Integrated Management and Control Architecture for New Generation Networks

Isabela Vasconcelos de Carvalho Motta and Antônio Marcos Alberti

***Abstract*— The paradigm shifts that are emerging in the future Internet (FI), together with the increasingly larger scales on number of devices, connectivity, and interactivity are challenging the traditional model of devices' control and management. Thus, it is necessary to re-examine the current control/management models under the optics of the FI proposals that arise in some emerging technologies, including Internet of things, software-defined networking, network function virtualization, information-centric networking and others FI concepts. This paper discuss emerging technologies for future Internet under the perspective of network management and control. It also proposes a new control/management model in the context of a future Internet proposal called NovaGenesis.**

***Keywords*— NovaGenesis; Management Network; Control Network; Future Internet.**

I. Introduction

Devices control and management (CM) are major difficulties in the current Internet architecture. Some of the most important concerns are: (i) the incremental and heterogeneous deployment of management and control protocols; (ii) scalability and interoperability of CM protocols; (iii) hardware exposition to software; and (iv) excessive human interference.

In 2008, the Instituto Nacional de Telecomunicações (Inatel), Brazil, started a future Internet architecture (FIA) [1] project called **NovaGenesis** (NG[1]), which is a "clean slate" convergent information architecture to be universally applied. NovaGenesis embraces not only content exchanging and distribution, *e.g.* Internet, transport networks, Internet of things (IoT) [2], or content centric networking (CCN) [3], but also content processing and storage, *e.g.* cloud computing services and applications [4]. In this context, it is imperative to identify and understand the limitations of current network/cloud CM models while proposing FIAs. This paper undertakes such a task, giving rise to the requirements and specification of CM architecture for NovaGenesis (covering computing and networking infrastructure).

While designing NovaGenesis, we frequently asked: *how should we control and manage an architecture like this?* This paper aims at analyzing the CM architectures existent today, drawing a parallel among: (i) emerging management approaches for IoT, information centric networking (ICN) [5], software defined networking (SDN) [6], network function virtualization (NFV) [7], [8], and cloud computing; (ii) and what we propose to NovaGenesis FIA. We contribute with a reference model for emerging CM networks that addresses effectiveness requirements such as scalability, interoperability, heterogeneity of resources, life-cycling and service-orientation.

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[1]http://www.inatel.br/novagenesis/

The paper begins with the main CM requirements and challenges for emerging FI paradigms in Section II. Next, in Section III, we briefly present NovaGenesis concepts and design choices, giving the background to introduce our CM model in Section IV. The idea is to give the required arguments to employ NovaGenesis as an integrative architecture for IoT, SDN, ICN, and NFV, not only covering network data plane, but also CM planes. Section V provides a brief comparison of our approach to the studied related work. Finally, in Section VI we conclude the paper, summarizing its main results and proposing future actions.

II. Requirements and Challenges for Next Generation Network Control/Management

The expectations towards CM approaches are growing exponentially in order to support new technologies, new services, heterogeneous networks (HetNets), IoT, as well as to reduce operational expenditure (OPEX), increase scalability and allow the introduction of software-as-a-service paradigm. In general, the following paradigms must become part of requirements and challenges for next generation architectures operation.

A. Internet of Things (IoT)

Management systems are expected to support unpredictable increase of CM traffic volumes due to scalability of IoT applications, which includes to discover, to configure and to recover the new elements. In the same way as it occurs in current networks, but on a larger scale, CM technologies for IoT must interoperate with a variety of software and middleware, being able to ensure security, performance, and reliability [9]. Emerging models to manage IoT are a hot topic now. FI-WARE (see https://www.fiware.org/) proposes a set of services to CM IoT devices. The most relevant for our discussion here is the IoT device manager. It instantiates an agent for one or more IoT devices being controlled. The agent translates IoT-specific protocols into the publish/subscribe model of FI-WARE context-broker. This enables FI-WARE services to track changes on values or configurations at IoT devices.

A recent standard created for IoT, called *oneM2M* just released a model for devices management. This technical specification (TS), which discusses usage models for machine to machine (M2M) communications, includes applications that must inform the status of the equipment and advise immediately if there is a failure or if the system reached some threshold previously configured. M2M CM is required in various areas such as oil and gas, sanitation, energy, telecommunication, industrial automation, health and environment. These devices must provide online information for management systems.

B. Software Defined Networking (SDN)

SDN paradigm can provide better management mechanisms compared to legacy methods. SDN fills the gap of lack of interoperability, which is a problem for CM tasks, with the promise of standardization of CM protocols. SDN allows various management activities to be flexibly performed by additional features over network controllers [10], in a way similar to applications in an operating system. The logically centralized control approach can favor effectiveness of network control. However, current SDN control, a.k.a. OpenFlow [11] is a southbound protocol very specialized, focused only in packet forwarding configuration. Other management areas as performance, accounting and security are unexplored in SDN. Concerned to the limited scope of OpenFlow, other SDN approaches are emerging: Procera [10] is a framework to improve device configuration using OpenFlow to communicate with the equipment. Simple network management protocol (SNMP) [12] can be used as an event source for Procera controller. Cisco's OpFlex [13] differs from OpenFlow because it centralizes control policies definitions in the Policy Manager. The intelligence is distributed in network nodes.

C. Information Centric Networking (ICN)

FIAs should recognize the structure of information objects (e.g. files, contracts, records, etc.) and provide access to information in a timeliness, reliable, location-independent, safe, private way. The most difficult is to contextualize and correlate information in the right scope in the midst of a lot of data that is being sensed from the physical world. The host-centric model of current Internet gives way to ICN, which supports location independent access to information. Emerging ICN architectures, like CCN, network of information (NetInf) [14], named data networking (NDN) [15] and recursive internetwork architecture (RINA) [16] are adopting a distributed CM model. RINA has a standardized implementation of Inter Process Communication (IPC). It separates CM functions, using IPC Controller and IPC Manager. The IPC Manager is responsible to allocate data flows, authentication, Common Distributed Application Protocol (CDAP) parser/generator, resource allocation, Resource Information Base (RIB) daemon. The IPC Controller implements (re)transmission and flow control.

D. Network Function Virtualization (NFV)

NFV is a very important aspect of FIAs, with CM systems being expected to be operational at full time. High availability features combined with high reliability data are critical to achieve this goal. Also, network virtualization is necessary to technologies such as SDN. It is essential to integrate network and cloud CM systems to optimize hardware resources and improve CM activities, such as latency and network performance control. Solutions have been proposed to manage virtual networks. OpenStack and OpenNebula are platforms able to manage resources in the cloud computing using infrastructure-as-a-service (IaaS). Also, autonomic management techniques have being used to manage the substrate network. In [17], the authors propose a self-organized management based on monitoring control loops, which explore neighbor measures via a virtual manager deployed on network nodes.

III. NovaGenesis: Concepts and Design Choices

NovaGenesis (NG) is a new convergent information architecture that integrates several FIA ingredients, like CCN, SDN, IoT, NFV, and others. It is an initiative to create a new architecture for information processing, storage, and exchanging. NG can be seen as an overlay for the current Internet, as well as a new Internet architecture that can integrate communication networks with clouds [18].

A. All existences are named

More and more things are being connected to the Internet and a new architecture must be prepared to recognize them by their names. Current networking architecture typically limits the available namespaces. For example, the Internet employs at least four namespaces: domain names, network and host names, sockets, and uniform resource names. NG supports naming of all things, not only natural language names (NLN), but also self-verifying names (SVNs), which are preferable for machine-language. All things could be named through NLNs and SVNs, which ensures an individual existence can be denoted in many ways, enabling the creation of a huge name graph. These names can be used to identify and locate"things", software, any other existence, which could be a service, a user or any network equipment, for instance. NG replaces those aforementioned namespaces used on transmission control protocol/Internet protocol (TCP/IP) by a generic naming approach, which enables any kind of naming scheme, including self-generated names from existences' immutable attributes, i.e. SVNs.

B. All contents and name bindings are subscribed via publish/subscribe services

Typically, SVN's are the output of encrypted hash functions, which are stored as keys or values on *name bindings*. NG stores the name bindings in a distributed hash table, which is operated by a hash table service (HTS). These NBs can be seen as identifiers and/or addresses, depending on the way they are linked to other names. NBs are published by services to a publish/subscribe service (PSS). The last piece of this puzzle is called generic indirection resolution service (GIRS). The GIRS selects an appropriate HTS to store content and NBs.

C. All physical existences are represented by services

A proxy/gateway/controller (PGC) is a service that represents "physical world" things in NG ecosystem, i.e. it represents an existence towards service exposition, discovery, negotiation, contracting, monitoring, releasing, etc. They expose features, attributes, names, states of the "things" they represent. The proxy service get the required service dynamically and according to service level agreement (SLA) previously established. We have demonstrated PGC idea on reference [18].

A PGC provides three features: (i) acts as a proxy representing "things" in NovaGenesis service ecosystem; (ii) acts as a gateway to encapsulate NovaGenesis messages over low level communication standards, like ZigBee, IEEE 802.15.4 or Bluetooth low energy (BLE); (iii) acts as a controller, configuring devices according to established contracts.

"Things" can not establish contracts alone. They require a software representative that can help them on this matter. The idea is, "things" must have resources, attributes, capabilities, status, and other contextualized data available to other peer services — services that can be interested on what a "thing" can do. This model can be applied to any physical world devices, including network and cloud infrastructure or ad-hoc equipment.

The heterogeneity of physical world devices is enormous. Therefore, the support to control/manage HetNets is mandatory in FIAs. We can consider that all networking equipment is a "thing" that should be controlled/managed by emerging software solutions. Gateways will be required to interoperate (in a message-basis) to a multitude of technologies.

IV. NovaGenesis Control/Management

FIAs should accommodate new CM requirements. For this, CM systems must be flexible and adaptive. NG CM must be hybrid to adapt to constant changes and new technologies. Also it must be build in blocks to support the market demand requirement of services that do not allow lengthy implementations. This proposal describes the way that the Manager and Controller should share the information with the managed elements or agents in the NG environment. In this context, Mediators Services must expose the features of heterogeneous CM protocols, set up contracts and control agents in order to optimize network resources seamlessly and automatically, using all the new features of a convergent programmable network. The communication between agents and Mediator Service will be started after contracts subscriptions.

There are multiple standards for implementing CM architectures. Also, FIAs have to live with multiple proposals harmoniously. Our proposal aims for a simple and scalable solution. The scalability is guaranteed by using a distributed architecture in southbound. Simplicity is achieved with logical centralized (but distributed deployed) CM in northbound. The northbound is composed by a Manager and a Controller, which form the NG orchestration plane. This plane provides a holistic vision of the infrastructure with full understanding of all components that form NG environment (Fig. 1).

- **NovaGenesis Manager** — The management is realized by a logical centralized manager that integrates the five management areas, i.e. FCAPS, and must have knowledge of the current state of the network, analyzing and detecting root cause of failures, making decisions and acting in managed elements, targeting constant network optimization. The NG Manager includes FIA management aspects, covering the requirements discussed in previous chapter, which include high robustness, security, diversity and scalability of managed elements. Manager, as well as Controller (described below), follows the service-oriented model where CM is seen as a service, disassociating producers and consumers by means of NG's name resolution service (NRS). The infrastructure Manager has a global vision of the network, but doesn't mean it's a single point of failure. Several Manager instances provide failure tolerance and resiliency. The CM information is distributed consistently in NRS using ICN paradigm. Managers and controllers work on named-CM objects.
- **NovaGenesis Controller** — NG Controller follows service-oriented life-cycling, including resources exposition, discovery, contracting, establishment of quality of service (QoS) requirements and security. Its aim is to analyze traffic information, routing, congestion control, implementing policies and access control mechanisms, dealing with conflicts and governance. This component comprises entirely aspects of IoT, SDN, ICN and NFV control, including analysis of network status, publication of topology information, discovery of devices connected to the network, distribution of network routing configurations and security mechanisms among services.
- **Mediator Service (MS)** — The mediation is made by a special service responsible for translating information and protocols. It implements a second-level manager to send and receive data from legacy elements. It "understands" multiple protocols and languages, simultaneously. These elements will represent the CM protocols in NG cloud. It will manage pure NG components through a CM protocol. The Mediator Service delegates CM responsibility to the CM planes. The Mediator Service must perform multiple tasks: (i) Aggregation; (ii) Filtering; (iii) Correlation and (iv) Decision making to provide contextualized information for infrastructure Managers and Controllers.
- **Proxy/Gateway/Controller and Management Agent (PGCMA)** —- We described the PGC function in previous Section. From the perspective of network control, the PGCMA is an specialized controller for legacy and new equipment. It represents those equipment maintaining contracts with one or more network Controllers. In this sense, it can be defined as a proxy, representing equipment requirements in terms of control plane. It has also a gateway function, which enables it to connect legacy elements. When representing/connecting to a NG element, it does not employ the gateway function.
- **Name Resolution Service** — NRS is a macro system formed by the three NG components related to naming and caching, namely HTS, GIRS, and PSS. They provide name, name resolution, and network caching for PGCMAs.

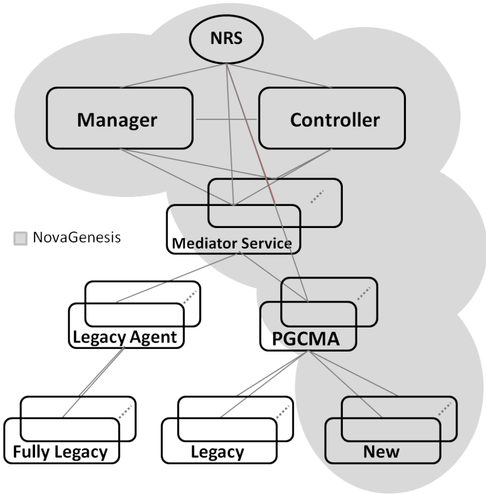

Fig. 1. NovaGenesis control and management model and services.

A. Scenario

Fig. 2 proposes a sequence diagram for the service-oriented CM scenario previously specified. The communication between the CM services must be done asynchronously by PSS located in NRS. Every content and published names are stored in NRS. NRS is responsible for disseminating the events generated by any CM Services. The entities of CM Service can be producers or subscribers of self-verifying named information objects.

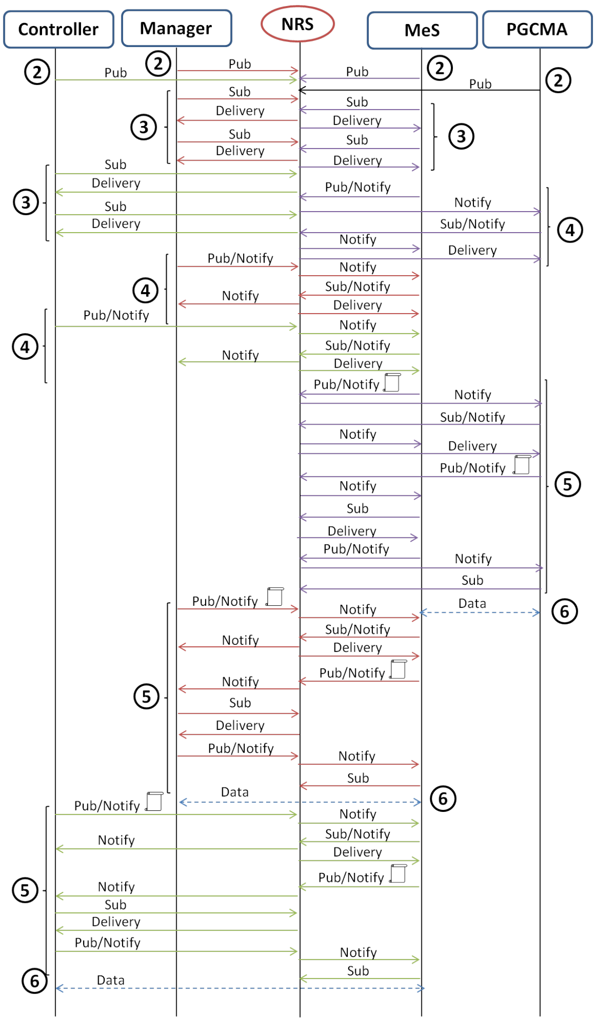

Fig. 2. Sequence diagram for CM services interaction.

1) **Initialization**: It is the starting point of CM life-cycle. All elements of the CM architecture are instantiated. The initialization step is not shown in the diagram.
2) **Exposition:** All the CM services expose (publish) their names, features, limitations, capabilities and conditions for service contracting. Natural language keywords are published to PSS. The links between natural language and auto-certifying names are stored in HTS;
3) **Discovery:** The services subscribe keywords and descriptors to select proper partners. The customer service sign again, seeking more details of the service;
4) **Offer:** After selecting candidate peers, CM services can publish contract offers according to the level of service to the newly discovered pairs. Invited services analyze the offers and decide on accepting or declining. If the decision is by continuing the service, the peer sign the offer and notifies the partner.
5) **Hiring:** A contract is formulated. The contract is based on responsibilities of each party and pre-established levels of service and quality. The partner is notified. The partner signs and analyses the contract. The partner adds a counter offer to the proposal and notifies the client. The counter offer is signed and analyzed. If it is accepted, it will be published an acceptance object to be signed. If the original contract is suitable for the partner, this counter offer step is no required.
6) **Admission and Operation:** CM services exchange CM information objects and monitoring of processing should be done according to established contract.

V. Comparison

Several initiatives have been proposed to CM of next-generation networks. In this section, we present a comparative analysis of the current architectures as well as emerging architectures described throughout this work. The aim is to contrast the features of each proposal with our reference model, which covers several limitations related to current CM technologies, addressing emerging approaches as IoT, SDN, ICN and NFV. Table 1 presents a summary of these points.

The proposed model brings together several innovative aspects to CM systems in FI, quite flexible to enable its development and integration with new initiatives. Such feature is quite interesting in the current technological scenario, where the technologies to meet existing limitations listed in Table 1, but not in a global way, where a technology covers a particular requirement and does not deal with the other. Then comes the need for a new proposal that above the current limitations in a unique, integrated, cohesive and harmonious architecture. We believe that the CM platform presented in this work is the solution for such requirements, since it combines the advantages of emerging paradigms (SDN, ICN, NFV, IoT) in the CM planes of FI.

VI. Conclusions

In this article, we specified a scenario for management and control requirements of NovaGenesis future Internet architecture. Initially, we listed several requirements for management and control of new generation networks, more specifically the ones related to NovaGenesis architecture. This specification can be employed to other FIAs. We presented and specified a NovaGenesis architecture for CM actions, proposing several services that operate in a contract-driven way, exposing its features, discovering peers, contracting adequate partners, and operating legacy/novel equipment in a distributed and hierarchical way. Future works include implementing a prototype of the specified services and performance evaluation of NG CM proposal.

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TABLE I

HOW NOVAGENESIS ADDRESSES CONTROL/MANAGEMENT CHALLENGES.

	Challenges	NovaGenesis Architecture
Internet	Pack loss due to the use of UDP. Existing implementations do not allow the use of TCP.	The current NG prototype does not implement retransmission. Future versions will have transmission control protocols. Due to the orchestration via representatives and contracts, CM critical information can automatically be carried by services that support relay.
	Heterogeneity of management protocols.	Allows customization of PGCMA/MeS for CM of diverse technologies, with or without TCP/IP. Allows representatives of heterogeneous resources, controlling SW/HW elements according to instructions provided by the Controller or Manager.
	Lack of CM interoperability.	The proposed model is generic and can be used with many different existing CM solutions.
	Excessive human interference	The life cycle of CM services can be integrated to autonomic loops. The hierarchical (contract-based) structure of services supports responsibilities division.
IoT	Support for new technologies	PGCMA acts as representative of the different elements. Legacy technologies can be integrated into the new ones.
	Scalability and elasticity	There may be several PGCMAs on the network, depending on the heterogeneity of the network and the number of devices in use. All services can be mirrored, sharing the workload. Naturally, NRS maintains consistency and versioning of data published by using hash generated names.
	Data provenance and integrity	NG operates with self-certifying names to all, including information objects, services, operating systems and networks elements. Through name bindings, all relationships among entities can be obtained by authorized elements. All data, controls, contracts have integrity check at the moment they are received.
	Diversity of programming interfaces	NRS provides a unique set of primitives for all CM actions.
CCN	Content and cache management	NovaGenesis has a distributed hash table service, which can run in multiple instances. Both Manager and Controller have authenticated/authorized access to NRS. The CM systems can be used to manage and control any services of NovaGenesis.
	CM does not take advantage of the network cache.	The components of the NRS are used for any service, including the CM services. Thus, the CM information objects take advantage of CCN/ICN paradigms.
SDN	Independent interfaces for data and control planes.	NG employs a unique API for all planes and CM services.
	Unique point of failure in the centralized controller.	Logical centralization of control is an innovative feature of SDN, but a controversial point. NG Manager and Controller are logically centralized services, but distributed deployed.
	Insufficient scalability for IoT	IoT control, mngt., and data planes will require scale proof solutions. NG CM model provides a distributed, self-organizing approach for IoT. PGCMA and MeS carry out mediation of CM information, supporting load balancing.
NFV	Complexity in operation of virtual/physical entities.	The NG CM functions employ the same solution for physical or virtual entities. A certain degree of auto-management is required. The Manager and Controller are able to accommodate self-* properties in their control loops.

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