Translator

Whenever we want to model a real network with routers and switches, we need to describe interconnection between devices and pass on setup of those devices onto their counterpart models. Usually, the configuration is a list of commands enforcing a required behavior of a device in the network. We could take the form of commands as declarative language. Hence, methodologies connected with formal languages could be used for parsing configuration with fitting grammar and translating it into a general form. Unfortunately every vendor has its own device specific syntax of commands thereby we usually need a different grammar for every vendor, or in the worst case for every platform.

Previous facts motivated creation of our ANSA Translator for analysis and processing of configuration files. We have decided to implement it as a grammar to existing tool ANTLR [6].

ANSA Translator is divided into two parts – a lexical and syntactical analyzer. Main goal of the lexical analyzer is to parse an input (plaintext configuration) lexems onto tokens. Those tokens are passed on to the syntactical analyzer where correctness of the syntax is checked. Consequently validated sentences are translated into a unified configuration in form of the XML structure.

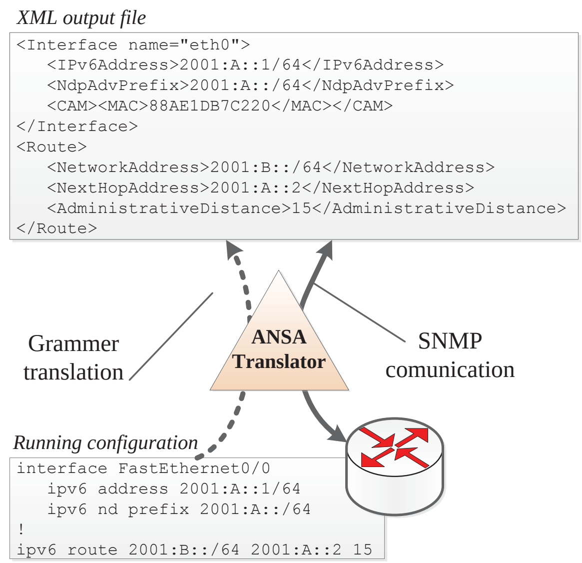

Figure 1. Translation example

ANSA Translator guarantees that only commands important for simulation and modeling from each configuration are translated. That relevant information consists of commands linked with the configuration of a device hostname, interfaces, VLANs, routing protocols, ACLs and others related to routing.

The running configuration itself is unable to represent dynamic state of any device. It lacks information depending on traffic or network convergence – e.g. content of CAM table or routing table, LLDP or CDP neighbors, etc. Hence, one component of ANSA Translator is also a SNMP manager capable of querying for dynamic data. Those data are extracted via SNMP and added to the XML output file.

Currently, ANSA Translator is able to process the syntax and semantic of Cisco, HP, 3Com and Extreme Network configuration, and the first steps have been made to implement SNMP manager. An output of ANSA Translator is a XML file, which consists of devices configuration and network topology. Based on the provided topology information – either obtained automatically or fine-tuned by network administrator appropriately to real network situation – ANSA Translator can generate an OMNeT++ network description file (NED) that defines a corresponding simulation model.

3.2 ANSA Router and ANSA Switch

In order to model active network devices and simulate their behavior in the real network, we have created new simulation models. ANSA Router is a model for the router based on existing `OSPFRouter` in INET and partially on architecture of Cisco routers. ANSA Switch is descendent of ANSA Router enhanced by L2 technologies and routing; thus, it is de facto L3 switch. Functionality of ANSA Router has been extended by routing protocols like RIP and OSPF and by filtering through access-lists in the past years [7]. ANSA Switch has the same capabilities as ANSA Router, and besides that, it supports VLAN and STP.

We have decided to implement a multicast support in OMNeT++ as follows:

- IPv6 routing – dual-stack ability, OSPFv3 (RFC 5340);
- Multicast group management – protocols IGMPv2 (RFC 2236), IGMPv3 (RFC 3376), MLDv1 (RFC 2710) and MLDv2 (RFC 3810);
- Multicast routing – protocols PIM-DM (RFC 3973), PIM-SM (RFC 4601) and PIM-SSM (RFC 3569).

The support of all of the previous features is provided by modules added to the compound module of ANSA Router or ANSA Switch. Figure 2 shows the structure of ANSA Router:

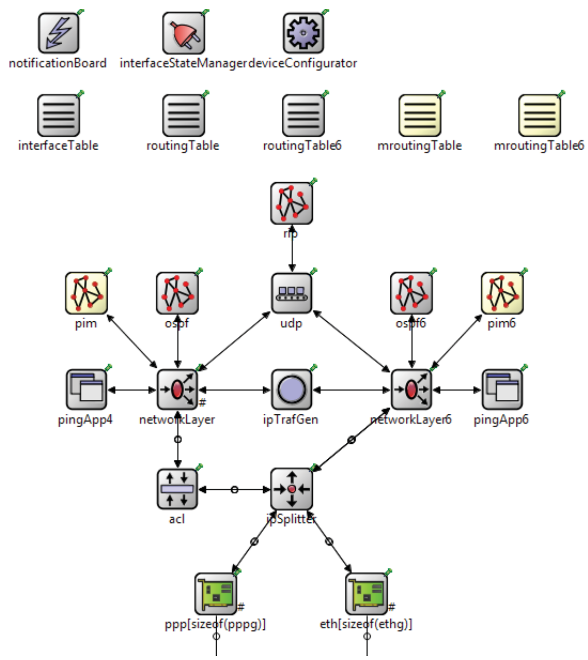

Figure 2. ANSA Router components interconnection

Brief description of each component from the bottom to the top:

Table 1. Components description

Name	Description
`ipSplitter`	ANSA Router is a dual-stacked – it supports coexistence of IPv4 and IPv6. This component recognizes IP protocol version and passes traffic to IPv4 `networkLayer`, or IPv6 `networkLayer6`.
`acl`	Module serves the same purpose as access-lists in Cisco routers – it filters incoming and outgoing traffic to `networkLayer`.
`igmp` and `mld`	The `igmp` module is placed inside `networkLayer` hence we have just implemented it appropriately. Besides that, another module – `mld` – is invisible at the picture. It is inside `networkLayer6` because it is direct sibling of IGMP for IPv6.
`ipTrafGen`, `pingApp4` and `pingApp6`	The `ipTrafGen` is for traffic generation. Two `pingApp` modules implement protocols ICMPv4, resp. ICMPv6 behavior and their purpose is to provide basic testing for network connectivity.
`ospf`, `rip` and `ospf6`	ANSA Router combines functionality of multiple unicast routing protocols. Completely implemented are OSPFv2 and RIP. OSPFv3 is in an early stage of implementation – it supports forming of adjacencies.
`pim`, `pim6`, `mroutingTable` and `mroutingTable6`	Variants of multicast routing protocol PIM will be implemented as two separated modules. They will closely cooperate with existing interfaces and unicast routing tables in a goal to feed modules of multicast routing tables with necessary information.
`InterfaceState Manager`	Helps to change and check status of interface – up or down according to simulation needs and schedule.
`device Configurator`	Module which is using XML file generated by ANSA Translator to set initial properties of other ANSA Router modules according to real device configuration.

4 MULTICAST GROUP MANAGEMENT

In this section we deal with multicast group management and its implementation. Multicast groups are represented by multicast addresses.

4.1 Protocol description

Both IGMP for IPv4 and MLD for IPv6 are protocols used to manage memberships in multicast groups. They are mediators between a client (host) and a multicast-enabled router (a.k.a. *IGMP Querier*) on the local segment. IGMP and MLD are closely related because MLDv1 is same as IGMPv2 and MLDv2 is direct sibling of IGMPv3. Currently, both versions of each protocol could be found in any multicast network; hence, we have decided to start implement them in chronological order with IGMPv2.

IGMPv2 uses three types of messages:

- *Membership Query* – Router asks with this message target client or all clients on segment whether they want to be members of the target or any multicast group;
- *Membership Report* – Client sends it either after the previous *Membership Query* solicitation from router or as unsolicited message. The goal is to inform the router about clients desire to become members of multicast group and receive data destined for this group;
- *Leave Group* – Client generates this message to announce that it is no longer willing to be a part of the target multicast group.

4.2 Implementation

We have continued in initial design plan and implemented `igmp` in the sense of IGMPv2 protocol behavior. All source files for IGMP are in the package `inet.ansa.igmp`. We have defined IGMPv2 messages in standard OMNeT++ `*.msg` file describing their structure. The `igmp` module behaves differently according to the configuration whether it is a part of routers or hosts `networkLayer`. Main abstract data structures are as follows:

- The `IGMPInterface` table stores all necessary information about multicast properties of interface (i.e. whether it is a querier or not, what is queriers address, general timers and also vector of next structure).

- The `IGMPGroupMembership` table consists of multicast group signed to target interface with all necessary properties (i.e. address of multicast group, who was the last reporter, values of group membership timers).

4.3 Testing scenario

For testing purposes we have altered existing multicast scenario in `examples.inet.multicast` by Jochen Reber as depicted on Figure 3. Besides that, we have also built this topology in laboratory using Cisco 2801 routers, point-to-point serial links and VLCPlayer on hosts.

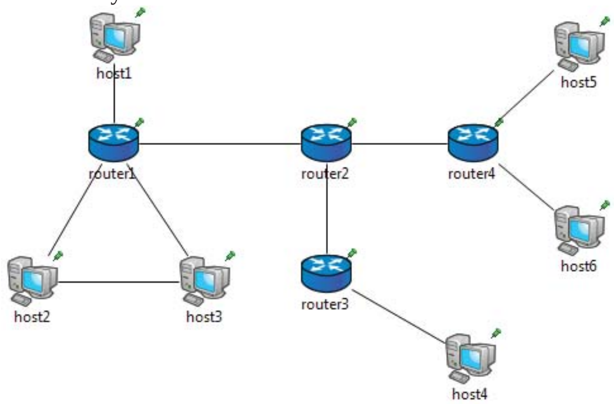

Figure 3. Scenario topology

Simulation of the multicast group management runs correctly through following phases in scenario topology:

1) Routers begin to send *Membership Query* messages after initiation.
2) Next *IGMP Queriers* on each segment are elected.
3) Then hosts (clients) send *Membership Report* on multicast addresses 225.0.0.1 and 225.0.0.2.
4) Routers process those messages and manage multicast and group membership on interfaces as records to `IGMPGroupMembership` and `IGMPInterface` tables.
5) Then routers ask on segments with *Membership Query* messages and as a next step, hosts refresh their membership with *Membership Query* in regular periods defined by timers.
6) Host1 is scheduled to sign off from multicast group 225.0.0.1 later during simulation. Therefore, the client generates *Leave Group* messages at that moment.
7) This leads Router1 to remove multicast group 225.0.0.1 from the target interface.

Figure 4 shows multicast group memberships on interfaces of Router1 in the end of simulation:

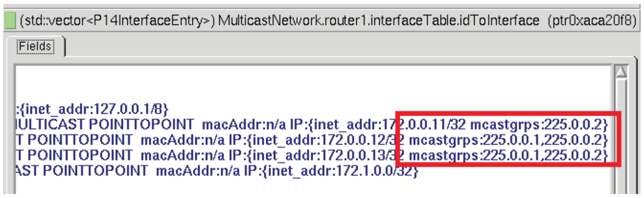

Figure 4. Final state of interface multicast group membership

Results of simulation – timing and proper order of IGMPv2 messages exchange – were successfully checked against the identical real topology, thus proving the same behavior as Cisco IGMPv2 implementation.

5 CONCLUSION

In this paper we discuss current options of modeling multicast routing and multicast data transfers. We give overview about existing proprietary tools and the status quo of this issue in the OMNeT++ environment. We unveil our ANSA extension and its two distinctive parts. The first one is a general translator and automated simulation generator called ANSA Translator. The second part is a description of simulation models of router and switch. In this respect we talk more about ANSA Router – its componential structure and functionality regarding to INET framework and OMNeT++. The present simulation experiment focuses on multicast group management via IGMPv2. Results show success in first steps to implement proposed architecture.

5.1 Future work

We plan to extend the functionality of ANSA Translator by SNMP. With the help of built-in SNMP manager we could extract dynamic state of network devices and pass it as a one of inputs to the simulation model. We will aim at following tasks in upcoming months of the ANSA Router development:

- To implement other host-router multicast group management protocols – IGMPv3 and MLD.
- To migrate from static to dynamic multicast routing – finish PIM-DM implementation and continue with PIM-SM and then PIM-SSM.
- To focus on IPv6 – the first step is to program the full OSPFv3 support.
- To focus on real-world simulations.

5.2 Additional information

ANSA Translator tool and ANSA Router/Switch simulation models are also based on work done by Vladimír Kojecký, Marek Černý, Zdeněk Kraus and Petr Mateleško, students of Brno University of Technology. The research is supported by the Czech Ministry of Education in frame of the ESF project CZ.1.07/2.3.00/09.0067 "TeamIT – Building Competitive Research Teams in IT". Source codes could be downloaded from SVN and more information about project on http://nes.fit.vutbr.cz/ansa.

6 REFERENCES

[1] IANA. *IPv4 Multicast Address Space Registry*. http://www.iana.org/assignments/multicast-addresses/multicast-addresses.xml#multicast-addresses-4, [online], November 2011.

[2] Hewlet-Packard Company. *HP Network Node Manager i software and HP Network Node Manager i Advanced software (Data Sheet)*. 4AA3-3907ENW, April 2011.

[3] Cisco Systems. *Cisco Multicast Manager 3.2 (Data Sheet)*. C78-658790-00, May 2011.

[4] Šimek, M., Komosný, D., and Burget, R. One Source Multicast Model Using RTP in NS2. *IJCSNS International Journal of Computer Science and Network Security*, Vol. 7, Iss. 10, pp. 69-75, 2007.

[5] X. Wang, C. Yu, H. Schulzrinne, and P. Stirpe. IP Multicast Simulation in OPNET. *CiteSeerX 10.1.1.18.7365* (1999).

[6] J. Bovet and T. Parr. *Another Tool for Language Recognition*. http://www.antlr.org/, [online].

[7] P. Matoušek, O. Ryšavý, G. de Silva, and M. Danko. Combination of Simulation and Formal Methods to Analyse Network Survivability. *Proceedings of the IEEE 3rd International ICST Conference on Simulation Tools and Techniques*, p. 6, Malaga, ES, 2010.