INTRODUCTION

Abstract—Recursive InterNetwork Architecture is a clean-slate approach to how to deal with the current issues of the Internet based on the traditional TCP/IP networking stack. Instead of using a fixed number of layers with dedicated functionality, RINA proposes a single generic layer with programmable functionality that may be recursively stacked. We introduce a brand new framework for modeling and simulation of RINA that is intended for OMNeT++.

Keywords—Recursive InterNetwork Architecture; RINA; OMNeT++; Delta-t;

The purpose of this paper is to present the community with RINASim – the RINA-capable framework for the OMNeT++ simulator – and describe its components and basic order of operations. This paper has the following structure. The next section covers a brief introduction to some of RINA concepts. Section III reveals components of our framework together with their description. Section IV describes flow lifecycle in two simple scenarios where a pair of hosts is exchanging data. The paper is summarized in Section V together with unveiling of our plans.

STATE OF THE ART

This section introduces basic RINA principles and terminology. However, astute reader is advised to consult additional information sources (see [4], [5] or [6]) because not everything can be explained due to the limited space of this paper.

Nature of applications in RINA is as follows: Application Process (AP) is program instantiation to accomplish some purpose; Application Entity (AE) is the part of an AP, which represents the application protocol and application aspects concerned with the IPC. There may be multiple instances of the Application Process in the same system. AP may have multiple AEs, each one may process a different application protocol. There also may be more than one instance of each AE type within a single AP. All application protocols are stateless; the state is and should be maintained in the application. Thus, all application protocols modify shared state external to the protocol itself on various objects (e.g., data, files, HW peripherals). Because of that, there is only one application protocol that contains trivial operations (e.g., read/write, start/stop, and create/delete).

As it was mentioned before, RINA separates mechanisms (fixed parts of a system) from policies (variable parts of a system) of any IPC. There are two types of mechanisms: a) tightly-bound that must be associated with every packet, which handle fundamental aspects of data transfers; and b) loosely-bound that may be associated with packet and which provide additional features (namely reliability and flow control). Both types are coupled through a state vector maintaining state information. Previous implies the existence of a single soft state data transfer protocol. This protocol controls data transfer with the help of different policies. Initial synchronization of communicating parties is done with the help of Delta-t protocol.
see ([7], and [8]). Delta-t was developed by Richard Watson, who proposed a timer-based synchronization technique. He proved that conditions for distributed synchronization are met if following three timers are bound: a) Maximum Packet Lifetime (MPL); b) Maximum time to attempt retransmission a.k.a. maximum period during which a sender is holding a packet for retransmission when waiting for a positive acknowledgement ($R_{\text{timer}}$); c) Maximum time before Acknowledgement ($A_{\text{timer}}$). Delta-t assumes that all connections exist all the time. The synchronization state is maintained only during the data transfer activity, but after 2$\Delta t$ or 3$\Delta t$ periods without any traffic the state may be discarded which effectively resets the connection, where $\Delta t = MPL + A_{\text{timer}} + R_{\text{timer}}$. Because of that, there is no need for hard state (with explicit synchronization using SYNs and FINs). Delta-t postulates that port allocation and synchronization are distinct.

The concept of RINA layer a.k.a. DIF could be further generalized to Distributed Application Facility (DAF) – a set of cooperating APs in one or more computing systems, which exchange information using IPC and maintain shared state. A DIF is a DAF that does only IPC. Distributed Application Process (DAP) is a member of a DAF. IPC Process (IPCP) is a special AP within a DIF delivering inter-process communication. IPCP is an instantiation of a DIF membership; computing system can perform IPC with the other DIF members via its IPC process within this DIF. An IPCP is specialized DAP. The relationship between all newly defined terms is depicted in Fig. 1.

We need to differentiate between different APs and also different AFs within the same AP. Thus, RINA uses Application Process Name (APN) as a globally unambiguous, location-independent, system-dependent name. Distributed Application Name (DAN) is a globally unambiguous name for a set of system-independent APs. An IPC Process has an APN so it can be identified among other DIF members. An address is a synonym for the IPCP’s APN with a scope limited to the layer and structured to facilitate forwarding. An APN is useful for management purposes but not for forwarding. The address structure may be topology-dependent (indicating the nearness of IPCPs). An APN and an address are simply two different means to locate an object in different context. There are two local identifiers important for the IPCP functionality – a port-id and a connection-endpoint-id. Port-id binds this (N)-IPCP and (N+1)-IPCP/AP; both of them uses the same port-id when passing messages. Port-id is returned as a handle to the allocator and is unambiguous within a computing system. Connection-endpoint-id (CEP-id) identifies a shared state of one communication endpoint. Since there may be more than one flow between the same IPCP pair, it is necessary to distinguish them. For this purpose, Connection-id is formed by combining source and destination CEP-ids with QoS requirements descriptor. CEP-id is unambiguous within an IPCP and the Connection-id is unambiguous between a given pair of IPCPs. Fig. 2 depicts all relevant identifiers between two IPCPs. Watson’s Delta-t implies Port-id and CEP-id to help separate port allocation and synchronization. The RINA connection is a shared state between protocol machines – ends identified by CEP-ids. The RINA flow is bound to ports identified by port-ids. The lifetimes of a flow and its connection(s) are independent of each other.

III. CONTRIBUTION

We are developing RNASim in the frame of FP7 project PRISTINE [9]. The goal is to provide the public community with a full-fledged RINA simulator to support ongoing research and academic activities. To understand RINA architecture means to understand each of its elements. This subsection starts with a description of high-level RINA network nodes and then goes deeper and outlines various implemented components.

There are only three basic kinds of nodes in RINA network. Each kind represents computing system running RINA: a) hosts, IPC end-devices containing AFs, they employ two or more DIF levels; b) interior routers, interim devices interconnecting (N)-DIF neighbors via multiple (N-1)-DIFs, they employ two or more DIF levels; c) border routers, interim devices interconnecting (N)-DIF neighbors via (N-1)-DIFs, where some of (N-1)-DIFs are reachable only through (N-2)-DIFs, they employ three or more DIF levels. Fig. 1 depicts simple RINA
network containing all kinds of nodes and their basic internal structure.

The internal structure of any RINA node could be divided into two parts – the one responsible for DAF operation and another one for DIF operation. DAF part contains one or more APs and a couple of management components, which are described in Table I. DIF part contains one or more IPCPs of different ranks interconnected to create a recursive stack. All IPCPs consist of a same set of subcomponents, which are depicted in Fig. 3 and summarized in Table II.

### TABLE I. DAF COMPONENTS OVERVIEW

| Name          | Description                                                                 |
|---------------|-----------------------------------------------------------------------------|
| application Process | AP module contains one or more AE instances. AE processes application protocol and uses IPCP to communicate with destination AE(s). |
| ipcResourceManager | IPC Resource Manager (IRM) manages DAF resources, which involve delegation of flow (de)allocation calls or management of a new DAF/DIF join or creation. IRM maintains information about all connections used by AE(s). |
| dif Allocator | DIF Allocator (DA) primary task is to return a list of DIFs where destination application may be found given APN and access control information. DA contains and works with multiple mapping tables to provide its services. |

### TABLE II. IPCP COMPONENTS OVERVIEW

| Name          | Description                                                                 |
|---------------|-----------------------------------------------------------------------------|
| flow Allocator | Flow Allocator (FA) processes (de)allocate calls. FA creates a Flow Allocator Instance (FAI), which manages each flow independently. FAI spawns separate EFCP instance to handle data and interconnects all involved components with binding to create data-path. FA translates application QoS requirements onto available RA’s QoS profiles. |
| efcp          | Error and Flow Control Protocol (EFCP) provides a mechanism to exchange data transfers, and it is split into two independent parts. Data Transfer Protocol (DTP) implements mechanisms tightly coupled with transmitted SDUs, e.g., fragmentation, reassembly, and sequencing. DTP works with packet header fields like source/destination addresses, QoS requirements, Connection-id, etc. |

RINA’s generic approach to an IPCP’s operation is met via NED interfaces. Each policy is represented as a simple module implementing specific interface. NED interfaces enabled us to use different implementations for a specific policy, which is not possible to do directly in C++. Policies related to static modules (RMT, FA) are specified via variables in a simulation configuration file (.ini) and policies related to dynamic modules (EFCP instances) are configured by an XML configuration file. Dynamic modules cannot be addressed in the .ini file before the start of the simulation because their names are not yet known due to randomness in generated names.

All inner IPCP interconnections are modeled with zero-time delay since processing messages between modules is a matter of a queue scheduling algorithm and not a network architecture. The bottommost interconnection between IPCPs represents the physical medium offering to set various properties (rate, delay, bit error rate). The recursiveness enables us to set the properties on all interconnections between IPCPs.

### TESTING

In this section, we present example scenario to illustrate the flow lifecycle. Simulation topology (shown in Fig. 4) consists of two hosts (Host1 and Host2) and one interior router (SW) performing relaying between the two hosts. Hosts AP_A and AP_B employ a ping-like application protocol exchanging request-response messages and measure one-way/round-trip time latencies.
The flow initialization can be separated into five phases. The odd phases belong to Host1, and even phases belong to Host2. The first phase describes beginning of the allocation.

1) AP_A on Host1 notifies IRM with its request;
2) IRM notifies IPCP1’s FA to check whether there is any flow available between applications A and B. Since there is neither data nor management (N)-flow, IPCP1’s FA invokes management flow allocation in order to create IPC channel for exchange of management messages;
3) IPCP1’s FA asks IPCP1’s RA to prepare (N-1)-flow for management. Flow allocation process is recursively repeated from the beginning whenever there is no available flow in the underlying DIF until it reaches medium, where flow allocation is considered inherent.

During the second phase, IPCP2’s FA of Host2 receives allocation request, which is accepted. Subsequently, bindings between bottom IPCP22 and IPCP2’s RIBd are formed.

During the third phase, Host1 IPCP1’s FA receives a positive allocation response for management flow and starts enrollment procedure. During enrollment Host1 and Host2 exchanges authentication data. Upon successful enrollment, Host1 continues initial data flow allocation.

1) Host1’s FA creates FAI for data flow. FAI spawns EFCP instance. Following next, FAI prepares bindings and lets RIBd send CreateFlowRequest;
2) CreateFlowRequest is processed by IPCP3’s FA where it needs to be forwarded to IPCP44. But before that underlying (N-1)-flow are recursively allocated, which is secured by IPCP3’s RA.

During the fourth phase, Host2 handles CreateFlowRequest for data flow.

1) IPCP2’s RIBd notifies Host2’s AP about flow allocation and connection attempt. AP_B accepts and governs IRM to prepare bindings and delegate flow allocation request;
2) IRM invokes IPCP2’s FA, which instantiates FAI. FAI spawns EFCP instance to provide data transfer service to the data flow. FAI prepares bindings and lets RIBd send positive CreateFlowResponse.

During the fifth phase, IPCP1’s RIBd receives a positive CreateFlowResponse and notifies about it FAI. Then, FAI notifies the application about the successful finalization of the flow allocation. Subsequently, the actual ping-like data transfer occurs between and using allocated data-paths.

When APs finish data exchange, the flow deallocation process is initiated. Deallocation is separated into three phases.

During the first phase, AP_A initiates data flow deallocation.
1) Before actual deallocation, AP_A releases connection notifying AP_B about this fact;
2) Following next, AP_A tells IRM about deallocation request, which delegates it to appropriate IPCP1’s FAI;
3) IPCP1’s FAI asks RIBd to deliver DeleteFlowRequest.

During the second phase, AP_B receives deallocation request.
1) IPCP2’s FAI on Host2 receives DeleteFlowRequest. It notifies AP_B about it, and initiates data flow deallocation by removing appropriate EFCP instance and disconnecting bindings;
2) RIBd of IPCP2 acknowledges deallocation by sending to IPCP1 DeleteFlowResponse on behalf of FAI. At this point, data flow and data-path from AP_B side on Host2 are deallocated.

During the third phase, deallocation is finalized on AP_A side. IPCP1’s FAI receives a DeleteFlowResponse and finishes data flow deallocation by removing EFCP and relevant bindings. Deallocation is complete, and port-IDs associated with AP_A and AP_B may be reused by other APs.

Simulation results and message confluence have been successfully verified against proposed behavior in RINA specification.

V. CONCLUSION

We have outlined the basic principles behind RINA, a clean-slate replacement of the traditional TCP/IP stack. We have introduced RINASim as an independent OMNeT++ framework providing simulation environment for educational and research purposes with this fresh architecture. We plan to carry on work and further refine our framework based on new knowledge and up-to-date specifications. An additional goal is to conduct a comparative evaluation of our simulation models with RINA implementation for Linux environment called RATI [10]. All source codes are publicly available on GitHub repository [11] under the MIT license. We encourage the reader to read accompanied documentation [12] or generate Doxygen documentation to get more insight.
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