Towards an Opportunistic, Socially-driven, Self-organizing, Cloud Networking Architecture with NovaGenesis

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Abstract: The exponential growth on the number of mobile devices and their capabilities are leveraging new possibilities of networking architectures for processing, storing, and exchanging of information. At a glance, existing architectures take advantage of these devices, the social behavior of their users, and/or the dynamicity on resource usage. Despite of the potential of existing initiatives, they do not interoperate which reduce their applications and deployment. As we walk towards a very dynamic world (regarding the user needs and characteristics, the information traversing the network, and the networking capability to adaptation at both users features and content of the demands levels), these architectures should merge into a solution that fits any type of scenario. In this paper, we specify an opportunistic, socially-driven, self-organizing, cloud networking architecture using a future Internet proposal named NovaGenesis. We highlight the requirements and solutions that NovaGenesis brings to accommodate the inherent challenges of today's dynamic networking scenario. Thus, we describe a convergent architecture, which integrates the new requirements with the already implemented NovaGenesis features.

1 INTRODUCTION

The way that users communicate nowadays is very different from a few years ago. The classic host-based paradigm, in which users would request specific content stored in specific locations, is giving room to new forms for users to exchange data. This is a product of not only devices becoming very portable, but also gathering the latest advancements in terms of processing, storage, and wireless technologies. Thus, users are able to produce and consume content anywhere and anytime, and such data exchange may take place through spontaneously formed networks. Furthermore, this content can be stored locally and/or on the users' personal clouds, as well as on public clouds.

Different networking approaches have emerged. Delay/disruption-tolerant networking (DTN) (Caini et al., 2008) deals with scenarios where intermittent connectivity is rather common among network nodes. Opportunistic Networking (ON) (Moreira et al., 2012) exploits different contact opportunities among users to exchange data. Cognitive Radio Network (CRN) (Ahmed et al., 2010), aims at exploring radio frequency spectrum holes to accommodate communication links. Information-Centric networking (ICN) (Xylomenos et al., 2014) emerged from the idea that people care for content itself no matter where it is, decoupling content identification ("what") from its location. User-centric networking (UCN) (Sofia and Mendes, 2008) includes user-provided devices and systems to build social-driven networks. These approaches are being used to address different challenges (e.g., intermittent connectivity, high mobility, longer delays, expensive infrastructure and/or connectivity) of emerging access networks. Also, cloud and big data systems have been integrated to these networking approaches as they can further increase the capabilities of the user devices and handle the vast amount of data that users produce.

One can observe that these networking approaches comprise a wide variety of data exchange and processing approaches that, despite of the already known

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potential, still operate for specific purposes and do not interoperate as required. Users are not so interested in the technicalities and employed approaches that allow them to exchange information. Instead, users expect an integrated cloud/networking infrastructure that allows them to share information directly with other peers, without relying on infrastructure and/or expensive connectivity services.

Despite the fact that existing networking and information access approaches share few concepts and concerns, they fail to cohesively integrate the aforementioned technologies (Alberti, 2012). We believe that such approaches can neatly come together as to form a converged architecture. Our starting point is NovaGenesis (www.inatel.br/novagenesis) initiative, which is a clean slate convergent information architecture (CIA) being developed by our team. By CIA, we mean an architecture that integrates information exchanging with processing and storage. It can be seen as a generic architecture, where Internet is converged to cloud computing and big data. NovaGenesis already integrates ICN, CRN, service-oriented architecture (SOA) (Papazoglou et al., 2007), software-defined networking (SDN) (McKeown et al., 2008), and Internet of things (IoT) (Conti, 2006). NovaGenesis paves the way to a CIA that advances integration efforts to include ON, ICN, UCN, and cloud.

In this context, the main aim of this work is to fulfil the need for a solution of converged architectures that allows for the application of different networking paradigms in a neat way. Each of these key ingredients strongly contributes to advance a specific designing dimension. When two or more of these ingredients are synergistically integrated, there is a "cross fertilization", a catalyzing effect, which favor global architectural advances instead of local ones. NovaGenesis is explored as the foundation for this architecture. New services are proposed to be integrated to NovaGenesis proposal. We contribute with a novel approach towards user-centric architectures.

This paper is structured as follows: we start by briefly overviewing the relevant networking paradigms to be considered by our convergent architecture in Section 2. In Section 3, we showcase NovaGenesis software-based CIA, the architecture we chose as the foundation of our social-driven initiative. Section 4 presents our contribution, showing a qualitative analysis regarding how NovaGenesis addresses the challenges behind the proposed architecture, pointing perspectives, pre-requirements, and open issues. Finally, Section 5 concludes the paper, also highlighting some future work.

2 RELEVANT NETWORKING PARADIGMS

This section presents the different paradigms that shall be comprised by our convergent architecture.

Opportunistic Networking (ON) exploits the contact opportunities taking place among users' devices to allow data exchange. Opportunistic forwarding can be seen from two perspectives regarding user social behavior, namely social-oblivious and social-aware approaches. From these approaches, the latter has gained much attention of the research community given the fact that social information is less volatile (i.e., changes less, favoring data exchange) than mobility (Moreira and Mendes, 2013). Our convergent architecture shall take into consideration the dynamism of user social behavior found in their daily routine in order to properly infer the different levels of social interactions among users and the interests of these users (Moreira et al., 2012) (Ciobanu et al., 2013) (Ciobanu et al., 2014b) (Moreira et al., 2014) since the dynamics of user social behavior does have an impact on the performance of opportunistic forwarding (Moreira and Mendes, 2015a) (Moreira and Mendes, 2015b). With that, our architecture is expected to provide the users with data exchange opportunities over only socially relevant links, thus with improved delivery probability while reducing associated cost and experienced latency.

With **Content-Centric Networking (CCN)**, data traverses the network according to the match between its name and the interests that users may have in such contents, independently of its location, resulting in an efficient, scalable, and robust content delivery. There are different efforts for defining a CCN architecture (DONA, NDN, NetInf), each with its own particularities (e.g., employ their own naming scheme) and looking into different CCN aspects (e.g., naming, security, routing, caching, transport) according to the application to which they have been devised (Xylomenos et al., 2014). With the advances in technology, devices have become more portable and with increased capabilities (e.g., processing, storage). In such dynamic networking scenarios, users are prosumers (i.e., producers and consumers) of information with a high demand to share/retrieve content anytime and anywhere, independently of the intermittency level of wireless connectivity, dynamic behavior of users, physical obstacles, lack of cooperation, closed (i.e, secured) networks, among others. Given its potential, the convergent architecture shall incorporate CCN features (end-to-end path abstraction, interest-based content-driven dissemination) as to cope with the dynamicity of today's networking scenario. Thus, our architecture shall provide the content that users demand based on their interests which they propagate while carrying on their daily routines.

User-Centric Networking (UCN) focuses on the user who is the main pillar for routing, security, and among other networking aspects (Sofia et al., 2014). This networking paradigm empowers the user that can easily provide services (e.g., connectivity, printing) to others. Within this context, the user besides producing and consuming content as mentioned before, now becomes a micro-provider (Sofia and Mendes, 2008) changing currently known Internet communication models (end-users comprise a user-provided network extending services, where user willingness in sharing resources/services allows scalable services).

There are different approaches that relate to user-provided networking spanning a vast range of applications: making use of proprietary equipment to share connectivity (SparkNet at htpp://sparknet.fi/); simply turning the end-user device into a sharing point (Whisher/WiFi.Com at http://www.whisher.com); creating a network for sharing resources (Wray Village' wireless broadband at http://www.infolab21.co.uk/livinglab). However, it is important to note that these approaches aim solely at sharing connectivity. This is indeed a type of resource that users are very much interested, but there is more to it. The ULOOP (siti.ulusofona.pt/˜uloop/) project clearly highlights this: ULOOP users are provided with th means to exchange resources as they wish based on the trust levels between these users and/or based on the exchange of virtual currency. The project considers they dynamic behavior of users to allow the exchange of different types of resource beyond connectivity. With this in mind, our convergent architecture aims at providing users with the means of sharing the resources they have the most and make use of resources they require at a given moment. By combining opportunism with content centricity, the convergent architecture is expected to further empower the users allowing them to naturally engage in the system y providing and consuming resources according to their current demands.

Cloud Computing Elasticity exploits the fact that resource allocation is a procedure that can be performed dynamically according to the demand for either the service or the user (Jamshidi et al., 2014). Our convergent architecture is expected to increase the number of network resources (e.g., routing elements, pre-processor nodes and gateways) in order to provide and keep a service level agreement (SLA) between the user and the Internet architecture assembled above the cloud. Virtual machine migration, addition and resizing are techniques that could be combined to offer an elasticity semantic for this novel Internet architecture. Additionally, we envision the reduction of subnet resources when the network demand is moderated, so contributing to implement green computing with energy saving (i.e., consolidation technique, shutting down VMs and the host node)

3 NovaGenesis (NG) ARCHITECTURE

NovaGenesis (Alberti et al., 2014) project started in 2008 to address this question: imagine there is no Internet architecture right now, how could we design it using the best contemporary technologies? We selected several technologies to best implement NovaGenesis design principles, looking for deep synergies among them. NovaGenesis can be defined as a convergent information architecture (CIA). By CIA we mean an architecture that synergistically integrates information processing and storage (as contended by cloud computing), as well as information exchanging (like the current Internet architecture or other emerging networks, e.g., software defined networks or mobile terminal networks). All the concepts presented in this section are summarized in Figure 1.

3.1 Names, Identifiers, and Locators

The NG cornerstone is naming. A *name* is a set of symbols that denote something, some existence. It is deeply rooted in language. For example, one can use the name "Paris" to denote a city in Europe. The same name can be used to denote many different existences, e.g. "Paris" is also the name of a famous north American socialite. In this context, an important decision choice we did was: what existences need to be named on a CIA? By existence we mean everything that simply is. People love to name everything - from cars to airplanes, applications to computers, photos to movies, etc. Additionally, an important requirement for future architectures is that they should be able to better "understand" the meaning of the language used by people - which is called semantic technology.

Many notable companies are investing on semantic computing. Examples are IBM's Watson and Google's Brain. With the advent of the Internet of things (IoT) - where virtually anything can belong to the Internet - we assumed that all possible entities could be named, bringing machines closer to people natural language. Naming should be very flexible and broad. However, not all natural language names (NLNs) are adequate for efficient and safe naming. Therefore, we adopted a second kind of naming in

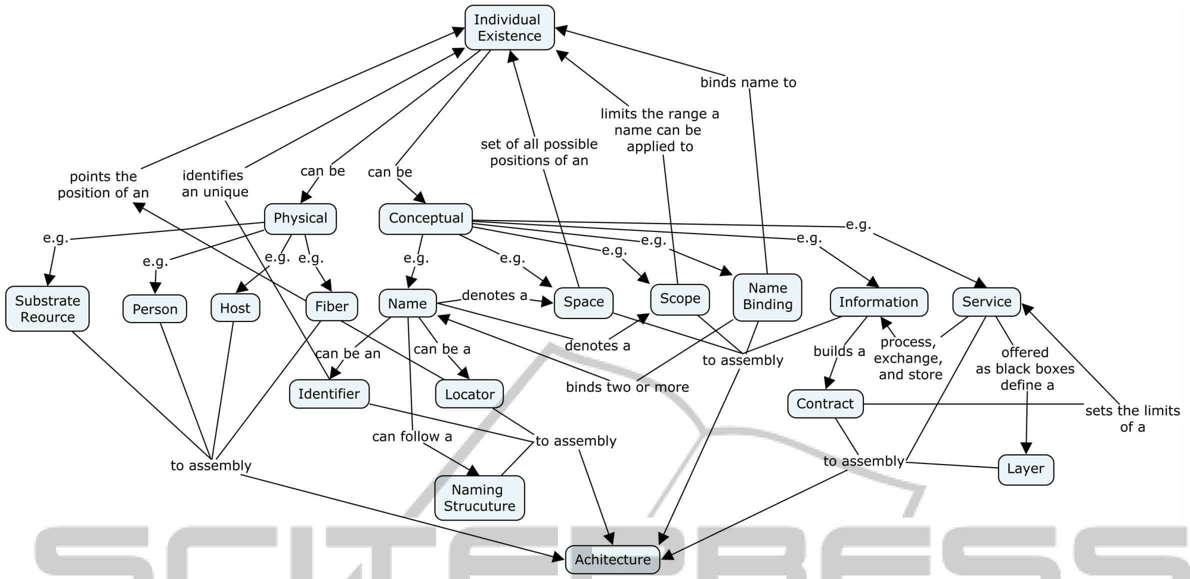

Figure 1: NovaGenesis concepts for convergent information architecture.

NG architecture. The so called *self-certifying names* (SCNs). A SCN is typically obtained by passing a input binary pattern by a hash function. The pattern can be the entity itself, e.g., a chunk of data of a photo, or a digital representation of some physical world attributed, e.g., the digitalized patterns of a fingerprint.

What is the use that NovaGenesis does for all these names? We asked these question many times while designing NG. The answer is: every information processing, storage, or exchanging depends on names and their relationships. The target of a communication is an unique name in a certain scope. The location of certain destination is also a name that provides the relative distance among possible targets. Ownership, equivalence, "is contained", and many other semantic operators can be represented by a *name binding* (NB). A NB can map several names to many other names/objects. Additionally, one can expect that people (and even machines in future) will denote other existences by names. Therefore, name bindings can represent the relationships (semantic operators) among named-existences. In this sense, a NB is itself another existence, a virtual/abstract one, which can be stored as a virtual object.

NovaGenesis is generic enough to enable the creation of any naming structure. A naming structure is an scheme to denote existences following some planned strategy. For example, in the current Internet hosts are denoted by an hierarchical name structure, where names have two portions: host and domain names, e.g., mycomputer.inatel.br. Using name bindings the CIA architects can design any naming convention. NG employs names to identify and locate communicating targets. All name bindings are stored in a distributed software forming a giant *name bindings graph* (NBG). Identification and location is a matter of scanning this graph to determine entities that belong to some scope or that inhabit some space. A communication target could be a content, a computer program, a computer, or any other existence.

3.2 Substrate Resources, Services, Contracts, Protocols, and Layers

Every software-based CIA (SB-CIA) is supported by physical world existences called *substrate resources*. Examples are antennas, fiber optics, microprocessors, memories, hard disks, etc. The exponential growth in computers capabilities is creating a phenomenon called *virtualization*. Maybe the most prominent example is the so called cloud computing where virtual machines (VMs) work like physical ones. More recently, virtualization on networking technologies is being addressed under the banner of network function virtualization (NFV) (Salsano et al., 2014). The idea is to replace customized hardware - many times deployed at difficult access sites - by software-implemented functionalities inhabiting VMs in the cloud. NG assumes that computing hardware is evolving so fast that software-based implementation of networking protocols is already possible for the majority of the network stack.

The increasing role of software in ICT architectures demand for excellence in software engineering. A technology for this purpose is to design software-as-a-service (SaaS). SaaS is often related to a service-oriented architecture (SOA). We define a service as an existence aimed at processing, exchanging, or storing information. According to this definition, a computer program (or a process) is a *service*. Any substrate resource can be represented by named services, e.g., infrastructure-as-a-service (IaaS). Even protocol implementations provide services.

In this paper, no distinction is done between "protocol implementation" and a service. According to our service definition, a protocol is implemented as a service that processes, stores, and exchanges information in order to build networks. Thus, services use other services indefinitely, starting from the ones required to implement a network. This paper proposes the concept of *protocol-implemented-as-a-services* (PIaaS). Observe that an interface to expose any service to other services is required. NG enables SCNs to be used for this purpose.

NovaGenesis envisions a service life-cycle that includes features exposition, peer discovery, negotiation, contracting, monitoring, evaluation, and releasing. All these steps take advantage of the NBG. Service descriptors and contracts are named using SCNs. A contract is defined as a piece of information that sets the limits, responsibilities, clauses to be respected, as well as the criteria for completion and punishment of services that were poorly executed.

The concept of a *layer* still prevails in NG. A definition that combines the concepts of (Tanenbaum, 2003), OSI model (Standardization, 1996), (Day, 2008), and (Chaitin, 2010) is: a layer is an abstraction for a cluster of services that is offered in a distributed way to other services, isolating rules implementation, following a shared language - a common syntax and semantics - its interface. In this paper we replace the terms: "protocol implementations that are offered in a distributed way to other layers" by "services offered in a distributed way to other services". Thus, a NG layer is composed by several services that are exposed to other services via a predefined language.

3.3 Current Proof-of-Concept

A first implementation of the NBG and PIaaS concepts, covering intra node and inter node service communication was coded in 2012. We adopted a pub/sub model, where NBs and contents are published and subscribed by services. The NBG is implemented using distributed hash tables (DHT). NBs are published by services and stored on DHT. Service life cycling is build over this distributed pub/sub service. We implemented some protocols for service exposition, discovery, contracting, and named-content forwarding and routing. The following services have been designed for current version:

Hash Table Service (HTS) - It provides a domain level hash table that is used to store published NBs. Name bindings are categorized to improve scalability.

Generic Indirection Resolution Service (GIRS) - It forwards name bindings (together with content) for one or more HTS instances.

Publish/Subscribe Service (PSS) - It is the narrow waist for NG services. Any service will use the publish/subscribe directives provided by the PSS hierarchical service. Services can publish NBs and associated content to other services and subscribe other name bindings of their interest.

Proxy/Gateway Service (PGS) - To facilitate migration and enable transport over other technologies, we envisioned the PGS. The current PGS provides software-based messages encapsulation, forwarding, and routing. Additionally, the PGS is also a proxy for core NG services inside an operating system (OS). It represents these core services during bootstrapping, forwarding public NBs to other friend PGSs, exposing them to enable name-based self-organization. The PGS can maintain inter node IPC without TCP/IP only using Ethernet/Wi-Fi.

Application (App) - The current implementation has a generic application capable to explore the pub/sub service (PSS) offered by the core.

4 ADAPTING NovaGenesis: REQUIREMENTS AND CHALLENGES

4.1 Rethinking Naming

The proposed architecture shall rely on a strong naming approach to capture relationships among entities. Not only SCNs should be enabled for all existences, but also natural language names (NLNs) to enable in-architecture ontologies accommodation. NovaGenesis already supports natural language and/or self-certified name bindings to converge human and machine languages. This improves services expressiveness, like in current SOA, e.g., web services. People's names can be related to their equipment, services, and content as illustrated on Figure 1. Distributed name resolution enables services to explore other services, users, and content context and scope. NovaGenesis already implements this on PSS/GIRS/HTS services. NG generic naming structure can support UCN, CCN, ON, cloud requirements for naming.

4.2 Addressing Heterogeneity

A PGS can be implemented to offer gateway functionality to each technology deployed at the UCN, ON, CCN, etc. For example, if ZigBee technology is employed, a PGS can be implemented at the ZigBee gateway to bridge frames from/to NovaGenesis. The same can be done for every technology in the network. We are expanding PGS to include software-defined control functionalities. This new service will include proxy/gateway/controller (PGC) functionalities. It can expose non NovaGenesis devices features (and available configurations) to other NG services. Hence, after contract establishment, other services can publish configuration change requests that are translated to other technology devices, like ZigBee, Bluetooth, etc. This allows NG services to configure the network directly, creating what we are calling service-defined architecture (SDA).

4.3 Encouraging Collaboration

UCN provides the means for cloud and big data systems to be accessible to users, increasing their processing and storing capabilities. Users' devices can be enhanced by being given the chance of exploiting other users' devices in the vicinity, and being able to access the content that is made pervasively available at the user's current location. NovaGenesis SOA favors paid collaboration via dynamic SLA negotiation and establishment. Free models of collaboration are also possible. NG approach should be merged with our previous work towards a convergent approach. Previous work like SENSE (Ciobanu et al., 2014a) can help clarify which are the requirements for enhancing collaboration. SENSE is a collaborative selfish node detection and incentive mechanism for mobile networks where collaboration among users is a must. Since information collected locally by each node may not be sufficient to reach an informed decision, nodes running SENSE collaborate through gossiping. After informing each other of their observations, nodes reach decisions individually based on their local and received information. New NG services will implement a range of collaboration models, i.e. selfish, paid, and free. Spontaneity cluster formation based on user labeling can also be implemented. Services to determine node popularity are welcome.

4.4 Supporting Broad Opportunism

Our convergent architecture will require contextualized opportunities detection, which can be implemented as NG opportunity detection services (ODSs). These services can be fully integrated with NG PGCs to enable self-orchestration of exposed substrate resources. The PGC services expose physical resources (hardware) for software orchestration. Opportunities can include proximity, battery, offloading, spectrum, etc. All the required information to expose and explore opportunities is available for authorized services via PSS/GIRS/HTS. The architecture needs novel solutions for data aggregation. Since nodes running PGC services are generally small hand held devices such as smartphones, their memory is limited. Moreover, the access speed is also very important when there is a contact between nodes, since the duration of an encounter between two nodes (i.e. the time window when they can exchange data) is relatively short, due to the high degree of node mobility. Opportunities can be detected and shared using ODS. NG approach should be merged with previous work. Examples are ULOOP (http://copelabs.ulusofona.pt/˜uloop/), UCR (http://copelabs.ulusofona.pt/index.php/research/-projects/past-projects/151-ucr). In other words, a convergent name-based opportunistic routing/forwarding approach will be required. Regarding proximity, not only physical world contacts can be explored, but also service contracts. Opportunity notification can be done via PSS.

4.5 Seeing Everything-as-a-Service

NovaGenesis PGC services expose hardware resources to software allowing all physical resources to be seen as a service. Controllers, proxies, and gateways can be exposed as a services. All the required orchestration for our convergent architecture will be service-based. Service life-cycling is intrinsic, covering all aspects from exposition, discovery, negotiation, contracting, content exchanging, quality monitoring, and releasing. The goal is to accommodate protocol implementation as services, enabling them to dynamic establish SLAs, giving rise to networking self-organization based on detected opportunities. Flexible smart network services can discover each other, prepare SLAs proposals, negotiate with possible peers, establish SLAs, work together to explore social- and context-aware opportunities, evaluate partners, and finish SLAs.

4.6 Security, Privacy and Trust

The distributed scenario behind the proposed architecture poses several challenges regarding security, privacy, and trust. Networking cache, traffic offloading, opportunistic collaborations, and cloud offloading are examples of user-centric approaches that will require new security models. NG employs a pub/sub communication model that favors the rendezvous among authenticated and authorized services. Content exchanging only happens after SLA establishment. Hence, it is secured by asymmetric cryptography. Publishers maintain a secure association with the PSS, which stores SCNs of authorized subscribing entities. Subscribers also have a secure association with PSS. The PSS only delivers the content after proper authentication and authorization. Additionally, the PSS provides revoking of published bindings, data, permissions, etc. The SLA-based self-organization enables the establishment of a trust network among peer services - which is ideal for UCN, ON, CCN, and clouds. All messages are confidential and have SCN-based integrity. We envision that NG will need new services for trust network formation, assertion, and management, as well as services for unbiased contract, reputation, and trust evaluation. NG name- and contract-based ”social security” goes beyond traditional mechanisms.

4.7 User-Centric Life-Cycling

User-awareness and social-behavior awareness need to be estimated properly to drive NG ecosystem. The aim is to adapt protocol implementations according to user/social data. Hence, new services to estimate social trends and achieve context-awareness will be necessary. NG enables users to define high level policies that can be published to other services by a policy definition service (PDS). Published policies can be subscribed by peer services and used in their decision cycles. Big data and cloud information can be shared together with policies to make all the environment user-aware/socially-aware. For example, imagine a user agrees on selling part of this bandwidth to other users' radios when its device battery is charged more than 50%. This policy can feed network level protocols, in order to establish opportunistic routing among users devices. Use cases and proper policies should be designed and new NG services created to implement UCN and content life-cycling. Social engagement can be derived from available public information and explored by these emerging services. Interest-driven is favored published ontologies, helping on establishing successful partnerships.

4.8 Tolerating Delays and Disruption

Long delays and disruptive communication represent a challenge for current Internet stack. TCP does not fit well on long delays scenarios and UDP requires excessive application level programming. The asynchronous communication model provided by the PSS together with the HTS networking cache enable NG services to change information in different time moments. Connectivity disruption does not impact on sockets since a new naming structure is provided, turning names perennial, independent of connectivity. Protocols implemented as a service (PIaaS) offer the required flexibility to deal with intermittent connectivity and long delays. These PIaaSs need to be designed and implemented using NG software. A hardware implementation is also possible, but will require complete new designs using FPGA.

4.9 Supporting Mobility of Everything

What are the entities one expect to move in future user-centric architectures? The answer we propose is everything, from terminals, people, services, up to entire opportunistic networks. NG naming structure enables any name that satisfies some requirements to become an identifier or a locator. This decouples ”what do you want” from ”where it is”. Mobility of everything is supported by rebinding names during movement. The identifier of what is moving remains the same - the only thing that changes are the locators. This solution relays on NG distributed NBs pub/sub and storage. UCN, CCN, NFV, and ON need mobility of everything support. NG can address this.

4.10 Integrating Cloud and Networking

Another important requirement is to alternate the use of computing and communication resources interchangeably. In other words, the lack of computing resources due to energy shortage or high load can be compensated by communication resources, which help on migrating the tasks to other machines. In contrary, when energy is limited (like in mobile devices), functions can be virtualized in the cloud (providing cloud offloading). Cloud networking is naturally supported. NG design should be merged with our previous work in cloud. Two approaches to be considered are: context-aware cloud computing infrastructure for taking good budgets. It is a SaaS that streamlines the interaction between for customers and sellers (salesman); and resource provisioning on cloud computing environments, which is an IaaS approach aimed to offer load balancing for a service that runs parallel applications. It consists in task migration considering the current pool of allocated processors. After that, if the SLA is not satisfied, our second approach will be to allocate new resources in order to run the application with the previous established requirements. Also, it comprises the deallocation of resources if they are super estimated for running the application. Finally, the resources used by services can vary along their lifetime in accordance with the application behavior.

4.11 Providing Self-Organization

The scenario we are imagining requires new approaches for management and control. One can not expect people will manage or control dozens of devices connected to others, manually. The current management model depends on frequent human interference, having poor scalability when considering the swarms of devices we expect on next years. Embedded control functions (usually, at equipment control plane) create a complex distributed states solution, which challenges operators to keep a coherent and efficient network configuration. Future architectures need to self-organize according to user needs and detected opportunities. We envision a hierarchy of control loops that follow user-awareness and social behavior awareness to autonomically configure and manage ICT architectures. NG enables services to self-organize using NBs and content pub/sub. Self-management is fundamental in the proposed architecture, since no one will be responsible alone to manage a socially driven, possibly infrastructure-less architecture. Or previous work on UCN, ON, and CCN can help on designing these hierarchical control loops.

4.12 Control and Management

To address the requirements of effective utilization and optimization of heterogeneous resources (storage, processing, and networking), the architecture requires an innovative software-defined everything (SDE) paradigm. NG addresses this challenge by means of PGCs. A PGC represents some hardware resource in the software layer and can establish dynamic contracts in the name of them. It also controls the hardware devices, e.g., software-defined systems and/or radio, to perform the changes required. It can even expose hardware status to other NG services, enabling them to proactively prepare cloud/network solutions in advance to user requirements. It is a paradigm shift towards service-based network control and management. NovaGenesis's PGC services will represent all physical world resources used. Controllers- and managers-as-a-service will establish contracts with PGCs to create a new control/management model. Decision loops can be formed by establishing chains of control/management services linked via NG service contracts.

4.13 Supporting Context-awareness

User-, regulation-, situation-awareness, and many other context-awareness features are required to make sound decisions - decisions that consider the relevant contexts to every situation. NG enables services to securely and privately subscribe the relevant contexts following their trust network. In other words, the PSS provides a distributed networking cache from where services can subscribe the relevant contexts for decision making. For example, a radio resource manager could subscribe spectrum usage data from a spectrum analyzer service. The manager can form a logically centralized view of radio frequency spectrum usage at some location, the so called situation-awareness. Another example is related to social-awareness.The dynamism of social behavior can be derived from big data services implemented at NG or at any other software. In the latter case, a NG service will be required to bridge legacy software to NG cloud. Well established social trends can be published by a big data service (BDS) in order to feed other services.

4.14 Implementing Decision Cycles

The architecture shall adapt its behavior (cloud and networking aspects) according to users needs and detected opportunities, changing protocol implementations, data paths, parameters, etc. The architecture should explore dynamically the available connectivity, frequencies, bandwidths, technologies, and nearby friends capabilities. It must configure itself to take advantage of perceived opportunities in a reasonable time. In long term, autonomic and cognitive decision cycling will be required for self-management, auto-piloting, and opportunistic networking. Specialized services could implement required decision cycles. The cycle starts with user generated objectives, policies, rules, and regulations. An existing plan is selected. The plan is executed. The obtained results are collected and analyzed to measure the degree of success. If success was achieved, the objective is considered as met. Else, decision making can select changing the plan (or adapting it). This is an aim for future.

4.15 Addressing Society Challenges

Digital inclusion is one of the main aims of user-centric, opportunistic, infrastructure-less (or public infrastructures) architectures. It could be an important driver for developing countries like Brazil and India. Also, social-driven proposal have the potential to change our society towards ”smart solutions”, where every resource is better used, optimized for inclusion, and green technologies requirements. We believe architectures like the one we are proposing on this paper have the important role of helping us to solve important social, economical, and environmental problems.

5 CONCLUSION

This paper proposed a convergent architecture that integrates emerging socially-driven, opportunistic, user-centric networking with NovaGenesis name-based, software-defined, information-centric, service-centric, self-organizing cloud networking proposal. Pre-requirements and open challenges regarding several topics have been discussed. NovaGenesis principles and current implementation provide a satisfactory substrate to implement the proposed architecture. NG joint orchestration of named-services and contents provides an appropriated environment to implement socially-driven/opportunistic/cloud/networking approaches as services. Even protocols are implemented as services, enabling the resultant architecture to react according to user-defined policies, rules, regulations, environment situations. Context-awareness can be included on decision making, changing protocol implementations according to social trends. The paper is a first step of an ongoing work that contributes to the community by discussing how to integrate so many relevant issues in only one architecture.

We envision that the proposed architecture can be implemented by: (i) specifying new NG services that meet the raised pre-requirements; (ii) adapting previous work techniques as new NG services; (iii) modifying NG core services accordingly; or (iv) integrating already existing software (without any modification) with NG via proxy/gateway/controller. This effort is expected to result into a convergent solution comprising the best of the considered architectures (ICN, DTN, UCN) and that allows users to seamlessly access content, and share resources anytime and anywhere in today's dynamic scenario over their powerful personal devices. Future work include NG performance, portability, and embedding on mobile devices.

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