# ADDRESSING THE CHALLENGES OF eNETWORK CYBERENGINEERING

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***Abstract.*** Vis-à-vis the State-of-the-Art we illustrate how our approach to opportunistic communications tackles the major challenges in Next-Generation Internet architecture.

***Keywords.*** eNetworks, Opportunistic Communication, Seamless Connectivity, Location Awareness, Sensor Network Integration

## I. INTRODUCTION

The Adaptive Risk Management Laboratory (ARM lab) [1] is concerned with the Engineering of infrastructures for tomorrow's Internet through development of universal models for integrating industrial systems (and the environments to which they are applied) with an overlay control network, - coined 'e-Network' [2]. Driven by the vision of "***complex systems as control paradigm for complex networks***" [3] the ARM Lab Team is looking into a plethora of natural, social and technical systems to extract relevant properties that would enable an intrinsic robustness of complex interdependent networks.

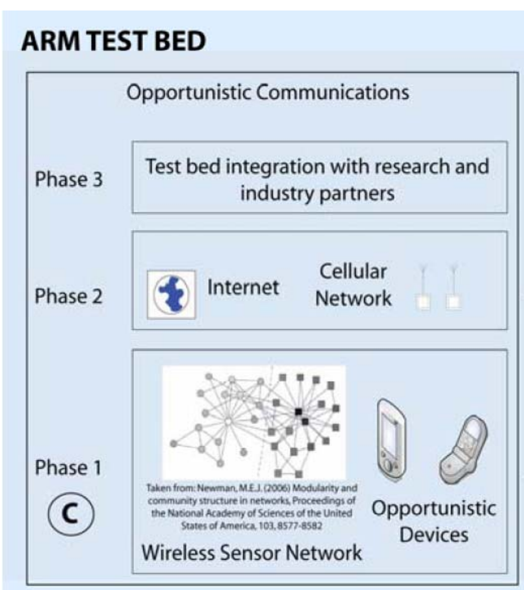


Fig. 1: Opportunistic Communications Module

To enable proof of the developed methodologies the ARM Lab provides a platform for design and evaluation of both the physically networked device interactions and the connecting infrastructure of hybrid networks (overlay control network – aka the eNetwork) grouping the devices in dynamical ecosystems. A detailed description of our approach is presented in [2]. Here we focus on how the Opportunistic Communications Module, Fig. 1, addresses the major challenges related to the design of the overlay control network (eNetwork).

## II. CHALLENGES

The two ways to approach the Future Internet Architecture are through either incrementally evolving the current internet architecture or developing a completely new framework. The former approach is more practical; however, the latter approach holds the promise of an architecture without patches and that supports mobility through fundamentally sound protocols [13]. ***The overall challenge lies in deciding for a radical shift versus incremental approach in tackling the Future Internet.***

### 1) Gateway Architecture Challenges

In the current internet, the prevalent integration approach for various unique network architectures (e.g., Wireless Sensor Networks, Switched Ethernet and WiFi) is to connect through a static gateway. While this is practical, it prevents uniform dissemination of control and routing information through the entire network and also creates a processing bottleneck at the gateway itself [13][11]. On the positive side the presence of a static base station limits the administrative traffic and keeps things simple in the sensor network. However, in many real life instances for e.g. emergency response management and asset management the following challenges are faced:

*Challenge: Resilient Gateway Architecture*

The base station in a WSN is the focal point for all data gathered and transferred to a backbone network or a different network that is not as resource constrained as the sensor network itself. The challenge arises when the base station is damaged either due to an emergency scenario, such as a rain storm, or because of a man made threat, such as a terrorist attack; this would cause the whole infrastructure to become useless unless another base station is programmed and replaces the damaged one. This gives rise to the need for a better and more robust gateway architecture.

2) Opportunistic Communication Challenges

In the current era of Information and Communication Technology (ICT), we not only come across more networks operating on different frequencies, [1] but also numerous devices that have multiple interfaces. [2] The concept of a path between network nodes has always been considered to be simple and fixed [13], however, with the increasing number of commercial devices with multiple interfaces and the different type of networks with overlapping coverage, this notion is rapidly bing replaced with that of a *definable link*.

*1st Challenge: Seamless connectivity*

Such an environment with definable links and multiple interfaces raises the challenge of always choosing the best connectivity option in a dynamic environment [15].

*2nd Challenge: Opportunistic Architecture through Mobile Code*

In communication networks the concept of “link” has usually been considered to be static during a particular session [13]. Only now, due to the rapid propagation of overlapping and un-interfering networks, has this concept started to change to a more “dynamic” link. Although, network complexity theory has dealt with the apprehension of dynamic links from a biological and social perspective [16], however, the implications on communication networks are only now being uncovered [17]. This poses the challenge of designing a flexible “opportunistic” architecture that tackles the link dynamics in addition to mobility and seamless connectivity amongst different networks.

[1] Quad Band GSM devices such as Nokia E61i and N95 (850\900\1800\1900)

[2] Nokia N95,N93 and N91 for e.g. have WiFi, Bluetooth and GSM\GPRS.

3) Challenges of Real World Deployment

*1st Challenge: Sensor Network Integration*

Some of the key challenges we face in order to achieve an efficient integration with the global internet are interfacing with lightweight sensor protocols, self-organization discovery, context awareness and data aggregation. Additionally, critical infrastructures are increasingly dependent on ICT infrastructures coupled with physical environments through these sensor networks.

*2nd Challenge: Flexible network architectures*

The new generation of architectures needs to support in-network programming [13]. This means that various networking entities (edge or core) should be remotely programmable. This runs counter to the fundamental application model of the current internet in which the principle of end-to-end connectivity dictates that processing can only occur on the edge of the network. While indeed ‘end-to-end’ connectivity has kept things simple, with the integration of pervasive systems such as sensor networks, *scalability and response time has become a growing concern and poses challenges for the end-to-end principle of the current internet.*

*3rd Challenge: Location Awareness*

A large community of researchers have come to the conclusion that the introduction of location identification capabilities is not only important for wireless networks but, in the much broader context, also for the future of the internet as whole [13]. *However, there is much research to be done in figuring out the challenge of how to integrate these capabilities in the evolving protocols for the Future Internet.* This integration should not only benefit internal aspects of the network, such as internal network optimization through routing, but also be easily accessible to the application layer for location aware-application development.

*4th Challenge: Self-Organization*

Ad-hoc network architectures are characterized by self-organizing protocols [13]. These are in turn dependant on the “opportunistic” discovery of resources in the surroundings [18]. However, this self-organization has generally been studied in environments with homogenous properties, such as those within a ZigBee network where each node has identical radio properties. *The Future Internet will be characterized by heterogeneous networks with different radio properties* such as clusters of ZigBee Networks overlapped with WiFi hotspots, which in turn overlap with a cellular GSM/GPRS network [14]. This raises new deployment questions and helps in augmenting our understanding of the self-organization principles in *heterogeneous* network environments.

4) Challenges of Critical Infrastructures

Any critical infrastructure is controlled and managed by networked information and communication technologies (ICT) systems. eNetworks [2] are the 'nervous system' of interdependent critical infrastructures and as such are the 'the weakest link'.

*1st Challenge : Inter-dependencies*

Networks are generally linked together and the services offered to or requested from a single network are dependent on other interdependent networks: as a consequence we do not have to deal with single isolated systems but with *systems of systems* [19]. Identifying all potential vulnerability of such systems and finding solutions to reduce the failure probability become very difficult and ambitious tasks [20].

*2ND Challenge: Robustness to Attacks*

With the growing fear of the increasing interdependence of every form of network that we have come to know and design, and the inherent risk of cascading failures [21], the ultimate challenge of any new architecture is to make sense of the interdependence and, in doing so, ensure network robustness [1].

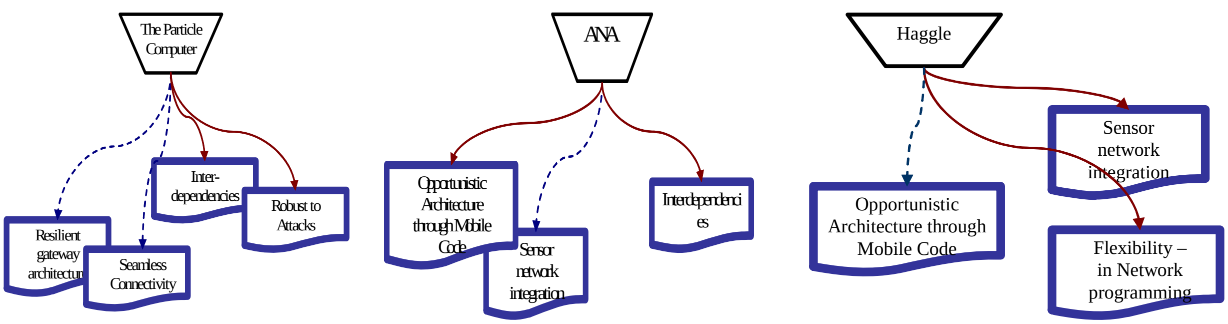


Fig. 4. (Left) The Particle Computer (Middle) ANA and (Right) Haggle Projects related to the Research Challenges

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## III. Addressing the Challenges

This section of the paper aims to position our work within the state-of-the-art relevant work in academia and industry while showing how the challenges are addressed by the ARM Platform. Each subsection is accompanied by a figure showing the relationship between the state-of-the-art projects and the challenges outlined earlier. The relationship is expressed from two perspectives. On one side (dashed arrows), we show the lack of focus in the projects that pose challenges, while on the other side (solid arrows), we present those issues that need to be addressed to enhance the project. The purpose is to establish a firm background to address all the research challenges stated in the previous section

### *a. The Particle Computer*

The Particle Computer project [22] evolved from the Smart-Its [23] project with the purpose to refine and enhance the previous prototypes. Smart-Its [23] concentrates on the task of inferring situational context (sleeping, talking on phone, reading, etc.) of a user in its immediate environment (devices present within one-hop range). This lacks emphasis on communication, networking, and data propagation. In Smart-Its, the devices are designed with specific support for sensor-to-context processing and offer less support for distributed communication [24]. Although, the Particle Computer tackles these insufficiency through a distributed protocol, its integrated architecture is still based on a static base station (called a bridge in their literature), which is not robust against attacks and which does not allow seamless connections Fig. 4.(Left).

The OCM of the ARM Testbed [7] puts emphasis on networking and data propagation by using state-of-the-art Motes from Crossbow. These Motes have been specifically designed for distributed communication. Additionally, by using principles from opportunistic communication we also aim to achieve a paradigm that is robust against attacks.

### *b. ANA*

The Autonomous Network Architecture (ANA) [25] project proposes a completely new networking architecture for the internet which addresses some of the challenges (such as scalability, addressing, mobility, etc.) that the current layered model has not been able to efficiently solve. Their primary focus is the integration of "self-*" (self-healing, self-reconfiguration, etc) properties in network nodes, hence making "realms" of autonomy based on these nodes. According to their plan, as the internet was progressively developed by the experience gained on testbeds and experimentation over prototype networks, hence, the design of prototypes is necessary for the implementation of any research architecture being considered for a deployable future infrastructure(for e.g. the Future Internet). However, the prototype testbed for ANA lacks focus on the role of interdependency amongst various realms ( different networks composed of autonomic nodes for e.g. WiFi, Cellular and Ethernet). According to the initial testbed deliverables (http://www.ana-project.org/autonomic/network/deliverables.html ), ANA also lacks completely the component of sensor networks Fig. 4. (Middle)

Having already the "self-*" capabilities integrated in it due to the Crossbow MoteWorks platform, the ARM testbed is perfectly placed as a prototype vision for ANA. The Wireless Sensor Network is the primary component of the OCM and it also aims to focus on the interdependencies amongst its various components.

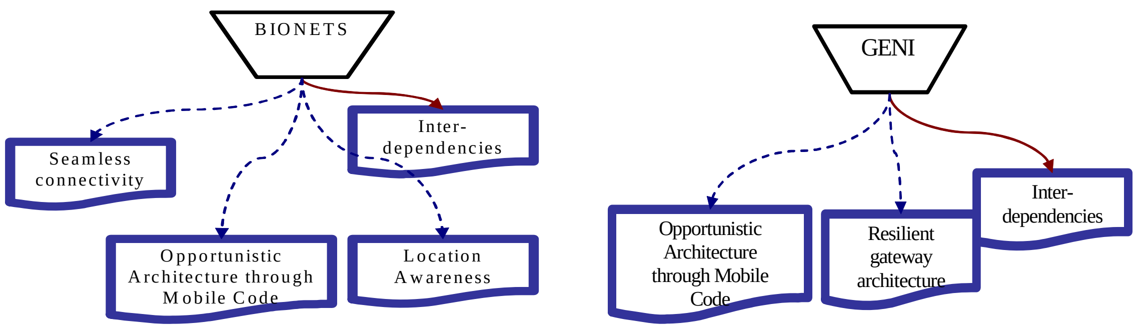


Fig. 5. (Left) BIONETS and (Right) GENI Projects and the Research challenges

### *c. Haggle*

The Haggle [25] project attempts to determine the best approach when the infrastructure for a communication network is significantly destroyed (e.g., the Base Station has been paralysed due to a man made threat like 9/11 or a natural disaster like Katrina). It attempts to solve this problem by instituting a completely ad-hoc technique in which peer-to-peer communication is one of the feasible ways to survive. This peer-to-peer infrastructure is enhanced by opportunistic networking [18] and other node properties such as localization and data transfer in motion. Currently, Haggle has no integrated sensor network; it also has no in-Network programming characteristics. If these characteristics were added in the proposed Haggle architecture, a flexible network through programmable network entities and a better emergency response through context awareness could be achieved. Although opportunistic communication is the main topic of the Haggle project, it lacks the perspective of Mobile Code, which could also enhance the resilience of the architecture Fig. 4.(Right).

OCM is architecturally distinct in the sense that it does not wholly depend on peer-2-peer techniques but also on a dynamic, robust and "alive" base station that moves to a safe location. OCM also relies on the concept of opportunistic networking, but is distinct from the Haggle's work because it works on the concept of mobile code and not the physical mobility of the base station itself.

### *d. BIONETS*

The BIOlogically-inspired autonomic NETworks and Services (BIONETS) research project envisions the ambitious task to create communication and service paradigms based on the theory of biological evolution. From an architectural point of view, devices are classified as either T-Nodes (localized and static sensors) or U-Nodes (mobile and not resource-constrained user devices) [17]. Communication between far-off devices takes place due to the mobility of the U-Nodes; the challenge of information overload is solved using techniques inspired from natural selection. In order to achieve this, there are several technical challenges that need to be overcome. Most of these challenges are identical to those outlined in the previous section. However, the most important challenges undertaken by the BIONETS vision are: Seamless connectivity between T-Nodes and U-Nodes; Opportunistic communication between the U-Nodes; and Location-awareness for the sake of efficient Service architectures. Additionally, BIONETS lacks focus on inter-dependencies Fig. 5. (Left). From a biological perspective the ARM Platform aims at embedding *change* as a constituent property in the next generation Internet.

This is based on the observation that biological systems show remarkable properties in terms of robustness and resilience in adapting to new, unforeseen conditions and of evolving new features and capabilities, while being able to successfully deal with scale issues. In addition we introduce security as a key property of eNetworks. Being 'intent-oriented', in that they emerge around a user's need, these eNetworked ecosystems are highly dynamic and unpredictable, therefore requiring high adaptability of the security mechanisms involved, which should be easily tuned to support service availability for the particular ecosystem configuration. Biologically-inspired techniques will be developed for designing the building blocks of an ***autonomic digital ecosystem*** as model for eNetworks, realized as software modules and demonstrated by means of a prototype system. In addition we will be prototyping ***holistic security ecosystems*** that will mirror the eNetworked ecosystem creation (emerging from dynamic composition of various services) - depending on the particular (mostly unexpected) threat that endangers the ***autonomic digital ecosystem*** - threat which needs to be counteracted / annihilated.

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### *e. GENI*

GENI (www.geni.net) is a new facility concept introduced by the network research community in the United States (primarily funded and lead by NSF) [26]. The goal of this facility is to provide a substrate for all network research and state-of-the-art transformation of the current ICT infrastructure. GENI is a very large scale experimental platform and aims to federate all major national and international testbeds. It covers almost all major disruptive innovative challenges that the network research community faces [27]. However, like most of the major projects presented in this section, GENI also lacks a focus on interdependencies between other networks (such as supply and social networks) [28]. Additionally, the concept of gateway architecture through opportunistic communication making use of mobile code could greatly enhance the resilience of communication networks in GENI Fig. 5 (Right).

Table I maps the projects to the challenges vis-à-vis our approach, underlining which challenges are specifically tackled (T), lack focus (F), and are not applicable at all (NA) to the projects. Challenges that have not been undertaken in the projects or those that could enhance the projects results are marked by X.

## IV. CONCLUSIONS

A task as ambitious as development of the eNetworks which will animate the future internet ecosystems cannot be accomplished in isolation. Major new long term initiatives in Europe (EU-FET Future Internet Research and Experimentation – FIRE) [29], the US (NSF NETS research program on Future Internet Network Design – FIND) [30] and CANARIE Inc. - Canada's advanced Internet development organization [31], foster participation of

TABLE I

STATE-OF-THE-ART PROJECTS RELATED TO ALL THE RESEADRCH

| Projects\Challenges | Resilient gateway architectures | Seamless connectivity | Horizontal Integration | Opportunistic Architecture through Mobile Code | Sensor network integration |
|---|---|---|---|---|---|
| The Particle Computer | F | F | T | NA | T |
| ANA | NA | T | T | F | F |
| Haggle | NA | T | T | F | X |
| BIONETS | NA | F | T | F | T |
| GENI | F | T | T | F | T |
| OCP-ARM | T | T | T | T | T |

| Projects\Challenges | Flexibility – in Network programming | Inter-dependencies | Robust to Attacks | Location Awareness | Self-organization |
|---|---|---|---|---|---|
| The Particle Computer | T | X | X | T | T |
| ANA | T | X | T | T | T |
| Haggle | X | T | T | T | T |
| BIONETS | NA | X | T | F | T |
| GENI | T | X | T | T | T |
| OCP-ARM | T | T | T | T | T |

international researchers from academia and industry based on the premise that only in collaboration and via consensus-building can this critical mission be accomplished.

To be a part of these developments we must team up with those who drive the development of tomorrow’s ICT world. We will involve the ARM platform in such large-scale clusters to contribute the global efforts dedicated to the design and development of methodologies for engineering Cyber-physical ecosystems.

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