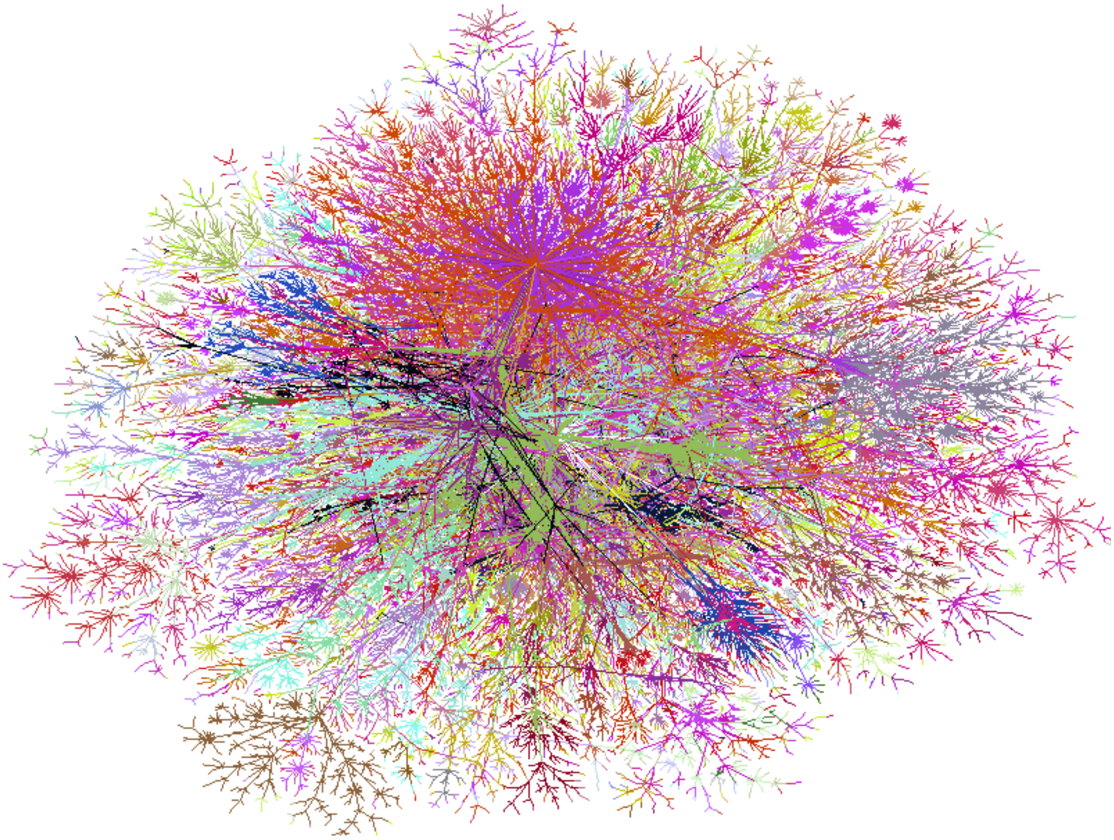
Architectures for next generation Internet

Αρχιτεκτονικές για το μελλοντικό Διαδίκτυο

Μωραΐδου Άννα

Θεσσαλονίκη 2012



"Map of Internet: colored by IP addresses" by W. R. Cheswick

Πανεπιστήμιο Μακεδονίας
ΔΠΜΣ Πληροφοριακά Συστήματα
Δίκτυα Υπολογιστών
Καθηγητής: A.A. Οικονομίδης

University of Macedonia
Master Information Systems
Computer Networks
Professor: A.A. Economides

Abstract

The Internet is used by billions of people worldwide for information exchange and access in advanced software services. It's evolution from an academic platform to a world wide commercial platform creates new demands, such as security, performance reliability, mobility and content distribution. Current internet architecture cannot fulfil these incremental demands. Until now the basic approach to the solution of this problem was the evolutionary. This approach is based on the current network infrastructure and aims to resolve the occurring problems according to its behaviour. Nowadays, research community is focusing on the clean-slate approach. The goal of this approach is to build a new architecture from the scratch. However, this brings up some crucial challenges such as the need for innovations in various aspects of the internet, the need for collaborative projects putting multiple innovations into an overall network architecture and the need for Test-Beds for real–scale experimentation. An overall view of these researches, which are being conducted from United States, European Union and Asia, are discussed below.

Περίληψη

Το Διαδίκτυο χρησιμοποιείται από δισεκατομμύρια ανθρώπους σε όλο τον κόσμο για την ανταλλαγή πληροφοριών και την πρόσβαση σε προηγμένες υπηρεσίες λογισμικού. Η εξέλιξη του από ακαδημαϊκή πλατφόρμα σε εμπορική δημιουργεί νέες αυξανόμενες απαιτήσεις για ασφάλεια, αξιοπιστία απόδοσης, επέκταση στα κινητά και στην διανομή περιεχομένου. Η τρέχουσα αρχιτεκτονική του Διαδικτύου δεν μπορεί να εκπληρώσει αυτές τις ολοένα αυξανόμενες απαιτήσεις. Μέχρι τώρα, η βασική προσέγγιση στην λύση του προβλήματος ήταν η εξελικτική. Αυτή η προσέγγιση βασίζεται στην υπάρχουσα υποδομή του διαδικτύου και αποσκοπεί στην επίλυση των προβλημάτων την ώρα που προκύπτουν και με βάση την συμπεριφορά τους. Σήμερα, η ερευνητική κοινότητα εστιάζεται στην προσέγγιση της εκ βαθέων λύσης. Ο σκοπός αυτής της προσέγγισης είναι ο επανασχεδιασμός της σημερινής αρχιτεκτονικής του Internet. Ωστόσο, αυτή η προσέγγιση εγείρει νέες προκλήσεις όπως η ανάγκη για καινοτόμες λύσεις σε πολλούς και διαφορετικούς τομείς, η ανάγκη για συνεργασία των ερευνητικών προγραμμάτων ώστε να ενοποιηθούν όλες οι λύσεις σε μία εξ' ολοκλήρου νέα αρχιτεκτονική και η ανάγκη για πειραματισμό σε δοκιμαστικά δίκτυα. Μία συνοπτική εικόνα αυτών των ερευνών που διεξάγονται από τις Ηνωμένες Πολιτείες, την Ευρωπαϊκή Ένωση και την Ασία, παρουσιάζεται παρακάτω.

Problems and challenges of current internet:
The current Internet was designed over 40 years ago with certain design principles. Consequently, its continuing success has been hindered by more and more sophisticated network attacks due to the lack of security embedded in the original architecture. Furthermore, IP's narrow waist, means that the core architecture is hard to modify, and new functions have to be implemented through myopic and clumsy ad-hoc patches on top of the existing architecture.
As Feldmann (2007, p.61) points out, the current set of design principles are intrinsic to the current architecture of the Internet and therefore hard to challenge and hard to change. Furthermore, advances in technology have made new capabilities available, which question some of the old design principles: fast packet optical components, wireless networks, fast packet forwarding hardware, virtualization techniques, and significant computational resources.
Consequently, as the Internet has evolved from an academic network to a broad commercial platform, the emerging demands for security, mobility, content distribution, performance reliability are hard to be met by incremental changes through ad-hoc patches. This brings up challenges in many aspects, especially in the commercial context.

Specifically, according to Jianli et al (2011, p.26), the most essential challenges for current Internet to be met are:
Security: Is not inherent feature and not integral part of the architecture. Instead, security enforcement is "perimeter-based". As Tronco (2010, p. 107) points out, too much information is send to the destiny users without previous authorization, e.g. email spam, pop-ups, malicious cookies, etc. It is necessary that the next generation allow the option of authentication of sources/destinations/intermediate systems, privacy of location, privacy of data, and data integrity guarantees. Similarly, the EC FIArch Group (2010, p.9) state that the Internet is not intrinsically secure and is based on add-ons (e.g. protocols) to secure itself. Protocols may be secure, but the overall architecture is not self-protected against malicious attacks. Furthermore, communications privacy is not only protecting/encrypting the exchanged data but even not disclosing that communication took place. It is not sufficient to just protect/encrypt the data (including encryption of protocols/information/content, tamper-proof applications etc), but also protect the communication itself, including the relation/interaction between (business or private) parties. (EC FIArch Group, 2010, p.7).
Content distribution: Is a simple "host-to-host" packet delivery paradigm instead of more diverse paradigm built around the data, content, and users instead of the machines.
Mobility: Access to networks is ubiquitous.

Solution:
New clean-slate architecture designs based on new design principles.
As Feldmann (2007, p.61) claims, there are two principal ways in which to evolve or change a system:

- incremental: a system is moved from one state to another with incremental patches.
- clean-slate: the system is redesigned from scratch to offer improved abstractions and/or performance, while providing similar functionality based on new core principles.

In the past 30 years the Internet has been very successful using an incremental approach. However due to its success, the community has now reached a point where people are unwilling or unable to experiment on the current architecture. Therefore, it might be time to explore a clean-slate approach consisting of: out of the box thinking, the design of alternative network architectures and experimentation with the architecture in order to evaluate the ideas and to improve them as well as to give them a realistic chance of deployment either in a new system or incrementally on/in today's network.

However, as Rexford & Dovrolis (2010, p.39) state, it is not enough for a clean-slate architecture to be "better" than the current Internet architecture. For the former to have real impact it should be able to replace the latter—otherwise it will remain an intellectual exercise. It is the question of real-world impact that differentiates clean-slate from evolutionary research and design.

Therefore, as Jianli et al. (2011, p.26) say, a clean slate solution on a specific topic may assume the other parts of the architecture to be fixed and unchanged. Thus, assembling different clean slate solutions targeting different aspects will not necessarily lead to a new Internet architecture. Instead, it has to be an overall redesign of the whole architecture, taking all the issues (security, mobility, performance reliability, etc.) into consideration. It also needs to be evolvable and flexible to accommodate future changes. In overall, the target goal is to build a holistic Internet architecture.

What is being done nowadays?

Nowadays, several programmers involving a great number of projects are in progress worldwide. However, the successes of all this research depends on the ability to test it in open virtual large scale networks without affecting existing services. This is because the current Internet is owned and controlled by multiple stakeholders who may not be willing to expose their networks to the risk of experimentation.

In summary, there are three consecutive steps leading toward a working future Internet architecture:

Step 1: Innovations in various aspects of the Internet

Step 2: Collaborative projects putting multiple innovations into an overall networking architecture

Step 3: Testbeds for real-scale experimentation.

However, it may take a few rounds or spirals to work out a future Internet architecture that can fit all the requirements.

Classification of researches:

Future Internet research efforts may be classified based on their technical and geographical diversity. In this survey, primarily based on the geographical diversity, is presented a short survey limited in scope to a subset of representative projects. Specifically, different approaches and structures of these different research programs are discussed.

While some of the projects target at individual topics, due to the holistic architecture goal, different projects may have some overlap by creating collaboration and synergy among individual projects.

Research programs specifically aimed at the design of the future Internet have been set up in different countries around the globe, including the United States, the European Union (EU), Japan, and China.

Key research topics: Every research has three basic aspects: its approaches, its major features, and its potential impact on the future. According to this point of view there are five key research topics filtered from worldwide researches:

1. **Content- or data-oriented paradigms**: The new paradigm shift (Wikipedia, n.d.) is content-centric networking (also content-based networking, data-oriented networking or named data networking). It is an alternative approach to the architecture of computer networks. Its founding principle is that a communication network should allow a user to focus on the data he or she needs, rather than having to reference a specific, physical location where that data is to be retrieved from. This stems from the fact that the vast majority of current Internet usage (a "high 90% level of traffic") consists of data being disseminated from a source to a number of users. Another perspective of new data oriented paradigms is given in the survey of Tronco et al. (Scenarios of Evolution for a Future Internet Architecture, 2010, p.60), see figure 1, where three scenarios for a future Internet architecture are examined: the user-centric, the object-centric and the content-centric. The user-centric scenario is related to provide a ubiquitous and comfortable service portfolio (communication, seamless mobility, ergonomics, trust, no wait times, etc.) to the people themselves. The content-centric scenario refers to convert the network nature itself, from a "link-structure" (set of a sparsely distributed nodes connected through links) to a "network of information", i.e., a receiver-driven information dissemination infrastructure, with information objects uncoupled from specific hosts locators. Its associated paradigm would be an "Earth-wide thinking machine" (intelligence spread everywhere like inside the human's brain). The object-centric scenario opens the Internet-scale connectivity to any imaginable real world object, expanding the host and device endpoint space to sensors and things. The so-called Internet of Things is based on the paradigm of "everything is a living and intelligent being", from clothes to streets. These scenarios are characterized by their network's attributes as sown in table 1.

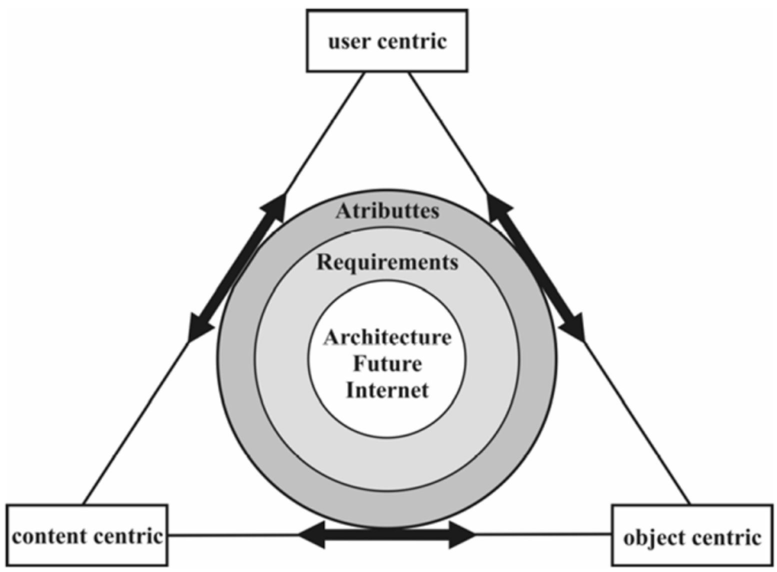


Figure 1: Future Internet Evolution Scenarios. The poster: "Future Internet Evolution Scenarios" (Tronco, 2010, p.60).

Table 1.*Common Attributes of the Three Scenarios.* (Tronco, 2010, p.60).

User-Centric Scenario	Object-Centric Scenario	Content-Centric Scenario
Ubiquity and Mobility Capacity, Reliability and Availability Security and Privacy		

Of course, as the survey of the FIA-Future Content Networks Group points out (2009, p.7), future Internet will not only bring new media and content. Attention should be also paid to the presentation, communications, services, infrastructure and privacy, which are essential building blocks of the FI. Yet, the content (new or traditional, broadband or narrowband, professional or user generated, pre recorded, live or interactive, broadcasted or personalized) is what the users will receive/enjoy from the Future Internet. Starting from the reasonable assumption that the content and the content representation (current forms and new media) is the basis of the Future Internet, and following a bottom up approach, we may assume that if the Future Internet is content centric, it can efficiently handle the content and this will lead to a new generation of the Internet.
In more details, as shown in Figure 2:

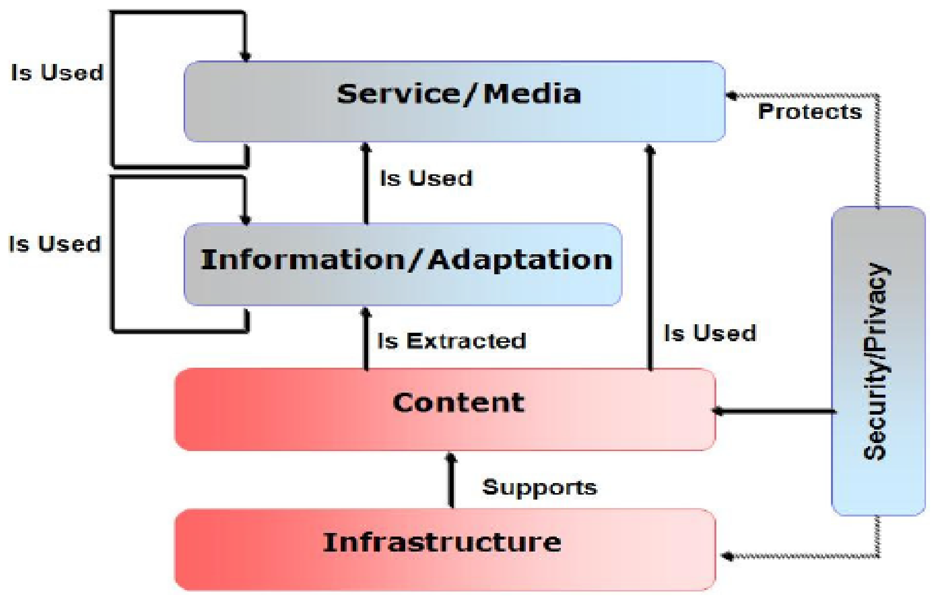


Figure 2: Future Content Centric Internet components interrelation (FIA-Future Content Networks Group, 2009, p.7).

• ***Content*** is any type and volume of media. Content may be pre recorded, cached or live, static or dynamic, monolithic or modular. Content may be combined, mixed or aggregated to generate new content and Media. It may vary from a few bits (e.g. the temperature that a sensor has measured) to interactive multi media sessions and immersive complex and multi dimensional virtual/real worlds' representations.

• ***Information*** is the product of a number of functions applied to the content or recursively to the information. By combining, mining, aggregating content and pieces of information, new information may be extracted or generated.
• ***Service*** is the result of a set of functions applied to the content, to pieces of information or recursively to services. By (manually or automatically) handling, managing, combining, personalizing, adapting content, information or services, new services may be composed or generated.
• ***Infrastructure*** (both private and public) will consist of transport, storage and processing functions in a distributed manner. This cloud offers the opportunity to deal with active content objects, rather than unstructured bit streams in the network. Thus, intelligent content centric infrastructure may efficiently support content and its derivatives (information and services).
• ***Security and Privacy*** will be a property of content, information, services and Infrastructure, allowing much more efficient control over content objects.

2. **Mobility and ubiquitous access to networks:** Based on the survey of Jianli et al (2011, p.27), the Internet is experiencing a significant shift from PC-based computing to mobile computing. Mobility has become the key driver for the future Internet. Convergence demands are increasing among heterogeneous networks such as cellular, IP, and wireless ad hoc or sensor networks that have different technical standards and business models. Putting mobility as the norm instead of an exception of the architecture potentially nurtures future Internet architecture with innovative scenarios and applications. A significant challenge in this aspect is how to trade off mobility with scalability, security, and privacy protection of mobile users, mobile endpoint resource usage optimization, and so on. Furthermore, as Tronco (2010, p.84) claims, ubiquitous computing leads to ubiquitous connectivity, i.e. connectivity anywhere, anytime, in anyplace, to anyone. Such connectivity could be provided by centralized approaches were cells size range from very small (picocells and femtocells) for high bit rate dense areas, up to large cells to cover rural areas. Nevertheless, decentralized mesh networks are emerging as strong candidates for future wireless connectivity. Independently, the aggregated traffic will be carried mainly by high capacity optical networks. Global coverage will be necessary and can be achieved by integrating terrestrial and satellite networks. Another fundamental requirement is to stay connected while moving, i.e. mobile connectivity. Also, it will be required to deal with a large.

3. **Cloud-computing-centric architectures**: According to ITU.(2009, p.8) , with the growth in IT expenditures as a component of business costs and operations, small and medium-sized enterprises are turning to third parties to outsource their IT needs. Cloud computing refers to the trend of outsourcing IT needs and its growing popularity as a business model will place further strains on the Internet, particularly with regard to security, reliability and cost of access. As Jianli et al (2011, p.27) see, migrating storage and computation into the “cloud” and creating a “computing utility” is a trend that demands new Internet services and applications. It creates new ways to provide global-scale resource provisioning in a “utility-like” manner. Data centers are the key components of such new architectures. It is important to create secure, trustworthy, extensible, and robust architecture to interconnect data, control,

and management planes of data centers. A major technical challenge is how to guarantee the trustworthiness of users while maintaining persistent service availability.

4. **Security:** As Subharthi et al. (2011, p.4) state, years of experience in security research has now established the fact that security is not a singular function of any particular layer of the protocol stack, but is a combined responsibility of every principal communication function that participates in the overall communication process. Such functions are security policies, trust relationships, names, identities, cryptography, anti-spam, antiattacks, and privacy.

5. **Experimental test-beds:** As Hu et al. (2011, p.731) any new ideas about future Internet architecture need a rigorous and large-scale network simulation testing, demonstration and test-run before their actual practical use and application. So to design a global network simulation platform for researchers has become an important issue.

RESEARCH PROJECTS FROM THE UNITED STATES

According to Jianli et al (2011, p.28), research programs on future Internet architecture in United States (some representative projects per category are shown in table 2) are administrated by the National Science Foundation (NSF) directorate for Computer and Information Science and Engineering (CISE).

Table 2. U.S. projects and clusters on the future Internet. (Jianli, 2011, p.28).

Categories	Project or cluster names (selected)
FIA	NDN, MobilityFirst, NEBULA, XIA, etc.
FIND	CABO, DAMS, Maestro, NetSerV, RNA, SISS, etc. (more than 47 total)
GENI	Spiral1: (5 clusters totally): DETER (1 project), PlanetLab (7 projects), ProtoGENI (5 projects), ORCA (4 projects), ORBIT (2 projects; 8 not classified; 2 analysis projects
	Spiral2: over 60 active projects as of 2009*
	Spiral3: about 100 active projects as of 2011*
* GENI design and prototyping projects can last for more than one spiral.	

GENI (Global Environment for Network Innovations)

GENI is a collaborative program aimed at providing a global large-scale experimental testbed for future Internet architecture test and validation. It is a general purpose large-scale facility that puts no limits on the network architectures, services, and applications to be evaluated; it aims to allow clean-slate designs to experiment with real users under real conditions. The key idea of GENI is to build multiple virtualized slices out of the substrate for resource sharing and experiments. It contains two key pieces:
• Physical network substrates that are expandable building block components
• A global control and management framework that assembles the building blocks together into a coherent facility.
Another notable and unique characteristic offered by GENI is that instrumentation and measurement support have been designed into the system from the beginning since the ultimate goal of GENI is to provide an open and extensible testbed for experimentation with various new Internet architectures. The GENI infrastructure (*Tronco et al., New Generation Internet Architectures: Recent and Ongoing Projects 2010, p.123)* is composed by a high-capacity optical network, a programmable and federated core, large clusters of CPUs and disks, diverse types of wireless access technologies and sensor networks. The experiments are scheduled and run independently of each other using programmable components via an end-to-end virtualized slice. The virtualization process is implemented by software-defined networking technology, e.g. OpenFlow, which is being developed by a research group at Stanford University. Design, prototyping and construction of GENI are performed by the research community with a special is emphasis on openness using virtualization**.**

NEBULA

Another FIA project is NEBULA, which is led by the University of Pennsylvania in collaboration with other 11 universities, and focuses on an architecture which is cloud-computing-centric. NEBULA is a future Internet architecture that meets the challenges of scalability, flexibility and economic sustainability as also it faces threats to the upcoming utility capabilities of cloud computing.
As Jianli et al (2011, p.29) stated, NEBULA design principles include:
• Reliable and high-speed core interconnecting data centers
• Parallel paths between data centers and core routers
• Secure in both access and transit
• A policy-based path selection mechanism
• Authentication enforced during connection establishment

The NEBULA internet future architecture, having in mind the above design principles, consists of the following key parts:

(1) the NEBULA Data Plane (NDP)
(2) NEBULA Virtual and Extensible Networking Techniques (NVENT)
(3) the NEBULA Core (NCore), as depicted in Figure 3,

which are three interrelated parts and especially: NDP defines policy-compliant paths and offers versatile access control as also defense against availability attacks, NVENT is a control plane providing access to application selectable service and network abstractions such as redundancy, consistency, and policy routing and NCore redundantly interconnects data centers with ultra high-availability routers.

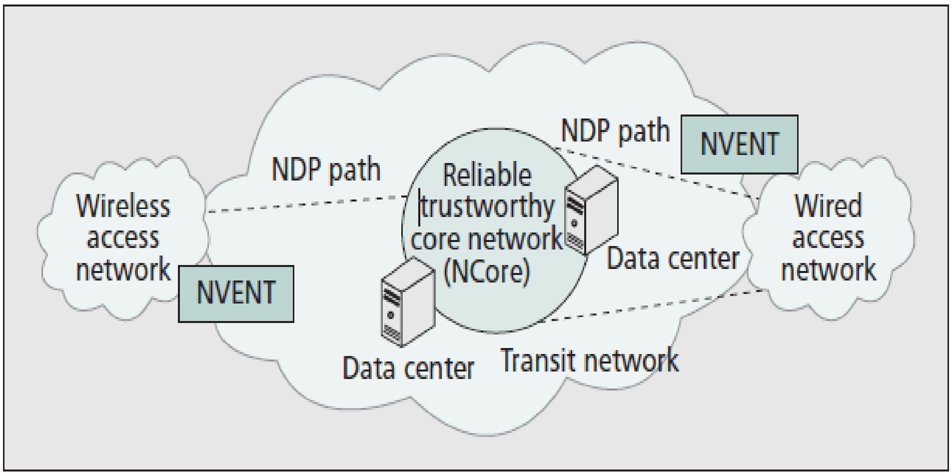


Figure 3: NEBULA architecture components and their interactions (Jianli, 2011, p.30)

NDP: It is impossible to predict what policies service providers may need in the future. As with the current Internet, it is possible that any future network on a global scale, to involve separate organizational service providers, so it is unpredictable the estimation of what policies service provider may need.

The goal is to offer an efficient yet neutral in policies data plane, which allow evolutionary policies to industries that reflect business needs, government regulations and users needs over the control on the route selection and the resource allocation.

The data plane model, as explained in Anderson's survey (n.d., p.2) is "deny by default": all parties, including the end user, internet service provider, cloud computing operator, and the application provider, must consent to the path and its behavior for the path to be used. Further, all parties can verify that their requirements have been met. Many of the security, reliability, and performance problems of the current Internet are due to the inflexibility and inherently unverifiable behavior of its policy enforcement mechanisms. This is the focus of the NEBULA data plane (NDP) effort.

NVENT: Due to many reasons such as inherent complexity of low level, operational semantics for the internet's control knobs and direct participation of internet administrators in performance optimization, the current internet abounds with configuration errors.

The focus of the NEBULA is security with policy-selectable network abstraction including multipath routing and use of new networks.

It is required a higher level approach for the improvement in reliability and security of the future Internet. In this direction, industry is already moving, but it needs more research in exploitation of these capabilities.

NCore:

According to Anderson et al. (n.d., p.14) the NEBULA Core will be built on a future generation of core routers that can support the highest transport speeds at any given time, while providing always-on availability. This latter requirement demands viewing future generation router control plane software as a fault-tolerant distributed system.

Routers will be fabricated in the same way as nowadays with modular components. These components will be assembled together in order to support the workload that is needed.
A router can be formed with the collection of hardware, which can be managed as a unified system, like a data center. That is, to have techniques in fault-tolerance to guarantee the availability at any given time, to upgrade individually at every level and finally to have the capability to redirect slices of traffic to new versions of hardware and software for the evolvement of new protocols and services
Except from the interdomain and intradomain aspects that mentioned above, the continuous operations of a router demands a third focus which is intrarouter. The effort of the NEBULA Core (NCore) is to conduct research for the realizing the potential of this approach where industry is already moving.

XIA (eXpressive Internet Architecture)

XIA is also a European project and it directly targets the security issue within its design, contrarily with other projects that faces the security problem by the avoidance of flaws in the current design.
According to Jianli et al (2011, p.29-30), there are three key ideas in the XIA architecture:
• Define a rich set of building blocks or communication entities as network principals including hosts, services, contents, and future additional entities.
• It is embedded with intrinsic security by using self-certifying identifiers for all principals for integrity and accountability properties.
• A pervasive “narrow waist” (not limited to the host-based communication as in the current Internet) for all key functions, including access to principals, interaction among stakeholders, and trust management; it aims to provide interoperability at all levels in the system, not just packet forwarding.

Firstly, Xia supports multiple communication styles whereas current internet architecture and protocols are optimized for host-to-host communication. In addition, XIA is focused on the deduction of a principal, where each type is associated with a different contract with the network and consequently enables a different communication style.
Secondly, XIA ensures inherent security properties with each communication, which enables an entity to attest its communication with the appropriate counterpart with no need to access in external databases, information or formulation. Intrinsic security, as Anand et al. (2011, p.2) mentioned, is central to reliable sharing of information between hosts and routers and to ensuring correct fulfillment of the contract between them. Also, it can be used to bootstrap higher level security mechanisms.
Finally, the narrow waist of current internet is fixed, while XIA supports a set of extensible principal types over the time, which can provide two kinds of evolvement. These are, according to Anand et al. (2011, p.1-2):

1) New application paradigms and usage models can be supported more effectively by adding native support for the appropriate principals.
2) Advances in computing and storage technology can be leveraged to enhance network support for a given principal (e.g., allow incremental deployment of principal-specific optimizations) in a clean, transparent fashion.

The above three requirements can get entitled as expressiveness, intrinsic security and evolvability, and XIA addresses them in its architectural design.

FIND (Future Internet Design)

FIND (National Science Foundation, n.d.) is a major new long-term initiative of the NSF NeTS research program. The philosophy of the program is to help conceive the future by momentarily letting go of the present - freeing our collective minds from the constraints of the current state of networking. The intellectual scope of the FIND program is wide. FIND research might address questions such as:

- How can we design a network that is fundamentally more secure and available than today's Internet? How would we conceive the security problem if we could start from scratch?
- How might such functions as information dissemination, location management or identity management best fit into a new network architecture?
- What will be the long-term impact of new technologies such as advanced wireless and optics?
- How will economics and technology interact to shape the overall design of a future network?
- How do we design a network that preserves a free and open society?

RESEARCH PROJECTS FROM THE EUROPEAN UNION

The European Union has also initiated a bundle of research projects on future Internet architectures. Currently, 150 projects are part of the European Seventh Framework Program (FP7). A subset of the projects is shown in Table 3.

Table 3. EU research projects on future Internet.. (Jianli, 2011, p.32).

Categories	Project names (selected)
Future Architectures and Technologies	4AWARD, TRILOGY, EIFFEL, SPARC, SENSEI, Socrates, CHANGE, PSIRP, etc.
Services, Software, and Virtualization	ALERT, FAST, PLAY, S-Cube, SLA@SOI, VISION Cloud, etc.
Network Media	3DLife, COAST, COMET, FutureNEM, nextMEDIA, P2P-Next, etc.
Internet of Things	ASPIRE, COIN, CuteLoop, SYNERGY, etc.
Trustworthiness	ABC4Trust, AVANTSSAR, ECRYPT II, MASTER, uTRUSTit, etc.
Testbeds	FIRE, N4C, OPNEX, OneLAB2, PII, WISEBED, G-Lab, etc.
Others	HYDRA, INSPIRE, SOCIALNETS, etc.

4WARD and FIRE, the two projects that are analyzed below, have been organized under FP7.

4WARD

4WARD is a European Project for the design of the Future Internet focusing in the main idea that the Future Internet must be extremely different from its initial design and to be designed for the environment of applications of the 21st century.
The key 4WARD design goals, as Jianli et al (2011, p.32) cited, are:

- To create a new "network of information" paradigm in which information objects have their own identity and do not need to be bound to hosts
- To design the network path to be an active unit that can control itself and provide resilience and failover, mobility, and secure data transmission
- To devise "default-on" management capability that is an intrinsic part of the network itself
- To provide dependable instantiation and interoperation of different networks on a single infrastructure.

In more detail, is pointed out:
The approach of 4WARD is to adopt an information-centric paradigm, than the node-centric one, in which the communication abstraction is based on transfer of application data objects, as depicted in Figure 4.

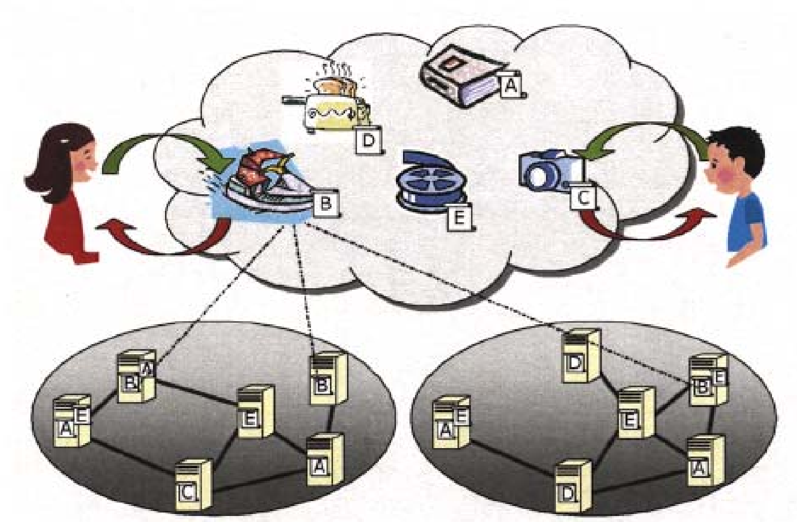


Figure 4: Networking of Information. (Niebert, 2008, p.3)

The present overload of the IP-address is replaced by a separation of information identifiers and locators. A new design where mobility and security are an integral part of the network architecture, rather than an additional solution, will be able to designed by 4WARD.

IP routers as Niebert et al. (2008, p.3) stated, may perceive the notion of a changeable topology, leading away from pure overlay networks with separate control to an integrated and possibly distributed management of data transport. The approach of 4WARD is to define the notion of a "Generic Path", able to efficiently realize "networking of information" by exploiting cross-layer optimization and multiple network paths.

For the aforementioned clean-slate solutions of the information-centric network and the generic paths, there must be a coexistence with the already used and other new approaches. Virtual networks are ideally capable for that coexistence. Consequently, virtualization is a smooth path for the transition to evolutionary approaches and not just the enabler of the coexistence of multiple architectures.

The goal is to develop a systematic and general approach to network virtualization. The virtualization of individual resources is the basis of the framework as shown in Figure 5.

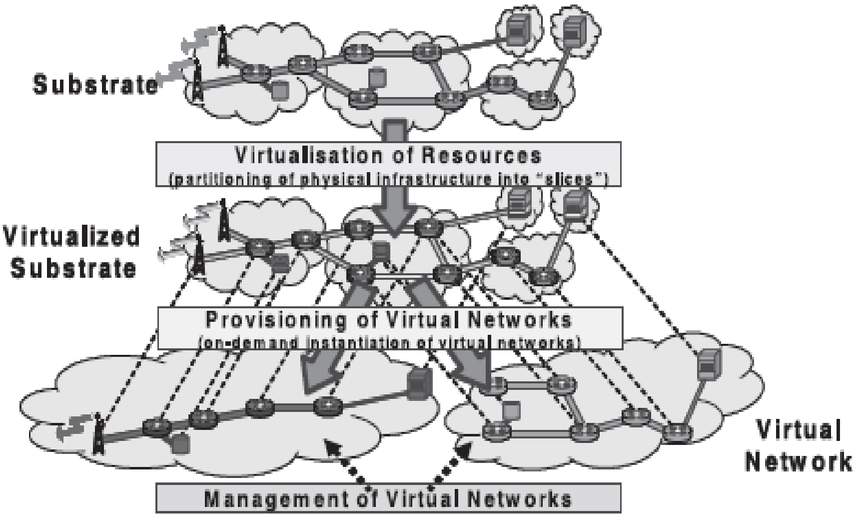


Figure 5: Virtualization framework. (Brunner, 2010, p.445)

Concluding, as Brunner et al. (2010, p.445) said, the main thrusts of 4WARD, a new architectural design including the information-centric paradigm, network virtualization and embedded in-network self-management, provide candidate solutions, which, after careful evaluation, should be appropriately incorporated into the architecture.

FIRE (Future Internet Research and Experimentation)

FIRE is another European project, started in 2006, by the creation of European expert groups who have been facilitated from the European Commission. FIRE has two interrelated dimensions (Community Research and Development Information Service, n.d.):

- The **FIRE Facility** shall evolve towards becoming fully operational. In parallel, it is planned to expand the concept, by addressing as well the service architecture layer, by supporting experimentation which cuts across layers, by enabling socioeconomic impact assessment, as well as by broadening the involvement of large user communities.
- The **FIRE experimentally-driven advanced research** shall further push the limits and define the challenges for the FIRE facility through visionary, multidisciplinary research, which considers the Internet as a complex system and therefore addresses all the associated aspects, in a holistic vision, at all relevant levels and layers.

On the one hand, visionary research related on new models and architectures is experimentally promoted; on the other hand, it is essential the creation of experimentations that support combination of newcoming and future internet technologies with testbeds for medium and long-term research.

Gavras et al. (2007, p.89), claims that FIRE is focused on exploring new and radically better technological solutions for the future Internet, while preserving the "good" aspects of the current Internet, in terms of openness, freedom of expression and ubiquitous access.

RESEARCH PROJECTS FROM ASIA

JAPAN

AKARI

AKARI (means, in Japanese, a small light in the dark pointing to the future) is a research program from Japan which aims in a clean-slate design. Specifically, (Wikipedia, n.d.) the AKARI Architecture Design Project (AKARI Project) is a large project for designing New Generation Network Architecture and is supported by the National Institute of Information and Communications Technology (NICT) of Japan.
The AKARI project has divided its schedule into two five-year periods, as depicted in Figure 6. At the first period from 2006 to 2010 it has aimed to complete its new generation design scheme and at the second five-year period, from 2011-2015, to evolve and develop testbeds.

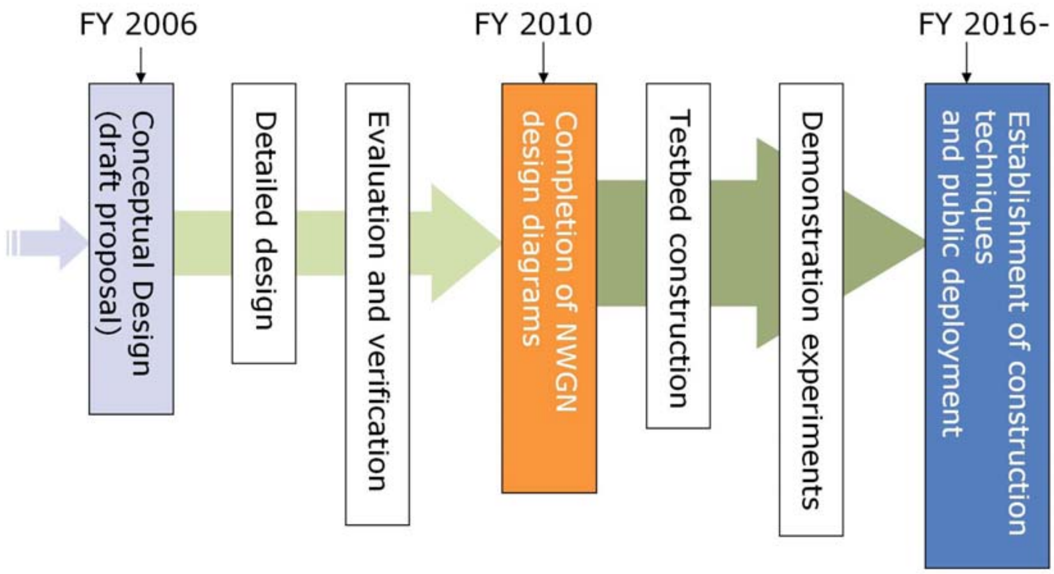


Figure 6: AKARI Architecture Design Project schedule (Harai, 2010, p.2)

As Harai et al. (2010, p.2) supported, the AKARI project will create a blueprint for a new generation network in Japan. This network will be based on future leading-edge technologies and will act as a foundation for supporting all communication services. The blueprint not only will be a design of the entire new generation network, but it will also indicate the directions of new generation network technologies for the industrial world with which the network will be interacting.
The project will design and build network testbeds which are consist the elements of the new network technology in order to assess the new generation network architecture. Via experiments that ran in collaboration with universities and industries and lead the way towards future standardization, the project will exhibit the validity of the NWGN (new generation network) architecture. In order to achieve this, will specify the following guidelines:

- ✓ Lead industries by presenting future actions and ensuring neutral innovations for promoting impartial competition among industries.
- ✓ Design the new generation network based on common basic principles, not aiming at progressing a specific component technology that would result in only suboptimal improvements of efficiency.
- ✓ Create and sustain an overarching vision of the future network that would be deployed in more than a decade from now and establish design capabilities based on practical experience.

The goal of AKARI, as Jianli et al (2011, p.33) mentioned, is based on three key design principles:

- "Crystal synthesis," which means to keep the architecture design simple even when integrating different functions.
- "Reality connected," which separates the physical and logical structures.
- "Sustainable and evolutional," which means it should embed the "self-*" properties (self-organizing, self-distributed, self-emergent, etc.), and be flexible and open to the future changes, as shown in Figure 7.

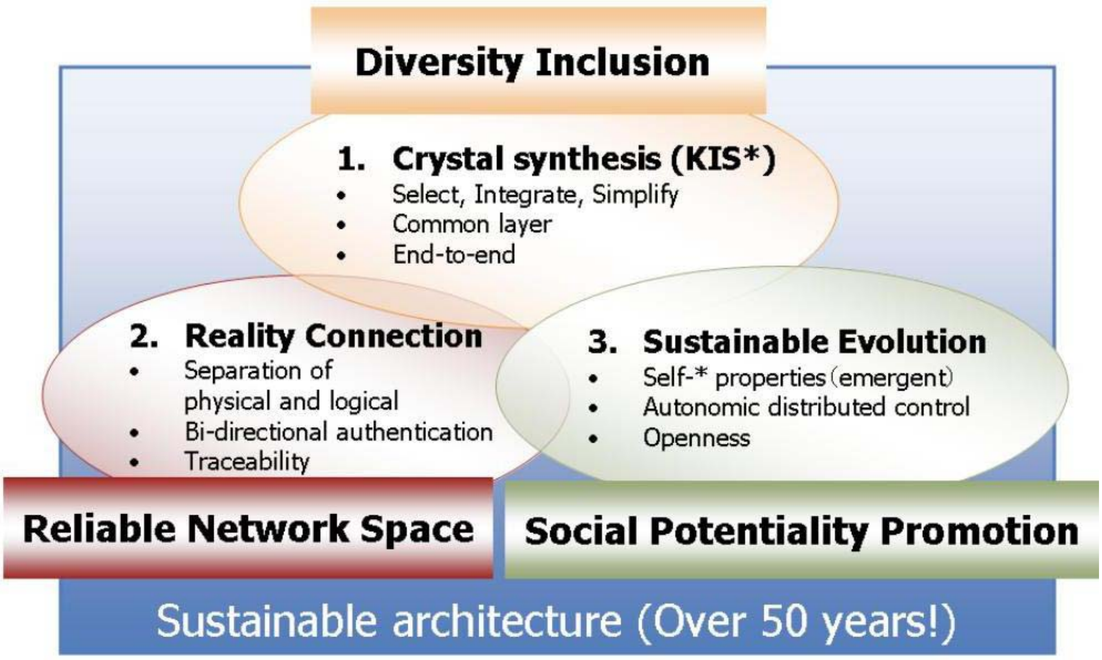


Figure 7: Basic design principles for New Generation Network architecture (Harai, 2010, p.62)

Crystal Synthesis: Talking about "Crystal Synthesis" we mean that the design must have a kind of simplicity even in cases of functional incorporations. In order to reduce the complexity, they inherit the "KISS (keep it simple and stupid)" design principle of current Internet architecture (by keeping the KIS* and altering the last S with scalable, sustainable, sophisticated, smart, secure, etc).

Reality Connected: Problem of Internet, according to Harai's et al. (2010, p.66) survey, is generated by having distance between network entities and real society. And once dividing entities from original structure identify for any purpose and restructure these is needed. Mapping between entities, authentication, and traceability keeping principle are needed. And, once dividing of entities having original identification structure for objects and restructuring these is needed.

Sustainable Evolution: A sustainable and evolutionary network architecture must be designed to meet the challenges of future applications. To accomplish requirements of the next generation network such as the support of new applications and adaptation to environmental changes, the new generation network must have the self-* features, as self-management, self-organization, self-repairment and self-adaptiveness.

CONCLUSIONS

In this paper, we have provided an overview of several projects on future internet architecture. Current internet's architecture needs to change in order to provide flexibility and scalability. Considerable research is clearly needed to meet the challenges arising from the design of the future worldwide network. The research community is focusing on the clean-slate approach, which aims in a considerably new architecture, better in terms and properties such as security and performance. A number of research projects are being conducted worldwide over the future network architecture.
The envision of GENI project is the radical design for the future network infrastructure that is based on people and content. It bases its experiments over various design testbeds, to permit the evolutionary architectural proposal to be tested. The new Internet architecture of NEBULA based on a high-performance highly-available core network and a new distributed control plane architecture which provides an interface with which network resources can be allocated. XIA supports that its architecture can provide secure content retrieval, multicast and disruption-tolerant communication.
The 4WARD project aims to create a set of credible and interoperable networks for omnipresent and instant access to information, in order to improve the Europeans' quality of life. In addition, it provides candidate solutions by including the information-centric paradigm and network virtualization. FIRE project focused on sophisticated networking approaches for architectures, protocols and interconnected testbeds for the next generation internet. It aims to encounter the emerging expectations on the Internet by setting innovative ideas and revolutionary proposals in its research.
The project idea of AKARI is finding the perfect solution and developing a new network architecture beginning from a clean slate, unhindered by the existing problems.

Another important aspect over that issue is the comparison between European research efforts, with the relevant GENI and FIND. The European approach is not a network architecture built from the scratch. Opposed to this, is dominated the opinion that firstly should be determined and validated the architectural ideas and subsequently to be planned and built. Consequently, for the support of the emerging networking concepts the European Union's approach is based on testbeds. In addition, a possible disadvantage of GENI project is that the virtualization technology will waste network resources and so to reduce the rate of utility as well to increase the complexity and the fault rate, due to the virtual process.

On the overall, further work is required to identify in detail where existing specifications can be adopted and promoted.

REFERENCES

Anand, A., Dogar, F., Han, D., Li, B., Lim, H., Machado, M., Wu, W., Akella, A., Andersen, D., Byers, J., Seshan, S., & Steenkiste, P. (2011). XIA: An Architecture for an Evolvable and Trustworthy Internet, 1-6

Anderson, T., Birman, K., Broberg, R., Caesar, M., Comer, D., Cotton, C., Freedman, M., Haeberlen, A., Ives, Z., Krishnamurthy, A., Lehr, W., Thau Loo, B., Mazières, D., Nicolosi, A., Smith, J., Stoica, I., van Renesse, R., Walfish, M., Weatherspoon, H. & Yoo, C., (n.d.),NEBULA - A Future Internet That Supports Trustworthy Cloud Computing. Retrieved from IEEE.

Brunner, M., Abramowicz, H., Niebert, N. & Correia (2010). 4WARD: A European Perspective towards the Future Internet. *Special Section on New Generation Network towards Innovative Future Society*,E93-B (3), 442-445

Community Research and Development Information Service. (n.d.). Future Internet Research & Experimentation. Retrieved from http://cordis.europa.eu/fp7/ict/fire/overview_en.html

EC FIArchitecture Group. (2010). Fundamental Limitations of Current Internet and the path to Future Internet. Status: Draft (Ver: 1.9), 1-16. Retrieved from IEEE.

Feldmann, A.(2007) Internet Clean-Slate Design: What and Why? *ACM SIGCOMM Computer Communication Review*, 37 (3), 59-64. Retrieved from IEEE.

FIA-Future Content Networks Group. (2009). Why do we need a Content Centric Future Internet? Proposals towards Content Centric Internet Architectures. *Future Internet Assembley*, (May 2009), 1-23. Retrieved from IEEE.

Gavras, A., Karila, A., Fdida, S., May, M., & Potts, M. (2007). Future Internet Research and Experimentation: The FIRE Initiative. *ACM SIGCOMM Computer Communication Review*, 37(3), 89-92

Harai, H., Inoue, M., Otsuki, H., Kuri, T., Nakauchi, K., Furukawa, H., Miyazawa, H., Xu, S., Kafle, V., Umezawa, T., Ohnishi, M., Fujikawa, K., Li, R., Andre, M., Decugis, S., Peng, C., Yagi, H., Kamiya, M., Murata, M., Teraoka, F., Morikawa, H., Nakao, A., Ohta, M., Imaizumi, H., Hosokawa, M., Aoyama, T., (2010). New Generation Network Architecture AKARI Conceptual Design (ver2.0). 1-333

Hu, H., Bi, J., Feng, T., Wang, S., Lin, P. & Wang, Y. A. (2011). Survey on New Architecture Design of Internet. *International Conference on Computational and Information Sciences*, 729-732. DOI 10.1109/ICCIS.2011.57.

ITU.(2009).. The Future Internet.. *ITU -T Technology Watch Report 10*, 1-15. Retrieved from IEEE.

Jianli, P., Subharthi, P., & Raj, J. (2011). A Survey of the Research on Future Internet Architectures, *Future internet architectures: design and deployment perspectives*, IEEE Communications Magazine, 11, 26-36. Retrieved from IEEE.

National Science Foundation. (n.d.). *Find: NSF Nets Find Initiative*. Retrieved from http://www.nets-find.net/.

Niebert, N., Baucke, S., EI-Khayat, I., Johnsson, M., Ohlman, B., Abramowicz, H., Wuenstel, K., Woesner, H., Quittek, J., & Correia L.M. (2008). The Way 4WARD to the Creation of a Future Internet. *(Invited Paper), 1-5*

Rexford, J. & Dovrolis, C. (2010). Future Internet Architecture: Clean-Slate Versus Evolutionary Research. Communications of the ACM, 53 (9), 36-40, doi :10.1145/1810891.1810906.

Subharthi, P., Jianli, P., & Raj J.(2011). Architectures for the Future Networks and the Next Generation Internet: A Survey. Computers Communications, 34 (1), 1-42, Retrieved from IEEE.

Tronco, T. ,(2010). *New Network Architectures: The Path to the Future Internet*. Studies in Computational Intelligence, S˜ao Paulo, Brazil, Springer, DOI 10.1007/978-3-642-13247-6

Tronco, T. R., Tome, T., Rothenberg, C. E., & Alberti, A. M..(2010). New Generation Internet Architectures: Recent and Ongoing Projects. *New Network Architectures,* SCI 297, 121-140. Retrieved from IEEE.

Tronco, T. R., Tome, T., Rothenberg, C. E., Alberti, A. M.,. Ongarelli, M. A., & Rego, B..(2010). Scenarios of Evolution for a Future Internet Architecture. *New Network Architectures,* SCI 297, 57-77. Retrieved from IEEE.

Wikipedia, the free encyclopedia. *AKARI_Project* (n.d.). Retrieved from http://en.wikipedia.org/wiki/AKARI_Project.

Wikipedia, the free encyclopedia. *Content-centric networking* (n.d.) . Retrieved from http://en.wikipedia.org/wiki/Content-centric_networking